SITE INVESTIGATION
Forsmark 2002–2007

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Cover photo: Lasse Modin. Kurre Granström registers drill cores retrieved during the night shift.
Inset: Gerd Nirvin, information officer, talking with Niclas Börjesson, landowner.

Site investigation Forsmark 2002–2007

Contents

A site in Forsmark

"The site investigation for a possible final repository for spent nuclear fuel in Forsmark has been concluded. One reflection, we are confident we have built a solid foundation on two footings: safe technical solutions and a consensus with the people who live in the district. Safety and acceptance – without both, it will not be possible to build a final repository for spent nuclear fuel, in Forsmark or anywhere else in the free world. This is what we have learned after six laborious but rewarding years."

These were the words of Moa Lillhonga-Åberg, Editor, and Kaj Ahlbom, Site Manager, when this book was published in December 2007 once the site investigation, which commenced in 2002, had been concluded.

The foreword ended with the words: "After six years we know a great deal about the site in Forsmark. But we still don´t know whether it will be the site of Sweden´s repository for spent nuclear fuel."

As this is being written, we know a lot more. At the beginning of June 2009, SKB chose Söderviken in the Forsmark industrial area as the site where we wish to locate the final repository for spent nuclear fuel. The process of issuing permits is currently in progress, with the authorities reviewing SKB's applications. The final decision is to be made by the government once Östhammar Municipality has been consulted.

The fact that Forsmark was chosen is certainly one of the reasons why this book continues to receive so much attention. It describes one of the most thorough site investigations ever conducted. In the book, you meet a few of the people who worked on the site investigation. There are weather statistics, information on the geological history of Forsmark, facts about rock stresses and the water in the rock as well as so much more. Basically, we reveal some of the knowledge gathered that formed the basis for choosing Forsmark.

We are now doing a reprint. We have chosen not to update the text, but rather let the words fall exactly as they did in Forsmark 2007 – after the concluded site investigation, but before the decision on the site was made. At page 111, you will find an up-to-date piece of text that explains the current situation and what will happen in the future.

Forsmark, April 2012

Let’s talk about **the weather**

Mean annual temperature

The mean annual temperature in Forsmark is just under plus seven degrees Celsius.

2003 – data not available.

2004 – 6.3 degrees.

2005 – 6.6 degrees.

2006 – 7.3 degrees.

2007 – 6.9 degrees.

Site Investigation Forsmark Östhammar Municipality 2002–2007

2002. 2003. 2004. 2005. 2006. 2007. The site investigation for a possible final repository for spent nuclear fuel in Forsmark has been under way for nearly six years. Most of the investigations were concluded on 30 June 2007; the drilling work was finished even earlier, on 10 March. A period of review and analysis of the investigation results commenced. This work is still in progress.

The site investigation in Forsmark has been conducted in an area southeast of the Forsmark nuclear power plant (see map overleaf). The candidate area, in other words the area where a final repository may be located, is approximately ten square kilometres in size. Certain investigations have been extended to an even larger area than that.

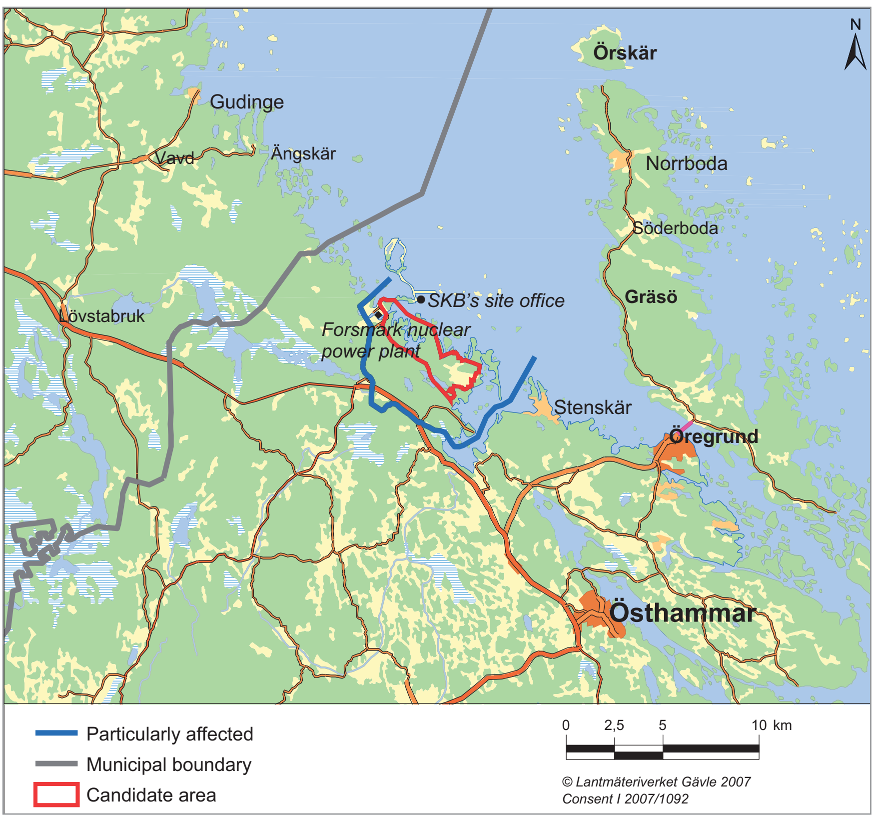
The area has high natural values, and this has imposed special requirements on how the site investigation has been conducted. The County Administrative Board is the supervisory authority for the natural and cultural environment and makes sure that SKB conducts the investigations in compliance with the law.

A mission in time

SKB's mission is to manage and dispose of the radioactive waste from the Swedish nuclear power plants. We also deal with radioactive waste from medical care, research and industry. It is SKB's task to develop and realize a method for safe disposal of this radioactive waste.

We are conducting site investigations for a possible siting of a final repository for spent nuclear fuel in two municipalities: Östhammar Municipality in northern Uppland and Oskarshamn Municipality in eastern Småland.

Aerial photo of the northwestern part of the investigation area. The final repository's central area may be located here, in the bedrock beneath the Forsmark plant's residential area. It is also here that the final repository's surface facilities may be located, as well as the shafts and the inclined tunnel that connect the facilities above and below ground.



The area outlined in red is what we call the candidate area, in other words the area where a final repository for spent nuclear fuel may be built. Those we call "particularly affected" by the site investigation live inside the blue boundary.

We also cooperate with Östhammar Municipality. Ever since the feasibility study and the start of the site investigation, the municipality has actively followed our work through its own working groups. This includes not only geology, technology and environmental considerations, but also how the repository affects the municipality and, in a broader perspective, society as a whole.

800 reports

The site investigation has resulted in nearly 800 reports describing the investigations and their results. In addition, we have published an annual report every year in which the activities are described in words and pictures. The studies and research surrounding a final repository have a much greater reach than just the candidate area. In consultation with the municipality, we have had the various consequences of the establishment of a final repository studied. Moreover, SKB funds an extensive social science research programme, which is carried out at the country's universities.

All reports from the site investigation, and all annual reports and reports on societal studies and societal research, can be downloaded from our website: *www.skb.se*.

The purpose of this book is to provide a summary picture of the site investigation. It is a complex picture and we have tried to describe it as clearly as possible. Sometimes it is difficult to completely avoid the use of technical terms and unusual concepts.

Feel free to contact us if you want to know more – we are more than happy to explain.

Christina Roshag, unit secretary, with some of the reports generated by the site investigation.

The Site Manager's **reflections**

Interview

Name: Kaj Ahlbom, geologist and Site Manager

Project manager for the feasibility study in Östhammar Municipality 1995–2001, site manager for the site investigation since 2002. Has been working with the final repository issue since 1978, among other things as project manager for the feasibility study in Storuman.

"I came to Östhammar for the first time late in the autumn of 1995. I was supposed to give information to the local politicians. It was a dark, rainy autumn evening and the meeting was held in a basement. Östhammar was not at its best, few places are on rainy autumn evenings. I remember it struck me that I would be spending many years here, and I have to admit it was a gloomy prospect. Claes Thegerström, then Vice President, gave me an encouraging pat on the shoulder and said: 'You'll do just fine, Kaj,' and then he went home to Stockholm ..."

Did you do just fine?

"Yes, I can say that now, twelve years later. It's been a good time, probably the most important time of my professional career. Busy, fun, challenging, tough and stimulating. That gloomy mood of that autumn evening in 1995 quickly evaporated.

"When the site investigation started in 2002, my task was to assemble a team that would get the job done. It was extremely important to select the right people; when it comes to doing something so big, so new and so important, choosing the right people is crucial. I picked my own team, and looking back I can now say I couldn't have wished for a better bunch."

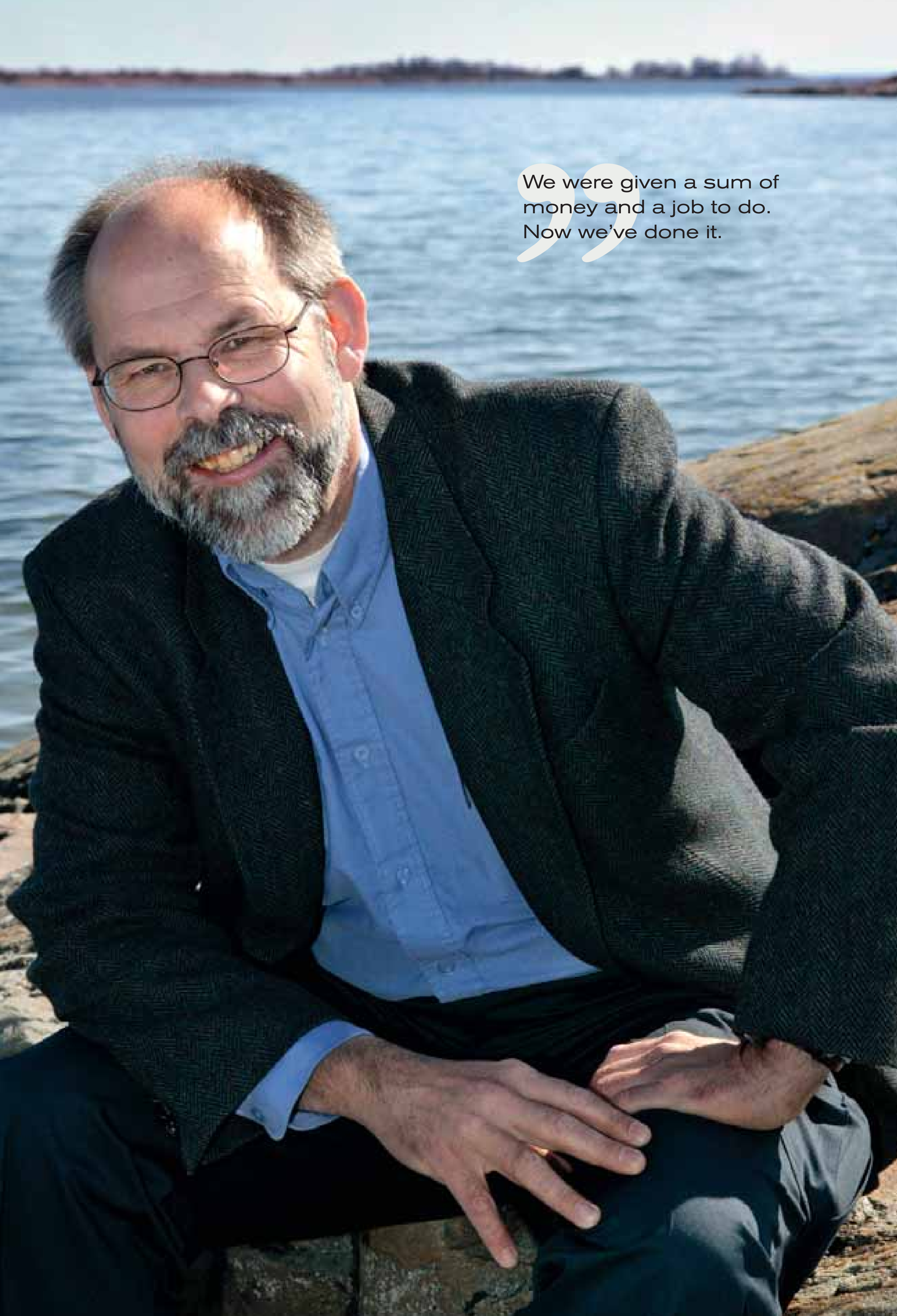
What do you mean?

"Well, for example: When I arrived in the morning I would usually check how things were going among my colleagues. There were problems almost every day. But the attitude was always: We have a solution in the works, and by this afternoon things should be fine."

"And that's how everyone has been all the time. Competent people who have always been there for each other, listened to each other and had the best interests of the project in mind. They have often worked long hours at crazy times, and always with a strong sense of responsibility. One thing I've learned over the years: If you give people clear instructions, they'll take responsibility for carrying them out."

You had experience from Storuman. Things didn't go as well there, did they?

"No, you could say I learned a lesson there and we all remember what it was like in Almunge back in 1985 during the test drilling. I totally misjudged the situation in Storuman, since I had the impression the mood was posi-



We were given a sum of money and a job to do. Now we've done it.

Photo Bengt Backström, Upsala Nya Tidning.

Almunge 1985. This is what it looked like in February 1985 when the local populace stopped the test drilling in Almunge. The drilling was never carried out.

tive. That was the picture that was painted for me, but the result of the referendum was a resounding 'No'. I learned then that speaking in front of crowds of people and trying to give them information just doesn't work. Most are silent, they don't say what they're thinking. In Östhammar we took a different approach; we spoke with the people, not at them. Only when you have a dialogue will people speak their minds about what's worrying them. It would have been a disappointing trip if we hadn't managed to get the residents on our side. That's why we met as many as we could in small groups. In that way we were able to solve the practical problems that were troubling them. For often it isn't the future final repository that concerns them but more immediate matters."

Like what, for example?

"That there would be a lot of traffic on the roads, that burglaries would increase, that we would destroy the countryside, that we would disturb hunters, things like that. We were usually able to put such fears to rest in direct contacts with people. Then, when we had solved the immediate problems, the other questions also came up, about a final repository in a broader perspective."

So you feel pretty good now?

"We all do."

"You might say we were given a sum of money and a job to do.
Now we've done it."

Conversations in Forsmark

Clockwise from top left: Erik Waernulf, Forsmarks bruk, and Gerd Nirvin, SKB.

Olle Olsson, SKB, and Bo Andersson, Söderön.

Marianne Kjellgren, Öregrund, and Inger Nordholm, SKB.

Kaj Ahlbom, SKB, and Sivert Jansson, Elvisjö.

Börje Andersson, Elvisjö, and Kaj Ahlbom, SKB.

Johan Swahn, the Swedish NGO Office for Nuclear Waste Review (MKG), Erik Setzman and Olle Olsson, SKB.

Göran Risberg, SGU, Inger Nordholm and Gerd Nirvin, SKB.

Above: Carl-Johan Nässén, Östhammar, and Kerstin Karlsson, Östhammar. Kaj Ahlbom and Bengt Leijon, both SKB, can be seen in the background.

Interview

Expert's **post script**

Name: Gerd Nirvin, information officer

Chief information officer since 1996, first for the feasibility study and then in 2002 for the site investigation in Forsmark.

"Face-to-face encounters are what's most important. Information material is all well and good, but nothing beats personal contact. In a dialogue you give and take. That's why we information officers at the site investigation in Forsmark have tried to meet as many people as possible. According to an opinion poll in the municipality, roughly half of those polled have had personal contact with us, which we think is a good result. But it has cost us many hours on the phone and lots of evenings running around in the villages. We can't expect people to come to us; we are the ones who have to seek them out and tell them what may be happening in their municipality. In addition, you have to provide open, straightforward and clear information."

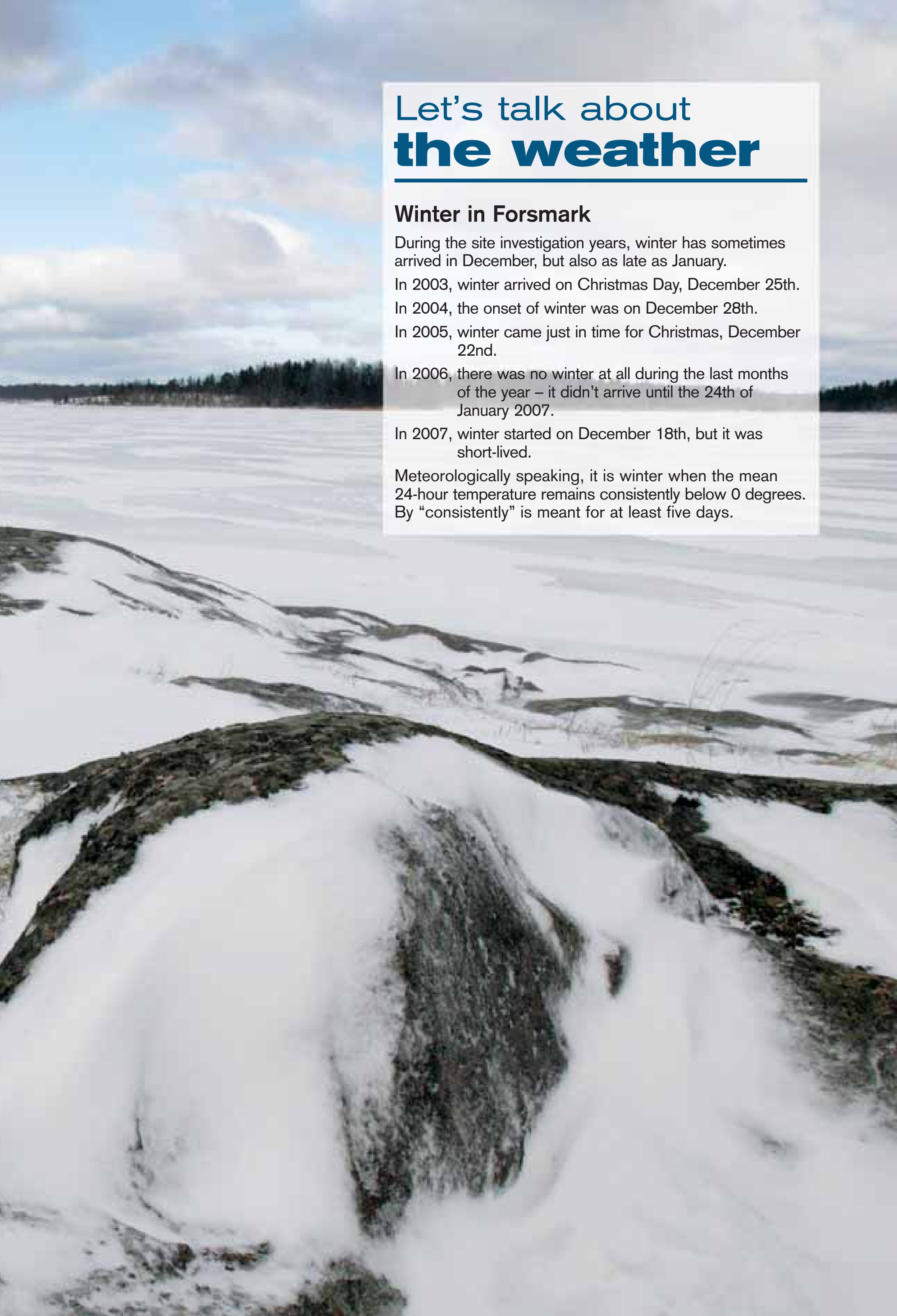
Has the information found its target?

"Naturally you can never know exactly how much of the information people absorb, but if you stick around you can hear their questions. During the feasibility study the information was of a more general character. We sought out companies and associations and we drove around to small communities, villages and the like. When the site investigation was about to begin in Forsmark, we made personal contact with around 260 households within a radius of about ten kilometres from the nuclear power plant. We phoned everyone up and invited them to information get-togethers in their own villages. There were meetings in local village halls, church halls, community centres and in people's kitchens. We have followed up these initial contacts with annual meetings and sent out newsletters."

But you haven't only contacted nearby residents?

"No, of course not. We have the entire municipality as our territory. For example, we've met some 1,000 healthcare and nursing home employees. During 105 two-day study trips to our facilities in Oskarshamn we have assembled and spoken to some 3,000 people. Just to give some examples. The information work is never-ending, you might say. And it will continue in the same way ..."

As so often before, Gerd Nirvin has to seek out Niclas Börjesson, landowner in the candidate area, out in the field to inform him of an urgent measure that affects his land.



Let's talk about **the weather**

Winter in Forsmark

During the site investigation years, winter has sometimes arrived in December, but also as late as January.

In 2003, winter arrived on Christmas Day, December 25th.

In 2004, the onset of winter was on December 28th.

In 2005, winter came just in time for Christmas, December 22nd.

In 2006, there was no winter at all during the last months of the year – it didn't arrive until the 24th of January 2007.

In 2007, winter started on December 18th, but it was short-lived.

Meteorologically speaking, it is winter when the mean 24-hour temperature remains consistently below 0 degrees. By "consistently" is meant for at least five days.

The geological history of Forsmark

More than 1,900 million years ago, the future site of Forsmark in northern Uppland in Sweden was at the bottom of a sea. "Forsmark" was then situated on the boundary of a continent of which there are now only a few remains in Norrbotten, in eastern Finland and in Russia. There were constant volcanic eruptions in the area.

A final repository for spent nuclear fuel must be safe for at least 100,000 years.

We don't know what will happen with the rock and the groundwater over such a long period of time, but we can make predictions if we know the geological history of the place and what geological processes may act on the bedrock and the groundwater in the future. This knowledge is also important for understanding what we see in Forsmark and being able to construct models of parts of the bedrock where our knowledge is limited. During the site investigation, important pieces of the puzzle have been added to the general knowledge that already existed, and now we know more about the geological history of Forsmark.

Forsmark did not exist "at the beginning of time". The age of the Earth is estimated at 4.6 billion years. The history of Forsmark began just over 1.9 billion years ago.

Repeated volcanic eruptions

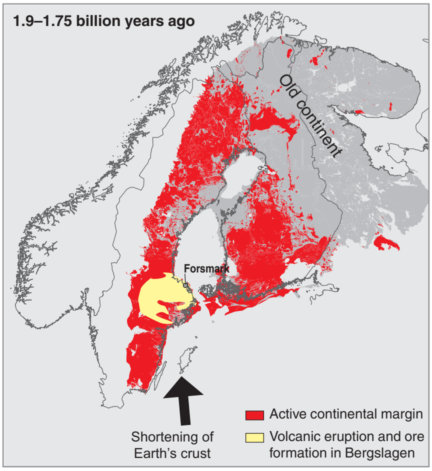
The bedrock in the Forsmark area belongs to the southwestern part of the Fennoscandian Shield. It was formed during the Svecokarelian Orogeny between 1.9 and 1.8 billion years ago on the boundary between a then-existing continent and an ocean. The conditions at that time were actually similar to what we see today in South America, where the ocean floor in the Pacific Ocean is being pushed down beneath the South American continent.

The oldest geological process was repeated volcanic eruptions, which formed thick layers of lava, ash and sediment as well as volcanic intrusions. The oldest rocks in Forsmark that we see on the surface today stem from these volcanic eruptions. Towards the end of this time, volcanism ceased and thick layers of sediment and limestone were formed. The hundreds of zinc, lead, copper and iron deposits that exist in Bergslagen were also formed during this period. Examples of large and important mineral deposits are the iron ores in the Stollberg Field and in Norberg, the copper and gold ores in Falun and the lead and silver ores in Sala. There are several small iron ore deposits near Forsmark, for example at Norrskedika. The best known mineral deposit, and the one that is most important for the district, is the one in Dannemora.

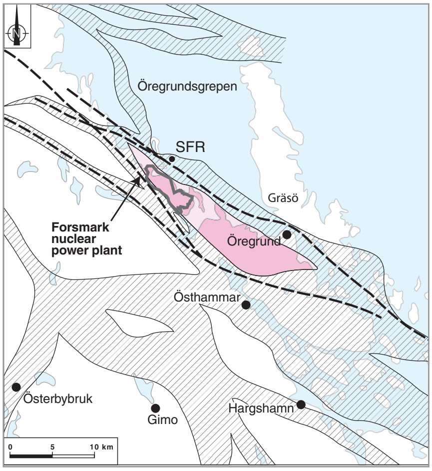
Different types of molten rock (magmas) penetrated into the ground and began slowly solidifying beneath the surface to form igneous plutonic rocks. The granite that forms the core of the tectonic lens in Forsmark was formed 1,867 million years ago by this process.

Orogeny – formation of a mountain chain

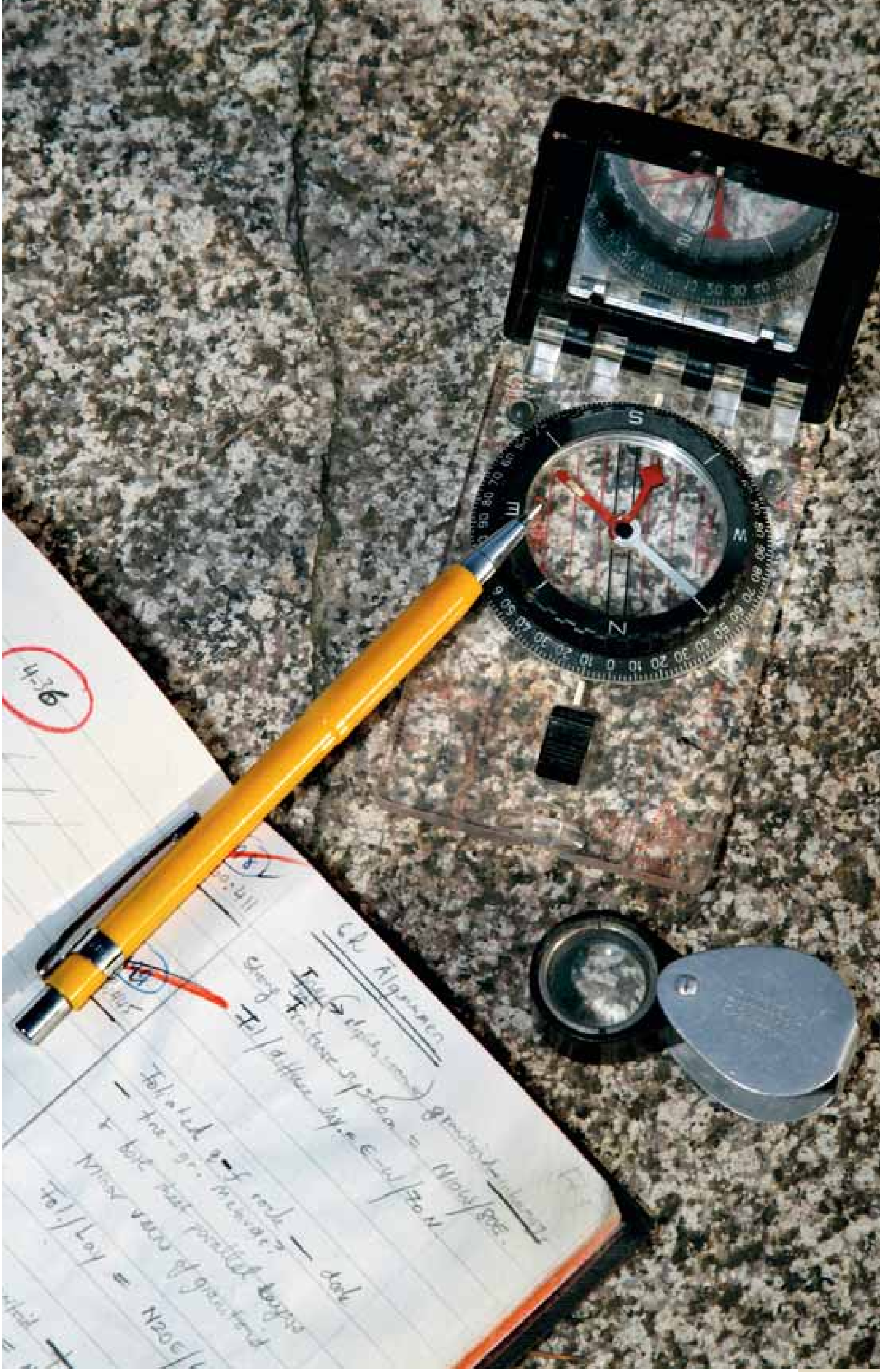
After 1,867 million years a mighty mountain chain began to be formed by the ongoing collision between the oceanic plate and the old continental plate in a process called the Svecokarelian Orogeny. The Earth's crust grew thicker and thicker, and "Forsmark" was many kilometres beneath the peaks of the mountain chain. The compression of the plates created movements which at this depth, and at the prevailing high temperature, caused metamorphosis and ductile deformation of the rocks. This deformation was concentrated in bands along which the rocks were heavily deformed, folded and foliated. Lens-shaped less deformed areas, tectonic lenses, formed between the bands. It was in this place and at this time that the tectonic lenses in northern Uppland were formed.



