

R-06-29

Oskarshamn site investigation

Programme for further investigations of bedrock, soil, water and environment in Laxemar subarea

Svensk Kärnbränslehantering AB

March 2006

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Preface

Since the summer of 2002, Svensk Kärnbränslehantering AB, SKB (the Swedish Nuclear Fuel and Waste Management Co), has been conducting a site investigation at Simpevarp and Laxemar in Oskarshamn Municipality for siting of a final repository for spent nuclear fuel. An equivalent investigation is also being conducted in Forsmark in Östhammar Municipality.

SKB's goal is to submit an application under the Environmental Code and the Nuclear Activities Act for siting of the final repository at one of these sites by the turn of the year 2008/2009. When the application is submitted, everything of importance for the final repository's safety, constructability and environmental impact shall have been investigated and analyzed. The investigations shall also provide data as a basis for configuring the facility to suit conditions and features on the site while limiting the impact on the environment and society.

SKB submitted a programme for the initial site investigation in Oskarshamn in September 2002. In March 2003, SKB submitted more precise and prioritized plans for continued investigations in the two subareas, Simpevarp and Laxemar. The initial site investigations for both subareas had been completed in the autumn of 2004 and SKB preliminarily prioritized the Laxemar subarea for further investigations. A framework for the remainder of the site investigation was presented, with a focus on investigations of bedrock, soil and water for the period up to the summer of 2005. These investigations have now been carried out and evaluated. It is therefore time to describe the investigations which SKB is planning for the remainder of the site investigation.

The direction of the site investigation in Oskarshamn and the investigation programme presented in this report is based on the assumption that the Laxemar subarea is prioritized for further investigations. A final decision on the direction of the site investigation in Oskarshamn is planned to be made in the spring of 2006 when preliminary safety reports have been presented for both Simpevarp and Laxemar. If the decision should then be that the Simpevarp subarea is chosen, a new investigation programme and a new timetable will be prepared.

The programme presented in this report has been prepared in close collaboration between the site organization in Oskarshamn and concerned subprojects within SKB's Deep Repository Project, particularly the Site Modelling subproject. The investigations will, as before, be conducted with great consideration given to residents, property owners and natural and cultural values so that they are not unnecessarily exposed to impact or disturbances. Just as before, the investigations will be continuously adapted to the knowledge that is gradually accumulated on the site. All important changes will be reported to the nearby residents, the authorities and other concerned parties.

Peter Wikberg
Site Manager in Oskarshamn

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Investigation Leader in Oskarshamn

This report is a translation of the report "Platsundersökning Oskarshamn. Program för fortsatta undersökningar av berggrund, mark, vatten och miljö inom delområde Laxemar" (SKB R-05-37) that was published in December 2005. The starting point for investigations according to this programme is the summer of 2005.

Summary

Since the summer of 2002, Svensk Kärnbränslehantering AB, SKB (the Swedish Nuclear Fuel and Waste Management Co), has been conducting a site investigation at Simpevarp and Laxemar in Oskarshamn Municipality for siting of a final repository for spent nuclear fuel. An equivalent investigation is being conducted in Forsmark in Östhammar Municipality. The initial part of the site investigations had been completed for the both of the subareas Simpevarp and Laxemar in the autumn of 2004. Based on the results of these investigations, SKB preliminarily prioritized the Laxemar subarea for further investigations. A programme was presented for the first stage of the complete site investigation in the Laxemar subarea, along with the main features of the remainder of the site investigation. The programme included investigations up until the summer of 2005 and was particularly aimed at obtaining answers to several vital questions so that the subsequent investigations could be focused on the rock areas judged to be most suitable for a final repository. These investigations have now been completed.

This report presents the programme for the remainder of the site investigation. The points of departure are the general goals for the Deep Repository Project during the site investigation phase, analyses and evaluations of data from completed investigations, and the needs for additional data to be able to evaluate the site as a siting alternative for the final repository. The account mainly covers the investigations on the site. All other work – analyses, site descriptive modelling, facility design, safety assessments and studies and assessments of consequences for the environment, human health and society – are only mentioned to the extent necessary in order to place the investigations in their context.

The direction of the site investigation in Oskarshamn and the investigation programme presented in this report is based on SKB's preliminary decision to prioritize the Laxemar subarea for further investigations. A final decision on the direction of the site investigation in Oskarshamn is planned to be made in the spring of 2006 when preliminary safety reports have been presented for both Simpevarp and Laxemar. If the decision should then be that the Simpevarp subarea is chosen, a new investigation programme and a new timetable will be prepared.

Goal

The overall goal of the site investigation phase is to obtain the permits required to site and build the final repository. The site investigations must therefore provide the data required for an evaluation of the suitability of the investigated sites for a final repository. The material must accordingly be comprehensive enough to:

- Show whether the selected site satisfies fundamental safety requirements.
- Show whether the construction-related prerequisites are met.
- Permit the final repository to be adapted to the conditions and features on the site.
- Permit an assessment of the impact of the final repository on the environment and society.
- Permit comparisons between the two investigated sites – Forsmark and Simpevarp/Laxemar.

The site

Figure 1 provides an overview of the site investigation area in Oskarshamn with the two subareas Simpevarp and Laxemar. The map also shows the regional model area and the local model areas which SKB works with when data from the site investigation is processed in site-descriptive models as a basis for the site description.

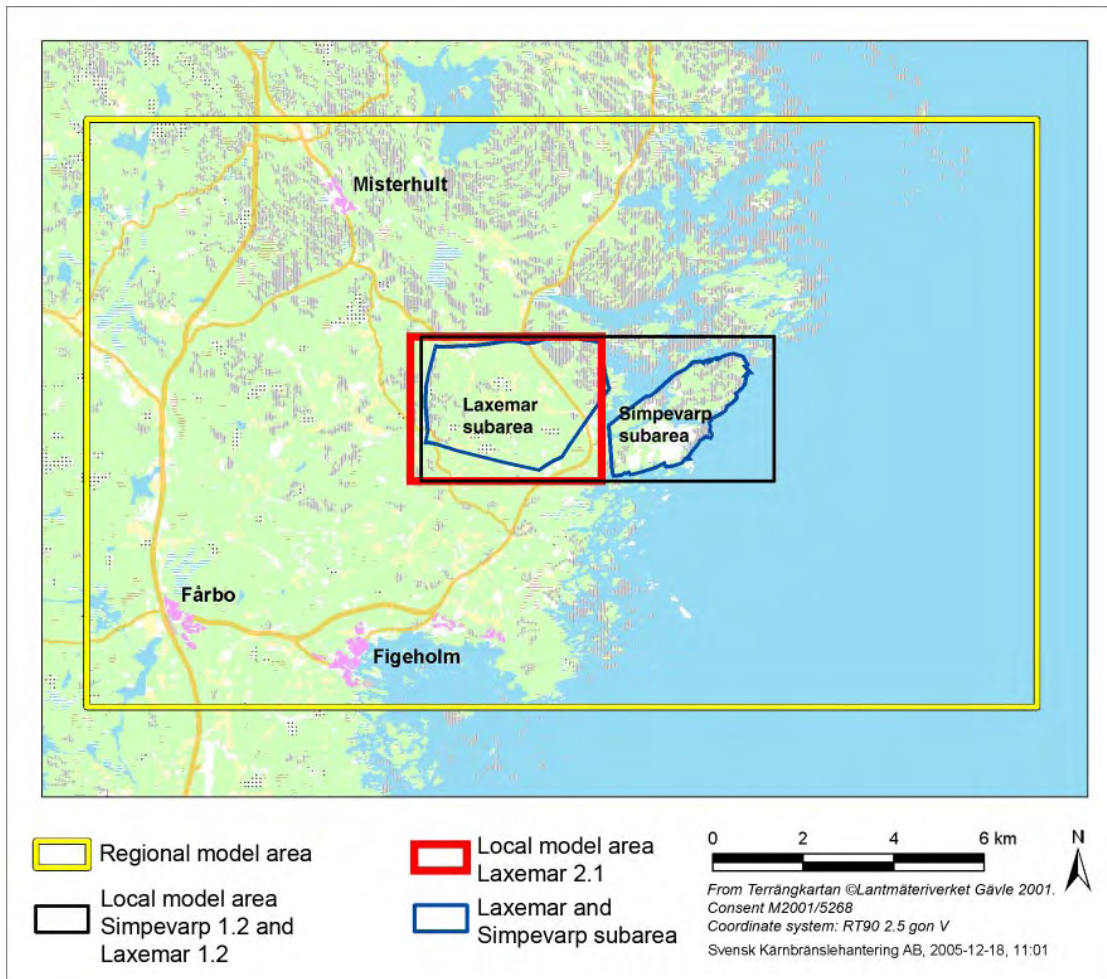


Figure 1. The site investigation in Oskarshamn with the two subareas Simpevarp and Laxemar, plus local and regional model areas.

State of knowledge

Prior to the site investigation phase, SKB presented fundamental requirements that had to be satisfied in order for a site to be considered for the final repository. Conversely, if one or more requirements are not met, the site is disqualified.

During the initial stages of the site investigation, the aim has been to gather data which – directly or indirectly – provides a basis for deciding whether the requirements can be considered to be met, and thereby whether further investigations are warranted.

SKB's assessment for **the Simpevarp subarea** is that good prospects exist there for building a final repository. The fundamental requirements are satisfied. It is possible to locate deposition areas so that all fuel fits in a one-storey repository. However, due to the major deformation zones that surround the subarea, together with local minor deformation zones within the area, the margins are small. Possible surprises in the form of more deformation zones may entail troublesome limitations. The Simpevarp subarea is surrounded by and partially included in areas of national interest and areas protected under the Environmental Code. It is not clear whether this entails limitations for the underground facility. It does, however, affect how the area can be used for a surface facility. Two good locations have been identified for the surface facility in the Simpevarp subarea: one at Clab and one on Hålö.

SKB's assessment for the Laxemar subarea is that this subarea also has good prospects of meeting the requirements for a safe final repository. Since the Laxemar subarea is moreover larger, SKB has preliminarily prioritized this area for the continued site investigation. The preliminary site description for the Laxemar subarea – which will be finished shortly – provides a good picture of the geoscientific state of knowledge on the subarea. The work with the preliminary site description has thereby comprised an important basis for determining what additional investigations are needed in order to make a final assessment of the subarea's prospects for final disposal of spent nuclear fuel.

Strategy

Taking into account the results to date, remaining uncertainties and stipulated goals and requirements on execution, SKB has formulated the following strategy for the remainder of the site investigation in Laxemar:

1. Focus the investigations on the central part of the Laxemar subarea and such a large portion of the southern and western part of the subarea that sufficiently large rock volumes suitable for the final repository can be verified.
2. Conclude or change the direction of ongoing and planned investigations north of EW007.
3. Obtain more information on the major deformation zones that are of importance for the final repository's boundaries and subdivision into deposition areas.
4. Characterize and understand the water-conducting properties of the rock mass.
5. Characterize and verify available rock volumes.

This strategy mainly involves characterization of the properties of the potential repository rock. Beyond this, knowledge of the surface systems will be improved, as well as the connection between surface systems and deep groundwater.

Investigation programme

Based on the aforementioned strategy, an investigation programme has been prepared for the entire remaining site investigation. The programme should be regarded as a best assessment based on current knowledge and the need for new information to be able to prepare a final site description. Due to the fact that the continued investigations and extensive analysis and site modelling work are constantly contributing new knowledge, new data needs may arise and current priorities may change. A necessary flexibility is therefore built into the plans for the execution of the programme.

Figure 2 illustrates existing boreholes and the drilling programme for the remainder of the site investigation. The location of the planned boreholes does not mark the exact position but rather a target area for each borehole. When possible, new boreholes will be drilled from existing drilling sites.

Focusing of the investigations

Based on work done thus far, it has not been possible on geoscientific grounds alone to clearly delineate any part of the Laxemar area that is more suitable for the final repository than any other part. Besides the major deformation zones, which restrict the possibility of finding suitable and sufficiently large deposition areas, the thermal conductivity and water-conducting properties of the rock have been judged to be particularly important geoscientific factors. Studies show that the centrally located east-west-oriented zone EW007 can be passed with transport tunnels, which means that deposition should be possible on both sides.

Thermal conductivity is slightly more favourable towards the north, while water-conducting properties are judged to be more favourable towards the south. The water-conducting properties of the rock are of importance for long-term safety, while its thermal properties mainly influence the space requirement and thereby the cost of the final repository. Due to these water-conducting properties, the south part of the area is thus deemed to be a more advantageous alternative than the north. The fact that the thermal properties are more favourable in the northwest also makes it interesting to include this part of the subarea. Taken together,

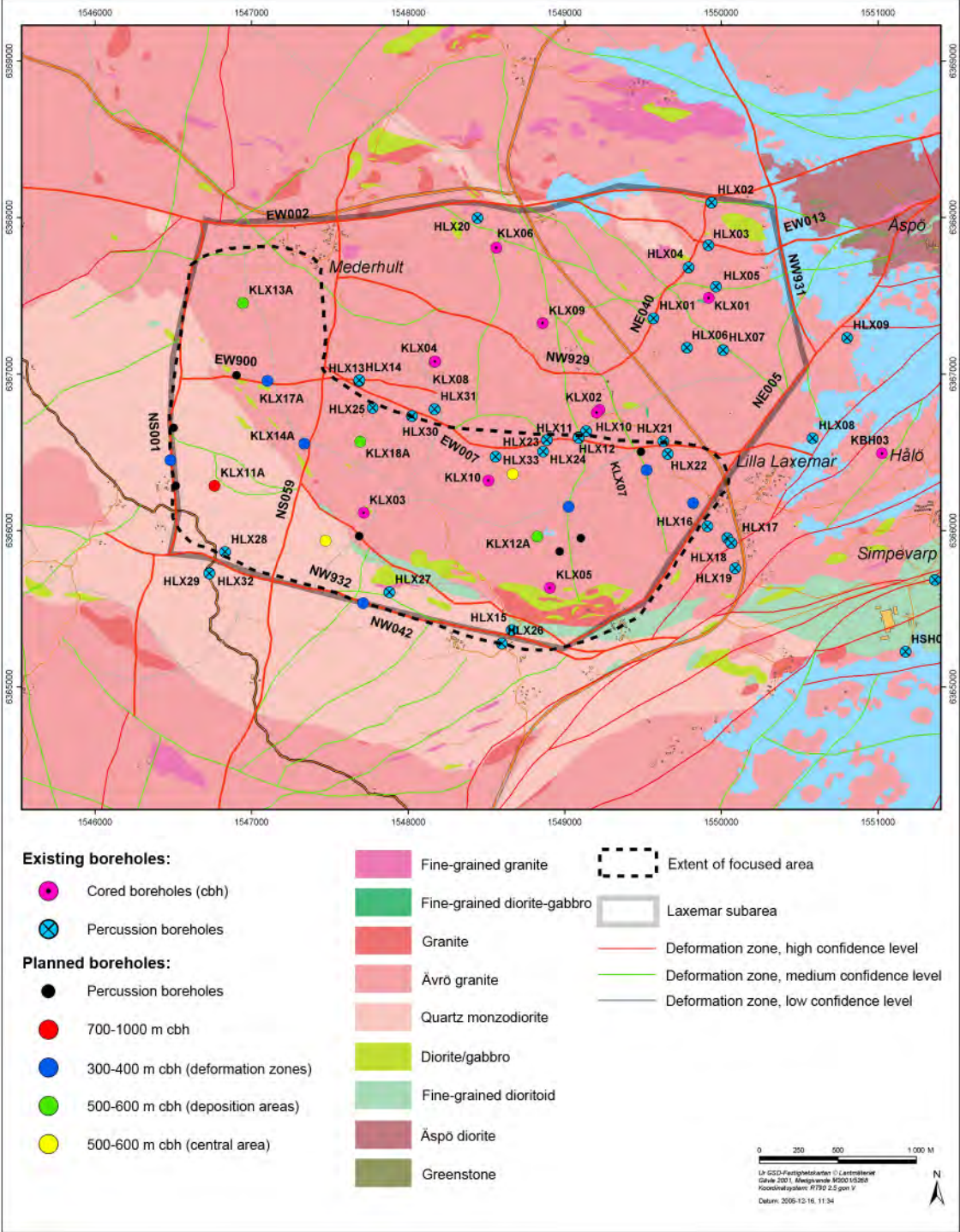


Figure 2. Focused area plus existing and planned boreholes. The location of the planned boreholes does not mark the exact position but rather a target area for each borehole. If possible, new boreholes will be drilled from existing drilling sites.

this means that the continued investigations of the bedrock will be focused on the southern and western part of the subarea.

Investigations north of deformation zone EW007

No new investigations will be initiated north of deformation zone EW007 for the purpose of investigating rock properties of importance for possible deposition areas. However, investigations that yield information that also applies to the southern and western part of the Laxemar subarea will be conducted.

Major deformation zones

More knowledge is needed on all major deformation zones that are of importance for the final repository's boundaries and subdivision into deposition areas. In some cases it may be sufficient to analyze existing data. In other cases it may be necessary to further investigate an interpreted deformation zone in order to obtain sufficient data. This may be done to either confirm or rule out the existence of the zone as well as to obtain more information on its properties.

In the case of deformation zone EW007 and the properties of the nearby rock at repository depth, the large quantity of existing data will first be analyzed to determine how the central rock volume on Laxemar can be utilized for the different parts of the final repository and which parts of the rock volume cannot be used.

The water-conducting properties of the rock mass

Investigations to characterize and understand the water-conducting properties of the rock mass include a) geological and geophysical methods that yield information on the structures and b) direct hydraulic measurement methods. The results of the detailed ground geophysics and the high-resolution airborne surveys carried out in the spring of 2005 will be utilized to clarify patterns and water-conducting properties for local minor deformation zones. After verifying field checks, suitable sites will be determined for verifying excavation and core drilling of short holes with associated investigations. Then the same methodology will be used on the focused area in the south and west, where detailed ground geophysics with magnetometry and resistivity will also be carried out. Furthermore, hydraulic measurements will be carried out in new boreholes, along with an in-depth analysis of geological, geophysical and hydraulic cored borehole data from the whole subarea.

Characterize and verify available rock volumes

The rock areas between the major deformation zones will mainly be used as deposition areas. It is therefore important that they are characterized enough so it can be determined whether they have properties suitable for such use. The water-conducting properties of the rock mass are among the most important properties. The other properties of the rock mass will be investigated with the objective of achieving the requisite certainty in the site-descriptive model. Thermal conductivity is one example, where greater knowledge of its variation will reduce uncertainty in the thermal model and thereby on how rock volumes can be utilized as deposition areas.

Surface systems

The investigations of the surface systems have several beneficiaries and purposes. The investigations provide input data to the safety assessment and the environmental impact

assessment, but also comprise an important part of the environmental control for the site investigation.

A large part of the investigation programme is aimed at giving the safety assessors the understanding required to build models and justify the assumptions that are made. According to the early safety evaluations that have been carried out, low points in the terrain – i.e. wetlands, lakes, sea – are of great interest, since such areas can constitute discharge areas for deep groundwater.

In order to be able to study the issues that will be dealt with in the environmental impact assessments, knowledge is needed of the site's properties, character and conditions, as well as natural and cultural environmental values. The investigations of the surface systems largely satisfy these needs. Supplementary information concerning, for example, health and living environment matters as well as assessments of natural and cultural environmental values will be collected in connection with the EIA work.

The rest of the site investigation primarily involves supplementing existing information on surface ecosystems by analyses of the chemical composition of deposits and biota, further process measurements and supplementary analysis of the properties of the wetlands. Beyond this, additional essential questions may be identified in the work with the site models and the environmental impact assessment.

Monitoring

The site investigation includes collection of time series for all important parameters that show a clear variation over time, i.e. parameters for which an instantaneous "snapshot" is not enough to characterize undisturbed conditions or processes or ones that can be expected to change as a result of the construction and operation of a repository. Natural variations of this kind are mainly associated with ecological, hydrological, hydrogeological and hydrogeochemical parameters measured near the ground surface. But there may also be parameters, mainly hydrogeological ones, that exhibit considerable variation over time at great depth as well. The programme further includes recording of seismic activity. In order to optimize the monitoring programme, SKB will continuously evaluate results and experience from the programme.

Investigations for operating facilities

On the whole, the foundation requirements for the final repository's facilities do not differ from what is usual for industrial construction, but there are certain differences between different parts.

The planned investigation programme includes the following points:

- Compile existing material from previous investigations that have been done in parts of the area.
- Roughly assess the geotechnical conditions for the entire area in question.
- Assess the foundation requirements for different parts of the final repository's facilities.
- Identify the need for supplementary investigations.

Investigations after the summer of 2007

According to SKB's plans, the site investigation in Oskarshamn will be concluded in the late summer of 2007. Monitoring will continue after this time. A large-scale interference test, combined with tracer tests, is also planned.

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1 Introduction

1.1 SKB's plan for final disposal of spent nuclear fuel

Spent nuclear fuel from the Swedish nuclear power plants is taken to Clab (Clab = Central interim storage facility for spent nuclear fuel) near Oskarshamn for interim storage in water pools. The plan is that after about 30 years of interim storage the fuel assemblies will be transferred to canisters, which will be sealed and transported to a final repository, where they will be permanently deposited in crystalline bedrock. Figure 1-1 shows the main features of SKB's plan for accomplishing this. The goal is to have a system for final disposal of spent nuclear fuel ready for operation by around 2017.

How long the final repository needs to be operated is dependent on the operating times of the nuclear power plants. SKB's planning assumption /SKB 2004b/ is that all reactors except Barsebäck 1 (shut down in November 1999) and Barsebäck 2 (shut down in May 2005) are operated for 40 years. This would mean that the operation of the final repository is concluded in the early 2050s and that the entire nuclear fuel programme can be concluded in around 2060. The programme permits both larger and smaller fuel quantities to be managed, the only consequences being that the total operating time of the waste management system, and the space requirement in the final repository, are affected /SKB 2004a/.

Before the system can be taken into operation, however, two nuclear installations – an encapsulation plant and a final repository – must be planned, approved and erected. This work is proceeding in stages and has been going on for many years. SKB's goal for the current stage, the site investigation phase, is to obtain the permits that are needed to site and build the encapsulation plant and the final repository. The current situation can be summarized in the following points:

- Two candidate sites are being investigated for the siting of the final repository: Forsmark in the municipality of Östhammar and Simpevarp/Laxemar in the municipality of Oskarshamn. The intention is that one of the candidate sites will be chosen later on as the site of the final repository, provided that the site satisfies the requirements on safety, environment and constructability.

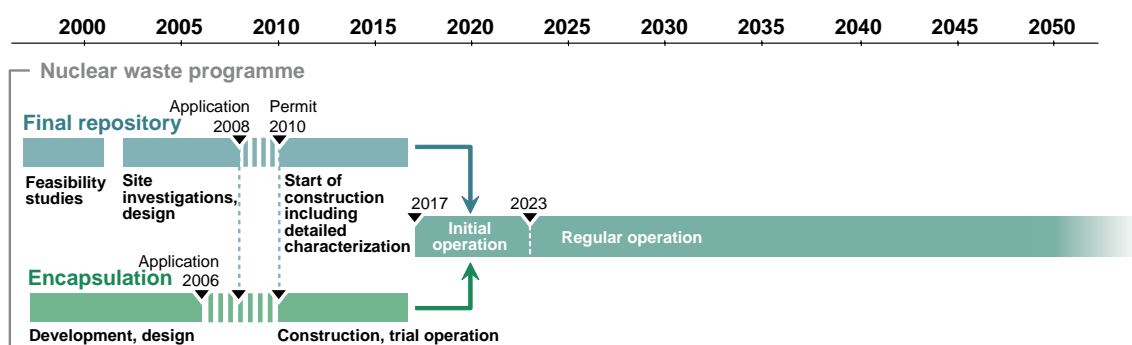


Figure 1-1. SKB's plan for siting, construction and operation of encapsulation plant and final repository for spent nuclear fuel.

- The selection pool for siting of the final repository that is currently available also includes other sites that remain as possible alternatives, in the event the investigations of the candidate sites do not have satisfactory results. Furthermore, a large body of comparison material is available from the study site investigations conducted previously at some ten sites in various parts of the country, as well as from investigations in the Finnish nuclear waste programme/SKB 2000b/.
- An encapsulation plant is planned at Clab. Design of the plant is under way, at the same time as development of the encapsulation technology is proceeding. As an alternative, siting at a possible final repository in Forsmark is being examined.
- Both the encapsulation plant and the final repository require permits under the Environmental Code and the Nuclear Activities Act. Statutory consultation procedures for this have been commenced, and the coming decision processes are well defined, see Figure 1-2.
- The development of the KBS-3 method, the disposal method that is SKB's main alternative, is in a phase featuring pilot- and full-scale tests and demonstrations of parts of the system. The Canister Laboratory and Äspö HRL are the main venues for these activities.

SKB's main task during the next few years is to gather and compile all the supporting material required for applications for permits to site and build the facilities. The encapsulation plant, the final repository and transportation require permits under the Nuclear Activities Act. SKI is preparing the matter for review by the Government. When the Government has granted permits, SKI will continue its processing and stipulate the stepwise conditions necessary to ensure nuclear safety. SSI stipulates the stepwise conditions necessary to ensure adequate radiation protection.

The encapsulation plant and the final repository also require permits under the Environmental Code. Licensing under the Environmental Code covers all types of environmental impact, including releases of ionizing and non-ionizing radiation. The licensing process is prepared in the Environmental Court, which reviews the application for comment and holds a main hearing before the Court issues a statement of comment and turns the matter over to the Government for permissibility assessment under Chapter 17 of the Environmental Code. In connection with the Government's processing of the matter, the concerned municipality is asked if they support or reject SKB's application.

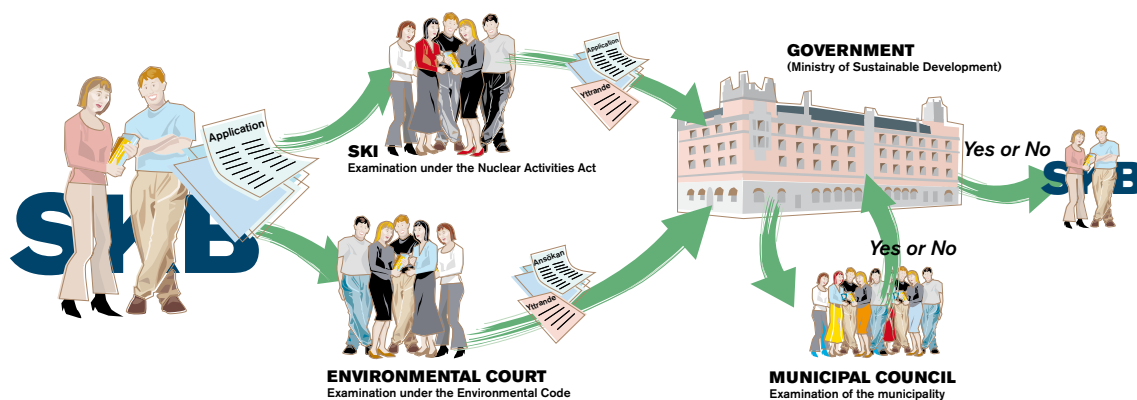


Figure 1-2. Licensing process under the Environmental Code and the Nuclear Activities Act.

The Government then makes its decision on permissibility. Provided that permissibility is granted, the matter is then remitted to the Environmental Court which, after another main hearing, grants a permit and stipulates conditions for the activity. As expert authorities, SKI and SSI are very important parties in the licensing process under the Environmental Code. In addition to these permits, a building permit is required under the Planning and Building Act.

I RD&D-Programme 2004 /SKB 2004a/, SKB presented an action plan covering separate application and licensing processes for the encapsulation plant and the final repository. Based on viewpoints from SKB's consultation parties on this procedure, SKB has conducted a new, in-depth analysis of the licensing scheme, resulting in a modified proposal, see Figure 1-3.

The licensing scheme entails the following in brief:

- 2006 SKB applies for a permit under the Nuclear Activities Act for the encapsulation plant. At the same time, SKB submits to SKI and SSI the following documents for review: a safety assessment focusing on the performance of the canister in the final repository (SR-Can), and a system analysis that describes and analyzes how the parts in the KBS-3 system interact.
- 2008 SKB applies for a permit under the Nuclear Activities Act for the final repository. At the same time, SKB modifies the aforementioned application for the encapsulation plant based on the statements of comment received during the period 2006–2008. SKB does not expect any final decision in the encapsulation matter until this modified application has been submitted. At the same time, SKB applies for permits under the Environmental Code for the encapsulation plant and the final repository.
- 2010 The Government can thereby make decisions at one and the same time on permits under the Nuclear Activities Act and permissibility under the Environmental Code for all constituent parts of the KBS-3 system, i.e. for both the encapsulation plant and the final repository. One decision occasion also permits joint circulation for comment of SKB's application documents.

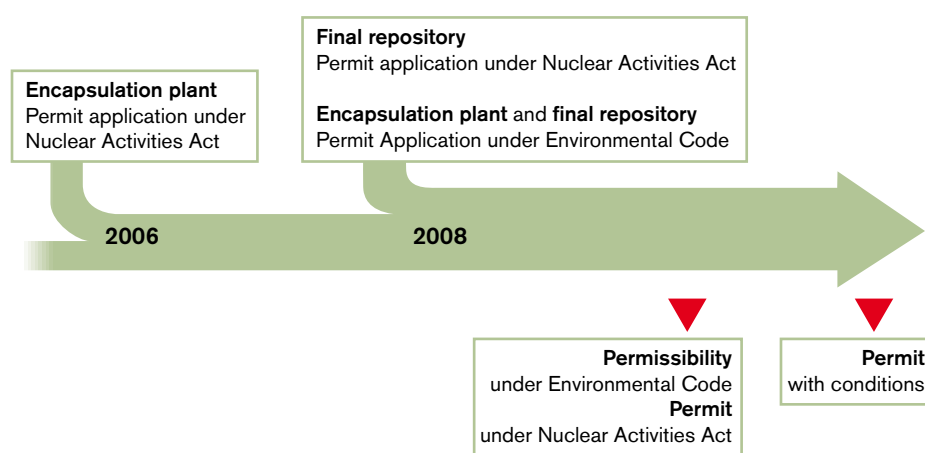


Figure 1-3. Applications and decision process for encapsulation plant and final repository.

1.2 Deep Repository Project

The work of gathering supporting material for the two siting alternatives for the final repository, up to the planned permit application in 2008, is being pursued in project form. The goals of the project are to:

- Gather material for an application for a permit to site and build the final repository for spent nuclear fuel.
- Gather the other material needed to initiate the construction phase.

Subprojects are to:

- Carry out **investigations in Oskarshamn**.
- Carry out **investigations in Forsmark**.
- Produce **descriptions of the investigated sites** as a basis for site-adapted repository solutions, safety assessments, environmental studies and environmental impact assessments.
- **Design** facilities, systems and infrastructure for final repositories on the investigated sites to a level that can serve as a basis for the facility descriptions and safety assessments that are to be included in the application.
- Produce **safety reports** for the long-term safety of the final repository and the operation (including transportation) of the facility on the investigated sites.
- Perform a renewed **system analysis**, i.e. an analysis of the entire system for disposal of spent nuclear fuel according to the KBS-3 method.
- Carry out studies as a basis for assessing the **impact on environment, human health and society** of planned facilities and activities.
- Carry out **statutory consultations** and other communication with concerned parties and the public.
- Devise a **programme for the construction phase**.
- Produce the **environmental impact statement** that must accompany the application.

In the final part of the site investigation phase, an integrated evaluation of all background material is made in order to be able to:

- **Select a site** for the final repository and justify this choice.
- Compile the **permit application**.

The project is carried out in two stages: initial and complete site investigation. After the initial stage, an evaluation is made that includes a comparison of collected data and conditions on the site with pre-established criteria /Andersson et al. 2000/. Furthermore, the possible configuration of a final repository with regard to local conditions is studied, and preliminary evaluations are made of the safety of such a repository. The goal is to verify the judgement that warranted the choices of candidate sites, i.e. that they have good prospects for meeting the requirements for a final repository. If it turns out that any of the sites do not meet the requirements, the site investigation can be discontinued. SKB's planning assumption is, however, that the site investigations will be completed on both the sites.

Site investigation is conducted in steps with investigations and reporting of site data (data freezes) followed by analyses and feedback. Such an iterative approach is necessary in order to maintain an overview of the current state of knowledge and manage the investigations in such a way that optimum use is made of resources and feedback can be obtained from the

users of the data. Investigation data are used to prepare a site description, a facility design, a safety assessment, an environmental study and an environmental impact assessment. Figure 1-4 is a simplified illustration of the links between the most important subprojects in the Deep Repository Project and the control of the information flow.

The organization of the project has been adapted to suit the described mode of working. Figure 1-5 shows a general organization chart for the Deep Repository Project.

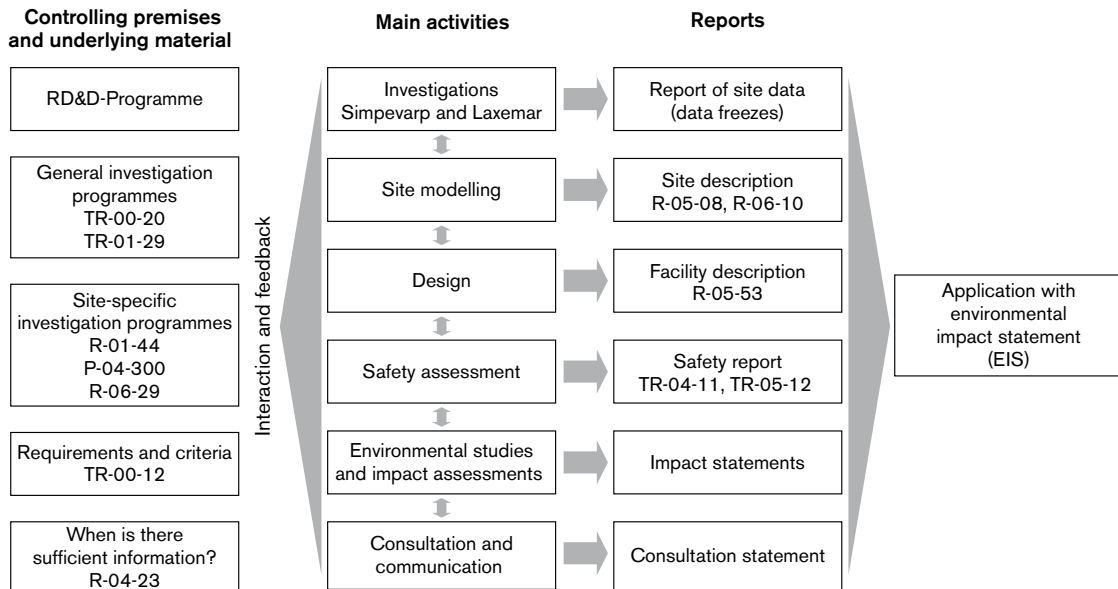


Figure 1-4. Simplified picture of the information flow within the Deep Repository Project – site investigation in Oskarshamn.

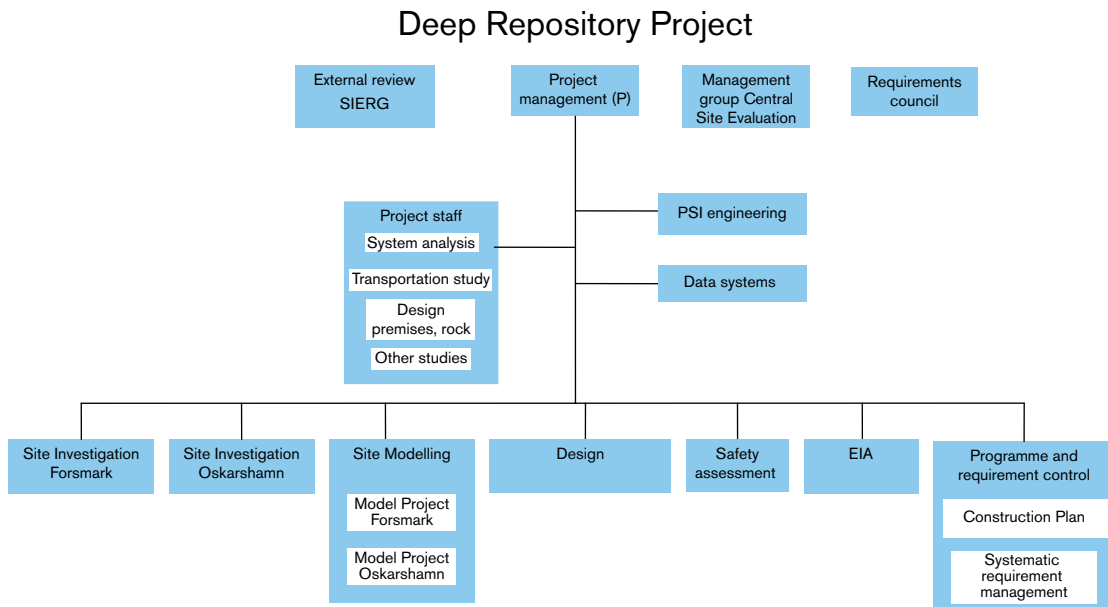


Figure 1-5. Organization of the Deep Repository Project.

1.3 The site investigation in Oskarshamn

Prior to the site investigations, SKB submitted a general programme for investigation and evaluation of sites for the final repository /SKB 2000a/. The programme was based on previously conducted safety assessments and experience from SKB's Äspö HRL. Furthermore, SKB presented an in-depth and detailed description of how the investigations of the bedrock and the surface ecosystems can be carried out /SKB 2001a/. This report specified what will or can be measured, what methods can be used, and how site-descriptive models will be set up.

Figure 1-6 illustrates schematically the different steps of the entire site investigation stage with the gradual narrowing-down of the investigation area described in the following. The primary purpose of the gradual narrowing-down and focusing has been to be able to choose a large enough rock area that can be expected to satisfy the requirements on long-term safety and is thereby potentially suitable for a final repository. With the exception of exploratory drilling, with associated investigations, a number of investigations are continuing outside the focused area as well.

In September 2002, SKB presented a programme for the initial site investigation in Oskarshamn /SKB 2001b/. Based on this programme, investigations (including drilling) were initiated during the summer of 2002 in the Simpevarp subarea, along with surface ecological inventories in the regional environs. Furthermore, geoscientific surface investigations were carried out, including geophysical helicopter surveys, within the entire 60 km² candidate area.

Based on the results of these investigations, in March 2003 SKB submitted more precise and prioritized plans for the continued investigations in Oskarshamn in two subareas, Simpevarp and Laxemar /SKB 2003/. The total surface area of the two subareas is 15 km². The investigations in the Laxemar subarea were commenced in January 2004, after SKB had reached an agreement with the concerned landowners.

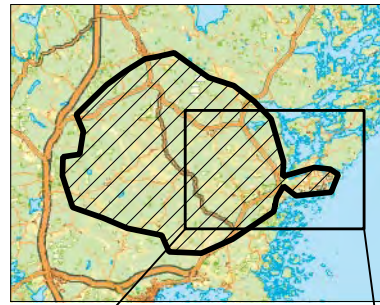
It became clear at an early stage that the Simpevarp Peninsula provides limited flexibility in repository layout due to its limited area. For this reason, SKB wanted to expand the investigation area to include Ävrö, Hålö and the nearby marine area as well. SKB petitioned Oskarshamn Municipality for permission for an expansion and more precise definition of the investigation area, which was granted by the Oskarshamn municipal council in September 2003.

The initial site investigations for both subareas Simpevarp and Laxemar had been completed at the end of October 2004. Based on the results obtained and analyses of the investigations on the two subareas, SKB preliminarily prioritized the Laxemar subarea for further site investigation. A programme for the first stage of the complete site investigation on the Laxemar subarea was presented in December 2004 /SKB 2004c/. The programme included investigations up until the summer of 2005 and was particularly aimed at obtaining answers to several vital questions so that the subsequent investigations could be focused on the rock areas judged to be most suitable for a final repository. These investigations have now been carried out /SKB 2006a/.

For the Simpevarp subarea, a comprehensive preliminary site description, version 1.2 /SKB 2005b/ and a preliminary safety evaluation /SKB 2005a/ have been presented. The work with a preliminary facility description is in its final phase /SKB 2006b/. For the Laxemar subarea, work on version 1.2 of the preliminary site description is in its final phase and the report is expected to be finished in March 2006 /SKB 2006/. The site description will then serve as a basis for the continued investigation programme, a facility description and a preliminary safety evaluation (PSE) for the Laxemar subarea.

Oskarshamn candidate area

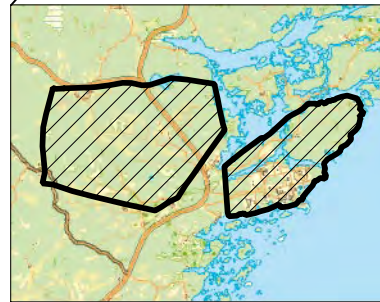
The feasibility study for Oskarshamn recommended site investigation on the Simpevarp Peninsula and the area west of there – the Oskarshamn candidate area /SKB 2000c, SKB 2001b/.



Laxemar and Simpevarp subareas

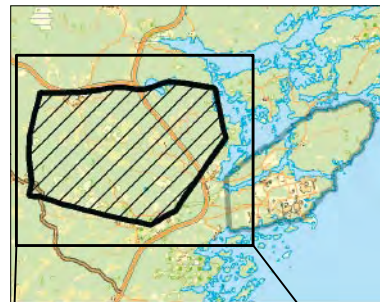
In March 2003, SKB presented its prioritization for investigations within the area west of Simpevarp – the Laxemar subarea /SKB 2003/.

In September 2003 the municipal council in Oskarshamn granted SKB's request to expand the Simpevarp area to also include Ävrö, Hålö and the nearby marine area – the Simpevarp subarea.



Laxemar subarea is prioritized

In the autumn of 2004, SKB tentatively prioritized the Laxemar subarea for complete site investigations /SKB 2004c/.



Focused area within Laxemar subarea

In the summer of 2005, SKB decided that the concluding stage of the complete site investigation should be focused on the southern and western part of the Laxemar subarea – the focused area within the Laxemar subarea /SKB 2006a/.



Figure 1-6. Illustration of the gradual narrowing-down of the investigation area in Oskarshamn – from the 60 km² candidate area to the focused area in the Laxemar subarea. The primary purpose of the gradual narrowing-down and focusing has been to be able to choose a large enough rock area that can be expected to satisfy the requirements on long-term safety and is thereby potentially suitable for a final repository. With the exception of exploratory drilling with associated investigations, a number of investigations are continuing outside the focused area as well. In order for the site investigation to be completed on the Laxemar subarea, the subarea must be finally prioritized when a preliminary safety evaluation for the subarea is published in early 2006.

Completed investigations, evaluations and the preliminary safety evaluation for the Simpevarp subarea shows that good prospects exist there for building a safe final repository. The space is limited, however, and possible surprises – for example the existence of other deformation zones in the area than those identified so far – could lead to troublesome limitations.

The site description for the Simpevarp subarea /SKB 2005b/ also included the Laxemar subarea. Even though the uncertainties were greater for the Laxemar subarea, it was nevertheless possible to make a first preliminary evaluation for the Laxemar area based on this site description. The evaluation showed that the Laxemar subarea also had good prospects for a safe final repository. Since the Laxemar area is moreover larger, SKB prioritized the Laxemar subarea for further site investigation. The aim of the site investigation in Oskarshamn and the investigation programme presented in this report is based on this prioritization. A final decision on the aim of the site investigation in Oskarshamn is planned to be made in the spring of 2006 when preliminary safety reports have been presented for both Simpevarp and Laxemar. If the decision should then be that the Simpevarp subarea is chosen, a new investigation programme and a new timetable will be prepared.

Results achieved to date, along with the programmes mentioned above, comprise an important point of departure and premise for remaining investigations of bedrock, soil, water and environment in the Laxemar subarea. The present report describes the programme for completing the complete site investigation in the Laxemar subarea, starting in the summer of 2005. The strategy is that the investigations of the bedrock should extend from the central part of the Laxemar subarea and cover such a large area around it that large enough rock volumes judged to be suitable for the final repository can be verified. The investigations are primarily focused on the southern and western part, since this combined area is judged to be most favourable for the final repository, Figure 1-6 /SKB 2006a/. This strategy provides ample opportunity to expand into the northern part of the Laxemar subarea as well, if necessary. Only minor investigations will be conducted in the Simpevarp subarea, mainly follow-up and monitoring.

Investigations of ecosystems, meteorology and hydrology of soil, sea, lakes and streams etc will continue as before within a larger area, in principle in the entire regional model area, see map in Figure 2-1.

How the concluding stage of the site investigation is arranged depends to a great extent on the results of the initial stage. What this means for the site investigation in Oskarshamn is explained in sections 2.3 and 2.4 and Chapter 3. The goal is to raise the level of knowledge on the site in question to the level required for preparing a permit application. The goal of being able to submit the application at the end of 2008 means that all work in the field that will serve as a basis for the application should be concluded by the summer of 2007. Monitoring will continue even after this.

1.4 Scope

The report describes the investigations of bedrock, soil, water and environment which SKB plans for the remainder of the site investigation. All other work for which the investigation results are used – calculation, modelling, design, safety assessment and studies and assessment of impact on environment, health and society – is only mentioned to the extent necessary in order to place the investigations in their context.

2 Premises

2.1 Goal

The overall goal of the site investigation phase is to obtain the permits required to site and build the final repository. The site investigations must therefore provide the data required for an evaluation of the suitability of the investigated sites for a final repository. The material must accordingly be comprehensive enough to:

- Show whether the selected site satisfies fundamental safety requirements.
- Show whether the construction-related prerequisites are met.
- Permit the final repository to be adapted to the conditions and features on the site.
- Permit an assessment of the impact of the final repository on the environment and society.
- Permit comparisons between the two investigated sites, Forsmark and Simpevarp/Laxemar.

Another way to express this is that the supporting material for the application should show that all parts of the final repository and its associated systems are feasible and safe and that there are sufficient rock volumes on the selected site that satisfy this requirement.

2.2 Site

2.2.1 Background

Prior to the site investigation in Oskarshamn, SKB prioritized the Simpevarp Peninsula and a large area on the mainland west of Simpevarp for further investigations, see Figure 1-6. The prioritization of these areas is based on the assessment that the bedrock is potentially suitable for a final repository, and that the areas are located close to an existing industrial area and nuclear installations on the Simpevarp Peninsula. The area west of Simpevarp is more than 50 km², which is considerably larger than the 5–10 km² needed to carry out all the steps in a site investigation. The reasons for choosing such a large area was that there were no natural geological boundaries, and that an initially large area provided flexibility to gradually narrow down the continued investigation work to one or more smaller areas where the site investigation has good prospects of leading to a desired result. Chapter 1, section 1.3, presents completed stages of the site investigation and the gradual focusing on a smaller and smaller investigation area.

The map in Figure 2-1 provides an overview of the site investigation area with the two subareas Simpevarp and Laxemar. The map also shows the regional model area, the local model area studied thus far and the area that will be studied in the work with site models and site description.

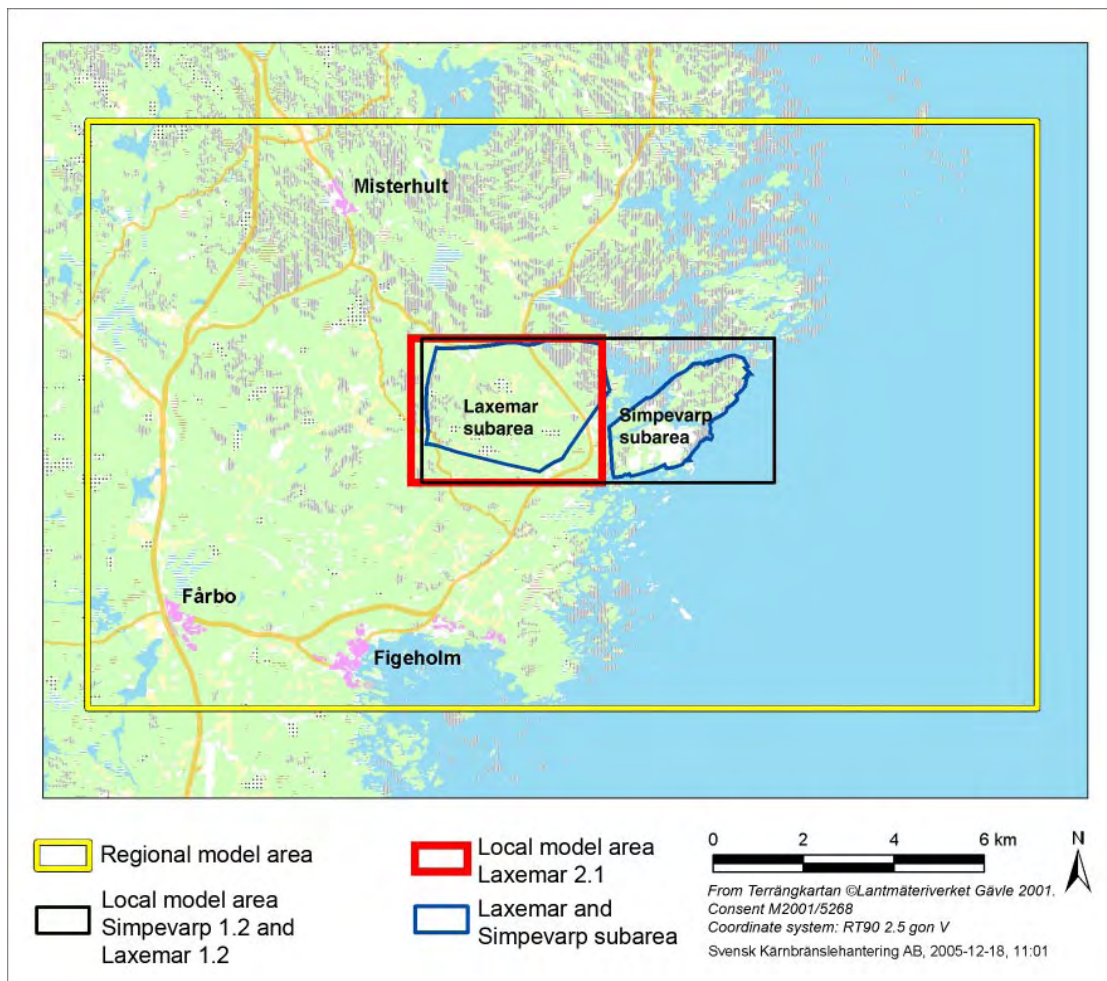


Figure 2-1. The site investigation in Oskarshamn with the two subareas Simpevarp and Laxemar plus local and regional model areas.

2.2.2 Geological conditions

Bedrock

The bedrock in the Laxemar subarea consists of approximately 1,800 million year-old intrusive igneous rocks that belong to the Transscandinavian Igneous Belt. Igneous mixing phenomena are common, and aside from certain mesoscopic shear zones and a weak foliation in parts, the rock types are well-preserved. For further information on the bedrock geology in the Laxemar subarea, see section 3.3.

The Laxemar subarea is dominated by two rock types, Ävrö granite and quartz monzodiorite (Figure 2-2). Ävrö granite dominates in the central and northern parts. It is reddish-grey to greyish-red, medium-grained and usually porphyritic, and varies in composition between granite and quartz monzodiorite, including quartz-monzonitic and granodioritic variants. The variations in chemical and mineralogical composition are also reflected in varying density values and thermal properties. Quartz monzodiorite dominates in the southern and southwestern part of the Laxemar subarea. It is grey to reddish-grey, medium-grained and even-grained to sparsely porphyritic in places. Its composition is relatively homogeneous, and modal analyses show a quartz monzodioritic to granodioritic composition.

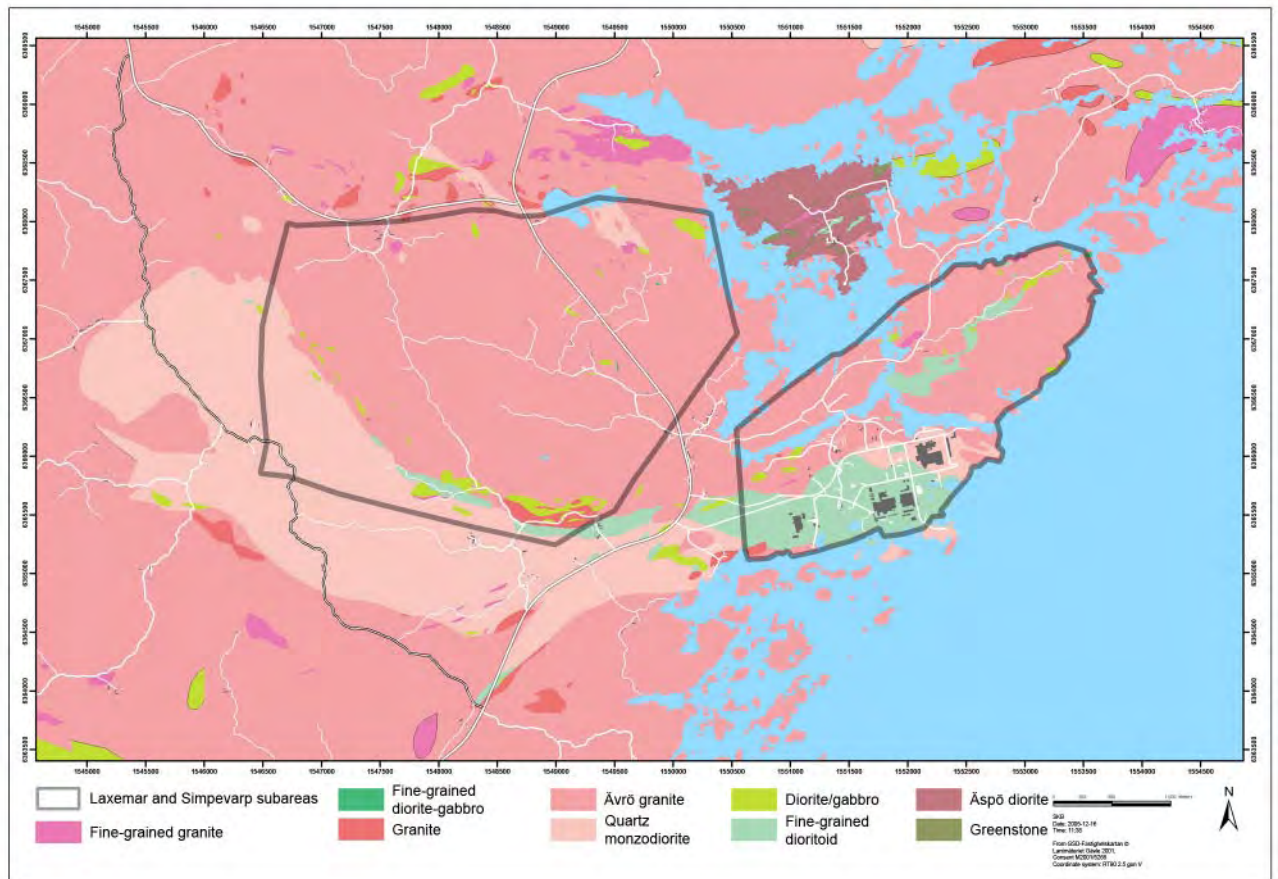


Figure 2-2. Bedrock geological map of the Laxemar and Simpevarp subareas with environs.

Of subordinate rock types in the subarea, fine-grained granite is the most important and frequently occurring, see Figure 2-2. Bodies and dykes of the fine-grained granite are judged to occur evenly distributed in the dominant rock types, although local variations occur. Pegmatite in the form of dykes and veins is also relatively common. Furthermore, diorite/gabbro, fine-grained dioritoid, fine-grained diorite-gabbro and granite (medium- to coarse-grained) occur as subordinate rock types in the bedrock.

Quaternary deposits

The Laxemar subarea is rather flat, but undulating. The Quaternary deposits in the area have been mapped and are presented in Figure 2-3. Sandy till is the dominant Quaternary deposit and covers about 45% of the investigated area. No distinct till accumulations have been observed, so the till surface largely reflects the morphology of the underlying bedrock. The till everywhere is coarse-grained with a high gravel content. At the surface the till often has a high content of stones and boulders. The thickness of the till is usually limited to no more than 3–4 m. Larger till thicknesses may occasionally occur in the valleys. Only a couple of small glaciofluvial deposits occur in the Laxemar subarea.