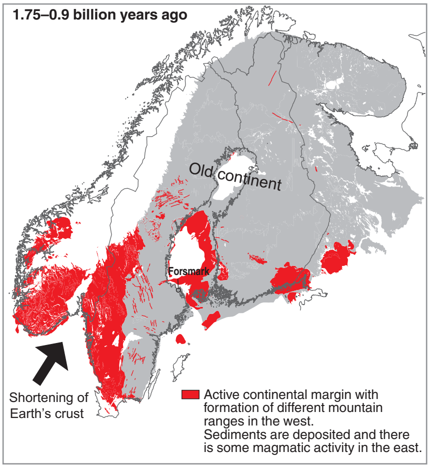
Formation of rocks between 1.9 and 1.8 billion years ago. Magmatic activity occurred along an active continental margin due to volcanic eruptions and powerful earthquakes.



The map shows the tectonic lens in Forsmark in pink, surrounded by rocks subject to strong ductile deformation, the shaded areas. The dashed lines show regional brittle deformation zones.



Tools of the geologist.



New rocks were formed between 1.8 and 0.9 billion years ago and the continent grew towards the southwest.


Fault along a mineral-filled fracture zone. The reddish rock in the lower part of the picture has been displaced to the left along the fault. The lens cover in the picture is about six centimetres in diameter.

Then, between 1,850 and 1,800 million years ago, the temperature in the bedrock fell to below 500 degrees. Ductile deformation continued along the broad bands between the tectonic lenses.

Colder rock

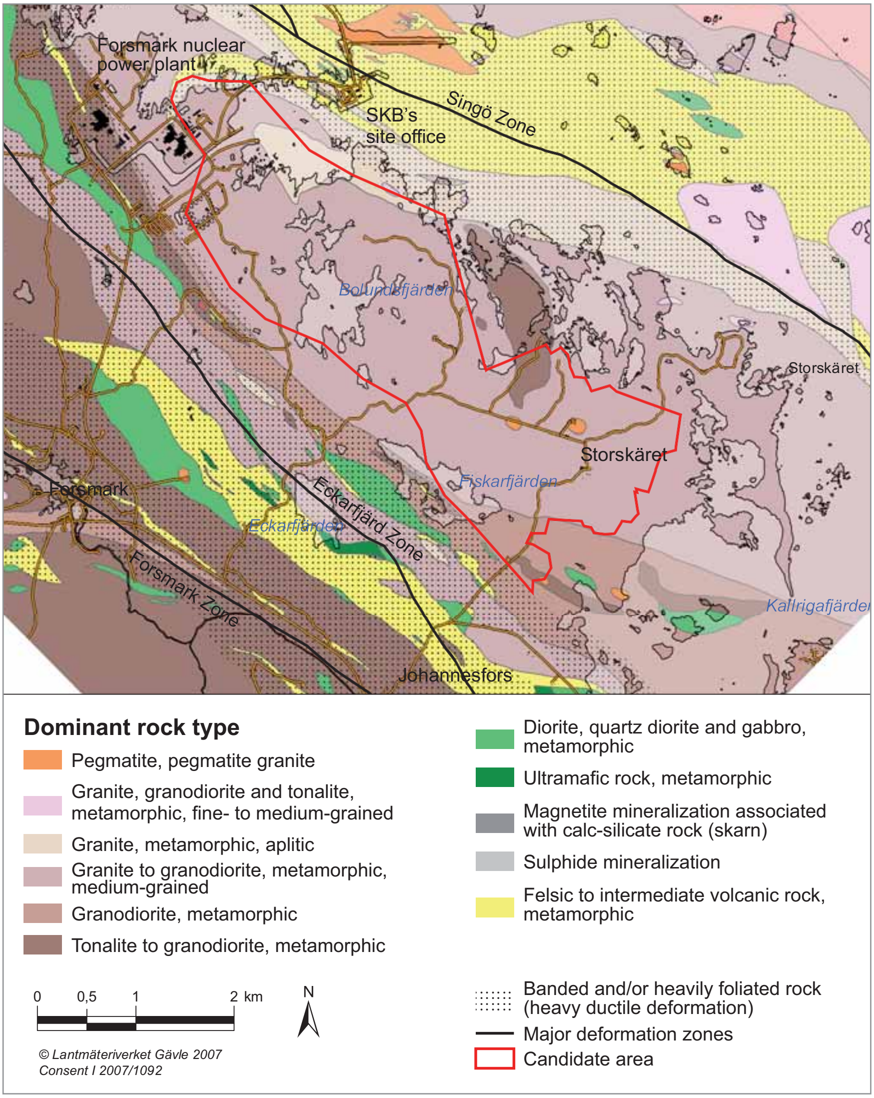
During the period between 1,800 and 1,730 million years ago, the depressed bedrock began to rise slowly and the temperature in the bedrock fell to below 300 degrees as this process continued.

The ductile deformation process became brittle. The scars consisting of heavily sheared and foliated rocks around the tectonic lenses were repeatedly activated. But now this took place in a much colder and more brittle rock mass, resulting in fracture zones and faults that were resealed with new mineral fillings after each activation.

By this time the mountain chain had eroded to something resembling today's Swedish mountain chain (the Caledonides). The hot and most dramatic period for the bedrock of Forsmark was at an end. An approximately 45 kilometre thick continental crust had now been formed in the area.

Activation of fracture zones

After the bedrock had been formed and the external forces that caused the ductile deformation had ceased, a relatively calm period ensued. The bedrock in the Forsmark area gradually stabilized. During this period, the centre of orogenic (mountain-building) events was shifted to the west and south. The



The map shows the distribution of different rock types in the Forsmark area. A reddish-grey metamorphic granite (metagranite) dominates the candidate area, and metamorphic tonalite and pegmatite are also found towards the southeast. Small bodies of amphibolite are common. They are too small to be included on the map. Outside the candidate area the bedrock is non-homogeneous. Besides metamorphic granite, granodiorite and tonalite there are also rocks of volcanic origin here which sometimes contain small iron mineralizations. Southwest of the candidate area, dark basic (quartz-poor) rocks such as metamorphic diorite and gabbro as well as ultramafite are common. The age of the candidate area's granite is 1,867 million years, making it slightly younger than the oldest rocks in Central Sweden.

267 whole cores

The many whole drill cores that have been retrieved in Forsmark are visible proof of the tight, dry rock. By "whole drill cores" is meant three-metre cores. A total of 267 such cores have been retrieved, most of them (75) from a cored borehole on drilling site seven (in the residential area). 40 whole drill cores were retrieved at drilling site five (Bolundsfjärden), 33 at drilling site one (the barracks village) and 83 from three boreholes at drilling site eight (the sewage treatment plant). See map of the drilling sites on page 108.

Gothian Orogeny took place during the period 1,700 – 1,560 million years ago. The old sealed fracture zones that had been established during the later phase of the Svecokarelian Orogeny in Forsmark were re-activated. Furthermore, new fracture zones were formed, but due to the thick continental crust in Forsmark and the distance to the Gothian Orogeny, there were no large movements along the fracture zones in the Forsmark area.

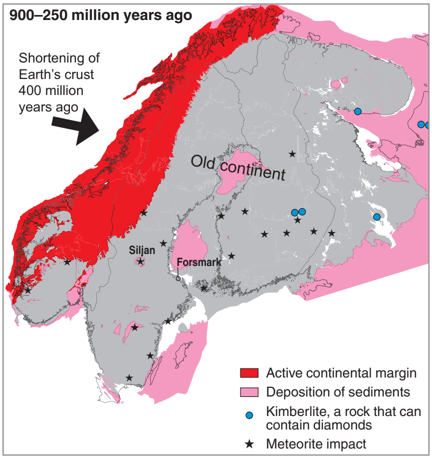
The next big geological event occurred in the west between 1,000 and 900 million years ago when different continents collided and formed a supercontinent called Rodinia. This can be seen today in southwestern Sweden, where the bedrock underwent severe metamorphoses and deformations. The Sveconorwegian Orogeny occurred in connection with this. Traces of this can be seen in the fracture zones in Forsmark. Some of the old and previously sealed fracture zones were re-activated, older fracture-filling minerals were dissolved and washed away, and new minerals sealed the fractures.

Deposition of rocks

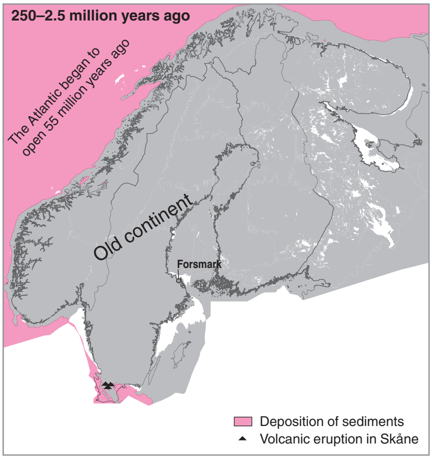
When the mountain chain formed by the Sveconorwegian Orogeny began to be eroded, weathering products were carried to more low-lying areas and covered large parts of today's southeastern Sweden. It has been estimated that the thickness of the sedimentary deposits at certain places may have been up to eight kilometres. Approximately 600 million years ago the deposits had been eroded away. The supercontinent Rodinia had been broken up when the continents had drifted apart again, forming the Iapetus Ocean (the former Atlantic Ocean).

Today's ground surface sees the light of day

At the transition between the Precambrium and the Cambrium, about 600 – 500 years ago, the Fennoscandian Shield was heavily eroded and levelled out. The ground surface we have today in large parts of southern Sweden, known as the sub-Cambrian peneplain, is largely the same as it was then. But after a while, large parts of the levelled-out Fennoscandian Shield were inundated by a shallow sea and sandy or clayey sediments were deposited. The sediments were eventually transformed to sandstones and alum shales.



New rocks were formed in the west between 900 and 250 million years ago.



No effects on the bedrock in Forsmark have been demonstrated during the period between 250 and 2.5 million years ago.

> *The tectonic lens in Forsmark is sort of like an avocado pit, you might say.*
>
> Assen Simeonov
> Site geologist

Life begins in earnest

Life on earth really took off about 540 million years ago. From previously having harboured only primitive multicellular organisms, the ocean floor was suddenly crawling with beetle-like organisms called trilobites.

During the subsequent 300 million years, various life forms evolved in the seas, from mighty coral reefs to primitive squids and different types of mussels and molluscs. When they died, thick deposits of limestone were deposited on the ocean floor, burying "Forsmark". Some of the organic matter was slowly transformed to oil, which seeped down into the basement rock along fractures. During the site investigation we have found small quantities of bitumen (an asphalt-like product) in the uppermost hundred metres of the bedrock in Forsmark.

New mountain chain formed

Approximately 510–400 million years ago the Iapetus Ocean gradually closed and the Swedish part of the Caledonian mountain chain was formed by a collision between the old continental plates Laurentia and Baltica. This was the Caledonian Orogeny. When the Caledonides began to be eroded, weathering products once again flowed out over the basement rock in the Forsmark area.

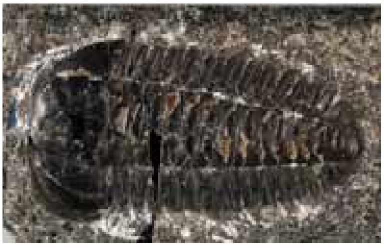
Small remains of bitumen.

Each time the basement was covered with sediments, the Earth's crust was depressed, and each time the sediments were eroded away the crust rose. This contributed to repeated re-activation of near-surface gently-dipping fracture zones.

Basement is exposed

Our knowledge of how the thickness of the sediment layers varied is sketchy, but Forsmark was gradually uplifted, at the same time as the basement was exposed when the sedimentary deposits were eroded away, probably during the Tertiary Period (65–2.5 million years ago). But remains of limestones can be found on the bottom of the Baltic Sea, for example in Gävlebukten northeast of Forsmark.

In southern Europe, the African plate was pushed northward against the Eurasian plate, and the Alps began to form around 100 million years ago. No effect on the bedrock in Forsmark has been found to have occurred in connection with this event. Nor are there any signs that fracture zones in Forsmark were activated when the Atlantic Ocean was formed as the North American plate and the Eurasian plate began to drift apart. This process began around 55 million years ago and is still ongoing. What we can conclude is that the direction of the maximum horizontal pressure in Forsmark corresponds to the pressure created by the widening of the Atlantic.



The trilobite – *Peltura scarabaeoides* – (natural size) is Cambrian and comes from Råbäck in Västergötland. It belongs to SGU's original collection and has previously been published by Westergård in SGU Ca18, 1922.

Over 16 kilometres of drill cores

A total of 25 cored boreholes with a length of between 100 and 1,000 metres were drilled at twelve drilling sites during the site investigation. Nine of them are 1,000 metres in length. A total of 18,028 metres of borehole were drilled and 16,348 metres of drill core were retrieved. They weigh 88,000 kilograms and are kept in a storehouse at Forsmarks bruk.

Let's talk about **the weather**

Autumn in Forsmark

Autumn usually makes its entrance in October.

In 2003, autumn arrived on October 3rd.

In 2004, autumn made its appearance on the same day: October 3rd.

In 2005, it was delayed until October 19th.

In 2006, autumn arrived on October 21st.

In 2007, autumn arrived on October 7th.

The official start of autumn is when the mean 24-hour temperature consistently (for at least five days) lies between 0 and 10 degrees Celsius and is falling.

Expert's post script

Interview

Name: Assen Simeonov, geologist

Activity leader for the geological investigations in Forsmark for the past four years.

"The geology profession is a small world where we all have a pretty good idea of what is going on in the world – but for me it was nevertheless like entering a new world when I arrived at the site investigation. I came from the mining industry, with its complex and often difficult-to-interpret rock, to the homogeneous and predictable bedrock in Forsmark."

Was that your first impression?

"Yes, and it's my lasting impression. The rock in Forsmark is simple and easy to interpret: A distinct tectonic lens consisting of a homogeneous rock, surrounded by large deformation zones. Sort of like an avocado pit, you could say. Once you're clear about the structures you can predict with fairly great precision what results you'll get in the next borehole."

No surprises, in other words?

"No, not really. To put it simply, the first models we made of the rock and the fracture zones are still valid today. A little surprise was the porous granites. They're spectacular, but on the other hand our analyses of the finds showed that they are insignificant in the overall context."

Any difficulties?

"No, none of those either. One possible disadvantage is that there aren't many outcrops in the area; the rock is mostly covered with soil. Due to special environmental considerations we were not able to dig as many pits as we would have liked to study the bedrock. But the information we have gathered from all the boreholes has made up for this. This has given us a very clear picture of the rock and the fracture zones in Forsmark."

What will you do now?

"Lots of things. I will finish the site investigation, I am working on analysis and modelling of the results, I am participating in the investigations in preparation for the extension of SFR, and soon I will be brought in on the design of a final repository for nuclear waste."

Interview

Expert's post script

Name: Johan Nissen, geophysicist

Activity leader for the geophysical surveys in Forsmark for four years.

"I didn't know anything about Forsmark before I came here – I know a lot more now. I can't imagine any other areas, at least in Sweden, where so many extensive geophysical surveys have been performed as in Forsmark and Laxemar (Oskarshamn). For example, we have measured the magnetic field in 427,000 points over an area of more than 11 square kilometres in Forsmark."

How has this work been carried out?

"The purpose of the geophysical surveys is to look below the ground surface without having to dig down. There are ten or so electrical, acoustic and electromagnetic methods that look down into the rock at different distances from the ground surface or in boreholes. We have carried out 85 geophysical activities, which have resulted in an equal number of reports. I am proud of the fact that we succeeded in gathering this huge amount of quality-assured data during the site investigation."

No problems?

"I had expected much greater logistical difficulties in view of the large number of different measurements in boreholes. Different activities have succeeded one another, sometimes at intervals of only a few hours. We have also been spared undesirable events, despite the fact that rushed deadlines can lead to risks. The worst thing that happened to us was that a high-voltage cable line was damaged during the seismic surveys, causing a power outage."

What about the results?

"They are good. For example, we have performed seismic refraction measurements on 43 profiles with a combined length of more than 30 kilometres. The most typical rock velocity is 5,400 m/s. The velocity along 88 percent of the profiles exceeds 5,000 m/s, which indicates a fracture-poor and 'good' rock."

What will you do now?

"I will keep an eye on the long-term monitoring. I will also be working with the site investigation for the extension of SFR in Forsmark."

Repeated ice ages

Approximately 2.5 million years ago, major climate changes occurred marking the start of the geological age in which we humans now live, the Quaternary Period. Characteristic of the Quaternary Period is a generally colder climate than the preceding period (Tertiary) as well as great climate variations. During the Quaternary Period we have therefore had both glacial periods (ice ages) and interglacial periods. If we look back in time we see that cold glacial periods lasting nearly 100,000 years have been succeeded by relatively short warm interglacial periods lasting approximately 10,000–15,000 years.

The temperature during the ice ages in Sweden may have been as cold as 20 degrees lower than the present, and Forsmark has been covered by a thick ice sheet several times.

Most recent ice age

The most recent ice age lasted between approximately 115,000 and 11,500 years ago. But the ice sheet did not extend over the whole of Sweden during this entire timespan. A tundra climate prevailed in the Forsmark area for long periods of time.

A great deal of water was bound up in ice sheets, so the surface of the oceans was at a much lower level than today. As a result, the Baltic Sea was probably not a sea during these tundra periods but a large, cold fresh water lake.

What we often mean by "the ice age" happened approximately 20,000 years ago. That is when the continental ice sheet reached its largest extent and the edge of the ice sheet was approximately where Berlin is located today. It is assumed that the ice was nearly three kilometres thick at its thickest in Forsmark.

The extension of the bedrock that occurred in connection with the depression of the Earth's crust, in combination with the pressure from the plate movements, created stresses that can be released in the form of earthquakes. In the site investigation we have had a special project to determine whether large earthquakes have occurred in northern Uppland since the ice sheet retreated from the area. Even though we have dug 48 long trenches with a total length of approximately 900 metres, no evidence has been found of this in the soil layers.

Upside down

The repeated depressions and uplifts of the Earth's crust, along with erosion and transport of the sediments, took place relatively slowly. When the most recent ice sheet retreated after having depressed the Earth's crust hundreds of metres, however, it proceeded very rapidly. Since depression and uplifting of the Earth's crust occurred in connection with every glaciation, the gently-dipping fractures in Forsmark were opened up and became permeable. This is common down to a depth of about 200 metres, and even deeper along certain gently-dipping fracture zones, above all in the southeastern part of the investigation area. Fractures filled with glacial sediments occur near the surface down to a depth of about 40 metres, after which the number declines with depth.

Deglaciation

After reaching its maximum extent, the continental ice sheet started to melt and the ice disappeared from the Forsmark area nearly 11,000 years ago. During this time, large quantities of meltwater formed containing slurry and sediments that had been transported by the ice. The muddy water found its way down through cracks in the ice, and the high water pressure created an environment where the spectacular sediment-filled fractures found at drilling site five could form.

Even though we have not found any traces of earthquakes, the Earth's crust has been rebounding continuously since the continental ice sheet began to retreat. The huge weight exerted by the ice sheet on the crust had depressed it considerably, and when this pressure was relieved it started to rise again. At first it rose rapidly, at a rate of nearly 3.5 metres per 100 years, but it gradually slowed down so that today the land is rising at a rate of 60 centimetres per 100 years.

When the ice left Forsmark, the Earth's crust was depressed so much that the water depth was approximately 190 metres in the candidate area. Since then the process of land uplift has continued in the area and new land areas have risen above sea level.

Example of a horizontal fracture filled with glacial sediments. The picture is from drilling site five. See drilling site map on page 108.

After the ice age

After the ice sheet had retreated from the Forsmark area, the climate got steadily milder and the edge of the ice moved northward. The temperature increased until 6,000 – 7,000 years ago when the summer temperature was a couple of degrees higher than today and the climate in southern Sweden was similar to that today in northern France. The climate was reflected in a different vegetation with deciduous forest much further north than today. The warm climate probably offered a pleasant environment for the humans living in the area.

Since then the temperature has fluctuated, but the general long-term trend shows that the temperature has gradually declined over the past few millennia. The colder climate has led to the spread of coniferous forest at the expense of deciduous species. Pine was long the dominant coniferous tree, while spruce, which is one of our most common trees today, became established in the Forsmark area approximately 2,000 years ago.

Salt and fresh

The salinity of the Baltic Sea has varied following the melting of the last ice sheet. The salinity has been much higher than today during certain periods. The highest salinity coincides with the warmest climate. During other periods the Baltic Sea has been isolated from the sea in the west, giving rise to fresh water conditions. For the past 9,500 years the Baltic Sea has had a connection to the North Sea via Öresund, making the water brackish.

The spruce – one of our most common tree – became established in Forsmark about 2,000 years ago.

Quaternary deposits in Forsmark

The bedrock is covered by overburden that consists of different Quaternary deposits. The properties of the different Quaternary deposits largely reflect how they have been formed and are of great importance for how we humans can use the soil and for what plants will grow at a given location. It is, for example, easy to see that areas with clayey soils are often used to grow crops, while stony till soil is often covered by forest. One thing that makes Forsmark special is that the topography is very flat. During the site investigation, however, we have come to realize that the top surface of the bedrock exhibits a much more undulating relief. You could therefore say that the soil depth in the area varies more downward than upward.

The extent of the different Quaternary deposits has been determined in many different investigations, on land and on lake beds. The results have been interpreted and compiled into a geological map (see next page) showing the distribution of the different Quaternary deposits as well as bare rock within the entire model area. In the highlands in the southwestern part of the area and on the islands, it is common to see small rock outcrops that rise above the till (red on the map).

> ***You could therefore say that the soil depth in the area varies more downward than upward.***
>
> Anna Hedenström
> Quaternary geologist

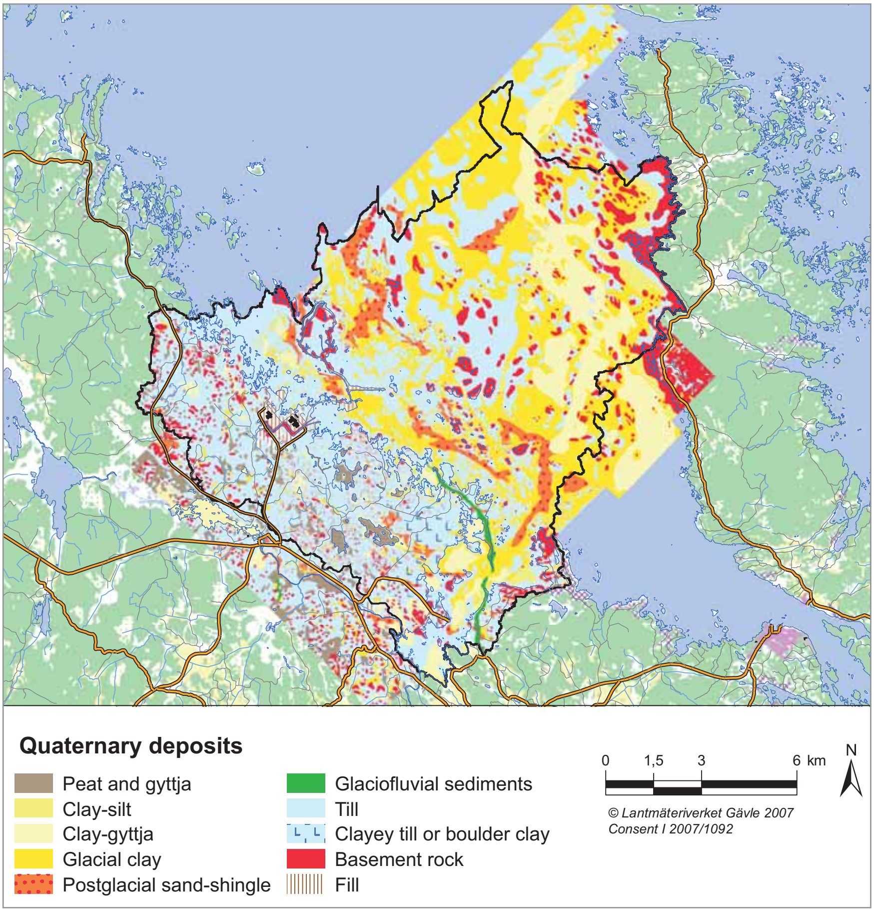
Glacial till (blue on the map) is both the oldest and the most common type of soil (Quaternary deposit) in Forsmark. As far as we know, all till in Forsmark was formed during various phases of the last ice age, i.e. during the past 115,000 years. This means that the Quaternary deposits are very young in relation to the rocks. But the Quaternary deposits consist for the most part of rock fragments that have been eroded and subsequently transported and deposited.

Till, which consists of unsorted material of varying particle sizes from small clay particles to large boulders, is material that has been picked up and later deposited by the ice sheet.

Two main types

The till in Forsmark can be divided into two main types based on particle size. The most common kind consists largely of sandy material with numerous boulders on the surface, covered for the most part by forest. Forsmark and parts of the Uppland coast are otherwise typified by a much more fine-grained till. The arable land on Storskäret consists of till with a more clayey composition and with few or no boulders on the surface.

It is difficult to determine the age of till, but by examining how the particles are oriented it is possible to reconstruct the direction in which the ice sheet was



A simplified geological map showing the distribution of the different Quaternary deposits and bare rock in the Forsmark regional model area, which has been modified. The map shows a compilation of the results of many different investigations and is based on both direct observations and interpretations of indirect measurements. The black line in the map shows the area where we have also made a model of the soil depth.

moving when the material was deposited. In this way a sequence of events can be reconstructed where different till beds can be dated relative to one another.

During the site investigation we have arrived at the conclusion that most of the till in Forsmark was deposited from the northwest, but there are also results showing ice movements more from the north. Due to the northerly transport direction, the ice was able to pick up limestone from Gävlebukten. That is why most soils in Forsmark have a high lime content, which explains why today's vegetation is so rich in orchids.

Esker

The green band visible in the southeastern part of the map is a small esker called Börstilåsen. The material in the esker consists of well sorted and rounded gravel and stones. When the continental ice sheet melted, large quantities of water were formed which gushed forth in large streams beneath the ice. When the flowing water reached the mouth of the glacial stream and entered the Yoldia Sea, stones, gravel and sand were deposited, forming eskers. See the box on the evolution of the Baltic Sea on page 74.

In Forsmark, Börstilåsen passes through the southeastern part of the area, from Kallrigafjärden to Tixelfjärden. But the esker begins south of Forsmark, roughly at Börstil Church. In the southern parts the esker is thicker and wider, but perhaps difficult to see because it has been flattened during the course of land uplift. The material that eskers are composed of is highly permeable, which means that the surface of eskers is often dry with vegetation consisting of pine and other plants that can grow on dry soil.

At sea there is a more even distribution between clay and till. There are thick layers of clay in the deep holes located in the

Fragrant orchid – a lime-loving plant.

Gräsörännan channel and a swath just off the coast (yellow on the map). The largest soil depth in the entire investigation area, 42 metres, has been measured in an area where both till and clay cover the bedrock outside the mouth of Kallrigafjärden. As the land has risen, some small surfaces of these clay areas have been exposed. The arable land in Forsmark does not, however, consist of clay that has been deposited on the sea floor as usual, but of the clayey till.

Continuing evolution

As new land areas rise out of the sea, the loose soils that have been exposed to waves and ocean currents will be transported and redistributed in new locations. For example, sand from till and the esker has partially eroded and been transported to protected locations where the sand has been deposited. These sediments are shown in orange on the map.

Clay and gyttja are also still being deposited in the shallow sea areas, bays and lakes.

Within the investigation area there are lots of small shallow meres where gyttje sediment is being deposited today, but these will soon silt up and contribute to a small-scale mosaic in the landscape. And so the evolution of the landscape continues ...

101 Soil wells

During the site investigation we have drilled a total of 101 soil wells. The soil wells go from the surface, through the overburden and several decimetres down into the rock. If we add them together we have drilled a total of 572 metres of soil wells. They vary in depth between two and 18 metres, which means that the soil depth varies greatly in the area.

Let's talk about **the weather**

Hot summer

In terms of the average temperature, the summer of 2006 was the hottest during the measurement period. The mean temperature for the three summer months was 17.5 degrees, with a peak of 19.0 in July.

The coldest summer was in 2004, with an average temperature of 15.3 degrees. The mean temperature for the other summers varied between 15.5 and 16.4 degrees.

Interview

Expert's post script

Name: Anna Hedenström, Quaternary geologist

Quaternary geologist at the site investigation in Forsmark 2003–2006. Participated in 1998–1999 in the feasibility study as a doctoral student at Stockholm University.

"I came to Forsmark in the autumn of 2002 to participate in the work of detailed Quaternary deposit mapping. I continued with that work and lake sediment investigations in 2003. Then we accumulated more knowledge about the soil layers in Forsmark. Now we are compiling and analyzing everything we have collected and are using in modelling. The site is a little special with its shallow lakes, which are really closed-off sea bays. It is a young area; Fiskarfjärden in particular is, geologically speaking, a very young lake, created just a few years ago."

Anything specific about the site?

"It is typical of the northern Uppland till coast with large boulders along the shore. The soil is very lime-rich, so there are plenty of orchids. The area is flat on the surface, but we were surprised when we drilled and dug through the soil layers. The flatness does not continue beneath the surface, which conceals a slightly undulating landscape. The thickest soil layer on land is 18 metres deep, and only five per cent of the area consists of exposed rock outcrops."

Surprises?

"Well, both yes and no. We had already seen some phenomena in the site investigations for construction of the nuclear power plant, for example the very hard clayey till called 'Old Blue'. It is so hard that you might think from the geophysical measurements that it was low-velocity rock. We also 'rediscovered' the open soil-filled fractures in the upper surface of the rock that were noted in the 1970s. We took samples of the soil in the fractures beneath the uplifted rock and found that it seemed to have been formed at roughly the same time as the overlying till."

Any particular difficulties?

"No, I wouldn't say so. But we had to show great consideration for the environment. In the investigations of the sea sediments we had to take both the white-tailed eagles and the ice conditions into consideration; that didn't leave so many days for possible field work. We also mapped on the nuclear power plant site, which you don't often do as a geologist."

What will you do now?

"I will continue to work on the soil depth model for the analysis group. I have also done some mapping in Värmland for SGU and have been made programme director for SGU's study programme."

Let's talk about the weather

The coldest day

The coldest temperature during the measurement period was measured at 3:30 a.m. on 15 March 2005, when the mercury fell to minus 20.5 degrees Celsius.

The coldest temperature other years was measured at 10:00 p.m. on 22 January 2004: minus 16.7 degrees. On 13 March 2006 it was minus 19.0 degrees at 6:30 a.m. in the morning, and on 22 February it was minus 20.2 at midnight.

Forsmark today

Today's Forsmark is a low-lying forest and shore area with special natural values that are not obvious at first glance. But after nearly six years of site investigation we can draw a clearer picture; the landscape is varying, the soil is lime-rich, the fauna is varied and the flora is unique in some respects. Beneath the surface lies the basement rock, water-rich at the surface but progressively drier at depth.

The terrestrial system (what we normally call "land") in Forsmark is rather young; the highest parts of the area rose out of the sea around 2,500 years ago. Large parts of the area are forested. The vegetation in the area bears witness to the lime-rich soil. Spruce and pine are dominant tree species in the forests, and the undervegetation consists largely of herbaceous plants and broad-leaved grasses, with a great number of orchids. The wooded areas contain some old-growth forest (virgin forest), but large parts consist of clear-felled areas in different stages of regrowth.

High water table

The groundwater table is generally fairly high in the area, which means there are quite a few wet tracts. Some of them are only wet during the spring, while others are permanently wet. There are, for example, some very fine meres (ponds) that are isolated from other aquatic environments (lakes and watercourses). There are no fish in them, which makes the species composition a little different. The red-listed pool frog (Rana lessonae) has been introduced in some of them. The pool frog is dependent on shallow and fishless small bodies of water for its survival. An inventory by the County Administrative Board shows that the releases in four of the area's small bodies of water have been successful; the species has survived and is reproducing.

The dominant terrestrial mammal is roe deer. Moose is also common, while hare is slightly less common than in other areas. The number of wild boar has increased sharply during the site investigation period. There are lynx in the region, and wolves visit sporadically.

Photo: Magnus Nyman

Mammals were inventoried during the first years of the site investigation as well as the last. A comparison of the results shows that wild boar, fox and squirrel have increased in number, while roe deer have decreased.

Lots of birds

In general, it can be said that the Forsmark area hosts a large number of bird species, both common species and species that are included on the Swedish Red List and/or in the EU's Directive on the Conservation of Wild Birds (Birds Directive). This is due to the fact that the area is situated on the border between northern and southern fauna regions, and that the area contains a mosaic of biotopes. The fact that the area has not had many visitors is also of importance. The number of individuals of different species varies naturally from year to year. The results of the inventory done in 2007 suggest that the number of individuals this year exceeds the number recorded during the first year of the site investigation (2002–2003).

Shallow lakes

The lakes in Forsmark are a little special. They are shallow and clear and are usually classified as oligotrophic hardwater lakes – in other words they contain a lot of lime but little nutrients. The lime is part of the explanation for the low nutrient content; phosphorus is assumed to be precipitated along with lime and ends up on the bottom of the lake, where it is not available as a nutrient for plants and plankton. Another reason is that the lakes are surrounded by forested areas

that do not release as much nutrients as agricultural land. This type of lake is not particularly common in Sweden as a whole but is common in this region, the northern coast of Uppland.

The lakes are so shallow that the entire bottom is sunlit, so there is no limitation on the spread of the benthic vegetation. The seabeds are therefore almost entirely covered by vegetation. The dominant species is a group of algae called stoneworts. Stoneworts thrive in nutrient-poor water and store lime in their "skeleton".

Stoneworts grow in the summer and wither in the autumn and winter. In the summer they grow so thickly that it can sometimes be difficult to navigate the water in a boat, since you get stuck in them. Stoneworts in themselves do not seem to be particularly appetizing; few animals eat them. Various groups of organisms live in the thick growth; it is a good place to hide if you are a small fish, for example. Perch and roach are common species in the lakes of Forsmark, as are tench and crucian carp. Crucian carp can survive low oxygen concentrations. It is therefore found in some of the really small lakes, which are almost completely silted up. The oxygen concentrations in these small pools can be very low during the winter.

Thick algal mat

Another detail that distinguishes the Forsmark lakes from many other lakes is the particularly thick layers of algae on top of the lake's bottom sediment. In everyday speech we call this an algal mat. It consists mainly of cyanobacteria, which form a clearly visible green layer in the sediment cores from the lake beds. The thickness varies within individual lakes, between different lakes, and over the year.

Some of the lakes are not yet completely cut off from the sea due to small level differences. This is particularly true of Norra Bassängen Lake, which receives influxes of salt water from the sea during extreme weather situations. Thus, water can "run backwards" in these systems under very strong low pressures (high sea levels).

> ***...there are very beautiful areas, such as Storskäret, which I fell in love with from the start.***
>
> Sara Nordén
> Site ecologist

Watercourses

The watercourses in the Forsmark area are very small and are more like excavated ditches than natural streambeds. At certain places the sides are nearly two metres high, giving the impression that great pains were taken in the past to try to increase the production of the surrounding forest land. Unlike the largely untouched lakes, the watercourses in the area have no known natural values. Long stretches dry up during the summer months.

The migration of spawning fish was studied one spring in the little stream that connects Norra Bassängen Lake with the Baltic Sea. Large quantities of ruffe, perch and pike migrated in to spawn in the area's lakes.

The marine area in Forsmark is of varying depth with a few more or less closed-off bays that are affected by fresh water, a more open but shallow archipelago, and open sea areas with high exposure to currents and waves. Kallrigafjärden, which borders on the eastern part of our investigation area, is heavily affected by all the fresh water that is carried into it via the Olandsån and Forsmarksån rivers. The bay is shallow with thick vegetation. It is used frequently as a stopover area by migrating seabirds on their way south. Parts of the bay are protected and are off limits during the period 15 July – 15 October.

The more exposed marine areas harbour different kinds of algae, such as bladderwrack. There are also large amounts of water moss (willow moss, *Fontinalis sp.*) in the coastal area. This moss is common in watercourse but is also found in lakes and brackish water. Further south in the Baltic Sea it disappears, probably because the water becomes too saline. The dominant species of benthic fauna in the area is the Baltic Tellin mussel (*Macoma balthica*). The most common fish species in Öregrundsgrepen are Baltic herring, roach and perch.

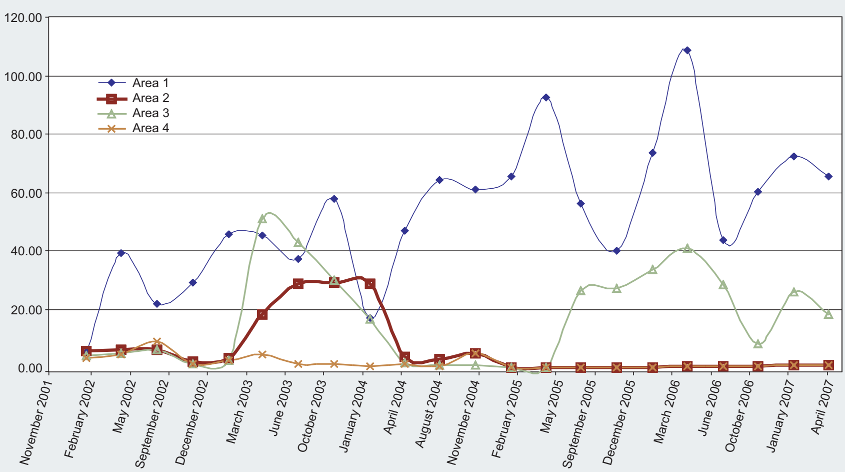
Warm water from the nuclear power plant's cooling water discharge provides a special environment in the artificial Biotest Lake and its outlet in Öregrundsgrepen. The environment has not been included in the site investigation, since a lot of information has previously been collected by the National Board of Fisheries.

Sparsely populated

The Forsmark area is very sparsely populated. There are a few permanent residents in our investigation area, but some vacation homes. Agriculture is practiced on Storskäret by farmers who do not live there. Otherwise the land in the area is mainly used for forestry. Other activities include hunting and mushroom and berry picking.

Disturbances in the field

Field activities during the different years and quarters of the site investigation are presented here. Area 1 is the area nearest the power plant where we have the most drilling sites and therefore the most activities. Area 2 is the area nearest Storskäret, where we only have one drilling site that was drilled in 2003 and early 2004. Area 3 is located outside the candidate area – around Gällsboträsket – while area 4 is located south of Fiskarfjärden closer to Johannisfors, where there have been few field activities. Compare with the map of drilling sites on page 108.



Did the site investigation have consequences?

The site investigation has entailed a significantly greater human presence in the Forsmark area compared with before. Besides the physical presence resulting from land occupied by drilling sites and various kinds of measurement installations, the number of people moving about in the area has increased substantially, resulting in more noise from traffic and sometimes from the actual investigations (for example the seismic surveys). The presence of people moving about in the forests can also disturb certain animal species. See box on page 44.

It is not always easy to measure or estimate the effects of disturbances. We have chosen to follow the range and breeding success of a number of sensitive bird species in the investigation area during the entire site investigation. The results show that the bird fauna has generally experienced an upswing between 2002–2003 and 2007. This agrees relatively well with what is happening at the national level. If the candidate area is compared with the regional model area, both have experienced upswings, but more outside the candidate area than inside.

If we look at a few selected species, we find for example that the black-throated diver (arctic loon) is stable in terms of the number of pairs and had two successful breedings in lakes during 2007. The honey buzzard had the largest number of occupied territories and good breeding success in 2007. The white-tailed eagle had an "in-between year" where half of the pairs bred successfully. The osprey is stable and had a good breeding year in 2007.

The same cannot be said of the Ural owl, which did not manage to produce a single chick. The lesser spotted woodpecker continues to increase, and there were once again more occupied territories in 2007.

Land has been exploited here and there in the area. Most cases involve establishment of drilling sites or the new road that was built in the initial phase. It was built so that the property owners at Habbalsbo would not be bothered by heavy goods and passenger traffic. Otherwise only a few road sections have been built between existing roads and drilling sites.

Interview

Expert's **post script**

Name: Sara Nordén, ecologist

Site ecologist 2002–2007 in Forsmark. After the site investigation was concluded she moved to the analysis unit in order to compile data on lakes and watercourses as a basis for the safety assessment.

"To me, Forsmark was just a blank spot on the map. I had never been here and I had no field experience. The investigation area isn't so big, but it's varied. It includes everything from clear-felled areas to virgin forest. There are also very beautiful areas, such as Storskäret, which I fell in love with from the start."

When you look back, what do you see?

"My discipline is very broad and I have learned a great deal. I have also learned from others. Our activity leaders all knew different things, so the conversations we had around a cup of coffee were both entertaining and educational. It was also nice to be able to alternate office work with field work."

"It was a fun time, and I realize now I will probably never get to do anything as wide-ranging again. I will look back on the site investigation as a special period in my career with a lot of work but also many experiences. Not least nature experiences – it was thrilling to see lynx tracks for the first time, to see white-tailed eagles almost daily, to row across shallow lakes and look at beautiful stoneworts, to see orchids everywhere and patches of cowslips where I would least expect them: in the midst of a spruce woods. That's due to the lime-rich soil, which makes the site unusual in many more respects. Furthermore it's a pristine area, and those are hard to find nowadays."

Was it your duty to "guard" the natural environment?

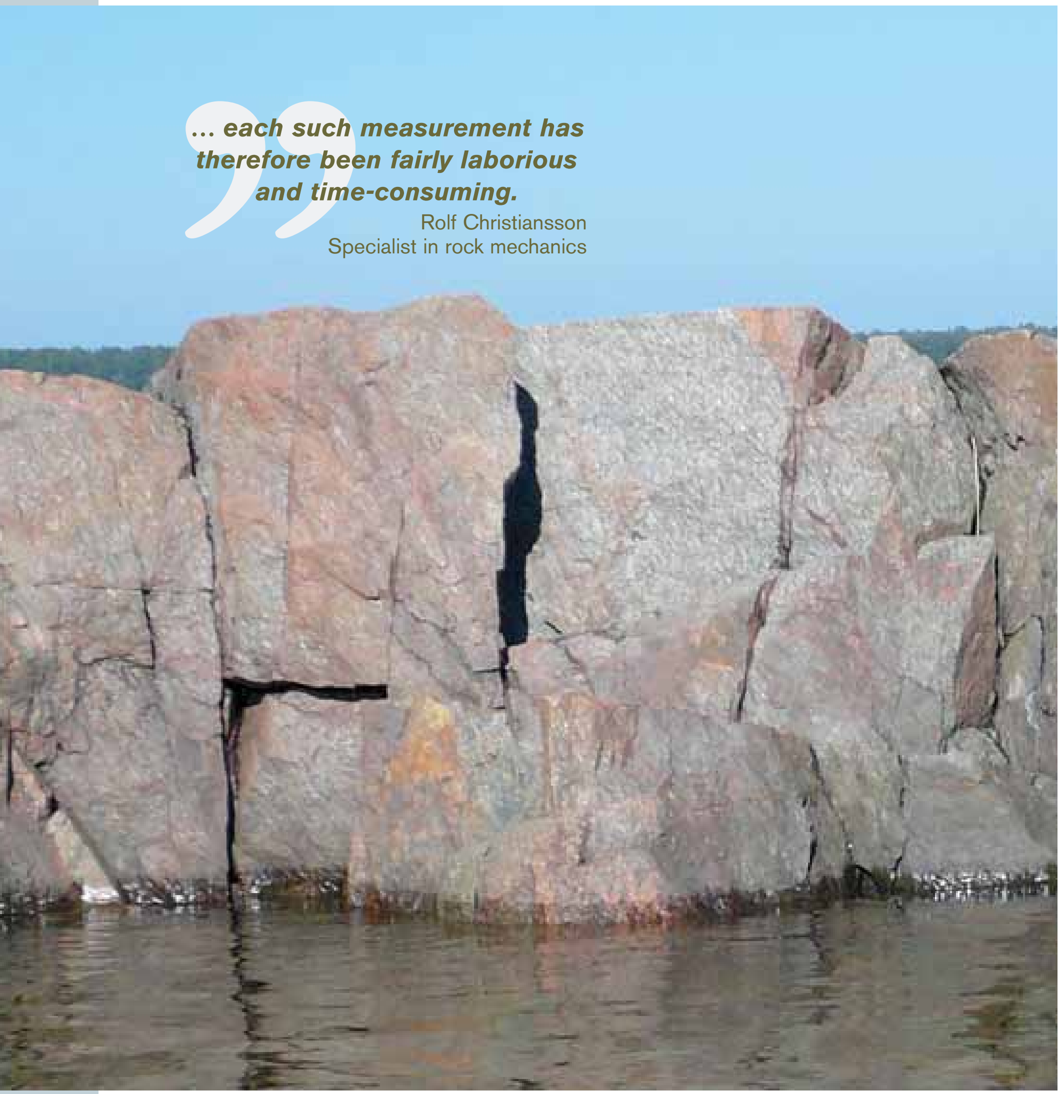
"Yes, it was, and it wasn't always easy to do. It took some time to find the right tone when I had to draw the line for colleagues who wanted to get things done out in the field but had to back off out of consideration for the environment. I felt I had management behind me when I guarded the area against disturbances – we had an obligation to be careful."

Rock stresses in Forsmark

Knowledge of the rock stress situation in the Forsmark area exists from construction activities there in the 1970s. The stresses were also thoroughly investigated during the construction of SFR in the mid-1980s. The results indicated that the area might have an elevated stress state compared with what is considered more normal in Sweden.

What are rock stresses?

Describing rock stresses – loads in the rock – entails describing a state, not a property. The weight of the rock itself gives rise to stress, which is usually given as weight per unit area. If a pillar of rock one metre square were cut out down



… each such measurement has therefore been fairly laborious and time-consuming.

Rolf Christiansson
Specialist in rock mechanics


Stina Åstrand, Vattenfall Power Consultant, and Rolf Christiansson, SKB, are shown here measuring rock stresses by means of the overcoring method.

to a depth of 500 metres it would weigh approximately 1,300 tonnes. That weight per square metre exerts a stress of 13 MPa. However, in old bedrock such as that in Scandinavia, the horizontal stress at depth is normally greater than the vertical stress. This is due to the large-scale tectonic forces that act on the Earth's crust. How large the horizontal stress is compared with the vertical stress depends on a number of factors. The less fractured the bedrock is, the more common high horizontal stresses usually are.

The importance of rock stresses

The rock stresses subject the rock at depth to a pressure from all directions, mainly horizontal. When a tunnel is built, the stresses are concentrated around it. The shape and orientation of the tunnel in relation to the greatest stress at great depth are of importance for whether the rock around the tunnel will remain stable or not.

If the strength of the rock is exceeded it will spall out towards the tunnel, at least locally. Since the rock is brittle, this can in extreme cases be an explosive event. This may be noticeable during the construction period, mainly as a working environment problem. It can affect the costs. Furthermore, uncertainty as to how much the rock has been loosened up nearest the tunnels and deposition holes due to high stresses may have a bearing on the assessment of the repository's long-term safety.

Different methods

The stress state can be measured by different methods. We have mainly used two independent methods. The basic principle is that a disturbance is created in one borehole and the response is then measured. Then the stresses are evaluated under certain assumptions concerning the material properties of the rock. Quality assurance of the measurement therefore includes all aspects of the actual measurement, as well as separate investigations to clarify to a reasonable extent whether the conditions and premises for each method are met. Each such measurement has therefore been fairly laborious and time-consuming.

The same measurements using the same methods have been carried out in parallel in the site investigation in Oskarshamn. Taken together, the results show that the methods have worked as intended in Oskarshamn and down to a depth of about 250–400 metres in Forsmark.

At greater depths in Forsmark, the usefulness of both methods has been limited, since the different conditions that have been assumed have not fully prevailed. This has led to a need for different studies of the measurement methods, the measuring equipment and the mechanical and thermal properties of the rock in which the measurements have been made. To gain a greater understanding of the processes that influence stress-induced failure in rock, we have conducted theoretical studies of this phenomenon in our hard rock laboratory on Äspö, where we have been able to initiate high stresses in tunnels at a depth of 450 metres and study the failure mechanisms.

Confidence in the methods

This experience has helped us create confidence in our measurement results. We have also learned that the failures that can be expected are in principle scale-independent. This means that the failures that could occur around a deposition hole could also occur around one of our investigation holes. With the support of careful geophysical measurements in our boreholes showing among other things the shape of the borehole – and thereby whether any rock fragments have fallen out due to high stresses – we have seen that

The German company MeSy Geo carried out hydraulic fracturing to measure the rock stresses at different levels at drilling site two. Investigation Leader Gerd Klee is shown in the picture.

We can build a final repository at a depth of at least 500 metres.
Rolf Christiansson
Specialist in rock mechanics

there are very few such observations down to a depth of 1,000 metres. We have thereby been able to set a limit on the greatest stress we could expect to encounter at great depth in Forsmark.

Since this estimated stress agrees well with the few credible measurement results we have managed to obtain at a depth of about 500 metres, we feel sufficiently sure that we could build a final repository in Forsmark without encountering stress-induced problems that could affect safety during the construction period. Nor do we believe that the rock stresses at this depth cause systematic loosening of the rock nearest tunnels and deposition holes that has an adverse effect on long-term safety.

We would not have been able to learn this without the broad participation of various specialists, both in Sweden and abroad. The technology development and quality assurance of measurement methods we have carried out, as well as the research results we have obtained concerning failure mechanisms in rock, have aroused international interest.

Results

We have concluded that the stresses existing in the investigated area in Forsmark are consistent with the geological conditions in the investigated tectonic lens. Already in the upper 100–150 metres, where the rock is characterized by gently-dipping, open and water-conducting fractures, we have measured horizontal stresses on the order of about 20–25 MPa. There are no similar observations in Sweden of this stress level so near the surface.

With increasing depth, where the fraction of open fractures in the rock is small, the stress increase is relatively even. We judge that at a depth of 450–500 metres, the greatest stress is 40–45 MPa. This is high compared with, for example, conditions at the Äspö HRL, but not in relation to what the rock in Forsmark could take if we build tunnels at that depth.

The main cause of the high stresses is the homogeneity and strength of the rock. The same prerequisites for such a build-up of rock stresses do not exist in a more fractured rock mass.

The main conclusion of ongoing rock mechanical studies in connection with the design of a final repository in Forsmark is that we can build a final repository at a depth of at least 500 metres without this causing any significant stress problems.

Interview

Expert's post script

Name: Rolf Christiansson, Specialist in rock mechanics

Activity leader at the site investigation in Forsmark since 2002. Employed at SKB since 1999, before that consultant. Participated in the design and construction of SFR in Forsmark in the 1980s.

"When I arrived at the site investigation in 2002 I was already very familiar with the site. The problem I was assigned to tackle was also very familiar. Since the construction of the nuclear power plant in the 1970s, it has been known that the rock in Forsmark has relatively high rock stresses. I also knew that we were faced with an advanced project in terms of measurement technology. There were lots of discussions of measurement methods."

How did it go?

"It was even more difficult than we expected. I have overrun many budgets in my efforts to obtain reliable and quality-assured measurement results. You could say we have accomplished a difficult task involving many problems. But on the other hand I have been allowed great freedom to develop methods and use international expertise. I have personally learned a lot, but we have also made new discoveries in rock mechanics. This has been useful to us in the site investigation in Oskarshamn, where I have also been activity leader."

"Rock stress is not a property but a state. By measuring disturbances in the rock caused by drilling or pressure changes, we have tried to calculate the stress state using different methods. Different methods are based on different assumptions. A major task has been to check that conditions and assumptions for our measurement methods have been met."

Results?

"The results have taught us a great deal about both measurement methods and the site. The possibility of conducting some theoretical studies in parallel at our hard rock laboratory on Äspö has helped us gain a better understanding of processes and measurement methods. Now I feel secure in our knowledge of the rock stresses in Forsmark. We know now that there will be no problems building a final repository at a depth of about 500 metres. We have achieved the knowledge level that is possible without going under ground. The programme we have carried out to quality-assure the data is among the most extensive in the world. It has also aroused some international attention."


SKB
SKB

Interview

Expert's post script

Name: Göran Nilsson, MSc. Eng.

Drilling manager throughout the site investigation.