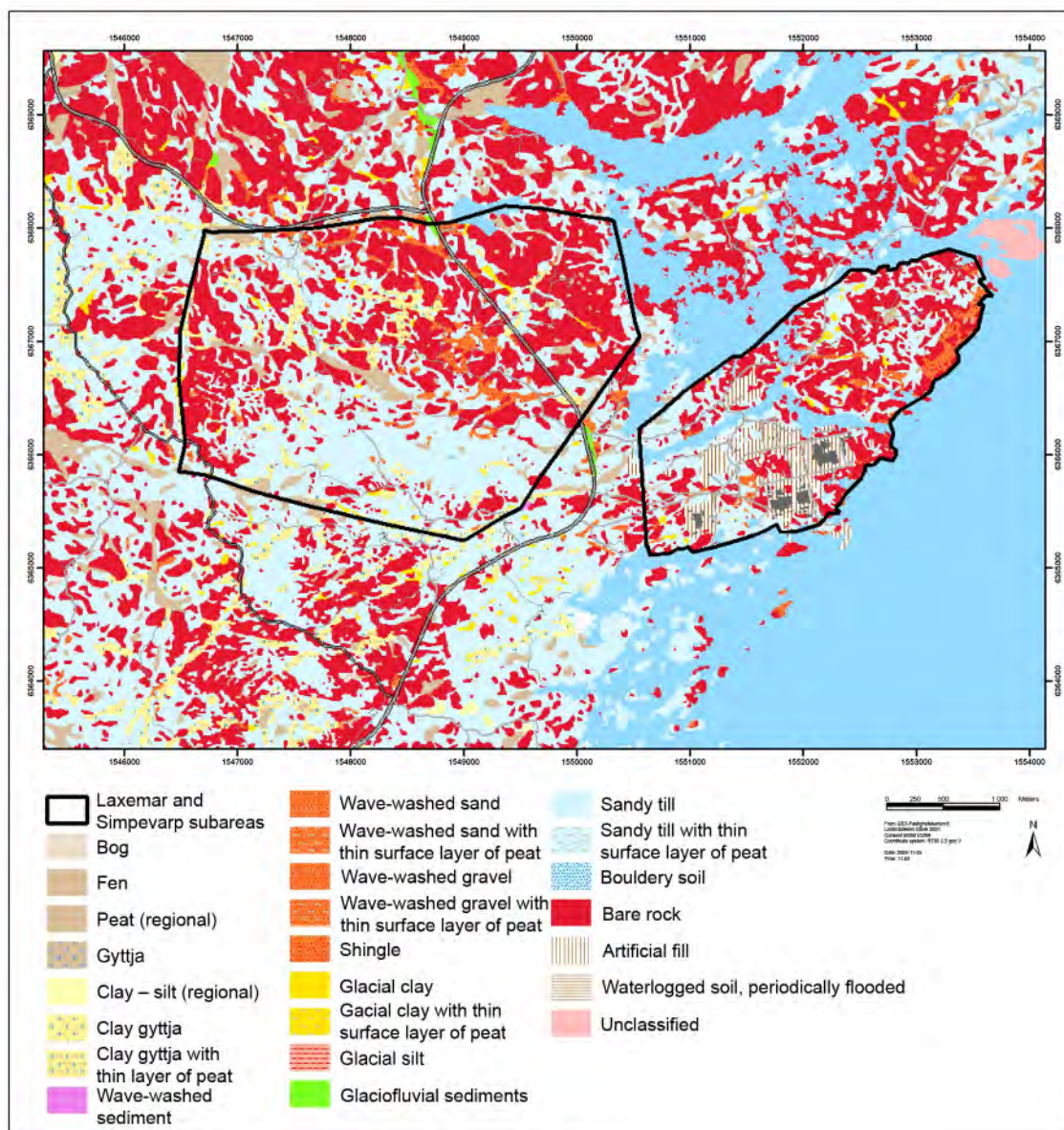


Figure 2-3. Simplified Quaternary deposit map of the Laxemar and Simpevarp subareas /Lindborg 2006/.

The narrow valleys generally contain clayey gyttja-bearing sediments, which are covered with peat in many places. These areas are largely used for agriculture. The gyttja-bearing sediments often overlay glacial clay, which in turn overlays till. The total thickness of the till is often several metres in the valleys. The glacial clay was deposited at a relatively great water depth just after the continental ice sheet had retreated from the area. The younger gyttja-bearing sediments were deposited in shallow sea bays when the landscape around Misterhult slowly rose up out of the sea. The ongoing deposition of gyttja can be studied in today's shallow sea bays with luxuriant reed growth.

The area has been exposed to the erosive effect of the waves over a long period of time. The result is heavily wave-washed till plus accumulations of wave-washed sand, gravel and shingle, which together cover about 4% of the surface. Peatlands occur all over the area, but are usually very small and cover a total of about 8% of the surface. These lands have often been drained in order to improve conditions for forestry and agriculture. However, small peat-covered bogs and fens occur all over the area.

2.2.3 Nature and culture

The area around the Laxemar and Simpevarp subareas lies in a geographical region which is characterized by a joint valley landscape with small elevation differences, bare skerries and stony shores. The forests and the many joint valleys dominant and characterize the area. The joint valleys have loose fine grained soils, and this is where most of the farmed land is, see Figure 2-4. It has generally been created by digging drainage ditches. In the intersections of several valleys there are more open districts, but they are comparatively small. The heights in the area are generally covered with relatively thin and poor till soil. They are often forested with many exposed outcrops, see Figure 2-5.



Figure 2-4. The valleys are covered with loose fine grained soils. On the geologists' maps the joint valleys are marked as lineaments, i.e. possible deformation zones in the bedrock.



Figure 2-5. Rock slabs with pines.

The archipelago offers a clear contrast to the more closed forest region. Between forest and open sea is an inner archipelago with flat forested islands. The outer archipelago is undeveloped and ranges from shoals and skerries to wooded islands with a narrow shore zone. There are few buildings and the flat coastline offers few landmarks, but the ones that do exist are distinctive: Blå Jungfrun (a large island comprising a nature reserve) and the reactor buildings on the Simpevarp Peninsula. With the exception of the reactor buildings, there is little evidence of cultural impact; the dominant impression is one of unexploited nature. The unprotected coastline outside Simpevarp and Ävrö is distinctive in being completely open to the east. Like the outer archipelago, the area is dominated by natural landscape.

The district has a history of both rural countryside with agriculture and forestry and coastal-archipelago culture with fishing and hunting. In addition there are the nuclear industrial activities on the Simpevarp Peninsula. These activities are noticeable in the form of the facilities on the Simpevarp Peninsula with numerous power lines radiating from them, and in the local community where OKG (the nuclear power plant operator) and SKB are the principal employers.

The impact of the industrial landscape on the cultural environment in the area is relatively limited. Due to the topography and the fact that a large part of the original land and vegetation are preserved, only a relatively limited area is affected by the industrial facilities. The industrial area extends a good distance inland from the peninsula in the form of the power lines with their cleared corridors. It is primarily from the sea side that the nuclear power plant can be seen from far away.

From a nature protection viewpoint, the area can be described as typical for coastal districts in this part of the country. The entire area is used for hunting and other recreational activities. Sport fishing is an important activity along the coastline. Towards the northeast is the Misterhult archipelago, with special protection interests. Like most of the Baltic Sea coast, the coastline in Oskarshamn Municipality is subject to restrictions on industrial sitings under Chapter 4 of the Environmental Code. Within the coastal area and the archipelago, the interests of tourism and outdoor recreation shall be taken into account when assessing the permissibility of development projects and/or other environmental intrusion¹, see Figure 2-7. Nuclear installations may not be established north of Simpevarp². South of Simpevarp, nuclear installations may only be established at places where such installations already exist³. These restrictions apply to the part of the site investigation area east of the coast road (highway 743), the only exception being the Simpevarp Peninsula. The Laxemar subarea west of the coast road is only an area of national interest for final disposal of spent nuclear fuel and nuclear waste. See map in Figure 2-6.

The area is rich in historical monuments with a large number of traces of human presence from various historical periods. There are particularly many archaeological remains from the Bronze Age. See Figure 2-8.

¹ Environmental Code Chapter 4 section 2.

² Environmental Code Chapter 4 section 3.

³ Environmental Code Chapter 4 section 4.

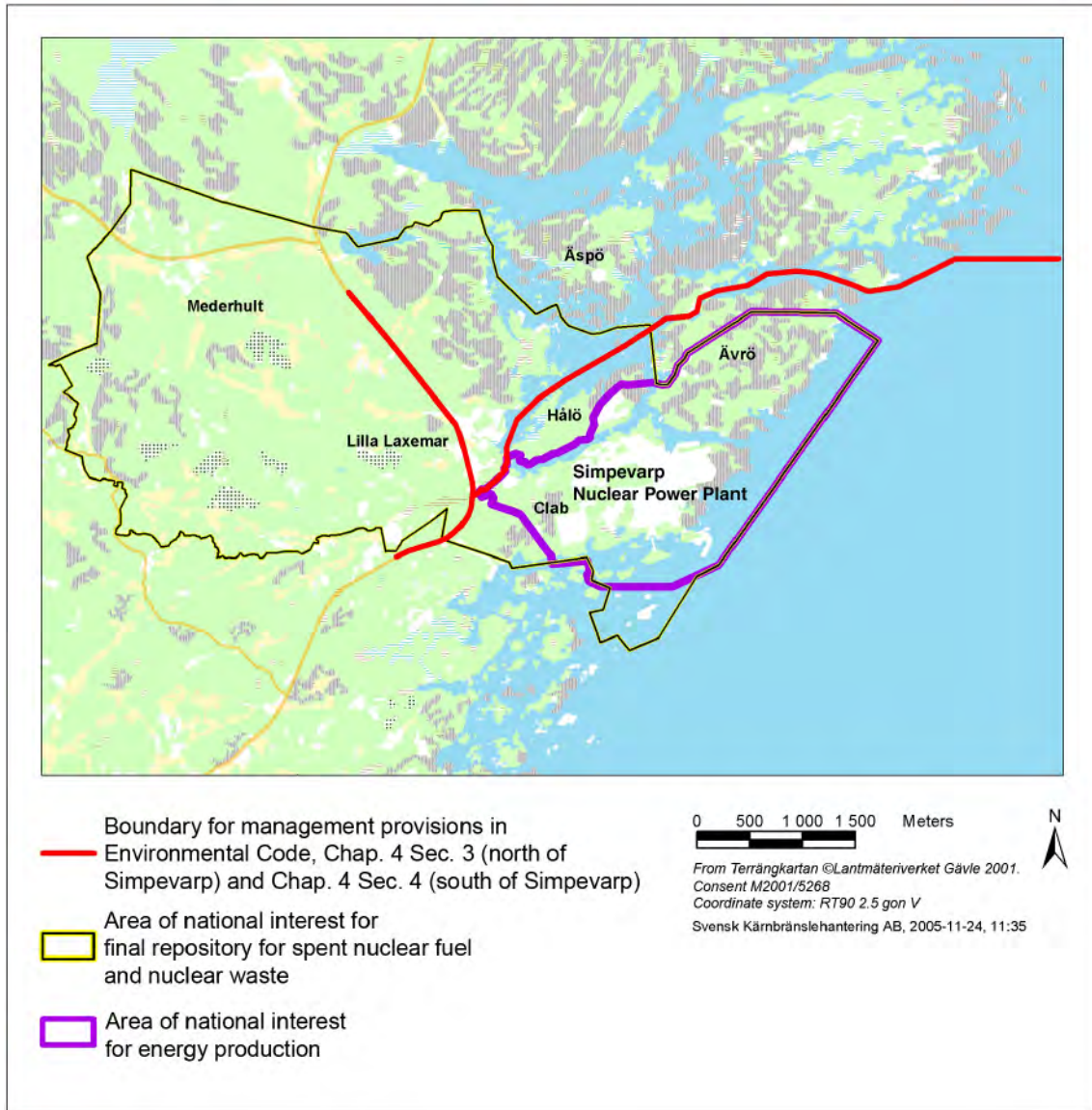


Figure 2-6. The site investigation area in Oskarshamn is affected by the management provisions in Chapter 4 of the Environmental Code, being an area of national interest for final disposal of spent nuclear fuel and nuclear waste and for energy production.



Figure 2-7. The area around Simpevarp is of national interest for nature conservation, recreation and outdoor life.

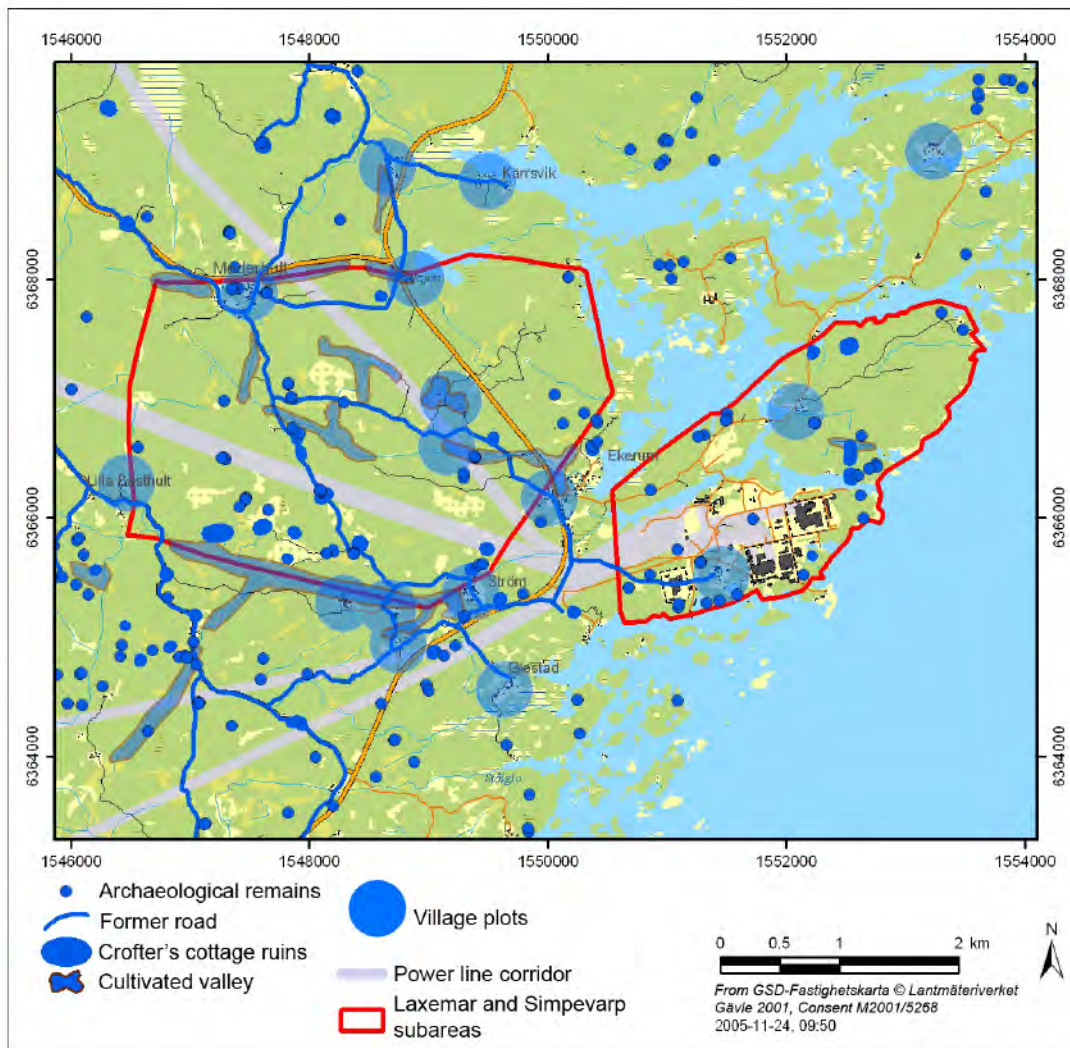


Figure 2-8. Archaeological remains, other historical relics and prioritized cultural environments on the Simpevarp Peninsula and in Laxemar /Lundqvist 2005/.

2.2.4 Industry and infrastructure

Figure 2-6 shows the area of national interest for a final repository for spent nuclear fuel and nuclear waste according to SKI's decision of 2 December 2004. If Simpevarp/Laxemar is chosen as the site for the final repository, this national interest must be considered along with other national interests. According to Chapters 3 and 4 of the Environmental Code, activities that significantly damage an area of national interest are not allowed. Examples of activities that could significantly damage an area of national interest for a final repository for spent nuclear fuel and nuclear waste that are mentioned by SKI in its decision are drilling down to repository depth and activities that are planned to be located at the same sites as those considered for the final repository's surface parts.

The Simpevarp subarea largely lies within the industrial area for which a detailed development plan exists (see Figure 2-5 in /SKB 2004c/). The industrial land is owned by OKG and SKB. The three nuclear reactors and Clab with associated facilities are located in the area, see Figure 2-9. North of Simpevarp is the Äspö HRL. Approximately 1,000 persons work in the area. Approach roads with high loadbearing capacity link the industrial area with highway 743, and there are a number of supply roads within the area. The internal harbour is used mainly for delivery of spent nuclear fuel from the nuclear power plants in Ringhals, Barsebäck and Forsmark to Clab and shipping of low- and intermediate-level waste to SFR.

According to a decision by Nutek (now the Swedish Energy Agency) of 24 October 1995, the Simpevarp Peninsula and part of Ävrö with associated water area are of national interest for energy production. The area of national interest coincides not only with the area of national interest for a final repository for spent nuclear fuel, but also with national interests for nature conservation and outdoor recreation, while also being subject to the management provisions in Chapter 4 of the Environmental Code. With its strategic location near existing infrastructure, the part of the area of national interest that includes Ävrö can, according to the municipality's comprehensive plan ⁴, be suitable for energy production, see Figure 2-6.



Figure 2-9. The industrial area in Simpevarp with the three nuclear power units, Clab and the Simpevarp harbour.

⁴Comprehensive plan 2000, adopted by municipal council on 10 March 2003.

2.3 State of knowledge after investigations completed by July 2005

2.3.1 Points of departure and overview

The site investigation in Oskarshamn was commenced at mid-year 2002. The plan was based on the following general programmes for site investigations:

- Geoscientific programme for investigation and evaluation of sites for the deep repository /SKB 2000a/.
- Site Investigations. Investigation methods and general execution programme /SKB 2001a/.

These documents were produced by SKB and reviewed by the regulatory authorities in conjunction with SKB's integrated account of method, site selection and programme prior to the site investigation phase /SKB 2000b/. A special programme /SKB 2001b/, adapted to site-specific questions and conditions in Oskarshamn, was published when the site investigation started.

The programmes together reflect the initial planning. Since then the iterative mode of working has meant that the planning has been periodically updated in response to the results obtained. Requirements and viewpoints that have emerged from the authorities and their external expert groups have also had a considerable impact on the investigation programme.

In April 2002, SKB gave notice of consultation for the site investigation to the Kalmar County Administrative Board, pursuant to Chapter 12 of the Environmental Code. The County Administrative Board stipulated in its statement that SKB could conduct the site investigation in keeping with the presented programme, and with the environmental protection measures described in the notification. The County Administrative Board's consultation statement says that SKB shall give notification of any investigations that could have an impact on the natural and cultural environment. In its decisions on these notifications, the County Administrative Board has stipulated conditions and recommendations for the activities in question. The entire process is regarded by the County Administrative Board as a continuous consultation where new information from SKB is categorized as notification, further details or information. SKB describes all new activities according to one of these three categories.

The site organization for planning and leading the investigation, currently some 35 persons, was established for the most part during 2002 in a newly-built site office on the Simpevarp Peninsula. Activity leaders for the various disciplines that are investigated procure, lead and oversee the field investigations and check the investigation results. For the most labour-intensive disciplines, assistant activity leaders and experts have been co-opted. In addition to resources at the Äspö HRL, special premises have been arranged for such activities as mapping and storage of drill cores. Infrastructure (roads, drilling sites, cable networks for power supply and data communications) to and within the investigation area has gradually been installed, giving careful consideration to the natural and cultural environment.

The situation in 2005 for investigations completed by then can be summarized as follows (see also section 1.3 in Chapter 1):

- In order to investigate the bedrock at depth, four deep (1,000 m) cored boreholes and 11 percussion boreholes have been drilled in the Simpevarp subarea. There were already one deep (700 m) cored borehole and a number of shallower percussion boreholes in the northern part of the area, on Ävrö. Eight deep (1,000 m) cored boreholes and 34 percussion boreholes have been drilled in the Laxemar subarea, including the 2 cored boreholes and 12 percussion boreholes that were drilled during the preliminary investigations for the Äspö HRL.
- The surface characterization of the area's geological and ecological conditions has largely been completed for both the Simpevarp and Laxemar subareas.
- A comprehensive preliminary site description (version 1.2) has been published for the Simpevarp subarea /SKB 2005b/ and is in the final stages for the Laxemar subarea /SKB 2006/.

Figures 2-10 and 2-11 show the situation in July 2005 for drilling of cored boreholes, percussion boreholes and soil wells in the Simpevarp and Laxemar subareas.



Figure 2-10. All cored boreholes and percussion boreholes in the Simpevarp and Laxemar subareas (July 2005).

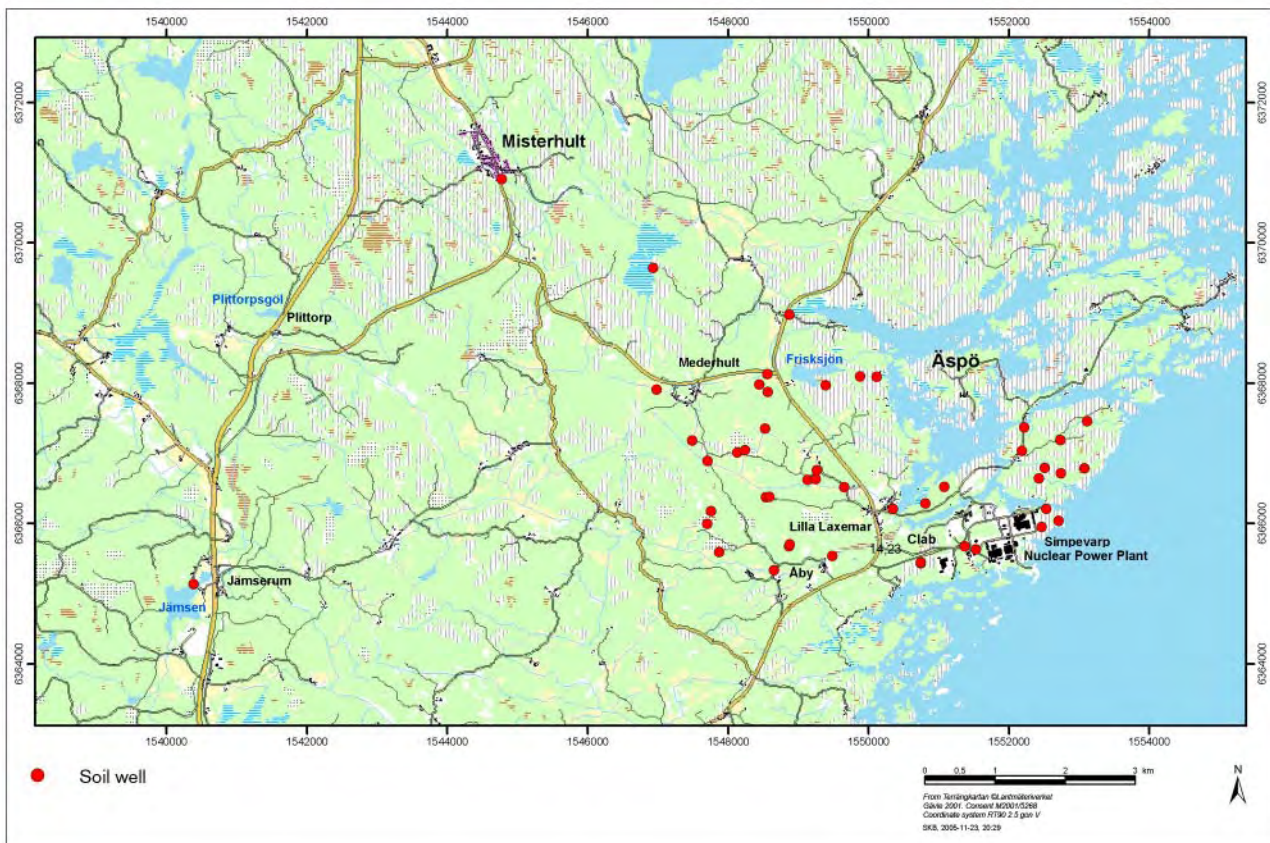


Figure 2-11. All soil wells in the Simpevarp and Laxemar subareas (July 2005).

2.3.2 Industrial establishment

Design, which includes developing a site-adapted layout of a possible final repository in Oskarshamn, is being pursued in parallel with the site investigations.

The main alternative presented in /SKB 2000b/ was that the above-ground facilities are built within the existing industrial area on the Simpevarp Peninsula, while the underground repository is located further west.

Since /SKB 2000b/ was published, SKB has carried out a study of the choice of a descent to the deposition area. The main alternative is now that descent should take place via a ramp for heavy and bulky goods, while a shaft with a skip (rock hoist) is used to transport rock and backfill materials. The reason is that a skip is advantageous environmentally, economically and from a safety point of view. Furthermore, simultaneous construction of shaft and ramp results in a shorter construction period for the entire underground facility. One result of this system solution is that all operating functions on the surface should be positioned directly above the underground part's central area. The main alternative described in /SKB 2000b/ is thereby no longer relevant. If the final repository is located within the Laxemar subarea, the surface facility will also be located there, see Figures 2-12, 2-13 and 2-14.

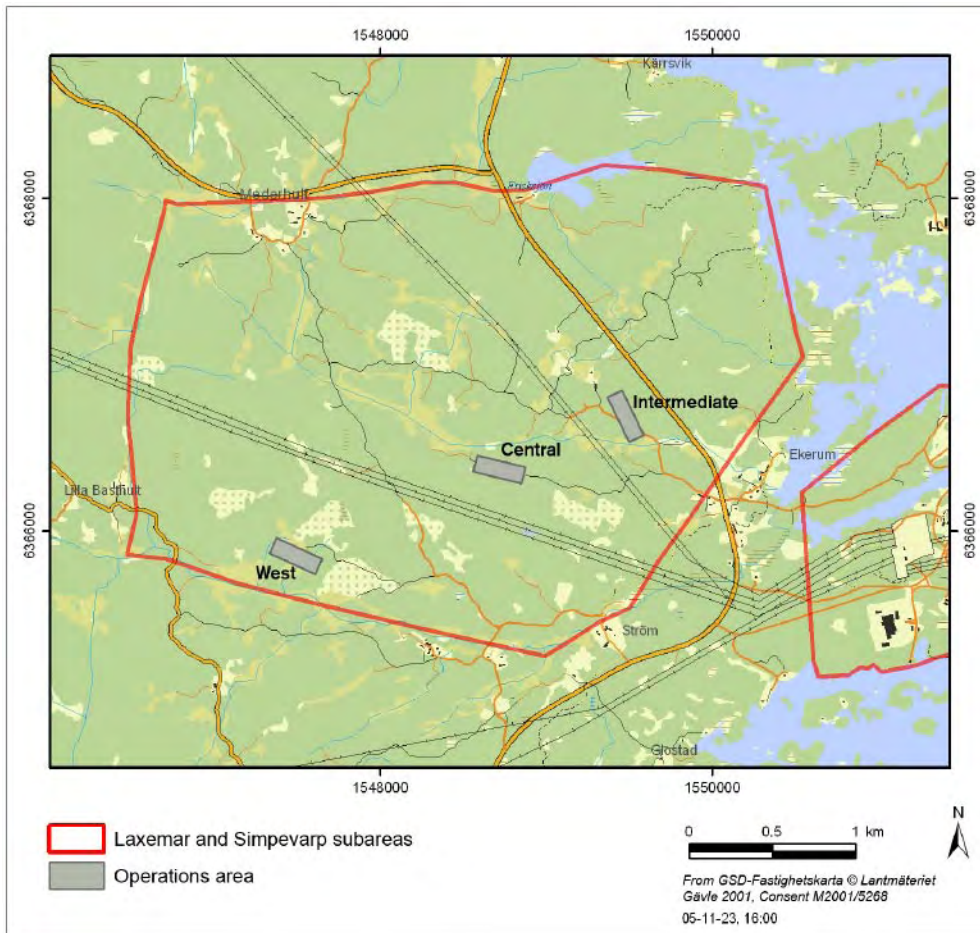


Figure 2-12. Possible locations for the final repository's surface facilities within the Laxemar subarea.



Figure 2-13. Example of a possible location and layout of the final repository's surface facilities at Laxemar, "Central" alternative.

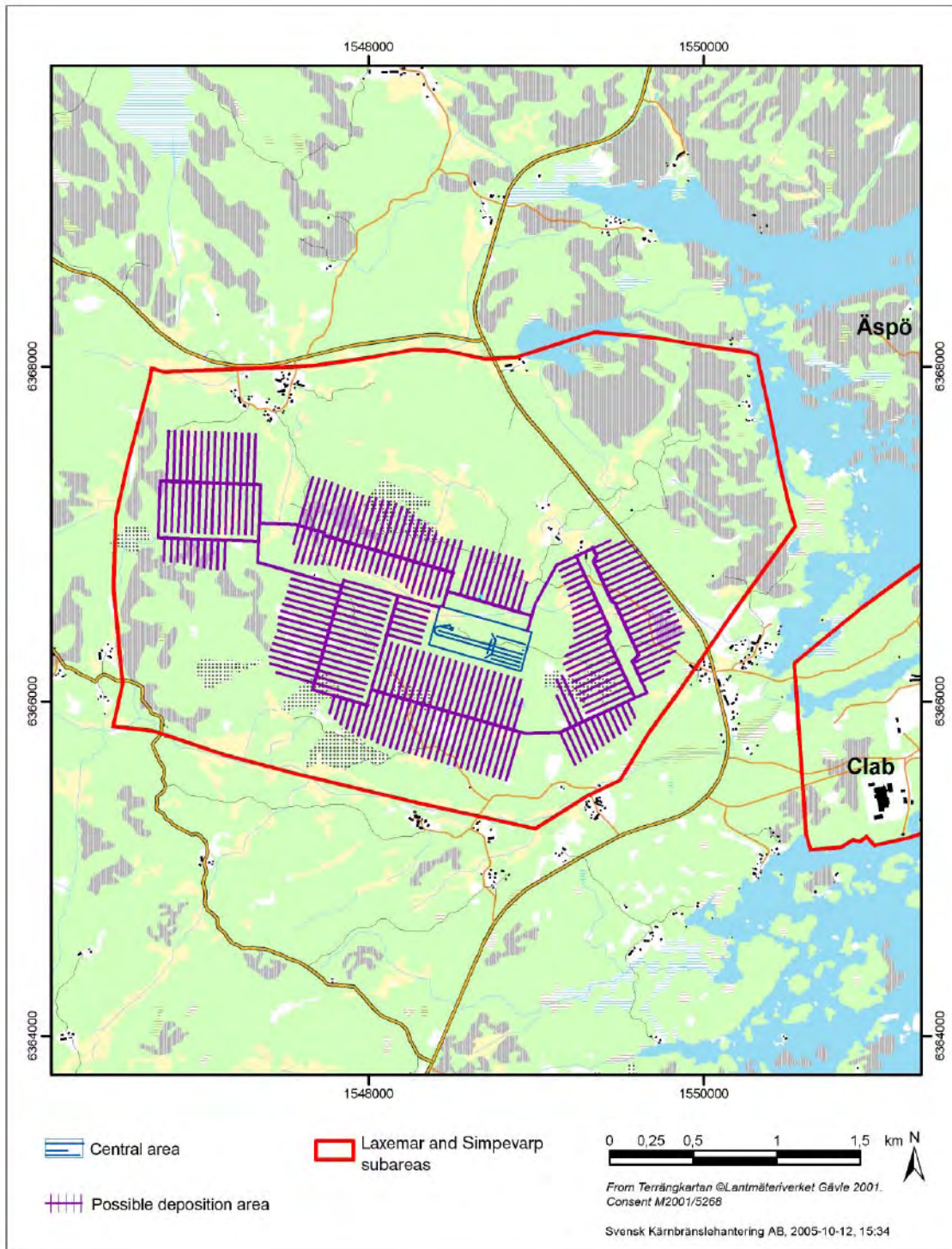


Figure 2-14. Example of a possible layout for a repository centrally situated at a depth of 500 m within the Laxemar subarea.

2.3.3 Cross-check against fundamental requirements

Geoscientific key questions

Prior to the site investigation phase, SKB presented fundamental requirements whose fulfilment had to be demonstrated in order for a site to be considered for the final repository /Andersson et al. 2000/. Conversely, if one or more requirements are not met, the site must be disqualified. Formulated briefly, the requirements are as follows:

- Regional ductile shear zones shall be avoided.
- The bedrock within the repository volume may not have ore potential.
- A repository must be able to be emplaced and given a technically reasonable layout within the available rock volume and taking into account fracture zones etc.
- The rock mechanical conditions must be such that serious stability problems do not arise in deposition tunnels and deposition holes.
- The groundwater at repository level may not contain dissolved oxygen.
- The total salinity (TDS = Total Dissolved Solids) of the groundwater at repository level must be lower than 100 g/l.

Beyond these requirements, it was stipulated that the suitability of a site can be questioned if a large fraction of the rock mass between fracture zones has a hydraulic conductivity greater than 10^{-8} m/s.

During the initial stages of the site investigation, the aim has been to gather data which – directly or indirectly – provides a basis for deciding whether the above requirements can be considered to be met, and thereby whether further investigations are warranted. An evaluation of the present state of knowledge in relation to the stipulated basic requirements is presented in /SKB 2004c/ for **the Simpevarp subarea**. A table there summarizes, for each of the requirements, aspects that are important to take into account with regard to site-specific conditions and the current state of knowledge. Remaining data needs if a complete site investigation were to be carried out on the Simpevarp subarea are also summarized briefly.

Based on completed investigations, the preliminary site description /SKB 2005b/, the preliminary repository description /SKB 2006b/ and a preliminary safety evaluation /SKB 2005a/, SKB makes the following assessment of the Simpevarp subarea:

There are good prospects for building a repository in the Simpevarp subarea. The fundamental requirements outlined above are met, as are most of the preferences outlined in /Andersson et al. 2000/. It is also possible to locate deposition areas so that all fuel fits in a one-storey repository. However, due to the major deformation zones that surround the subarea, together with local minor deformation zones within the area, the margins are small. Possible surprises in the form of more deformation zones may entail troublesome limitations.

The Simpevarp subarea is surrounded by and partially included in areas of national interest and areas protected under the Environmental Code, see Figure 2-6. It is not clear whether this entails limitations for the underground facility. It does, however, affect how the area can be used for a surface facility. Two good locations have been identified for the surface facility in the Simpevarp subarea: one at Clab and one on Hålö/SKB 2006b/.

The preliminary site description (version 1.2) for **the Laxemar subarea**, which is currently being compiled based on investigation data up to 30 October 2004, will provide an up-to-date interpretation of the geoscientific state of knowledge in its entirety

/SKB 2006/. Pending completion of the site description, the following summary must therefore be regarded as preliminary. This summary is also based on the investigation results obtained during the initial part of the complete site investigation, i.e. during the period November 2004 to June 2005 /SKB 2006a/. Even though the analysis and evaluation are not completely finished, SKB's judgement for **the Laxemar subarea** is nonetheless ready: existing knowledge of the subarea warrants further investigations according to the proposals presented in section 2.4 and Chapter 3 below.

Laxemar subarea – summary of requirements, state of knowledge and remaining data needs

Requirement 1 Regional ductile shear zones shall be avoided

Site-specific aspects

The Äspö shear zone (NE005) is situated between the Simpevarp and Laxemar subareas.

Status/state of knowledge

The Äspö shear zone is well-known on Äspö and its properties are known. There is some uncertainty as to whether the properties of the Äspö shear zone can be fully extrapolated to the mainland. This is particularly true of the uncertainties regarding the zone's brittle components. These are of importance for the zone's water-conducting properties.

Remaining data needs

In view of the uncertainty regarding the zone's brittle properties on the mainland, more information is needed on this. Moreover, further information is needed regarding the zone's movements (kinematics) during its ductile development phase, as well as the zone's impact on surrounding rock domains. The zone can affect the available volume, since with the current focus it constitutes the final repository's eastern boundary.

Requirement 2 No ore potential

Site-specific aspects

If ore potential is found, this may mean that a final repository cannot be built on the site. The Laxemar subarea is situated at a great distance from the central Swedish ore province, centred in Bergslagen.

Status/state of knowledge

A special ore geology study has been carried out, including an overall assessment of the geological situation, airborne geophysics and geochemical analyses /Lindroos 2004/. The study shows that Götemar granite in the north has some potential for quarrying of ornamental and building stone and small potential for occurrence of tin and tungsten. Furthermore, the Uthammar granite in the south has limited potential for ornamental and building stone.

Remaining data needs

The requirement is judged to be met and no additional data are needed. The issue will nevertheless be followed up in conjunction with future drilling.

Requirement 3 A repository must be able to be emplaced and given a technically reasonable layout within the available rock volume

Site-specific aspects

The main factors with a bearing on this requirement in the Laxemar subarea are:

1. The occurrence and principal properties of major deformation zones.
2. The properties of the rock mass between the major deformation zones, and specifically in possible deposition areas.

1. The occurrence and principal properties of major deformation zones.

It is above all the geometry and water-conducting capacity of these zones that delimit the underground part of the final repository and separate available rock volumes in deposition areas. Identifying regional and local major deformation zones was an important part of selecting and delimiting the Laxemar subarea.

2. The properties of the rock mass between the major deformation zones

determines how well the available rock volume within the possible deposition areas can be utilized for canister emplacement. Three partially interdependent properties are of greatest importance here:

2a. Local minor deformation zones and individual fractures in the rock mass

largely determine the abundance and flow of groundwater, see 2b. It is the rock mass between the major (deterministically described) deformation zones that will be utilized for deposition areas. There are deformation zones in this rock mass as well, although of smaller size. Some of these zones may have such properties that they should not occur within a deposition area, i.e. they may not be intersected by deposition tunnels. Other locally smaller zones may very well be present within a deposition area, but are not permitted in canister holes. Single fractures do not usually affect individual canister positions, unless they have an average radius of 50 m or more /Munier and Hökmark 2004/. Along with the major deformation zones, the presence of local minor deformation zones and individual fractures in the rock mass is of particular importance for the water-conducting properties of the rock and its mechanical stability in conjunction with a possible earthquake associated with a future glaciation of the Scandinavian peninsula. These minor structures are all described stochastically during the site investigation and are not verified as individual features until the detailed characterization that is performed during the repository's construction and operating phases.

2b. The water-conducting capacity of the rock mass

affects calculations of transport properties in the rock nearest the deposition hole and how large a fraction of possible canister positions have to be excluded due to direct contact with a water-conducting fracture. The water flow in the rock mass thus influences the size of the repository and the rock volume that needs to be utilized. The occurrence and water-conducting properties of fine-grained granites were considered as a special issue in earlier programmes /SKB 2001b, 2004c/.

2c. The thermal conductivity of the rock

affects the necessary spacing between the canister holes. This property does not affect the long-term safety of the repository but does affect its size and thereby the volume of rock that needs to be utilized.

Status/state of knowledge and remaining data needs

1. The occurrence and principal properties of major deformation zones.

The following major deformation zones are deemed to be of importance for the placement of the final repository and its division into deposition areas. The review is mainly restricted to the deformation zones that have been modelled with a high confidence level within and adjacent to the focused area /SKB 2006/, see Figure 2-15.

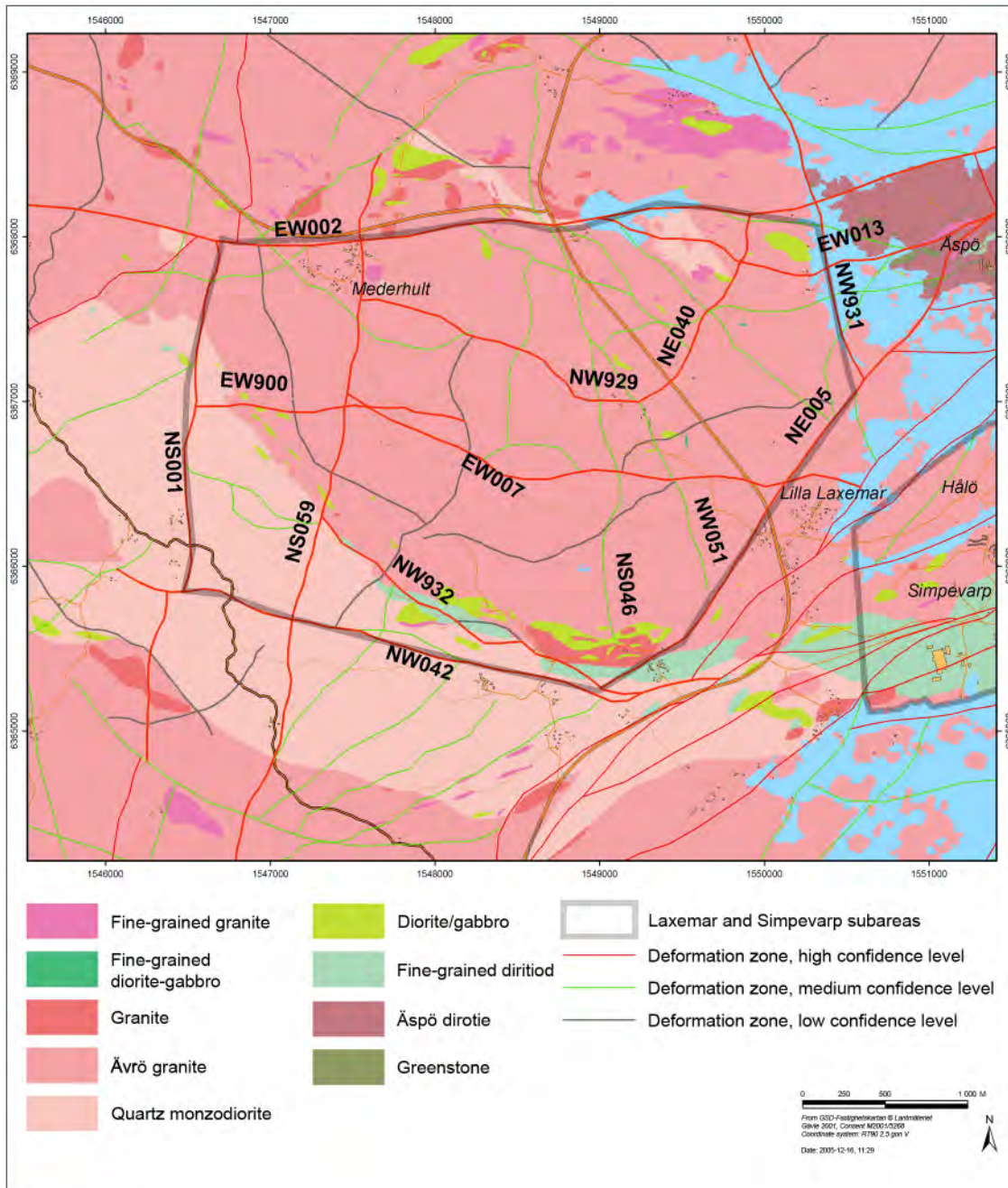


Figure 2-15. Bedrock map with principal lineaments and deformation zones in the Laxemar subarea.

EW007 can, together with EW900, be regarded as a relatively complex belt of deformation zones extending through the Laxemar subarea in an east-west direction whose properties are not yet fully known. EW007 strikes approximately 280° and dips $40\text{--}45^\circ$ towards the north according to the current model. Its existence is confirmed by magnetic data, topographical data, seismic refraction and reflection surveys and data from cored and percussion boreholes.

The cored boreholes KLX07 and KLX08 and the percussion boreholes that have been drilled through EW007 provide a very complex picture of the zone, which is also verified by recently conducted detailed ground geophysics, see 2a /Thunehed and Triumf 2005/. At the present time, important new information (Boremap, geological single-hole interpretation) from boreholes KLX07 and KLX08 that is needed to clarify the geometry of EW007 has not been analyzed. There is good reason to believe that EW007 consists of several subzones, including one subvertical part in the west and one in the east that dips $40\text{--}45^\circ$ toward the north. The elevated fracture frequency in sections in KLX07 and the slightly elevated one in KLX08 suggest that it may also potentially be north-south minor deformation zones that have been intersected. The complex geometry and properties of EW007 will therefore be further analyzed with the new information and kinematic studies.

EW900, which constitutes the western portion of the aforementioned zone complex EW007, strikes approximately 100° . This is based on magnetic and topographical data. The dip approximately 70° towards the south is based on a seismic reflector. EW900 is situated within the western part of the focused area and its geometry and properties need to be studied further.

NS059 strikes approximately 0° and is judged to dip subvertically. Its somewhat different character north and south of EW900 warrants dividing the description into these two parts of the zone:

– **northern part.** Data confirming the existence, strike and dip of the deformation zone are available from magnetic, topographical, ground geophysical and seismic refraction surveys as well as water-conducting percussion boreholes north of EW900. It has also been sufficiently investigated by excavation.

– **southern part.** Here the lineament's topographic component is very indistinct. Seismic refraction in the spring of 2005 revealed only an unclear and small reduction of the speed of sound in rock along the measured profile. Since the possible zone is situated within the focused area, it must be further investigated.

NW042 is judged to be an important boundary zone that bounds the Laxemar subarea on the south. With a focus on the southern part, the zone will be close to a possible final repository. NW042 strikes approximately 105° , based on co-interpreted lineaments and magnetic, seismic refraction and topographical data. The dip is probably subvertical, and slightly towards the south. This assumption is based on the fact that KLX05, which was drilled from north to south, does not exhibit a high frequency of fractures or other indications of a major deformation zone. Percussion drilling has so far not lent any true clarity to the geometry and properties of the zone, which means that it needs to be further investigated.

NS001 is a persistent boundary zone that bounds the Laxemar subarea as well as the focused area on the west. It has a clear topography and, according to groundwater models, controls the flow within the area and thereby the chemistry situation in a possible final repository. The deformation zone has also been indicated by seismic refraction. NS001 needs to be further investigated.

EW002 is a regional major deformation zone (Mederhult Zone) that bounds the Laxemar subarea on the north. The existence, strike and dip of EW002 are mainly based on lineament interpretation of magnetic and topographical data as well as data from seismic refraction profiles. EW002 strikes approximately 90° and dips $65\text{--}70^\circ$ towards the south, which is verified by cored borehole KLX06, where there is an elevated fracture frequency between 300 and 495 m, and by seismic reflection data. Since the continued site investigation is focused on the southern and western part of the subarea, a possible final repository will be far from EW002. Further data from EW002 are therefore not considered essential.

NE005 (Äspö shear zone) is a primarily ductile deformation zone that strikes approximately 60° , which is based on co-interpreted and structural field observations. It bounds the focused area on the east. The dip is judged to be subvertical with certain local variations. Its properties have been investigated on Äspö, but no cored boreholes have been drilled through the zone during the site investigation. Due to the relative closeness of the deformation zone to a possible final repository, supplementary data from the mainland are also needed.

NW932 is judged to strike 120° and dip vertically. Preliminary information from KLX05 and KLX03 provides only weak indications. Seismic refraction, geophysical profiles and field mapping provide no additional data. Additional processing of data from KLX03 and KLX05 is under way. At present, no further field investigations are planned specifically for this deformation zone.

Subhorizontal deformation zones. Seismic reflection surveys indicate an interpreted subhorizontal deformation zone **NW928** in the northern part of the Laxemar subarea that has an interpreted strike of 120° and a dip of 30° . This can be correlated with an interpreted deformation zone in the lower part of KLX04. It is expected to be well below repository depth in the focused area, so no additional investigations are judged to be needed. In the site-descriptive model Laxemar 1.2 it has been ascribed a confidence level of medium.

Other major deformation zones. In addition to the above-mentioned NW928, some of the major deformation zones have been ascribed a confidence level of medium in the site-descriptive model. They include **NS046** and **NW051**, see Figure 2-15. Their existence is often based solely on information from airborne geophysical, topographical and ground geophysical profiles. A couple of the larger ones are judged to require further investigation.

Another four deformation zones (NW929, NE040, NW931 and EW013) have been ascribed a confidence level of high, see Figure 2-15. Since these deformation zones are situated outside the focused area, they are not described here. But they are accounted for in the preliminary site description version 1.2 for Laxemar /SKB 2006/.

2. The properties of the rock mass between the major deformation zones.

2a. Local minor deformation zones and individual fractures in the rock mass.

During the spring of 2005, high-resolution aerial photography and detailed laser scanning were performed for the purpose of creating a detailed digital elevation model on a scale suitable for identifying this type of deformation zone. Furthermore, a detailed ground geophysical survey programme was carried out over approximately 2 km^2 of the subarea. Co-interpretation of data from these surveys on selected control squares and field checks showed that these deformation zones exhibited a uniform pattern (frequency and orientation) over the entire subarea. However, further knowledge of these structures is needed since they are assumed to control the water-conducting pattern of the rock mass to a great extent. Efforts will be concentrated on the focused area.

2b. The water-conducting capacity of the rock mass.

According to 2a. above there is nothing to suggest any great difference in frequency and orientation between the minor structures in the rock mass. Dominant fracture directions show a pattern that can be recognized over the entire area. These structures control groundwater flow in the rock mass to a great extent.

Direct measurements of the hydraulic conductivity of the rock mass are performed in all cored boreholes as they are finished. Hydraulic conductivity is measured mainly by means of the two methods difference flow logging and hydraulic injection tests. Pumping tests and interference tests have also been performed. Fracture transmissivity does not appear to vary between rock types. Hydraulic conductivity on the 3–5 m scale tends to be lower in quartz monzodiorite and in the more basic rock types than it is in granite, fine-grained granite and Ävrö granite. Compared with the mean for all rock types, narrow dykes (< 1 m) of fine-grained granite in other rock types do not appear to raise hydraulic conductivity. Hydraulic conductivity is above all elevated in the uppermost 300 m or so, and a depth trend can be distinguished for all areas except Äspö. The volume around EW007 is more conductive, but south of there hydraulic conductivity appears to be lower. Knowledge of the water-conducting capacity of the rock mass and its variation within the subarea and between different rock types needs to be improved by additional measurements in boreholes combined with analysis of the structures in the rock mass according to 2a.

The preference that most of the rock mass between fracture zones should have a **hydraulic conductivity** of less than 10^{-8} m/s on a test scale of 30 m is fulfilled, according to preliminary assessments. More data are needed to confirm this assessment.

2c. The thermal conductivity of the rock.

Just as in the Simpevarp subarea, the thermal conductivity of the rock is relatively low in the Laxemar subarea. A large number of laboratory analyses of samples taken from drill cores and the rock surface representing different rock types and geographical parts of the subarea were therefore performed in the spring. Calculations based on mineral composition and density logging have also been done. In the case of the principal rock types Ävrö granite and quartz monzodiorite, the variations turned out to be largely controlled by the quartz content. There are two variants within the Ävrö granite: one more quartz-rich and one more quartz-poor, both spread over the entire area with some concentration of the more quartz-rich variant in the central part of the subarea. The thermal conductivity of the rock in the subarea has been modelled using the lithological model as a point of departure. Four defined thermal domains have thereby been defined. The lowest mean value is 2.6 W/m·K and the highest 2.9 W/m·K, but the variations within the domains are great. The coefficients of thermal conductivity are relatively low, and even the higher value may mean that the spacing between the canisters has to be more than the 6 m assumed in the reference design. The highest thermal conductivity is in a central band with a northwesterly trend. On either side of this domain the mean thermal conductivity is lowest, while the value for the domain in the south and southwest is in between. The thermal model is deemed to be reliable, but it should be further improved by means of additional targeted samplings/analyses and calculations from mineral composition and density logging.

Requirement 4 No serious instability in deposition tunnels and deposition holes

Site-specific aspects

Stability is determined by the rock stress conditions, the mechanical properties of the rock and the chosen design with regard to tunnel directions and cross-sections. High rock stresses may entail some fracturing adjacent to openings and require rock support measures.

Status/state of knowledge

The investigations have consistently revealed rock of normal strength which, together with the assumption of rock stresses of normal magnitude and normal fracture frequency, suggests good mechanical properties. These measurement results agree with the situation on Äspö.

Rock stress measurements have been performed in two cored boreholes (KLX02 and KLX04) in Laxemar. The results for KLX02 agree with the conditions on Äspö. The measurement results for KLX04 deviate from those obtained in KLX02 and in boreholes in Simpevarp and on Äspö. Numerical simulations of the stress state in the rock at KLX04 indicate that the nearness to an east-west deformation zone that dips towards the north can affect the stress situation. Measured rock stresses are not critical, but their variation in different directions can affect the site adaptation of the final repository.

Remaining data needs

Additional data on the strength of the rock are needed to supplement and verify the present picture. It must also be verified whether the rock stresses are really different in the Laxemar subarea compared with the Simpevarp subarea and Äspö, or whether the deviation is due to the fact that the measurements in Laxemar were performed near a deformation zone.

Requirement 5 No dissolved oxygen in groundwater at repository level

Site-specific aspects

Prior to the start of the site investigation, data from previous investigations in the area showed that the groundwater on Äspö and the Laxemar subarea contains iron and sulphide and is free of dissolved oxygen. This meant that the requirement was judged to be satisfied.

Status/state of knowledge

Complete chemical characterization was performed during the site investigation in a borehole in the Laxemar subarea, KLX03. Results obtained thus far confirm the aforementioned conditions.

Remaining data needs

Even though the requirement is now considered to be satisfied, further measurements will be carried out in cored borehole KLX08.

Requirement 6 The salinity (TDS) of the groundwater at repository level may not exceed 100 g/l

Site-specific aspects

The coastal location means that saline groundwater can be expected. Data available prior to the start of the site investigation showed that the fresh water cushion in the Laxemar subarea is deeper than on Äspö. Increasing salinity is not expected until a depth of around 500–1,000 m. Salinity increases markedly at even greater depths than 1,000 m, amounting to 80 g/l at a depth of 1,700 m.

Status/state of knowledge and remaining data needs

The salinity of the groundwater was measured in all boreholes and used in the evaluation of the long-range transient flow conditions. Varying climatic conditions over a glaciation cycle affect the occurrence of saline and fresh water. When the ice retreats, fresh meltwater can be pressed down to great depths, and when the land is covered by sea the bedrock is infiltrated by saline sea water. In the interim, rainwater infiltrates and fills the groundwater reservoir. Samplings during drilling have shown that the salinity down to repository depth is lower than in the Baltic Sea. Complete chemical characterization in KLX03 shows how the salinity increases from 2.5 g/l at a depth of 400 m to 7 g/l at 750 m and 17 g/l at 975 m. Geophysical measurements (TEM) are performed to provide a picture of how the depth to saline water changes further west towards European highway E22.

2.3.4 Remaining uncertainties in the site description – need for additional data

This section reports remaining uncertainties in the site-descriptive model of the site investigation area in Oskarshamn, with a special focus on the Laxemar subarea. The discussion is based on the work with the site-descriptive model Laxemar 1.2, primarily on the account of uncertainties given in Chapter 12 of the preliminary site description /SKB 2006/. The assessments include issues that have a bearing on safety assessment and design. The additional data that are needed to reduce the uncertainties in the model are specified for each submodel.

Uncertainties in details regarding the spatial distribution of different rock types lead to uncertainties in the **rock domain model**, see Figure 2-16. As an example, there are both quartz-rich and quartz-poor variants of Ävrö granite in the Laxemar subarea. Furthermore, there are uncertainties regarding the distribution and orientation of dykes and bodies of subordinate rock types, plus uncertainties regarding the spatial distribution and degree of hydrothermal alteration in the bedrock, for example red-staining of the rock. These uncertainties are not critical factors for safety assessment or design, but affect above all the thermal properties of the rock (quartz content) and thereby the repository's space requirement, as well as to some extent the transport properties of the rock (alteration). More data from cored boreholes, including borehole geophysics, with documentation of subordinate rock types will reduce the uncertainties. Equivalent information from exposed rock surfaces is also of importance. More chemical analyses and model analyses are needed to obtain a better understanding of differences in composition. Uncertainties regarding alteration can be reduced by microscopic examination of rock samples from outcrops and drill cores.

The principal uncertainties in the **deformation zone model** relate to the fact that all zones that are interpreted on the surface have not yet been verified at depth by means of boreholes. Another uncertainty concerns the interpretation of the length of the deformation zones, their geometry, and how they terminate against other zones and geological features. Furthermore, the possibility cannot be excluded that there are hitherto unknown deformation zones that have not yet been detected by surface investigations and boreholes. The model may also contain deformation zones that may have been incorrectly interpreted to exist or have been ascribed too large a geometric extent. In the model, the character and properties of the deformation zones are associated with uncertainties, as is the understanding of the spatial variation of the properties within individual zones. The deformation model provides the geometric premises for the hydrogeological modelling and is also important for the rock mechanics model (rock stresses). The properties of the deformation zones, but above all their geometry, are essential for design and safety assessment. Data from drilling campaigns targeted at selected local major zones in important parts of the subarea, mainly in the southwestern part, are needed to reduce the uncertainties. Where possible (manageable soil depth), the possibility of verifying the zone with an excavated trench is also considered. Furthermore, the already completed detailed ground geophysical survey, together with new detailed aerial photography and laser scanning, will provide data that will further reduce the uncertainties associated with local minor deformation zones.

As far as the **geological DFN model** is concerned, the uncertainties are mainly associated with: identification of fracture sets (exposed rock surfaces are subhorizontal and boreholes are subvertical and mapped with different resolutions), fracture length distributions (when these are based on interpolation between interpreted lineaments and results of outcrop mappings), and finally fracture intensity (frequency and how fracture intensity varies). Our current hypothesis is that fracture intensity is linked to rock domain and that the linkage is even stronger to individual rock types. For the safety assessment it is of special interest to obtain good estimates of uncertainties associated with intensities for fractures with a length in the size range 10–500 m. Lineament interpretations based on new surface information (laser scanning, detailed ground geophysics and field checks) are carried out to reduce the uncertainties. The efforts will be focused on lineament data in the length range from exposed rock surfaces (about 50 m) up to 1,000 m. Furthermore, data are needed from superficial inclined cored boreholes to better associate information from outcrop observations with depth information. Moreover, verifying analyses are performed of existing data from the Äspö HRL (TBM⁵, True Block Scale⁶ and Prototype Repository⁷).