"I have been working in SKB projects since the 1970s, but I knew nothing about the rock in Forsmark before I came here in 2002. Rumours in the rock business talked about high rock stresses, which usually means good and intact rock. And lo and behold: the rumours were true, the rock at depth was mainly dry and intact!"

Your first impression when you started drilling?

"Depressing! Water came gushing out of all holes, and I thought to myself, 'That's that with Forsmark'. But after the summer vacation in 2002 – which was not a fun vacation! – things improved and we started bringing up intact drill cores from dry rock. We got no water at all, so first we thought there was something wrong with our gear. But there wasn't, the hydrotests confirmed the dryness. Then the same picture was repeated in our other cored borehole – first lots of water in the superficial rock, and then dry as a bone at depth ..."

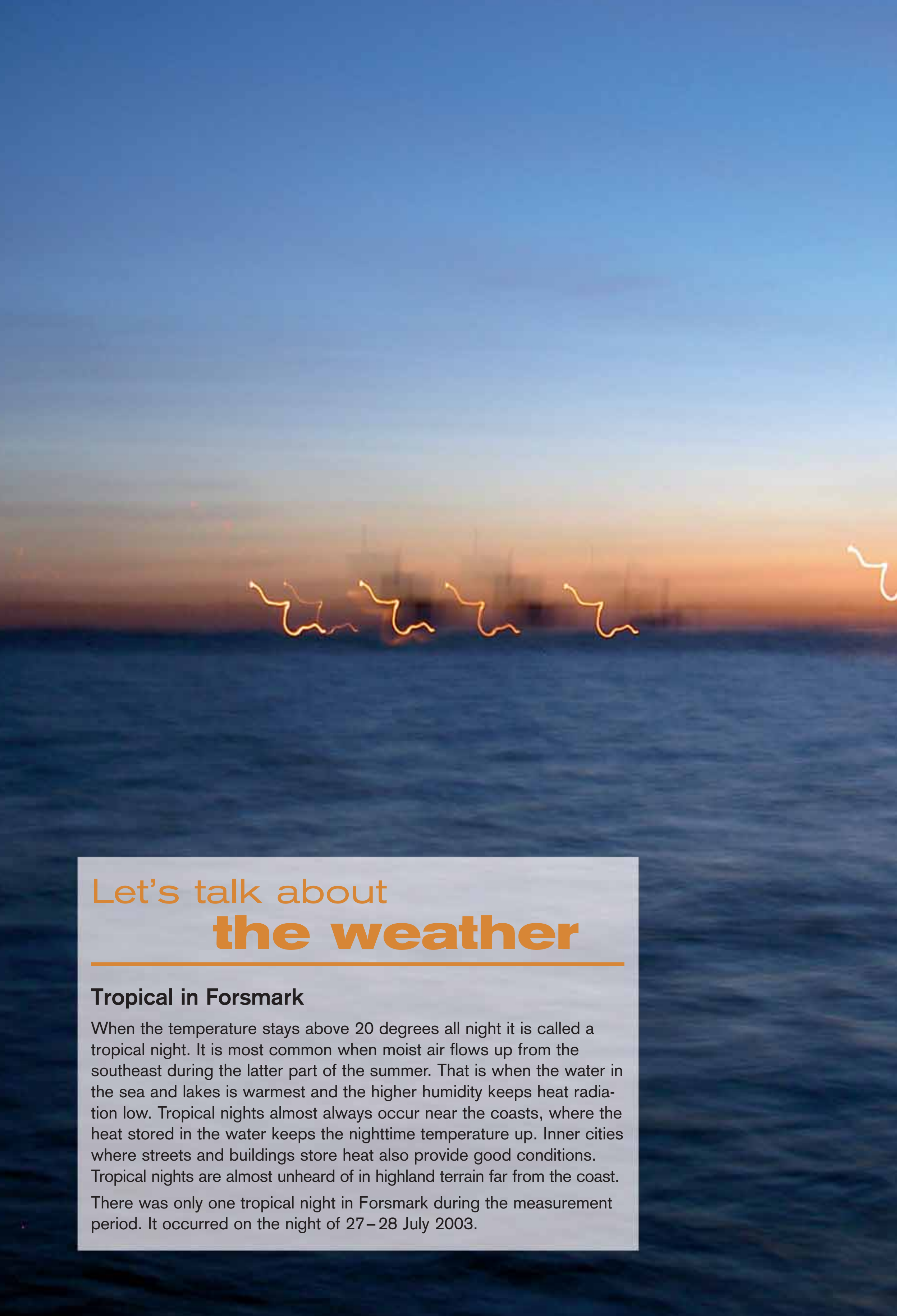
And then?

"The pattern was repeated in more boreholes, and our picture of the rock started to clarify and was then confirmed. In the fifth cored borehole we started counting intact cores – such intact rock was actually not quite normal. I stopped worrying, things calmed down in the organization, we stopped tip-toeing around, you could say. We knew what kind of rock we had, and ultimately we began to think intact drill cores were normal rather than exceptional. The only disadvantage was that the drill bits wore out twice as fast as in ordinary granite. In the beginning it was a challenge to find good equipment to work with."

All's well that ends well?

"You could say that. It is also thanks to the good quality of the rock that we have been able to carry out the drilling programme largely without problems."

"The pace has been high for five years, I couldn't take five more at the same pace. 190 nights sleeping in the barracks per year is a few too many. Now we are doing some supplementary design work and are waiting for permission to test-drill for the SFR extension. It will be a new start – we're going down into the repository beneath the sea to drill."



Let's talk about the weather

Tropical in Forsmark

When the temperature stays above 20 degrees all night it is called a tropical night. It is most common when moist air flows up from the southeast during the latter part of the summer. That is when the water in the sea and lakes is warmest and the higher humidity keeps heat radiation low. Tropical nights almost always occur near the coasts, where the heat stored in the water keeps the nighttime temperature up. Inner cities where streets and buildings store heat also provide good conditions. Tropical nights are almost unheard of in highland terrain far from the coast.

There was only one tropical night in Forsmark during the measurement period. It occurred on the night of 27–28 July 2003.

Water in Forsmark

Any picture we draw of how the water moves in the investigation area, on the surface and down in the rock centres on two conditions: wet and dry. The rock exhibits these two distinct sides: there is rock with a lot of water and there is rock with little water.

Let us start with the water that falls down over the investigation area in the form of rain and snow. Precipitation has been measured at two stations in the site investigation area since the middle of May 2003. It amounts to about a half a metre of precipitation per year. To be exact, the annual mean precipitation during the four-year period June 2003 – May 2007, corrected for wind losses etc., was 555 millimetres. This can be compared with a normal value of 559 millimetres per annum. The normal value was determined by SMHI for the 30-year period 1961 – 1990, based on data from surrounding SMHI stations.

Altogether, precipitation was nearly normal during the period, but the difference between the wettest and the driest year was nearly 100 millimetres.

Based on the site investigation's measurements of temperature, wind, relative humidity and global radiation, potential evapotranspiration (see explanation) has been calculated to be 526 millimetres per year.

From rainwater to groundwater

Some of the precipitation is caught in the vegetation and evaporates before reaching the ground. The rest infiltrates the soil or runs off as surface water. The soil's infiltration capacity is generally so great that all water infiltrates except in areas where the groundwater table is at the ground surface for all or parts of the year. The infiltrating water refills the soil water reservoir and forms groundwater.

How this groundwater flows is determined not only by groundwater recharge (infiltration) but also by the topography and the hydraulic properties of the soil and rock strata. The terrain in the site investigation area is flat with a small-scale topography. Nearly the entire area is lower than 20 metres above sea level.

As explained in the section on Quaternary geology (page 32), till is the dominant type of soil. It is usually silty-sandy, but in the Storskär area it is clayey. The hydraulic properties of the till are characterized by a permeability that declines

WE EXPLAIN

Evapotranspiration, evaporation of water from ground covered with vegetation. Evapotranspiration consists partly of evaporation from bare ground, open water (puddles, snow cover etc.) and free water (rain or snow) on the vegetation, and partly of transpiration of water that passes through the plants from the soil.

Bolundsfjärden.

from the surface down to a depth of just under one metre. It declines from $K>10^{-5}$ m/s near the ground surface to about $K=10^{-6}$ and 10^{-7} m/s deeper down in the coarser and finer till, respectively. Furthermore, the total porosity of the till decreases from about 35 percent at the ground surface to barely 25 percent deeper down. The fraction of the porosity that is drained when the groundwater table falls also declines with depth, from about 15 percent at the ground surface to 3–5 percent deeper down.

This means that even a very limited groundwater recharge results in a substantial rise of the groundwater level when the groundwater table is located a little deeper down. Ten millimetres of water input causes the water table to rise by 20–30 centimetres. The groundwater then rises quickly to the uppermost and most permeable levels of the soil profile. Due to the topography and the hydraulic properties of the till, most of the groundwater flow takes place in small and superficial systems.

High groundwater level

The groundwater level in the soil layers is located less than a metre below the ground surface for most of the year in the greater part of the site investigation area. The near-surface groundwater is affected indirectly and directly by the plants' water uptake. This is illustrated by 24-hour variations in the superficial groundwater levels, caused by variation of evapotranspiration during the day, and by the fact that the groundwater level in the vicinity of the lakes is lowered below the level of the lake surfaces under dry summer conditions.

Higher in soil than in rock

At the places in the central investigation area, within the tectonic lens, where the groundwater level is measured in both soil and rock, the groundwater level in soil is generally significantly higher than in rock. This means that the necessary conditions exist for a groundwater flow from soil to rock, but the relatively large level differences indicate that the hydraulic connection is relatively poor and the flow is thereby small.

Within the tectonic lens, the groundwater levels in rock are very equalized and lie just below sea level. The equalized and low levels can be assumed to be due to the highly penetrative horizontal and subhorizontal fractures present in the uppermost parts of the rock. The limited fraction of the groundwater recharge that enters the rock can be drained off in these fractures at even very small gradients.

Surface water runoff

The superficial groundwater flows out into wetlands, watercourse and lakes and becomes runoff. Surface water runoff has been measured in four stations in the site investigation area. The first station, which measures the runoff from a 5.6 square kilometre area upstream of Bolundsfjärden, was put into use in April 2004. The mean runoff at this station during the three-year period June 2004–May 2004 was 26.1 litres per second, which is equivalent to a specific runoff of 147 mm/y

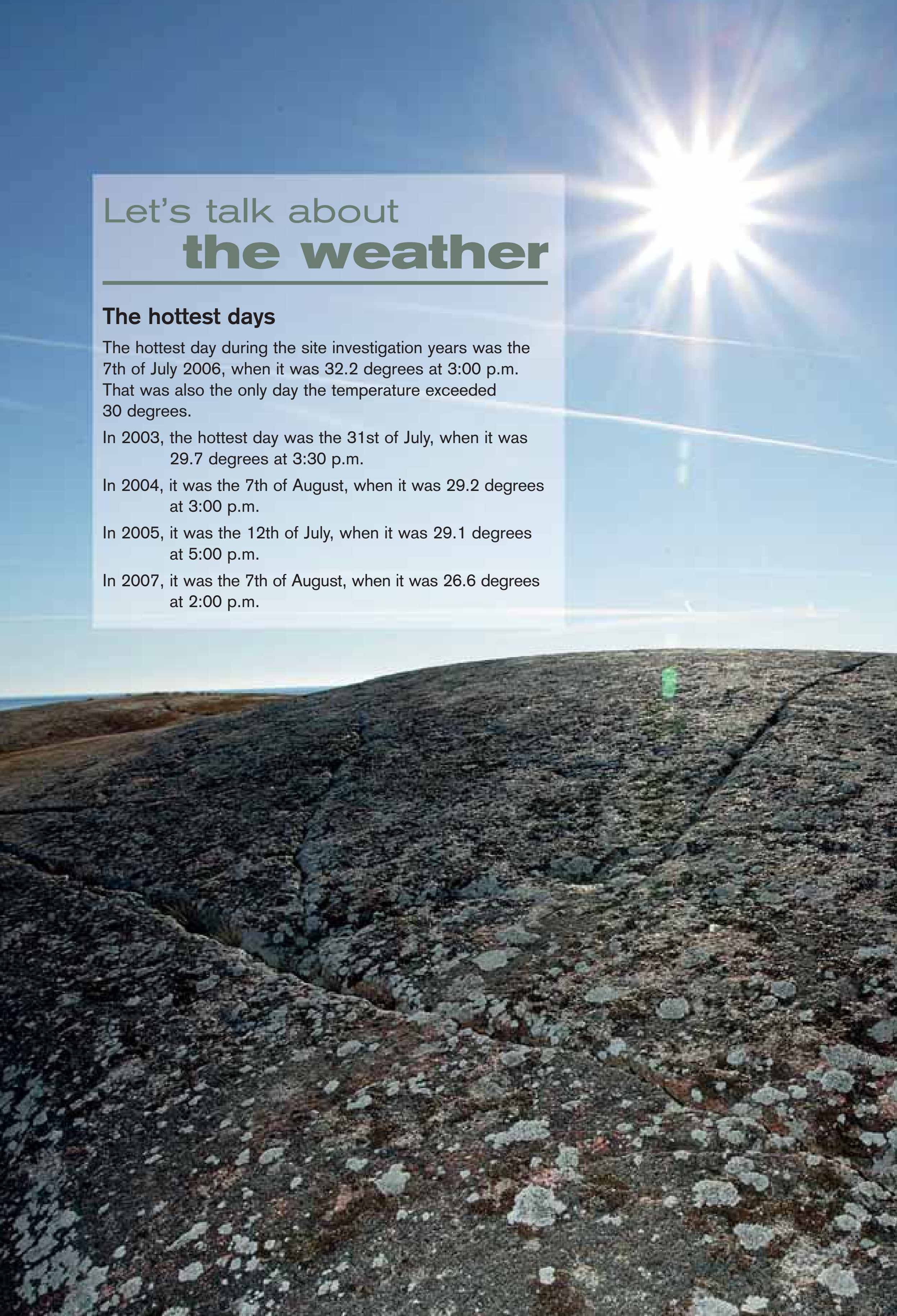
Niclas Karlsson measures depth to groundwater table.

(4.67 L/s/km^2) and can be compared with the mean precipitation of 534 mm during the same period.

The measurement series for precipitation and runoff from the site investigation are too short to say anything definite about normal values for the water balance, but based on the measurement results and comparisons with SMHI's nearby precipitation stations, normal precipitation can be estimated at about 560 millimetres/year, runoff at 160 millimetres/year and actual evapotranspiration thereby at 400 millimetres/year.

> ***Most of the groundwater flow takes place in small and superficial systems.***
> P-O Johansson
> Hydrogeologist

Monitoring stations for water in the northwestern part of the candidate area.



Let's talk about **the weather**

The hottest days

The hottest day during the site investigation years was the 7th of July 2006, when it was 32.2 degrees at 3:00 p.m. That was also the only day the temperature exceeded 30 degrees.

In 2003, the hottest day was the 31st of July, when it was 29.7 degrees at 3:30 p.m.

In 2004, it was the 7th of August, when it was 29.2 degrees at 3:00 p.m.

In 2005, it was the 12th of July, when it was 29.1 degrees at 5:00 p.m.

In 2007, it was the 7th of August, when it was 26.6 degrees at 2:00 p.m.

Interview

Expert's **post script**

Name: Per-Olof Johansson, hydrogeologist

Has participated in the site investigation since 2002, Activity leader for the meteorological, hydrological and near-surface hydrogeological investigations since 2003.

"Forsmark is characterized by small topographical differences in the till-dominated landscape. In other words, the landscape is flat. In large parts of the investigation area the groundwater is near the ground surface, on average less than one metre deep. The groundwater table follows the topography of the land surface closely, which means that the area has many small superficial groundwater flows. This is not unusual, that's how it usually is if the landscape looks like it does in Forsmark."

Any practical problems?

"No, not really. I feel quite content. What's more, the work has been very interesting considering how many disciplines have been involved. The amount of material we have collected is unique."

Have you found anything particularly interesting?

"I can mention a few particulars: The vegetation around the shallow lakes in the area absorbs so much water that the groundwater levels are periodically lower than the lakes. Another example is that twice – in January 2005 and January 2007 – storms (Gudrun and Per) have caused the sea to run into the shallow lakes, inundating them with salt water. Usually the opposite happens – the water in the lakes runs out into the sea …"

"It's also very interesting that where we measure the groundwater levels in soil and rock at the same place they are higher in soil, especially in the central parts of the investigation area. We interpret this as indicating that because the permeability of the till decreases with depth, most of the water runs in the soil layers nearest the surface. The small amount of water that percolates down into the rock can be carried off in the highly permeable superficial rock at even small inclinations of the water table in the rock."

What will you do now?

"I still have some work to do when it comes to reporting results to analysis. I will also participate in the follow-up of the Sida (Swedish International Development Cooperation Agency) project to save the temples of Luxor and Karnak in Egypt. The temples of the Pharaohs are threatened by rising groundwater levels. I am also involved in investigations for new sources of drinking water in Hudiksvall and Örebro."

Photo Björn Ullhagen

Water in the rock

The two sides of the rock, the wet and the dry, are opposites in many respects, which goes far in explaining the results of our measurements. The "wet part" is closest to the ground surface, in other words the upper parts of the rock within the tectonic lens are highly conductive. A well drilled here yields on average 20 times more water than the average well in Sweden.

One reason for this is that the gently-dipping/horizontal fractures that occur near the ground surface are highly water-bearing.

These gently-dipping fractures are also very extensive. Pumping tests in the "wet part" show that wells drilled at different places communicate with each other, in other words pressure changes are propagated very rapidly through, and over great distances in, the superficial gently-dipping fractures.

As an example it can be mentioned that in pumping tests it is not unusual to observe an effect half a kilometre from the pump hole after only ten minutes of pumping.

In the "dry part", i.e. the rock beneath the gently-dipping surface fractures, the frequency of water-conducting fractures gradually decrease with depth, and below 200–300 metres there are very few water-conducting fractures.

This is what it looked like when the cooling water channel to the nuclear power reactors was blasted in the 1970s. In the channel wall you can clearly see the long horizontal fractures that are so typical of the upper part of the rock in Forsmark. Photo: Göran Hansson/N

Another typical Forsmark phenomenon: Long, intact drill cores in three-metre lengths retrieved from the deep rock. Christian Steen carries drill cores from drilling site five at Bolundsfjärden.

Jakob Levén, Activity leader for water in rock.

Superficial groundwater flow

Due to the flat topography in Uppland – which is located on the Precambrian peneplain (see explanation) – it is mainly the local topography in Forsmark that determines how the water in the rock moves. The groundwater level in the superficial rock in large parts of the investigation area is very close to sea level. A working hypothesis is that the gently-dipping, highly water-conducting fractures in the uppermost 100 metres of the bedrock are connected to the Baltic Sea and thereby act as a topographical low point, and that this controls the water flows in the area. The water that does not run off on the surface and is not taken up by plants seeps down in the soil and into the rock until it meets the gently-dipping fractures and is carried out to the Baltic Sea.

Dominant zone

Within the investigation area there are a number of water-conducting gently-dipping fracture zones that slope gently towards the southeast. The most dominant zone, A2, divides the investigation area into two parts: above and beneath zone A2. The rock beneath A2 has very few fractures, and there are very few water-conducting fractures below a depth of 300 metres. It is on this rock that we have focused our investigations, and the volume is criss-crossed by a dozen or so cored boreholes. This is the "dry part" of the rock.

The rock above A2 located in the southeastern part of the investigation area is criss-crossed by several gently-dipping zones similar to A2. They are all water-conducting, and pumping tests between different boreholes have shown that they are very extensive. See map of the drilling sites on page 108.

WE EXPLAIN

A peneplain is a flat, horizontal erosion surface that has been worn down by the action of the elements, such as wind and water. In Sweden, the Precambrian peneplain is the flat basement rock surface on which the Cambrian rocks were deposited. By "Precambrian" is meant the time more than 570 million years ago.

Let's talk about **the weather**

Midsummer in Forsmark

The hottest Midsummer Day during the site investigation was in 2006. The mean 24-hour temperature on 24 June 2006 was 16,3 degrees. The temperature on the other Midsummer Days was as follows:

21 June 2003 – 11.8 degrees.

26 June 2004 – 14.3 degrees.

25 June 2005 – 13.1 degrees – and 23 June 2007 – 14.4 degrees.

Interview

Expert's post script

Name: Sven Follin, hydrogeologist

Engaged back in 1995 in the feasibility study as a hydrogeological expert. Activity leader for hydrogeology in Forsmark and Oskarshamn during the first years of the site investigations. Others then assumed these duties while Sven Follin continued in the role of specialist in charge of hydrogeology in the Forsmark site modelling project.

"The job of activity leader was too much for me, and we needed help. The data quantity increased and more questions needed to be answered, both near the surface and at depth. This became particularly evident when we started the modelling and analysis work."

How has it gone?

"I have a strong feeling that we have managed to get a very good total picture of the site. Perhaps I can use the expression 'credible insights'? But getting here has been an arduous and stressful journey. We have succeeded thanks to very good leadership and fantastic cooperation, as well as lots of helpfulness between activity leaders and modellers."

What about the results?

"Forsmark is special and the picture is clear. Superficially we have gently-dipping zones that are heavily conductive within large areas. I have really never seen anything like them! Beneath them the rock is exceptionally tight and dry, and whatever water is present is older than the water in the zones. The clear picture of a wet part and a dry part of the rock provides certain answers but also some new questions that we are working further with."

"We need to think a little more about how we can best use this tight, dry rock for final disposal. Perhaps we should build the final repository in several levels? We may need nuclear power for some years to come, I think."

What happens now?

"The work in the modelling and analysis group is continuing with great intensity. We have many steps left to take before design and the work with the safety assessment and the environmental impact statement. But I think we will be able to provide an adequate body of material. All the detailed knowledge of all the experts together comprises an overall picture, an integrated view."

Let's talk about **the weather**

High summer in Forsmark

The best summer was in 2006, at least if you count the number of high summer days. A high summer day is a day when the temperature is at least 25 degrees Celsius.

In 2003 we had 20 high summer days, three in June, 14 in July and three in August.

In 2004 we only had six high summer days, one in June and five in August.

In 2005 we had nine high summer days, two in June, six in July and one in August.

In 2006 the best summer, we had eight high summer days in June, 13 in July and three in August.

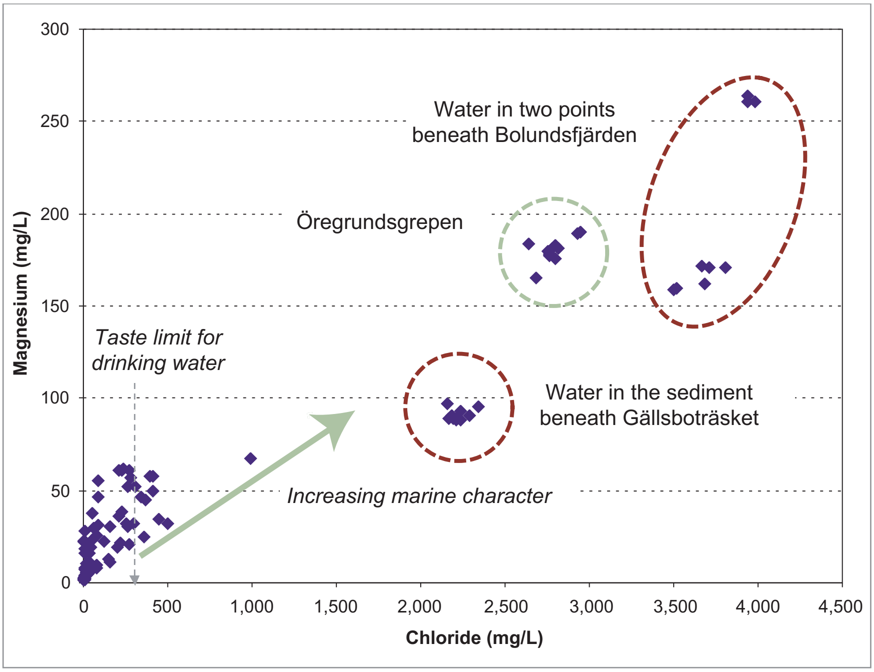
In 2007 we only had seven high summer days, two in July and five in August.

Hydrochemistry

The surface waters and the groundwaters in the soil layers in Forsmark typically have high ionic strength – i.e. they are hard and saline – compared with similar waters at many other places in Sweden. This is partly due to the lime-rich till in the area, and partly to the fact that the area was covered by the sea until relatively recently. Weathering of the lime-rich till contributes to high concentrations of calcium, high alkalinity and high pH, creating the oligotrophic hardwater lakes* typical of the area. The water chemistry is further affected by marine residues in the soil layer and by the recurrent intrusions of sea water that still occur today in low-lying parts of the area. The marine influence causes elevated sodium, chloride and magnesium concentrations.

An important question from a repository perspective is whether there is any upward flow of deep groundwater to the superficial systems. No observations made during the chemical investigations suggest this. On the other hand we have encountered pockets of old marine water, presumably from the Littorina Sea, that have been left behind at fairly moderate depths in the soil layers. This water has been captured in the ground and will probably not reach the surface due to the stagnant conditions that prevail, and because the flow directions are more downward than upward.

* Oligotrophic hardwater lakes are lime-rich but nutrient-poor. This gives rise to a characteristic flora and fauna.



Magnesium versus chloride concentration in surface water (including brackish sea water) and in the groundwater in the soil layers. The graph shows how the marine influence increases the magnesium and chloride concentrations and the fact that we have pockets of old marine water (Littorina Sea) in the soil layers with chloride concentrations that are higher than those we see in Öregrundsgrepen today.

… the water here is isolated, with extremely long residence times.

Ann-Chatrin Nilsson
Site chemist

An old story

The groundwater in the part of the rock in Forsmark where a final repository may be located is probably more than a million years old. This part of the rock is bounded upward by the gently-dipping fracture zone A2, which, due to its higher fracture content and permeability, conducts another younger groundwater with a clearer content of water from the Littorina Sea.

Today's groundwater tells an old story, and the water composition reveals how old. With the aid of chemical analyses we can establish that our groundwater samples from the bedrock consist of different mixtures of 1) modern or old surface water, 2) meltwater from the continental ice sheet, 3) water from the Littorina Sea and 4) extremely old and saline "deep water" from the deep bedrock. The latter water is thus a saline water that is not a sea water (non-marine).

The groundwater in Forsmark is relatively saline, and at a depth of only 100–150 metres the chloride concentration is already higher than in the sea off Forsmark. Then the chloride concentration is more or less constant down to a depth of about 600 metres, where we once again observe a rising trend.

The saline contribution comes from water of marine origin – the Littorina Sea – or from non-marine old and saline deep water. The concentrations of magnesium, potassium and sulphate as well as the bromide and chloride ratios reveal whether the water is of marine or non-marine origin or a mixture of the two. Low oxygen-18 values indicate admixture of water originating from a very cold climate, which is interpreted as being meltwater from the continental ice sheet. The occurrence of old groundwater is evident from determinations of the isotopes carbon-14 and chlorine-36, as well as the presence of helium gas, which is formed in the Earth's crust and mantle and is transported upward. Admixture of very young surface water – from the 1950s and younger – is revealed by detectable quantities of the hydrogen isotope tritium (^{3}H).

Lots of samples…

Many water samples have been taken from different bodies of water in Forsmark over the years.
Here is what we have sampled: Precipitation: 41 samples. Surface water (sea bays, lakes and streams): 1,230 samples. Groundwater in the overburden down to the rock: 330 samples. Groundwater in the bedrock down to 1,000 metres: 375 samples. Total: 1,976 samples.

We see a connection

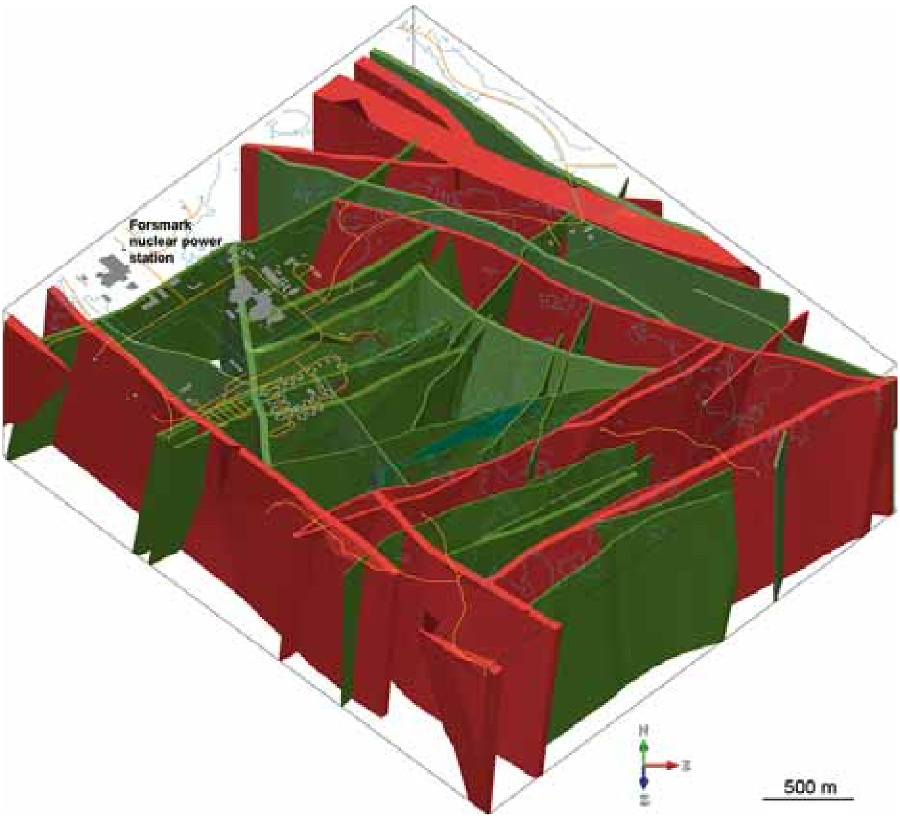
With access to groundwater data and geological information from all investigated boreholes in the candidate area, we can now see a connection between the area's hydrochemistry and the properties of the rock. The observations that have been made in the depth interval between 100 and 1,000 metres are summarized briefly in the points below.

- Groundwater with a heavy contribution from the Littorina Sea has been observed at between 100 and 600 metres vertical depth, but only in gently-dipping fracture zones and in a small area with relatively fractured rock down to a depth of 200 metres. In tighter and less fractured rock, a relatively small fraction of Littorina water is encountered down to a depth of 300 metres, after which it disappears entirely.
- In fracture-poor rock between zones where water from the Littorina Sea has not been able to penetrate, the groundwater consists of a very old non-marine water.

Cecilia Berg from Geosigma takes water samples.

Report this summer

There is naturally much more to tell about Forsmark, and we will do that in the report which we will now be working on up to the summer of 2008. Not least important is to describe the uncertainties that remain and to set limits on how great they are. Then the designers and the safety assessment group can incorporate these uncertainties into the continued work. In conclusion, however, we have great confidence in the parts of the model that are important for the design of the repository and its long-term safety. The remaining uncertainties will probably not be of crucial importance for a decision to build a repository in Forsmark.



Three-dimensional model showing the vertical and steeply-dipping deformation zones within the priority area for a possible final repository in Forsmark. The model is viewed from above off to the side looking northward. The red zones are longer than three kilometres, and the green zones are smaller zones shorter than three kilometres.

We have analyzed the following substances in the water samples:

Main components: Na, K, Ca, Mg, Si, HCO3, Cl, SO4, Br, F, Fe, Mn, Li, Sr.

Chemical/physical parameters: pH, electrical conductivity, redox potential, water temperature, dissolved oxygen.

Nutrients: (NO_3, NO_2, PO_4, NH_4, N-tot, P-tot), silicate and organic carbon.

Particulate carbon, nitrogen and phosphorus and colour index – only in surface water.

Chlorophyll – only surface water.

Stable and radioactive isotopes: _^{2}H, ^{3}H, _^{18}O, _^{36}Cl, ^{37}Cl, _^{13}C, ^{14}C (pmC), ^{10}B^{11}B, ^{87}Sr/^{86}Sr, _^{34}S, ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn.

Trace metals including rare earth metals: Al, Zn, Ba, Cr, Mo, PB, Cd, Hg, Co, V, Cu, Ni, P, As La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, SC, In, Th, Rb, Zr, Sb, Cs, Tl, Y, Hf, U.

Dissolved gases (composition and quantity).

Colloids (composition and quantity). Microbes (number and type).

All determinations are not performed on each sample.

When the ice is thin it's prudent to have a boat standing by. Micke Borgiel from Sveriges Vattenekologer AB takes samples in Bolundsfjärden.

Interview

Expert's **post script**

Name: Ann-Chatrin Nilsson, chemist

Activity leader for hydrochemical investigations in Forsmark during the entire site investigation. Has worked with SKB since 1988.

"The groundwater chemistry in Forsmark is less complex than might be expected. It is usually difficult to see any systematics, but here in Forsmark the picture is quite clear. In simple terms, there is plenty of water down to a depth of about 200 metres, but below that water is scarce. And the waters have different origins depending on how fractured the rock is."

What do you mean?

"There is a big difference between the water in gently-dipping fracture zones and the water in individual fractures in fracture-poor rock. The water in the zones has a clear marine origin, since water from the Littorina Sea has seeped down, while the water in the tighter rock at corresponding depth lacks a marine signature and is older. We see no marine signature at all in the water at the planned repository depth in the priority area, which means that there has been virtually no contact upward for several thousand years, or even over a million years! It is good that the rock is so very watertight and isolating."

Is this an unusual property?

"I myself have never encountered such dry, tight rock before. It is very unusual that there is so little water at a depth of a few hundred metres that it is scarcely possible to take water samples. For us chemists this has been a practical problem, but from the repository viewpoint it is a good thing."

Are the hydrochemical investigations finished?

"We have performed thousands of water analyses and written some 60-odd reports. We aren't completely finished – the long-term sampling work will continue until at least 2009 and site selection. I have also started the work of planning hydrochemical investigations in the site investigation for extension of the final repository for radioactive operational waste – SFR – in Forsmark."

For us chemists this has been a practical problem, but from the repository viewpoint it is a good thing.

Let's talk about **the weather**

Winter average

The average temperature in December, January and February 2005/2006 was minus 2.6 degrees.

The warmest winter days were in December 2006, with an average of nearly plus 4 degrees (3.9).

From data to site understanding

All the knowledge that has been gathered during the site investigation has to be interpreted and reviewed. From the site investigation the material goes to site modelling. The purpose of site modelling is to utilize all data – and the knowledge of the site that has gradually emerged over the year – to arrive at a description of the site. The description of the characteristics of the site is needed to design the planned repository in a way that suits the site and to conduct a safety assessment and assess the environmental consequences of an establishment. In other words, we have to describe the characteristics of the site not only where data have been collected, but also between boreholes and other sampling points, and explain as far as possible why things are the way they are. Furthermore, we need to stipulate what uncertainties there are in the description and evaluate them.

Time for the grand finale

The site modelling takes place in an analysis group consisting of persons with special knowledge in different areas. Since the site investigation started the analysis group has produced several preliminary descriptions, but now it's time for the grand finale – the final site description. Virtually all analysis and modelling work was concluded in 2007, and now all that remains is to put down the story of Forsmark on paper.

The geological model is the backbone of our description. The types of rock and their distribution determine the thermal properties of the rock and also affect the strength. The location and size of the fracture zones and the occurrence of fractures in the rock between the zones affect how the groundwater moves in the rock and its composition. The size and direction of the rock stresses are also related to the structural geology of the site. In order for us to have confidence in the model and the site description we arrive at, we must first of all have faith in the geological model, but our interpretations and analyses of other data – hydrogeological, hydrochemical and rock stress data – must also fit the composite picture.

Are we satisfied?

Even though we are not completely finished yet, we can already say that we have a good picture of what the site looks like and why. With reference to the geological evolution of the site, we can explain why we have a relatively homogeneous rock type composition inside the lens. But also why there are differences in the directions of the fracture zones between the northwestern part of the candidate area and the southeastern part and why the frequency of fractures varies between the superficial and the deep rock (see the section on the geological history of Forsmark).

We can also note that our geology model today is largely the same as before, despite a great deal of new data. Differences in the fracturing of the rock are another possible explanation for the large quantity of groundwater flowing in the more superficial rock and the largely dry rock at depth. We now have a lot

The safety assessment group discusses the site model. From left: Kristina Skagius Elert, Anders Ström and Raymond Munier.

Now it's time for the grand finale – the final site description.
Kristina Skagius Elert
Project manager for the site modelling

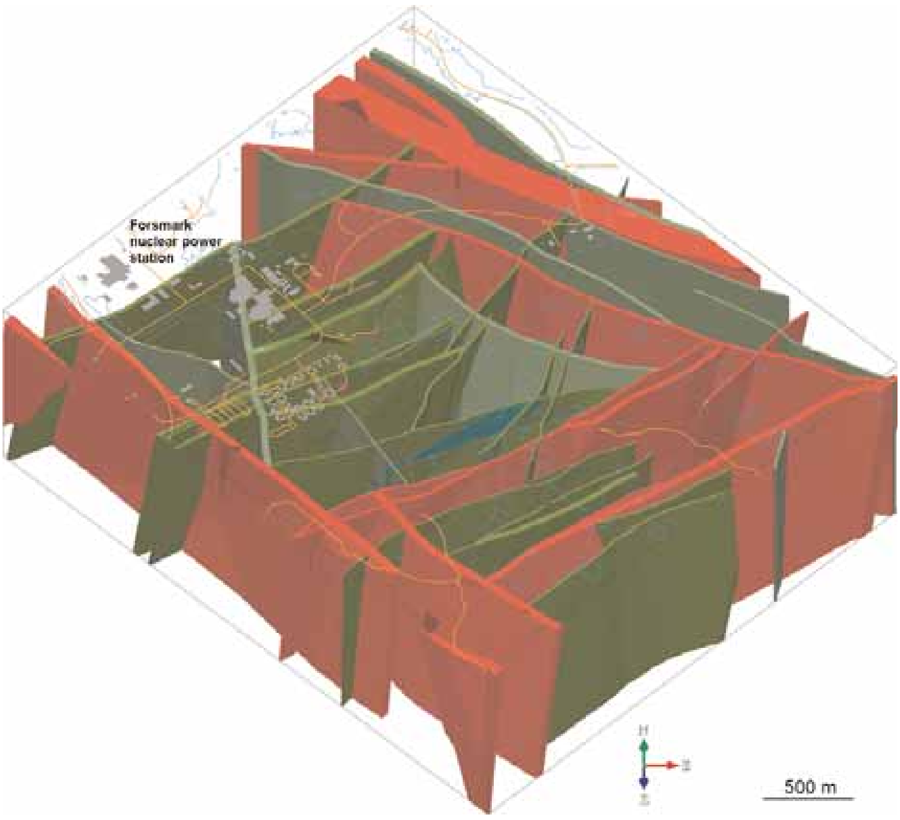
of hydrogeological data that confirm these slightly unusual groundwater conditions – and the chemists' analyses and interpretations of the groundwater composition fit the same picture.

Stresses difficult to measure

Rock mechanics has long been our biggest problem. Not in terms of the mechanical properties of the rock, there the picture has been stable for quite some time, but in terms of the rock stresses, which in Forsmark are relatively high and therefore difficult to measure. By making an integrated evaluation of all rock stress data and observations that indirectly provide information on stresses and linking this to our knowledge of the geology in Forsmark, we have now developed a stress model which we judge to be sufficiently credible for the designers to proceed with.

Report this summer

There is naturally much more to tell about Forsmark, and we will do that in the report which we will now be working on up to the summer of 2008. Not least important is to describe the uncertainties that remain and to set limits on how great they are. Then the designers and the safety assessment group can incorporate these uncertainties into the continued work. In conclusion, however, we have great confidence in the parts of the model that are important for the design of the repository and its long-term safety. The remaining uncertainties will probably not be of crucial importance for a decision to build a repository in Forsmark.



Three-dimensional model showing the vertical and steeply-dipping deformation zones within the priority area for a possible final repository in Forsmark. The model is viewed from above off to the side looking northward. The red zones are longer than three kilometres, and the green zones are smaller zones shorter than three kilometres.

Expert's **post script**

Interview

Name: Michael Stephens, state geologist

Geological specialist and in charge of the geological modelling work in Forsmark. Well acquainted with the geology of Forsmark since the time of the feasibility study in 1996.

"We had a clear picture of what the bedrock in Forsmark looked like very early on. This is due firstly to the fact that we had a good body of material from the construction of both the nuclear power plant and the final repository for radioactive operational waste, SFR, and secondly to the investigations performed by SGU in the municipality on behalf of SKB. It was SGU that helped identify the areas – of which Forsmark was one – with possible suitable bedrock for a final repository. We already had the picture of a bedrock with gently-dipping water-conducting zones, elevated rock stresses and a tectonic lens surrounded by major fracture zones in our heads when the site investigation began."

What about the results?

"The picture we had has now been confirmed. Besides a few occurrences of porous granite and fractured bedrock down to a depth of about 200 metres, what we have found is what we thought we would find. It has been hard work, but extremely interesting. There are no other areas in Sweden that have been so thoroughly investigated as the candidate areas in Forsmark and Oskarshamn. The site investigation has been an interplay between different disciplines, and this interplay has led to a well integrated understanding of the site. We have gathered a very important body of material, in fact I'm not sure we really appreciate its importance."

"There is another unusual aspect of our work as well: Transparency has been total. All data, models and reports have been available to anyone."

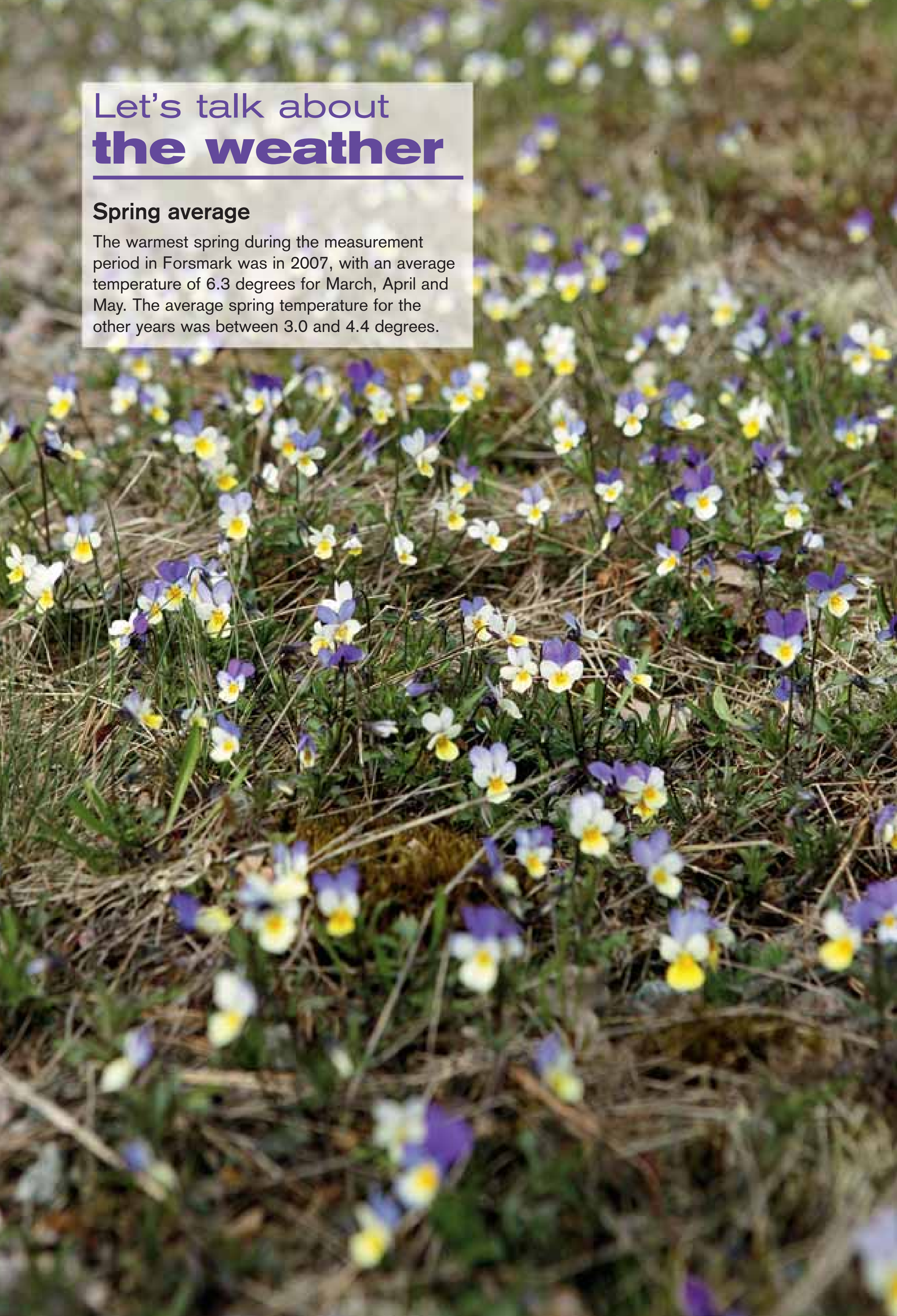
What happens now?

"We are nearly finished. An integrated model as a basis for the safety assessment should be available in March 2008. In May we will present the results to Insite (SKI's advisory international review team), and the final report will hopefully be printed in the summer of 2008. We expect a widespread response. The work of presenting the information in scientific articles continues. Then we will see if the review and decision process leads to supplementary investigations."

Let's talk about **the weather**

Spring average

The warmest spring during the measurement period in Forsmark was in 2007, with an average temperature of 6.3 degrees for March, April and May. The average spring temperature for the other years was between 3.0 and 4.4 degrees.



A possible future in Forsmark

Everything we have done and are doing in Forsmark is aimed at enabling a final repository to be built on the site – if it is SKB's choice. If so, it will entail activities of a radically different kind and on a bigger scale than the scientifically oriented site investigation. Then an industrial enterprise will be established with all that entails in terms of resources and an organization for building activities above and below ground, and eventually facility operation.

Parts of the industrial area in Forsmark would once again become the site of a big construction project, albeit not of the same scale as when the nuclear power plant was built. What will be built first will not be the repository's facilities, but new housing to replace the present-day barracks village, which would eventually get in the way of the repository. The new housing complex will be a project for Forsmarks Kraftgrupp AB, which has devised a plan for the project together with SKB. More about this on page 92.

Construction and operation

Assuming we get all the permits we need, construction of the final repository's facilities can start after that. Temporary construction arrangements will then be made on the future operations area, so that the rock excavation work for the accesses to the repository (shafts and ramp) can begin. The earthmoving works will be done simultaneously, as infrastructure is installed and the first buildings take shape. Construction activities will then gradually increase in scope over a period of several years, involving 400–500 people at most. The facilities should be ready to be put into operation six or seven years after the start of construction.

Compared with the intensive and dynamic construction phase, operation can be described as a static activity that will continue for several decades. Operational activities will be built up gradually over the course of several years. To start with, the entire facility will undergo trial operation without spent nuclear fuel in order to make any necessary technical and organizational final adjustments. When everything is working like it should and the regulatory authorities have issued a licence, deposition of canisters of spent nuclear fuel can begin. The pace will be limited at first, gradually picking up speed to the planned operating capacity of about 160 canisters per year. Routine operation is then expected to continue for about 50 years. The operating organization is expected to include just over 200 persons during this period.

Design

Design is the collective term for all the engineering work that goes into producing the documentation needed to build and operate the final repository. It involves developing and optimizing technology, preparing drawings for the repository facilities, and planning an industrial establishment.

Like the site investigation, design is divided into stages, but comes a half step after in order to be able to take full advantage of the results. The last year of the site investigation has provided the platform for the design stage that will produce the finished result.

By "finished" we mean that drawings and other documents must be available describing the layout of all facilities and designs of installations, machines and vehicles, construction plans etc. with sufficient detail to be included in an application to the regulatory authorities for a permit to build the final repository in Forsmark, if that is SKB's choice.

Wetland in Forsmark that may be used for purification of leachate.

Preliminary site plan for an operations area on Söderviken, on the south side of the cooling water channel. A new bridge will be built between the existing bridge and the channel intake. A rock spoil heap may be located on land where parts of the barracks area are today.

Adjustments

We believe that the preliminary design of a repository in Forsmark – which we have presented previously – will remain unchanged, but the premises have been adjusted on a couple of points. One is the location of the operations area where all above-ground facilities will be accommodated and from which the accesses to the repository (shafts and ramp) depart. It now looks as if the operations area will be located between the southern shore of Asphällsfjärden (Söderviken), the cooling water channel and the barracks area. Data from the final phase of the investigations indicate that this location offers more favourable rock conditions for the accesses than the previous preliminary location at the barracks area. Locating the operations area on Söderviken also permits infrastructure to be coordinated with the nuclear power plant, while at the same time the site is sufficiently out of the way so it will not disturb existing activities. The above illustration shows a preliminary site plan for an operations area on Söderviken.

The second adjustment is that the recommended repository depth has been increased from 400 metres to somewhere between 450 and 500 metres. The reason is that new measurements and analyses of rock stresses show that these stresses have less impact on the repository depth that has previously been assumed. Other aspects may be given greater weight when the repository depth has been determined. The main reason in favour of a slightly greater depth is that the available area for a repository increases.

Two key groups

With the transition from fairly general design in the early phases to more detailed and complete design, the scope of the work has increased considerably. Many in-house employees and several teams of consultants are now engaged. We cannot describe all of them, but we would like to present two consultant teams who have key roles in the work.

Designing all the underground rock facilities in the final repository is a big and, in many respects, unique task. The assignment has gone to a team of consultants under the leadership of Bengt Hansson at Tyréns AB in Göteborg. Besides personnel from the principal consultant Tyréns AB, the team also includes experts from Vattenfall Power Consultants AB, Sigma Integra AB and Lars Aas AB as subcontractors. For most members of the team, Forsmark as a site is a new acquaintance, but they have great experience in rock engineering, geotechnical matters and process analysis from other projects.

The cranes of Göteborg can be seen in the background. Members of Tyrén's consulting team gathered in their home town. From left: Saad Jamil, Stein Kleiven, Thomas Janson, Bengt Hansson, Martin Bergström and Thomas Hogander.

The assignment's three main parts

Layout: The arrangement of the hard rock facilities in three dimensions – the layout – must be adapted to the geological conditions on the site and to numerous requirements related to construction and function. Based on the limitations set by geology, the potential and flexibility of the site are then exploited in the gradual build-out of the repository's deposition areas. Assessments of how large a portion of the available rock volume can be utilized for deposition must also be made and possible reserve areas designated.

Function: The repository must be planned so that different activities do not conflict with each other and unacceptable bottlenecks do not occur. In hard rock facilities where many different activities and flows of goods have to be coordinated in limited volumes, this is always complicated. For the final repository, there is the additional complication that tunnelling for progressive build-out has to proceed for many years at the same time as operation with deposition of canisters is proceeding in already built-out parts. It is important to be able to simulate all the activities with rock construction and operation so that many points of conflict can be eliminated before they occur and the system can be optimized.

Sealing and rock support: Sealing and rock support is a step in the construction process that is of great importance for time required, costs and the final result. Seepage of groundwater into the hard rock facilities must be controlled and lim-

Planning the construction of all the rock openings in the final repository is a big undertaking. Dimensions have to be set, construction methods chosen and the need for rock support and sealing measures determined.

ited. Based on investigation data on fractures and water flow, expected seepage in different parts of the facility is calculated. This in turn forms the basis for calculating the need, and finding solutions, for sealing of the rock in conjunction with tunnelling. The work sequence is roughly the same for rock support: determine the need and plan the rock support work. Methods include installing steel bolts in the tunnel roofs to eliminate the risk of stone blocks coming loose and falling down.

Other key roles

The industrial architects at Lange Art AB have the other key planning role in planning what is needed on the surface, above the repository: buildings for different purposes, handling areas, traffic corridors, rock heaps and much else.

The company, whose offices are located in the Old Town in Stockholm, are not newcomers to the project. Ever since the first sketches of the final repository began to take shape around 15 years ago – way before any candidate sites had emerged – Lange Art has been involved as a driving force behind the project. But the company's presence in Forsmark dates back even further. The founder, Fritz Lange, was involved when the nuclear power plant was built in the 1970s, and he was the architect of the SFR facility in the 1980s.

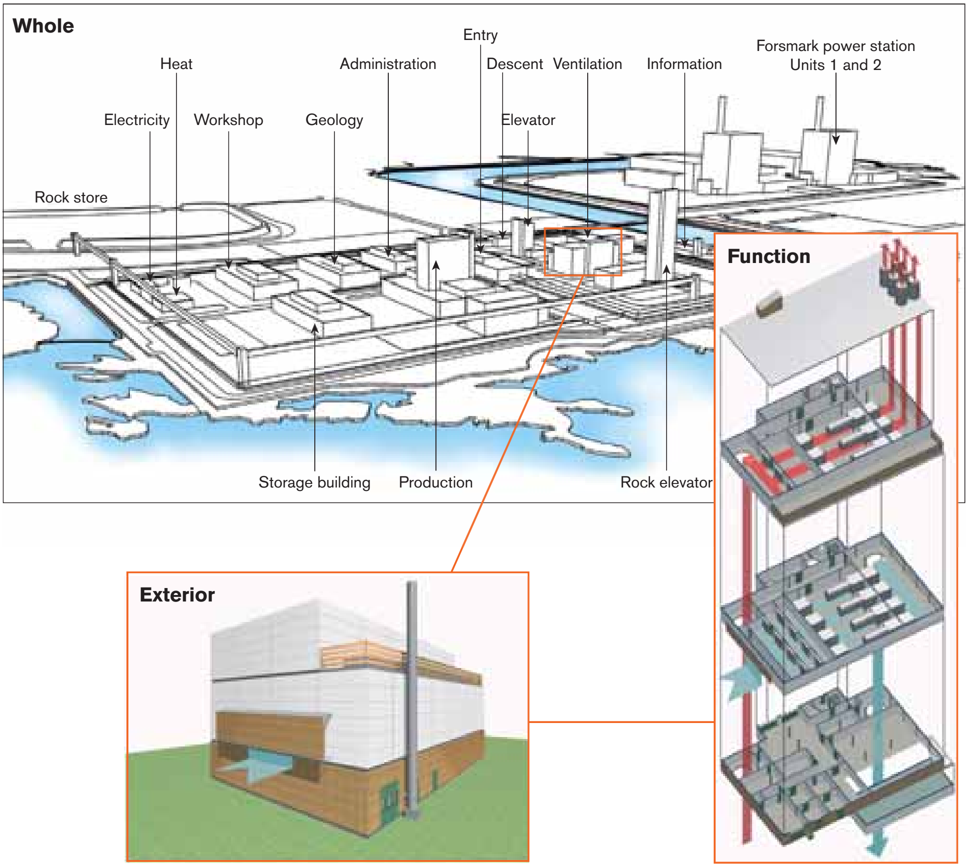
Meeting at Lange Art's offices. From left: Kaj Westerholm, Fritz Lange, Agneta Sallstedt, Fredrik Moberg and Fredrik Lange.