The uncertainties in the **rock mechanics model** relate to the size of the rock stresses and their distribution in the Laxemar subarea. The same applies to the division of the local model volume into different rock stress domains. Uncertainties in our understanding of rock stresses are important for design, since high stress levels affect rock stability and estimates of the same. Uncertainties in the mechanical properties of the rock mass derive from uncertainties in the existence and extent of local minor (stochastically described) deformation zones in the rock between the deterministically described deformation zones. There are also uncertainties concerning the strength of the intact matrix rock in quartz monzodiorite and Ävrö granite in the southern part of the Laxemar subarea. New rock

⁵ TBM: Part of the access tunnel to the underground parts of the Äspö HRL bored by a Tunnel Boring Machine.

⁶ True Block Scale: Project in the research field “Natural Barriers” on Äspö. Characterization, modelling and tracer tests in a fracture network in a rock volume of size 1000×100×50 m /Winberg et al. 2002/.

⁷ Prototype Repository: Full-scale trial with TBM-bored deposition tunnel with full-scale deposition holes. /Wiborgh et al. 2004/.

stress measurements in boreholes in the Laxemar subarea will reduce uncertainties in the stress model. Observations of the lack of “core diskings” (cracking of the drill core caused by stress relief) can possibly be utilized as “soft information” to determine an upper limit of the stress level. The data need for improving the mechanical model includes additional test results from intact rock, mainly Ävrö granite and quartz monzodiorite in the southern part of the Laxemar subarea. Uncertainties associated with the mechanical properties of the deformation zones can be reduced with the aid of existing data (relationships between length, width and properties) from the Äspö HRL. To this can be added verification by comparisons between empirically classified properties of the rock mass and the actual outcome during tunnelling at the Äspö HRL.

Uncertainties in the model of the **thermal properties of the rock** are associated with the distribution of thermal conductivity, the in situ temperature in the rock, and the thermal expansion of the rock. These uncertainties are of no importance for the safety assessment, but are of importance for design since they affect the canister spacing. Direct measurements of thermal conductivity (TPS) on all rock types (including altered rocks) together with support from the discipline of geology will reduce the uncertainties in thermal conductivity and its upscaling. For Ävrö granite, both density determinations and measurements of thermal conductivity on samples with low and high thermal conductivity are needed to strengthen established relationships between density and thermal conductivity. Furthermore, measurements of in situ temperature, performed under conditions of minimal mixing in the boreholes, are needed.

The principal uncertainties in the **hydrogeological model** are associated with the deformation zones and their hydraulic connectivity, transmissivity and spatial distribution. In addition to the inherent uncertainties in the geological DFN model, there are uncertainties in the hydraulic DFN model as well due to incomplete knowledge of the fracture transmissivity distribution and its possible directional dependence. The hydraulic properties of the rock domains D, M(A) and M(D) in the southern part of the Laxemar subarea (see map in Figure 2-16 and 3D-illustration in Figure 2-17) are currently only characterized with data from borehole KLX03 and partially from KLX05 (the designations M(A) and M(D) refer to the parts of the M01 domain that are dominated by Ävrö granite and quartz monzodiorite, respectively). Quantification of uncertainties in the hydraulic DFN model, its anisotropy and a possible coupling to the rock domain in identified deposition volumes are of great importance for safety assessment and design. The uncertainties can be reduced by further hydraulic tests utilizing inclined holes (directional dependence) and tests in the rock mass (between major deformation zones) that has not yet been investigated to a sufficient extent, i.e. D, M(A) and M(D). The uncertainties in connectivity and properties of deformation zones are not as important for safety assessment and design. The data need includes new hydraulic tests in cored boreholes in deformation zones and in the rock mass (between deformation zones), above all in the rock domain D (quartz monzodiorite) and in the mixed domains M(A) and M(D).

The uncertainties in the **hydrogeochemical model** are due to the fact that only a few data points are available from great depths. This also results in an uncertainty for identification and choice of hydrogeochemical type waters. Furthermore, a better understanding is needed of the chemical composition of the pore water in the intact rock matrix. The latter question is partly a sampling problem where consideration must be given to possible problems with destressing of rock samples. Remaining model uncertainties are associated with equilibrium calculations and the reactions and transport and mixing processes that created the present-day groundwater chemistry. The aforementioned uncertainties in groundwater chemistry are not of any crucial importance for safety assessment and design, since the resultant groundwater compositions lie well within the desired conditions. Reducing the uncertainties mainly requires representative chemistry data at depth and analyses of matrix fluid and type

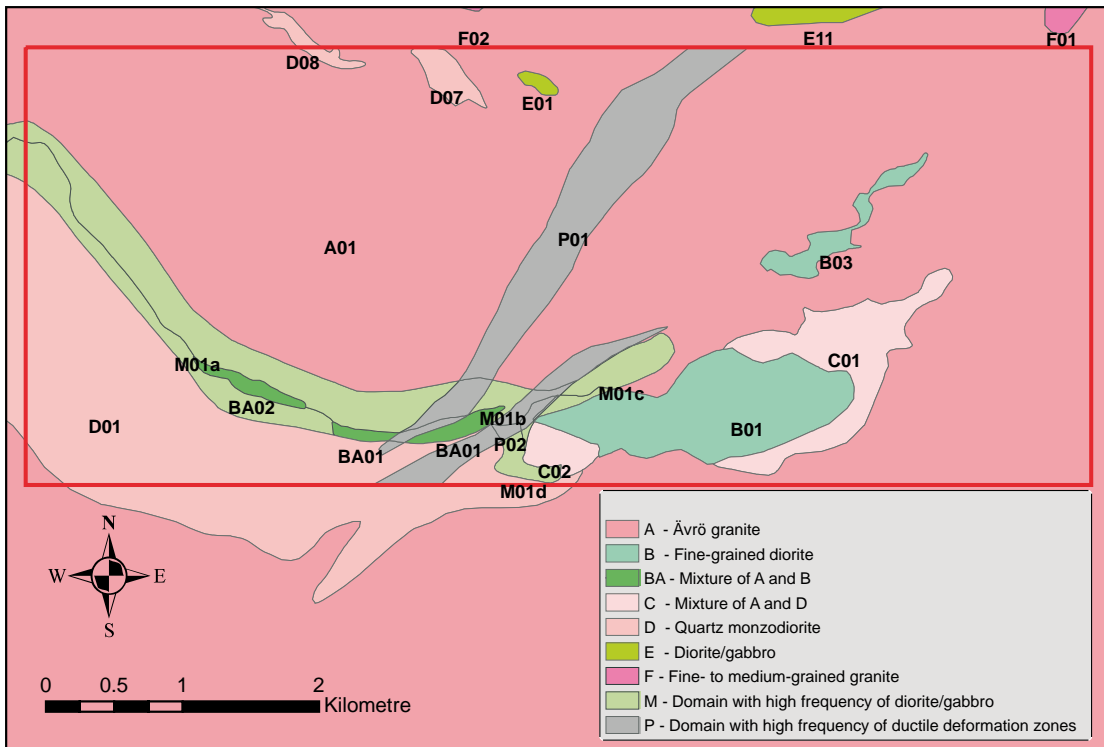


Figure 2-16. Rock domains in the Laxemar area. The rock domain M01 is traversed by the domains P01 and P02. The rock blocks on either side of P01 and P02 have been designated M01a-d. The black line inside the M01 domain marks the boundary between Ävrö granite, M(A), in the northwestern to northern part and quartz monzodiorite, M(D), in the southwestern to southern part of the M01 domain.

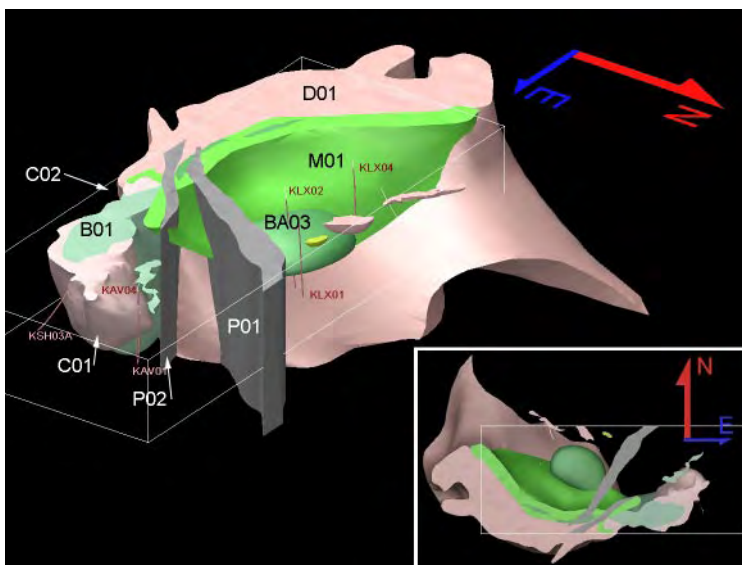


Figure 2-17. Three-dimensional illustration of rock domains shown in Figure 2-16. The Ävrö granite-dominated domain A01 is transparent. View from northeast.

waters (“end members”). Knowledge of redox processes can be increased by more data on in situ Eh, fracture mineralogy and mineralogy of the rock matrix. Moreover, further analysis and evaluation of data from recharge and discharge areas are needed for a better understanding of the seasonal variation in the chemistry of the surface water.

When it comes to the **transport properties of the rock**, there are uncertainties in sorption and diffusion parameters for intact rock from the Laxemar subarea (unaltered/alterd), as well as in data from the Simpevarp subarea and the Äspö HRL. Similar uncertainties exist for these properties based on geological material from fractures. This also applies to scaling of these parameters (averaging (effective values) for large areas/volumes). With regard to safety assessment and the long-term aspects of radionuclide retention, however, the above uncertainties are overshadowed by those associated with the F factor (determined by the flow-wetted surface, the connectivity of the flow paths and possible piping). In the same way, the fracture properties are of limited importance for the safety assessment.

Reducing the uncertainties in the F factor mainly requires evaluation of primary data with alternative models and concepts, but also more fracture transmissivity data from flow logging (PFL) in boreholes. More diffusion and sorption data are needed to reduce the uncertainties regarding these properties.

The uncertainties in the **description of the surface system** in the Laxemar subarea are mainly due to insufficient data. The description of sediments and Quaternary deposits (depth and thickness of individual soil layers and chemical, physical and hydraulic properties) is therefore uncertain. These parts of the model comprise a part of the transition zone between the biosphere and the rock system. Furthermore, there are considerable uncertainties in time and space for the discharge rate in the streams in the Laxemar subarea (no data or short time series). Moreover, there is no quantification of the components of the water balance for the Laxemar subarea (evapotranspiration, runoff, etc). This is of importance for the calibration of hydrological models, for example. Furthermore there are uncertainties regarding solute transport in the terrestrial system, the chemical composition of biota and the properties of the terrestrial vegetation.

Based on the above discussion of remaining uncertainties for the rock system, a general prioritization can be done based on the concrete needs of safety assessment and design. Even though no verification has yet been obtained of the geometry and properties of certain local major deformation zones by means of drilling and investigations in boreholes, mainly in the southern parts of the subarea, the prioritized investigation activities are aimed at quantifying the properties of the rock mass (especially hydrogeological and thermal properties) and how they vary in potential deposition areas. This priority is reflected in the investigation programme.

2.4 Further investigations

2.4.1 Strategy

SKB’s strategy for the continued site investigation in Oskarshamn is based on the following points of departure:

- The investigations shall provide supplementary data for the geoscientific key questions outlined in section 2.3.3 and reduce the remaining uncertainties outlined in section 2.3.4. Particular priority is given to investigations to quantify the properties of the rock mass and their variability in possible deposition areas.

- Points of departure for the investigation programme are the site-descriptive model for Laxemar version 1.2 /SKB 2006/, the results of the work with focusing in Laxemar /SKB 2006a/, and the initiated analysis within the framework of model step Laxemar 2.1.
- The investigations shall be planned and executed so that time is available for coordination with, and feedback of facts and viewpoints from, other subprojects in the Deep Repository Project.

The strategy is as follows:

1. Focus the investigations on the central part of the Laxemar subarea and such a large area of the southern and western part of the subarea that sufficiently large rock volumes suitable for the final repository can be verified.
2. Terminate or change the direction of ongoing and planned investigations north of EW007.
3. Obtain more information on the major deformation zones that are of importance for the final repository's boundaries and subdivision into deposition areas.
4. Characterize and understand the water-conducting properties of the rock mass.
5. Characterize and verify available rock volumes.

This strategy mainly involves characterization of the properties of the potential repository rock. Beyond this, knowledge of the surface systems will be improved, as well as the connection between surface systems and deep groundwater.

Chapter 3 describes what boreholes and investigations are planned to implement the strategy.

2.4.2 Timetable

According to the overall planning for the entire Deep Repository Project, a permit application will be submitted in 2008, see timetable in Figure 2-18. In the final phase it is necessary to allow time for the analyses and evaluations that need to be done, both site-specific and more general, prior to site selection and application. For this reason the investigations in the field and at laboratories which generate primary data should be finished and the results reported by mid-2007. This is a large task, since test drilling in the Laxemar subarea could not begin until the spring of 2004. It is, however, necessary in order that all essential primary data on deposition areas can be analyzed and site-descriptive model version 2.3 for the Laxemar subarea can be constructed. This shall be able to be presented as a site description for the Laxemar subarea in mid-2008. The site description is in turn used for a final facility description and safety assessment for a final repository in the Laxemar subarea.

Figure 2-18 shows a general timetable for the Deep Repository Project with subprojects and milestones for the site investigation in Oskarshamn.

The starting point for investigations according to this programme report is the summer of 2005, after data freeze 2.1 for Laxemar. Data freeze 2.1 has provided data for the work in model step 2.1, which is in the final phase. The work in this step has primarily been aimed at providing feedback from modelling to investigations and has in Laxemar's case concretely taken place within the framework of the work of choosing within which part of the Laxemar area the concluding stage of the site investigations is to be carried out. Analysis of primary data based on data freeze 2.1 is being done for all disciplines, whereas site modelling is only being done for a few disciplines.

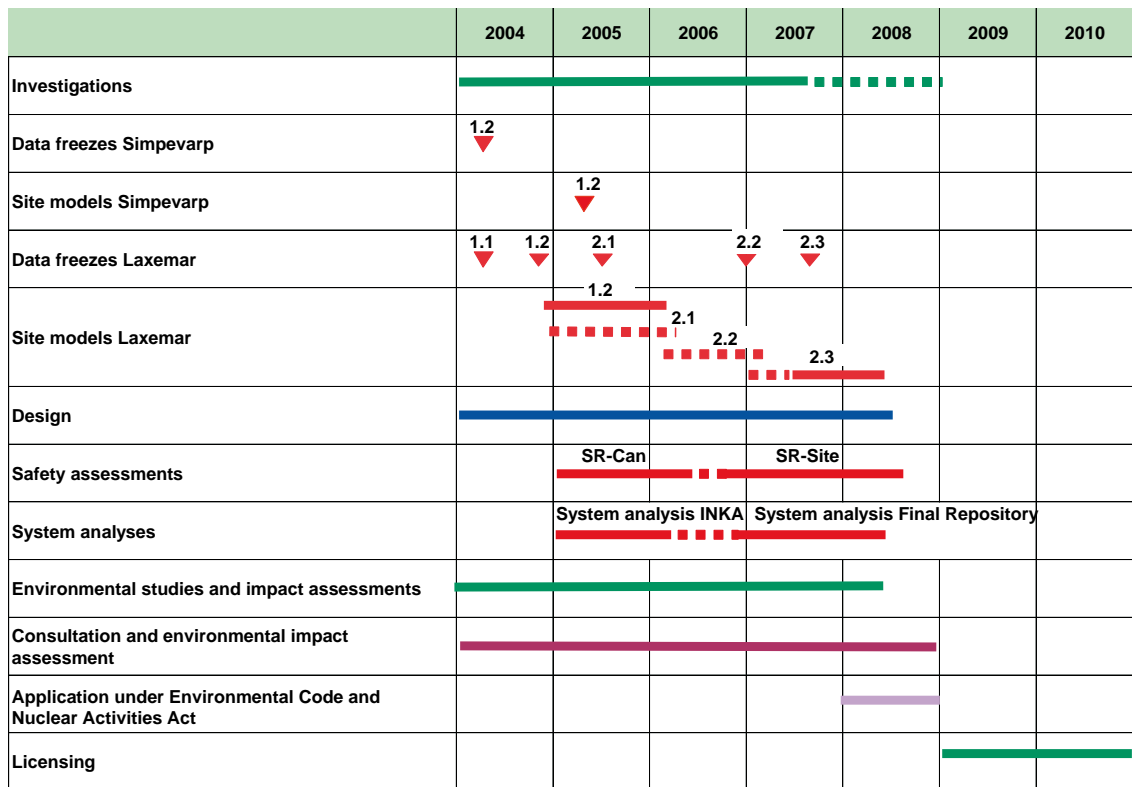


Figure 2-18. General timetable for the Deep Repository Project and the site investigation in Oskarshamn.

The milestones for the remainder are two more data freezes and two site models with the following principal purposes. The purpose of data freeze 2.2 is to provide the principal data for site model 2.2, which in turn is the basis for design (layout D2) and the safety assessment based on that. Much of the data processing in preparation for site model 2.3 is being carried out in parallel with this work. The purpose of data freeze 2.3 is to provide supplementary and verifying data for site model 2.3.

Thus, all investigations that provide input data for site description, facility description, safety assessment and environmental impact assessment – in other words, the supporting material for SKB’s application for permits to build and operate the final repository – shall be completed after data freeze 2.3. Pending the results of evaluations and SKB’s site selection, SKB’s plans call for a limited quantity of supplementary and verifying measurements, as well as different types of monitoring, to be carried out even after the summer of 2007.

2.4.3 Mode of working

The Deep Repository Project’s organization and subprojects, and the stepwise mode of working are described in section 1.2. Besides the interaction between the subprojects, readiness must be maintained to deal with possible requirements and viewpoints from the regulatory authorities and their expert groups, as well as from the County Administrative Board, the municipality and local stakeholders via the established consultations. The programme must therefore allow for supplementary work at a late stage of the site investigation.

Investigation results are processed immediately, and primary data are quality-controlled and stored in SKB's databases (Sicada and GIS). On a number of occasions (called data freezes), predetermined primary data sets shall have been entered in the database. These primary data sets are used by the site modelling subproject for analyses and updating of site-descriptive models, which are subsequently transferred to other subprojects at appointed times so that the work of facility design, safety assessment and environmental studies can be carried out according to plan. Flexibility and efficient collaboration between the subprojects are necessary for the success of the project. An example is the organized collaboration that has been established between investigations, modelling and design. The purpose is to strengthen cooperation between the subprojects so that the concluding part of the site investigation in the Laxemar subarea provides maximum benefit in relation to resource input. Other examples include the intensified cooperation that has been established between the disciplines of geology and hydrogeology to achieve higher efficiency and consistency in the work of constructing the hydrogeological DFN model, the intensified collaboration that is planned between hydrogeology and hydrogeochemistry with the ambition of producing a joint background report at the end of the site investigation phase, and the strengthened cooperation between the disciplines of geology and surface systems.

The flexibility requirement involves continuous development and adaptation of the investigation programme in response to the growing body of knowledge emerging from investigations, site modelling, design and impact assessments. Feedback from the subprojects to detailed planning of the investigations is very important. Determining preliminary locations for both the final repository's deposition areas and other underground facilities (central area, accesses) is a prerequisite for being able to optimize the positioning of boreholes and other investigation activities, as well as for being able to present at an early stage the design and impact of facilities above and below ground at EIA consultations so that possible viewpoints can be taken into consideration in the continued work.

In order to progressively improve our geoscientific understanding of the site, preliminary evaluations are made as a basis for future drilling and associated investigations. For example, qualified forecasts are made of the most important properties of the rock mass along a planned borehole before it is drilled and investigated. The forecast is then compared with the results of the drilling and investigations to provide some gauge of our knowledge of these properties and how it is progressively improved.

Another aspect that must be taken into consideration is that certain investigations require undisturbed conditions. This is true, for example, of measurements of natural groundwater conditions, interference tests between boreholes and tracer tests. These measurements may be disturbed by nearby drilling, which must be taken into consideration in the planning. For example, a large-scale interference test in combination with a tracer test should not be performed until the regular investigations have been completed.

3 Investigations

SKB's strategy for the remainder of the site investigation in the Laxemar subarea is presented in Chapter 2. The strategy has been devised on the basis of results obtained to date, remaining uncertainties and established goals and requirements for the site investigations. Based on this strategy, a programme for further investigations of bedrock, soil, water and environment in Oskarshamn has been prepared.

The chapter begins with a programme overview and a preliminary drilling programme. This is followed by a presentation of the programme under the appropriate discipline headings. In practice the investigations are often carried out jointly for several disciplines. For each discipline, first the purpose and goal of the investigations is presented, and then important results from completed investigations and questions that remain to be answered. Finally, the investigation programme for the remainder of the site investigation is presented.

3.1 Investigation programme – an overview

SKB's plan for the continued investigations is presented and explained in this section for each of the strategic points presented in section 2.4.1. The site investigation programme covers the entire remaining site investigation and should be regarded as a best assessment based on current knowledge and the need for new information to be able to prepare a final site description. Due to the fact that the continued investigations and extensive analysis and site modelling work are constantly contributing new knowledge, new data needs may arise and current priorities may change. A necessary flexibility is therefore built into the plans for the execution of the programme.

The execution of the programme is controlled by project plans that are based on the contents of the programme. This is true of both investigations and site modelling. A separate activity plan is prepared for each individual investigation, based on the project plan for investigations. The activity plan, with reference to the relevant method description and other instructions, controls execution with respect to technology, quality and environment. Separate decisions are made for all cored boreholes with reasons and other information essential for execution. This means that the site organization constantly maintains good documentation and traceability of the execution of the activities.

In all essential respects, the investigation methods presented in the general execution programme /SKB 2001a/ will be used. How the methods are carried out is controlled by method descriptions and method instructions, which are included in SKB's management system.

3.1.1 Focus the investigations

Completed investigations and evaluations have led to the decision that the continued investigations should extend from the central part of the Laxemar subarea and cover such a large area around it that large enough rock volumes suitable for the final repository can be verified /SKB 2006a/. With current knowledge, the overall conditions are judged to be slightly more favourable within the southern and western part of the subarea, so the investigations will primarily be concentrated in this part of the area.

Based on work done thus far, it has not been possible on geoscientific grounds alone to clearly delineate any part of the Laxemar subarea that is more suitable for the final repository than any other part. Besides the major deformation zones, which restrict the possibility of finding suitable and sufficiently large deposition areas, the thermal conductivity and water-conducting properties of the rock have been judged to be particularly important geoscientific factors. A separate study presented in /SKB 2006a/ regarding the possibility of passing deformation zones has shown that the centrally situated east-west-oriented zone EW007 can be passed with transport tunnels, so deposition on both sides should be possible. Thermal conductivity is slightly more favourable towards the north, while water-conducting properties are judged to be more favourable towards the south. The water-conducting properties of the rock are of importance for long-term safety, while its thermal properties mainly influence the space requirement and thereby the cost of the final repository. Due to the water-conducting properties, a focus towards the south is thus deemed to be more advantageous than towards the north. The fact that the thermal properties are more favourable in the northwest also makes it interesting to include this part of the subarea. Taken together, this means that the investigations will be concentrated in the southern and western part of the subarea.

Studies of possible layouts for the final repository show – based on current knowledge of deformation zones at repository depth – that the prospects are more favourable south than north of EW007. Several placements of the surface facility have been studied, with respect to both feasibility of execution and environmental impact. Two of the studied sites are situated south of EW007. Both are realistic alternatives, situated within the part of the Laxemar subarea on which the continued investigations will be focused, see Figure 2-12 /SKB 2006a/.

3.1.2 Investigations north of EW007

No new investigations will be initiated north of deformation zone EW007 for the purpose of investigating the deposition-related properties of the bedrock in this area. However, investigations that yield information on properties that is also valid for the southern and western part of the Laxemar subarea will be conducted.

3.1.3 Major deformation zones

All major deformation zones of importance will be modelled as individual features. In some cases it may be sufficient to analyze existing data. In other cases it may be necessary to further investigate an interpreted deformation zone in order to obtain sufficient data. This may be necessary both to confirm (or rule out) the existence of the zone and to obtain more information on its properties. Deformation zone EW007 and the properties of the nearby rock at repository depth will be studied specifically to determine how the rock volume in the centre of the Laxemar subarea can be utilized for the different parts of the final repository and which parts cannot be used.

Investigation methods are detailed ground geophysics, ground geophysical profile surveys, seismic refraction, percussion drilling and core drilling with associated investigations. The cored boreholes are planned to be 300–400 m long for this category of investigations, and in most cases interference tests between are planned between cored boreholes and percussion boreholes. Detailed planning will be done in conjunction with site modelling and design.

Based on the presentation of the state of knowledge in section 2.3.3, the following activities are planned to obtain more knowledge of the major deformation zones.

Deformation zones with high confidence level

Our current assessment for deformation zones to which a high confidence level has been ascribed (see Figure 2-15) is as follows:

- **EW007.** The geometry and properties of EW007 are of importance for how the central rock volume in the Laxemar subarea can be utilized. To start with, an extensive analysis will be made of the large quantity of data that already exists. This includes ongoing and planned measurements of a basic character in KLX02, KLX07, KLX08 and some percussion boreholes. Then it will be determined whether further drilling and other investigations are required, which will then yield data for data freeze 2.3.
- **EW900.** The repository area can also extend north of EW900, which means that these properties need to be investigated for a deterministic description of the zone. This will mainly entail detailed ground geophysics, possibly seismic refraction and, depending on the results of the ground geophysics, a couple of percussion boreholes. Ready for data freeze 2.2. Based on the results of these investigations, a decision will be made on whether a cored borehole is to be drilled, which is also expected to be finished by data freeze 2.2.
- **NS059.**
Northern part: No further investigations are planned.
Southern part: The southern part of the zone is relatively unclear and is perhaps rather a local minor than a major deformation zone. Since it is located within the focused area, knowledge of the zone needs to be improved. Detailed ground geophysics will be done, after which a suitable site for a relatively short cored borehole will be determined. The drilling results will be finished by data freeze 2.2.
- **NW042.** Current geophysical profiles and percussion boreholes, plus cored boreholes (KLX05) from the north, need to be supplemented to obtain a better understanding of the zone. Detailed ground geophysics and/or strategically selected ground geophysical profiles will be done by data freeze 2.2. This will provide a basis for placement of a 300–400 m deep cored borehole, ready by data freeze 2.3.
- **NS001.** The zone is indicated by topographical and geophysical lineament interpretation as well as seismic refraction. However, the existence and geometry of the zone need to be confirmed by percussion borehole by data freeze 2.2. A medium-long (300–400 m) cored borehole will then be drilled with the possibility of an interference test with the percussion borehole, ready by data freeze 2.3.
- **EW002.** No further investigations are being planned at present, partly because the zone is located at a relatively great distance from planned deposition areas.
- **NE005.** Regional ductile deformation zone well known from Äspö, so data from KAS17 will also be used. Measurements of magnetic anisotropy and kinematic studies are being conducted on the mainland portion in the autumn of 2005 (by data freeze 2.2). A medium-deep cored borehole (approx. 300–400 m) is tentatively planned for investigation of the possible brittle properties of the deformation zone, by data freeze 2.3. Depending on the results of coming investigations and modelling efforts, other more urgent boreholes and investigations may be prioritized, in accordance with the flexibility inherent in the programme.
- **NW928 and NW932A.** No further investigations will target these zones in particular, but existing information will be analyzed.

Deformation zones with confidence level of medium

In the site-descriptive model, some of the local minor deformation zones have been ascribed a confidence level of medium (green on map in Figure 2-15).

To verify and characterize some of the deformation zones that are situated within the focused area, tentatively NS046 and NW051, geophysical profiles, percussion drilling and core drilling (depth about 300–400 m) will be done.

3.1.4 The water-conducting properties of the rock mass

The water-conducting properties of the rock mass are of central importance for how large a portion of the rock can be utilized for deposition areas. The groundwater flow in crystalline rock is mainly controlled by its brittle structures. Along with the major deformation zones, the presence of local deformation zones and individual fractures in the rock mass is of particular importance for the flow pattern and other water-conducting properties, as well as for mechanical stability in conjunction with an earthquake. These minor structures are all described stochastically during the site investigation and are not verified as individual features until the detailed characterization that is performed during the repository's construction and operating phases.

Investigations to characterize and understand the water-conducting properties of the rock mass include both geological and geophysical methods that yield information on the structures and direct hydraulic measurement methods.

Patterns and water-conducting properties for local minor deformation zones

The results of the detailed ground geophysics and the high-resolution airborne surveys (aerial photography and laser scanning) carried out in the spring of 2005 will be utilized to clarify patterns and water-conducting properties for local minor deformation zones. After verifying field checks, suitable sites will be determined for verifying excavation and core drilling of short (10–100 m) holes with associated investigations. These activities will mainly be carried out at KLX10 and KLX09. Then the same methodology will be used on the focused area in the south and west where detailed ground geophysics with magnetometry and resistivity will also be carried out. Furthermore, an in-depth analysis will be conducted of geological, geophysical and hydraulic cored borehole data from the entire subarea.

Characterization of the superficial rock mass for DFN modelling

Detailed fracture mapping has been performed on exposed rock surfaces in both subareas for the main purpose of providing input data from the rock surface for DFN modelling. Where possible, the outcrops have been selected adjacent to a deep cored borehole. Another detailed fracture mapping will be carried out in the Laxemar subarea. To obtain equivalent DFN data on the superficial rock mass, a number of short (approx. 100 m) cored boreholes will be drilled on two sites at KLX09 and KLX11. In this way both Ävrö granite and quartz monzodiorite will be investigated. Detailed fracture mapping has been or will be performed on both sites. In this way, fracture data from the same sites is obtained from the rock surface, the superficial rock mass and from greater depths. The boreholes will be set out in an optimal manner for modelling, particularly with respect to the hydrotests and interference tests that are intended to furnish input data for the hydro-DFN modelling.

3.1.5 Available rock volumes

Characterize and verify deposition areas

The rock areas between the major deformation zones will mainly be used as deposition areas. It is important that these areas be characterized to such an extent that their suitability as deposition areas can be verified. The water-conducting properties of the rock mass are among the most important properties and are therefore dealt with as a special point in the

strategy (3.1.4 above). The other properties of the rock mass will be further investigated to the extent required to achieve the requisite safety in the site-descriptive model. The thermal conductivity of the rock is an example, where increased knowledge of its variation within available rock volumes reduces the uncertainty in the thermal model.

The existing site-descriptive model, preliminary layout and information from detailed ground and airborne surveys furnish information to guide where core drilling should be done. 2–3 cored boreholes are planned to characterize and verify deposition areas. The boreholes must reach repository depth, i.e. they must be 500–600 m long.

Characterization of central area, shaft and ramp

For the permit applications for the final repository, more detailed knowledge is needed on potentially suitable locations for the repository’s central area with access parts (shafts and ramp). The purpose is to clarify that there are good possibilities for descent and suitable location of the central area. To achieve this, site modelling will construct a somewhat more detailed model for this part. Data for this additional detail will be obtained by optimizing the drilling programme with respect to defined locations for the repository’s surface parts and central area. This applies to both the “Central” alternative just south of EW007 and the “West” alternative. Two additional 500–600 m long cored boreholes are planned, one for each of the two alternative locations. A percussion borehole may also be drilled. The investigations are being planned in consultation with design, and will be carried out so that the results can be included in data freeze 2.3.

After data freeze 2.3, supplementary geotechnical preliminary investigations will be carried out for the surface part of the final repository, see section 3.11. These investigations do not provide supporting material for permit applications, but are a part of the construction preparations.

Verifying large-scale interference test with tracer tests

A large-scale interference test in combination with tracer tests will be conducted at the end of the site investigation. The purpose of the test is not so much to construct site-descriptive models as to verify existing models. The results will therefore not be included in data freeze 2.3. The test includes the rock mass on the large scale, i.e. including any local major and minor deformation zones. This type of test is called LPT (long-term pumping test). Since the test is time-consuming (about 3+3 months) and furthermore requires calm hydraulic conditions over a large area, it will be carried out directly after data freeze 2.3.

Other investigations that continue after data freeze 2.3 are primarily various kinds of monitoring.

3.1.6 Drilling

Core drilling

Based on the chosen strategy, a drilling programme has been prepared, see Table 3-1 and Figure 3-2. The programme is well defined for the first cored boreholes, after which it is necessarily more preliminary. It includes deep (700–1,000 m), two categories of medium-deep (300–400 and 500–600 m) and short (10–100 m) cored boreholes. The map in Figure 3-1 illustrates the borehole programme with markings on the bedrock geology map. Existing cored boreholes have also been marked (cored borehole KLX09 and KLX10 are shown in the category “planned boreholes” but will be completed when this report is published). Table 3-1 describes the planned measures in greater detail and relates them to the above-mentioned purposes. The programme will continuously employ two heavy core drilling machines some

time into 2007. Beyond this, a smaller drilling machine will periodically be used for the short cored boreholes. After KLX11, no additional deep (700–1,000 m) cored boreholes are planned. The preliminary core drilling programme is described in greater detail in section 3.9.

The majority of the planned boreholes will be documented and investigated with a number of geoscientific investigation methods in roughly the same way as so far. Because the boreholes have different purposes, the investigation programme for each borehole will be adapted accordingly. More information on the various borehole investigations is provided in the discipline-specific programme descriptions in sections 3.3–3.8 and 3.10.

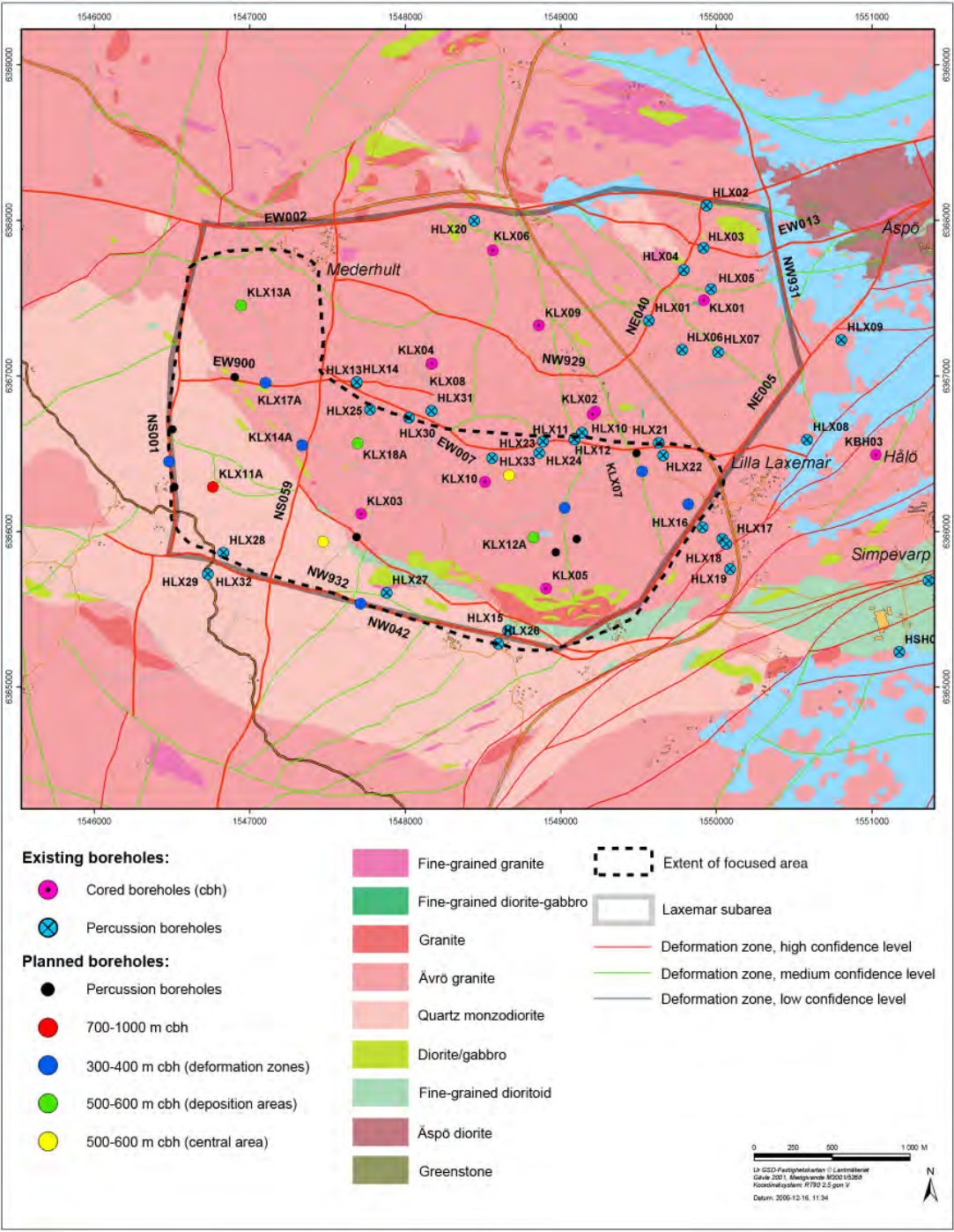


Figure 3-1. Focused area plus existing and planned boreholes. The location of the planned boreholes does not mark the exact position but rather a target area for each borehole. If possible, new boreholes will be drilled from existing drilling sites.

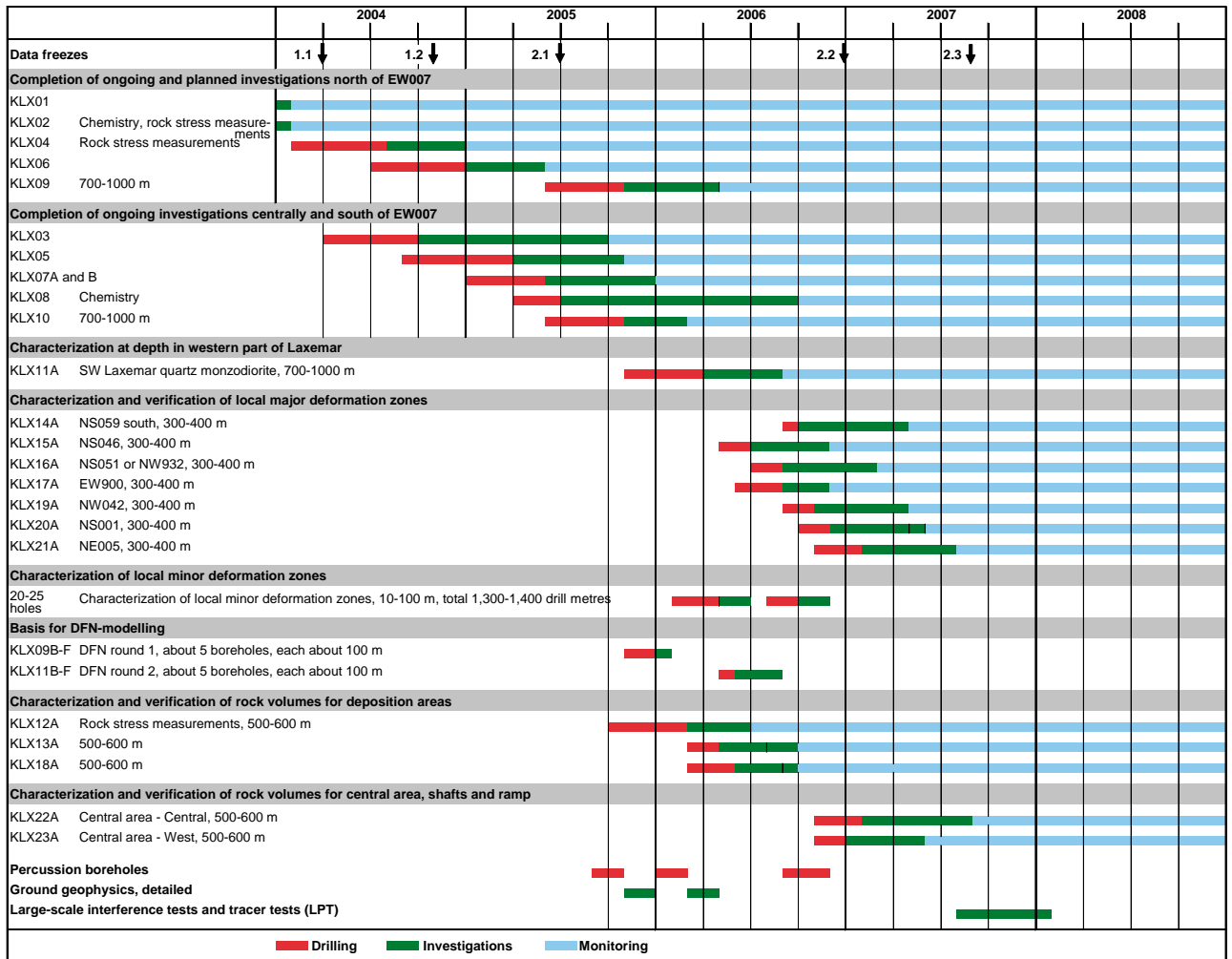


Figure 3-2. Preliminary timetable for drilling and investigations in the Laxemar subarea.

Percussion drilling

Percussion boreholes are normally about 200 m deep and do not yield a core, but are much faster and less expensive to drill than the cored holes. They are suitable for investigating the importance of interpreted lineaments and for investigating near-surface, gently-dipping fracture zones. It is tentatively estimated that another 10 or so percussion boreholes are needed, mainly to verify and characterize the major deformation zones. Percussion drilling is usually preceded by ground geophysics, which must give a clear indication of where the borehole should be drilled.

In the same way as previously, percussion boreholes will also be used as wells for flushing water for core drilling. Some percussion boreholes will be drilled near a cored borehole so that interference tests can be used to verify and characterize the hydraulic properties of the deformation zones.

Soil drilling

Soil drilling and soil sounding are done to determine soil depth and to characterize the soil layers. Monitoring wells are often sunk in conjunction with soil drilling so that the ground-water table can be monitored and water samples can be taken. Some soil wells are set out specifically for environmental monitoring adjacent to drilling sites.

Table 3-1. Programme for remaining core drilling in the Laxemar subarea. (The necessary flexibility means that planned activities may be changed in response to gradual development and improvement of the site-descriptive model.)

Designation (see Figure 3-1)	Planned work (see further sections 3.3–3.10)
Completion of ongoing and planned investigations north of EW007	
KLX01, 02, 04, 06	Ongoing investigations and monitoring of cored boreholes are continuing according to plan. Complete chemical characterization has been carried out in KLX02 before the site investigation. Rock stress measurements have been carried out in KLX02 and KLX04.
KLX09	Drilling of KLX09 in the northern part of the Laxemar subarea began in August 2005. Even if further investigations are concentrated to the southern part, KLX09 will continue at least until repository depth has been passed. Then a decision will be taken whether this borehole should continue or be terminated.
Completion of ongoing investigations centrally and south of EW007	
KLX03, 05, 07A, 08	Ongoing investigations and monitoring of cored boreholes will continue according to plan. Complete chemical characterization has been carried out in KLX03 and will be carried out in KLX08.
KLX10	Drilling of KLX10 in the central part of the Laxemar subarea began in June 2005.
Characterization at depth in the western part of the Laxemar subarea	
KLX11A	The focusing on the southern part of the Laxemar subarea requires a deep cored borehole in the western part where no borehole data have yet been obtained from great depth. A 700–1,000 m subvertical cored borehole is planned, chiefly to confirm the rock mass (quartz monzodiorite) at that depth. Drilling site KLX11 is planned to be used for other purposes as well, if possible, for example to investigate zone NS001.
Characterization and verification of major deformation zones	
	6–7 medium-long cored boreholes are planned to verify and characterize the selection of major, primarily local, deformation zones that are to be investigated according to section 3.1.3. The planned length of most of these boreholes is between 300 and 400 m. Detailed planning of the boreholes will be done in conjunction with site modelling and design. In certain cases a hole will be percussion-drilled near the cored borehole. Interference tests will be conducted in most cases when all cored boreholes and percussion boreholes have been drilled to verify and characterize the specific zone. Some of the boreholes will be drilled with a telescopic part, while others will be drilled without one, depending on whether pumping tests are to be conducted or on the scope of hydromonitoring.
Characterization of local minor deformation zones	
	In order to characterize patterns and water-conducting properties for local minor deformation zones in the area, approximately 20 short cored boreholes (10–100 m, without telescopic part) are planned.
Data as a basis for DFN modelling	
At drilling sites KLX09 and KLX11	Some 10 or so 100-m-deep cored boreholes are planned specifically to provide data as a basis for DFN modelling. These boreholes will be drilled around drilling site KLX09 (in Ävrö granite) and at drilling site KLX11 (in quartz monzodiorite). The boreholes will be accompanied by detailed fracture mapping and hydraulic tests. The holes will be drilled without a telescopic part and will be planned in consultation with site modelling.
Characterization and verification of rock volumes for deposition areas	
Southern and western part of Laxemar	Two to three medium-long cored boreholes will be drilled to confirm the rock volumes that are judged to be suitable as deposition areas between the major deformation zones. The majority of these holes will thus be drilled down to repository depth or below, which means a planned length of between 500 and 600 m. The aim is that all of these boreholes will be drilled within the southern and western part of the Laxemar subarea. One is planned to be drilled from drilling site KLX05 and comprise the main alternative for rock stress measurements. Detailed planning of these boreholes will be done in consultation with site modelling and design.
Characterization and verification of rock volumes for central area, shafts and ramp	
	A couple of cored boreholes will be drilled to provide the necessary data for characterization of the central area, shafts and ramp. One hole will be drilled for the “Central” alternative, just south of EW007, and one for the “West” alternative. The planned length of these holes is 500–600 m.

3.2 Surface systems

3.2.1 Purpose

The investigations of the surface systems have several beneficiaries and purposes. The purposes are described in the strategy reports for the site descriptions published in 2003 and in a number of other reports /Lindborg and Kautsky 2000, Löfgren and Lindborg 2003/. A brief summary follows below.

Safety assessment

A large part of the programme is aimed at giving the safety assessors the understanding required to build models and justify the assumptions that are made. Some of the collected data are used directly in the modelling, some after processing either via site description or in the safety assessment. According to the calculations presented in the interim report for the safety assessment SR-Can /SKB 2004/, low points in the terrain (i.e. wetlands, lakes, sea) are in particular of great interest, since such areas can constitute discharge areas for deep groundwater.

Environmental Impact Assessment

In order to be able to study the issues that will be dealt with in the environmental impact assessments, knowledge is needed of the site's properties, character and conditions, as well as natural and cultural environmental values. The investigations of the surface systems largely satisfy these needs. Supplementary information concerning, for example, health and living environment matters as well as assessments of natural and cultural environmental values will be collected in connection with the EIA work. Further investigations may be necessary if questions arise in the EIA process that require special studies not included in this programme.

Environmental management during the site investigations

To enable the impact of the site investigation to be described and any effects minimized, knowledge is needed of where sensitive species and biotopes are located. This knowledge, together with information on ongoing and planned land use as well as protected and valuable areas, is also needed for environmental studies and assessment of consequences for environment and human health stemming from construction and operation of the final repository on the selected site. See Appendix B.

Site-descriptive models for surface systems

The site-descriptive model for the surface systems /Lindborg 2005, 2006/ summarize data from the site investigation in the form of discipline-specific models (ecology, hydrology, oceanography etc). Figure 3-3 shows an example of an ecosystem model. This compilation of data will then be used as a basis for the work with the safety assessment and the environmental impact assessment.

3.2.2 Important results from completed investigations

During the initial stage of the site investigation, the investigations were concentrated on obtaining data for spatial models of ecosystems and the local model area. A large part of the ecosystem survey has now been completed and is described in the ongoing work with the site description of the surface ecosystems /Lindborg 2005, 2006/.

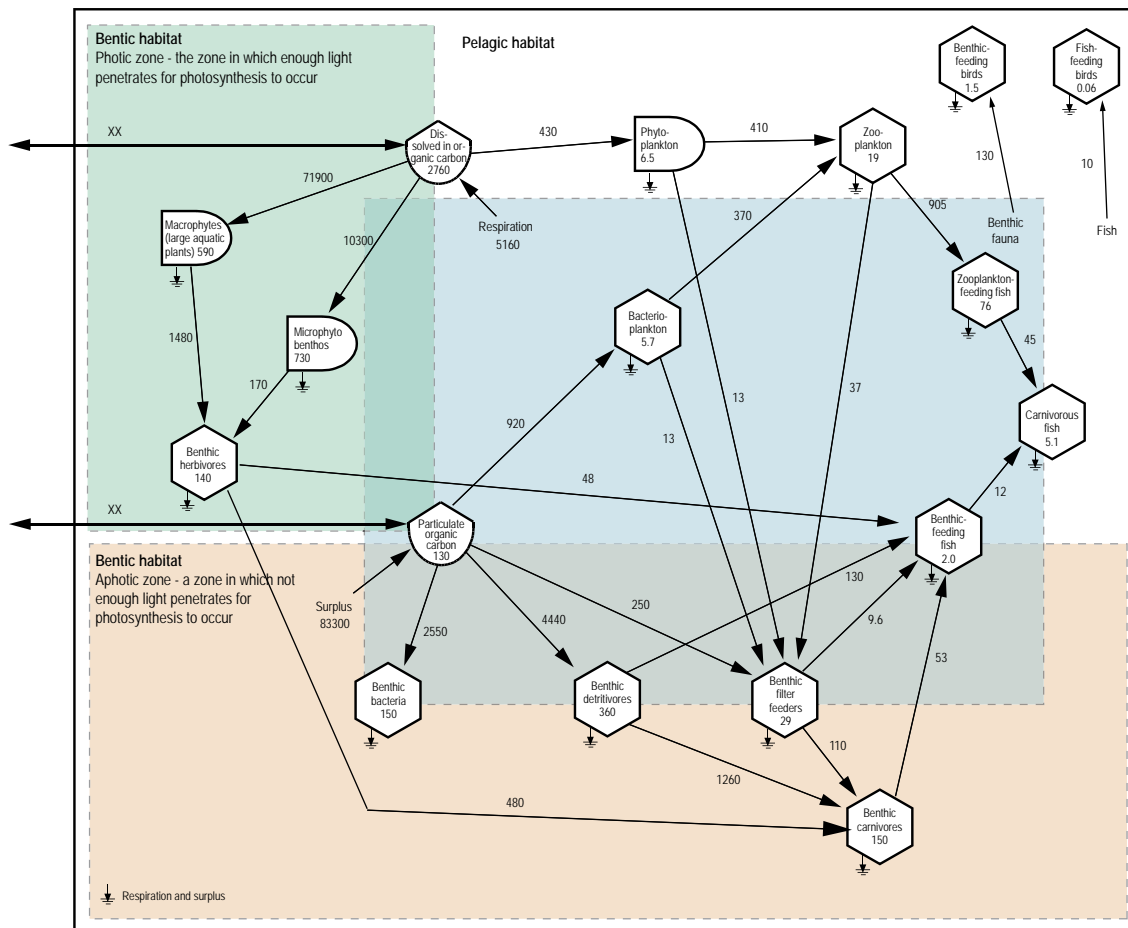


Figure 3-3. Example of ecosystem model with carbon budget and flows (10^4 g C per year) in Borholmsfjärden /Lindborg 2005/.

The description of the surface ecosystems is divided into descriptions of deposits, hydrology, chemistry and oceanography plus the various ecosystems (terrestrial, lacustrine and marine). An integrated description of all parts is provided in a landscape model. The models describe the flow of matter (carbon) and water within and between the systems.

Most of the surface water, and thereby a large portion of the transport of matter in the landscape, takes place in one catchment area, catchment 10, the Laxemarån River's catchment area (see map in Figure 3-4) with Borholmsfjärden as the recipient. A smaller fraction flows into Lake Frisksjön, whose recipient is Granholmsfjärden /Brunberg et al. 2004, Lindborg 2005/.

The **terrestrial ecosystem model** describes carbon fluxes and pools in the landscape and also includes wetlands. The most important constituents of the model are the vegetation, which binds carbon via photosynthesis, and the soil, where decomposition and accumulation of carbon takes place. Animals and man are also included, but their importance as consumers of organic matter is small compared with other fluxes in the terrestrial ecosystem. Carbon is accumulated in most types of terrestrial vegetation in the site investigation area. An exception is clear-cuts and young forests, which release more carbon than is sequestered. The greatest accumulation takes place in vegetation, but an appreciable fraction is also stored in the soil. Most accumulation in soil takes place in wetlands, where a high groundwater level inhibits the decomposition rate. Decomposition is the next-largest carbon flux, after primary production. Some supplementary investigations will be conducted to determine the size of the decomposition, particularly in wetlands.

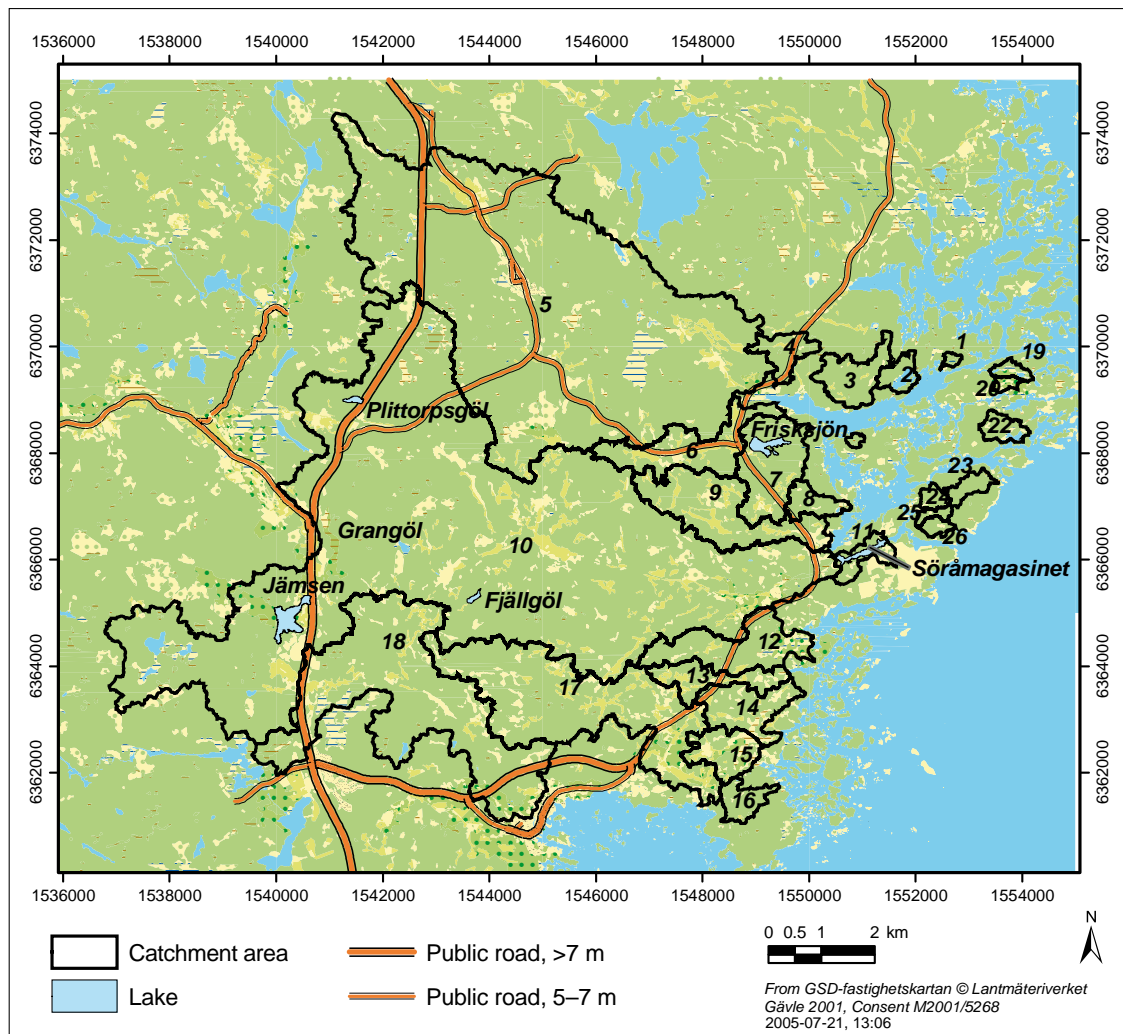


Figure 3-4. Catchment areas in the Laxemar subarea with environs /Lindborg 2006/.

The **limnic ecosystem model** describes the carbon and water budget for Lake Frisksjön. The largest fluxes of carbon into and out of the lake take place via primary production and respiration. On an annual basis the lake is a carbon sink where a larger quantity of carbon is lost as respiration than is stored in primary production. Nearly one-third of the carbon that enters via runoff sediments.

The **marine ecosystem model** describes a number of basins with great differences in how carbon is bound and flows through the system. The inner basins are dominated by primary producers, mainly macrophytes that bind large quantities of carbon that either is deposited or is transported to the outer basins. In the outer basins, the water flux (oceanographic flows) greatly affects the fluxes of carbon, but the filtering organisms on the shallow coastal bottoms also account for a large portion of the carbon turnover. Benthic production (the accumulation of carbon in benthic organisms) in the inner basins is calculated in the site-descriptive model Laxemar 1.2 based on both site-specific and generic data. Owing to their great importance for the system, field measurements are currently being performed to confirm the calculated values. A large portion of the carbon in the system is also expected to sediment. Field investigations will be carried out in 2006 to confirm this.

3.2.3 Completed investigations

During the initial site investigation, surveys of the properties of the surface ecosystems have been conducted in the following areas.

Deposits

- Soil inventory /Lundin et al. 2004/.
- Sediment sampling in peatlands/wetlands, lakes and shallow sea bays /Nilsson 2004/.