Function and environment

The main tasks for Lange Art are now to prepare a final site plan for the final repository's operations area and to design all the buildings and other facilities that will be built there. This is a big job, where both details and the whole picture must be developed in parallel. Dimensions, form and function of individual buildings must be clarified, at the same time as the whole area must function as an industrial enterprise.

It is also a project that spans a broad field of competence, from design to aesthetics, from sociology to behavioural science. The requirements of function and a good working environment must be combined with those of architecture and consideration for the natural environment.

The assignment also includes revising the layout of the facilities based on changing premises. Such changing premises may be, for example, choice of methods and materials for buffer and backfill or new regulatory requirements. Among other things, the tougher requirements made by the regulatory authorities on safety and external protection require changes in the layout of the facilities.



The whole and the details must both be taken into consideration when facilities and systems are designed. At the same time as the operations area takes shape, the architecture and function of individual buildings are considered, here exemplified by a ventilation building.

New accommodations

A decision was made during the year that may have consequences for many of those who work in Forsmark. It concerns the site of possible new accommodations for temporary personnel at Forsmarks Kraftgrupp and SKB, contractors for revisions and many others. If the final repository is built in Forsmark, the land where FKA has its housing barracks will sooner or later be needed for the needs of the final repository. The barracks will then have to be demolished, but overnight accommodations will still be needed – in fact, more housing will be needed for construction of the final repository. New accommodations are therefore planned, ready to be put into use before the existing barracks have to be torn down.

FKA has, together with us, studied where and how new facilities can be built. Two possible locations emerged: Igelgrundet, which is today a small wooded area bordering on FKA's visitors' centre, the water tower and the road out towards SFR, and Kattskäret, a promontory on the south side of Asphällsfjärden.

In the background we see the nuclear power plant, in the foreground a photomontage showing planned accommodations on Igelgrundet, which is today a wooded area west of the road out to SFR.

The choice fell on Igelgrundet, which was found to have important advantages in the form of nearness to many workplaces at the nuclear power plant and coordination possibilities with existing activities. The facilities sketched on Igelgrundet are fairly extensive, with a total of 550 overnight rooms in a number of houses of two or three storeys, reception, a sports centre and various rooms for operation and maintenance. The planning will now be carried on with proper design of buildings, electrical and plumbing systems etc. to produce construction documents. Procurement of contractors and start of construction may take place in 2010.

Modified detailed development plan

The Forsmark industrial area is covered by a municipal detailed development plan that regulates how land may and may not be used in different parts of the area. Planning matters are regulated in the Planning and Building Act and are the responsibility of the municipality. Östhammar Municipality is trying to modify the planning conditions in Forsmark so that they permit the construction of a final repository. This is a prerequisite in order for building permits to be granted, if and when the time comes. At the same time, changes are being made for other reasons, such as to permit construction of the new accommodations and a future extension of SFR.

The planning work is proceeding in steps, with successive decisions based on increasingly detailed information. Our role in the process is to furnish information on the planned project and to assist with resources as requested by the municipality.

Draft documents have been produced during the year and been referred to experts and others during a consultation phase. The documents include maps, plan and implementation descriptions as well as an environmental impact statement (plan-EIS). Based on the viewpoints from the consultative round, the documents were revised, after which the municipal building committee decided in November to proceed with the matter. The next step was then to exhibit the revised drafts to give affected parties an opportunity to submit additional viewpoints before the plans are adopted.

> It’s a matter of coming up with the right technical solutions.

Expert's **post script**

Name: Bengt Leijon, Ph D. Min. Eng.

Project leader, facility planner for a final repository in Forsmark.

"Since I was around during the feasibility study in the 1990s, I knew that the bedrock in Forsmark was 'very promising', but not so much more."

Now you know more?

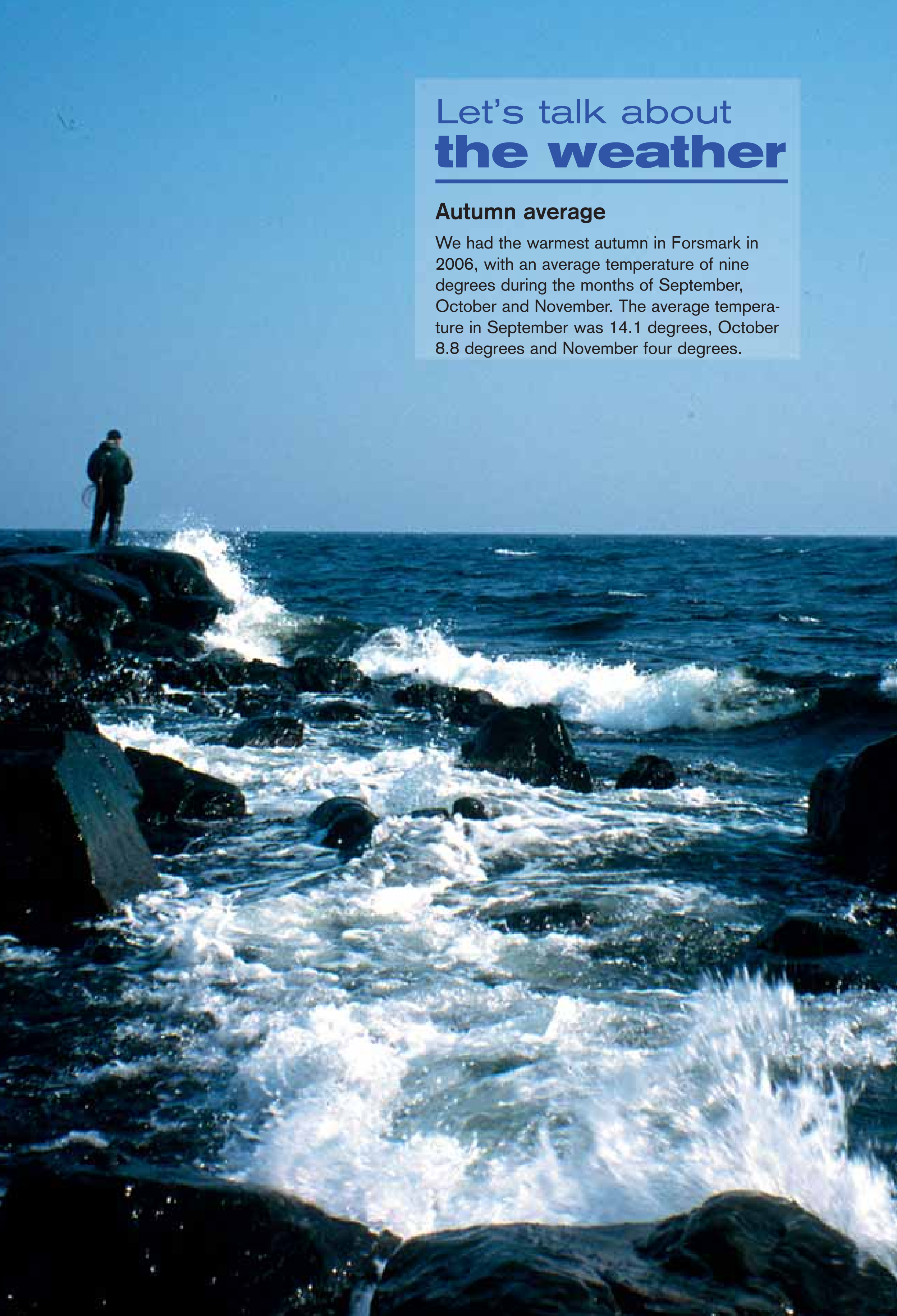
"A lot more. For example, that the rock at depth is even more intact and watertight than we thought from the start. But also two things we should have great respect for in Forsmark: Firstly that there is a lot of water in the rock near the surface, and secondly that the rock stresses are relatively high. These are both factors that have to be taken into consideration during construction. You could say that the results of the site investigation feel reliable enough to be able to adapt the facility to the actual conditions on the site. But we won't have all the answers until we're down under ground. Then we will have to adapt the details to prevailing conditions in the rock."

What's happening right now?

"We in the design group are working on facility and systems design – for both the repository and the surface facilities. This is engineering work, and the work load is increasing dramatically right now. It's a matter of coming up with the right technical solutions."

What else are you doing?

"Planning of the facilities is proceeding as planned, and a great deal needs to be coordinated with FKA's activities in Forsmark. That is one of my duties. There is also a lot of work involved in studying the environmental consequences of the construction of a final repository. This includes noise, traffic and other disturbances. Then I am playing a small part in the societal studies we are conducting in consultation with Östhammar Municipality, work that gives us different slants on the project."



Let's talk about **the weather**

Autumn average

We had the warmest autumn in Forsmark in 2006, with an average temperature of nine degrees during the months of September, October and November. The average temperature in September was 14.1 degrees, October 8.8 degrees and November four degrees.

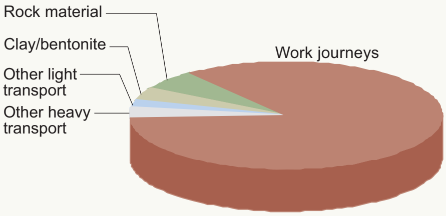
Impact on the surrounding area

The work of studying how the construction and operation of the final repository will affect the surrounding area goes hand in hand with the design work. The environmental legislation imposes stringent requirements on the reporting of the consequences for man and the environment, and how environmental aspects have been taken into consideration in the planning of the project.

Transportation

An important prerequisite is that the operations area for the final repository can be accommodated within the existing industrial area. This will ensure that the activities on the site will not be noticed much outside the industrial area. What will be noticed outside the area, however, are transportation activities. Design provides the basis for calculating the transport need in different phases, and during the year we revised our previous preliminary estimates. Transport activities will naturally enough be most extensive during the construction phase, when the personnel requirement is greatest and considerable quantities of surplus rock will be produced.

When operation begins, the total transport need will diminish and then become constant for many years, with the exception of shipments of clay material (for buffer and backfill) from Hargshamn. The graphs on the next page have been taken from the transport calculations for the operating phase. The pie chart shows the absolute and relative numbers of vehicle passages on the entrance road to the industrial area generated by transport to and from the final repository during a 24-hour period. Work journeys for personnel and visitors account for the largest portion of the vehicles by far. It can nevertheless be predicted that it is heavy goods haulage – above all of rock spoil – that will be most noticeable and risks giving rise to disturbances.

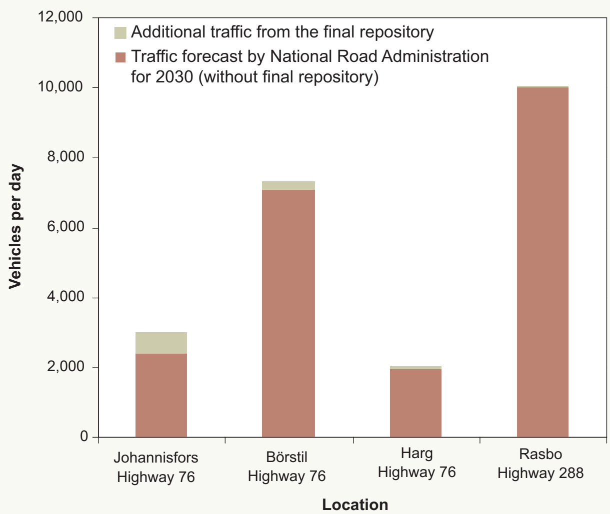


Type	Number	Percentage
Work journeys	515	84%
Other light transport	16	3%
Rock material	38	6%
Clay/bentonite	22	4%
Other heavy transport	18	3%

Estimated transport need, expressed as vehicles per day, during the operating phase of the final repository. Work journeys by car are by far the most numerous, but goods haulage by truck can be expected to be the most noticeable.

Additional traffic

The traffic to and from the final repository will be distributed on the local road network. We can assume on good grounds that most will go towards Östhammar, and considerably less towards Österbybruk and Gävle. The bar graph shows estimated traffic volume at some places: highway 76 at Johannisfors, Börstil and Harg, and highway 288 at Rasbo. The reddish-brown bars are taken from the National Road Administration's traffic forecasts for 2030 (regardless of whether a final repository is built). Our own calculations of transportation generated by the final repository during the operating phase have been added to these figures. It is quite naturally at the nearest place – at Johannisfors – that the additional traffic from "our" transport activities means the most. The additional traffic on the already heavily trafficked highway 288 at Rasbo near Uppsala is scarcely noticeable, on the other hand.

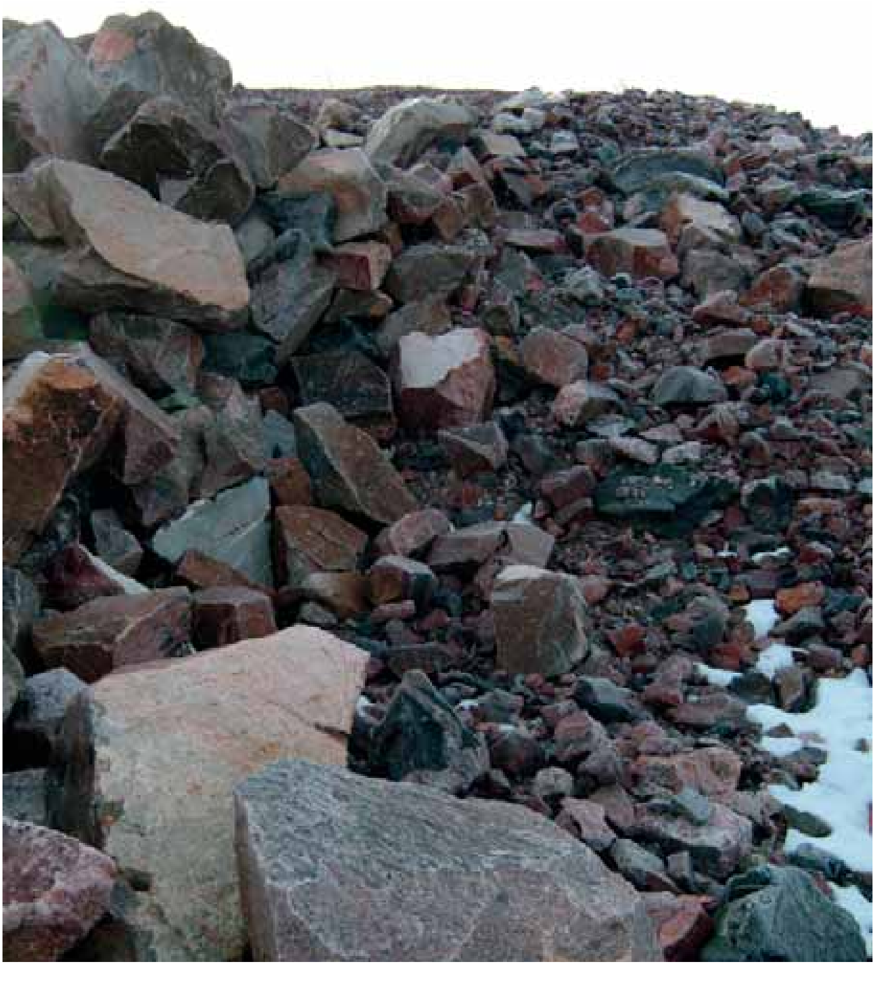


Traffic forecasts for four locations in the region, with and without a final repository in Forsmark. The forecast applies to 2030, when the final repository is in operation.

Rock spoil

At the start of construction there will be a need for rock spoil as fill in the operations area. But fairly soon the construction of the repository's hard rock facilities will generate large quantities of surplus rock. The rock volumes are usually given in either solid measure (the actual tunnel volume) or in loose measure (rock spoil as blast rubble). The total amount estimated for the final repository is nearly three million cubic metres, loose measure. This can be compared with the volume of rock spoil that was handled when the Forsmark nuclear power plant and SFR were built: The total then was around 1.9 million cubic metres.

We regard the rock spoil as a resource that should be utilized. Where and how is an open question. The closer a use can be found for them, the better. The main alternative is therefore to haul the rock spoil by road to users in the region. A small quantity could perhaps be shipped out from the Forsmark harbour, but the capacity there is very limited. We will also need areas for temporary storage of the rock and for the handling that is required.



Groundwater

Seepage of groundwater is an important issue for the hard rock facilities and it can also have effects on the surface if the groundwater level falls. Preliminary calculations show that groundwater drawdown will be limited to an area around the repository's access tunnel and shafts. Drawdown will mainly occur when the accesses are built. In the future, when operation is concluded and the repository is closed, the groundwater levels will gradually be restored.

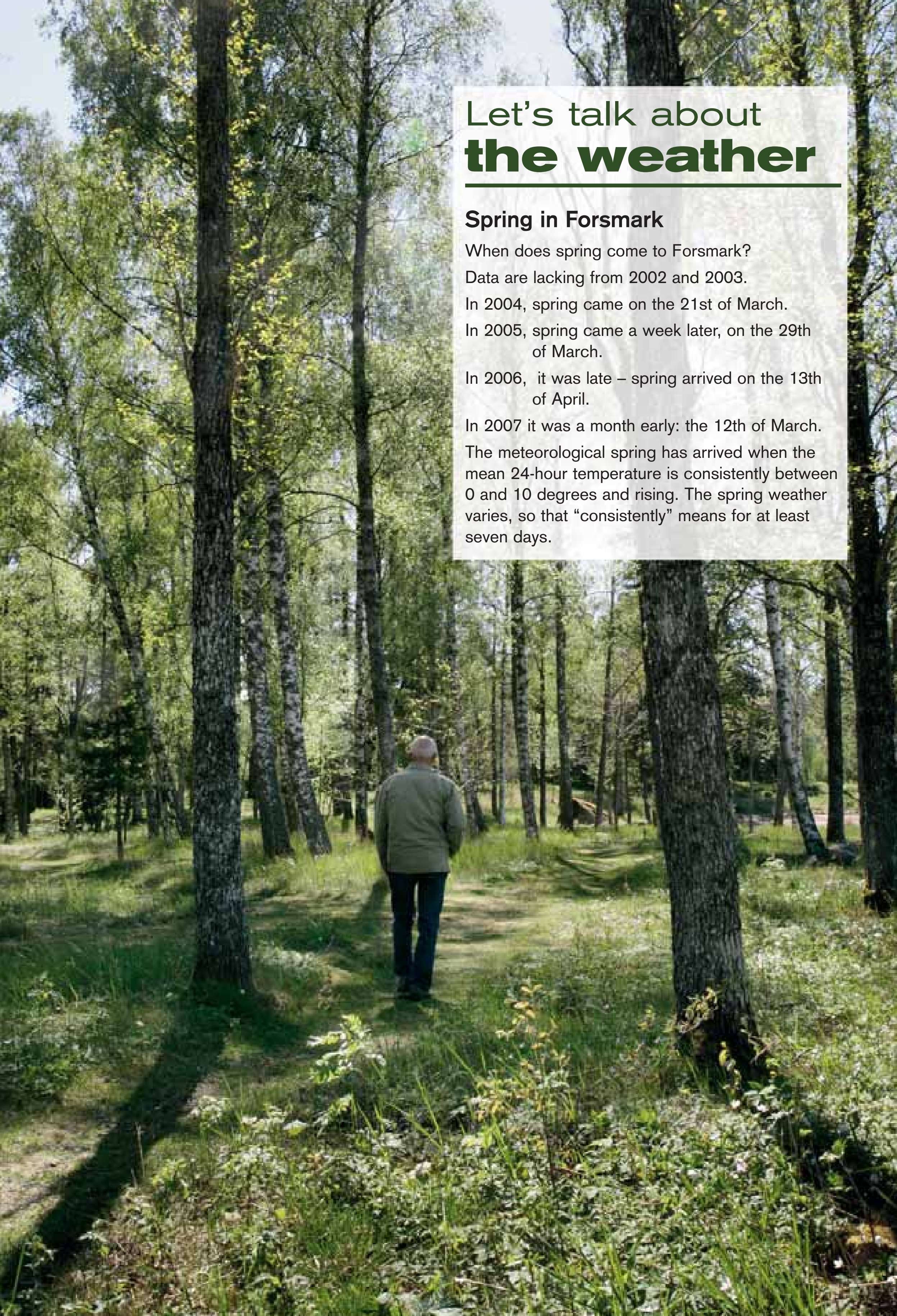
The groundwater that seeps into the repository must be pumped up and dealt with. It may contain particles, oil residues and various nitrogen compounds. Particles and oil residues will be separated by sedimentation basins and oil separators, respectively. The pumped-up water, along with the leachate from the rock heap, will then be conducted to a wetland where the nitrogen compounds will be transformed to harmless nitrogen gas by biological processes. The purified water will then be discharged to the cooling water channel.

Noise and vibration

The blasting and rock handling work during construction and operation will generate some noise and vibration in the vicinity of the final repository. Another source of noise is the road traffic, mainly on the entrance road and highway 76. Based on the estimated transport needs, the noise levels can be calculated fairly accurately. Such calculations are performed as a basis for an environmental impact statement.

Atmospheric emissions

The final repository will not generate any significant quantities of air pollution. Certain activities during construction and operation do cause air pollution, however, mainly transportation. Some dust may be generated by rock handling, and there will be some emissions of explosion gases. However, these emissions will be small and mainly local.



Let's talk about **the weather**

Spring in Forsmark

When does spring come to Forsmark?

Data are lacking from 2002 and 2003.

In 2004, spring came on the 21st of March.

In 2005, spring came a week later, on the 29th of March.

In 2006, it was late – spring arrived on the 13th of April.

In 2007 it was a month early: the 12th of March.

The meteorological spring has arrived when the mean 24-hour temperature is consistently between 0 and 10 degrees and rising. The spring weather varies, so that "consistently" means for at least seven days.

Reviewer

Östhammar Municipality

Name: Margareta Widén Berggren, former mayor (s)

Has been a politician for 15 years. Term of office as mayor 2002 – 2006. Now leader of the opposition party. Member of the municipality's reference group for the final repository issue.

"I have been following this issue for many years. As mayor during the previous term, you might say that I worked very intensively with the final repository issue. Even though my party is now in opposition, we feel just as involved in the process."

Your experience?

"We have learned a great deal. The site investigation has introduced many aspects – it has to do with so much more than just the rock. But it is a very long-term matter – interest cannot remain at a peak all the time. Furthermore, it's a time-consuming project, a lot to read, a lot to review and comment on, a lot to meet about, a lot to decide on, a lot to discuss and many questions to pose but also to answer."

What's the upside?

"Besides having learned a great deal, I am pleased we have been able to work so well together with the other site investigation municipality, Oskarshamn. We have managed to pursue these matters jointly. Our cooperation with SKB has also gone well. The company has made an effort to answer our questions."

Downside?

"That it is taking so long. The matter takes a lot of time for us at the municipality to deal with, even if we don't have to pay for it. It still costs energy and attention. We assume that SKB will make a decision on site selection by 2009, we wouldn't like to see things delayed. If there is a postponement of site selection, there will have to be very good reasons. Besides, I don't think it's good in the long run for the nuclear waste to lie open in Clab. No, we have to find a solution to the waste problem."

What happens now?

"I hope that the rest of the country will get more interested, so that this is not just viewed as an issue for the site investigation municipalities. It's a matter of interest for all of Sweden and even beyond – Åland, for example. I have also wondered what criteria will finally decide what site is selected. What could it be if not the best rock?"

Interview

Interview

Reviewer

County Administrative Board

Name: Mats Lindman

Chief Administrative Officer at the County Administrative Board in Uppsala County, where he has worked since the 1980s. For several years also secretary of the Swedish National Council for Nuclear Waste. The work at the County Administrative Board is focused on the nuclear enterprises in Forsmark, both SKB and Forsmarks Kraftgrupp.

"I have a coordinating role at the County Administrative Board in this long nuclear waste process. During the site investigations, SKB has to pay special consideration to the natural environment and conduct statutory consultations. The candidate area in Forsmark has very high natural values. The County Administrative Board has therefore stipulated special precautions, which are included in the conditions for SKB's work. SKB also has to conduct consultations with all concerned regulatory authorities, municipalities, private citizens and organizations before preparing the environmental impact statement that must be included with the permit applications for the final repository."

Can you give examples of how the County Administrative Board has worked?

"The County Administrative Board has followed with great interest SKB's investigations of the natural environment and the geological barrier for a final repository. As an authority under the Environmental Code, we have taken a stand on SKB's proposals for the conduct of the site investigation and the siting of each drilling site. We have stipulated requirements on limits, protective measures and remediation. For example, because of these requirements SKB has avoided excavation and other earthmoving works within particularly sensitive parts of the area and has given special consideration to the breeding periods of birds and the spawning periods of fish. We have also decided where flushing water from the drilling sites should be discharged to avoid disturbing natural salt balances."

How has it gone?

"The consultations with SKB have been and still are a major project. It is important to handle the final repository issue with care. SKB has resources and does a good job, you might say the company does its utmost and tries to find the best competence to gather reliable data as a basis for licensing. The consultation processes are proceeding smoothly in well functioning forms. Many people are very engaged, so it takes time but that's how it has to be."

What happens now?

"There's still a lot of work to do. SKB's consultations are in a final phase where the County Administrative Board is supposed to make sure that the environmental impact statement has the contents and scope needed for licensing."

Let's talk about
the weather

Winter days in Forsmark

It wasn't in January that Forsmark had the most winter days – in other words, ten degrees below zero or colder – but in March!

The 2003/2004 winter season had 15 winter days during December, January and February.

In 2004/2005, there were 17 cold winter days, most of which were not during the winter months of December, January and February but during the spring month of March!

In 2005/2006, we had 24 winter days – once again most (13) in March!

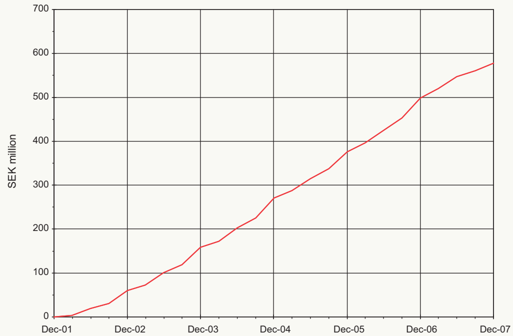
The 2006/2007 winter season was a normal winter with all 14 winter days during January and February.