See also investigations presented in section 3.3 Geology.

Topography, hydrology, oceanography and surface chemistry

- Running waters and catchment areas /Carlsson et al. 2005/.
- The area's lakes and lake habitats /Brunberg et al. 2004/.
- Chemical and physical parameters in surface water /Ericsson and Engdahl 2004a/.
- Detailed marine survey in shallow coastal waters /Ingvarsson et al. 2004/.
- Oceanographic measurements in coastal waters /Lindow 2005/.

See also investigations presented in sections 3.6 Hydrogeology and 3.7 Hydrogeochemistry.

Terrestrial biota

- Vegetation map /Boresjö-Bronge and Wester 2003/.
- Dominant plant species and their biomass /Andersson 2004/.
- Amount of dead wood /Andersson 2005/.
- Production and respiration measurements /Tagesson 2004/.
- Woodland key habitats /Sturesson 2003/.
- Game /Cederlund et al. 2005/.
- Mammals /Cederlund et al. 2004/.
- Small rodents (voles and mice) /Cederlund et al. 2005/.
- Birds /Green 2003, 2004, 2005/.
- Amphibians and reptiles /Andrén 2004/.
- Mammals /Tannerfeldt and Thiel 2004/.
- Bats /Ignell 2004/.

Marine and limnic biota

- Phytoplankton and zooplankton /Sundberg et al. 2004/.
- Sampling of freshwater fish /Engdahl and Ericsson 2004/.
- Benthic fauna in lakes and streams /Ericsson and Engdahl 2004b/.
- Marine benthic fauna /Fredriksson 2004, 2005a/.
- Population estimate of pelagic fish /Enderlein 2005/.
- Inventory of underwater vegetation in shallow sea bays /Fredriksson and Tobiasson 2003/.

3.2.4 Ongoing investigations

Supplementary investigations have been initiated in certain areas. Investigations are currently being conducted of:

- The quantity of falling litter and its decomposition rate.
- Quantification of the quantity and extent of fine roots.
- Production and respiration measurements in aquatic environments.
- Characterization with respect to elements and radionuclides in various media such as marine and limnic sediments, peatlands and wetlands, the different soil types and vegetation.
- The extent and chemical composition of typical soils, different transitions, and root depth in a number of typical profiles in the area.
- Population estimate of fish in near-coastal areas.

3.2.5 Important questions remaining to be answered

The rest of the site investigation primarily involves obtaining additional information on surface ecosystems by e.g. analyses of the chemical composition of deposits and biota, further process measurements and supplementary determination of the properties of the wetlands. Beyond this, additional essential questions may be identified in the work with the site models and the environmental impact assessment.

Deposits, hydrology

In modellings and descriptions of surface systems, particular interest has been devoted to lakes, wetlands and agricultural land, since these are generally considered to be discharge areas and thereby potential recipients for deep groundwater. Many wetlands in the Oskarshamn area are used as agricultural land today and are therefore of special interest for the safety assessment. To some extent the wetlands in Oskarshamn have already been investigated. For example, stratigraphic sequences have been mapped on a number of typical peatlands and wetlands (see Figure 3-5). The collected information needs to be supplemented with more detailed information regarding how they have formed and the hydrological properties of the different layers. Supplementary investigations are therefore planned and will probably be carried out in one or two wetlands that are characteristic of the area. In order to describe the future evolution of the landscape, more detailed knowledge is also needed of erosion and deposition of sediments in sea bays and lakes. An investigation is therefore planned to quantify the sedimentation rate from the deglaciation up to the present. The marine description in site model Laxemar 2.1 /Lindborg 2006/ shows a large surplus of carbon in certain parts of the area. It is probable that a larger portion of the produced biomass than calculated sediments. The actual sedimentation must therefore be determined so that a better description of the marine systems can be made.

Hydrological questions are dealt with further in sections 3.6 and 3.10.2.

Terrestrial biota

Knowledge of the terrestrial biota in the area is used as input data to several different descriptive models, for example the terrestrial ecosystem model and the safety assessment's landscape model. In spite of extensive investigations, some gaps in the state of knowledge on the Simpevarp subarea exist today. How important are the wetlands for the carbon



Figure 3-5. Sandy/silty layer at a depth of 280–300 cm in one of the investigated wetlands in the area /Nilsson 2004/.

fluxes in the terrestrial systems and how has the succession of vegetation and soils taken place? Bioturbation is of great importance for redistribution, degradation and transport of organic matter in the soil. It can vary quite a bit between soils, depending on the quantity of bioturbating fauna, but no site-specific knowledge exists today.

Limnic and marine biota

The important functional groups in the ecosystems have been quantified, but knowledge of the importance of the watercourses for fish migration and which species are present is lacking. An investigation will therefore be conducted in 2006. The knowledge will be used to describe the environmental impact of repository construction and show the importance of fish for the transport of substances in the aquatic ecosystems.

Surface chemistry

The work with the safety assessment requires knowledge of how elements are distributed in the surface systems, both in deposits and in biota. The chemical composition of the surface systems are used to describe their components stoichiometrically and thereby flow paths for different elements (both macronutrients and trace elements).

3.2.6 Investigation programme

Deposits

Additional information will be collected on stratigraphic sequence and the soils in the various layers, as well as the character of peatlands and wetlands.

Sedimentation rate

Sedimentation rates in lakes and sea bays, as well as the growth of peat in the wetlands, will be quantified. This will be done by dating the different soil layers. The carbon-14 method will be used above all, but other absolute dating methods, for example caesium or lead dating, may also be used. Already sampled material will be used to a great extent for these datings.

Stratigraphy and chemical/physical properties in wetlands and agricultural land

In order to describe stratigraphy and the properties of the soils (for example porosity, sorption properties, chemical composition), soil samples will be taken from profiles, since previous reference samples are not sufficient. Agricultural land and wetlands will be selected, particularly in the valley of the Laxemarån River and in catchment areas 5, 6 and 9, see Figure 3-4 /Brunberg et al. 2004/.

Description of the historical evolution of the landscape

Analyses of pollen and microfossils in wetlands will be done. Results of pollen analyses provide a picture of the terrestrial postglacial evolution of the vegetation in the area. The results of such investigations will also be used to model the future evolution of the vegetation in the area. The sediment cores previously sampled in lakes, wetlands and sea bays may be used for such analyses. Samples from the discharge areas (wetlands, agricultural land and sea bays) identified in the hydrogeological modellings will be analyzed.

Climate and hydrology

The programme is described in sections 3.6 Hydrogeology and 3.10 Monitoring.

Surface chemistry

Analyses of material from deposits and terrestrial vegetation (including fine roots) will be analyzed during 2005–2006 with respect to their composition of elements, oxides, persistent organic pollutants and radionuclides, see compilation in Appendix A.

Analyses of elements and radionuclides in biota

As a complement to these analyses, the chemical composition of different functional groups in the ecosystems will be determined, both on already collected samples of e.g. fish and small rodents, but also on samples that will be collected during 2006. Samples from the functional groups will be determined based on their importance for material transport and represent different trophic levels in the different ecosystems and the importance of the groups as food for humans. The following samples are planned to represent the different ecosystems:

- Terrestrial biota: Rodents, deer, moose.
- Limnic biota: Benthic detritivores, fish.
- Marine biota: Macrophytes, benthic detritivores, benthic filter feeders, fish.

Other surface water chemistry investigations are described in section 3.10.3.

Terrestrial biota

Description of large-scale succession patterns

A succession of vegetation and soils takes place over long periods of time, in conjunction with e.g. land uplift. In order to be able to describe this succession, studies will be conducted along straight lines starting at the coast and working inland. Changes in the frequency and extent of e.g. types of forest (pine, spruce, broad-leaved, mixed) and wetland (peat-forming, minerogenic) will be studied with the aid of maps and a number of field visits during the spring and summer of 2006.

Verification of vegetation map

The vegetation map of the Simpevarp subarea plays a central role today in the description of many properties within the regional model area, for example the soil map, carbon concentrations in the soil, tree species distribution, wetland types, etc. The ability of the vegetation map to describe these properties correctly therefore needs to be verified. This is done by studying – systematically or randomly – selected sites, which are distributed among a number of classes in the vegetation map. Then field visits are made where a number of pre-selected properties are described. See /Alling et al. 2004/ for a more detailed method description. The preliminary choice of vegetation transects is shown in Figure 3-6.

Respiration and production measurements on wetlands

The CO₂ flux from the soil to the atmosphere provides a measure of production in the field layer and the total autotrophic and heterotrophic respiration in and below the ground. Replicated measurements with the aid of an infrared gas monitor (EGM-4) and a closed chamber will be performed on two to four open wetlands plus an alder fen (a mire and the forested wetland from /Löfgren 2005/). Eight measurements are made on permanent plots at each locality and on each measuring occasion (see Figure 3-6, vegetation survey on wetland). The measurements are expected to get started around the turn of the year and continue for one year with a total of 12–14 measurement occasions. For a more detailed description of the methodology, see /Tagesson 2005/.

Quantification and description of bioturbation for a number of vegetation types

The bioturbating fauna is mainly associated with more or less well-drained vegetation types where the groundwater table is not at the level of the ground surface at any time during the year. Quantification of the bioturbating fauna will therefore be done in spruce forest, deciduous forest, pine forest, grassland and arable land, preferably on the same localities that were used in /Löfgren 2005/. The study will be done during the summer vacation of 2006. Planned localities are shown in Figure 3-6.

Limnic and marine biota

Fish sampling in stream

Fish sampling will be carried out during the summer of 2006 at three places in the Laxemarån River and two places in the Ekerumsbäcken Stream. The electrical fish sampling method that will be used is described in /Swedish Environmental Protection Agency 2005/. The investigation may be supplemented with another fish sampling method to quantify large spring migrations of fish in the Laxemarån.

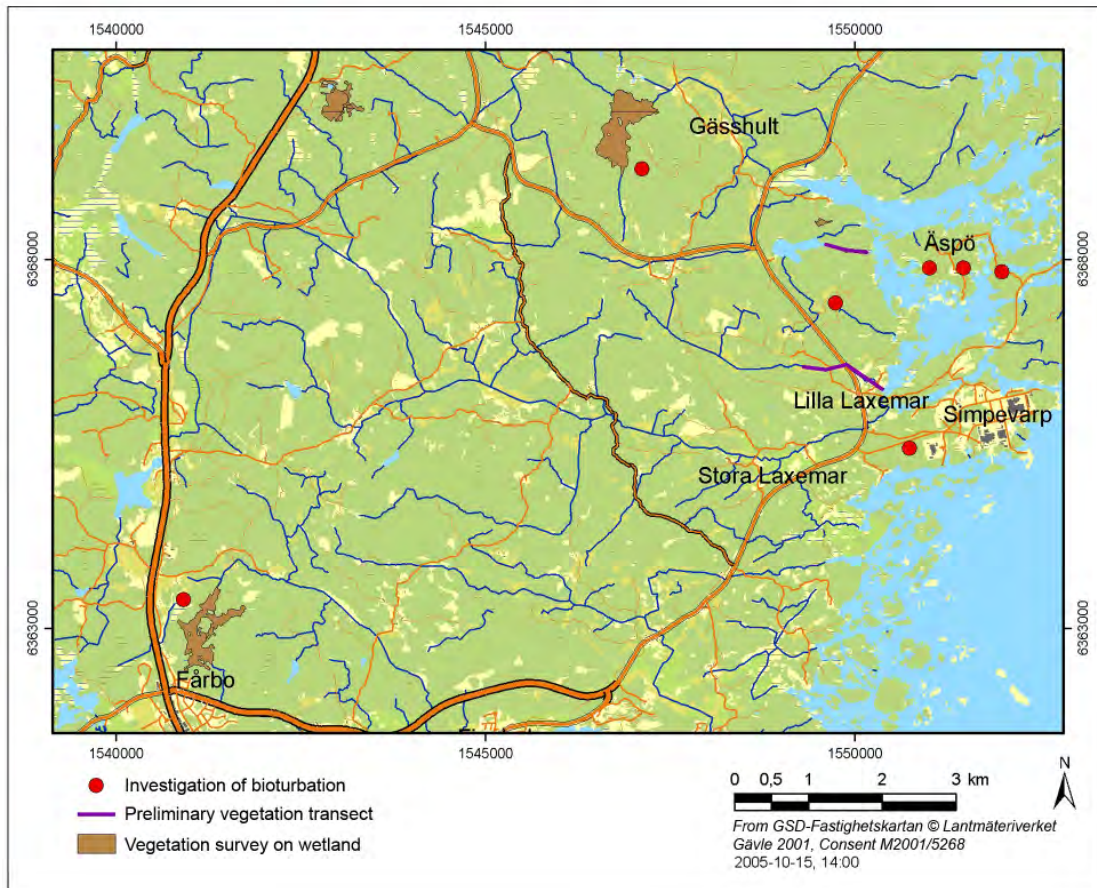


Figure 3-6. Planned localities for investigation of bioturbation and vegetation survey on wetlands plus preliminary vegetation transects.

3.3 Geology

3.3.1 Purpose and goal

The purpose of the geological investigations during the initial phase of the site investigation in Oskarshamn has been firstly to achieve a conceptual understanding on a regional scale of both the crystalline bedrock (rock types and deformation zones) and the Quaternary deposits in the investigation area, and secondly to obtain a reliable body of data for a focusing of the investigations. The work has been pursued along two main lines: 1) detailed investigation of the extent of the rocks and soil layers on the surface, and 2) characterization of rock volumes down to a depth of about 1,000 m by means of cored and percussion boreholes. Eight strategically located cored boreholes (telescopic boreholes) to a depth of about 1,000 m and 34 percussion boreholes to a depth of about 200 m have been drilled in the Laxemar subarea (including those previously drilled within the Äspö HRL's preliminary investigation programme) to investigate the properties of the rock volume within the candidate area and document the occurrence of deformation zones. Brittle deformation zones of various size are a key issue for the site description, since they can conduct groundwater and be of crucial importance for the configuration of a possible final repository on the site.

The Quaternary deposits constitute a central part of the geosphere-biosphere interface. A large portion of the superficial groundwater is transported through the Quaternary deposits, and knowledge of the three-dimensional extent of the different types of deposits is therefore essential for the surface hydrology modelling. The extent and properties of the Quaternary deposits (known as the regolith) are also of importance for the radionuclide retention time.

All geological data collected so far have been, or are being, analyzed. Analyzed and processed data comprise the basis for the site-descriptive models Simpevarp 1.2 /SKB 2005b/ and Laxemar 1.2 /SKB 2006/. The site-descriptive geological model Laxemar 1.2 is finished and the report is under preparation /Wahlgren et al. 2006/. The geological site models constitute the basis for rock mechanical, thermal, hydrological, hydrogeological and hydrogeochemical modelling, as well as for modelling of the rock's transport properties. The geological site models thereby also comprise the basis for the assessment of long-term safety and for the layout of the final repository's underground facilities.

3.3.2 Important results from completed investigations

Bedrock geology

A bedrock map of the Laxemar subarea with environs was compiled in the autumn of 2004, see Figure 2-2 in section 2.2. The map has been compiled from a large number of field observations /Nilsson et al. 2004/ as well as complementary analysis data from samples collected mainly during the field activities /Wahlgren et al. 2005/. In compiling this map, interpretation of geophysical data from airborne surveys has been integrated with bedrock geological field data and analysis data. The bedrock map of the Laxemar subarea has been combined with the equivalent map for the Simpevarp subarea /Wahlgren et al. 2004/, resulting in an integrated bedrock map of the Simpevarp and Laxemar subareas.

The data describing the properties of the various rock types in the Laxemar subarea derive primarily from mineralogical, geochemical, petrophysical and geochronological analyses /Mattsson et al. 2004c, Wahlgren et al. 2004c, 2005/. The Laxemar subarea is dominated by the porphyritic Ävrö granite, which exhibits a variation in composition between primarily granite and quartz monzodiorite. Available analyses indicate that the Ävrö granite in the central part of Laxemar is dominated by granitic to granodioritic variants, while the peripheral parts are dominated by Ävrö granite of quartz monzodioritic composition.

The southern and southwestern part of the subarea is dominated by quartz monzodiorite. Diorite to gabbro occurs as inclusions/enclaves and small bodies, particularly along the contact between the Ävrö granite and the quartz monzodiorite in the southern part of the Laxemar subarea.

Dykes of fine- to medium-grained granite and pegmatite comprise the dominant subordinate rock types. Both the granitic and the pegmatitic dykes exhibit a dominant northeasterly strike, but the dip varies considerably.

The bedrock in the Laxemar subarea and its immediate environs is structurally well-preserved. However, a normally weak foliation with an east-westerly to northwesterly strike and a varying dip occurs in places.

In conjunction with the bedrock mapping within the Simpevarp subarea, samples were taken for dating (U-Pb-zircon and -titanite dating). The age of the Ävrö granite was found to be $1,800 \pm 4$ million years and the quartz monzodiorite $1,802 \pm 4$ million years. The results confirm previously obtained dating results from the area /Wikman and Kornfält 1995/.

A high frequency of mesoscopic, low-grade ductile shear zones with a northeasterly strike and a subvertical to vertical dip occurs between the Laxemar and Simpevarp subareas. These shear zones define two branches of the Äspö shear zone, which have also been modelled as two separate rock domains in the geological model Laxemar 1.2, as shown in Figure 2-1. Scattered shear zones of similar character are also found within the rest of the Laxemar subarea, although to a lesser extent.

In an integrated effort within the discipline of geophysics, a two-dimensional model of lineaments /Triumpf 2004/ in the investigation area was created by utilizing airborne geophysical, topographical and bathymetric data, as well as the results of older seismic refraction surveys, see Figure 3-7. An alternative identification of lineaments, based on the same body of data, was also done by the Geological Survey of Finland (GTK) and resulted in roughly the same interpretation results. Together with ground geophysical surveys and borehole investigations, the lineament map comprises an important basis for determining and modeling the deformation zones in the area, a selection of which is presented in Figure 2-15.

During the spring of 2005, high-resolution aerial photography and detailed laser scanning were performed for the purpose of creating a detailed digital elevation model on a scale suitable for identifying local minor deformation zones, see Figure 3-8. Furthermore, a programme of detailed ground geophysical surveys was carried out over approximately 2 km² of the Laxemar subarea, see section 3.4.2. A preliminary co-interpretation of data from these two surveys on selected control squares and field checks indicated that these local minor deformation zones exhibited a uniform pattern (frequency and orientation) over the entire subarea. However, further knowledge of these structures is needed since they control the water-conducting pattern of the rock mass to a great extent. Further efforts will be concentrated on the focused area, i.e. the southern and western part of the Laxemar subarea.

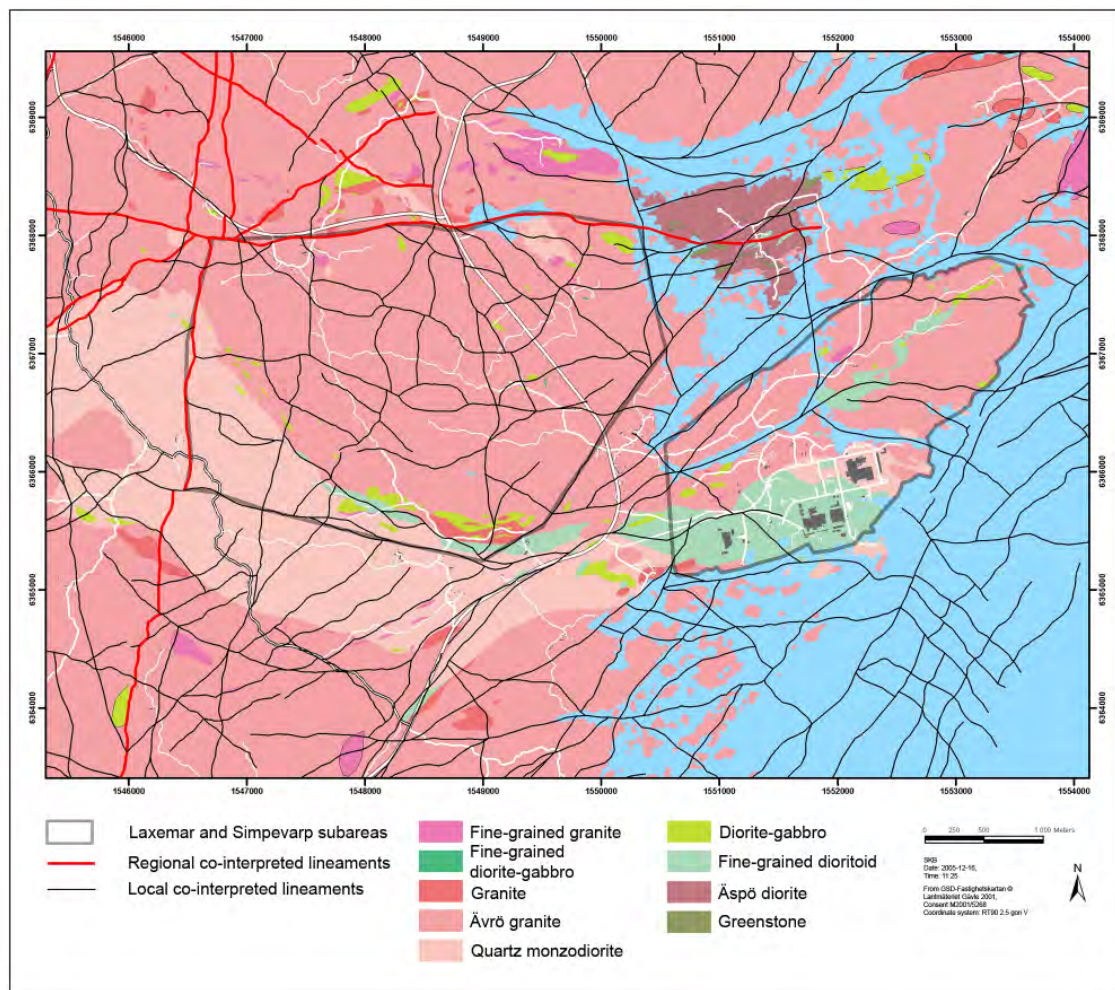


Figure 3-7. Lineament map of the investigation area in Oskarshamn.

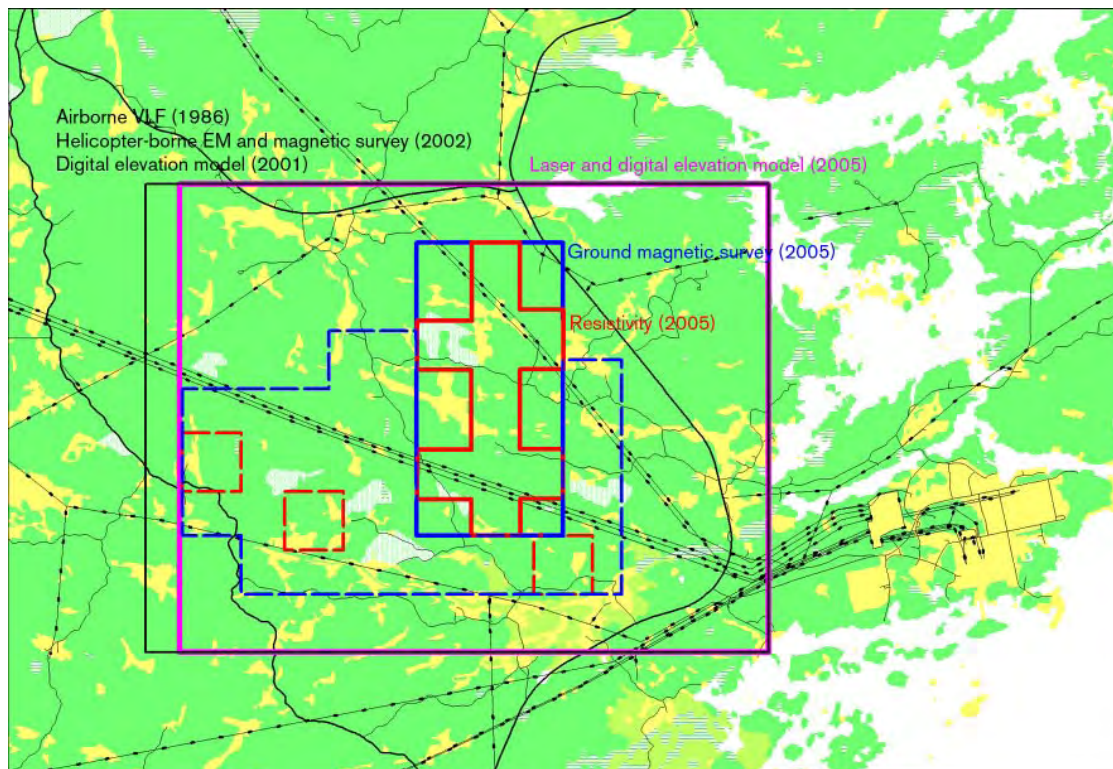


Figure 3-8. Area investigated during the spring of 2005 by high-resolution aerial photography and detailed laser scanning plus detailed ground geophysics in order to identify local minor deformation zones. New surveys are planned in the spring of 2006. The broken blue line shows new magnetic measurements while the broken red line shows new resistivity measurements.

Detailed fracture mapping has been carried out at seven locations, of which three in the Laxemar subarea (two of which are drilling sites) and four in the Simpevarp subarea (one of which is a drilling site). The locations are regionally scattered and represent the three dominant rock types in the investigation area. Furthermore, scan line mapping of fractures has been carried out at 24 locations in the Laxemar subarea and at 16 locations in the Simpevarp subarea. All cored boreholes and accompanying drill cores and percussion boreholes have been mapped in detail with respect to rock types, alterations and fractures. The results of the fracture mapping in the boreholes, together with fracture data from the surface, are being used to construct a discrete fracture network model (DFN model) of the entire rock volume /Hermansson et al. 2005/.

The DFN model describes the length distribution, orientation and intensity of the fractures in three dimensions and comprises a basis for hydrogeological models of the hydraulic conductivity of the rock mass. Knowledge of length distribution and intensity is particularly critical for a good understanding and can be reinforced by detailed studies between outcrops and nearby inclined boreholes.

Geological single-hole interpretation has been performed of each individual cored borehole and percussion borehole /e.g. Hultgren et al. 2004/, based on data from core mapping /e.g. Ehrenborg and Stejskal 2004a/, geophysical borehole logging /e.g. Nielsen and Ringgaard 2004/, including BIPS (borehole video) and radar logging /e.g. Gustafsson and Gustafsson 2004/. The purpose of single-hole interpretation is to determine the vertical position of main lithological units and possible deformation zones by co-interpretation of existing measurement data, see Figure 3-9. Single-hole interpretations comprise a basis for the three-dimensional modelling of rock domains and deformation zones in the investigation area.

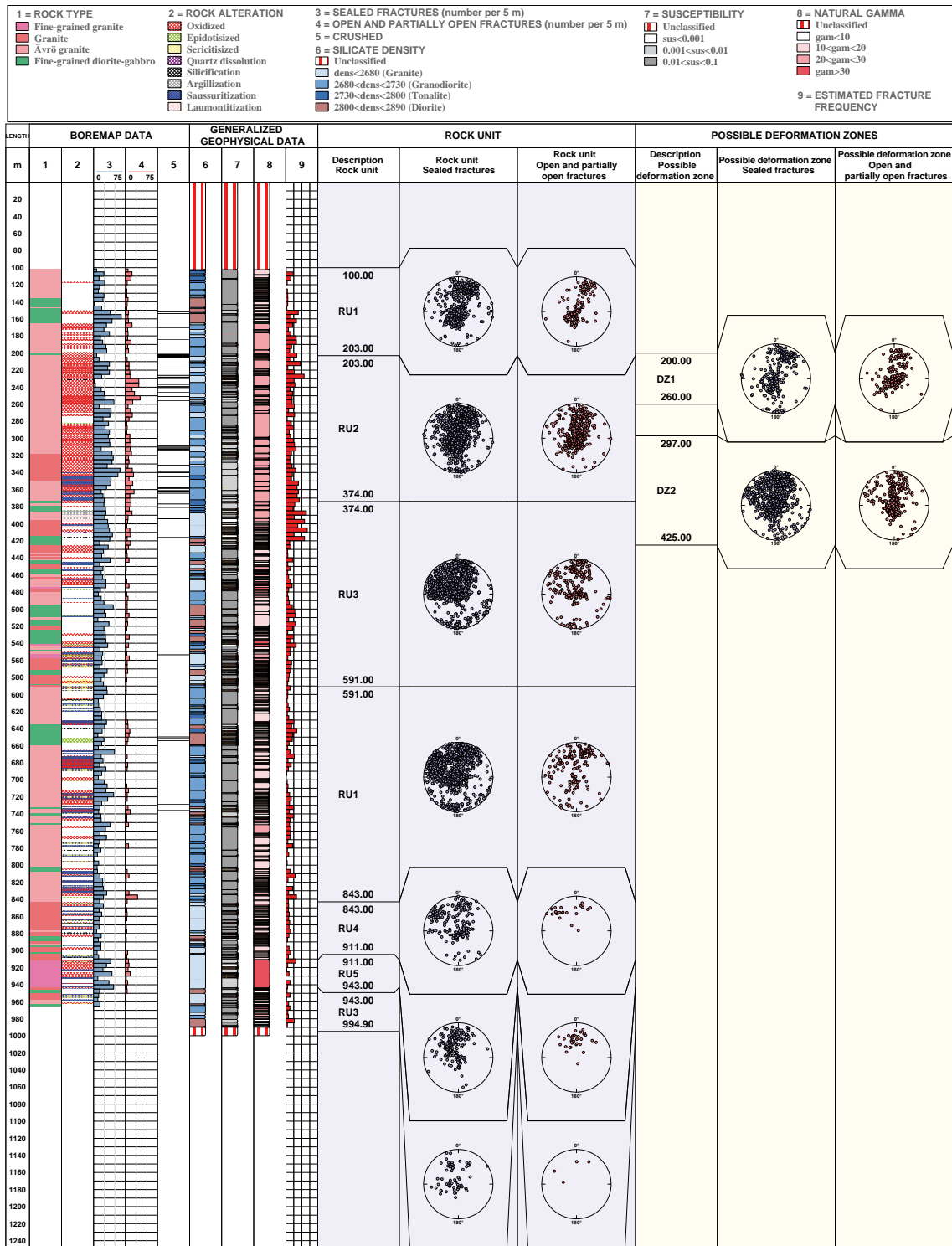


Figure 3-9. Single-hole interpretation of borehole KLX06.

Drilling and analyses of associated borehole investigations have verified that the character of the bedrock at a depth of 1,000 m is equivalent to what we see on the surface. They have also verified some of the interpreted deformation zones, for example the Mederhult Zone (EW002). Borehole KLX06 intersects the aforementioned zone at a depth of 300–400 m, which gives the zone a dip of about 65° towards the south. Several percussion boreholes have been drilled through the east-west deformation zone (EW007), which intersects the central part of Laxemar, and through the southern boundary zone (EW042) and through some of the north-south deformation zones. The state of knowledge concerning the different deformation zones was presented in section 2.3.3, under requirement 3.

Quaternary geology

The Quaternary geological investigations have been focused on surveying the extent of the deposits on land and in lakes. The mapping has resulted in a Quaternary geology map that covers the Simpevarp and Laxemar subareas /Rudmark et al. 2005/, see Figure 2-3 in Chapter 2. The smallest area that has been mapped is only 10×10 m, so the map gives a detailed picture of the spatial distribution of different Quaternary deposits. Sandy till is the most common Quaternary deposit in the area, covering about 45% of the surface. A slightly less detailed survey was made in parts of the regional model area. The smallest marked area in this area is about 1,500 m². The methodology and Quaternary deposit classification are the same for both areas.

The results are based on direct observations in the ground surface and in cuts as well as in boreholes and trenches. More than 300 stratigraphic sequences have been investigated to depths of two to three metres using simple hand augers. Thicker soil layer sequences have been studied and documented by machine excavation on some 15 or so sites. In conjunction with mechanical soil drilling, soil depths down to about 12 m have been encountered in joint valleys. In pits and trenches, samples have been taken and analyzed with respect to particle size and lime content, among other things.

The Quaternary deposit mapping shows that the overburden in the area is thin, so that the bed rock is exposed in many places. There are clear and distinct glacial striations on many of these exposed rock surfaces. They occur mainly in the archipelago, often on well-formed roche moutonnées. The striations show that the most recent ice sheet moved from the Baltic Sea Depression in southeast towards northwest during the deglaciation phase.

At some places, glacial clay occurs with thicknesses of up to about three metres. This fine-grained material was deposited, particularly in marked valleys, during the withdrawal phase of the continental ice sheet. The glacial clay is often overlain by younger fine-grained sediments or peat.

The investigation area is rather flat and undulating. In narrow valleys there are generally gyttja-bearing sediments, which are utilized as agricultural land. The sediments were deposited in sea bays or shallow lakes when the landscape slowly rose up out of the sea. The sediments in the higher-lying areas are thus older than those at lower levels and closer to the present-day coast. The ongoing deposition of gyttja can be studied in today's shallow sea bays with luxuriant reed growth.

Completed marine geological investigations (see section 3.4.2) have resulted in a map showing the extent of the Quaternary deposits on seabeds /Elhammer and Sandkvist 2005, Ingvarson et al. 2004/, see Figure 3-10.

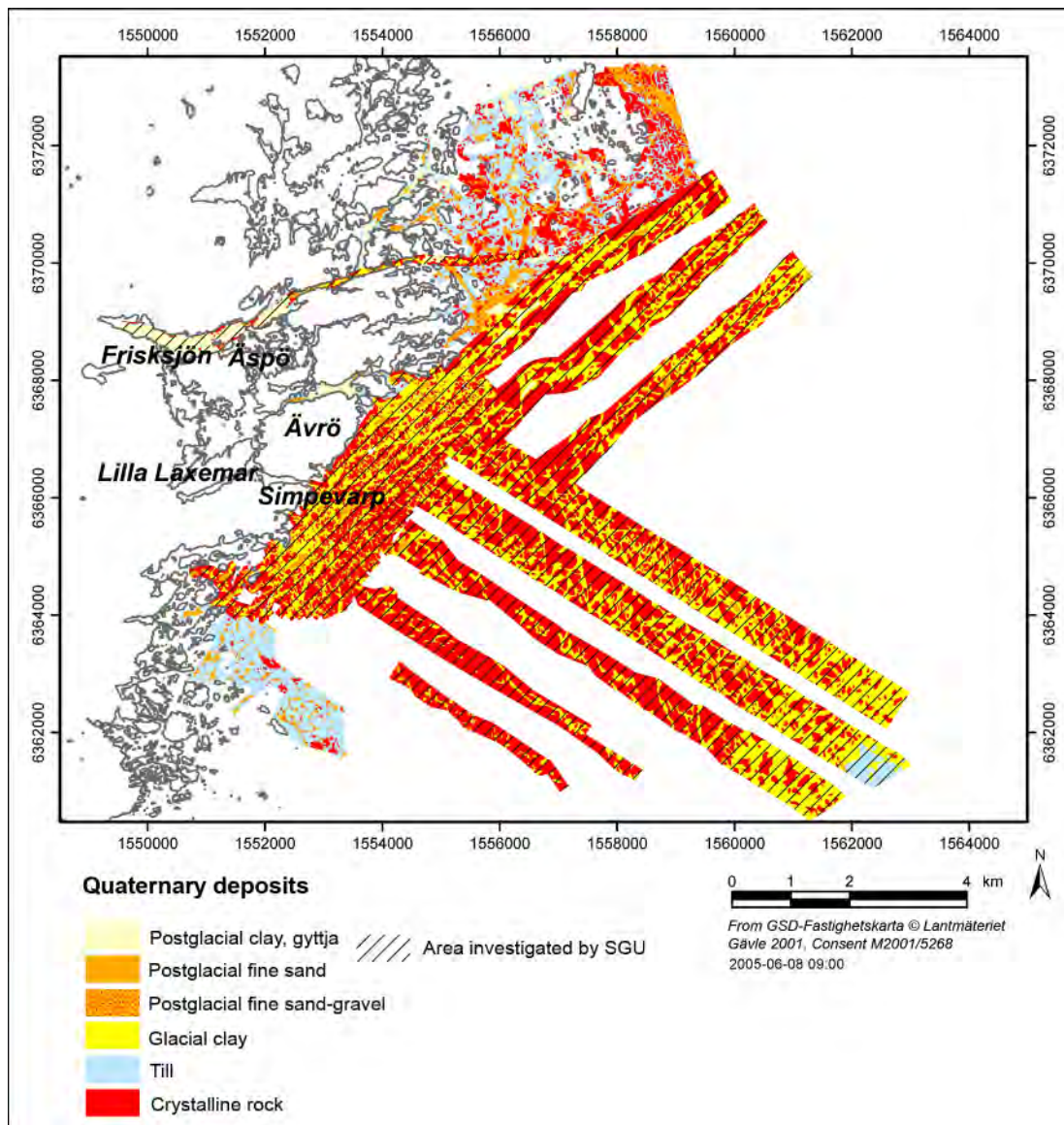


Figure 3-10. Marine geology outside Simpevarp and Ävrö.

Late- to postglacial movements

Investigations of indications of possible postglacial tectonics have been conducted for two field seasons and are planned to be concluded in 2005.

In the initial interpretation of aerial photographs, a number of prominent and relatively persistent escarpments were noted in the mainland part of the investigation area, see Figure 3-11. These scarps could indicate recent fault movements. The majority of these scarps were checked in the field in 2004 and found to be more or less heavily scoured by the ice sheet and thereby older than the most recent deglaciation.



Figure 3-11. Investigation area for different steps of the neotectonic study.

Stratigraphic investigations in machine-dug trenches with an aggregate length of about 170 m were carried out in 2004 at three localities along the Fårboåsen esker west of Simpevarp /Lagerbäck et al. 2004/. Deposits consisting of loosely packed sand and coarse silt were encountered in nearly all the trenches, and in some of them a clayey bed covered the sandy-silty deposits. When shaken by strong earthquakes in a water-saturated state, such deposits are highly prone to liquefaction, leading to deformations of the primary sediment structures. No such deformations have been encountered, but the fact that the investigated sites are situated 30–100 m above sea level means that they must have been raised above the ancient sea fairly soon after the deposition of sediments. Consequently, the sediments were waterlogged and susceptible to liquefaction only during a limited period of time.

Stratigraphic investigations of soil layer sequences will be conducted at about 12 locations between Mönsterås and Västervik in the autumn of 2005.

3.3.3 Important questions remaining to be answered

Since the geological description comprises the basis for the site descriptions in other disciplines as well, it is important that the knowledge level be progressively raised and uncertainties reduced. The remaining uncertainties in the site-descriptive model are summarized in section 2.3.4. The remaining questions can be briefly summarized in the following points:

- Characterize the spatial distribution of the rock masses between the deformation zones within the focused area in terms of rock type composition, occurrence and distribution of subordinate rock types and occurrence of local minor deformation zones.
- Kinematics, i.e. the pattern of movement in ductile and brittle deformation zones.
- Geological characterization and geometry of deformation zones.
- Fracture frequency, geometric properties and controlling geological factors for DFN modelling of the rock mass between the deformation zones.
- Properties of Quaternary deposits.

3.3.4 Investigation programme

Bedrock geology

The geological investigation programme presented here is based on the programme overview provided in section 3.1.

In the case of the rock domain model, the primary task is to improve the characterization of the rock domains in terms of mineralogical and chemical composition with the aid of more chemical and modal analyses of samples from drill cores, particularly from repository depth. An improved understanding of the occurrence and spatial distribution of subordinate rock types in the rock domains is also important. The Ävrö granite, which completely dominates rock domain A01 (see Figure 2-16), exhibits great variation in composition, which means that the properties of rock domain A01 are poorly defined. One goal during the complete site investigation is, if possible, to divide the A01 domain, which is dominated by Ävrö granite, into a more quartz-rich (granitic to granodioritic) and a less quartz-rich (quartz-monzodioritic) domain within the Laxemar subarea. This requires samples from cored boreholes and will, if the domain subdivision is possible, lead to a better characterization of the rock mass. Since thermal conductivity is coupled to the composition of the rock mass, a domain subdivision where the properties of the rock exhibit as small a range of variation as possible is of great importance for design, since the thermal conductivity of the rock affects the size of the final repository and how available rock volumes can be utilized.

Improved knowledge of the fraction of subordinate rock types and their spatial distribution in the rock domains is also important for the thermal modelling and the design of the final repository. This requires more information from boreholes as a basis for a statistical analysis and forecasts of the occurrence and distribution of subordinate rock types within the domains.

Improved knowledge of the degree of alteration of the rock mass in the different rock domains between the deformation zones is an important factor for the transport properties of the rock mass as well as for the thermal modelling. This also requires information from future boreholes for subsequent investigation and processing.

The main purpose of the planned drilling programme described in section 3.1 is to geologically define and characterize the rock volume within the focused area and establish and characterize local major and minor deformation zones. Planning of the boreholes is primarily done based on the three-dimensional model of rock types and deformation zones, but also with reference to other properties for which information has been compiled and modelled three-dimensionally. An example of such borehole planning presented on a relevant deformation zone model is shown in Figure 3-12. Geological borehole investigations,

Interpreted lineaments need to be investigated with respect to how representative they are as indicators of deformation zones. A lineament study is therefore planned during the autumn of 2005, where the plan is to dig pits across a number of representative and distinct interpreted deformation zones for detailed study of the rock surface. The new detailed lineament interpretation also provides a reference for field checks of minor lineaments over outcrop areas to provide better knowledge of local minor deformation zones. It is also possible to cross-check seismic refraction profiles and minor lineaments via field checks.

A geochronological investigation employing the $^{40}\text{Ar}/^{39}\text{Ar}$ and (U-Th)/He methods is being conducted to achieve a more accurate dating of the geological evolution of the bedrock under both ductile and brittle conditions. This will provide an important basis for determining when movements took place and the relative direction of movement along the deformation zones between different bedrock blocks.

Discrete fracture network (DFN) model

Another detailed fracture mapping will be carried out, this time at drilling site KLX11. Together with information from already mapped outcrops, existing and new cored boreholes and short DFN boreholes, the detailed mapping will serve as a basis for the discrete fracture network (DFN) model.

Regular fracture mapping in increasingly deep cored boreholes provides the large quantity of data for DFN modelling. The short DFN boreholes will be drilled on drilling site KLX09, which is dominated by Ävrö granite (rock domain A01) and on drilling site KLX11, which is dominated by quartz monzodiorite (rock domain D01). The boreholes will be about 100 m long and strategically set out on the drilling site to provide optimal information on fracture geometries. Detailed fracture mapping has been, or will be, done on both sites, making it possible to couple fracture information from boreholes with surface-mapped data.

The detailed lineament analysis provides further information on major fractures and local minor deformation zones which, together with DFN boreholes and detailed outcrop mapping, permits the geometric properties of the fracture population to be estimated on a scale of 30 to 500 m.

Pattern of local minor deformation zones in the rock mass

An investigation of the importance of local minor deformation zones for the final repository and the design work will start in the autumn of 2005. This programme will be carried out to obtain a better understanding of the properties of local minor deformation zones in the Laxemar subarea. Regional and local major deformation zones can be expected to influence the placement of deposition areas, while local minor deformation zones only influence canister placement.

The purposes of the investigation programme are:

- to try to locate and identify local minor deformation zones by comparative studies of geophysics and photographs,
- to provide a basis for assessment of the frequency and orientation of local minor deformation zones,
- to characterize different types of local minor deformation zones, particularly with respect to the water-conducting properties of the zones,
- to devise a methodology for identification of local minor deformation zones in boreholes by comparative studies of BIPS, borehole geophysics, radar, difference flow logs and core mapping,

- to study the occurrence and character of indicated subhorizontal deformation zones,
- to be able to carry out comparative studies of Äspö data regarding the occurrence and character of local minor deformation zones on rock surface, in boreholes and in tunnels.

The objective is to obtain greater knowledge and understanding for assessment of the area's hydraulic patterns, properties and the need for grouting by compiling the coupling of existing structures to lithology, geophysical properties, rock stresses, groundwater conditions and tectonics.

Quaternary deposits and typical profile surveys

By investigating the rock type and mineral content of the till, information is obtained on the properties of the Quaternary deposits (e.g. weathering tendency), and whether the composition of the till reflects the local bedrock. This can be done by visually determining the mineralogy in gravel, stones and boulders from different parts of the area. This is normally done in conjunction with other activities when the soil layers are stripped by digging.

Typical profile surveys are an integrated package of investigations that will improve understanding in several disciplines, mainly surface ecology, geology and hydrogeology. The main purpose of the investigations is to obtain greater knowledge of the soil layers. This includes Quaternary deposits, soil and the depth distribution and properties of these layers. The investigations are being conducted over a number of selected joint valleys and include both excavation of trenches and soil drilling.

If possible the bedrock and the deformation zones in the profiles where trenches are dug will also be studied.

3.4 Geophysics

3.4.1 Purpose and goal

Geophysics is not a separate discipline in the site-descriptive model, but an “auxiliary science”, primarily in support of bedrock and Quaternary geology. The purpose and goal of the geophysical investigations therefore coincide for the most part with those of geology. Secondly, geophysics is also of use for rock mechanics and thermal properties, hydrogeology, hydrogeochemistry, transport properties and to some extent surface systems for characterization of the soil layers. In the presentation of investigation methods prior to the site investigation /SKB 2001a/, different types of ground geophysical and borehole geophysical methods are described in terms of execution and potential. From the perspective of the site investigation, important purposes of the geophysical investigations are to:

- indicate the distribution of deformation zones (brittle and ductile; fracture zones and fractures) and the properties of the rock mass in between the zones,
- detect possible mineralizations (which can have a bearing on possible ore potential) within the investigation area,
- determine soil cover thickness,
- measure salinity distribution and the temperature of the bedrock in boreholes,
- measure the geometry of the boreholes (inclination, direction and diameter).

3.4.2 Important results from completed investigations

So far five large and important geophysical surveys have been carried out during the site investigation. The results have in different ways served as a basis for development of the site-descriptive model. The surveys are:

1. Airborne geophysical surveys of a regional area, covering a total of about 85 km², see Figure 3-13.
2. Seismic reflection surveys covering 9.9 profile kilometres in the Laxemar subarea and 3.7 km on Ävrö.
3. Marine geophysical (and geological) surveys off the Simpevarp Peninsula and Ävrö.
4. Seismic refraction surveys of lineaments in the sea off the Simpevarp Peninsula and Ävrö.
5. Detailed ground geophysical surveys with magnetometry and resistivity over a 2 km² area centrally located in the Laxemar subarea. The purpose of the surveys was to provide a basis for further focusing towards a smaller investigation area in Laxemar.

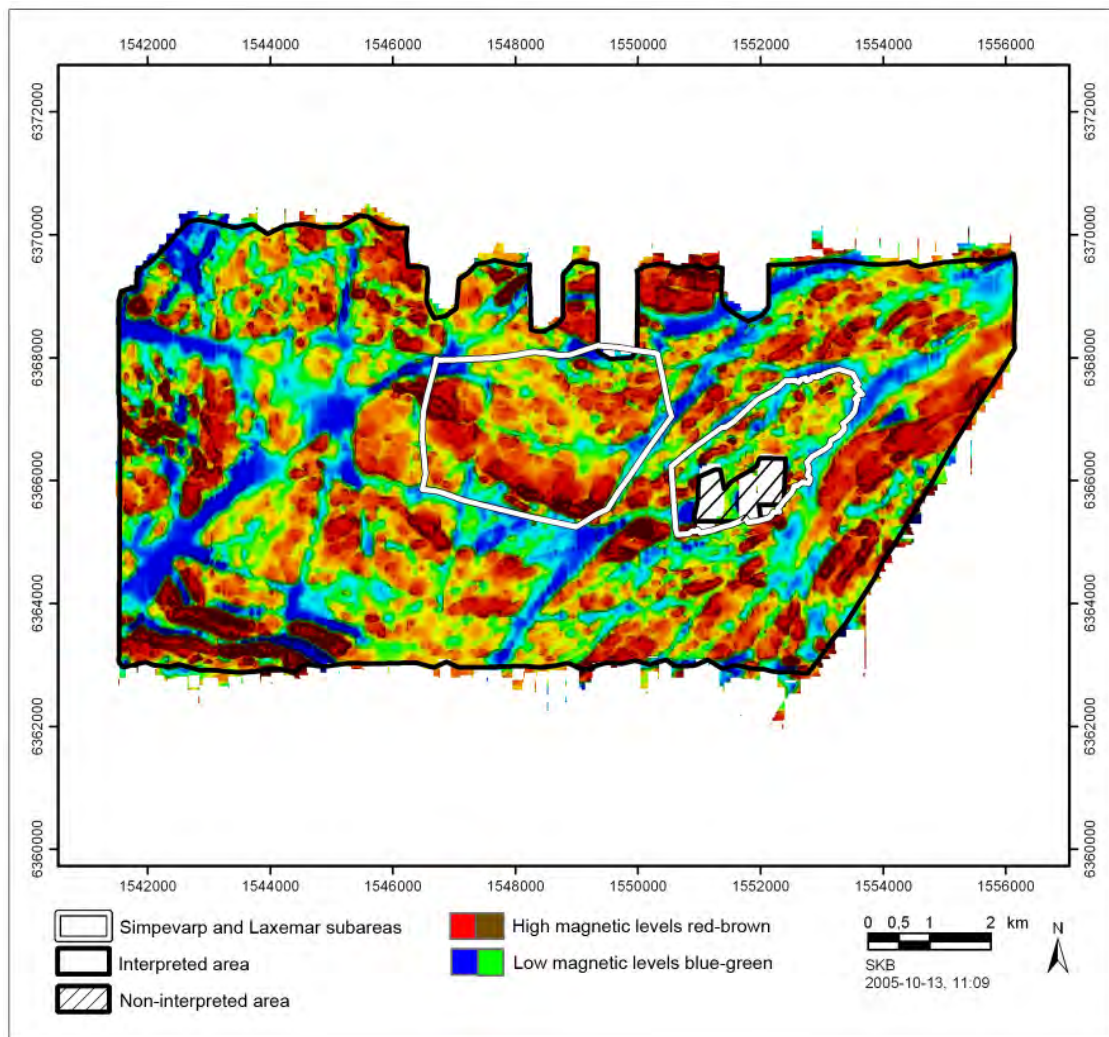


Figure 3-13. Magnetic anomaly map of the Oskarshamn area from helicopter-borne geophysical surveys carried out during 2002. Blue-green colours correspond to low magnetization, while red-brown colours correspond to high magnetization. Low magnetization generally indicates deformation zones (fracture zones and fractures).

The results of the airborne geophysical surveys /Triumpf et al. 2003/ and a rough line mapping comprises the basis for SKB's delimitation of the Laxemar subarea in March 2003. The results have also been important for lineament interpretation /Triumpf 2004a/ and for subsequent surveys and setting-out of cored and percussion boreholes. The focus has been on the centrally located interpreted deformation zone EW007 in the Laxemar subarea.

With the aid of the seismic reflection surveys, it has been possible to explore the bedrock down to a depth of about three km /Bergman et al. 2002, Juhlin et al. 2004a/. The results show that there are both steeply-dipping and gently-dipping reflectors in Laxemar, Figure 3-14, while there are steeply-dipping reflectors outside Ävrö. Reflectors can be caused by both fracture zones and contacts with mafic rocks (gabbro to diorite, etc). The reflectors on Ävrö are located northwest and southeast of Ävrö and dip in under the island /Juhlin et al. 2004a, Schmelzbach and Juhlin 2004/.

The marine geological and geophysical surveys have mainly provided information on seabed topography and rock surface topography, which has served as a basis for lineament interpretations and provided information on exposed bedrock and Quaternary deposits, see Figure 3-10.

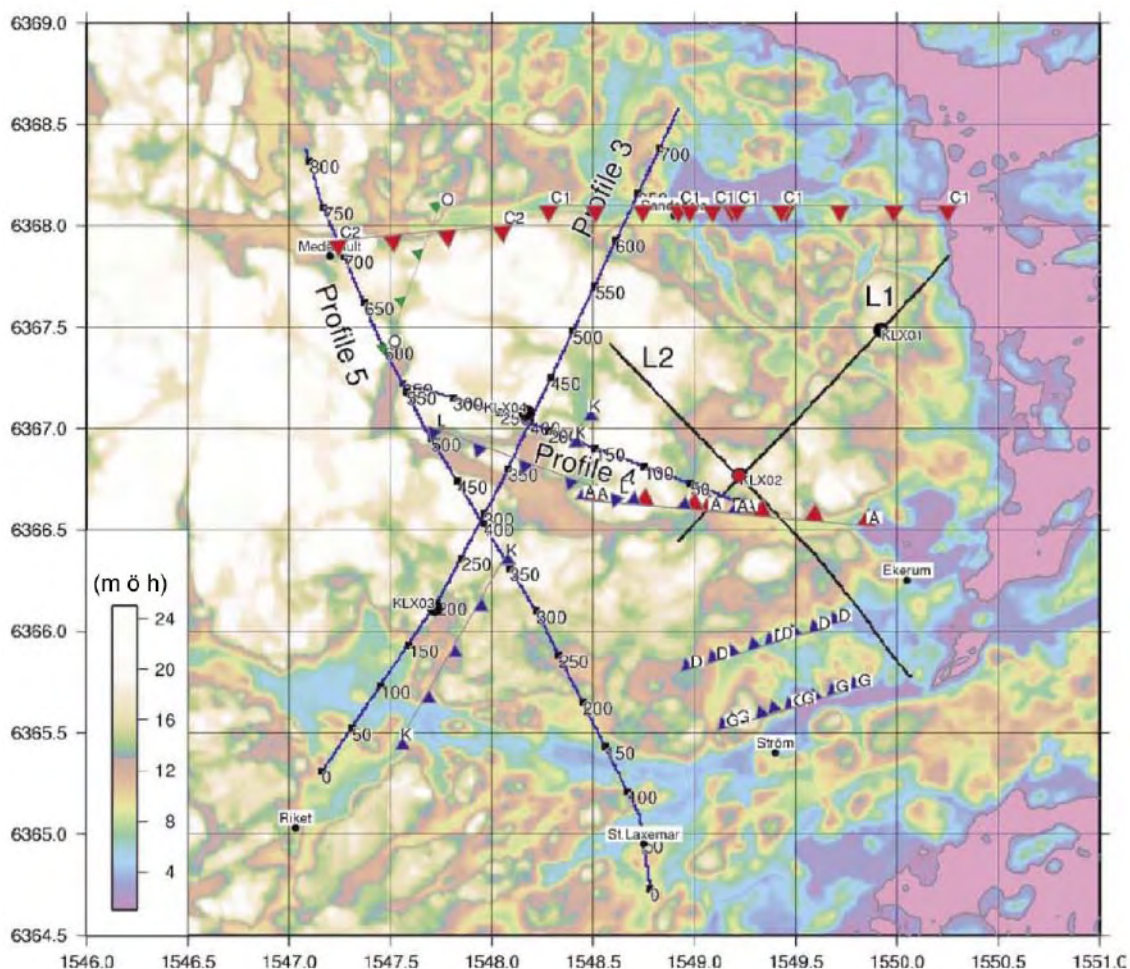


Figure 3-14. Results of seismic reflection surveys in the Laxemar subarea. The red reflector C dips 70° towards the south in under the Laxemar subarea and corresponds to the surface expression of the Mederhult Zone (EW002). The red reflector A dips towards the north and corresponds to the exit of the eastern part of EW007. A red reflector designates a certain interpretation (1), blue designates a probable interpretation (2) and green a possible interpretation (3) /Juhlin et al. 2004b/.

In order to investigate whether subsea lineaments near the coastline off the Simpevarp Peninsula and Ävrö constitute deformation zones, seismic refraction surveys were conducted in the sea in the late autumn of 2003, Figure 3-15. Small charges were detonated under water and the sound waves were recorded by geophones placed on the seabed /Lindqvist 2004a/. The sound waves are slowed down in, for example, a fracture zone in the rock, which can thereby be detected.

Petrophysical samplings and measurements have been performed in both the Simpevarp subarea and the Laxemar subarea in order to determine the physical properties of rock samples such as density, magnetic susceptibility and electric resistivity /Mattsson and Thunehed 2003, Mattsson et al. 2003, 2004c/. The results assist and constrain the interpretation of other geophysical measurements and are used as a basis for the geological description of the bedrock.

A large number of ground geophysical surveys have been conducted. Besides the aforementioned seismic refraction surveys done at sea, magnetometer and slingram surveys have been conducted to indicate the locations of fracture zones for setting-out of boreholes /Triumf 2003/. Magnetometer and CVES (continuous vertical electrical sounding) measurements have been performed in the form of profile groups in order to determine soil depth and deformation zones in the rock /Thunehed et al. 2004/. Figure 3-16 shows a slingram survey. Seismic refraction surveys have also been conducted along the aforementioned profile groups for determination of soil depth and location of fracture zones in rock with lower seismic velocity /Lindqvist 2004b, 2005/ or as individual profiles to determine soil depth /Lindqvist 2004c/.



Figure 3-15. Recording instrument for seismic refraction survey conducted off the Simpevarp Peninsula and Ävrö in the late autumn of 2003 /Lindqvist 2004a/.



Figure 3-16. Two coils, a transmitter and a receiver, are used for electromagnetic methods such as slingram. An electromagnetic field is transmitted from the transmitter. If there is a fracture zone in the rock that conducts electric current, for example if it contains clay minerals or water, a new field is created due to electric currents generated by the transmitter field. The new field can then be detected in the receiver as a change /Triumpf 2003/.