The site investigation in figures

Price tag nearly SEK 600 million

The site investigation in Forsmark has cost about SEK 100 million a year. That means that as of the end of 2007 the total cost for the period 2002–2007 amounted to nearly SEK 600 million. Of this amount, around SEK 80 million stayed in the municipality of Östhammar, while SEK 189 million was spent in the region including Uppsala, Norrtälje, Tierp, Älvkarleby and Gävle. SEK 308 million went to the rest of Sweden and the world – we have had suppliers in Norway, Finland, Germany and Canada, among other countries.

Costs for site investigation 2002–2007.



631 suppliers

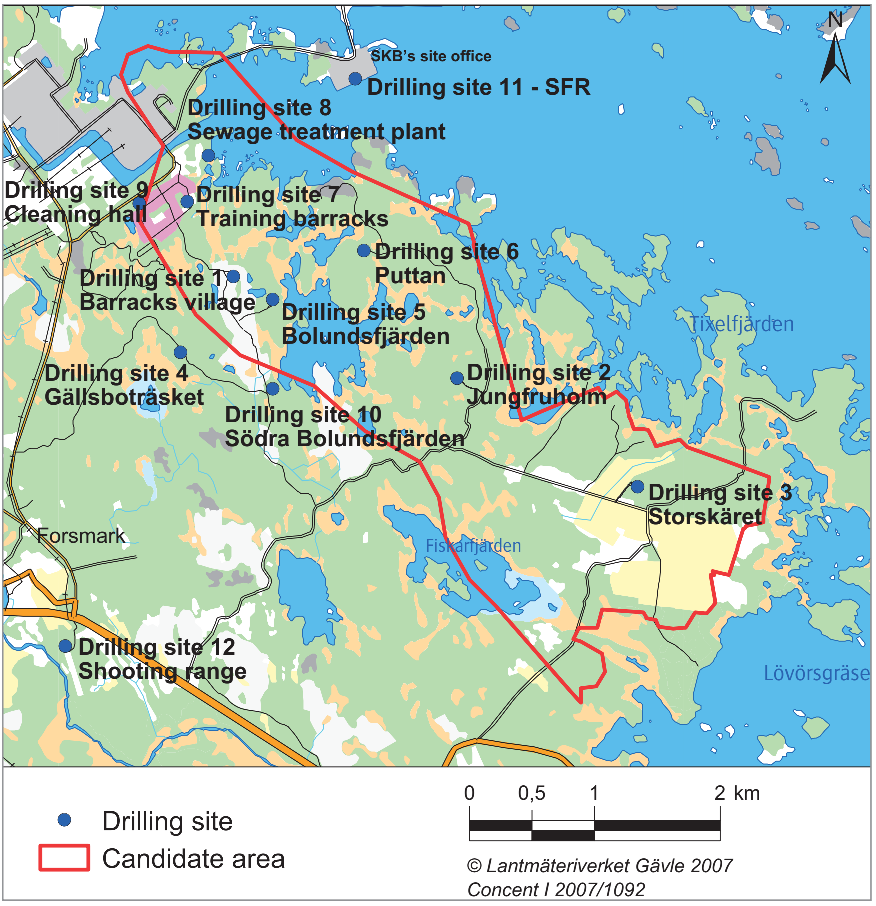
A total of 631 suppliers participated in the site investigation. Nine of them had assignments worth over SEK 10 million. Another example is that 93 suppliers had orders of between SEK 100,000 and 500,000, while 240 had assignments worth less than SEK 10,000. Some of the biggest suppliers are Drillcon Core AB, Forsmarks Kraftgrupp AB, Geosigma AB, Sven Andersson i Uppsala AB and the Geological Survey of Sweden in Uppsala.

Drilling most expensive

The site investigation made a total of 1,456 orders over the years. Most had to do with drilling, and they also cost the most. 155 orders worth nearly SEK 70 million can be attributed to drilling. The investigations in the disciplines of geophysics, hydrogeochemistry, geology, hydrogeology and rock mechanics cost between SEK 30 and 40 million each. Infrastructure cost nearly SEK 29 million, and the ecological work just under SEK 16 million. Orders for public information activities carry a price tag of SEK 1.8 million.

Opinion polls

Temo conducted opinion polls in Östhammar Municipality during a five-year period. Each year, 800 persons were asked for their views on a final repository in the municipality. The responses were overwhelmingly positive, and the percentage in favour increased from 66 to 77 percent. The result of the 2007 opinion poll shows that 77 percent are in favour of a final repository in Forsmark. The support is strongest in Östhammar – 83 percent – and weakest in Alunda – 67 percent. Other rural towns: Öregrund 81 percent, Österbybruk 73 percent and Gimo/Hargshamn 74 percent.



The twelve drilling sites we have established.

1,000 litres of water per metre

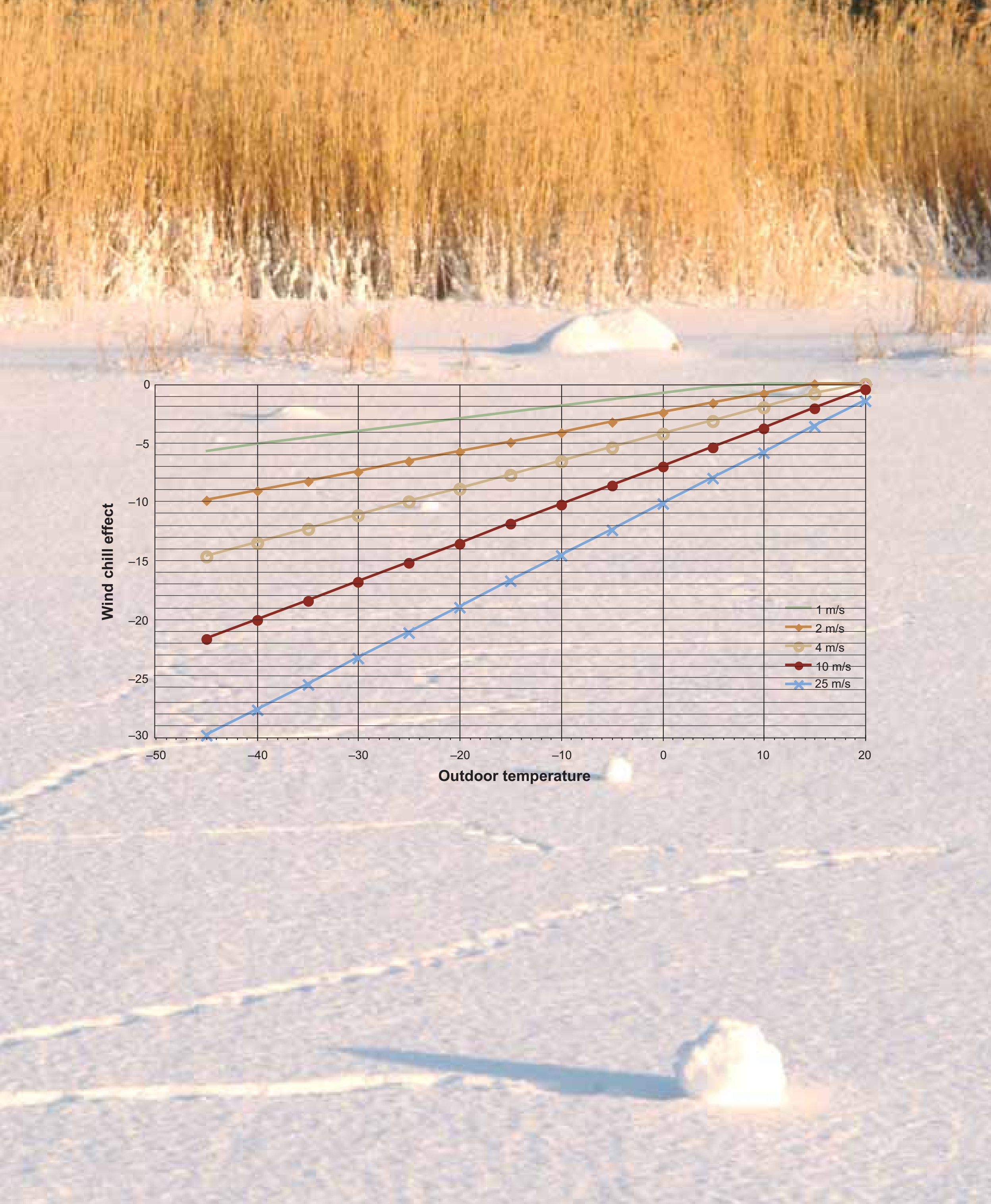
19,408 cubic metres of flushing water were used to 18,028 metres of cored boreholes. This is equivalent to nearly 400 tank trucks of 50 cubic metres each, or more than 1,000 litres of flushing water per metre of drill core. But since the superficial part of the rock contains so much water, we got back more than twice as much: nearly 44,000 cubic metres. All return water was discharged back into the sea or nearby lakes in compliance with the directions of the County Administrative Board.

530 tonnes of drill cuttings

When the 38 percussion boreholes were drilled, all drill cuttings were collected in containers. It amounted to a total of about 200 cubic metres of drill cuttings or about 530 tonnes. Most of the cuttings were then used for road improvements in the area.

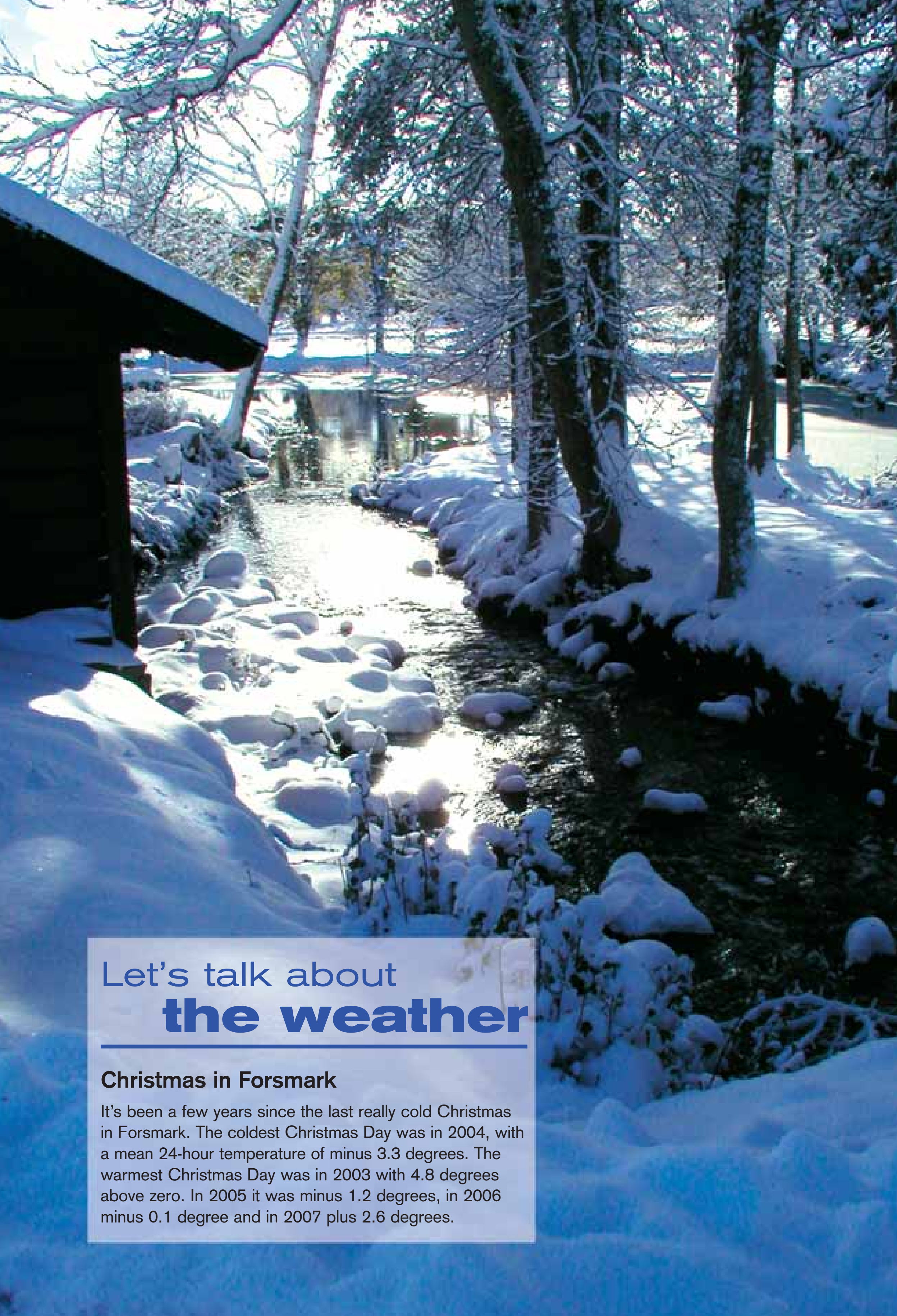
Tonnes of salt

The storms Gudrun (January 2005) and Per (January 2007) led to heavy sea salt water intrusion of Bolundsfjärden. Based on the water level changes in the lake and salinity measurements, the quantity of chloride that entered the lake on the two occasions is estimated to be 40 tonnes during Gudrun and much more, about 250 tonnes, during Per.



How cold is it, actually?

In the picture above, the wind has rolled snowballs in Forsmark. It's so windy the cold cuts to the bone. It's zero degrees in the air, but feels a lot colder. How much colder does the wind make it? The diagram shows the wind chill effect at different temperatures and wind speeds. For example, at an outdoor temperature of 10 degrees below zero Celsius and a wind speed of 25 metres per second, the wind chill effect is minus 14.6 degrees, so the perceived temperature is minus 24.6 degrees.



Let's talk about the weather

Christmas in Forsmark

It's been a few years since the last really cold Christmas in Forsmark. The coldest Christmas Day was in 2004, with a mean 24-hour temperature of minus 3.3 degrees. The warmest Christmas Day was in 2003 with 4.8 degrees above zero. In 2005 it was minus 1.2 degrees, in 2006 minus 0.1 degree and in 2007 plus 2.6 degrees.

What happens now?

On 3 June 2009, SKB made public the choice of Forsmark as the site where we wish to build the final repository for spent nuclear fuel, the Spent Fuel Repository. At the time, all the information from the site investigations in Laxemar in Oskarshamn Municipality and Forsmark in Östhammar Municipality had been compiled. The site descriptive models for both of the sites had then been created with the help of this information.

The relatively dry and fracture-poor rock was the main reason why Forsmark was eventually chosen. ”The rock has spoken,” as Claes Thegerström SKB´s CEO expressed it.

On 16 March 2011, the applications for permission to build the Spent Fuel Repository in Forsmark were submitted to the authorities, the Swedish Radiation Safety Authority and the Land and Environmental Court in Stockholm. One of the most important documents within the applications is the safety analysis, which shows that the site in Forsmark fulfils the strict requirements that the authorities have set on long-term safety.

A large number of respondents will have the chance to express their opinions concerning the applications on several different occasions. The Municipalities of Östhammar and Oskarshamn, environmental organisations, the Swedish National Council for Nuclear Waste and various other authorities are among the consultative bodies.

The review, conducted by both Swedish and international experts, will take several years. The schedule has been somewhat delayed compared to what had originally been estimated. It now looks like the government could have the matter on its desk sometime around 2015. Before the final decision is made, Östhammar Municipality will also have a say in whether the construction shall go ahead. The estimated time for construction start could be around 2017-2018 at the earliest.

A large numbers of respondents will have the chance to express their opinions.

Let's talk about the weather

Warm winter days

Winter is not always winter. There have been many warm winter days with a temperature of more than ten degrees above zero during the measurement period.

We had the most warm winter days during the 2006/2007 winter season. During the last month of 2007 there were no days warmer than ten degrees above, but also none colder than ten below.

Permeability of the rock

The permeability of the rock is an important property for a final repository. It affects the assessment of the final repository's long-term safety, but is also of importance for its design and operation. Among other things, permeability determines what sealing measures need to be adopted during the construction of tunnels and shafts.

In previous annual reports we have presented results regarding the permeability (hydraulic conductivity) of all cored boreholes. The results for the last five boreholes are presented on the following pages. Two of the holes lie outside the candidate area. The purpose of these holes was to investigate two major deformation zones and measure their hydraulic conductivity. The last figure is a compilation of measurements of hydraulic conductivity in all cored boreholes during the years of the site investigation.

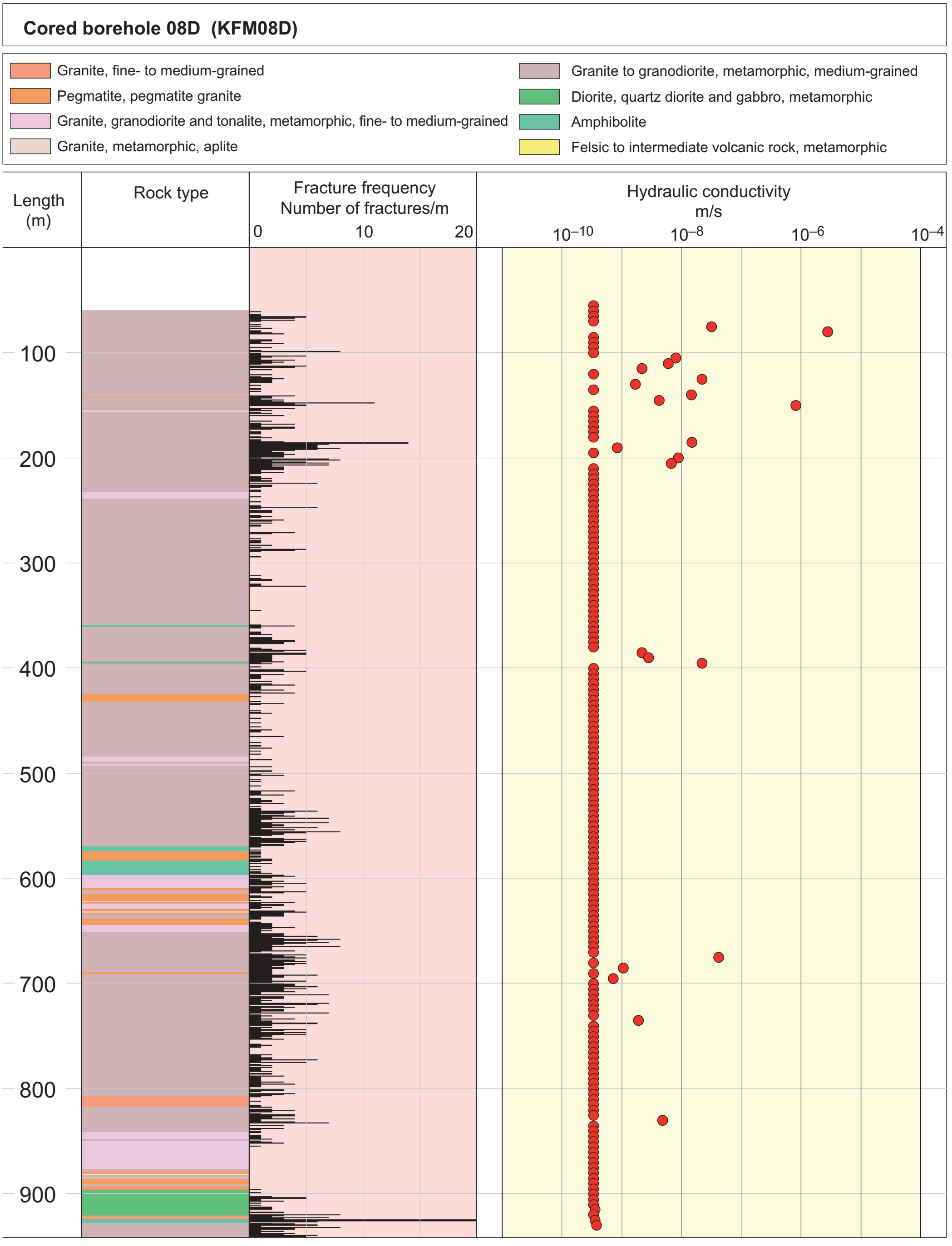
Borehole results

In the charts of borehole results on the following pages, the capacity of the rock to conduct water, permeability, is given as hydraulic conductivity. Each point on the scale indicates how much water can be forced into (or pumped out of) a borehole section at a given pressure (positive or negative). The scale in the charts is logarithmic, which means that each increment on the scale represents an increase in hydraulic conductivity by a factor of ten. The hydraulic conductivity is thus roughly 200,000 times greater at the far right on the yellow part of the scale (1×10^{-4}) than at the measurement limit at the far left of the scale.

The values of permeability in the cored boreholes that are shown in the charts on the following pages have in most cases been determined by difference flow logging. The measurement equipment used for these measurements has been the Posiva Flow Log (see 2003 annual report, page 46). Each value shows the permeability in a five-metre section. The measurement limit varies slightly for different boreholes, but is around 5×10^{-10} m/s. This means that only about 1.5 ml of water per minute can flow through the fractures in a five-metre-long borehole section if a positive or negative pressure (hydraulic gradient) of 10 mWC (metres water column) is applied. Flows lower than this cannot be measured with this method. Measurements of permeability in certain boreholes were done with equipment for hydraulic injection tests (see 2004 annual report, page 55). With these tests the measurement limit can be lowered further, in favourable cases down to about 5×10^{-11} m/s.

Thus, if a measurement value is at the measurement limit, this may mean that the actual hydraulic conductivity is even lower.

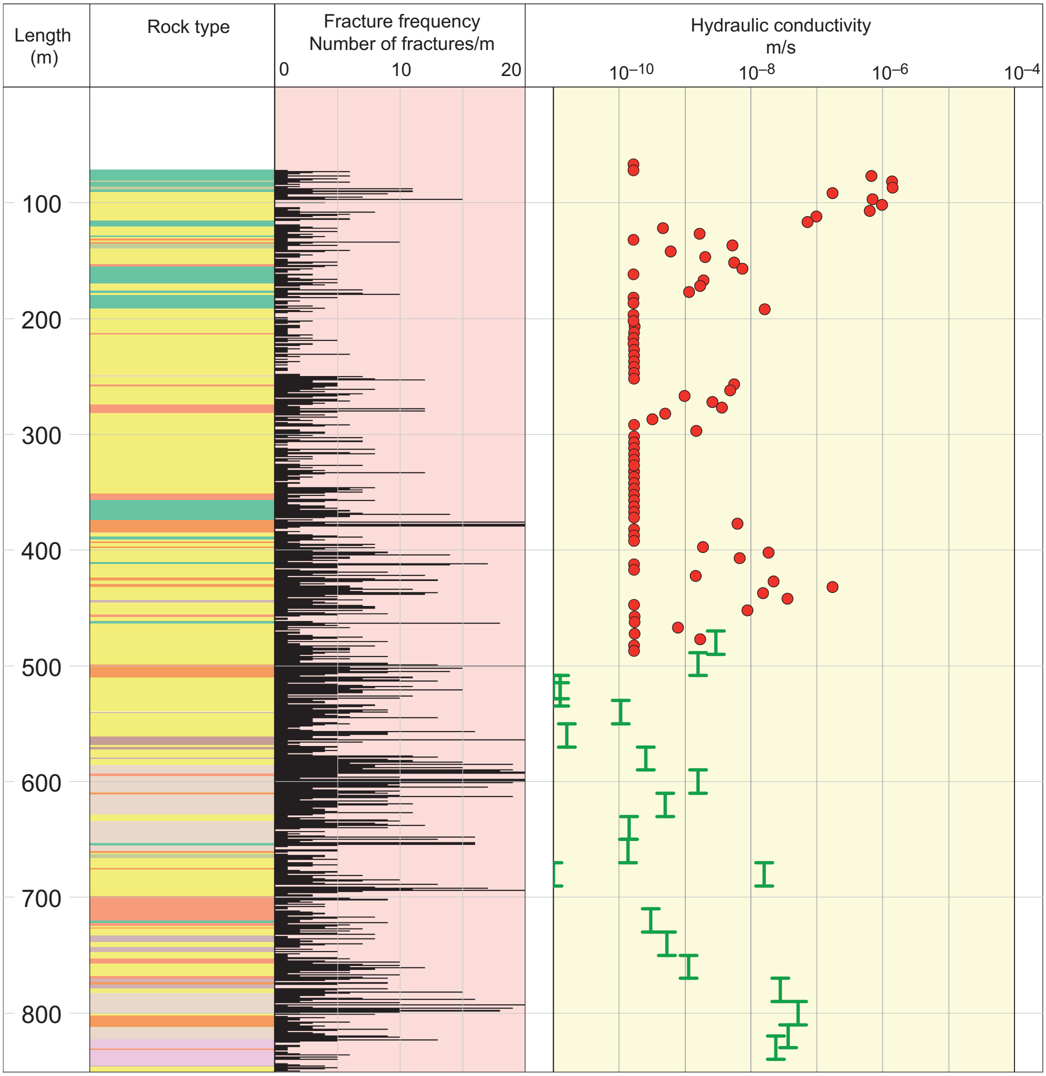
Pages 118 – 119 show a summary of all boreholes where we have measured hydraulic conductivity with the PFL log (Posiva Flow Log). The charts only show where the measurement instrument has measured a permeable section. The measurements have been converted to hydraulic conductivity in five-metre sections. The results of hydraulic injection tests are also shown for certain boreholes.



Borehole 8D is a supplementary hole that was drilled at the end of the site investigation. It is located in the central portion of the potential repository area and is inclined 55 degrees from the horizontal plane, intersecting an envisioned repository at a depth of 450 metres at 555 metres. The purpose was mainly to investigate minor deformation zones that had been indicated by geophysical surveys. Hydraulic conductivity was measured by a PFL log. Aside from water-conducting fractures in the surface rock and a few such fractures at greater depth, the rock is watertight. Dating of water samples taken from the water-conducting fractures at a borehole length of about 700–800 metres show that the water is probably around a million years old, see page 74.

Cored borehole 11A (KFM11A)

Granite, fine- to medium-grained	Granite to granodiorite, metamorphic, medium-grained
Pegmatite, pegmatite granite	Granodiorite, metamorphic
Granitoid, metamorphic	Amphibolite
Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained	Calc-silicate rock (skarn)
Granite, metamorphic, aplite	Felsic to intermediate volcanic rock, metamorphic



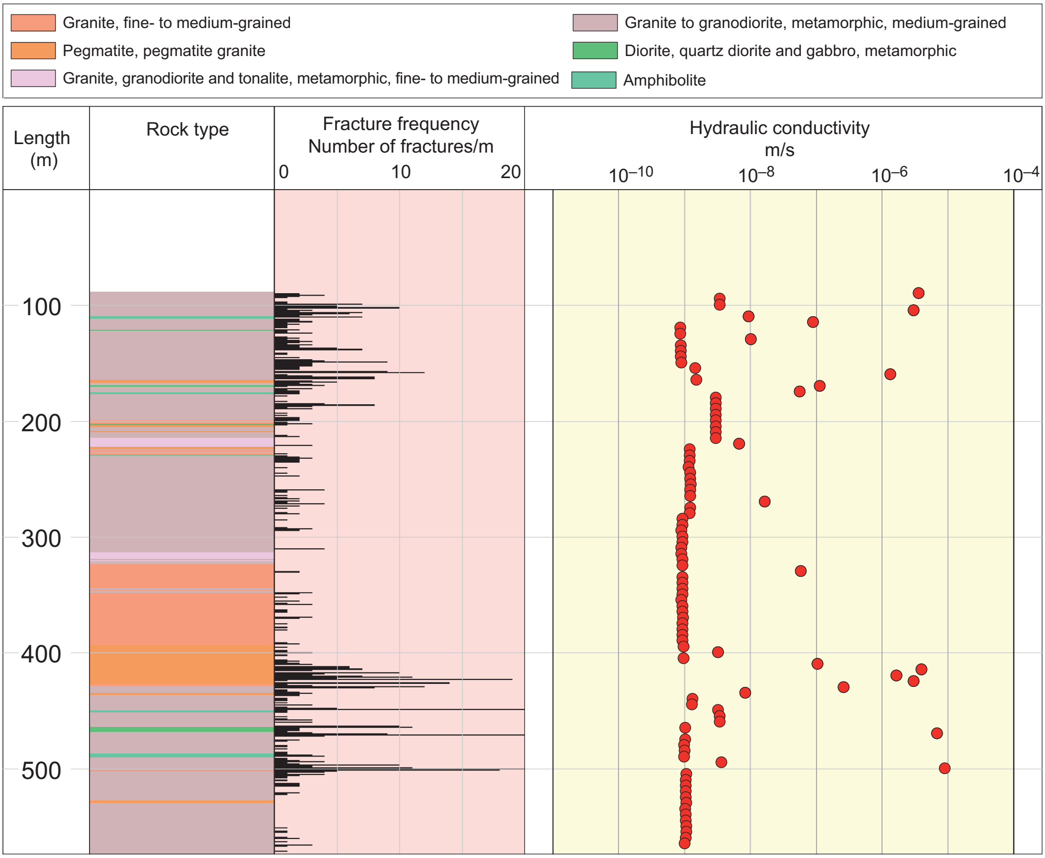
Borehole 11A investigates the large deformation zone called the Singö Zone located about one kilometre outside the candidate area to the northeast. The borehole is inclined 60 degrees from the horizontal plane and is 851 metres long. Measurements of hydraulic conductivity were done with a PFL log down to a borehole length of 500 metres and by hydraulic injection tests between 500 metres and the end of the borehole. The borehole intersects the Singö Zone between 250 and 800 metres. There are water-conducting fractures along almost the entire borehole. The most fractured part of the Singö Zone (between 500 and 650 metres) appears to be less conductive than the peripheral parts of the zone, however.

Borehole 12A (above) investigates the other big deformation zone, the Forsmark Zone, which is located more than two kilometres southwest of the candidate area. The borehole is inclined 60 degrees from the horizontal plane and is 601 metres long. The Forsmark Zone is penetrated between a borehole length of about 150 and 400 metres. Hydraulic conductivity was measured with the hydraulic injection test equipment. With few exceptions there are conductive fractures in the entire borehole.

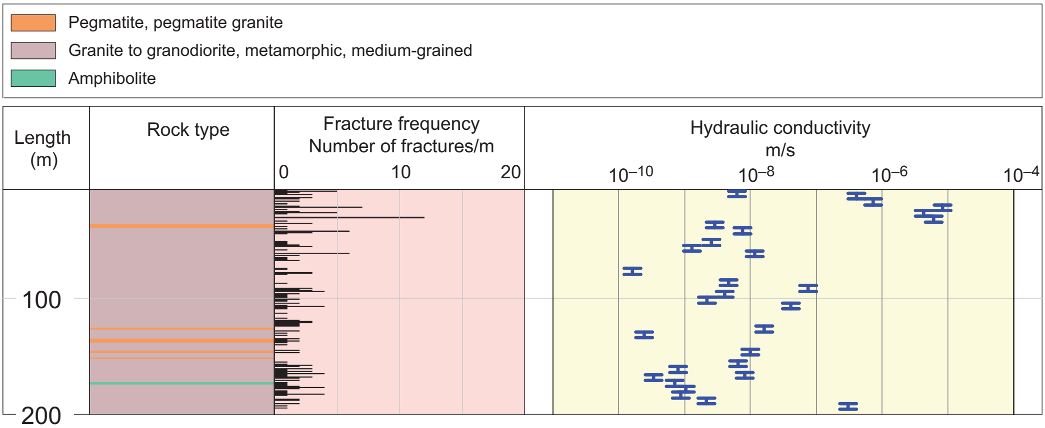
Borehole 2B (top right) is nearly vertical and about 574 metres long. It was drilled almost parallel to the previous borehole 2A. At a depth of 400 metres the distance between them is 50 metres. The purpose of the borehole was to measure rock stresses and perform tracer tests in the gently-dipping and permeable fracture zone "A2" located at a borehole length of about 400 metres. Hydraulic conductivity was measured by a PFL log. The measurements show a great similarity between this hole and previous measurements in borehole 2A (see 2003 annual report).

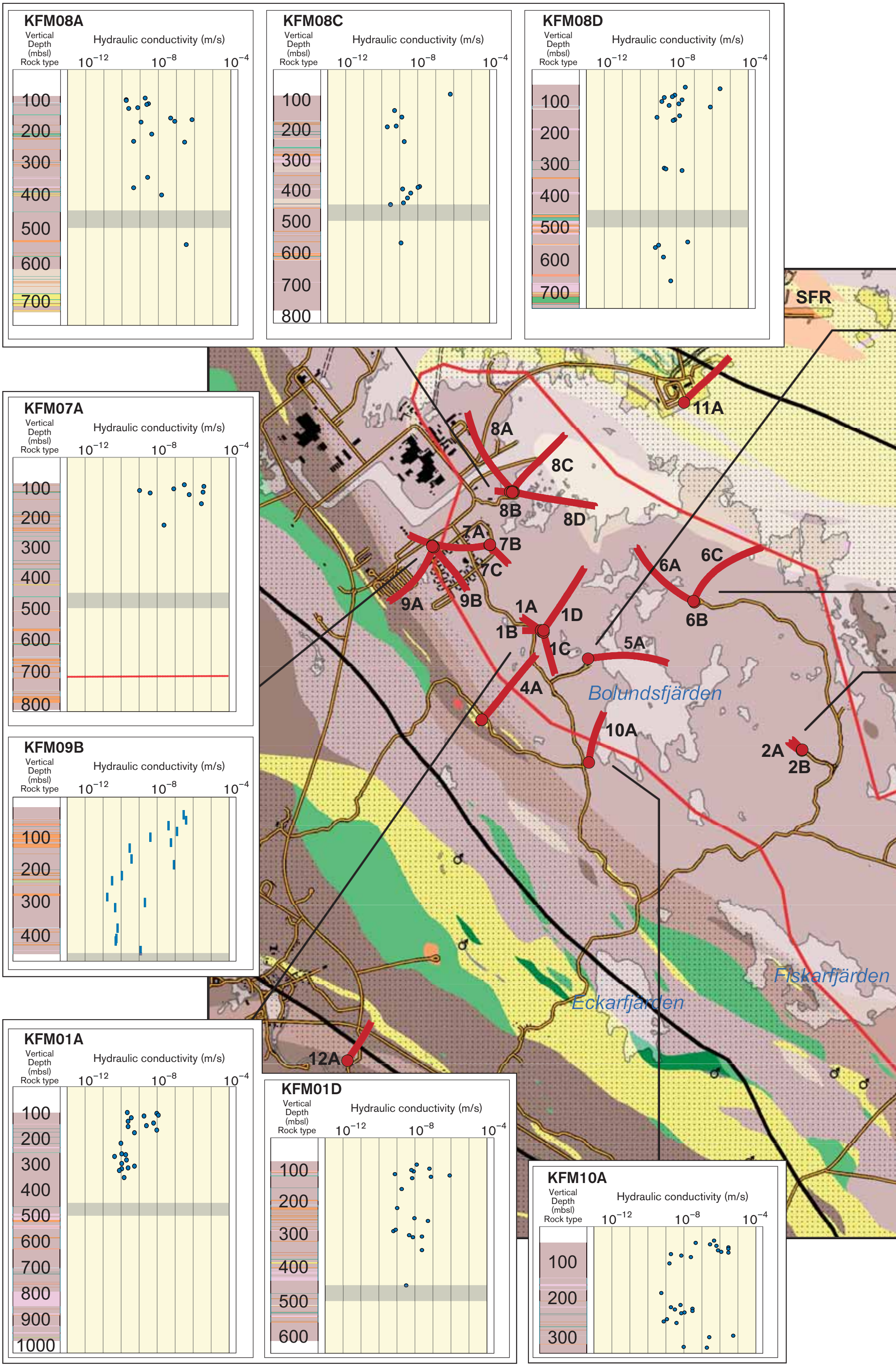
Borehole 8B (bottom right) is a short cored borehole that supplements other boreholes on drilling site eight (at the sewage treatment plant). The borehole is inclined 60 degrees from the horizontal plane and is 200 metres long. The purpose of the borehole was to obtain drill cores and measure the hydraulic conductivity in the superficial rock. The measurements, which were done with the equipment for hydraulic injection tests, show that the bedrock is permeable, but with a lower hydraulic conductivity than at drilling site nine (the cleaning hall). This has been a factor in adjusting the location of shafts and ramp, which we describe on page 87.

Cored borehole 02B (KFM02B)

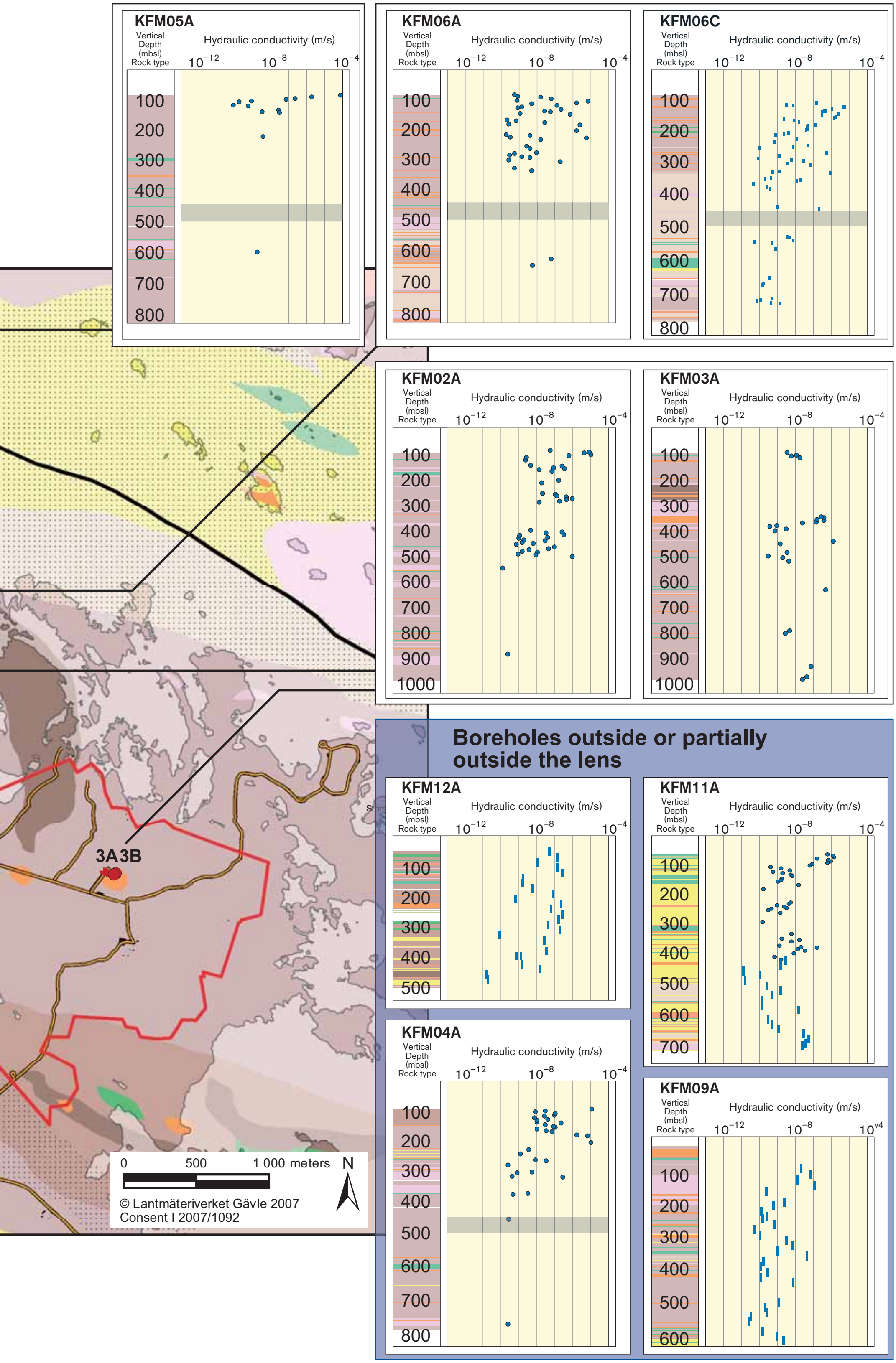


Cored borehole 08B (KFM08B)





The figure shows results from all boreholes where hydraulic conductivity was measured with the PFL log (points). Only values above the measurement limit are included. For certain holes, results from hydraulic injection tests are also shown (lines). In this figure, hydraulic conductivity is shown versus



depth and not borehole length as on the preceding pages. For the boreholes that investigate the rock in the potential repository area, the recommended repository depth of 450–500 metres has been indicated by a shaded line. A red line in the chart for borehole 7A indicates that data are lacking below this line.

Observer

Regional Council

Interview

Name: Lucie Riad, geologist

Information officer at the Uppsala Regional Council since October 2006. Her assignment is to inform regional politicians, civil servants, entrepreneurs and others and to initiate a dialogue on the final repository issue in the region.

"The site investigation for a possible final repository for spent nuclear fuel in Forsmark concerns not only Östhammar Municipality but also the neighbouring municipalities and the entire region. The effects of an establishment of this size extend far beyond the municipal boundaries. The information must also do so, but I think that people outside Östhammar Municipality are poorly informed about the waste."

What did you know about the project before?

"I really didn't know much about it, but I knew it was going on. As a geologist it is interesting for me to follow new rock projects, and it isn't so often such extensive investigations are conducted. The site investigation has yielded a great deal of new knowledge, including pure basic research."

What do you know about the site today?

"I can't say much about the results. But I have learned that there is widespread ignorance of the fact that the nuclear waste already exists. It's as if people had 'forgotten' that we have to deal with the big environmental problem it represents, which has nothing to do with whether we invest in more nuclear power or not. It's important to remind people that the waste exists and it is dangerous."

What will you do afterwards?

"I have pondered this question during the past year and it hasn't been particularly easy to keep track of everything that has happened and is still happening. Next year I will be more informed and take the next step: In other words, I will try to create a dialogue with the general public in the region, not least with the environmental movement. We will discuss the concrete disposal of the nuclear waste and make comparisons with other methods. We will also work strategically with the issue from an industrial perspective."

Let's talk about the weather

Summer in Forsmark

In 2003, summer came to Forsmark on the 30th of May.

In 2004, summer came on the 5th of June.

In 2005, summer arrived on the 25th of May.

In 2006, summer arrived on Sweden's National Day, the 6th of June.

In 2007, summer started in May – on the 28th.

The meteorological summer is here when the mean 24-hour temperature is consistently at least plus ten degrees. By "consistently" is meant for at least five days.

Downloading knowledge

SKB has a “report factory” that churns out hundreds of scientific reports every year. All of these reports – including around 800 dealing with the site investigation in Forsmark – can be downloaded from our website at *www.skb.se* under the tab headed “Publications”.

In addition to these scientific reports, we also publish a large body of material every year aimed at non-scientists. These publications include the site investigation’s annual reports, the annual reports on consultations, yearbooks on societal research and more municipality-specific societal studies.

All of these publications can also be found on our website.

If you need more information about this material, phone Eva Nevelius at +46 (0)173 883 67 or e-mail to *eva.nevelius@skb* and we will contact you to discuss what material you need.

SFR and SKB's site office in Forsmark Harbour.

Guests in Forsmark

Not always – but often – we have a camera handy when guests visit. On the following pages we show pictures and give examples from our visitors' statistics from the period 2002–2007. We cannot include all of them, but we want to give an idea of the breadth of our visits. The guests come from near and far, from Duderö as well as from Taiwan. Some are experts on geology or nuclear waste, others have no specialist knowledge. Some are young, some are old. But they have one thing in common: They are all equally welcome.

At right: Madelén Eriksson from Snesslingekulla has paid us a visit every year since the year she was born. Here she is shown at a nearby resident get-together in 2006.

FROM OUR GUEST BOOKS 2002–2007

Thousands of visitors have visited the site investigation in Forsmark during the past six years. Leaf through parts of our guest books!

2002

Visitors from Hagby Asahi, a supplier of drilling equipment

Moderate party from Öregrund (February)

Vallonbruk i Uppland (tourist organization) (March)

Swedish National Pensioners' Organization in Gimo (May)

Parliamentary candidates for the Centre Party (May)

Summer residents in Stenskär (August)

Swedish Steel Producers' Association, Stockholm (September)

School kitchen staff in Östhammar Municipality (October)

Environmental Health Committee, Östhammar Municipality (December)

Vattenfall Service, Hallstavik (December)

School kitchen staff in Östhammar Municipality

Nearby resident get-together

2003

Staff from Öregrund School

Östhammar Business Association on a study trip to Oskarshamn

Radio Uppland (January)

TV4 Uppland (January)

Svenska Dagbladet, Stockholm (January)

Educational Radio's series "The World is Flat" (March)

Moose management organisation of the Forsmark area (April)

Police from Uppsala and Stockholm (April)

Turbine operators from the nuclear power plant in Barsebäck (April)

Swedish Security Service (April)

National Land Survey of Sweden, Östhammar (May)

Nearby residents visit a drilling site

Visitors from Russia (May)

Oskarshamn Municipality (May)

Members of Parliament (May)

Royal Institute of Technology, Stockholm (June)

Öregrund Tourist Office (June)

Österby Gjuteri AB (August)

Swedish Rolls Royce Club (August)

Korsnäs AB, Gimo (October)

Rebeckalogen, Östhammar (November)

Delegation from Bulgaria (November)

Sveaskog AB, eastern Uppland (November)

Luleå University (November)

Police from Uppsala and Stockholm

2004

Visitors in the core mapping facility, Assen Simeonov talk about the rock

Vaggsång Choir, Östhammar (January)

Stockholm University (February)

Östhammar Business Association (February)

Sandvik Coromant, Gimo (April)

SKB's counterpart in France, Andra (April)

Local safety committee in Varberg Municipality (May)

Södertörn University College (May)

Synerco (May)

Study Mission, Japan (May)

Rolf Sturegård and Mats Lindman, County Administrative Board in Uppsala County

Swedish Nuclear Power Inspectorate with guests from Lithuania

Red Cross in Gävle (June)

Åke Tunnelbyggare, Stockholm (June)

US Waste Management, USA (June)

Vattenfall Research & Development (June)

The Kopec organization from Korea (June)

ABB Westinghouse (June)

Norrskedika Sports Association (September)

Uppsala University (September)

SKB's counterpart in Hungary, Puram (September)

Committee on Radioactive Waste Management, UK (September)

International oceanographers, hosted by the National Board of Fisheries (October)

SKB's counterpart in Lithuania, Rata (October)

SKB's counterpart in the UK, Nirex (November)

Hultsfred Municipality (November)

National Board of Health in Denmark (November)

Arctic Sea scientists from Canada (November)

Rotary Club, Lövstabruk (November)

Delegation from Japan, RWCM (November)

NIERA – Nuclear, Industrial and Environmental Regulatory Authority, Russia (December)

Nearby resident get-together

2005

Drilling manager Göran Nilsson gives information to Taiwanese visitors

Boliden Mineral (January)

Ministry for Foreign Affairs (February)

SKB's counterpart in Canada, NWMO (February)

SKB's counterpart in Taiwan, Sinotec (February)

SKB's counterpart in Finland, Posiva (March)

VNIPIET, All-Russian Scientific Research and Design Institute of Energy Technology, Russia (March)

Lion's Club in Österby (March)

Nordea's Board of Directors, Östhammar (March)

Delegation from Lappeenranta, Finland (April)

Nejonöga inget för kungen

ÄLVKARLEBY

Älvkarlebys delikatess nejonöga är inget som faller kungen i smaken.

– Nej, nej, nej. De tillhör släkten rundmunnar och är inte min favorit, sa kung Carl Gustaf med en bestämd min.

I går besökte kungen och drottningen Älvkarleby för att få information om utvecklingen inom energiområdet.

Det är inte första gången som kungen besöker Älvkarleby. Sist han var här invigde han hängbron Karl XVI bro. Han provade också fiskelyckan i Dalälven, men utan resultat.

– Det krävs mer tid, försvarade kungen sig med varför han inte fick upp någon lax den gången.

Vid besöket i Älvkarleby i går stod den framtida energiförsörjningen i fokus. Kungaparet besökte dagen innan Forsmark där de bland annat gjorde ett besök i reaktorhallen.

– Jag kände ängslan inför besöket och tänkte mycket på olyckan i Tjernobyl. Men nu har min ängslan lagt sig, sa drottning Silvia Forsmark för att se hur varsamt de hanterar kärnbränsleavfallet.

KUNGLIGT BESÖK. I går besökte kungen och drottningen Älvkarleby för att få information om utvecklingen inom energiområdet. Kungaparet fick bland annat en guidning i kraftstationen, samt information om Vattenfalls forskning inom energiområdet. Foto: DAVID HOLMQVIST

Drottningens första besök

För drottningen var det första besöket i Älvkarleby. Hon kände inte till något om bygden, däremot tyckte hon att det var vackert här vid älven.

Kungen såg nöjd och glad ut att vara tillbaka.

– Det är trevligt att vara tillbaka och se på fortsatta utveckling som drivs här. Det är inte bara vatten som strömmar utanför porten utan det görs forskning på framtida energiutveckling. Och vi försöker ta till oss av det här på bästa sätt, sa kungen som tycker att besöken har varit lärorika.

– Det är skojigt att se att vi har möjlighet att ligga i framkant när det gäller forskning inom energifrågorna.

Har inte besökt Ockelbo

Besöket i Älvkarleby parade i en guidning i kraftstationen samt information om den forskning som Vattenfall utveckling bedriver. Efter besöket i Älvkarleby skulle kungaparet åka till Uppsala för att diskutera framtida energikällor.

– Det går inte att lösa energifrågorna med en enda kraft utan det måste vi göra tillsammans. Det är enda möjligheten, menade kungen.

– Jag tror man ska ta tillvara på alla möjligheter.För att man har hittat en möjlighet utan forska vidare, sa drottningen.

På frågan om vad kungaparet tycker om Ockelbo, där kronprinsessan Victorias pojkvän Daniel Westling kommer ifrån, sa kungen att de aldrig har varit där. De har heller ingen resa inplanerad dit.

– Men de har en väldigt fin park där, sa drottning Silvia.

Katarina Lönnberg

Arbetarbladet, 25 May

Association for Advanced Drilling (May)

King Carl-Gustaf and Queen Silvia (May)

Centre Party in Östhammar (May)

Roslagen Vaulting Club, Östhammar (May)

John Bauer Gymnasiet (upper secondary school), Gävle (May)

Gimo Riding Club (May)

National Network for Working Life Development (August)

Mission Church in Alunda (August)

Vattenfall Nordic Generation (August)

Ferry Line, National Road Administration, Öregrund (September)

Deputy County Governor Leif Byman, Uppsala (September)

Delegation from Brazil (October)

ÖsterbyGallring, Österbybruk (December)

Site Manager Kaj Ahlbom, Minister Tomas Östros, Barbro Andersson Öhrn and Alf Lindfors

Minister Lena Sommestad, SKB President Claes Thegerström, Bengt Leijon and Gerd Nirvin (both SKB)

*Tomas Östros,
Minister for Industry
and Trade (August)*

*Lena Sommestad,
Minister for the
Environment
(September)*

Russian visitors

Association for Advanced Drilling

Gimo Sports Association

2006

Deputy Governor Sergey Subbotin (middle) from Murmansk

Swedish Business Archives Support Fund, Stockholm (January)

Left Party's Government Offices staff, Stockholm (January)

Real estate agents in the region (May)

Swedish NGO Office for Nuclear Waste Review – MKG – (May)

Korsbron Åkeri (trucking company), Gimo (May)

Gimo Swimming Society (May)

Mannheimer Swartling Advokatbyrå (law firm), Stockholm (August)

Archipelago women around the Baltic Sea (August)

Board of Directors of Hargs Hamn AB (port authority) (August)

Representatives of Tierp Municipality and from Tierps twintowns Hauho, Forssa and Janakkala in Finland (September)

Swedish Nuclear Power Inspectorate with Russian guests (October)

Swedish Nuclear Power Inspectorate with French and Finnish guests (October)

Samhall, Uppland (October)

Board of Directors of the Nuclear Waste Fund (October)

Nearby resident get-together

Japanese Embassy (November)

Group of women from Oskarshamn (November)

Lundellska School, Uppsala (November)

Swedish Museum of Natural History (November)

Norwegian Radiation Protection Authority – (November)

SVT (The Swedish Public Service Television) News (November)

Delegation from Korea (November)

Svergies Natur magazine (Swedish Society for Nature Conservation) (November)

Delegation from Hungary (December)

Delegation from Russia (December)

Kaj Enhorn (nearby resident)

Margareta Widén Berggren, mayor, and Gerd Nirvin, SKB

2007

Drilling Manager Göran Nilsson is interviewed by Ulrika Lindqvist from Swedish Radio P3.

SMHI, Arlanda

Furuhöjd Church in Alunda (January)

Ambulance personnel from Uppsala (February)

Royal Institute of Technology, Stockholm (February)

National Board of Fisheries, Öregrund (March)

John Bauer Gymnasiet (upper secondary school), Gävle (March)

Swedish Radiation Protection Authority (April)

Swedish University of Agricultural Sciences, Uppsala (April)

Södertörn University College, Stockholm (April)

Swedish Business Archives Council, Stockholm (May)

Members of the press from Switzerland (May)

Guests from Brazil

Board of Directors of BHP Billiton, one of the world´s largest mining company with 39,000 employees in 25 countries (May)

Postal employees from Östhammar and Norrtälje (May)

Swebus, Uppsala (June)

Social Democratic Members of Parliament, Uppland (June)

Rural Economic and Agricultural Association, Uppsala (June)

Directors of tourist offices in Uppsala County (June)

SKB's counterpart in Spain, ENRESA (June)

Municipal leadership, Uppsala Municipality (August)

Delegation from Brazil (August)

Local healthcare centre, Gimo (August)

SMHI, Arlanda (September)

Rotary Club, Östhammar (September)

Nearby residents (September)

Swedish Radiation Protection Authority with Slovenian guests (October)

CARL, a multinational social science research project into the effects of stakeholder involvement on decision-making in radioactive waste management (September)

Swedish Radiation Protection Authority with Belorussian guests (October)

Swedish National Pensioners' Organization, Österbybruk (October)

United States Ambassador to Sweden (November)

Social Democratic members of the Swedish Parliamentary Committee on Defence (November)

Delegations from Korea, Lithuania, Russia (December)

SKB

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