A gravimetric profile and scattered gravimetric stations have been measured over the whole Laxemar subarea. The purpose of the gravimetric measurements was to determine whether the quartz monzodiorite occurring in the southern part of the Laxemar subarea, and a belt with a frequent occurrences of diorite and gabbro near the quartz monzodiorite, dips towards the north or not. The gravimetric measurements support the interpretation that the quartz monzodiorite contact dips towards the north, probably caused primarily by the presence of gabbro and diorite bodies in the Ävrö granite /Triumpf 2004b/.

Detailed ground geophysical surveys with magnetometry and resistivity have been conducted over a 2 km² area centrally located in the Laxemar subarea. The surveys were conducted together with the detailed aerial photography and laser scanning described in section 3.3.2 to identify the pattern of local minor deformation zones (Figure 3-8). The purpose of the surveys was to provide a basis for continued focusing towards a smaller area within the Laxemar subarea. The results of the ground magnetic surveys are shown in Figure 3-17, where the ground magnetic survey is shown together with the results of the helicopter-borne magnetic surveys /Thunehed and Triumpf 2005/. The results of the geophysical ground surveys show considerably greater richness of detail. The properties of the blue to green-coloured anomalies, local minor deformation zones (long fractures), will be checked in the field in various ways, in some cases by means of excavation, drilling or geological mapping on a stripped or exposed rock surface.

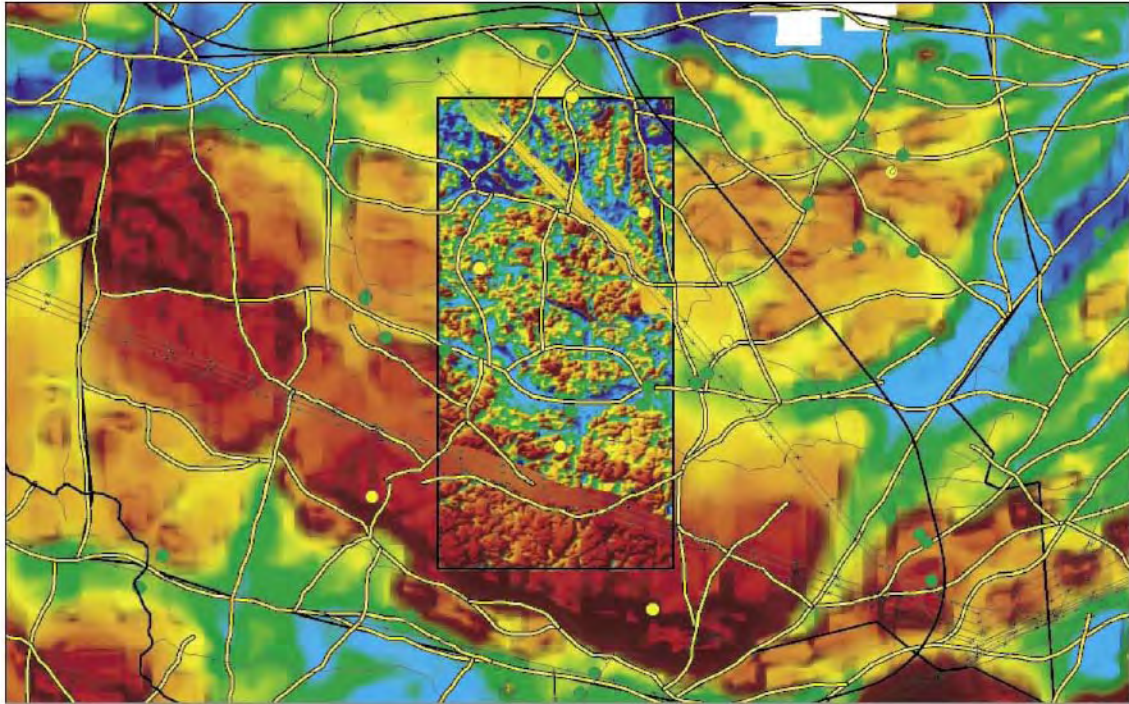


Figure 3-17. Results of the detailed ground magnetic surveys displayed together with the results of the helicopter-borne magnetic surveys /Thunehed and Triumph 2005/.

Traditional geophysical logging has been performed in the nine cored boreholes drilled thus far, KSH01–KSH03, KAV04, KLX03–KLX07, and in most of the percussion boreholes /see e.g. Nielsen et al. 2005ab, Nielsen and Ringgaard 2004/. Furthermore, BIPS logging (video photography of the borehole wall) and borehole radar with dipole antenna and directional antenna (the latter only in cored boreholes) has been performed for determination of the direction and location of fracture zones, fractures and other contact planes in the borehole /see Gustafsson and Gustafsson 2005abc/. Figure 3-18 shows a result from a BIPS logging where the borehole wall is shown as a drill core and a schematic illustration where the probe is being lowered into a borehole. The geophysical borehole logging data have been processed and interpreted and used as a basis for boremap mapping /see e.g. Mattsson 2005 and Mattsson and Keisu 2005/. The processed and interpreted data have further contributed information for geological single-hole interpretation of boreholes /see e.g. Hultgren et al. 2004, Mattsson et al. 2005ab/. Both BIPS and radar as well as the processed resistivity, density, susceptibility and natural gamma logs have proved valuable in connection with the geological single-hole interpretation.

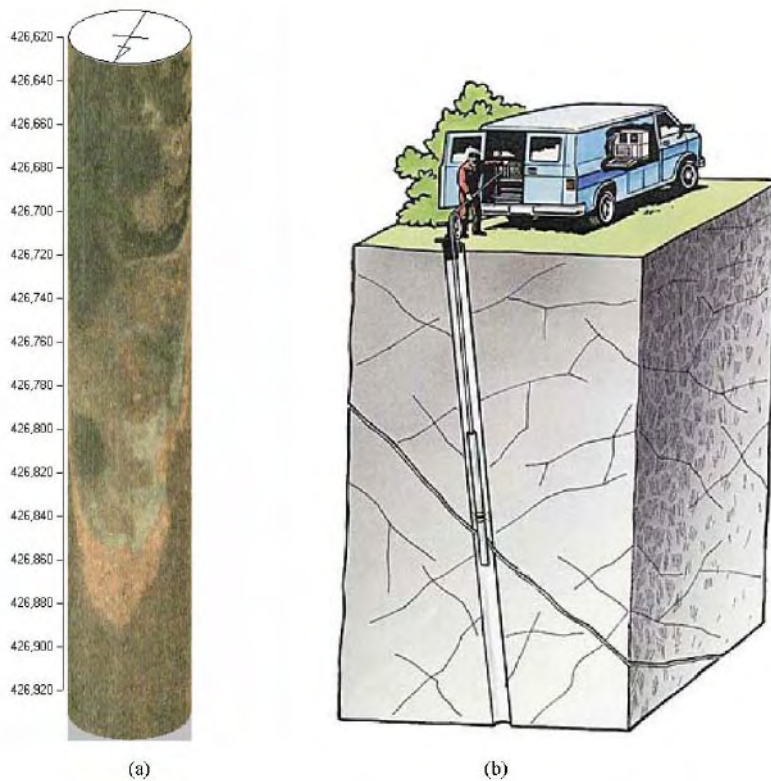


Figure 3-18. BIPS (Borehole Image Processing System) is a TV logging system used to videotape the borehole wall from inside the borehole. The BIPS image is then used for interpretation by comparison with information from the drill core where rock types and fracture-filling minerals can be studied in detail (a). The orientation of fractures or the angle at which fractures intersect the longitudinal direction of the borehole is calculated using information from the TV image. A schematic drawing showing the BIPS probe being lowered into a borehole is shown in (b).

3.4.3 Important questions remaining to be answered

Based on the programme overview in section 3.1, the geophysical investigations are expected to make important contributions to the following questions:

For geology

- Whether lineaments comprise deformation zones.
- Location and geometry of deformation zones (ductile and brittle).
- Determination of location and orientation of fractures.
- Three-dimensional vertical extent of rock bodies.
- Anisotropy of magnetic susceptibility in ductile deformation zones and their surroundings.
- Soil depth.

For rock mechanics

- Determination of the rock's propagation velocity (P-waves) in the borehole for comparison with measurements on the drill core. Any systematic differences may be information of interest for assessment of the microfracturing of the drill cores, which is in turn of importance for interpreting test results (porosity and strength) from core samples. P- and S-wave measurements from the borehole can also be used for empirical determination of the rock's in situ modulus of elasticity, shear modulus and Poisson's ratio, for comparison with the results of the methods usually used to determine these parameters, which are based on laboratory tests and drill core mapping.
- If the rock stresses are high in relation to the strength of the rock, they can give rise to ruptures in the borehole wall (breakouts), which means that data on the geometry of the borehole (variation in diameter and ovality) can be used as an indication of the stress state.

For thermal properties

- Determination of rock temperature and temperature gradient.
- Determination of rock density by density logging (corrected density) for calculation of spatial distribution of thermal conductivity in Ävrö granite.
- Determination of borehole geometry (direction and inclination).

For hydrogeology

- Location of water-conducting fractures (fracture zones).
- Borehole geometry (direction, inclination and diameter).
- Soil depth.
- Location of saline water at depth in the Laxemar subarea and in the regional environs to the west.

For hydrogeochemistry

- Location and water-conducting properties of deformation zones (fracture zones and fractures).
- Electrical conductivity of water and temperature of rock.
- Location of saline water at depth in the Laxemar subarea and in the regional environs to the west.

For transport properties

- Location and water-conducting properties of deformation zones (fracture zones and fractures).
- Electrical conductivity of bedrock for calculation of the rock's transport properties and formation factor.

For surface systems

- Soil depth (thickness and physical properties).

3.4.4 Investigation programme

Southern and western part of Laxemar subarea

The continued investigations will primarily focus on the southern and western part of the Laxemar subarea, and the following investigations are considered important in the discipline of geophysics, see also programme overview in section 3.1:

- Detailed ground geophysical surveys, magnetometry and resistivity with the CVES Lund method will be conducted within a 3.8 km² area within the Laxemar subarea, see Figure 3-19. Equivalent surveys have previously been conducted on an approximately 2 km² area. The detailed magnetic surveys are mainly being done to learn more about local minor deformation zones (both ductile and brittle) and the homogeneity of the bedrock and to obtain information on the degree of alteration of the bedrock, particularly close to both ductile and brittle deformation zones. Some of the measurement area will cover areas where quartz monzodiorite, diorite and gabbro occur. The resistivity measurements will be performed within three small detail plots (400×400 m) to learn more about the fracturing of the rock mass (local minor fracture zones and occurrence of fractures). The resistivity measurements supplement the magnetic measurements, primarily with regard to long fractures or fracture zones with increased electrical conductivity, i.e. they provide an indication of which fractures are water-conducting or contain clay minerals. The fracturing of the rock mass is of great importance for the hydraulic conductivity of the bedrock.

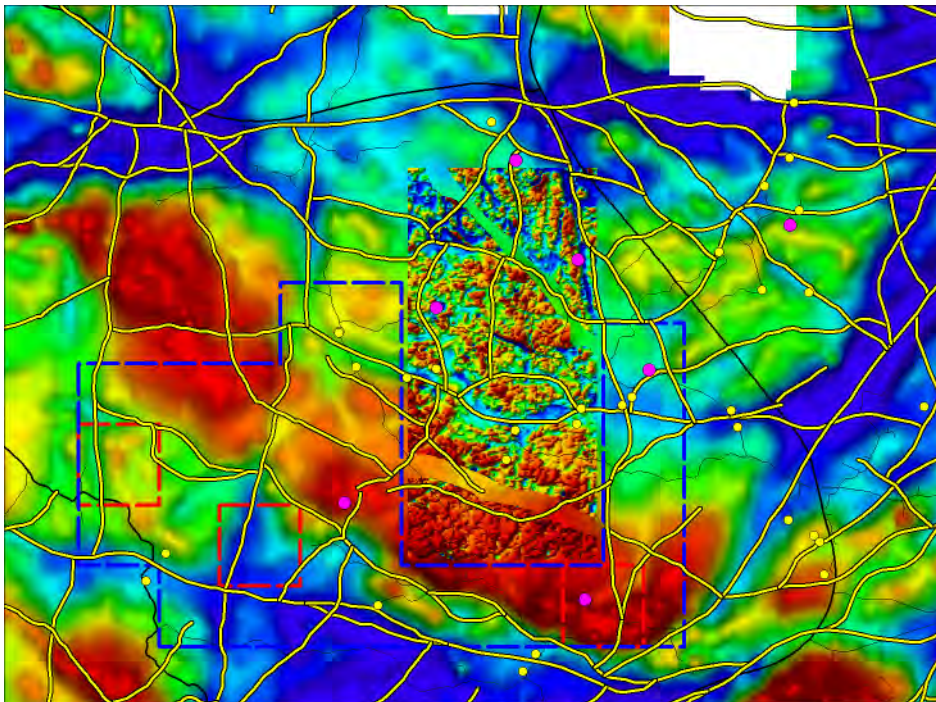


Figure 3-19. Detailed ground geophysical surveys will be conducted within a 3.8 km² area in the Laxemar subarea. The broken blue line shows new magnetic measurements (3.8 km²) while the broken red line shows new resistivity measurements (3 x 400×400 m).

- Around ten ground geophysical profiles or profile groups with magnetometer and resistivity will be placed in the Laxemar subarea over interpreted lineaments to determine the location of possible fracture zones prior to verification by drilling of medium-long cored boreholes or percussion boreholes. The location of the ground geophysical profiles will be based on interpretation of aerial photos and the results of helicopter-borne geophysical surveys. The ground geophysical profiles will be supplemented by seismic refraction. Each ground geophysical profile normally has a length of 500–1,000 m.
- BIPS (video photography of the borehole wall) and radar measurements will be performed in cored and percussion boreholes for the purpose of locating and providing information on rock types and structures. BIPS gives a 360° picture of the borehole wall which is folded out and serves as a basis for boremap mapping. Fractures with a width of 1 mm or more are detected. An orientation of fractures in three dimensions is obtained. Borehole radar provides information on the orientation of minor and major structures that intersect the borehole. Both methods are expected to be performed in all cored boreholes and percussion boreholes in the drilling programme, see section 3.1, Table 3-1.
- Geophysical borehole logging provides information on the geometry of the borehole (inclination, direction and diameter), rock types (density, magnetic susceptibility and natural gamma radiation), ductile and brittle deformation zones (fracture zones and fractures) (resistivity and sound propagation velocity), the salinity of the groundwater and the temperature of the rock. Interpretation of borehole geophysics provides support for Boremap mapping and geological single-hole interpretation. Geophysical borehole logging is expected to be conducted in all cored boreholes and in about two-thirds of the percussion boreholes.

Laxemar subarea with regional environs

The following investigations in the discipline of geophysics are planned for the Laxemar subarea, even outside the focused area, and its regional environs:

- A measurement programme with TEM (transient electromagnetic sounding) will be carried out to obtain better information on the location of saline groundwater at depth in the Laxemar subarea and in the regional area, up to just west of motorway E22. In measurements with TEM, a transmitter unit is laid out in the terrain in the form of an up to 3,000 m long electric cable in a polygonal loop, see Figure 3-20. A receiver coil is moved to five different measurement points inside and outside the loop. Measurement is performed by generating an electromagnetic pulse in the transmitter loop.
- A measurement programme with VES (vertical electrical sounding) will be carried out to obtain better information on the electrical conductivity and other properties (e.g. thickness) of soil layers and thereby get an estimate of the depth to the bedrock. VES will be conducted on some 30-odd sites.
- Measurement of magnetic susceptibility (AMS = anisotropy of magnetic susceptibility) will be carried out to obtain better information regarding at what distance perpendicular from a major ductile deformation zone (Äspö shear zone) the rock is affected by deformation. The orientation of the magnetic anisotropy and the change in magnetic properties in different directions will be studied by sampling in the field and measurement in laboratory. The measurements of magnetic anisotropy will be performed by collecting some 45 or so oriented rock samples along one or more perpendicular profiles over the Äspö shear zone. The equivalent rock samples will be examined by a geologist, including studies of thin sections.

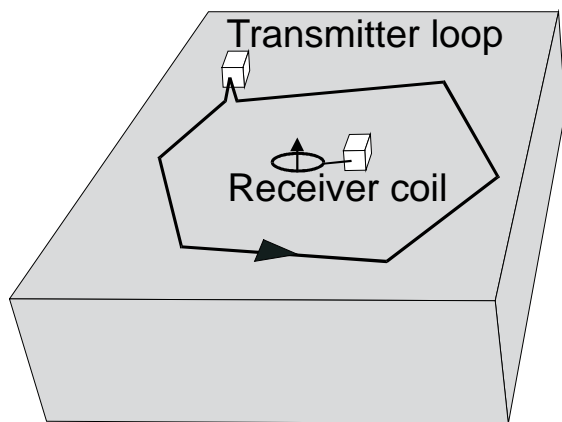


Figure 3-20. Measurement with TEM (transient electromagnetic sounding). The sketch at the left shows the principle with a transmitter (a large closed loop of cable) and a receiver (a coil). The photo at the right shows an operator at the instrument, which has been placed next to the receiver coil.

3.5 Rock mechanics and thermal properties

3.5.1 Purpose and goal

The **rock mechanical conditions** put constraints on how the repository can be configured and built, but are also of importance for long-term stability. These conditions are governed by the prevailing loads – rock stresses – and the mechanical properties of the rock. The mechanical properties of a rock volume are dependent on the properties of the intact rock, as well as on the occurrence of fractures (frequency, length, orientation) and their mechanical properties. Different rock types have different strength and deformation properties. The strength and deformation parameters of intact rock samples, and to some extent also fractures, can be determined by laboratory tests, but there are scale effects that must be taken into consideration before data can be used for analysis of large rock masses.

The rock stresses in a rock mass are known by experience to exhibit considerable regional and local variation in both size and orientation. Determinations must therefore be done by in situ measurements.

The discipline of rock mechanics includes measurement and analysis of the rock's strength, deformation and thermal properties, as well as measurement and analysis of the stress state in the bedrock. With the support of these data, predictions are made of stability conditions as a basis for both facility design and safety assessment.

The goal of the rock mechanical investigations is to:

- Describe the rock stress distribution within the investigation area with the support of measurements, indirect observations and modelling.
- Determine the mechanical properties of the rock mass and their distribution within the investigation area, including properties of intact rock and fractures.
- Gather data to permit the identification of possible problems where tunnels have to pass fracture zones.

The **thermal properties** of the rock are of importance for the transport of heat from the canisters in the final repository. This determines the minimum spacing between emplaced canisters, and thereby the space requirement for the whole repository. The rock's thermal conductivity is the crucial parameter in this context. This can be determined by means of laboratory tests, but scale-dependent variations and thermal anisotropy may have to be taken into consideration. In order to be able to calculate thermomechanical effects (induced thermal stresses and deformations), data on the rock's thermal expansion properties are also needed, normally expressed as the coefficient of thermal expansion.

The goal of the thermal investigations is to:

- Determine the thermal properties of relevant rock types.
- Describe how the thermal properties vary in the rock mass.

3.5.2 Important results from completed investigations

Mechanical properties of the rock

Knowledge of the rock's mechanical properties in the Laxemar subarea comes from testing of cores from the boreholes KLX02, KLX03, KLX04 and KLX06. Furthermore, data have been compiled on the mechanical properties of the rock on Äspö and in the site investigation area /SKB 2005b, 2006/.

The lithological composition of the rock in the Laxemar subarea is deemed to be very similar to that in the Simpevarp subarea and there is nothing to suggest that any of the rock types occurring within the Laxemar subarea has significantly differing mechanical properties.

Laboratory determination of the mechanical properties of the rock has yielded the following results /SKB 2006/:

- The first rock mechanical tests from the Simpevarp Peninsula, on quartz monzodiorite and fine-grained dioritoid, showed some unexpectedly low strength values. This was probably due to the fact that the samples contained sections with sealed fractures. The subsequent tests on the Ävrö granite from boreholes in the Laxemar subarea show high mean strength and less variation.
- The mean uniaxial strength of the Ävrö granite is 195 MPa with a standard deviation of 20 MPa.
- The mean modulus of elasticity for the Ävrö granite is 70 GPa with a standard deviation of 5 GPa.
- The mean tensile strength (indirect testing) of the Ävrö granite is 13 MPa.
- Tests with normal and shear loading of fractures indicate fairly constant properties. The mean angle of friction for the fracture plane is 37°. So far no differences in results due to the orientation of the fractures have been noted. Possible bias (systematic error) in sampling has not been studied more closely.

Rock stresses

Knowledge of rock stresses is necessary for the design of the final repository (repository depth, orientation and configuration of tunnels, rock support), and for predictions regarding possible stress-related stability problems.

Knowledge of the stress conditions in the bedrock within the site investigation area is available from completed site investigations in the Simpevarp and Laxemar subareas, but also from the extensive investigations and studies that have been conducted at the Äspö HRL /e.g. Jansson and Stigsson 2002/.

Rock stresses have been measured within the Laxemar subarea both in cored borehole KLX02 in conjunction with the investigations preparatory to the construction of the Äspö HRL /Ljunggren and Klasson 1997/ and in KLX04 as a part of the ongoing site investigations /Sjöberg and Perman 2005/. The hydraulic fracturing method was used in KLX02 (as previously in KSH01) while the overcoring method was used in KLX04 (as previously in KAV04).

An general conclusion is that the stress situation varies within the area. The stress level at repository depth is clearly lower in the Simpevarp subarea (KAV04, KSH01 and KSH02) than on Äspö and in the Laxemar subarea (KLX04 and KLX02). The measurements in KLX04 show a deviant orientation, with the greatest principal stress dipping 14–60°, but in Äspö the greatest principal stress is usually oriented northwest-southeast with a gentle dip. The stress situation along KLX04 is probably influenced by the fact that the hole intersects deformation zone EW007. This has been illustrated by stress modelling in the work with site-descriptive model Laxemar 1.2.

The overall assessment based on the current limited body of data is that the rock stresses can be a factor that influences the site adaptation of the final repository. Above all, the rock stresses can influence the choice of repository depth, since an increase in these stresses with depth increases the risk of breakout in the deposition holes, which would result in a loss of deposition holes. There is some uncertainty in the model for stress magnitude due to the fact that a variation in the stress field within the area, caused by movements in the major deformation zones, cannot be ruled out. Owing to the risk of breakout, it is important to reduce the uncertainty regarding the strength of the rock.

Thermal properties

The thermal conductivity of the bedrock influences how closely the canisters can be spaced in a final repository and thereby the space requirement for the whole repository.

The thermal properties of the rock in the Laxemar subarea have been determined by measurement (TPS method⁸), calculation from mineral composition, and calculation from density logging in cored boreholes⁹. Density logging has only been used for Ävrö granite, where a relationship between thermal conductivity and density has been established that is modified from that in site-descriptive model Laxemar 1.2.

After analysis and evaluation of available data, the Laxemar subarea has been divided into four domains with differing thermal properties, see Figure 3-21 /SKB 2006a/:

1. In the southwest, quartz monzodiorite with an estimated average thermal conductivity of 2.74 W/m K (thermal domain TD).
2. In the west and south, Ävrö granite with low conductivity – on average 2.58 W/m K (thermal domain TA3).

⁸ TPS (transient plane source) = method for determination of thermal diffusivity and thermal conductivity.

⁹ Calculation of the rock's thermal conductivity based on data from density logging is based on an empirically determined relationship between the density and thermal conductivity of the rock.

- Centrally, Ävrö granite with a slightly higher thermal conductivity – on average 2.93 W/m K (thermal domain TA2).
- In the northeast, Ävrö granite with an estimated average thermal conductivity of 2.74 W/m K (thermal domain TA1).

There is, however, great variation within these domains.

Data from cored boreholes show that the properties at depth are more or less the same as on the surface, see Figure 3-22 /SKB 2006a/. Rock with low thermal conductivity is found mainly in boreholes KLX03 and KLX05 in the south, and KLX01 and the lower part of KLX06 in the north. Ävrö granite with relatively high thermal conductivity occurs in the centrally located boreholes KLX02 and KLX04 as well as in the upper part of KLX06. The variations in the thermal properties of the Ävrö granite are also evident in cored boreholes KLX05 and KLX02. There are measurement values below 2.4 W/m K, locally down to 2.2 W/m K, particularly in domains 1 (TD) and 2 (TA3).

In addition to the work of determining the rock's thermal conductivity, the coefficient of thermal expansion has been determined by laboratory tests. These tests indicate that the coefficient of thermal expansion lies in the range $5 \cdot 10^{-6}$ to $9 \cdot 10^{-6}$, which are normal values.

Temperature logging shows wide variation between different boreholes, leading to considerable uncertainties.

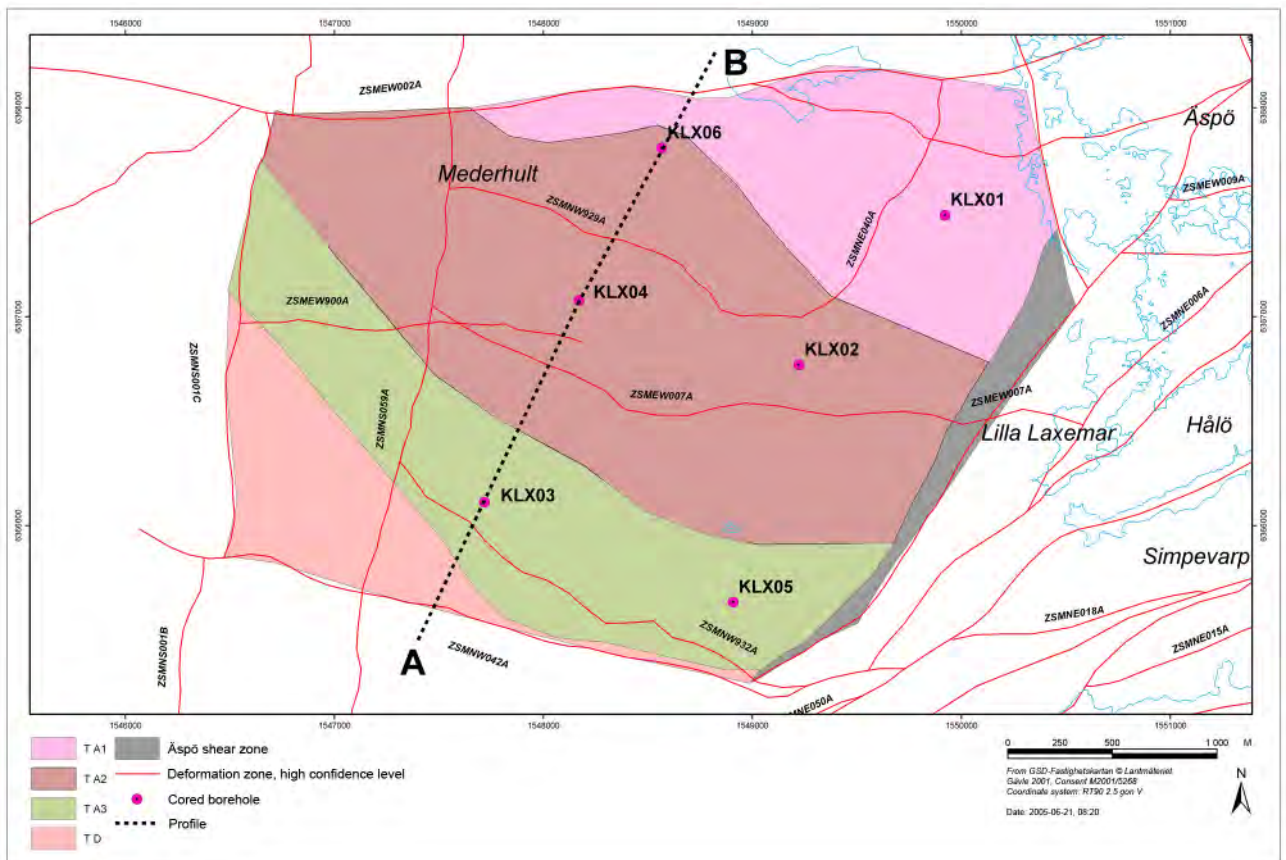


Figure 3-21. Thermal domains in the Laxemar subarea.

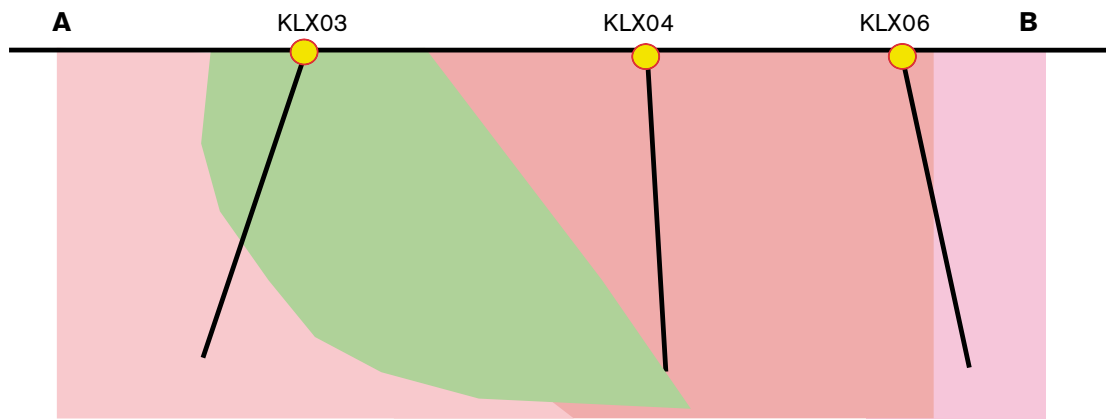


Figure 3-22. Schematic profile of thermal domains in direction A–B, see Figure 3-21.

3.5.3 Important questions remaining to be answered

Rock mechanical strength data with good statistical certainty will be obtained for the most frequently occurring rock types within the subarea. Mechanical testing of intact rock and fractures must therefore continue. The uncertainty that exists today is due mainly to the fact that samples only exist from a limited number of boreholes. This may mean that the entire rock type variation in the Laxemar subarea is not covered, for example the variation in quartz content of the Ävrö granite. It is also possible that data from the rock type in the relevant repository areas is underrepresented. This is particularly evident when site investigation results for strength testing are compared with equivalent testing results from recent years in Äspö, for example the Pillar Stability Experiment /Staub et al. 2004/.

The mechanical properties for major deformation zones must be clarified in those cases where they have to be built through. However, experience from the construction of the Äspö HRL /Stanfors et al. 1997, Andersson and Söderhäll 2001/, the Oskarshamn nuclear power plant and Clab /Curtis et al. 2003/ indicate that tunnel passage with conventional methods through the types of zones that were encountered in these cases was possible without difficulties.

The rock stress situation in the Laxemar subarea is rather uncertain and both of the measurement points are located in the northern part of Laxemar; there is no measurement point in the focused area. If the stresses should turn out to be high, this could increase the risk of stress induced problems and thereby be of importance for the site adaptation of the repository.

There is still great uncertainty regarding the thermal properties. It is, for example, unclear whether data obtained thus far provide a fair picture of those parts of the rock being considered as deposition areas. The boundaries between the thermal domains shown in Figure 3-21 are uncertain on the surface and even more uncertain at depth. Perhaps the most central question remaining is being able to describe how the thermal properties vary in the rock. This question is important for the continued modelling work and for being able to optimize the layout of the repository.

3.5.4 Investigation programme

Based on the programme overview in section 3.1, an investigation programme is presented in this section for determining the mechanical properties, stresses and thermal properties of the rock.

Mechanical properties

Better knowledge of uniaxial and triaxial compressive strength in different directions, including at a higher stress level, is needed for rock mechanical modelling and stability analyses. How many uniaxial strength tests, triaxial tests, indirect tensile tests and thermal expansion measurements are needed will be determined by the geological situation in each borehole. Samples will mainly be taken within the depth interval 300–500 m for dominant rock types. Tests on diorite-gabbro, which has not previously been tested, and on samples with altered Ävrö granite will be included, regardless of where in the boreholes these rock types are encountered. Mechanical testing, i.e. estimation of normal and shear stiffness as well as shear strength, will be done to the same extent as previously on open fractures as well as on a few healed fractures. The testing procedure for fracture tests has been modified during the course of the investigations. Additional tests are therefore needed in order to obtain sufficient data from tests with the new method.

P-wave measurements will continue in those parts of the area where such measurements are lacking. The purpose of the measurements is to get an idea of the depth at which the microfracturing in the drill core begins and an indication of microfracturing in conjunction with stress relief.

Furthermore, comparison testing will be done for certain testing methods during the spring and summer of 2006.

Rock stresses

In previous rock stress measurements in the Laxemar subarea, the stress orientation has probably been affected by deformation zone EW007. In order to improve knowledge of the rock stresses in the Laxemar subarea, rock stress measurements with both overcoring and hydraulic fracturing will be done in a borehole (KLX12) in early 2006. This borehole will be drilled in “the good rock” at sufficient distance from deformation zones. If the measurements are successful and the results credible, and provided they do not indicate such a high stress level that it is of importance for design or safety assessment, the quantity of data may be considered sufficient. Otherwise, measurements will have to be performed in additional boreholes. There is some uncertainty whether enough results will be available by data freeze 2.2.

Thermal properties

Further efforts aimed at obtaining greater certainty regarding the thermal properties of the rock have high priority. The thermal samplings will be focused on the Ävrö granite and the gabbro, while samplings in quartz monzodiorite will be done to check and compare with previous results. Altogether, sampling and laboratory tests will be carried out on a selection of drill cores from around 10 cored boreholes. Laboratory measurements of thermal conductivity will also include secondary rock types and altered rock.

Laboratory tests of thermal conductivity and thermal expansion are done today on unloaded specimens. This can yield values that are systematically lower than for specimens under loads that correspond to conditions in situ. The difference may be of minor importance, but the effect of the pressure dependence will be examined for some samples to confirm the hypothesis that constraint is unimportant, at least for water-saturated samples.

In order to gain a better understanding of how mineral composition, particularly alteration products, affects thermal conductivity, modal analyses will be performed on a selection of samples from laboratory measurements. Alteration products will be quantified as much as possible by the modal analysis.

Corrected density logs from several boreholes and measurements of thermal conductivity on samples with low and high conductivity are needed to verify established relationships and to obtain a better understanding of how thermal conductivity varies within Ävrö granite. To further reduce uncertainty regarding thermal conductivity on a canister-relevant scale, SKB has started a study of suitable technique for large-scale determination of thermal conductivity.

Moreover, the possibility of conducting measurements of in situ temperature that are of high quality and performed at suitable times is being explored.

3.6 Hydrogeology

The hydrogeological programme includes meteorology, hydrology and hydrogeology in soil layers and bedrock. Like the meteorological measurements linked to water quantity, water flow rate and water level, the hydrological measurements are also utilized in the programmes for surface ecosystems and hydrogeochemistry. In a similar manner, measurements linked to the composition of the surface water and groundwater that are performed within surface ecosystems and hydrogeochemistry are also used in the hydrogeology programme as an aid to clarifying the area's water balance and the water's flow paths.

3.6.1 Purpose and goal

The purpose of the continued hydrogeological investigations is to obtain a better hydrogeological understanding and update the hydrogeological description of the area so that it meets the needs of design and safety assessment.

In order to facilitate this description, three-dimensional hydrogeological models are being constructed of the area with a focus on (1) the near-surface hydrogeology (the soil layers and the uppermost part of the rock) and (2) the hydrogeology of the deep rock. The models are being built with the aid of three types of hydraulic domains: soil layers, deformation zones and the rock mass between the deformation zones. All three domain types must be characterized to a varying degree.

The body of data should include both geometric and physical properties, and the discipline of hydrogeology is dependent here on data from other disciplines. Examples of geometric properties are topography, water depth and the location and extent of the soil layers and the fracture zones. Examples of physical states and properties are initial and boundary conditions for pressure and salinity and material properties such as porosity and permeability.

Numerical modelling is used as an aid to a better understanding of the area's hydrogeology. By means of numerical simulation, aimed at describing the magnitude and flow paths of the groundwater flow, assumptions made in the conceptual hydrogeological model will be able to be demonstrated and tested. For example, what is the significance of the uncertainties in parameter values given in the hydrogeological description? Can simulated results, for example with regard to pumping tests, be verified by measured data? The results of the simulation are expected to show whether supplementary field investigations are needed or whether the body of data already collected is sufficient. Moreover, modelling is an important tool in generating input data for repository design, safety assessment and environmental impact assessment.

To verify the picture of the area's hydrogeochemical evolution, see section 3.7.1, transient groundwater flow calculations have been carried out covering the time since the most recent

deglaciation. These simulations have succeeded in simulating the hydrogeochemical conditions that exist today.

Hydrogeological modelling is done at different scales, both a local scale around a hypothetical final repository, and a regional scale within a larger area.

Most of the planned investigations will be concentrated in the southern and western part of the Laxemar subarea, known as the focused area. The main goals are to describe the hydraulic properties of the rock at repository level and to describe the hydraulic properties of major deformation zones surrounding the rock deemed suitable for the final repository. The investigations should also provide information for description of the soil layers, as well as the contacts between soil and rock and between surface water and groundwater.

The area outside the focused area will also be investigated, but to a lesser extent than within the focused area. This means that the body of data underlying the local hydrogeological model for the focused area will be greatly improved, while the data in the other parts will not be changed to the same extent. Monitoring will, however, continue in surrounding areas as well, which means that additional data will be obtained for them too.

3.6.2 Important results from completed investigations

Generally speaking, the results of different types of hydrotests in rock have shown good agreement. These are results from various measurements in cored boreholes, including pumping tests during drilling (with a wireline probe), PFL (Posiva Flow Log) measurements and injection tests with PSS (Pipe String System) equipment. The general picture of the transmissivity distribution along the borehole obtained with these methods has been consistent, taking into account their different measurement limits and test scales. PSS and PFL provide different types of information but are partially overlapping with respect to transmissivity determination. This agreement strengthens our confidence in the investigation methodology as we continue our investigations.

The most important hydrogeological results so far are the hydraulic characterization of the soil layers and the bedrock down to a depth of about 1,000 m. These results can be summarized in four points:

1. The Quaternary geological investigations have shown a very broken-up cover of overburden that is more contiguous in the southern than in the northern part of the Laxemar subarea, see Figure 3-23. The soil layers are generally dominated by till, sometimes overlain by sand and/or clay. There is a high proportion of outcrops and sub-outcrops rock in the area. There are often boulders on top of the more fine-grained soils, sometimes even at greater depth. The thickness of the soil layers averages about 2–3 m and is greatest in the valleys. The greatest soil layer thickness encountered is about 12 m. Hydrogeologically, four typical types or areas have been identified:
 - High-lying terrain with rock that is exposed or covered with a thin layer of soil.
 - Valleys with thicker soil layers, including postglacial sediments such as clay, gyttja and peat.
 - Glaciofluvial deposits in the form of esker material.
 - Undulating till areas.

The groundwater table in the soil layers is generally located about a metre below the ground surface. The greatest distance from the ground surface to the groundwater in the soil layers that has been encountered is three metres. The hydraulic conductivity of the till (K) has been determined by slug tests and grain size distribution analyses, and averages around $4 \cdot 10^{-5}$ m/s /Werner et al. 2005/. No measurements have been performed on other Quaternary deposits than till (for example glaciofluvial sediments or clay).

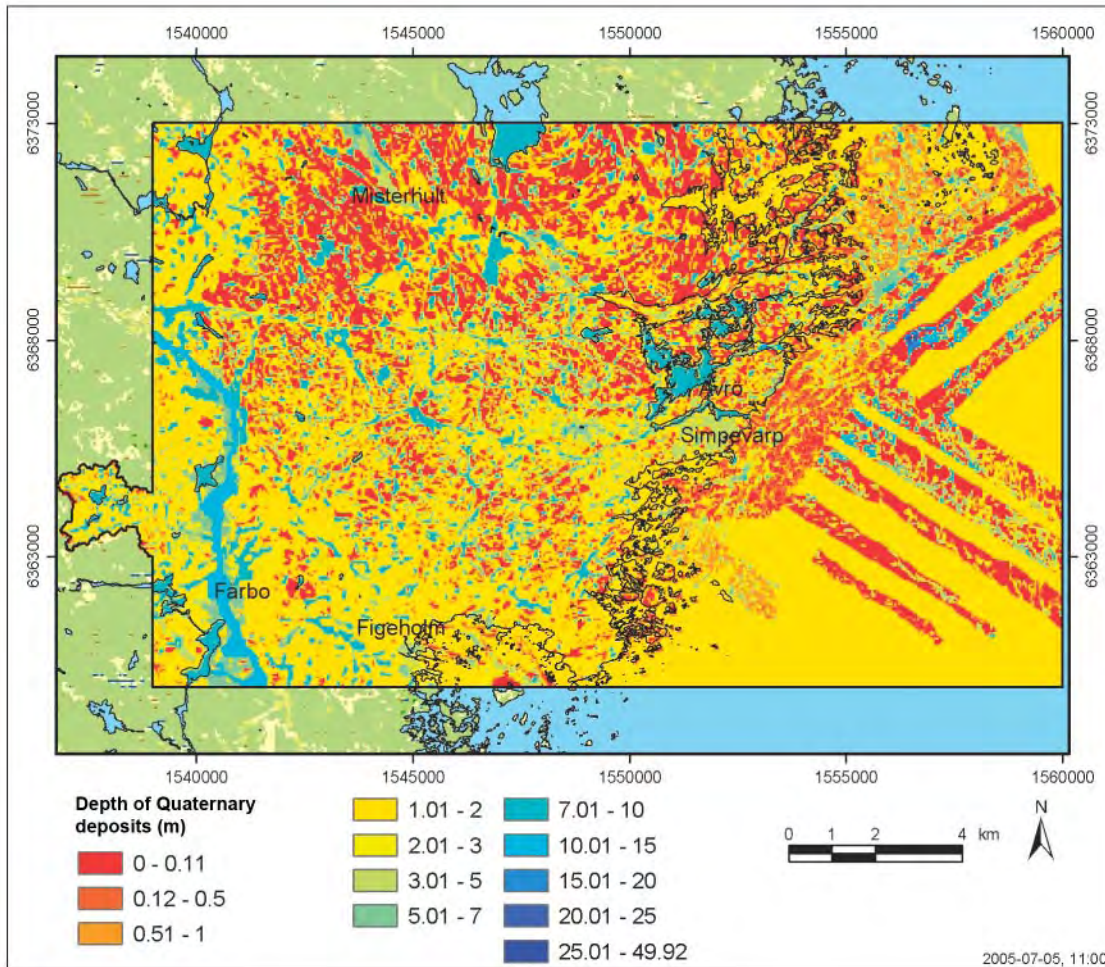


Figure 3-23. Modelled depths of the Quaternary deposits /Nyman 2005/.

2. The rock down to a depth of about 200–400 m is often very fractured and the hydraulic conductivity is relatively high. Further down there are fewer water-conducting fractures and the hydraulic conductivity there is much lower, at least ten times lower than in the upper section of the hole, except in borehole KLX07A, where the hydraulic conductivity is relatively high along the entire hole. There seems to be a trend of declining hydraulic conductivity with depth, see Figure 3-24. This applies to both the Laxemar subarea and the Simpevarp subarea, but has not been encountered in previous investigations on Äspö.
3. The average hydraulic conductivity varies between different rock types. Rock domains dominated by mafic rocks have a slightly lower hydraulic conductivity than granitic ones. The fracture transmissivity of the various rock types is roughly the same, however.

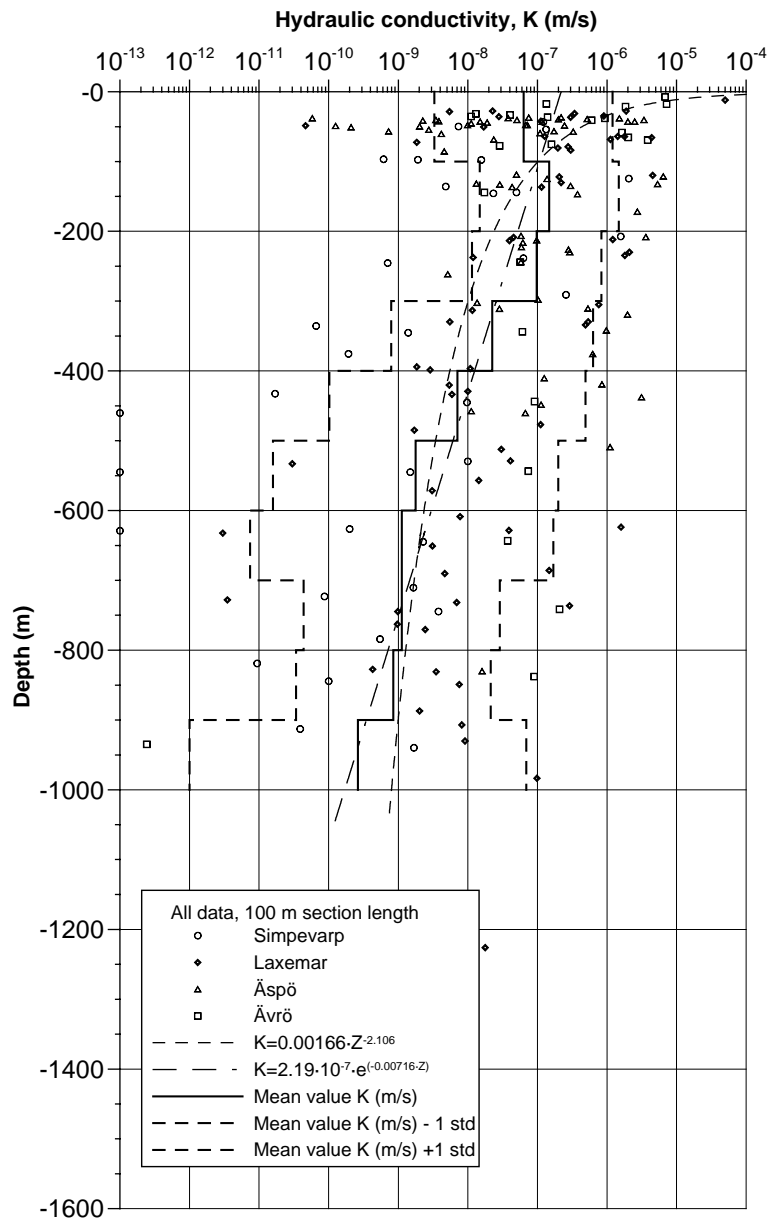


Figure 3-24. Hydraulic conductivity (m/s) as a function of depth (metres above sea level) from 100-m tests in the Laxemar subarea, the Simpevarp subarea and on Äspö /SKB 2006/. The hydraulic conductivities were evaluated by means of different methods and represent “best choices”.

4. Extensive hydraulic measurements have been performed in the major deformation zones as follows:

EW007: The measurements showed that the zone is highly hydraulically conductive, at least in the upper parts down to 200 m. Individual tests have shown that the upper parts of the zone have a transmissivity in the range $8 \cdot 10^{-5}$ – $8 \cdot 10^{-4}$ m²/s. It appears to be less conductive in its central section, since no hydraulic connectivity could be detected between the eastern and western parts of EW007. The transmissivity of the zone has been set in the site-descriptive model to $5 \cdot 10^{-5}$ m²/s /Table 3-7 in SKB 2006a/.

EW002: Within the Laxemar subarea, only the boreholes KLX06 and HLX20 have been drilled towards EW002. These are situated 200 m from each other at the ground surface and are hydraulically connected. Individual tests have shown that the transmissivity is $4 \cdot 10^{-5}$ – $3 \cdot 10^{-4}$ m²/s. The transmissivity of the zone has been set in the site-descriptive model at $4 \cdot 10^{-6}$ m²/s /Table 3-7 in SKB 2006a/.

NW042: Interference tests indicate that this deformation zone is not hydraulically connected along its entire length. The zone is highly conductive in its western and central parts. Here, individual transmissivities were obtained in the range $1 \cdot 10^{-5}$ – $4 \cdot 10^{-4}$ m²/s. However, the hydraulic connectivity between these parts has not been confirmed, since the response in interference tests is uncertain. The eastern part seems to be relatively impermeable, since a couple of holes have proved dry on drilling, but it has hydraulic contact with the central more permeable part. The transmissivity of the zone has been set in the site-descriptive model to $4 \cdot 10^{-7}$ m²/s /Table 3-7 in SKB 2006a/.

NS059 northern part: Drilling and interference tests between two percussion boreholes in this deformation zone confirm the occurrence of a fracture zone with a high transmissivity of about $2 \cdot 10^{-4}$ m²/s.

Another important result is that measurement systems for monitoring of meteorological, hydrological and groundwater parameters have been put into operation. This is a cornerstone for collection of data for the site-descriptive model for several disciplines and forms also the basis for the environmental impact assessment. The system is described in section 3.10.

Aside from the site-specific results that have been obtained, important method-related results have also emerged, especially when it comes to hydraulic detailed characterization of cored boreholes. The two standard methods that have been used for the detailed characterization are injection tests (conducted with PSS) and difference flow logging (conducted with PFL).

Table 3-2. Distribution of hydraulic conductivity at a measurement scale of 5 m measured with Posiva Flow Log for different rock types in the Laxemar subarea and the Simpevarp subarea (KAV01, KAV04A, KSH01, KSH02A, KLX02, KLX03 and KLX04). The table is based on lithological units that are longer than 1 m in the drill core (Sicada code Rocktype). The data includes deformation zones interpreted from single-hole interpretation and the RVS model /SKB 2006/.

Rock type	Hydraulic conductivity, K (m/s) (geometric mean value)	Standard deviation (Log ₁₀ K)	Number of observations	Comment
All rock types	$9.8 \cdot 10^{-11}$	1.72	1,426	
Fine-grained dioritoid	$4.7 \cdot 10^{-11}$	1.58	327	
Diorite/Gabbro	–	–	5	Only one measurement above measurement limit. Probably comparable to fine-grained dioritoid and quartz monzodiorite.
Quartz monzodiorite	$1.7 \cdot 10^{-11}$	2.05	167	
Ävrö granite	$1.2 \cdot 10^{-10}$	1.74	827	
Granite	$1.5 \cdot 10^{-9}$	1.74	20	
Pegmatite	–	–	2	Only one measurement above measurement limit: K = $1.1 \cdot 10^{-9}$ m/s.
Fine-grained diorite-gabbro	$5.0 \cdot 10^{-12}$	2.99	28	
Fine-grained granite	$1.8 \cdot 10^{-9}$	1.29	50	

Experience from investigations of two cored boreholes in the Simpevarp subarea (KSH01A and KSH02) indicate that the two investigation methods overlap to some extent but yield different types of data. Results from both methods are important for the evaluation of permeability in the analysis work. As an example, it can be mentioned that PSS has a larger measurement range with regard to permeability (hydraulic transmissivity) than PFL. Above all, low transmissivities can be better quantified by PSS than by PFL; PSS complements where PFL is lacking.

The disadvantage of PSS is that the minimum length of a measurement section in the borehole is five metres with the current design of the equipment. Consequently, PSS measures transmissivity with a geometric resolution of five metres. The resolution along the hole in PFL measurements is, on the other hand, as high as 0.1 m. Individual fracture transmissivities can therefore be determined with PFL. Together with mapping of the drill core, Boremap data, and digitized TV logging of the borehole wall (BIPS) these methods provide useful information for the work with the fracture model of the area (the Hydro-DFN model). PFL can also be used to measure electrical conductivity in specific fractures, which contributes to a better understanding of the hydrogeological and hydrogeochemical models.

A method evaluation has also been done for measurements of absolute pressure during drilling. The measurements are performed with a probe in the drill string (wireline probe). This evaluation has preliminarily shown that measurements performed thus far give a pressure that corresponds to the hydrostatic pressure, which is interpreted as indicating that no abnormal pressure conditions exist in the area, which was also expected based on the area's relatively flat topography.

Numerical groundwater flow modelling on a regional scale have been carried out based on model version Laxemar 1.2 /Hartley et al. 2006/. The modelling has made use of chemistry data such as salinity, isotope ratio ($\delta^{18}\text{O}$) and mixing proportions of different water types to test and calibrate the numerical model. The current numerical model is able to describe the spatial distribution of salinity, $\delta^{18}\text{O}$ and mixing proportions fairly well, in the same way as the observations in boreholes. However, chemistry observations are scarce in certain areas, so further water sampling will permit better testing of the regional groundwater flow model. New samples for describing the spatial distribution of salinity, glacial water and Littorina water are believed to be particularly important.

3.6.3 Important questions remaining to be answered

A number of important questions remain to be answered, but some stand out from the rest. The most important questions can be summarized in the following five points. Efforts aimed at quantifying the properties and variability of the rock mass in potential deposition areas are prioritized, according to the discussion in section 2.3.3.

- **Hydraulic properties of major deformation zones.**

A great deal of effort and resources have so far been devoted to characterizing and understanding the major deformation zones. This work will continue and be focused on the major deformation zones that bound and divide the deposition areas. Investigations according to (a) in section 3.6.4 below.

- **Hydraulic properties of local minor deformation zones.**

So far the characterization has been focused on the major deformation zones. A remaining task is characterizing the spatial distribution and water-conducting properties of local minor deformation zones, which control the groundwater flow in the rock mass. Investigations according to (b) in section 3.6.4 below.

- **Characterization of the rock mass for DFN modelling.**
A better understanding of the coupling between the geometry of the fracture system and hydraulic properties is necessary to achieve better agreement between measurements and models. Two studies of the rock mass beneath thoroughly mapped outcrops will be used for this purpose. The key factor in this context is confidence in an extrapolation from superficial to deeper parts of the rock. Investigations according to (b) in section 3.6.4 below.
- **Verification of deposition areas.**
An important part of future investigations is to verify the hydraulic properties of the rock within the rock volumes that are designated as possible deposition areas. In these areas, targeted and optimized investigations are needed using the same investigation methods as before. The investigations will also include installation of supplementary soil wells in the soil layers in those areas that may be affected by the repository. Investigations according to (b) and (d) in section 3.6.4 below.
- **Characterization and understanding of the hydrogeological conditions in important discharge areas and in contact zones between soil and rock and between surface water and groundwater.**
The investigations of rock and soil layers conducted thus far have been carried out separately, and the modelling as well has focused on the individual subsystems. Both investigations and modelling need to take into account the contact zone between soil and rock to a greater extent, which is why targeted investigations need to be done for this purpose. Characterization and understanding of important discharge areas, particularly those that can be expected to be of importance for modelling of radionuclide transport, and the contact between surface water and groundwater also need to be improved. Investigations according to (c) and (d) in section 3.6.4 below.

The overall strategy and the timetable for the investigations to answer the above questions are presented in sections 2.4.1 and 2.4.2, respectively. The objective, purpose and programme for the continued hydrogeological investigations are presented in the following section 3.6.4.

3.6.4 Investigation programme

The main goal of the continued investigations in the focused area is to gather hydrogeological data (variables and parameters) for the site-descriptive modelling. These data will reveal more about the hydraulic properties of the major deformation zones that bound and divide the deposition areas and about the hydraulic properties of the rock mass on repository level and of the soil layers.

The geological and hydrogeological investigations of the major deformation zones are aimed at providing an overall picture of their geometry and character. From a hydrogeological viewpoint, more needs to be known about the properties of the zones (mainly transmissivity) and how they are hydraulically connected to other major zones. Interference testing is one method that confirms both the interpretation of a zone's geometry and its hydraulic connections with nearby zones. Data from interference tests can also be used to test the more large-scale behaviour of the groundwater flow models (although relatively locally viewed from a regional perspective). Spatial variability of transmissivity (mainly depth dependence) will be estimated on the basis of the investigations, but the estimates must be based mainly on general observations for several deformation zones. Detailed studies of certain deformation zones, which are based on interference tests and geological and hydrogeological borehole data representative of the deformation zones and the vicinity of the zones, also contribute to an increased understanding of how the heterogeneity of the

zones should be described and modelled. Both PSS and PFL measurements are expected to provide data indicating how the heterogeneity of the zones should be described.

The hydraulic properties of the rock mass between the major deformation zones are described stochastically, usually with hydraulic fracture models. This description is most important at repository level. In order to generate enough data for the hydraulic fracture models, just focusing on repository depth is not enough. The models are based to a high degree on integrated information from both the deformation zone model of the major zones and mapping of outcrops and boreholes to obtain data on distributions of both the size and orientation of fractures and zones. These data will primarily provide a basis for credible, relatively near-surface fracture models which can be modified (if necessary) with the aid of borehole data to describe depth dependence.

Two important subprogrammes aimed at providing better data for the modelling of fractures and fracture zones are planned during the site investigation: Characterization of local minor deformation zones and data for DFN modelling, see section 3.1 and Table 3-1 plus subsequent description in this chapter. These two subprogrammes are expected to confirm that the methodology used by geology and hydrogeology to construct fracture models that describe both minor fractures and minor fracture zones works well. A number of boreholes will be drilled in the rock volume that is judged to be suitable as a deposition area in order to provide important data. Information from the boreholes is expected to provide a basis for an assessment of the large-scale spatial variability of the permeability of the rock at repository level and for constructing hydraulic fracture models that are relevant for repository level based on borehole data and near-surface observations.

Not only will the rock model be improved during CSI, but the soil layer model and the surface rock model will also be updated with new investigation data. This will be done so that near-surface hydrological processes can be modelled in a sufficiently accurate manner.

The hydrogeological investigation programme presented below is based on the programme overview in section 3.1.

Overview of coming investigations

The hydrogeological investigation programme presented below is based on the programme overview in section 3.1.

The continued investigations will preferably be conducted in the focused area: the southern and western part of the Laxemar subarea. The purpose of the complete site investigation is to complete the geoscientific characterization of the focused area and supplement existing knowledge. For the main hydrogeological activities, this entails:

- a. investigating in greater detail the properties, position and extent of possible local major fracture zones within the focused area,
- b. investigating the hydraulic properties of the rock mass between the major deformation zones from the ground surface and down below repository depth with deep boreholes within the focused area,
- c. supplementing the survey of the near-surface hydrology with in-depth investigations of hydrological and hydrogeological conditions within important discharge areas, particularly those where the hydraulic contact between soil and rock and between surface water and groundwater can be studied,
- d. supplementing the survey of the near-surface hydrogeology (rock and soil) within and near the focused area. The investigations include installation of soil wells and determination of the hydraulic properties of the soil layers,

- e. if the ongoing modelling shows that substantial benefit can be gained by substantiating boundary and initial conditions, certain hydrogeological investigations may be undertaken in the regional area.

Investigations of soil aquifer and near-surface hydrology

The investigations described here mainly refer to points (c) and (d) above.

In order to find out more about the water fluxes in the area and refine the conceptual model on which the numerical simulations are based, it is important to further study the hydraulic contact between surface water, soil groundwater and rock groundwater. A number of soil trenches have been dug to expose the rock deformation zones. These investigations consist of particle size analysis of the soil layers and mapping of the fracturing of the exposed rock in contact with the soil layers. The investigations will contribute to the description of the contact zone between soil and rock and thereby shed light on the prerequisite of hydraulic contact between soil and rock groundwater. Low-lying tracts in the terrain, such as wetlands, will be studied to determine whether they comprise discharge areas or separate hydrological systems. Efforts will be concentrated in the areas expected to be important for an understanding and quantitative modelling of radionuclide transport.

The monitoring that is being done in Oskarshamn includes collection of meteorological data, stream discharges and surface- and groundwater levels, making it possible to study the effects of both natural changes and of human activities. Examples of questions that can be illuminated are how soil and rock groundwater levels in different parts of the area are changed by heavy precipitation and sea level variations, how the groundwater levels in soil and rock covary, whether the lakes in the area always constitute discharge areas, and how the water level in soil wells changes due to pumping for interference tests in nearby boreholes in the rock. The plans for continued monitoring are described in sections 3.10.1 and 3.10.2.

In order to study groundwater recharge, targeted investigations involving interference and/or tracer tests and monitoring of water chemistry are planned, in addition to stream discharge measurements and hydrochemical analyses.

Investigations will be carried out at three so-called “characteristic” profiles in order to determine the hydraulic contact between the soil and the rock aquifer. There are both percussion boreholes and soil wells at these profiles, see Figure 3-25. Characterization of the soil and rock contact consists of two components:

- An interference test where percussion boreholes in rock are pumped and the groundwater level in soil wells is observed. The percussion borehole is sealed with two packers for pressure observation in three sections during the test. Tracer tests with conservative tracers may be performed in conjunction with the interference test. When the tests are finished, pressure will be measured in percussion boreholes and soil wells will be instrumented for monitoring.
- Monitoring of groundwater pressure, meteorological parameters and stream discharge, see section 3.10.5. Monitoring makes it possible to follow the groundwater levels in the rock and soil aquifers over long periods of time. This makes it possible to study the correlation between precipitation and responses in groundwater and surface water reservoirs. This information is expected to contribute to characterization and understanding of the soil-rock contact and of local groundwater recharge.

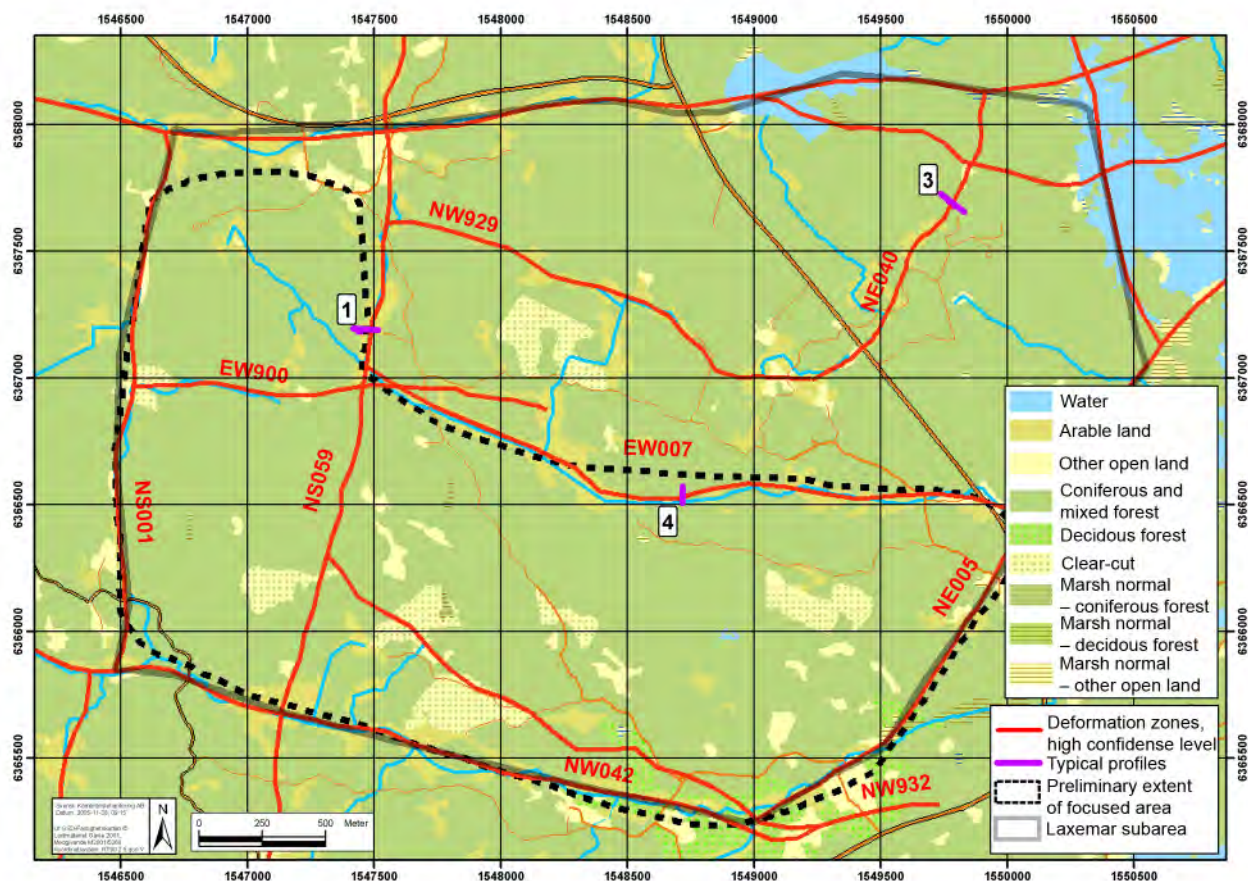


Figure 3-25. Typical profiles in the Laxemar subarea where investigations will be carried out for the hydrogeological characterization of the soil/rock contact. (The numbering of the profiles refers to the previous profile surveys that were done at a total of six profiles. Three of these (1, 3 and 4) have been selected for further hydrogeological investigations.)

There is a need for additional soil wells, and the strategy for siting these soil wells is primarily governed by needs in the modelling of near-surface hydrogeology. At present, an additional 20 or so soil wells are planned to be drilled for the following purposes:

- Supplementary mapping of soil layers and the soil aquifer, including wetlands. These targeted measures are planned for better characterization of the interaction between wetland and soil aquifer. Furthermore, the modelling may give rise to questions that are best answered by supplementary drilling.
- Characterization and monitoring of soil aquifer within repository area. The area where the repository is located will be subjected to groundwater lowering (drawdown) during its operating period. In order to obtain a reference time series in the area where the greatest drawdown can be predicted, soil wells will be drilled in the focused area.
- Supplementary investigations for characterization of the locations of the soil wells in terms of recharge/discharge and evaluation of whether the soil wells are representative for the area as a whole.
- Characterization of soil layers in lakes and sea bays. For this purpose, 1–2 soil wells are planned to be drilled in Frisksjön Lake and 1–2 soil wells in Norre Fjärd situated east of Frisksjön. Together with existing installations and characterizations, a complete east-west profile is obtained where the hydrodynamics in the surface water and groundwater system can be followed.

The soil well investigations will as previously consist of slug tests and instrumentation of groundwater tables for monitoring. Furthermore, slug tests will be performed in old wells, which have not previously been tested because they have been dry or have been utilised for environmental monitoring in conjunction with core drilling.

There are a large number of private wells in soil and rock within the area. A repository in the area could affect the groundwater tables in the wells, so monitoring of the groundwater tables is planned. The scope of this monitoring and when it will start have not yet been determined.

Investigations in core drilled and percussion drilled boreholes

The investigations that are described here mainly relate to points (a), (b), (d) and (e) above. The drilling programme is described in sections 3.1 and 3.9.

Core drilled boreholes

Pumping tests will be performed in all cored boreholes except for in the short holes (10–100 m), according to the drilling programme in Table 3-1. Pumping tests with a wireline probe are planned to be performed every 100 m during core drilling according to a previously developed methodology, and groundwater level recovery will be measured about every 300 m by means of transient pumping testing. The pressure measurements performed during drilling thus far have been evaluated, and the result is a discontinuation of these measurements during 2005.

The positions and properties of water-conducting fractures comprise very important information that is gathered for the majority of the boreholes in the site investigation. The hydrogeological detailed characterization of deep cored boreholes will include both difference flow logging (PFL), see Figure 3-26, and injection and pumping tests (PSS), see Figure 3-27. The use of the methods will be continuously evaluated and focused to meet the needs that emerge in the modelling.

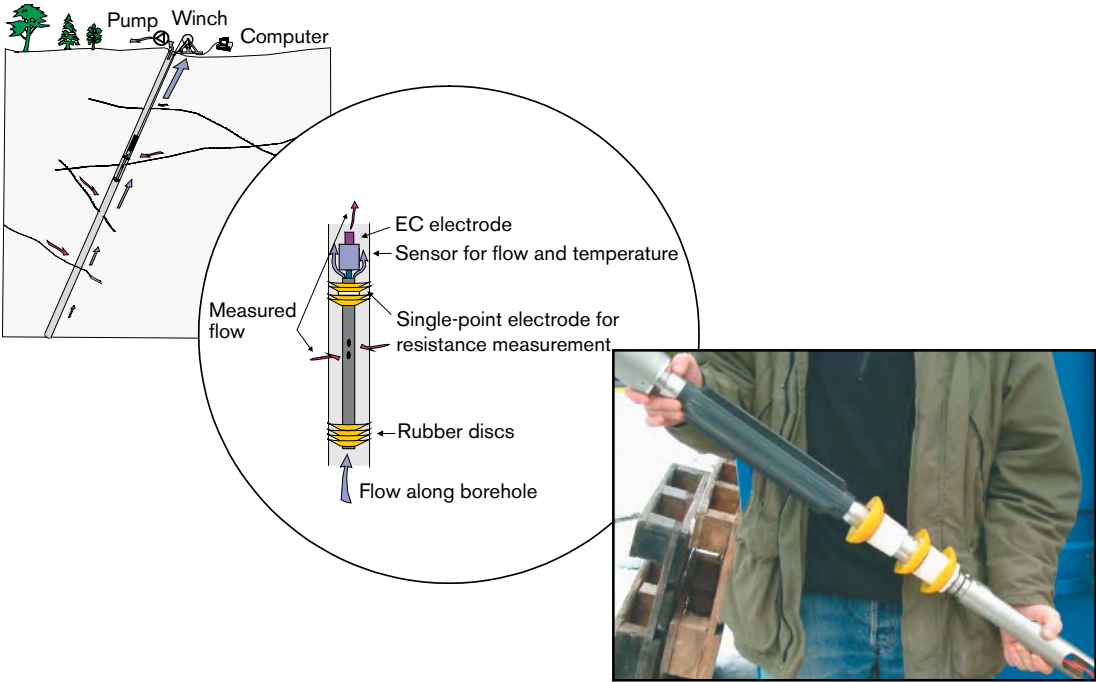


Figure 3-26. Schematic illustration of PFL probe. Together with PSS, this measurement method comprises a cornerstone of the hydrogeological characterization in cored boreholes.

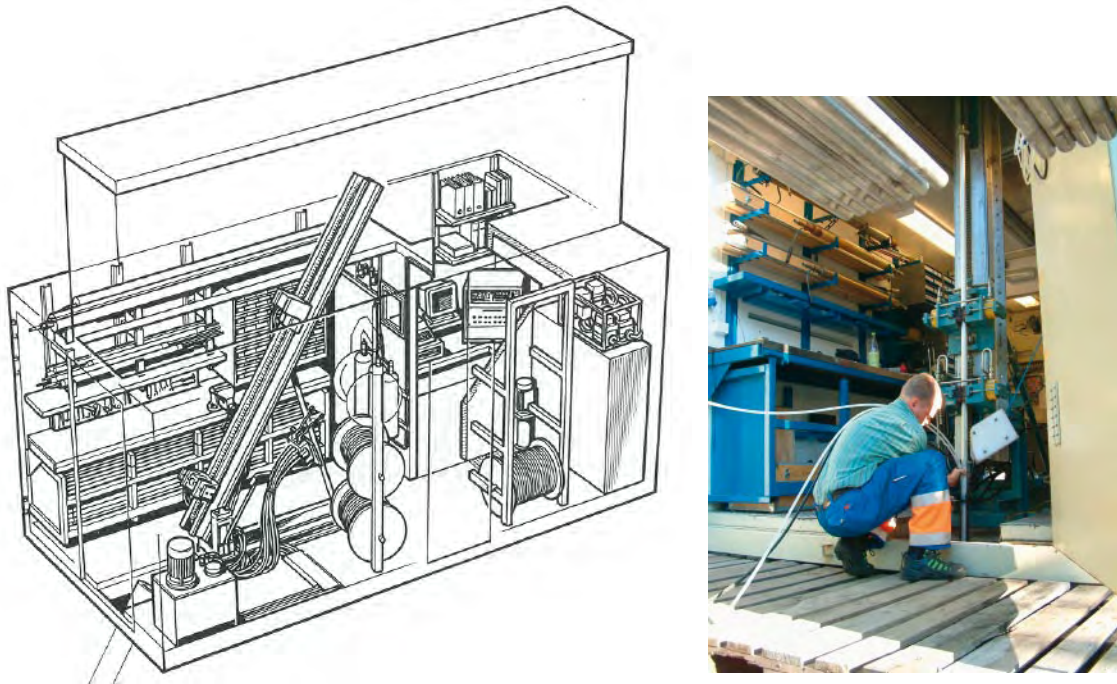


Figure 3-27. Schematic illustration of PSS equipment. Together with PFL, this measurement method comprises a cornerstone of the hydrogeological characterization in cored boreholes.

The reason the investigation methodology includes both methods (PSS and PFL) is that they furnish information that is of importance for the site modelling. Focused investigation programmes for each method could possibly be applied in certain cored boreholes in the future.

The hydraulic injection tests are performed with either 100, 20 or 5 m sections (5 m only in the interval 300–700 m, i.e. at potential repository depth). The more extensive tests (the larger programme) will be performed in about seven boreholes; tentatively these are KLX10 and KLX11 plus five of the medium-long boreholes (500–600 m) that are drilled for characterization and verification of rock volumes for deposition areas and the central area.

Injection tests will not be used for characterization of the short cored boreholes (max 100 m), where hydraulic characterization will only be done with PFL.

In conjunction with the injection tests, pumping tests of individual hydraulic structures and/or sampling of groundwater for chemical analysis will be performed as needed (see section 3.7 Hydrogeochemistry). Pressure responses from pumping tests will be recorded in surrounding observation boreholes.

Measurements of natural groundwater flow are planned in an additional three boreholes: KLX08, KLX10 and KLX11. These measurements will be performed in 3–5 sections per borehole using a dilution method. Together with the measurements in KLX03 and KSH02, these measurements provide a quantification of the natural groundwater flow along an imaginary profile that runs through the rock volume for a possible deposition area in an east-west direction. The measurements will be performed in cooperation with the Transport properties discipline, see section 3.8, which will also perform SWIW tests in conjunction with the groundwater flow measurements.

A number of interference tests will be performed, which are discussed in a separate section further on in this section.

Percussion drilled boreholes

Hydrogeological information is obtained already when percussion boreholes are drilled, since groundwater inflows are monitored continuously and the drilling rate is recorded as well. Immediately after drilling, simple pumping tests are performed in all percussion boreholes. The purpose of these tests is to determine the transmissivity of the borehole and if possible observe pressure responses in surrounding boreholes. Further characterization with injection tests and flow logging is done as needed. In conjunction with the pumping tests, water samples are taken for chemical analysis.

Approximately eight new percussion boreholes are planned for the period 2006–2007. They will be tested as described above.

Flow logging has so far not been performed in the percussion boreholes in the Laxemar subarea due to the fact that hydraulic response measurements have been prioritized. Pumping tests with flow logging (HTHB) will be performed in approximately 5 to 10 percussion boreholes. The holes are selected primarily based on results from drilling, geological mapping and the single-hole pumping tests.

Interference tests

The investigations that are described here mainly relate to points (a), (b), (d) and (e) above.

Interference tests are used to understand the hydraulic contact within the investigation area. Information on how fracture zones and fracture networks are hydraulically connected is used to support the hydrogeological model, among other things. A number of interference tests will be performed.

Interference tests will have a particular focus for the following purposes:

- **Major deformation zones.**

These investigations mainly relate to point (a) above. By penetrating a deformation zone with boreholes at several locations, the variability of the properties in the zone can be studied and, if the zone is not of too low transmissivity, the geometry and extent of the zone can be confirmed by interference tests. Furthermore, any hydraulic contact with nearby deformation zones can be confirmed. The observation points should not be located further away than about 500 m from the tested section in the borehole being pumped. The pumping, which is preferably done with the PSS equipment, must normally continue for several days and be followed by a recovery phase of roughly equal length. It is very important that other activities that might disturb the pressure should not take place during the pumping or recovery phase. In some of these tests it may be of interest to perform tracer tests to confirm connectivity between zones and obtain information on the transport properties of the zones. Tracer tests are planned from case to case and probably require that the boreholes be spaced at less than 500 m. Depending on the transmissivity of the fracture zone, the spacing may be much shorter.

- **Local minor deformation zones in the rock mass (about 10–1,000 m long fractures and fracture zones).**

These investigations mainly relate to point (b) above. In cooperation with the discipline of Geology, the character of local minor deformation zones near the ground surface will be investigated, see 3.3.4. The purpose is both to document a methodology for identifying local minor deformation zones that can be applied to all boreholes and to link geophysical and topographical anomalies to what can be regarded as local minor deformation zones expected to be of importance for the final repository. In this way, data can be obtained for the spatial description of local minor deformation zones in statistical

terms. The zones will be characterized with the aid of a cored borehole in which PFL is performed, and a percussion borehole that is used as a pumping hole in interference testing with the cored borehole.

- **Characterization of the rock mass for HydroDFN.**

These investigations mainly relate to point (b) above. Both the hydraulic DFN models (HydroDFN) and the geological DFN models (GeoDFN) must be better related to both surface data and borehole data, and take any possible depth trends into account in a relevant way. Due to a lack of data, detailed DFN models are constructed near the ground surface in order to verify that data from various sources can be represented by the DFN models. This is then a prerequisite for being able to extrapolate the models towards greater depth, see 3.3.4. For this purpose, five 100 m deep specially positioned boreholes will be drilled at two sites. Both hydraulic single-hole tests and interference tests must be performed in these holes. PFL will be used as the main equipment at both sites. This is a special type of interference test that will be tried to provide a basis for the DFN modeling. This method has not previously been tried by SKB, and depending on the outcome the interference tests may be performed using traditional methodology with pumping between packers and observation of the pressure in the surrounding environment. In the interference tests, three of the holes will be pumped, one at a time, and at the same time PFL logging will be performed in the other four holes. Altogether, three interference tests are planned with one pumping hole and four observation holes each. Tests of this type are tentatively planned to be performed at KLX09 (spring 2006) and KLX11 (autumn 2006). The measurement programme for the autumn of 2006 will be modified based on experience from the measurements performed in the spring of 2006.

- **Large-scale interference test.**

These investigations mainly relate to points (a) and (b) above. In combination with tracer tests, this test is primarily intended to verify site-descriptive models of the deposition area. The tests include the rock mass on the large scale, i.e. including any local major and minor deformation zones. These tests are time-consuming (about 3+3 months) and requires stable hydraulic conditions over a large area. They will therefore only be performed after other investigations have been finished, i.e. after data freeze 2.3, see also sections 3.1 and 3.8.

3.7 Hydrogeochemistry

3.7.1 Purpose and goal

The discipline of hydrogeochemistry includes investigations of chemical conditions in surface water and groundwater down to a depth of about 1,000 m in the bedrock. The two principal purposes of the hydrogeochemical investigations are /SKB 2001a/:

1. To characterize and describe the groundwater with respect to chemical composition, origin, evolution, principal flow paths and retention times, and to identify the chemical reactions and processes that have influenced the evolution of the groundwater up until today in order to be able to predict its future evolution.
2. To obtain representative and reliable values for certain chemical components that are important for designing a final repository for spent nuclear fuel and for carrying out assessments of the long-term safety of the repository. The components referred to here are ones which can, in very high or in some cases too low concentrations, accelerate the corrosion of the copper canisters enclosing the nuclear waste, weaken the barrier of bentonite clay, have a bearing on the design of the backfill material in the tunnels, or enable radionuclides to be transported in the water if a copper canister should begin to leak.

The primary purpose of the planned hydrogeochemical investigations is to provide a more complete picture of the groundwater situation in the Laxemar and Simpevarp subareas by augmenting, verifying and increasing the quantity of data, especially when it comes to deep groundwaters. Chemistry data obtained to date have been used to describe, for example, the depth dependence of the groundwater chemistry. More data from more boreholes will make it possible to interpolate the results to a three-dimensional distribution of the groundwater chemistry in the Laxemar subarea.

Results of hydrochemical investigations under the auspices of the international cooperation at the Äspö HRL and from other investigations (study areas) in Sweden and Finland have yielded a clear picture of the area's large-scale hydrogeochemical evolution. It is described for a near-coastal site in Figure 3-28. The most important factor for the area's evolution is the retreat of a continental ice sheet with subsequent sea stages that cover the area for different lengths of time, depending on the distance to the shoreline today. This conceptual hydrogeochemical model is verified by the ability of hydrogeological calculations to recreate these conditions, cf section 3.6.1.

Distributions of dissolved components, as well as isotope ratios, are needed to provide information on the origin and history of the groundwater. This information, together with a groundwater flow model that describes the dynamic evolution of the groundwater chemistry in the Laxemar and Simpevarp subareas (see Figure 3-28), provides support for the choice of the different type waters (original waters), such as meteoric water, Baltic Sea water, water from the Littorina Sea, glacial meltwater etc, that should be included in mixing calculations. Such calculations are done for the purpose of trying to recreate water compositions in actual water samples with the aid of different proportions of the type waters. Differences between calculated and measured concentrations show to what extent chemical reactions and biological processes have occurred. Equilibrium calculations between chemically active rock minerals and chemical components dissolved in the groundwater show to what extent the hydrogeochemical system is stable or dynamic. The calculations are of importance for the interpretation of the groundwater's turnover times.

Certain chemical components are important for design and safety assessment, and there are stipulated preferences and even requirements regarding their concentrations in the groundwater if the site is to be considered suitable for a final repository. It is, for example, important to show that anoxic (oxygen-free) conditions exist in the groundwater, since the presence of oxygen affects both the tendency of the copper canister to corrode and the solubility of radionuclides. Furthermore, total salinity and concentrations of divalent cations are important for the function of the bentonite. The groundwater's pH and content of colloids and microbes are of great importance for its ability to transport radionuclides. Colloids and microbes can act as carriers of radionuclides. For all these parameters, relatively few data of high quality are needed from repository depth and from the planned repository site.

3.7.2 Important results from completed investigations

A two-year-long sampling campaign for **surface water** in sea bays, lakes and streams was concluded in December 2004. Data were gathered from some twenty sampling points and 37 sampling occasions. The results show that the surface water in the site investigation area is for the most part mesotrophic (neither rich nor poor in nutrients) with a high concentration of humic substances. The results also show that the buffering capacity of the lakes and most of the running waters is good. Most of the sampling points at sea show low concentrations of nutrients, but the nitrogen concentration was elevated in the sheltered near-coastal points /Engdahl 2004a, Ericsson and Engdahl 2004a/. The chloride concentrations in the various sampling points are shown in Figure 3-29.

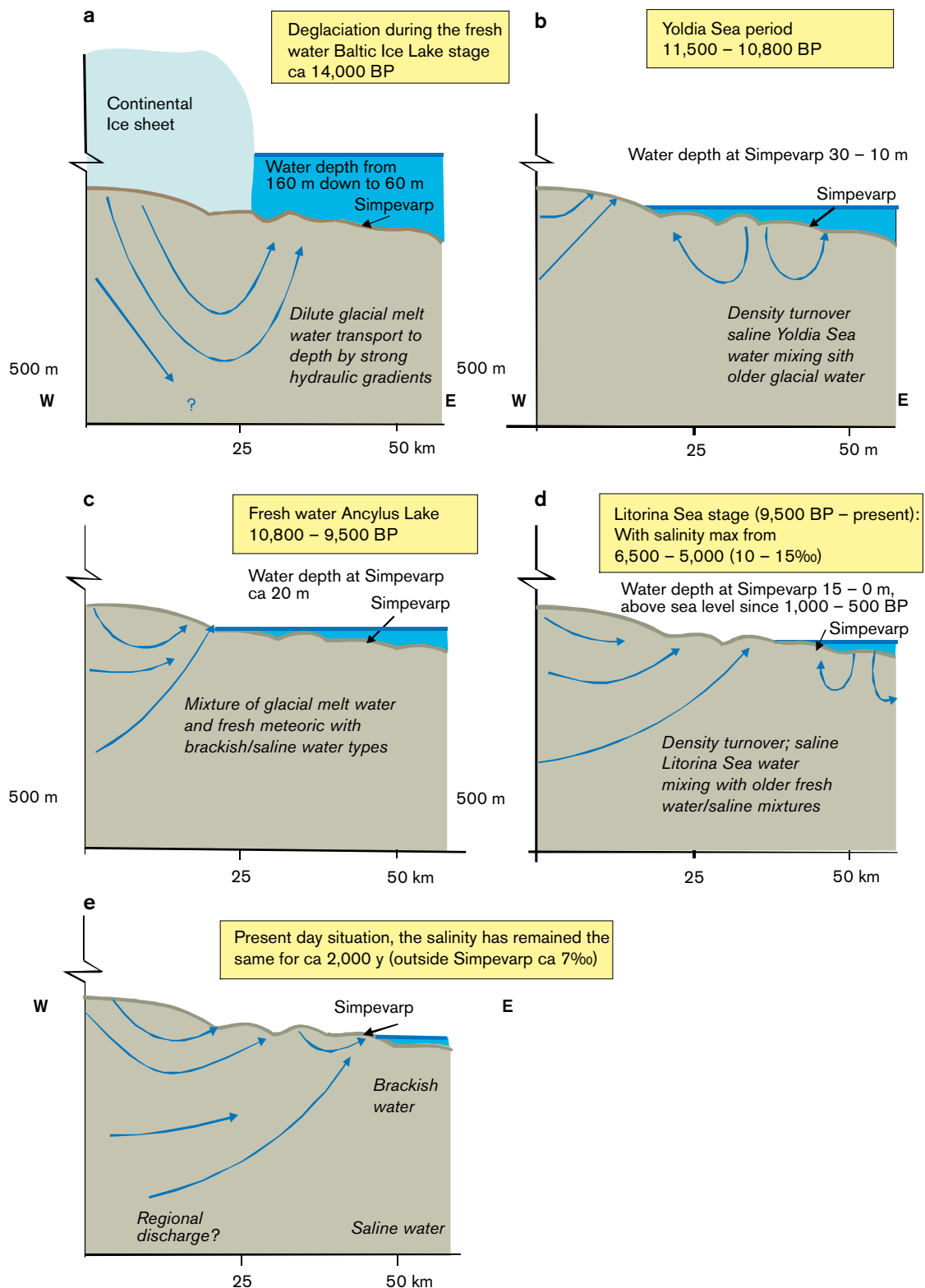


Figure 3-28. Different stages in the history of the Baltic Sea at Simpevarp since the most recent ice age: a) Ice age-Baltic Ice Lake, b) Yoldia Sea, c) Ancylus Lake, d) Littorina Sea, and e) present-day Baltic Sea. These stages with alternating fresh and saline water, as well as the process of land uplift, have affected the evolution of the groundwater and resulted in today's groundwater composition /Laaksoharju et al 2004/.

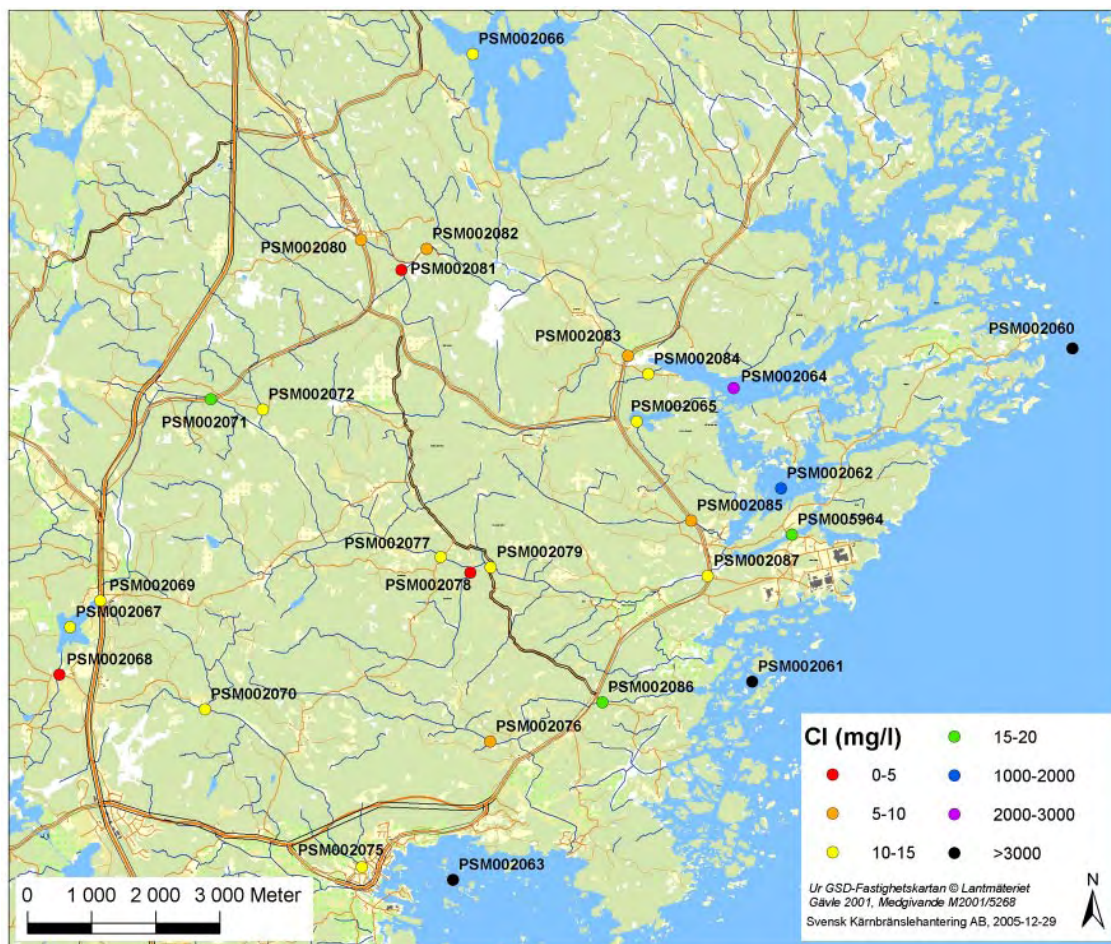


Figure 3-29. Map with sampling points for surface water. The water type is indicated by means of a colour scale from red to black for low to high chloride concentration.

The sampling campaign for **near-surface groundwaters** in the Simpevarp subarea was concluded in June 2005. The results of the sampling include analyses of water samples from 10 soil wells (sampling has continued in one of the soil wells due a deviant chemical composition). Equivalent sampling in soil wells in the Laxemar subarea started a year or so later and will be concluded during the summer of 2006 /Ericsson and 2004b/. The sampling points are presented in Figure 3-30.

Hydrogeochemical data have also been obtained from some twenty percussion boreholes and eleven cored boreholes. As a rule, the samples from the percussion boreholes represent the entire borehole, while five of the cored boreholes (KSH01A, KSH02, KLX03, KLX04 and KLX06) have been investigated in a number of delimited sections. In all cored boreholes, samples have been taken in conjunction with drilling and hydrochemical logging (hose sampling).

In Figure 3-31, the chloride concentrations from percussion boreholes and investigated sections of the cored boreholes have been plotted against depth. For the percussion boreholes it is the average depth of the boreholes that is given in the graph. The graph shows clearly how the chloride concentration in the Simpevarp subarea increases sharply with depth, levelling out at just over 7,000 mg/ in the depth interval 150 to 600 m. The salinity increases again at greater depths. The situation is different in the Laxemar subarea. There the fresh water profile reaches much deeper than in the boreholes in the Simpevarp subarea.



Figure 3-30. Sampling points for near-surface groundwaters during the first two-year-long surveying campaign.

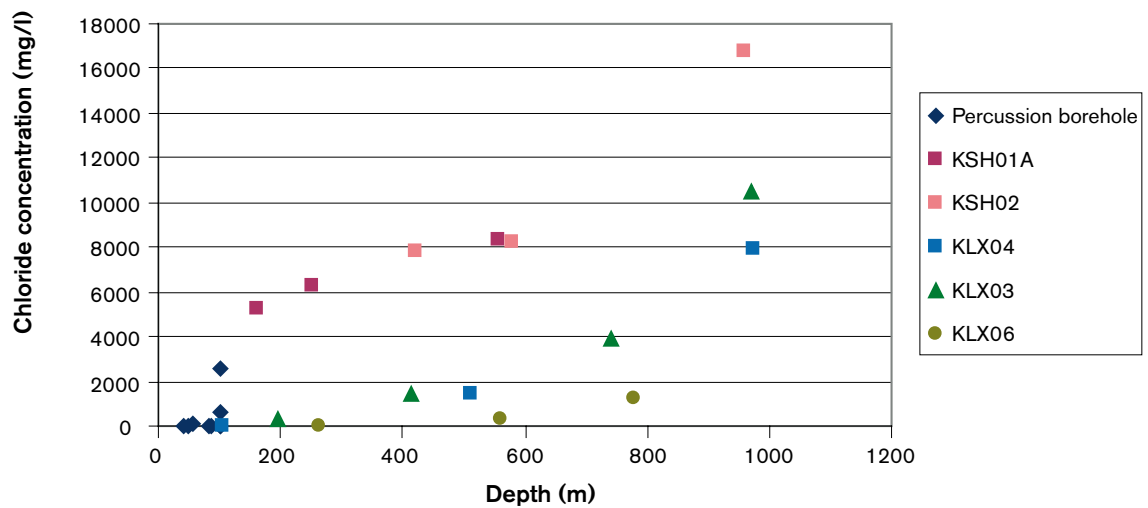


Figure 3-31. Chloride concentrations at different depths in the Simpevarp and Laxemar subareas. For the percussion boreholes, the points have been plotted at the average depth for the boreholes.

On explanation for this may be that the Laxemar subarea rose out of the sea earlier after the most recent ice age than the Simpevarp subarea did. As a result, the originally saline water has gradually been replaced by less saline water. This process has gone on for a longer time in the Laxemar subarea than in the Simpevarp subarea.

In order to show that reducing (anoxic) conditions prevail in the groundwater, redox potential measurements have so far been performed in a total of seven borehole sections at different depths in two cored boreholes (KSH01A and KLX03). The redox potentials lie between -160 mV and -260 mV, which confirms that the conditions are anoxic. Figure 3-32 shows an example of redox potential measurements where the value stabilizes at around -200 mV /Wacker et al. 2004/.

Microbiological investigations have been conducted in sections of the cored boreholes KSH01A and KLX03. The results from KSH01A show that the total number of microorganisms varied between $7.2 \cdot 10^4$ and $1.4 \cdot 10^5$, and the number declines with depth, see Table 3-3. This agrees with earlier observations from the Fennoscandian shield /Pedersen and Kalmus 2004/.

Table 3-3. Results of microbe investigations in KSH01A. The table shows the total number of microorganisms in the different sections.

Borehole (section, m)	Total number of microorganisms (microorganisms ml ⁻¹)	Standard deviation	Number of observations
KSH01A (156.5–167)	$1.4 \cdot 10^5$	$5.8 \cdot 10^4$	8
KSH01A (245–261.6)	$1.0 \cdot 10^5$	$1.5 \cdot 10^4$	6
KSH01A (548–565)	$7.2 \cdot 10^4$	$9.3 \cdot 10^3$	6

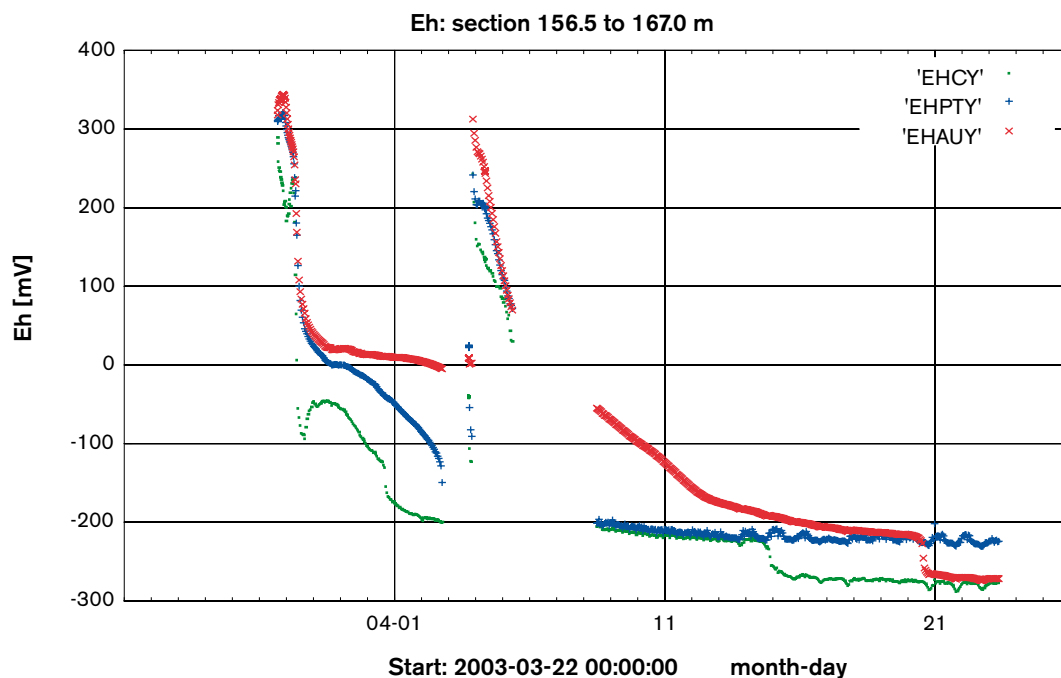


Figure 3-32. Measurements of redox potential (Eh) in cored borehole KSH01A, section 156–167 m. The curves represent different measurement electrodes. The first period in the measurement with a sharp downward trend is due to the fact that the oxygen introduced into the borehole with the equipment has to be consumed. (The increase in redox potential just after 1/4-04 is due to the fact that the equipment was lifted up out of the borehole for a pump change).

3.7.3 Important questions remaining to be answered

The southern and western part of the Laxemar subarea is now the focused area for continued investigations. In the western part in particular, the water composition at repository depth and below needs to be determined in the boreholes drilled there. Data are also needed from the boundary zones that bound the investigation area and from EW007.

Sediment pore water from drill cores taken in wetlands, lakes and sea bays remains to be analyzed. Water that has passed through sediment contains high concentrations of waste products from organic degradation and therefore has a composition that deviates from that of other types of water. The sediment pore water may therefore be a type water that should be included in mixing calculations.

The water's colloid content may be of importance for nuclide transport, since colloids can act as carriers of radionuclides. It is difficult to determine the colloid content of the groundwater, since the concentration can be affected by virtually every change in e.g. pressure, pH, concentration and temperature of the groundwater. Two methods for colloid determination are currently used: 1) fractionation through two cylindrical membrane filters with different permeabilities, i.e. molecules up to a given size pass, and 2) filtration through a series of filters with decreasing pore size.

Important aspects for the continued hydrochemical site modelling are:

- Origin and evolution of the groundwater.
- Hydrochemistry in different transmissive zones and the rock matrix.
- Interaction between surface water and deep water systems.
- Circulation depth for active modern groundwater.
- Occurrence and chemistry of discharge areas.
- Spatial variability.

Additional questions may emerge as the evaluation of chemistry data proceeds, and other prioritizations may become necessary when the analysis has progressed further.

3.7.4 Investigation programme

Continued investigations mainly relate to deep groundwaters. The two-year-long chemical surveys of surface water and precipitation are finished /Ericsson and Engdahl 2005a, Ericsson 2005/. Water sampling in a few select sampling points will be transferred to the monitoring programme, see section 3.10.

Planned hydrogeochemical investigations include cored boreholes, percussion boreholes and certain remaining activities pertaining to near-surface groundwaters. The investigations presented below are based on the programme overview in section 3.1.

Hydrogeochemical investigations in cored boreholes

The hydrogeochemical investigations that are planned in cored boreholes, listed in chronological order from the time of drilling onward, are:

1. Extraction of water samples during drilling with a water sampler developed especially for this purpose is planned in all new cored boreholes (except for boreholes that are only 10–100 m).
2. Hydrochemical logging (hose sampling) is planned in the cored boreholes that are drilled to repository depth and below. Hose sampling is carried out just after completion of the cored borehole in order to obtain an overall picture of the water composition in the borehole after drilling. Furthermore, data can be used to understand the variability in the chemistry and the difference between the chemistry in fracture zones and in open boreholes.
3. Complete chemical characterization is planned in one more cored borehole (KLX08). Sampling is planned in four sections in this borehole. The complete chemical characterization includes colloid and bacteria sampling as subactivities. Fracture-filling mineral analyses are performed in the same borehole sections as chemical characterization of the groundwater.
4. In a few selected cored boreholes where complete chemical characterization is not carried out, supplementary hydrochemical investigations of water chemistry will be performed in conjunction with hydrotests/pumping tests and during dilution measurements/SWIW (see 3.8.4). The plan is for this to be done in six boreholes and a total of 12 borehole sections.
5. Pore water analysis on samples from drill cores (matrix water) is planned to be performed in one more borehole (KLX08).

The above investigation programme for cored boreholes may be modified somewhat as the modelling work progresses. In some cases it may be necessary to perform special groundwater analyses in order to further determine the origin and properties of the groundwater. Special isotope studies (^{36}Cl , $^3\text{He}/^4\text{He}$ and U-series isotope studies) and inert gas analyses (helium, argon, neon, krypton and xenon) can be used in certain cored boreholes to trace the origin of the water, redox conditions and interaction between surface and depth systems.

Hydrochemical investigations in percussion boreholes

In the percussion boreholes where flow logging will be done in the hydrogeological programme, groundwater will also be sampled for chemical analyses. This sampling entails only a little extra labour. The samples provide chemistry data with good distribution over the area and of sufficiently good quality for the three-dimensional hydrogeochemical model and for mixing calculations.

Hydrochemical investigations of near-surface groundwaters

The following hydrogeochemical investigations are planned in near-surface groundwaters:

1. The two-year-long sampling campaign for near-surface groundwaters will be concluded during 2006. Then the sampling will phase into a monitoring programme, see section 3.10.
2. Pore water in frozen sediment cores taken in the summer of 2004 will be analyzed during 2006. These samples represent a sea bay, a wetland and a bog.

3.8 Transport properties

3.8.1 Purpose and goal

The main purpose of the programme is to provide the safety assessment with data for determination of the transport properties of the rock and for calculations of radionuclide transport. The most important transport properties in this context determine the rock's capacity to retard radionuclides:

- Sorption (retention on fracture surfaces and in the pores of the rock).
- Diffusion (penetration into microfractures and pores).

In the case of reactive (sorbing) substances, some of the most important parameters are matrix diffusivity (a measure of how rapidly a substance can penetrate or diffuse through the rock matrix), matrix porosity and sorption coefficients (parameters that measure the rock's capacity to retain different substances on fracture surfaces and in pores). Matrix diffusivity can also be calculated on the basis of determinations of the formation factor (the ratio between diffusion in the rock matrix and in free water). These parameters are determined primarily by laboratory measurements on pieces of drill cores, but also indirectly by means of tracer tests and interpretation of the rock's resistivity.

The advantage of laboratory measurements is that they can be conducted under controlled conditions, while the disadvantage is that they are conducted in a disturbed environment, where the samples have been destressed and where the chemistry is different from that in the natural environment. An attempt is made to overcome this problem and obtain a better understanding of these processes by employing a combination of laboratory measurements and field methods (for example tracer tests and resistivity measurements).

The strategy that serves as a basis for the site-descriptive transport model consists of a strategy for laboratory measurements and their interpretation /Widestrand et al. 2003/, plus a modelling strategy /Berglund and Selroos 2003/. In the former, the quantity of samples and the selection of typical rock types and fracture types to be investigated are specified. The strategy also includes a procedure for how samples that will undergo more extensive analyses of porosity distribution and sorption properties are to be selected. The strategy also stipulates, together with the method descriptions, how data are to be evaluated.

The foundation of the modelling strategy is to combine the three-dimensional flow models of the area with the measured transport parameters. The former provide a statistical description of the spatial distribution of the flow paths, the associated groundwater travel times, and the transport resistances. The transport parameters are utilized to devise a site-descriptive retardation model that describes the retardation of radionuclides in the rock.

An example of what a description of a fracture type can look like is given in Figure 3-33. Co-interpretation between geology, mineralogy, hydrogeochemistry and transport properties is an important part of the site-specific retardation model.

3.8.2 Important results from completed investigations

The goals to date have been to commence time-consuming laboratory measurements on core pieces and to conduct groundwater flow measurements in one of the first deep cored boreholes /SKB 2001a/. These goals have been met with the start of batch sorption measurements in the spring of 2005 and the performance of groundwater flow measurements and single-hole tracer tests (SWIW tests = single-well injection-withdrawal tests) in KLX02 and KLX03 in the Laxemar subarea and in KSH02 in the Simpevarp subarea /Gustafsson and Nordqvist 2005/.

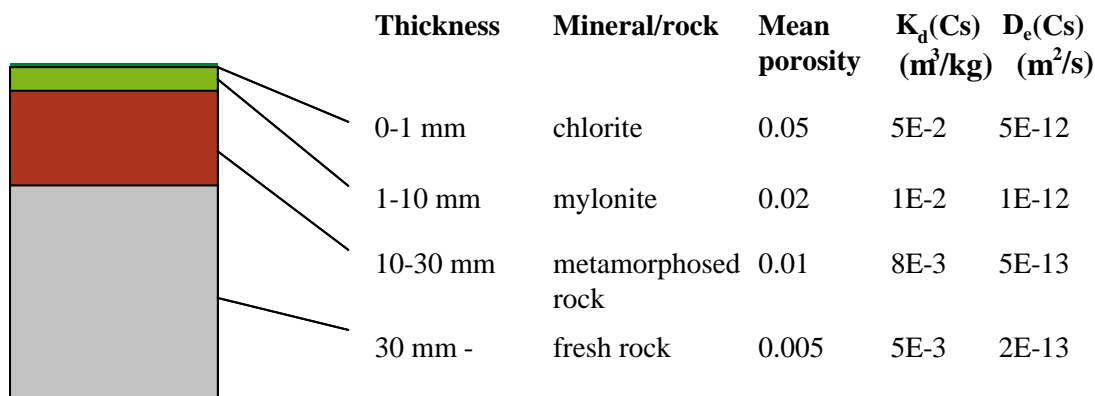


Figure 3-33. Example of description of the rock near a fracture surface with typical retention parameters, K_d (sorption coefficient) and D_e (matrix diffusivity) /Widestrand et al. 2003/.

Through-diffusion measurements on core pieces have been conducted since the spring of 2004, but it has only been possible to determine some 20 or so diffusivity values due to the slow diffusion rate /Börjesson and Gustavsson 2005/. The measurements show that the matrix diffusivity for HTO (tritiated water) lie in the range $D_e = 0.5\text{--}13 \cdot 10^{-13} \text{ m}^2/\text{s}$, which is of the same order of magnitude as has previously been measured in Swedish crystalline bedrock. In order to obtain a larger body of data, diffusivities have mainly been determined indirectly by means of calculations of the formation factor from in situ logging of resistivity in boreholes. This has been done from boreholes KLX03 and KLX04 in the Laxemar sub-area and KSH01A and KSH02 in the Simpevarp subarea /Löfgren and Neretnieks 2005ab/. Figure 3-34 shows the statistical distribution of the formation factor in KLX04. These determinations have also been supplemented with laboratory measurements of resistivity on a hundred or so core samples /Thunehed 2005, Thunehed and Triumpf 2005/.

Porosity measurements performed on approximately 270 samples indicate low porosities in the rock matrix, 0.1–0.5%, for all major rock types /Börjesson and Gustavsson 2005/, which is in parity with what is expected for Swedish crystalline bedrock.

Other important input data for calculation of radionuclide transport are groundwater flow, distribution of flowing fractures and hydrogeochemical properties. Groundwater flow measurements with SKB's dilution probe have been conducted in a total of seven sections in the boreholes KLX02 and KSH02 (depth interval 170–960 m) and measurements are under way in another eight sections in KLX03 (depth interval 120–980 m). The results show great variation in flows and a tendency for the flow to decrease with depth. Hydraulic gradients calculated on the basis of the measured flows lie around 2–9% /Gustafsson and Nordqvist 2005/.

Two single-hole tests (SWIW tests) have also been performed in KSH02 and another is currently being performed in KLX03. The tests are performed using both a non-sorbing tracer (uranine) and a sorbing tracer (caesium). The results from KSH02 show that caesium sorption is on the same order of magnitude as has previously been measured in tests at the Äspö HRL /Winberg et al. 2000, 2002/. Figure 3-35 shows a model simulation of breakthrough curves for uranine and caesium where it can be seen that the fit to the uranine curve is not good for more later times, which may indicate that other processes, for example diffusion, need to be taken into account in order to explain the appearance of the curve.

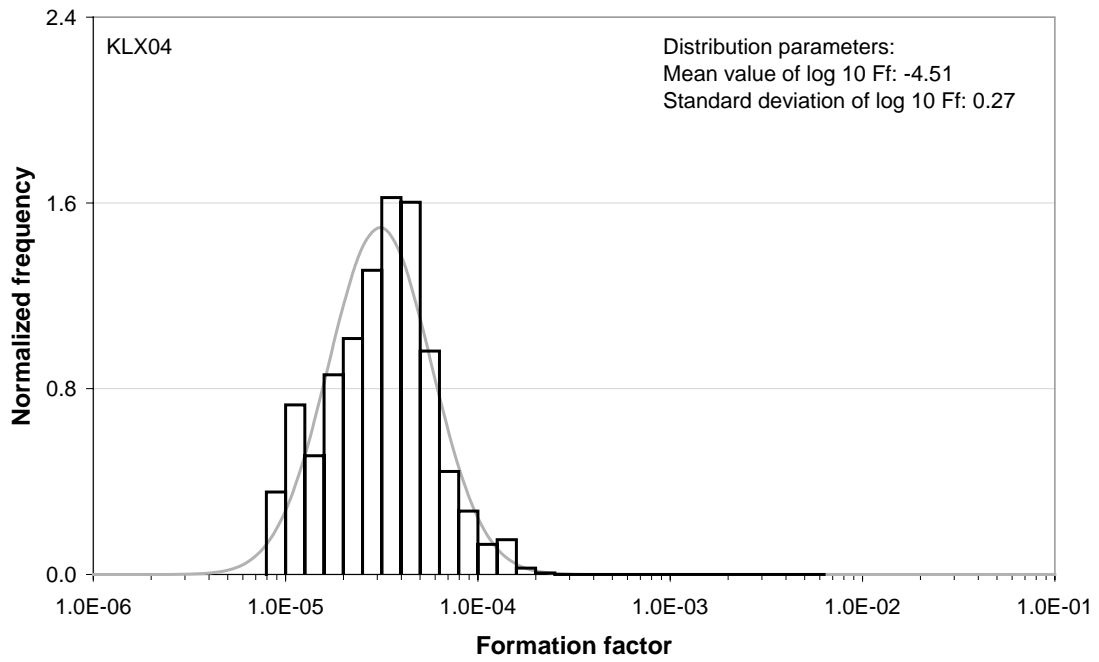


Figure 3-34. Distribution of formation factors for the rock matrix in KLX04.

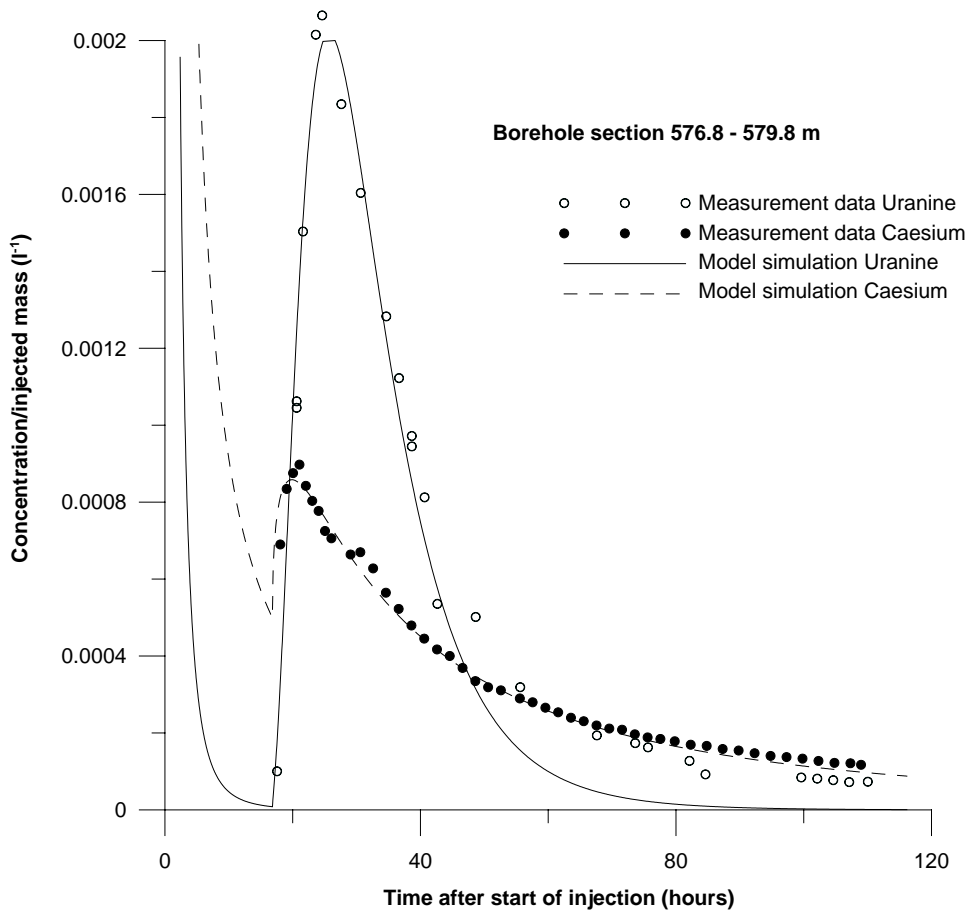


Figure 3-35. Example of model simulation of breakthrough curves from SWIW test with uranine and caesium in section 576.8–579.8 m in borehole KSH02.

3.8.3 Important questions remaining to be answered

Since many of the measurements that are supposed to furnish the modelling with site-specific transport data are still in progress, the modelling work to date has been based on only a small portion of the planned body of data. This has limited the opportunities to identify detailed questions in connection with observations during evaluation and modelling of site data. It should be noted in this connection that site-specific sorption data have not yet been available, and that the description of diffusion properties has largely been based on data from resistivity measurements.

The porosity and diffusivity data that have been presented so far generally indicate relatively great spatial variability. It remains to be seen whether this variability on the measurement scale is also important on the relevant model scales. It is also essential for the modelling to try to determine whether the differences in the properties of different rock types are sufficiently great (i.e. statistically significant) for them to be treated as different units in the transport model. It should also be noted that so far the modelling has not had access to results from measurements on materials from fractures (fracture-filling materials, materials on fracture walls and altered rock materials near fractures), and that the parameters that describe these materials are an essential feature of the “retardation models” that will be presented /Widestrand et al. 2003/.

An important task for the transport programme will be to accumulate a solid body of data regarding the diffusion and sorption properties of the rock mass and the fracture zones. It is important to investigate the spatial variations in the parameter values for the intact rock and to collect data for an identification and description of “typical fractures”, in accordance with the proposed strategy /Widestrand et al. 2003/. It should be possible to obtain this information for the most part from the ongoing laboratory experiments, augmented to some extent during the continued site investigations.

During the work with site-descriptive modelling of transport properties, it has also been found that presentations of other site data and modelling results that can provide support to the description will probably be more important than was assumed from the start. This means that it must be shown that the retention processes that are included in the description will also be activated on the site in question and that the parameter values given for these processes are reasonable. Collection and analysis of data from other disciplines have thus been important in the modelling done to date, see /Byegård 2005/. The use of supporting data and modelling, including process-based modelling, will need to be further developed later on.

It is also important to clarify the natural movements of the groundwater within the investigation area and its boundary zones. How large are the water flows through the area? What are the most important zones from a flow viewpoint, and what are their flow properties? Such questions can be answered by measuring groundwater flows in fractures and fracture zones and thereby estimating the hydraulic gradient. Connections between fracture zones at depth and the highly transmissive superficial part of the bedrock are of special interest, but connections between fracture zones are also important to establish, as well as how the water flow varies with depth along a fracture zone. These questions will be dealt with in close cooperation with the hydrogeological programme.

Other important questions for the disciplinary programme are clarifying the highly transmissive fractures and fracture zones and their interconnections, as well as the importance of radionuclide retardation in the soil layers of varying thickness that are found in the area. The sorption properties of the soil layers will therefore be studied by means of laboratory measurements (batch sorption).

3.8.4 Investigation programme

Based on the programme overview in section 3.1, the investigation programme for the transport properties of the rock is presented here.

Most of the laboratory programme will be finished in 2006, but through-diffusion measurements will probably continue until 2007 in the impervious rock types. Batch sorption measurements, both in the soil layers and on drill cores, and porosity distribution determinations using the PMMA method /Siitari-Kauppi et al. 1998/ will be completed during 2006. It may be necessary to perform supplementary measurements in important boundary zones.

Determinations of the formation factor by analysis of resistivity measurements have proved to be a good method for obtaining a large body of statistics for evaluating diffusivities in the rock matrix. Analysis will therefore be performed for all deep cored boreholes. In situ results will be verified by taking drill core samples in certain selected boreholes and measuring resistivity in the laboratory. The results of the resistivity measurements will be able to be used in the modelling to evaluate the spatial variability and scale dependence of the diffusivity.

Groundwater flow measurements and single-hole tracer tests (SWIW tests), which are being performed in cored borehole KLX03 during the autumn of 2005, will be performed in 2–3 additional cored boreholes during 2006–2007. At present, measurements are planned in KLX08, KLX10 and KLX11. The exact choice of borehole and borehole section is influenced by what the transmissivity distribution looks like in the boreholes.

Hydrogeological characterization of major deformation zones by means of interference tests is described in 3.6.4. The possibilities of performing a controlled cross-hole tracer test in a part of the zone or in one or more of these tests will be examined. The purpose of such a test would be to obtain a verification of the connectivity and geometry of the zone and, if possible, an idea of the transport properties of the zone, for example indications of piping.

Large-scale cross-hole tracer tests often require preparations in the form of an infrastructure with a number of instrumented boreholes. By “instrumentation” is meant in this case that the boreholes are divided into isolated sections, permitting pressure recording and tracer injection in individual fracture zones. Cross-hole tracer tests, which must be performed late in the programme when other disturbing activities have been concluded, can provide a comprehensive picture of the magnitude of the water transport and the transport pathways in the area. Besides the above-mentioned tracer tests in individual deformation zones, a large-scale tracer test is planned in the entire rock mass, including local major and minor deformation zones. In view of the fact that these tests need to be performed under relatively undisturbed conditions and over a long period of time (months), it would be appropriate to perform a large-scale tracer test in combination with a long-term pumping test (LPT) as a verifying test at the end of the site investigation, when other investigations have been completed, i.e. after data freeze 2.3, see also section 3.1.5.

Tracer tests in an individual fracture or fracture zone for the purpose of demonstrating that sorption and diffusion parameters determined from laboratory experiments also apply on a larger scale are not currently planned during the site investigation. Instead, these tests are planned to be performed under ground during the final repository’s construction phase.

When possible with respect to distance and time aspects, tracers will be added to the flushing water in conjunction with the drilling of future cored boreholes so that transport between the flushing water well and the cored borehole can be studied.

3.9 Drilling

3.9.1 Purpose and goal

Drilling is not a discipline of its own in the sense that it is included in the site-descriptive model. Rather, it is a support activity and a necessary prerequisite for being able to collect discipline-specific data from under ground for the site-descriptive models.

Drilling and borehole investigations are the only methods that can provide exact descriptions of conditions at depth in the bedrock. Surface-covering geological and geophysical surveys from the ground surface and from the air are necessary complements as a basis for an integrated analysis of soil and rock below the ground surface. Drilling provides an opportunity to take samples of the material in the form of drill cuttings (rock chips) or drill cores. The borehole is then used to investigate by means of various borehole methods the properties of the rock (mineral distribution, fractures, stresses, permeability etc), as well as groundwater flows and chemical composition of the groundwater, in other words the investigations in boreholes that are described in sections 3.3–3.8. Drilling provides detailed information along the borehole, but the information on the rock volume is in the form of more or less sparse random samplings. This is a clear limitation, since the bedrock often displays great spatial variation. Drilling and borehole investigations are a necessary complement to the surface-covering geological and geophysical surveys from the ground surface and from the air to obtain the body of data needed for an integrated analysis and 3-D modelling of bedrock properties.

Three main types of boreholes are utilized in the site investigation:

- Cored boreholes, for investigating the rock down to a maximum depth of about 1,000 m /Ask et al. 2005c/.
- Percussion boreholes, through soil layers and the superficial part of the bedrock, down to a maximum depth of about 300 m /Ask et al. 2005b/.
- Soil boreholes, down into or through the overburden and a short way down into the surface rock /Johansson and Adestam 2004/.

3.9.2 Important results from completed investigations

The maps in Figure 2-10 and Figure 2-11 show locations and types of all boreholes drilled to date in the investigation area.

The investigations for which the boreholes are used impose special requirements on borehole designs and high quality of execution. These requirements pertain, for example, to straightness and other geometric properties, choice of materials in installations, cleanliness, flushing water handling and documentation of the drilling process. These requirements have largely been met. The technical modifications that have been made have been aimed at simplifying and improving efficiency, without compromising quality.

This is not to say that the drilling work has proceeded entirely without mishap, since this would hardly be possible, especially when core drilling to great depths. But as a whole the disruptions have been few and not serious. The successful drilling can be attributed to both the methodological knowledge accumulated in earlier phases of the nuclear waste programme (study areas, Äspö HRL, and preparations for the site investigations) and the skill of the drilling contractors.

Core drilling

The situation at mid-year 2005 is that a total of nine drilling sites have been established in the Simpevarp and Laxemar subareas. Ten cored boreholes with lengths of around 1,000 m have been completed during the site investigation on the two subareas, drilling of the eleventh cored borehole has just started and the twelfth will soon begin. In addition there are three 100-m boreholes and one 200-m borehole. With the necessary drilling equipment, arrangements for flushing water handling, utility systems, peripheral equipment, storage areas and access road, a drilling site resembles a small building site. See Figure 3-36, which shows the drilling site at KLX05.

Table 3-4 summarizes technical data for the cored boreholes that had been drilled up to 1 July 2005. The holes are either nearly vertical or inclined at about 60°. Completely vertical holes, as well as holes with an inclination of less than 60°, are avoided for measurement-related reasons, although they would not entail any drilling-related problems. In core drilling the diameter of the cored hole is 75.8 mm and the diameter of the core is 50.2 mm.



Figure 3-36. Drilling site KLX05 in the Laxemar subarea.

Table 3-4. Technical data for cored boreholes drilled during the site investigation in Oskarshamn.

Designation	Type	Orientation (bearing/ inclination)	Length (m)	Vertical depth (m)	Comment
Simpevarp subarea					
KSH01A	Telescopic borehole	174/81	1,003	964	Drilled to obtain geological information from the eastern part of the Simpevarp Peninsula and provide a basis for further investigation at depth. Complete chemical characterization performed. /Ask et al. 2004a/
KSH01B	Cored borehole	178/88	100	100	At KSH01A. Drilled to get core from the first 100 m.
KSH02	Telescopic borehole	331/86	1,001	993	Drilled centrally on the Simpevarp Peninsula for investigation of the bedrock down to about 1,000 m. Rock stress measurements performed with overcoring method. /Ask et al. 2004b/
KSH03A	Telescopic borehole	125/59	1,001	827	Drilled for investigation of deformation zone NE024 in the eastern part of the subarea. /Ask et al. 2004c/
KSH03B	Cored borehole	128/64	101	90	At KSH03A. Drilled to get core from the first 100 m.
KAV04A	Telescopic borehole	77/85	1,004	990	Drilled on Ävrö to investigate a lineament dipping from the north. Rock stress measurements performed with overcoring method. /Ask et al. 2005a/
KAV04B	Cored borehole	134/90	101	101	At KAV04A. Drilled to get a core for the first 100 m.
Laxemar subarea					
KLX03	Telescopic borehole	199/75	1,000	952	Drilled in the southwestern part of the Laxemar subarea for an initial investigation of the bedrock there. Complete chemical characterization performed. /Ask et al. 2005d/
KLX04	Telescopic borehole	0/85	993	963	Drilled centrally in the subarea for investigation of the bedrock. Rock stress measurements performed with overcoring method. /Ask et al. 2005c/
KLX05	Telescopic borehole	190/65	1,000	871	Drilled in the southern part of the subarea to investigate the contact between granite and quartz monzodiorite and whether the deformation zone NW042 dips toward the north. /Ask et al. 2005e/
KLX06	Telescopic borehole	330/65	995	798	Drilled in the northeastern part of the subarea to investigate deformation zone EW002. /Ask et al. 2005f/
KLX07A	Telescopic borehole	175/60	845	628	Drilled from the same drilling site as KLX02, but southward to investigate the rock volume beneath deformation zone EW007, eastern part.
KLX07B	Cored borehole	174/85	200	197	Drilled as a B hole to both KLX02 and KLX07A to get core from the first 200 m.
KLX08	Telescopic borehole	199/60	1,000	828	Drilled from the same drilling site as KLX04, but southward to investigate the rock volume beneath deformation zone EW007, western part. Complete chemical characterization will be performed.

Designation	Type	Orientation (bearing/ inclination)	Length (m)	Vertical depth (m)	Comment
KLX09	Telescopic borehole	267/85	Begun 26 August 2005		Drilled centrally in the northern part of the subarea to obtain more knowledge of the properties of the rock mass and the occurrence of local minor deformation zones.
KLX10	Telescopic borehole	251/85	Begun 18 June 2005		Drilled in the central part of the subarea to obtain more knowledge of the properties of the rock mass and the occurrence of local minor deformation zones.

The long cored boreholes are all of telescopic design, see Figures 3-37 and 3-38. This means that the first 100 m are percussion-drilled with a diameter of 200 mm, or 250 mm if stabilization and/or sealing is needed. If this is the case, the whole borehole is lined with a stainless steel casing and the whole gap to the rock is sealed with cement. Otherwise casing is only set through soil and about 10 m down into the rock and the gap is grouted so that no soil water will penetrate into the borehole. A loose support casing is then installed together with pumping and measurement equipment. Finally, another support casing is fitted to centre and support the drill string. When this has been done, core drilling from 100 m to full depth can be carried out. During drilling, the wide upper part of the borehole is airlift pumped so that as much flushing water and drill cuttings as possible will be transported up

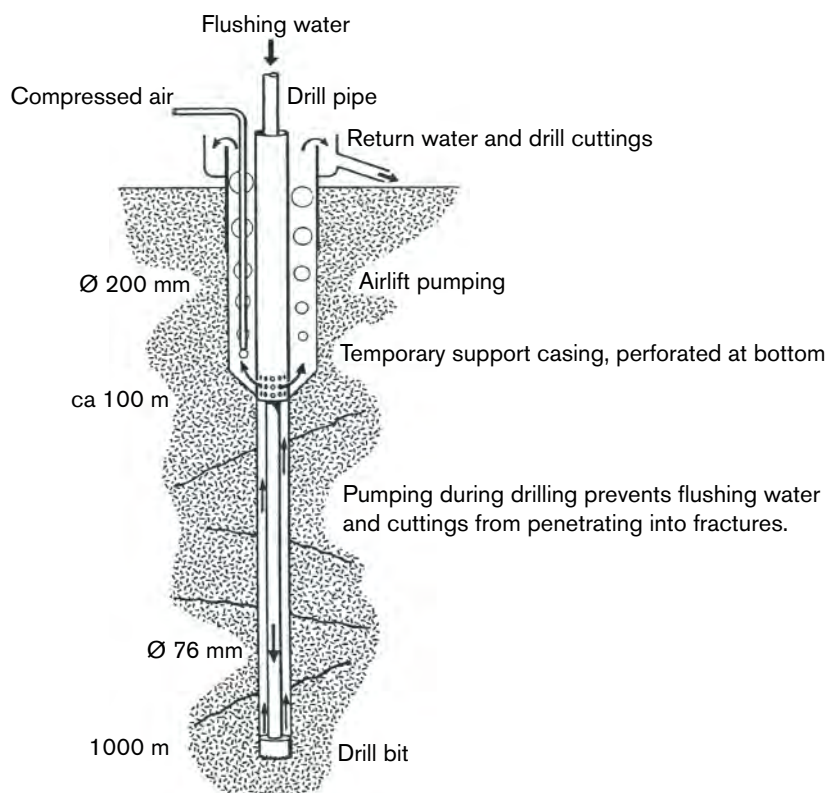


Figure 3-37. Drilling of cored borehole with telescopic part. After drilling the temporary support casing is removed. Thanks to the design of the borehole, pumping tests can then be performed with a submersible pump and an extensive packer system for groundwater monitoring can be installed (see Figure 3-48).

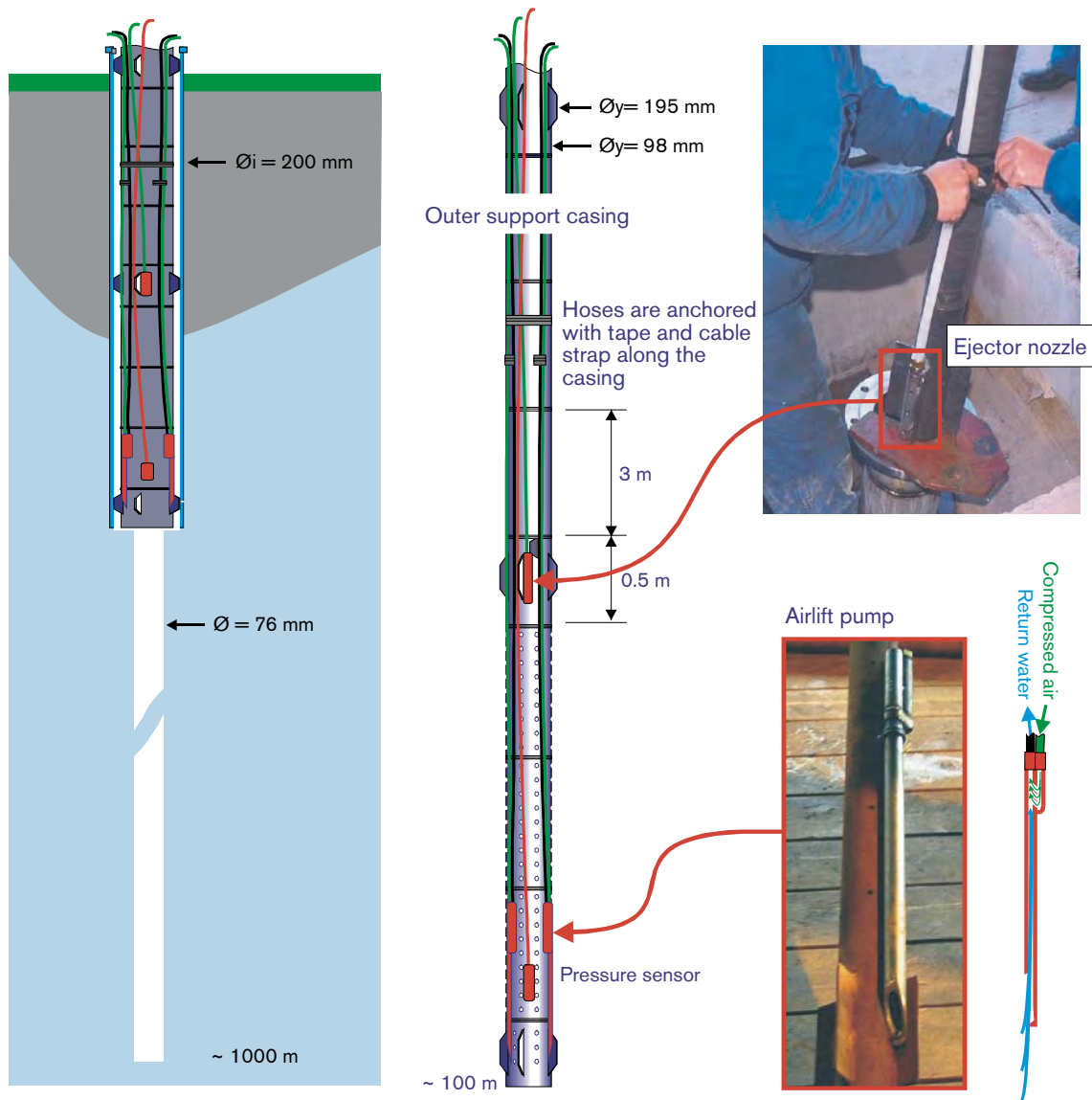


Figure 3-38. Schematic illustration of support casing in the telescopic part of the cored borehole and installations for airlift pumping during core drilling.

out of the borehole. After completed drilling, depth calibration grooves are cut in the borehole wall approximately every 50 m, after which the casing is removed and the deviation is measured. The deviation of the borehole is checked during drilling and if it is greater than the limit set for the borehole, directional drilling is used as needed.

The average core drilling capacity has been about 80 m per week (7-day week with drilling 12 hours per day). On average, each drill bit has managed about 80 m of drilling, after which it has been necessary to change the bit. Including time for establishment etc, it takes about three to four months to drill a long cored borehole.

No great water inflows have been encountered in the percussion-drilled part of the telescopic holes, see Figure 3-39. During the entire core drilling process from about 100 m to about 1,000 m, pumping tests for capacity determination and water sampling have been performed every 100 m, sometimes at closer intervals if a distinctly water-conducting fracture zone has been indicated. If more than 1 litre/minute has been measured, a pressure measurement was performed in the same section, see also section 3.6.2.

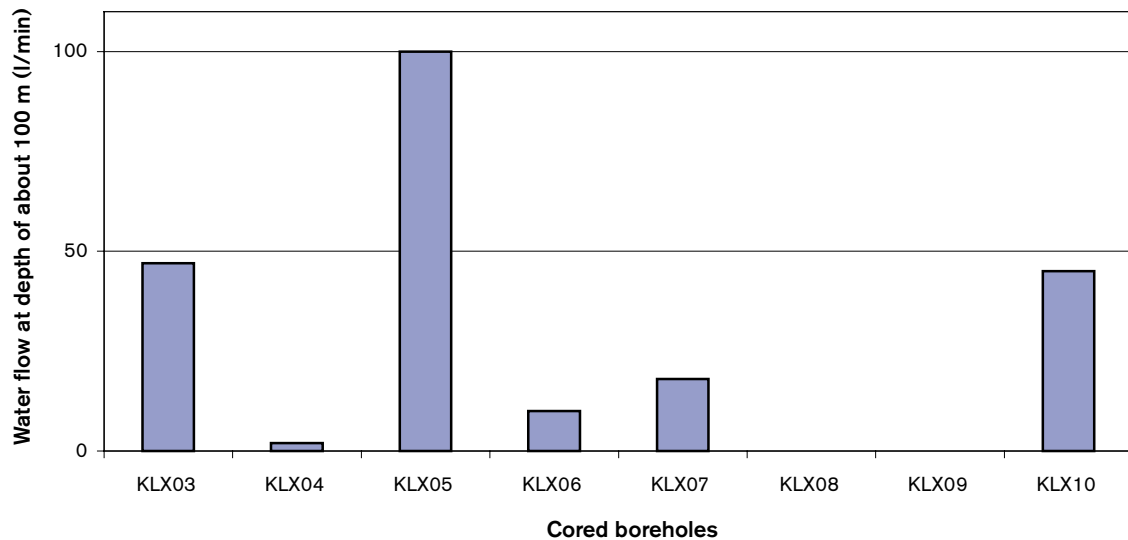


Figure 3-39. Measured water inflows in telescopic parts of cored boreholes done prior to core drilling during the site investigation in the Laxemar subarea. In borehole KLX03, watertight casing was installed along the entire telescopic part, and in KLX05 the 75–100 m section was stabilized with cement before core drilling continued from a depth of 100 m.

Flushing water quality

Flushing water for core drilling has been taken from four different percussion-drilled flushing water wells:

- HSH03 – supplied flushing water to KSH01, KSH02, KSH03 and KAV04.
- HLX14 – supplied flushing water to KLX03.
- HLX10 – supplied flushing water to KLX04, KLX05, KLX07, KLX08 and KLX10.
- HLX20 – supplied flushing water to KLX06 and KLX09.

Before the water is used for flushing its quality is checked primarily with respect to salinity and organic content. The water is pumped from the approved well to the drilling site, where pressurized nitrogen bubbling is done to minimize the concentration of dissolved oxygen in the water. After irradiation by UV light and marking with a tracer, the water is ready to be pumped down into the borehole. The purpose of UV irradiation is to kill bacteria and prevent organic growth. Marking with uranine tracer makes it possible to keep track of the flushing water that comes in return during drilling and to detect any residues of flushing water in water samples taken during pumping tests, which are performed both during drilling and in later stages of the site investigation.

Percussion drilling

The procedure for percussion drilling of holes has been developed since the site investigation started, which has led to more efficient drilling. With the procedure that is currently used, a 200 m borehole is finished in 3–4 days. Figure 3-40 shows geological mapping of drill cuttings during percussion drilling.

Altogether, 35 percussion boreholes have been drilled during the site investigation in Oskarshamn, see Figure 2-10. They have a diameter of 140 mm and the majority are 100–200 m long. With few exceptions, the percussion boreholes have been drilled through water-conducting fracture zones. Figure 3-41 shows depth and measured flows for all

percussion boreholes drilled in the Laxemar subarea. As shown by the figure, the water flows cannot be correlated with hole depth, but mainly with whether any water-conducting structure has been penetrated.



Figure 3-40. Percussion drilling and mapping of drill cuttings in HLX17.

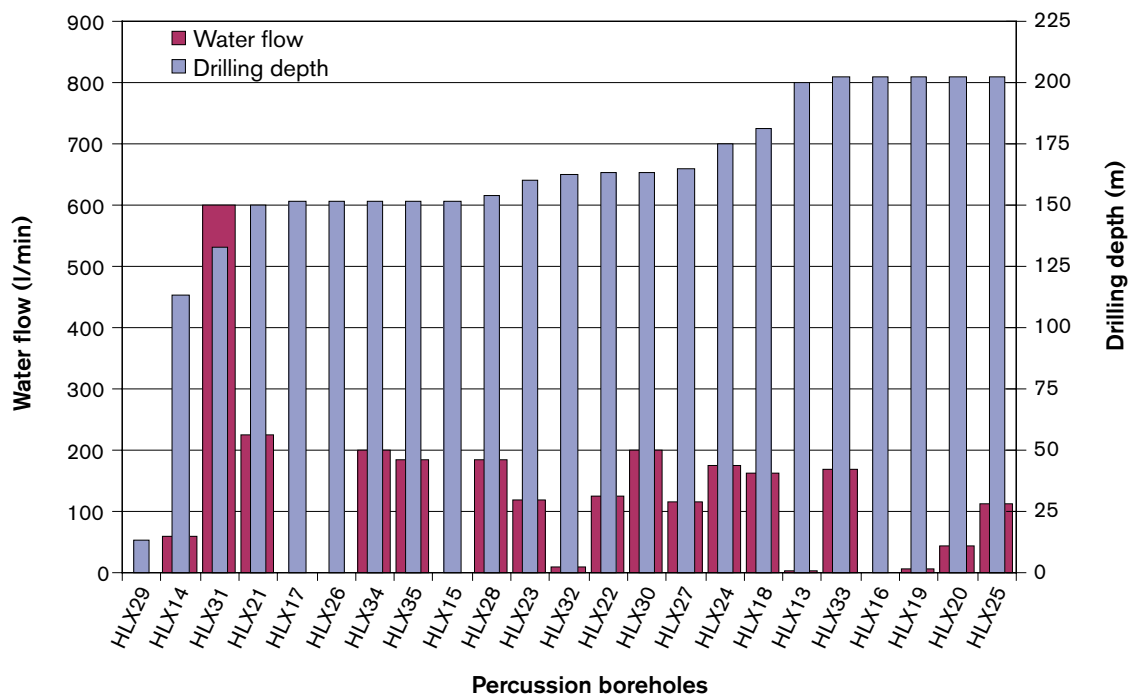


Figure 3-41. Borehole lengths and measured water inflows in percussion boreholes in the Laxemar subarea.

Soil drilling

Soil drilling has been carried out for two main purposes. Firstly, wells (about 15) have been bored for environmental monitoring at the drilling sites, and secondly holes have been bored to determine soil depth and type, to measure the hydraulic conductivity of the soil layers, and to take samples of groundwater. Most soil boreholes are included in the monitoring programme for groundwater levels, and some are used to monitor groundwater chemistry and ecosystems. The location of the soil boreholes is shown in Figure 2-11. Soil drilling is done using conventional techniques. The boring machine is chosen based on requirements on capacity and off-road mobility. Figure 3-42 shows a photograph of a soil drill rig.

3.9.3 Investigation programme

Core drilling

The background and strategy for the continued investigations are described in Chapter 2, while Chapter 3 (section 3.1) presents an overview of the investigation programme, including the remaining drilling (Table 3-1). Table 3-5 shows ongoing and planned cored boreholes with concise information on purpose, planned length, direction and inclination. The uncertainty regarding the specifications for an individual borehole increases the farther ahead in time its execution lies. Minor departures in execution may be made based on the results of drilling and other investigations as the investigation work proceeds. The total quantity of core drilling is estimated to be about 10,000 m from July 2005 up to the conclusion of drilling in the spring 2007. Planned locations for remaining cored boreholes are shown in Figure 3-1.



Figure 3-42. Soil drill rig.

Table 3-5. Planned cored boreholes in the Laxemar subarea, cf Table 3-1.

(The particulars are preliminary in many cases and are subject to modification, partly because the results of continued investigations may warrant modification of the purpose and partly in conjunction with the detailed planning. The final particulars are determined in borehole decisions.)

Designation	Location	Length (m)	Direction/inclination	Comment
Completion of ongoing and planned investigations north of EW007				
KLX09	New drilling site	700–1,000	W/85°	Telescopic borehole, started 26 August 2005.
Completion of ongoing investigations centrally and south of EW007				
KLX10	New drilling site	700–1,000	W/85°	Telescopic borehole, started 18 June 2005.
Characterization at depth in the western part of Laxemar				
KLX11A	New drilling site	700–1,000	Probably E/85–75°	Telescopic borehole. Investigation of quartz monzodiorite at depth in the southwestern part of the area.
Characterization and verification of local major deformation zones				
KLX14A	New drilling site	300–400	Not decided	Investigation of NS059. No telescopic part.
KLX15A	Possibly same as KLX05	300–400	Not decided	Investigation of NS046. No telescopic part.
KLX16A	New drilling site or same as KLX03	300–400	Not decided	Investigation of NW051 or NW932. No telescopic part.
KLX17A	Possibly same as KLX14	300–400	Probably N/about 60°	Investigation of EW900. No telescopic part.
KLX19A	New drilling site	300–400	Probably S/about 60°	Investigation of NW042. Telescopic borehole.
KLX20A	Same drilling site as KLX11	300–400	Probably W/about 60°	Investigation of NS001. Telescopic borehole.
KLX21A	Not decided	300–400	Not decided	Investigation of NE005. No telescopic part.
Characterization of local minor deformation zones				
KLX MDZ	Not decided	10–100	Not decided	20–25 short cored borehole without telescopic part. Total about 1,300 m.
Data as a basis for DFN modelling				
KLX09B–F KLX11B–F	Not decided	about 100	Not decided	2x5 boreholes. No telescopic part. Total about 1,000–1,200 m.
Characterization and verification of rock volumes for deposition areas				
KLX12A	Same as KLX05	500–600	Probably NW/about 75°	Telescopic borehole. Rock stress measurements performed with overcoring method.
KLX13A	New drilling site	500–600	Probably S/steep	Telescopic borehole.
KLX18A	Possibly same as KLX14	500–600	Not decided	Telescopic borehole.
Characterization and verification of rock volumes for central area, shafts and ramp				
KLX22A	Not decided	500–600	Nearly vertical	Central area, location alternative "Central". Telescopic borehole.
KLX23A	Possibly same as KLX19	500–600	Nearly vertical	Central area, location alternative "West". Telescopic borehole.

The technical execution is more or less unchanged with two heavy machines working in parallel. A third heavy machine will probably be used during the final phase of the drilling at the end of 2006/beginning of 2007. The lengths of the boreholes will mainly vary between 400 and 600 m. Telescopic parts will not be drilled in certain boreholes with lengths around 400 m that are drilled for investigation of geological structures (deformation zones). Besides the two heavy machines, a lighter machine will be used to drill cored boreholes with lengths around 100 m or in certain cases even shorter and with a diameter of 75.8 mm. The lighter core drilling machine requires only a tractor road and does not require such a big and well-equipped drilling site as the heavy machines. The purpose of the short holes is partly to provide data for a statistical fracture model (DFN) and partly to permit investigations of local minor deformation zones (MDZ).

A general timetable with projected sequence for the remaining core drilling is shown in Figure 3-43 below.

Percussion drilling

It is estimated that about 10 percussion boreholes will be drilled for the remaining investigations. The majority of the percussion boreholes will be drilled to obtain geometric information on deformation zones before positioning of cored boreholes.

Soil drilling

A small number of soil boreholes will be drilled for environmental monitoring and for other investigations of overburden, see also the programme for hydrogeology in section 3.6.4.

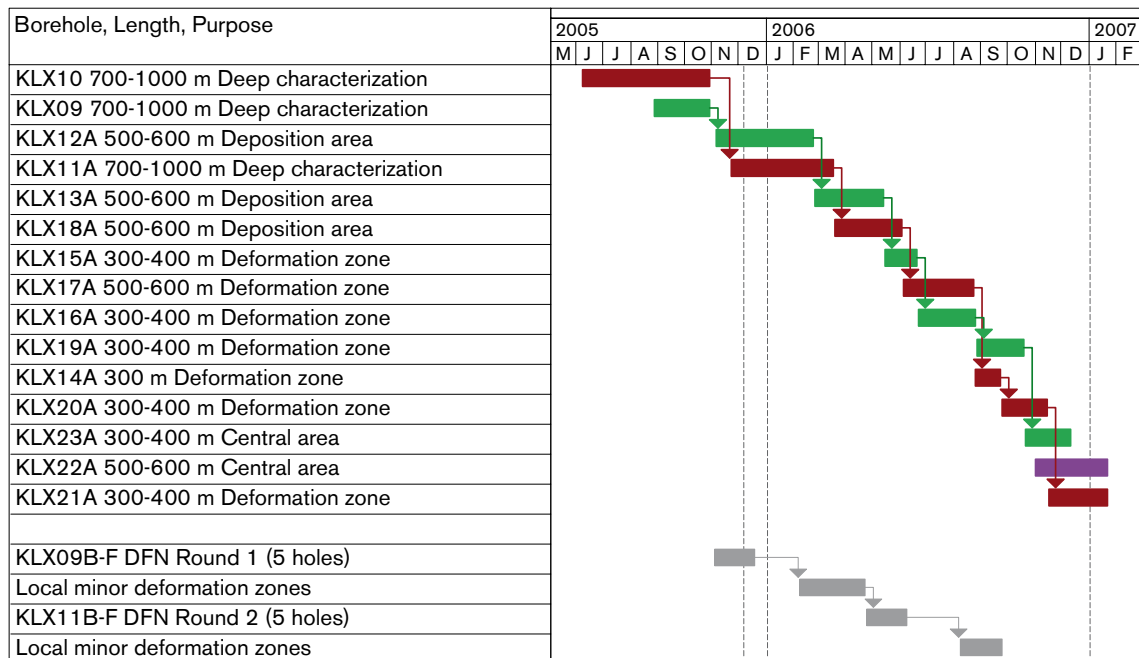


Figure 3-43. Timetable and projected sequence for the remaining core drilling. The two heavy core drilling machines are shown with brown and green and the lighter machine with grey. During the final phase of the drilling a third heavy machine will be used, which is shown with purple.

3.10 Monitoring¹⁰

Monitoring is important for many of the parameters included in the site investigation for several reasons. Partly to understand natural variations and process, but also to obtain a frame of reference for both safety assessment and repository design, as well as for assessment of the impact on environment and health.

Many of the investigated parameters, such as precipitation and groundwater levels, will exhibit variations over time. One reason for this is seasonal variations in precipitation and temperature. There may also be other, more unpredictable causes, such as long-range variations or trends in meteorological parameters, as well as random events, which cause one or more parameters to vary over time. Furthermore, investigations and work in soil layers and in the bedrock may affect the parameters.

Being able to interpret and understand variations over time is an important part of the work of establishing primary baseline data for the site. Monitoring is therefore an important part of the site investigation. With the site's primary baseline data as a reference, it is possible to detect changes that are due to the construction of the final repository, and differentiate between natural changes and variations in time and space that are due to human activities.

Time series are needed for parameters that exhibit clear variation over time, for at least two reasons. In the first place, the site investigation includes for many parameters an estimate of "typical" values (mean value, median value etc) or extreme values (minimum, maximum, etc), as well as a measure of how these values vary. Knowledge of patterns in and the scope of variations over time can be of great importance for our ability to describe site-specific conditions correctly and to model important processes. In the second place, many site-specific conditions will change during the construction and operation of the final repository, both for natural reasons and as a consequence of the activities on the site. In order to be able to discover and quantify these changes, it is necessary to have a clear picture of "undisturbed" conditions on the site. Moreover, knowledge of undisturbed conditions, together with good reference data, can greatly improve our ability to distinguish between natural changes and changes caused by activities on the site.

The site investigation therefore includes collection of time series for all important parameters that show a clear variation over time, i.e. parameters for which an instantaneous "snapshot" is not enough to characterize undisturbed conditions or processes or ones that can be expected to change as a result of the construction and operation of a repository. Natural variations of this kind are mainly associated with ecological, hydrological, hydrogeological and hydrogeochemical parameters measured near the ground surface. But there may also be parameters, mainly hydrogeological ones, that exhibit considerable variation over time at great depth as well. The programme further includes recording of seismic activity.

In order to optimize the monitoring programme, SKB will continuously evaluate results and experience from the programme. The choice of parameters, sampling points, and frequency of sampling and analysis will be based on evaluation and analysis of previously collected data. The current selection of parameters and sampling points for monitoring is thus based on the results of investigations conducted to date. Observed variations over both time and space have for several disciplines been important factors in this choice.

¹⁰ Monitoring is defined in /Bäckblom and Almén 2004/ as: "Continuous or repeated observations or measurements of parameters to increase the scientific understanding of the site and the repository, to show compliance with requirements or for adaptation of plans in the light of the monitoring results".

The site investigation will only yield time series covering a few years. To find out about more long-term trends, this information will therefore be supplemented with already available long-term measurements of e.g. hydrological and meteorological data. Furthermore, the programme presented below is planned to be followed by a programme for monitoring during the entire construction and operating phase /Bäckblom and Almén 2004, Andersson et al. 2004/.

The programme for monitoring during the site investigation phase is dealt with in the following sections. Even though the programme is primarily presented under headings for the different disciplines, several activities will be coordinated.

3.10.1 Meteorology

Meteorological measurements are necessary input parameters for calculation of an area's water balance and comprise an important basis for defining boundary conditions for the hydrological and hydrogeological calculation models. Meteorological statistics are also important input data for noise measurements and noise calculations, since the propagation of noise is greatly affected by the weather situation.

Completed investigations

In view of the extent of the investigation area, it is important to capture the difference in climate between coast and interior. SKB has therefore established and put into operation its own meteorological monitoring stations at Äspö and at Plittorp about 2 km west of the Laxemar subarea, see Figure 3-44. The stations are located on either side of the Laxemar subarea and about 9 km from each other in an east-west direction. Meteorological data on precipitation, temperature, wind, relative humidity, barometric pressure, cloud cover and global insolation are measured and recorded at the monitoring stations, which have been built and are operated by SMHI for SKB. Snow depth and the water content of the snow have been measured at a couple of localities in the regional model area, see Figure 2-1.

Collection of data started in September 2003. Collected data are first sent to SMHI for quality control and are then stored in SKB's HMS (Hydro Monitoring System), which is a recording, data storage and display system for hydrogeological, surface hydrological and meteorological data /Lärke et al. 2005/.

Investigation programme

Data collection will continue according to the procedures and the technology established during the initial site investigation. Meteorological data are used as a basis for the site description and as input data to and for calibration of the hydrological and hydrogeological models (local and regional) of the Simpevarp and Laxemar subareas. The scope of the measurements is shown by Table 3-6. No further meteorological installations are planned.

Reference data

A number of peripheral SMHI stations serve as a reference and baseline for comparison with the data that will be collected at SKB's stations in and near the investigation area, see /Larsson-McCann et al. 2002/. Data from some of these stations are already utilized today together with site investigation data from the Simpevarp and Laxemar subareas.



Figure 3-44. Meteorological monitoring station at Plittorp.

Table 3-6. Meteorological measurements.

Parameter	Recording frequency	Äspö	Plittorp
Wind direction and speed (at height of 10 m)	every 30 min (mean value)	x	x
Barometric pressure	every 30 min (mean value)	x	x
Air temperature	every 30 min (mean value)	x	x
Relative humidity	every 30 min (mean value)	x	x
Precipitation	every 30 min (total)	x	x
Global insolation	every 30 min (mean value)	x	–

3.10.2 Hydrology

Most surface hydrological measurements, as well as hydrochemical data for surface water from lakes, streams and the sea off Simpevarp, are essential for the disciplines of surface ecosystems and chemistry and are therefore carried out in cooperation with these programmes.

Completed investigations

A surface hydrological survey of topography, locations of streams, lakes and springs, and delineation of drainage basins was performed in the initial stage of the site investigation. Supplementary work has been done since, in particular seven water level stations in lakes and the sea have been prepared and put into operation. Data collection was begun during the first quarter of 2004. Two types of stream discharge stations have been installed: control section for naturally constricting sections where no artificial damming has been necessary, and V-notch weirs. Examples are shown in Figure 3-45.

Investigation programme

Many of the environmental consequences that could potentially arise in conjunction with the construction and operation of the final repository are associated with water. It is therefore of great importance that SKB monitors the groundwater and surface water on the site, both water levels and composition. Moreover, data on surface water are needed as input data to the hydrological and hydrogeological models, and for their calibration. Data collection from the stream discharge stations, which besides flow rate also includes continuous recording of temperature and electrical conductivity, will continue throughout the site investigation in accordance with established procedures. In a similar manner, continuous recording of the water level will continue at seven water level stations, three in lakes and four in the sea. The location of the monitoring stations is shown on the map in Figure 3-46. Rating curves must, however, be plotted for all monitoring stations, which is expected to be finished by mid-year 2006.



Figure 3-45. Stream discharge stations. The left-hand picture shows the weir at monitoring station PSM000347. The right-hand picture shows monitoring station PSM000353 at a naturally constricting section. The locations of the stations are shown in Figure 3-46 below. Sensors for measurement of level, temperature and electrical conductivity are mounted on poles in the middle of the stream.

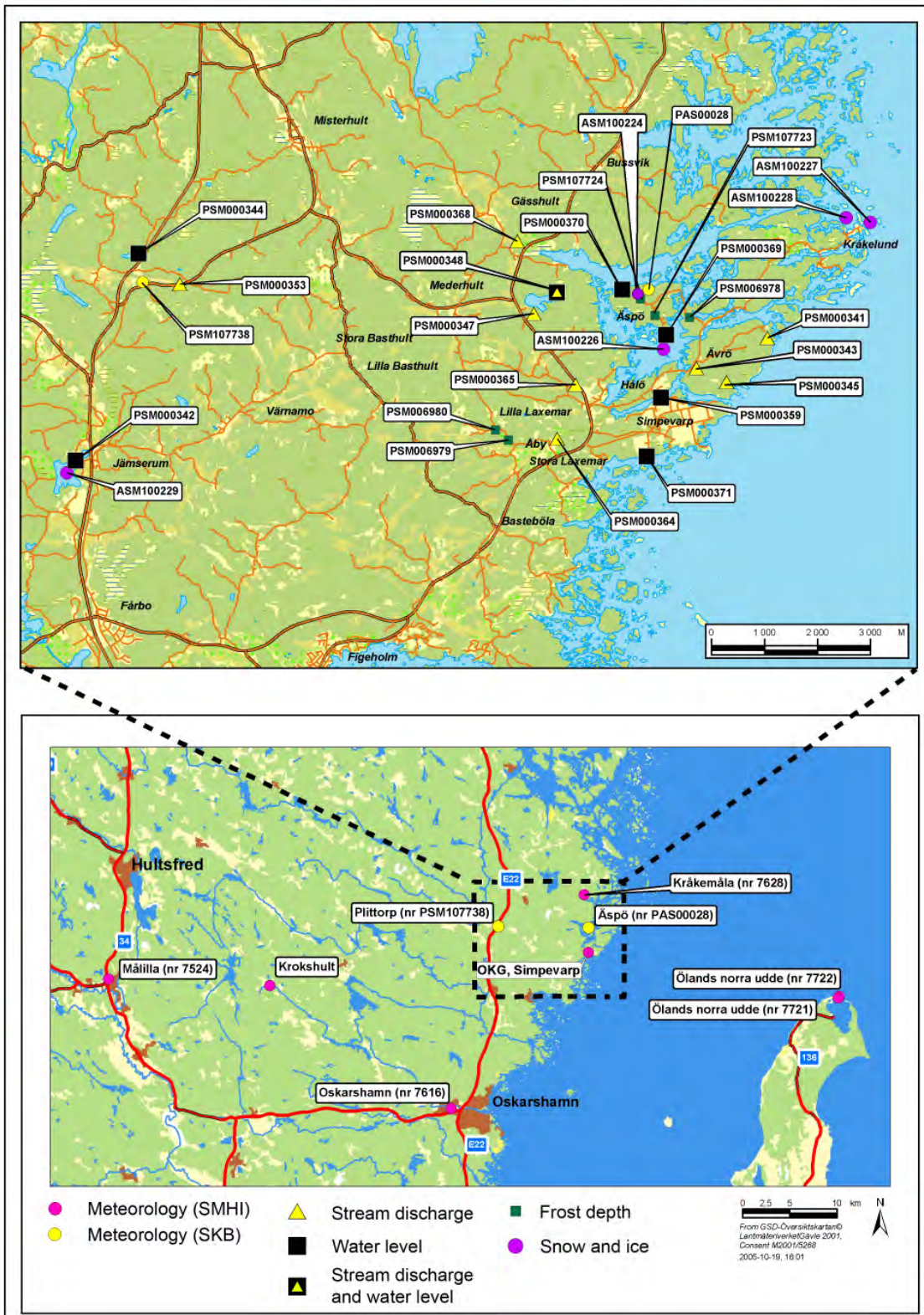


Figure 3-46. Map with all monitoring stations for continuous recording of meteorological and hydrological parameters.

Reference data

Continuous measurements have been made within the investigation area since 1972. At that time OKG (nuclear power plant operator) started monitoring stream discharge in the Laxemarån stream. In the beginning the measurements were made with a frequency of once a week, more recently much less frequently. Furthermore, stream discharge has been measured in another drainage basin, which connects to the Laxemarån's drainage basin about 2 km west of Fårbo. Data from these measurements constitute a reference for the measurements performed in the site investigation. OKG's stream discharge data are being compiled and analyzed. The measurements are expected to be of great importance as a basis for the hydrological site description, since they have been conducted over such a long time. In order to extend the time series collected during the site investigation, it is also possible to simulate stream discharge based on meteorological data.

3.10.3 Hydrogeochemistry

Completed investigations

A comprehensive chemical survey was performed of the surface water in the area during the initial site investigation, see section 3.7. In January 2005, the surface water programme then phased into a monitoring programme with a reduced number of sampling points and reduced sampling frequency.

The two-year precipitation programme also phased into a monitoring programme in January 2005. However, this programme does not differ in scope from the base programme. During the base programme only a few precipitation samples (six per years) were sent to external laboratories. The same will apply to the monitoring programme.

Investigation programme

Long-term monitoring entails periodic measurement of the water composition in a number of monitoring points in surface water, soil wells, precipitation and sections of percussion boreholes and cored boreholes. The purpose is to use the results to help understand the area's hydrology and hydrogeology, to see whether and how the site investigation work affects the composition of the groundwater, and to obtain data in long time series for modelling purposes.

The continued hydrochemical monitoring programme includes the following:

- Analysis of precipitation samples, six per year.
- Analysis of surface water from sampling points in lakes, streams and the sea, see Figure 3-47; sampling takes place once a month and the scope of the analysis varies over the year; the sampling frequency may be changed when the programme is reviewed once a year. The monitoring programme for surface water is being carried out in collaboration between the disciplines of hydrogeology, hydrogeochemistry and surface ecosystems.
- Analysis of water samples from near-surface groundwaters in soil wells, approximately five selected monitoring points (one point in the Simpevarp subarea and four in the Laxemar subarea), four times a year.
- Analysis of water samples from percussion boreholes. Sampling is begun as instrumentation of the boreholes is completed. All boreholes will probably be instrumented by the end of 2006 or beginning of 2007. The monitoring programme will tentatively include 13 boreholes, one section in each borehole, twice a year.

- Analysis of water samples from cored boreholes. Sampling is begun as instrumentation of the boreholes is completed. All boreholes will probably be instrumented by the middle of 2007. The monitoring programme will tentatively include 15 deep cored boreholes and 12 medium-long cored boreholes, two sections in each borehole, twice a year. The installations are described in section 3.10.5

Reference data

Chemistry samplings in surface waters (sea, lakes and streams), near-surface groundwaters (soil wells) and deeper groundwaters (percussion boreholes and cored boreholes) have been performed in the area both before and during the site investigation. Results from these samplings comprise reference data for the investigations that will be conducted later on. All results from the investigations are stored in the Sicada database.



Figure 3-47. Sampling points for monitoring of surface water.

3.10.4 Ecology

Within the discipline of surface ecosystems, monitoring is planned for surface waters (see section 3.10.3 Hydrogeochemistry), game and birds, all three of which have parameters that exhibit variation over time and may be affected by the construction and operation of the final repository.

Game

SKB needs knowledge about possible changes in game populations of interest to man in the concerned area as well as in the reference area. Such knowledge comprises a basis for deciding if and how SKB's activities affect the game populations. For this, SKB has chosen to continue with the moose management programme, i.e. the collection and counting of moose carried out by the hunting parties, for which SKB pays the analysis costs. The monitoring will be done annually, primarily during the period 2005–2008.

Birds

Birds are the part of the fauna of greatest interest to the public and can be sensitive to disturbances from SKB's activities. Keeping track of the bird life in the area is therefore an important part of the monitoring. For this purpose, breeding success will be followed for rare and/or sensitive species (such as certain birds of prey). The territory mapping that has been done around a number of drilling sites for two years will be followed up once during the continued site investigation. The monitoring will mainly be carried out during the period 2005–2008. The line and point counts that were done earlier in the area (2002–2004) will be repeated once during the continued site investigation.

Reference data

Data from investigations and monitoring within surface ecosystems can be compared with results from equivalent measurements in other areas in Sweden. The results of such measurements can be found in databases kept by, for example, the Swedish Environmental Protection Agency, the Swedish University of Agricultural Sciences (SLU) and Svensk Viltförvaltning. Figures from the annual bird survey in Oskarshamn are compared with data from the Swedish bird count that is carried out at several hundred locations all over Sweden. In a similar manner, comparisons are made between Oskarshamn's investigation area and Blankaholm north of there with regard to certain species of game.

3.10.5 Hydrogeology and transport properties

Hydrogeological monitoring is performed to serve as a basis for describing the hydrological and hydrogeological relationships, including the groundwater's pressure and flow distribution, in the area, in other words rock aquifers, soil aquifers and the contacts between surface water, soil groundwater and rock groundwater and the relationships within each subsystem. The purpose is to measure natural groundwater level variations prior to the construction of a final repository, but the equipment is also used to measure pressure responses during single-hole pumping tests and interference tests. At a later stage, the monitoring system will, after some modification, also be used to measure pressure responses during the final repository's construction phase. Monitoring data are used for calibration of groundwater flow models and comprise a baseline time series with relatively undisturbed groundwater levels prior to the construction of the final repository. Other hydraulic disturbances, for example from drilling, can also be measured and in some cases contribute to the basis for the hydrogeological model /SKB 2001a/.

Monitoring involves sectioning off deep cored boreholes by means of expandable rubber packers so that the groundwater's pressure level can be measured in each section, see Figure 3-48. It is possible to isolate up to ten sections with packers. The number of sections in boreholes with few fractures and fracture zones may be considerably less. Of the ten pressure sections, two sections per borehole can be equipped so that it is possible to circulate and sample the water in the section (for hydrogeochemistry and transport properties). The flow through the packered-off section is determined by adding a tracer and measuring its dilution with time. These sections also comprise possible injection points or sampling points in cross-hole tracer tests at later stages of the site investigation (for transport properties).

In percussion boreholes it is possible to use up to three packers, which means groundwater pressure can be measured in four sections, one of which can also be a circulation/dilution section. In soil wells, only the groundwater level is measured in one section. Pressure sensors measure the groundwater pressure, which is converted to levels. Data are stored in the previously mentioned HMS system.

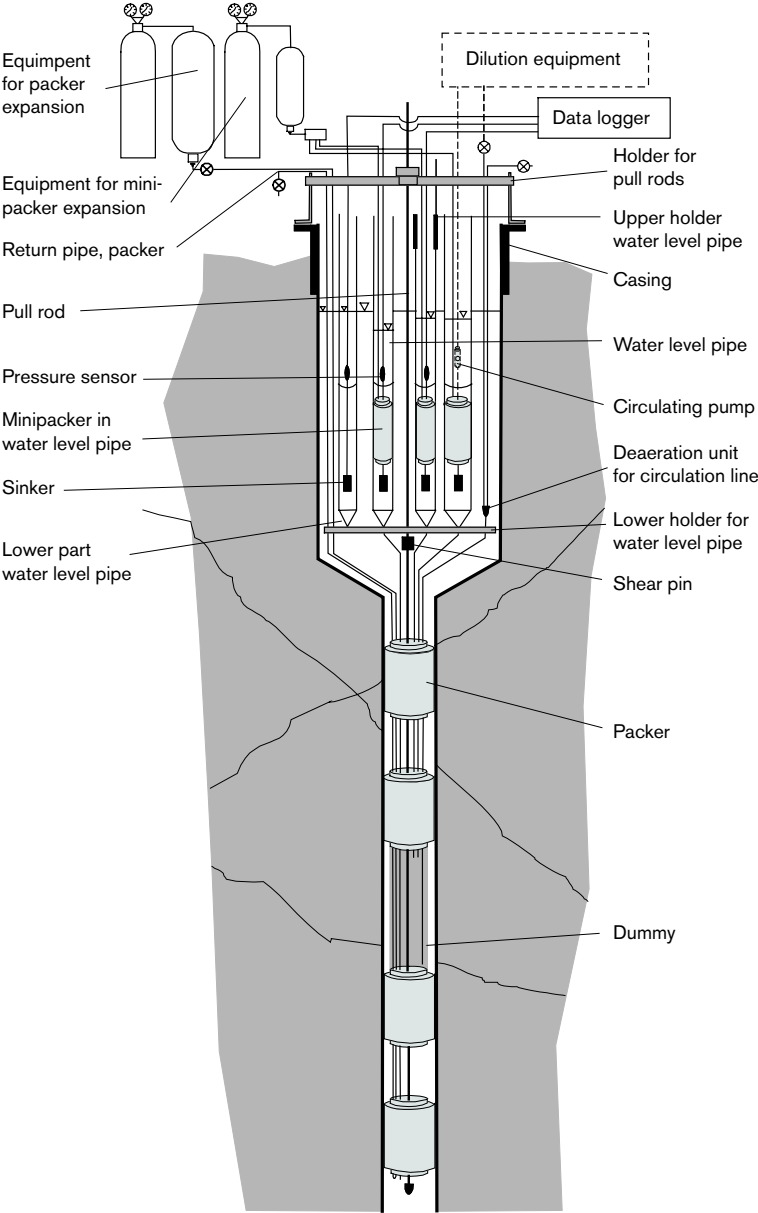


Figure 3-48. Schematic illustration of instrumentation in a cored borehole for monitoring of groundwater levels in sectioned boreholes.

Monitoring of groundwater flows is done for the purpose of quantifying the natural groundwater flow. Flows, and changes in flows, can be used to calibrate hydrogeological models. Furthermore, data from monitoring can serve as a baseline for judging whether a change in groundwater flow may have been caused by construction and operation of the final repository.

An open borehole constitutes a hydraulic short-circuiting of fracture systems at different levels in the borehole. The monitoring equipment also serves to isolate these systems from each other and thereby prevent an uncontrolled mixing of groundwaters from different levels, and possibly with differing chemical composition. The monitoring should be commenced as soon as all other borehole investigations are finished. On the other hand, since the installation work for monitoring is quite extensive and costly, especially in cored boreholes, it is essential to be sure that the borehole does not need to be used for additional investigations before the installation of monitoring equipment is started.

Completed investigations

Monitoring of groundwater level (pressure recording) is being done in 15 cored boreholes with a varying number of sections and in some 25 percussion boreholes and 27 soil wells. All equipment is newly designed (based on experience from the Äspö HRL's monitoring system) and newly manufactured. There have been certain teething problems. Upon solving these problems, the pressure recordings have proceeded smoothly and are very valuable for recording of pressure responses to different types of disturbances (mainly drilling) that occur during the site investigation. Measurement results through October 2004 are presented in /Nyberg and Wass 2005/.

The groundwater level measurements in the soil wells will provide important information on the position and variation of the groundwater levels in different parts of the investigation area, and the groundwater's flow direction and hydraulic gradients. These measurements, together with measurements of water levels in surface water and in rock, also provide knowledge about recharge and discharge conditions.

Investigation programme

The groundwater monitoring will gradually be expanded as new cored boreholes and percussion boreholes are drilled and new soil wells are installed.

The timetable for further installations of monitoring equipment during the continued site investigation is completely dependent on when boreholes are drilled and investigations completed. Most boreholes will be instrumented as soon as investigations are completed in them.

Reference data

Groundwater level and the groundwater's chemical composition in the surficial part of the bedrock (down to at most about 200 m) are monitored in relatively many percussion boreholes in the site investigations. In SKB's judgement, data from these investigations can serve as a reference for each other, so there is no need for additional reference data. Moreover, long time series with relatively undisturbed conditions exist for several percussion boreholes from the investigations in connection with the Äspö HRL, which should be able to complement ongoing investigations as far as reference data are concerned.

3.10.6 Geology

Geological monitoring includes measurements of slow creep movements along fracture zones in the rock, and recording of earthquakes in the proximity of the investigation sites Oskarshamn and Forsmark, as well as all over Sweden /SKB 2001a/.

Completed investigations

Movements in the rock

Tiny movements, called creep movements, can occur along major deformation zones (ductile and brittle fracture zones). In order to get an idea of possible creep movements along deformation zones, a method study with GPS-based measurement technology was conducted in Oskarshamn between 2000 and 2004 /Sjöberg et al. 2004/, see Figure 3-49. Solar activity was elevated during the period the method study was conducted, and the results must therefore be interpreted with some caution. The interpretation that was nevertheless made is that observed movements may have been caused by the fact that the rock blocks rotate counter-clockwise in relation to each other. The movements were very small – on a level with the measurement error. Nevertheless it is possible to discern a tendency towards movement during this period, particularly between the stations Knip and Kidr, Figure 3-49 /Sjöberg et al. 2004/. The conclusion of the study is that long time series are needed, preferably measurements over a whole solar activity cycle (11 years). SKB decided to terminate the GPS measurements in Oskarshamn. One study using basically the same technology was begun in Forsmark during 2005 and will continue for three years. After re-evaluation of the GPS technology, GPS measurements may therefore be performed on the site finally chosen for the final repository.

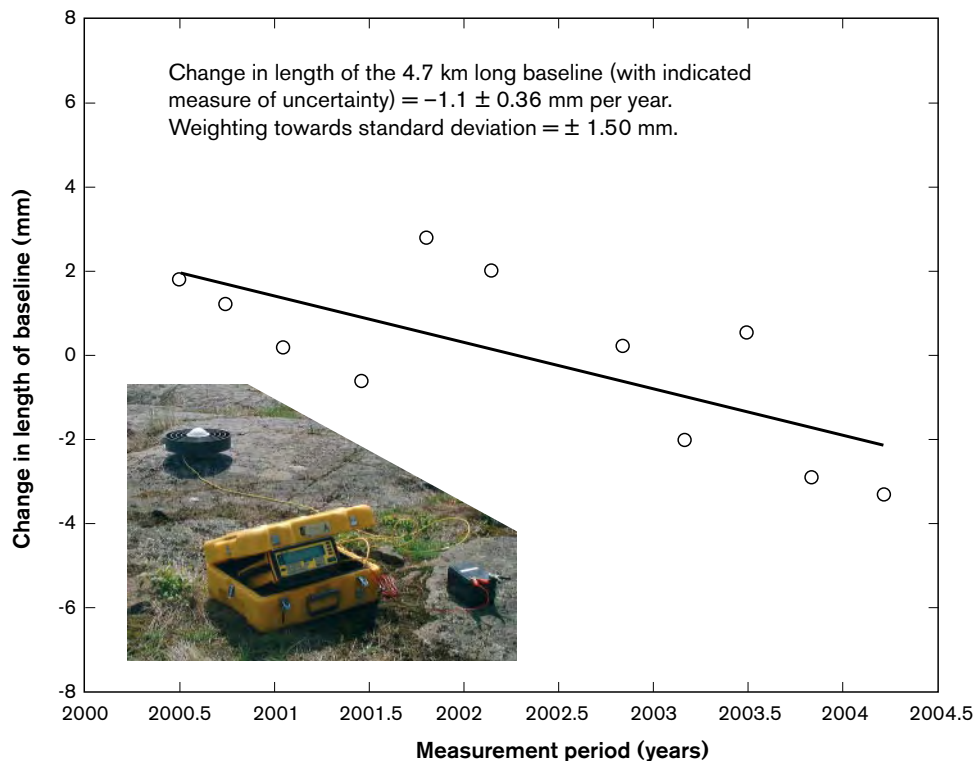


Figure 3-49. Method study of deformation measurements using GPS technology. The photo shows a Trimble 4000 SSE receiver and an antenna /Sjöberg et al. 2004/. The graph shows the movement between the stations Knip and Kidr during the period. Even though the movements were scarcely measurable, it is possible to discern a tendency towards movement. The baseline between Knip and Kidr has become about 1.1 mm shorter per year /Sjöberg et al. 2004/.

Other methods will also be considered in order to find out more about conditions in the vicinity of the sites being investigated. An example of this is satellite-based radar interferometry (dInSar, length measurement using radio waves), which will be performed in Forsmark. With this method, vertical movements (such as subsidences) can be detected on an mm scale. The previously mentioned GPS method primarily measures horizontal movements.

Earthquakes

The national seismological network, extending from Gävle in the north to Blekinge in the south, was built out during 2002, with financing from SKB. The goal of the seismological network is to record earthquakes down to a magnitude of near zero on the Richter scale. Figure 3-50 shows earthquakes and recorded explosions (mainly blasts) that occurred in 2004. Most of the recordings stemmed from explosions /Böðvarsson 2005a/.

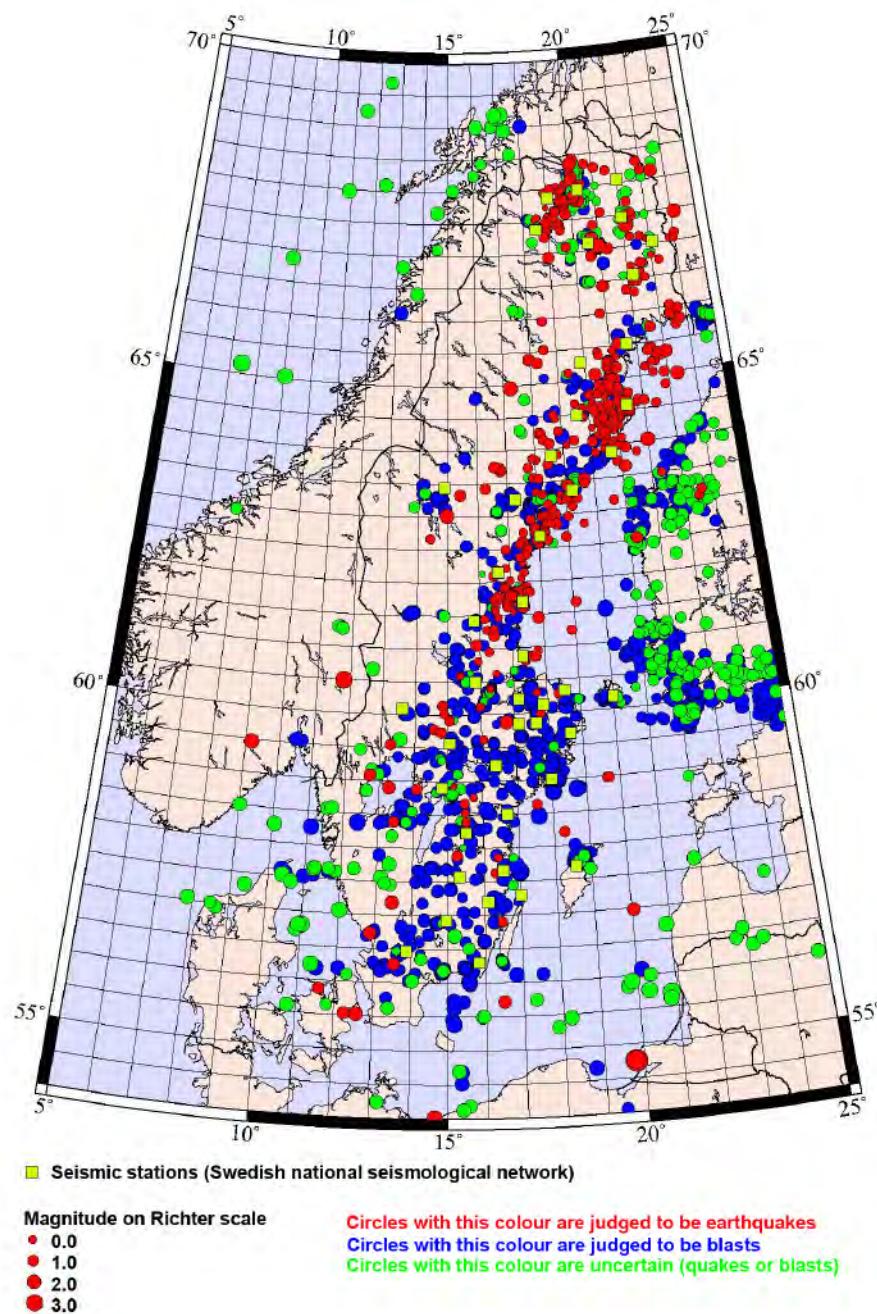


Figure 3-50. Earthquakes and explosions (blasts) recorded during 2004.

Movements in the rock

The method study of GPS-based measurement technology in Oskarshamn has been concluded. SKB will instead try other methods for recording small rock movements. Satellite-based radar interferometry is currently being tested in Forsmark.

Earthquakes

The goal of the seismological network is to be able to record earthquakes down to a magnitude near zero on the Richter scale and to be able to determine with greater accuracy the location, magnitude and direction of earthquakes. Measurements of earthquakes are expected to continue until at least 2011. The seismological network was expanded in 2005 with two new stations. One was placed in Forsmark and one in Oskarshamn (at drilling site KLX03). The present-day national seismological network is shown in Figure 3-51. It may later be decided to install additional seismic stations in Forsmark and/or Simpevarp/Laxemar, which in that case will be reported in the programme for detailed characterization.

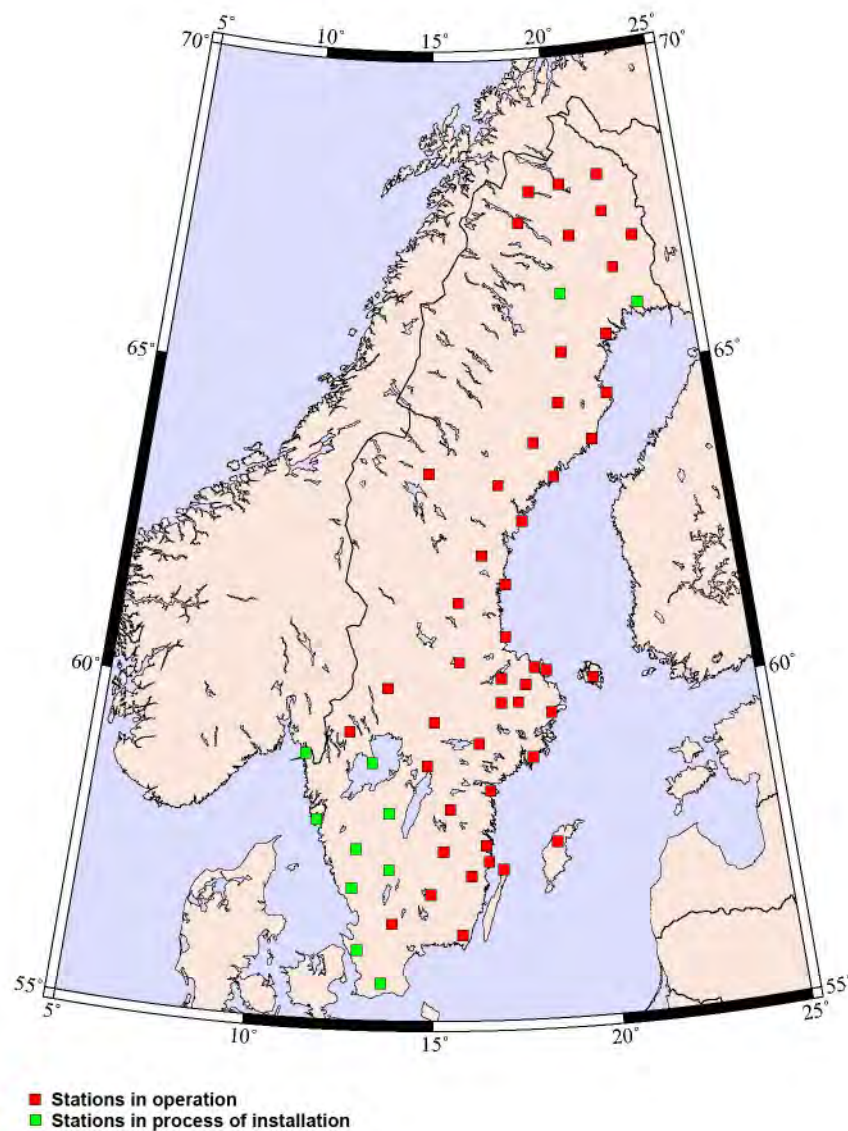


Figure 3-51. The national seismological network in 2004 /Böðvarsson 2005b/.

3.11 Investigations for operating facilities above and below ground

3.11.1 Facilities above ground

Figures 2-13 and 2-14 give an idea of the surface facilities which a final repository in the Laxemar subarea would require and Figure 2-12 shows three possible locations for these facilities in the Laxemar subarea. The figure shows tentative proposals based on information that was available in the spring of 2005. Further processing will be required with respect to the documentation being made of the cultural environment, surface ecosystems and Quaternary and hydrogeological conditions.

On the whole, the foundation requirements for the final repository's facilities do not differ from what is usual for industrial construction, but there are certain differences between different parts. Most of the area will be occupied by conventional buildings, roads and storage yards. The exceptions are production buildings and shaft superstructures, which may require more foundation work. Knowledge of soil and groundwater conditions is also required for the rock heaps that are planned.

The planned investigation programme includes the following points:

- Compile existing material from previous investigations that have been done in parts of the area.
- Roughly assess the geotechnical conditions for the entire area in question.
- Assess the foundation requirements for different parts of the final repository's facilities.
- Identify the need for supplementary investigations, and perform them.

It is expected that such investigations will be limited and can be performed using conventional technology, including seismic methods. Similar investigations may also be required for roads and other additional infrastructure.

3.11.2 Facilities under ground

The scope of the drilling needed to obtain data as a basis for a site-adapted configuration of descents and the central area is preliminary at this time. Of the programme for investigation drilling that is presented in sections 3.1 and 3.9, two 500–600 m long cored boreholes are specifically aimed at obtaining rock engineering data for descents and the central area. Additional drilling and investigations may be needed to obtain sufficient information for the facility design, including selected locations and possible configurations of ramp, shafts and central area that will be specified in the final phase of the site investigation.

4 Investigations after the summer of 2007

According to SKB's plans, the site investigation in Oskarshamn will be concluded in the late summer of 2007, see Figure 2-18. By that time, according to the objective for the site investigation phase, all investigations needed to prepare and submit applications under the Environmental Code and the Nuclear Activities Act will have been completed.

Certain supplementary investigations may need to be done during the period up until an application is submitted at the end of 2008. Among other things, a large-scale interference test, combined with tracer tests, is planned. This can only be carried out when there is no longer any risk of disturbances from other investigations that could affect the groundwater. Since the results of the test are mainly aimed at verifying the site-descriptive models, they can be performed after data freeze 2.3. Monitoring as described in section 3.10 will be conducted continuously after data freeze 2.3, even though the scope can vary depending on the type of parameter and the need for long time series.

The longer term planning naturally depends on which site is chosen for the final repository. For the site not chosen, it is a reasonable assumption that SKB will wind down all field activities to a minimum. Some type of follow-up and monitoring activities will probably be carried out on this site as well, however.

For the site that is chosen, resources and infrastructure will probably be retained and certain preparations made, at the same time as follow-up and monitoring continue. When applications have been submitted and while they are being reviewed and considered, the reviewing bodies may request supplementary information requiring further investigations on the site. SKB does not find this very likely, but must nevertheless plan for this possibility. It is not possible to say in advance what types of investigations or work may be called for.

If Laxemar is selected as the site of the final repository, construction documents and other supporting material will be needed for a building permit application. Geological investigations and other site surveys may be necessary to prepare these documents and for other detailed design of the final repository.

Once SKB has obtained permits to build and operate the final repository, extensive investigations will begin along with the construction activities. These investigations, often referred to as detailed characterization, will be conducted both from the surface and from the shafts and tunnels built in the initial part of the construction phase. SKB will present a programme for this detailed characterization along with the applications under the Environmental Code and the Nuclear Activities Act.

5 References

Alling V, Andersson P, Fridriksson G, Rubio Lind C, 2004. Validation of GIS-maps and inventory of vegetation types in Forsmark. Forsmark site investigation. P-04-314, Svensk Kärnbränslehantering AB.

Andersson J, Ström A, Svemar C, Almén K-E, Ericsson L O, 2000. What requirements does the KBS-3 repository make on the rock? Geoscientific suitability indicators and criteria for siting and site evaluation. TR-00-12, Svensk Kärnbränslehantering AB.

Andersson C, Söderhäll J, 2001. Rock mechanical conditions at the Äspö HRL. A study of the correlation between geology, tunnel maintenance and tunnel shape, R-01-53, Svensk Kärnbränslehantering AB.

Andersson J, 2004. Vegetation inventory in part of the municipality of Östhammar, P-04-20, Svensk Kärnbränslehantering AB.

Andersson J, 2005. Investigation of the amount of dead wood. Oskarshamn site investigation, P-05-87, Svensk Kärnbränslehantering AB.

Andersson J, Munier R, Ström A, Söderbäck B, Almén K-E, Olsson L, 2004. When is there sufficient information from the Site Investigations? R-04-23, Svensk Kärnbränslehantering AB.

Andrén C, 2004. Amphibians and reptiles in SKB special area of investigation at Simpevarp. P-04-36, Svensk Kärnbränslehantering AB.

Ask H, Morosini M, Samuelsson L-E, Stridsman H, 2004a. Drilling of cored borehole KSH01. Oskarshamn site investigation. P-03-113, Svensk Kärnbränslehantering AB.

Ask H, Morosini M, Samuelsson L-E, Ekström L, 2004b. Drilling of cored borehole KSH02. Oskarshamn site investigation. P-04-151, Svensk Kärnbränslehantering AB.

Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2004c. Drilling of cored borehole KSH03. Oskarshamn site investigation. P-04-233, Svensk Kärnbränslehantering AB.

Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2005a. Drilling of cored borehole KAV04. Oskarshamn site investigation. P-05-25, Svensk Kärnbränslehantering AB.

Ask H, Samuelsson L-E, Zetterlund M, 2005b. Percussion drilling of boreholes HLX21, HLX22, HLX23, HLX24, HLX25, HLX30 HLX31 and HLX33 for investigation of lineament EW007. P-05-55, Svensk Kärnbränslehantering AB.

Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2005c. Drilling of cored borehole KLX04. P-05-111, Svensk Kärnbränslehantering AB.

Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2005d. Drilling of cored borehole KLX03. Oskarshamn site investigation. P-05-167, Svensk Kärnbränslehantering AB.

- Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2005e.** Oskarshamn site investigation. Drilling of cored borehole KLX05. P-05-233, Svensk Kärnbränslehantering AB.
- Ask H, Morosini M, Samuelsson L-E, Ekström L and Håkanson N, 2005f.** Oskarshamn site investigation. Drilling of cored borehole KLX06. P-05-233, Svensk Kärnbränslehantering AB.
- Berglund S, Selroos J-O, 2003.** Transport properties site descriptive model. Guidelines for evaluation and modelling. R-03-09, Svensk Kärnbränslehantering AB.
- Bergman B, Juhlin C, Palm H, 2002.** Reflection seismic imaging of the upper 4 km of crust using small charges (15–75 grams) at Laxemar, southeastern Sweden. *Tectonophysics*, 355, 201–213.
- Boresjö Bronge L, Wester K, 2003.** Vegetation mapping with satellite data of the Forsmark, Tierp and Oskarshamn regions, P-03-83, Svensk Kärnbränslehantering AB.
- Brunberg A-K, Carlsson T, Brydsten L, Strömgren M, 2004.** Identification of catchments, lake-related drainage parameters and lake habitats. Oskarshamn site investigation. P-04-242, Svensk Kärnbränslehantering AB.
- Byegård J, 2005.** Bedrock transport properties. Preliminary site description Simpevarp subarea – version 1.2. R-05-05, Svensk Kärnbränslehantering AB.
- Bäckblom G, Almén K-E, 2004.** Monitoring during the stepwise implementation of the Swedish deep repository for spent fuel. R-04-13, Svensk Kärnbränslehantering AB.
- Böðvarsson R, 2005a.** Swedish National Seismic Network (SNSN). A short report on recorded earthquakes during the fourth quarter of the year 2004. P-05-32, Svensk Kärnbränslehantering AB.
- Böðvarsson R, 2005b.** Swedish National Seismic Network (SNSN). A short report on recorded earthquakes during the second quarter of the year 2005. P-05-200, Svensk Kärnbränslehantering AB.
- Börjesson S, Gustavsson E, 2005.** Laboratory data from the site investigation programme for the transport properties of the rock. Data delivery for data freeze Laxemar 2.1. Oskarshamn site investigation. P-05-106, Svensk Kärnbränslehantering AB.
- Carlsson T, Brunberg A-K, Brydsten L, Strömgren M, 2005.** Characterisation of running waters, including vegetation, substrate and technical encroachments. Oskarshamn site investigation, P-05-40, Svensk Kärnbränslehantering AB.
- Cederlund G, Hammarström A, Wallin K, 2004.** Surveys of mammal populations in the areas adjacent to Forsmark and Oskarshamn. Results from 2003. 2003, P-04-04, Svensk Kärnbränslehantering AB.
- Cederlund G, Hammarström A, Wallin K, 2005.** Survey of small rodent populations in the areas adjacent to Simpevarp. Results from 2004. Oskarshamn site investigation. P-05-84, Svensk Kärnbränslehantering AB.
- Curtis P, Elfström M, Stanfors R, 2003.** Compilation of structural geological data covering the Simpevarp peninsula, Ävrö and Hålö. Oskarshamn site investigation. P-03-07, Svensk Kärnbränslehantering AB.

- Ehrenborg J, Stejskal V, 2004.** Boremap mapping of core drilled borehole KFM02B. Oskarshamn site investigation. P-04-129, Svensk Kärnbränslehantering AB.
- Elhammer A, Sandkvist Å, 2005.** Detailed marine geological survey of the sea bottom outside Simpevarp. Oskarshamn site investigation. P-05-35, Svensk Kärnbränslehantering AB.
- Enderlein O, 2005.** The abundance of nightly pelagic fish in the Baltic Sea outside Simpevarp nuclear power station, P-05-057, Svensk Kärnbränslehantering AB.
- Engdahl A, Ericsson U, 2004.** Sampling of freshwater fish. Description of the fish fauna in four lakes. Oskarshamn site investigation, P-04-251, Svensk Kärnbränslehantering AB.
- Ericsson U, Engdahl A, 2004a.** Surface water sampling in Oskarshamn – Subreport October 2003 to February 2004. Oskarshamn site investigation. P-04-75, Svensk Kärnbränslehantering AB.
- Ericsson U, Engdahl A, 2004b.** Benthic macro invertebrates. Results from sampling in the Simpevarp area 2004. Oskarshamn site investigation. P-04-252, Svensk Kärnbränslehantering AB.
- Ericsson U, 2005** (in manuscript). Oskarshamn site investigation. Precipitation at Simpevarp 2004. P-05-175, Svensk Kärnbränslehantering AB
- Ericsson U, Engdahl A, 2005a.** Oskarshamn site investigation. Surface water sampling at Simpevarp 2004. P-05-118, Svensk Kärnbränslehantering AB.
- Ericsson U, Engdahl A, 2005b.** Oskarshamn site investigation. Sampling of shallow groundwater at Simpevarp 2004. P-05-280, Svensk Kärnbränslehantering AB.
- Fredriksson R, Tobiasson S, 2003.** Inventory of macrophyte communities at Simpevarp nuclear power plant. Area of distribution and biomass determination. Simpevarp site investigation, P-03-69, Svensk Kärnbränslehantering AB.
- Fredriksson R, 2004.** Inventory of the soft-bottom macrozoobenthos community in the area around Simpevarp nuclear power plant. Oskarshamn site investigation, P-04-17, Svensk Kärnbränslehantering AB.
- Fredriksson R, 2005a.** Inventory of the marine fauna attached to hard substrates in the Simpevarp area. Oskarshamn site investigation, P-05-45, Svensk Kärnbränslehantering AB.
- Green M, 2003.** Fågelundersökningar inom SKB:s platsundersökningar 2002 Simpevarp, P-03-31, Svensk Kärnbränslehantering AB.
- Green M, 2004.** Bird surveys in Simpevarp 2003. Oskarshamn site investigation, P-04-21, Svensk Kärnbränslehantering AB.
- Green M, 2005.** Bird monitoring in Simpevarp 2002–2004. Oskarshamn site investigation, P-05-42, Svensk Kärnbränslehantering AB.
- Gustafsson J, Gustafsson C, 2004.** RAMAC and BIPS logging in boreholes KSH03A, KSH03B, HAV09, HAV10 and BIPS in KAV01. Oskarshamn site investigation. P-04-48, Svensk Kärnbränslehantering AB.

- Gustafsson E, Nordqvist R, 2005.** Groundwater flow measurements and SWIW tests in boreholes KLX02 and KSH02. Oskarshamn site investigation. P-05-28, Svensk Kärnbränslehantering AB.
- Gustafsson J, Gustafsson C, 2005a.** RAMAC and BIPS logging in borehole KLX06. Oskarshamn site investigation. P-05-30, Svensk Kärnbränslehantering AB.
- Gustafsson J, Gustafsson C, 2005b.** RAMAC and BIPS logging in boreholes KLX05 and HLX32. Oskarshamn site investigation. P-05-82, Svensk Kärnbränslehantering AB.
- Gustafsson J, Gustafsson C, 2005c.** RAMAC directional logging in borehole KLX05 and RAMAC and BIPS logging in borehole HLX20. Oskarshamn site investigation. P-05-161, Svensk Kärnbränslehantering AB.
- Hartley L, Hoch A, Hunter F, Marsic N, 2006** (in manuscript). Regional hydrogeological simulations – Numerical modelling using ConnectFlow. Preliminary site description Laxemar subarea – version 1.2. Svensk Kärnbränslehantering AB.
- Hermanson J, Forssberg O, Fox A, La Pointe P, 2005.** Statistical model of fractures and deformation zones. Preliminary site description, Laxemar subarea, version 1.2. R-05-45, Svensk Kärnbränslehantering AB.
- Hultgren P, Stanfors R, Wahlgren C-H, Carlsten S, Mattsson H, 2004.** Geological single-hole interpretation of KSH03A, KSH03B, KLX02, HAV09 and HAV10. Oskarshamn site investigation. P-04-231, Svensk Kärnbränslehantering AB.
- Ignell H, 2004.** Investigations on mammals – bats. Investigation of the fauna of mammals in selected places within SKB investigation area. Oskarshamn site investigation, P-04-237, Svensk Kärnbränslehantering AB.
- Ingvarson N, Palmeby S, Svensson O, Nilsson O, Ekfeldt T, 2004.** Marine survey in shallow coastal waters. Bathymetric and geophysical investigation 2004. Oskarshamn site investigation. P-04-254, Svensk Kärnbränslehantering AB.
- Jansson T, Stigsson M, 2002.** Test with different stress measurement methods in two orthogonal bore holes in Äspö HRL. R-02-26, Svensk Kärnbränslehantering AB.
- Johansson T, Adestam L, 2004.** Drilling and sampling in soil. Installation of groundwater monitoring wells in the Laxemar area. Oskarshamn site investigation. P-04-317, Svensk Kärnbränslehantering AB.
- Juhlin C, Bergman B, Palm H, Tryggvarsson A, 2004a.** Reflection seismic studies on Ävrö and Simpevarpshalvön, 2003. Oskarshamn site investigation. P-04-52, Svensk Kärnbränslehantering AB.
- Juhlin C, Bergman B, Palm H, 2004b.** Reflection seismic studies performed in the Laxemar area during 2004. Oskarshamn site investigation. P-04-215, Svensk Kärnbränslehantering AB.
- Laaksoharju M (ed), Smellie J, Gimeno M, Auqué L, Gómez J, Tullborg E-L, Gurban I, 2004.** Hydrogeochemical evaluation of the Simpevarp area, model version 1.1. R-04-16, Svensk Kärnbränslehantering AB.

- Lagerbäck R, Sundh M, Svedlund J-O, 2004.** Searching for evidence of late- or postglacial faulting in the Oskarshamn region. Results from 2003. Oskarshamn site investigation. P-04-192, Svensk Kärnbränslehantering AB.
- Larsson-McCann S, Karlsson A, Nord M, Sjögren J, Johansson L, Ivarsson M, Kindell S, 2002.** Meteorological, hydrological and oceanographic information and data for the site investigation program in the community of Oskarshamn. TR-02-03, Svensk Kärnbränslehantering AB.
- Lindborg T, Kautsky U, 2000.** Variabler i olika ekosystem, tänkbara att beskriva vid platsunderökningar för ett djupförvar. R-00-19, Svensk Kärnbränslehantering AB.
- Lindborg T (ed), 2005.** Description of surface systems. Preliminary site description Simpevarp sub area – Verison 1.2. R-05-01, Svensk Kärnbränslehantering AB.
- Lindborg T (ed), 2006.** Description of surface systems. Preliminary site description Forsmark area – version 1.2. R-06-11, Svensk Kärnbränslehantering AB.
- Lindow H, 2005.** Oskarshamn site investigation. Oceanographic measurements. P-05-191, Svensk Kärnbränslehantering AB.
- Lindqvist G, 2004a.** Refraction seismic measurements in the water outside Simpevarp and Ävrö and on land on Ävrö. Oskarshamn site investigation. P-04-201, Svensk Kärnbränslehantering AB. Svensk Kärnbränslehantering AB.
- Lindqvist G, 2004b.** Refraction seismic measurements in Laxemar. Oskarshamn site investigation. P-04-134, Svensk Kärnbränslehantering AB.
- Lindqvist G, 2004c.** Refraction seismic measurements in Laxemar autumn 2004. Oskarshamn site investigation. P-04-298, Svensk Kärnbränslehantering AB.
- Lindqvist G, 2005.** Refraction seismic measurements in Laxemar spring 2005. Oskarshamn site investigation. P-05-155, Svensk Kärnbränslehantering AB.
- Lindroos H, 2004.** The potential for ore, industrial minerals and commercial stones in the Simpevarp area. R-04-72, Svensk Kärnbränslehantering AB.
- Ljunggren C, Klasson H, 1997.** Drilling of KLX02 – Phase 2. Lilla Laxemar, Oskarshamn. Deep hydraulic fracturing rock stress measurements in borehole KLX02, Laxemar. U-97-27, Svensk Kärnbränslehantering AB.
- Lundin L, Björkvald L, Hansson J, Stendahl J, 2004.** Surveillance of soils and site types in the Oskarshamn area. Oskarshamn site investigation. P-04-243, Svensk Kärnbränslehantering AB.
- Lundqvist L (ed), 2005.** Kulturmiljöanalys Simpevarp/Laxemar. P-05-248, Svensk Kärnbränslehantering AB.
- Lärke A, Hillgren R, Wern L, Jones J, Aquilonius K, 2005.** Hydrological and meteorological monitoring at Oskarshamn during 2003–2004. P-05-227, Svensk Kärnbränslehantering AB.
- Löfgren A, Lindborg T, 2003.** A descriptive ecosystem model – a strategy for model development during site investigations. R-03-06, Svensk Kärnbränslehantering AB.

Löfgren A, 2005. Estimation of biomass and net primary production in field and ground layer, and biomass in litter layer of different vegetation types in Forsmark and Oskarshamn. Oskarshamn/Forsmark site investigation. P-05-80, Svensk Kärnbränslehantering AB.

Löfgren M, Neretnieks I, 2005a. Formation factor logging in situ by electrical methods in KLX03 and KLX04. Oskarshamn site investigation. P-05-105, Svensk Kärnbränslehantering AB.

Löfgren M, Neretnieks I, 2005b. Formation factor logging in situ and in the laboratory by electrical methods in KSH01A and KSH02. Measurements and evaluation of methodology. Oskarshamn site investigation. P-05-27, Svensk Kärnbränslehantering AB.

Lövgren L, Puigdomenech I, 2005. Effects of complexing compounds on sorption of metal ions to cement. R-05-72, Svensk Kärnbränslehantering AB.

Mattsson H, Thunehed H, 2003. Measurements of petrophysical parameters on rock samples during autumn 2002. Simpevarp site investigation. P-03-19, Svensk Kärnbränslehantering AB.

Mattsson H, Thunehed H, Triumf C-A, 2003. Compilation of petrophysical data from rock samples and in situ gamma-ray spectrometry measurements. Oskarshamn site investigation. P-03-97, Svensk Kärnbränslehantering AB.

Mattsson H, Stanfors R, Wahlgren C-H, Stenberg L, Hultgren P, 2004a. Geological single-hole interpretation of KSH01A, KSH01B, HSH01, HSH02 and HSH03. Oskarshamn site investigation. P-04-32, Svensk Kärnbränslehantering AB.

Mattsson H, Stanfors R, Wahlgren C-H, Carlsten S, Hultgren, P, 2004b. Geological single-hole interpretation of KSH02 and KAV01. Oskarshamn site investigation. P-04-133, Svensk Kärnbränslehantering AB.

Mattsson H, Thunehed H, Triumf C-A, 2004c. Compilation of petrophysical data from rock samples and in situ gamma-ray spectrometry measurements. Stage 2 – 2004 (including 2002). Oskarshamn site investigation. P-04-294, Svensk Kärnbränslehantering AB.

Mattsson H, 2005. Interpretation of geophysical borehole measurements from KLX06. Oskarshamn site investigation. P-05-44, Svensk Kärnbränslehantering AB.

Mattsson H, Keisu M, 2005. Interpretation of geophysical borehole measurements from KLX05. Oskarshamn site investigation. P-05-189, Svensk Kärnbränslehantering AB.

Munier R, Hökmark H, 2004. Respect distances. Rationale and means of computation. R-04-17, Svensk Kärnbränslehantering AB.

Swedish Environmental Protection Agency, 2005. Handbok för miljöövervakning, Elfiske i rinnande vatten, Version1:3 020620. www.naturvardsverket.se.

Nielsen U T, Ringgaard J, 2004. Geophysical borehole logging in borehole KAV01. Oskarshamn site investigation. P-04-232, Svensk Kärnbränslehantering AB.

Nielsen U T, Ringgaard J, Horn F, 2005a. Geophysical borehole logging in borehole KLX06. Oskarshamn site investigation. P-05-31, Svensk Kärnbränslehantering AB.

Nielsen U T, Ringgaard J, Dahl J F, 2005b. Geophysical borehole logging in boreholes KLX05 and HLX32. Oskarshamn site, P-05-144.

Nilsson G, 2004. Investigation of sediments, peat lands and wetlands. Stratigraphical and analytical data. Oskarshamn site investigation. P-04-273, Svensk Kärnbränslehantering AB.

Nilsson K P, Bergman T, Eliasson T, 2004. Oskarshamn site investigation. Bedrock mapping 2004 – Laxemar subarea and regional model area. P-04-221, Svensk Kärnbränslehantering AB.

Nyberg G, Wass E, 2005. Groundwater monitoring program report for December 2003 – October 2004. Oskarshamn site investigation. P-05-205, Svensk Kärnbränslehantering AB.

Nyman H, 2005. Depth and stratigraphy of Quaternary deposits. Preliminary site description Laxemar subarea – version 1.2. R-05-54, Svensk Kärnbränslehantering AB.

Pedersen K, Kalmus A, 2004. Oskarshamn site investigation. Total numbers and metabolic diversity of microorganisms in borehole KSH01A. P-04-276, Svensk Kärnbränslehantering AB.

Sjöberg J, Perman F, 2005. Oskarshamn site investigation. Overcoring rock stress measurements in borehole KLX04. P-05-69, Svensk Kärnbränslehantering AB.

Rudmark L, Malmberg-Persson K, Mikko H, 2005. Investigation of Quaternary deposits 2003–2004. Oskarshamn site investigation. P-05-49, Svensk Kärnbränslehantering AB.

Schmelzbach C, Juhlin C, 2004. 3D processing of reflection seismic data acquired within and near the array close to KAV04A on Ävrö, 2003. Oskarshamn site investigation. P-04-204, Svensk Kärnbränslehantering AB.

Siitari-Kauppi M, Flitsiyan E S, Klobes P, Meyer K, Hellmuth K-H, 1998. Progress in physical rock matrix characterization: Structure of the pore space. In: I G McKinley, C McCombie (ed:s), Scientific Basis for Nuclear Waste Management XXI, Mat. Res. Soc. Symp. Proc. V. 506, pp. 671–678.

Sjöberg L, Pan M, Asenjo E, 2004. A deformation analysis of the Äspö GPS monitoring network from 2000 to 2004. Oskarshamn site investigation. P-04-196, Svensk Kärnbränslehantering AB.

SKB, 2000a. Geoscientific programme for investigation and evaluation of sites for the deep repository. R-00-30, Svensk Kärnbränslehantering AB.

SKB, 2000b. Integrated account of method, site selection and programme prior to the site investigation phase. TR-01-03, Svensk Kärnbränslehantering AB.

SKB, 2000c. Förstudie Oskarshamn. Slutrapport. Svensk Kärnbränslehantering AB.

SKB, 2001a. Site Investigations. Site investigations – Investigation methods and general execution programme. TR-01-29, Svensk Kärnbränslehantering AB.

SKB, 2001b. Geovetenskapligt program för platsundersökning vid Simpevarp. R-01-44, Svensk Kärnbränslehantering AB.

SKB, 2003. Prioritering av områden för platsundersökningen i Oskarshamn. R-03-12, Svensk Kärnbränslehantering AB.

SKB, 2004. Interim main report of the safety assessment SR-Can. TR-04-11, Svensk Kärnbränslehantering AB.

- SKB, 2004a.** RD&D-Programme 2004. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste, including social science research, Svensk Kärnbränslehantering AB.
- SKB, 2004b.** Plan 2004. Kostnader för kärnkraftens radioaktiva restprodukter. Svensk Kärnbränslehantering AB.
- SKB, 2004c.** Program för fortsatta undersökningar av berggrund, mark och vatten. Platsundersökning i Oskarshamn. P-04-300, Svensk Kärnbränslehantering AB.
- SKB, 2005a.** Preliminary safety evaluation for the Simpevarp subarea. Based on data and site descriptions after the initial site investigation stage. TR-05-12, Svensk Kärnbränslehantering AB.
- SKB, 2005b.** Preliminary site description. Simpevarp subarea – version 1.2, R-05-08, Svensk Kärnbränslehantering AB.
- SKB, 2006.** Preliminary site description Laxemar subarea – version 1.2. R-06-10, Svensk Kärnbränslehantering AB.
- SKB, 2006a.** Utvärdering av platsdata inför fokusering av de fortsatta undersökningarna inom delområde Laxemar. P-05-264, Svensk Kärnbränslehantering AB.
- SKB, 2006b** (in manuscript). Preliminär anläggningsbeskrivning för slutförvar inom delområde Simpevarp. R-06-31, Svensk Kärnbränslehantering AB.
- Stanfors R, Olsson P, Stille H, 1997.** Äspö HRL – Geoscientific evaluation 1997/3. Results from pre-investigations and detailed site characterization. Comparison of predictions and observations. Geology and mechanical stability. TR-97-04, Svensk Kärnbränslehantering AB.
- Staub I, Andersson J C and Magnor B, 2004.** Äspö Pillar Stability Experiment. Geology and mechanical properties of the rock in TASQ, R-04-01, Svensk Kärnbränslehantering AB.
- Sturesson E, 2003.** Nyckelbiotopsinventering i Simpevarpsområdet. Platsundersökning Oskarshamn. P-03-78, Svensk Kärnbränslehantering AB.
- Sundberg I, Ericsson U, Engdahl A, Svensson J E, 2004.** Phytoplankton and zooplankton. Results from sampling in the Simpevarp area 2003–2004. Oskarshamn site investigation. P-04-253, Svensk Kärnbränslehantering AB.
- Tagesson T, 2004** (in manuscript). Aspects of the carbon cycle in terrestrial ecosystems of northeastern Småland. Svensk Kärnbränslehantering AB.
- Tagesson T, 2005** (in manuscript). Seasonal variation and controlling factors of soil carbon dioxide efflux in six vegetation types in southeast of Sweden. Svensk Kärnbränslehantering AB.
- Tannerfeldt M, Thiel L, 2004.** Survey of mammal populations at Simpevarp. Spotlight survey 2004. Oskarshamn site investigation. P-04-238, Svensk Kärnbränslehantering AB.
- Thunhed H, Triumf C-A, Pitkänen T, 2004.** Geophysical profile measurements over interpreted lineaments in the Laxemar area. Oskarshamn site investigation. P-04-211, Svensk Kärnbränslehantering AB.

- Thunehed H, 2005.** Resistivity measurements and determination of formation factors on samples from LX04 and KSH02. Oskarshamn site investigation. P-05-75, Svensk Kärnbränslehantering AB.
- Thunehed H, Triumf C-A, 2005.** Detailed ground geophysical survey at Laxemar. Magnetic total field and resistivity. Oskarshamn site investigation. P-05-188, Svensk Kärnbränslehantering AB.
- Triumf C-A, 2003.** Geophysical measurements for the siting of a deep borehole at Ävrö and for investigations west of CLAB. Oskarshamn site investigation. P-03-66, Svensk Kärnbränslehantering AB.
- Triumf C-A, Thunehed H, Kero L, Persson L, 2003.** Interpretation of airborne geophysical survey data. Helicopter borne survey data of gamma ray spectrometry, magnetics and EM from 2002 and fixed wing airborne survey data of the VLF-field from 1986. Oskarshamn site investigation. P-03-100, Svensk Kärnbränslehantering AB.
- Triumf C-A, 2004.** Oskarshamn site investigation. Joint interpretation of lineament in the eastern part of the site descriptive model area. P-04-37, Svensk Kärnbränslehantering AB.
- Triumf C-A, 2004a.** Joint interpretation of lineaments. Oskarshamn site investigation. Oskarshamn site investigation. P-04-49, Svensk Kärnbränslehantering AB.
- Triumf C-A, 2004b.** Gravity measurements in the Laxemar model area with surroundings. Oskarshamn site investigation. P-04-128, Svensk Kärnbränslehantering AB.
- Wacker P, Berg C, Bergelin A, 2004.** Oskarshamn site investigation. Complete hydrochemical characterisation in KSH01A. P-04-12, Svensk Kärnbränslehantering AB.
- Wahlgren C-H, Ahl M, Sandahl K-A, Berglund J, Petersson J, Ekström M, Persson P-O, 2004.** Bedrock mapping 2003 – Simpevarp subarea. Outcrop data, fracture data, modal and geochemical classification of rock types, bedrock map, radiometric dating. Oskarshamn site investigation. P-04-102, Svensk Kärnbränslehantering AB.
- Wahlgren C-H, Bergman T, Persson Nilsson K, Eliasson T, Ahl M, Ekström M, 2005.** Oskarshamn site investigation. Bedrock map of the Laxemar subarea and surroundings. Description of rock types, modal and geochemical analysis. P-05-180, Svensk Kärnbränslehantering AB.
- Wahlgren C-H, Hermanson J, Curtis P, Forssberg O, Triumf C-A, Tullborg E-L, Drake H, 2006.** Geological description of rock domains and deformation zones in the Simpevarp and Laxemar subareas. Preliminary site description Laxemar subarea – version 1.2. R-05-69, Svensk Kärnbränslehantering AB.
- Werner K, Bosson E, Berglund S, 2005.** Description of climate, surface hydrology and near-surface hydrogeology – Laxemar 1.2. R-05-61, Svensk Kärnbränslehantering AB.
- Wiborgh M, Papp T, Svemar C, 2004.** Äspö Hard Rock Laboratory. NET.EXCEL. Final Technical Report. IPR-04-54, Svensk Kärnbränslehantering AB.
- Widestrand H, Byegård J, Ohlsson Y, Tullborg E-L, 2003.** Strategy for the use of laboratory methods in the site investigations programme for the transport properties of the rock. R-03-20, Svensk Kärnbränslehantering AB.
- Wikman H, Kornfält K-A, 1995.** Updating of a lithological model of the bedrock of the Äspö area. SKB Progress Report 25-95-04. Svensk Kärnbränslehantering AB.

Winberg A, Andersson P, Hermanson J, Byegård J, Cvetkovic V, Birgersson L, 2000. Äspö Hard Rock Laboratory. Final report of the first stage of the tracer retention understanding experiments. TR-00-07, Svensk Kärnbränslehantering AB.

Winberg A, Andersson P, Byegård J, Poteri A, Cvetkovic V, Dershowitz W, Doe T, Hermanson J, Gomez-Hernandez J, Hautjärvi A, Billaux D, Tullborg E-L, Holton D, Meier P, Medina A, 2002. Final report of the TRUE Block Scale project 4. Synthesis of flow, transport and retention in the block scale. TR-02-16, Svensk Kärnbränslehantering AB.

Analysis of samples from deposits and biota

Table A-1. Organic microcompounds (environmental toxins) that will be analyzed in samples from deposits (sediments, peat- or wetlands) and biota.

Compound
EOX – Sum parameter for extractable organohalogen compounds.
Chlorobenzenes (tri-hexa) – Used as solvents, in pesticides, in production of other chemicals and in transformer fluids. Toxicity generally increases with degree of chlorination. Hexachlorobenzene and pentachlorobenzene are priority hazardous substances and trichlorobenzene is a priority substance according to the Water Framework Directive.
PCB7 – Polychlorinated biphenyls. PCB7 is the sum of 7 congeners (congener = variant in the same group with the same basic molecular structure but different degrees and/or location of the halogen atoms). There are a total of 209 PCB compounds. Divided into planar and non-planar PCBs where the planar are sometimes classified with dioxins due to similar properties. The source of PCBs is for example transformer oils and plastic caulking compounds (sealants). The compounds are poorly degradable, fat-soluble and bioaccumulating. Highly toxic and affect human health via weakened immune system, disrupted hormonal and enzyme balance, increased frequency of cancer and impact on central nervous system.
PCDDs/PCDFs – Polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs). Formed in combustion processes such as refuse incineration and at steel smelters. Previously a large source was also chlorine bleaching of paper and chloralkali plants with graphite electrodes. Automotive exhaust emissions and burning of wood are other sources. High toxicity can cause skin injuries in man (chloracne) following acute exposure. Genotoxic carcinogens, plus effects on immune system and reproduction.
2,4-dinitrotoluene – Solid yellow substance. Used in manufacture of dyes, polyurethane, explosives and ammunition. Carcinogenic aromatic nitrogen compound. Acute effects: respiratory distress, risk of chemical pneumonitis, impact on CNS, dry eczema, nausea and vomiting.
1,2-dichloroethane – Colourless liquid with chloroform-like odour, highly fat-soluble. Wide technical use, for example as intermediary in manufacture of vinyl chloride, ethylene glycol diacetate and ethylenediamine. It has been used as a petrol additive together with the anti-knock compound tetraethyl lead.
Dichloromethane – Methylene chloride, colourless, volatile and non-flammable liquid with chloroform-like odour. Used as solvent, for example in degreasing and decolouring, and is manufactured on industrial scale by direct chlorination of methane.
BTEX – collective term for benzene, toluene, ethylbenzene and xylene. Components in fuel and solvents. In man, exposure to these compounds can cause injuries to the central nervous system. Benzene is also carcinogenic.
Chlorinated aliphatic hydrocarbons – Group of organic chemicals most of which are colourless liquids at room temperature. Consist of straight, branched or cyclic hydrocarbons with 1–5 carbon atoms with a varying degree of chlorine substitution. Used in production of PVC and as solvents in the manufacture of other chemicals.
Fractionation aromatic hydrocarbons – The basic structure of an aromatic hydrocarbon is a ring of 6 carbon atoms. Fractionation groups of aromatic hydrocarbons according to the number of carbon atoms.
PAH-16 – Polycyclic aromatic hydrocarbons. PAHs are contained in tar, creosote, asphalt, rubber, plastics, paints and insecticides. Formed when carbon or hydrocarbons, for example in the form of oils, are heated without enough oxygen for complete combustion to carbon dioxide. Are usually fat-soluble and in some cases bioaccumulating. PAH-16 is a sum parameter for the 16 most common PAH compounds defined by the USEPA. Divided into carcinogenic (7 compounds) and other (9 compounds) PAHs. Certain PAH compounds are prioritized hazardous substances under the Water Framework Directive.

Fractionation aliphatic hydrocarbons – Aliphatic hydrocarbons consist of straight or branched carbon chains. Fractionation groups of aliphatic hydrocarbons according to the number of carbon atoms.

MTBE – Methyl tertiary butyl ether. Added to petrol to raise its octane rating. At room temperature MTBE is a volatile, flammable, colourless liquid that dissolves readily in water.

PBDEs – Polybrominated diphenyl ethers. Brominated flame retardants that occur in a variety of products such as electronics and textiles. Are prioritized substances under the Water Framework Directive.

DEHP – Di(2-ethylhexyl)phthalate is one of a group of compounds called phthalate esters. Often used as a plasticizer in plastics. Classified as toxic to reproduction. Prioritized substance under the Water Framework Directive.

Nonylphenol – or alkylphenol ethoxylates belong to the group nonionic surfactants. Prioritized hazardous substance under the Water Framework Directive.

Nitroaromatics – A certain type of organic nitrogen compounds that are manufactured in large volumes. Used for manufacture of pesticides, pharmaceuticals, explosives, polymers, dyes, etc. Many nitroaromatics and their degradation products are toxic and, in some cases, carcinogenic.

Table A-2. Macronutrients and inorganic substances that will be analyzed in samples from deposits (sediments, peatlands or wetlands) and biota.

Macronutrients			Metals		
Atomic no	Chemical formula	Substance	Atomic no	Chemical formula	Substance
Total-C			3	Li	Lithium
TOC	Total Organic Carbon		4	Be	Beryllium
Total-N			21	Sc	Scandium
Organic N			23	V	Vanadium
PO ₄			24	Cr	Chromium
			27	Co	Cobalt
			28	Ni	Nickel
			29	Cu	Copper
			30	Zn	Zinc
			31	Ga	Gallium
			37	Rb	Rubidium
			38	Sr	Strontium
			39	Y	Yttrium
			40	Zr	Zirconium
			41	Nb	Niobium
			42	Mo	Molybdenum
			47	Ag	Silver
			48	Cd	Cadmium
			50	Sn	Tin
			51	Sb	Antimony
			55	Cs	Caesium
			56	Ba	Barium
			57	La	Lanthanum
			58	Ce	Cerium
			59	Pr	Praseodymium
			60	Nd	Neodymium
			62	Sm	Samarium
			63	Eu	Europium
			64	Gd	Gadolinium
			65	Tb	Terbium
			66	Dy	Dysprosium
			67	Ho	Holmium
			68	Er	Erbium
			69	Tm	Tulium
			70	Yb	Ytterbium
			71	Lu	Lutetium
			72	Hf	Hafnium
			73	Ta	Tantalum
			74	W	Tungsten
			80	Hg	Mercury
			81	Tl	Thallium
			82	Pb	Lead
			90	Th	Thorium
			92	U	Uranium

Table A-3. Physical and chemical parameters that will be analyzed in samples from deposits (sediments, peatlands or wetlands).

Parameter
pH, C, N,
Fe, Al, Mn – soil surfactant substances.
Base cations – exchangeable cations with NH ₄ Ac (ammonium acetate). “Total” leaching with aqua regia ¹ .
K and P (fractionation with Al and HCl).
pF-curve – Relationship between soil water pressure head and water content of a soil sample. Provides information on the water retention properties of a soil. By pF is meant ¹⁰ log(-Ψ) where Ψ is the water pressure head expressed in cm water gauge.
Hydraulic conductivity.
Porosity.
Dry weight, compact and bulk density.

¹ A mixture of concentrated nitric acid and concentrated hydrochloric acid, often in a volume ratio of 1:3.

Environmental impact of the site investigation

This appendix examines the environmental impact to which the planned investigation activities can give rise during the continued site investigation in Oskarshamn and what measures are planned to minimize this impact. Experience from the first years of site investigations with application and development of the environmental management and environmental optimization of the activities that was presented in /SKB 2001b/ comprises an important basis for this account. At the end of the appendix, the activities deemed to cause potential impact to the environment are presented in a table.

B.1 Environmental management of the site investigation

B.1.1 General

SKB's objective is that the site investigations should be executed in such a manner that they cause as little environmental impact as possible, at the same time as the quality and scientific level of the investigations are satisfactory. In order to achieve this, we are integrating environmental aspects in the planning of the activities. This is done with the aid of an environmental control programme for activities performed in the field. The environmental control programme has been developed continuously during the course of the site investigations and includes checklists for different types of activities, such as excavation, sampling in the field, drilling and seismic surveys. An example of a checklist (for core drilling and roadbuilding) is presented in Table B-1 below.

As a result of the environmental control programme, before an investigation, SKB:

- knows which natural and cultural values can be affected,
- has given the landowners an opportunity to offer viewpoints on the execution of the investigations,
- has given the County Administrative Board an opportunity to offer viewpoints on the planned investigations.

Many of the investigations are conducted by consultants and contractors. To minimize risks and limit the negative consequences for human health and the environment, SKB requires suppliers to comply with SKB's environmental policy and overall goals. All contractors and consultants who carry out assignments in the site investigation area undergo special training before they are allowed to start work. On completion of this training, they get a

Table B-1. Excerpt from checklist for core drilling and roadbuilding.

Activity type	Control measures											
	Accessibility map	Field check of natural and cultural values	Photo documentation	Reference sample soil chemistry	Reference sample water chemistry	Check of groundwater levels	Consultation authorities	Consultation/information landowners	Information residents	Environmental requirements to contractors	Noise measurement	Final check (signature activity leader)
Road construction and preparation of drilling site	X	X	X				X	X	X	X		

conditions. The map shows the location of sensitive areas, species worthy of protection, archaeological remains or cultural heritage assets. After the initial site investigations, this map is very extensive and comprises a valuable document for management of the activities so that environmental impact can be avoided or minimized.

B.1.3 SKB's contacts with the County Administrative Board

In April 2002, SKB gave notice of consultation for the site investigation in Oskarshamn to the Kalmar County Administrative Board, pursuant to Chapter 12 of the Environmental Code. The County Administrative Board stipulated in its decision of 19 June 2002 that the investigations could be conducted in accordance with the notification, provided the precautionary measures presented in the notice were adopted. SKB has since had an active dialogue with the County Administrative Board regarding the environmental impact of the site investigation and how it can be avoided or minimized. At a meeting with a representative from the County Administrative Board on 4 June 2004, it was decided that contacts should be made in different ways depending on the nature of the investigation:

- Notice of consultations according to Chapter 12 section 6 of the Environmental Code; sent to the County Administrative Board at least six weeks before an intrusion that has not previously been notified.
- Supplementary information; sent to the County Administrative Board during ongoing consultation period for a notification matter (above), for example the exact location of a cored borehole.
- Information To County Administrative Board; sent to the County Administrative Board 1–2 weeks before minor intrusions such as cored boreholes, soil wells, minor excavations and seismic surveys.

B.1.4 SKB's contact with landowners

All activities in the field require the consent of the concerned landowner. Furthermore, SKB works actively to maintain a good dialogue with nearby residents and other concerned parties. These consultations and contacts are included in the environmental checklists for the various activities, which are an important part of SKB's environmental control programme.

B.2 Experience from the initial site investigation

Early in the site investigation, inventories were made of vegetation, key habitats, game, birds etc in order to get a good picture of the area before road construction, drilling and other more disturbing activities were commenced. In this way, SKB found out early on where in the area species and environments worthy of protection are located. The accessibility map has been continuously updated with this information and comprises a very important planning document for the continued investigations. A certain running-in period was needed to achieve effective environmental control of all field activities, partly because the organization was growing and partly because a lot of activities were being started up during a relatively short period of time. SKB's site ecologist is in charge of performing and documenting these checks, but the checks themselves are initiated by the relevant activity leader based on SKB's environmental control programme. After completed checks, any precautions and necessary changes in the timetable are introduced in the planning of the activity in consultation between the site ecologist and the concerned activity leader. In this way, it has been possible to protect sensitive environments from serious impact and unnecessary disturbances.

Since 2002, about 300 different investigations have been conducted and no major mistakes have been made. Table B-2 describes the deviations that have been reported.

As the investigations have progressed and we have gained more experience, we have made some changes and additions to SKB's environmental control programme. For example, new environmental checklists have been added and control steps have been reformulated. The environmental control programme is undergoing extensive review and modification during the autumn of 2005 by reason of the work with the current investigation programme.

SKB has notified a number of activities and investigations to the County Administrative Board for supplementary consultation in accordance with Chapter 12 of the Environmental Code. This includes establishment of drilling sites, erection of hydrological monitoring stations, excavation of pits for determination of Quaternary deposits and location of seismic profiles. Some of the County Administrative Board's decisions have included conditions, for example measurement and reporting of the return water's chloride content in connection with core drilling, and noise limits (see for example the County Administrative Board's statement of 26 January 2004). An evaluation of the flushing water handling was submitted to the County Administrative Board on 23 May 2005.

Table B-2. Description of deviations in completed investigations and the measures that were taken.

Time	Event	Remedial measure
2003–2004	At three percussion drilling sites, larger areas (about 10–50 m ² larger) than prescribed in the accessibility protocol were gravelled or occupied.	In two cases the sites were remediated, and in one case nothing was done since the landowner preferred having the area gravelled. No areas with special natural values were affected.
Autumn 2003	During execution of seismic profiles, about 10 young spruces were broken off and marking rods were left in place along the profiles, which was discovered by a contractor and the landowner, respectively.	The profiles were cleaned up.
2004	On three occasions during 2004, diesel fuel was pumped into a 200-litre oil drum on Äspö and transported to the Simpevarp Peninsula in the bucket of a backhoe-loader. Oil drums are not approved for transport of diesel fuel.	Two diesel tanks approved for transport are now set up on the Simpevarp Peninsula.
June 2004	Ground preparation was begun (about 10 m ²) for percussion drilling in a key habitat. The reason was that the work started before the accessibility check had been done.	The work was interrupted (but the site was not remediated since it was decided that this would do more harm than good) and continued on another site. The intrusion resulted only in a temporary eyesore.
August 2004	A borehole was unfortunately drilled in a field against the leaseholder's desire to locate the hole at the edge so as not to get in the way of subsequent tillage of the field.	No remedial measure.
August 2004	A wild apple tree was knocked down by a contractor while drilling a percussion borehole.	SKB has offered an apology.
Summer 2005	An excavation site was not notified to the County Administrative Board.	The site was notified afterwards (no natural or cultural values were harmed).

B.3 Investigations with potential environmental impact

The following sections describe which activities in the field can lead to environmental impact. The measures that will be adopted to minimize the impact of the various activities are also described below, along with what types of investigations will be notified for supplementary consultation in accordance with Chapter 12 of the Environmental Code.

B.3.1 Roads and infrastructure

Description

Early during the site investigation the objective has been to minimize the intrusions and thereby also the length and size of new roads in the area. In cases where core drilling sites have been established away from existing roads, it has been necessary to build new roads, for example to KLX03, KLX06 and KLX09. New access roads have been built up to some percussion boreholes. In most cases it has only been necessary to strengthen existing logging roads (“Ävrö style”) to enable a tractor and a track-mounted drilling rig gain access. The roads have deliberately been built so that passenger cars cannot negotiate them, so that they do not become permanent.

There is very little need for any more roads. In most cases only short branch roads are needed to provide access to future drilling sites. But in some cases it may be necessary to establish drilling sites that are not located along the existing road network. Short roads will then have to be built up to these drilling sites. To avoid roadbuilding wherever possible, as from the autumn of 2005 access to certain percussion boreholes and planned short cored boreholes will primarily be permitted by laying down log mats or metal sheets. The same applies to drilling with the light core drilling machine, see section 3.9.3

The roads to the core drilling sites must be negotiable by cars and trucks with trailers (length 24 m, width 2.6 m, height 4.5 m, gross vehicle weight 50 tonnes). The loadbearing capacity of the road must permit heavy traffic year-round. The roadway is designed so that haulage and use of aggregate material to build the road are minimized. If possible, dewatered drill cuttings are used as fill in building drilling sites and branch roads.

Stationary installations are made for monitoring. The stationary installations that will be made during the continued site investigation comprise a number of soil wells for monitoring of the groundwater level. Small sheds such as freight containers or the like are required for some of the installations. Low-energy technology is preferred for these installations. Meteorological monitoring employs equipment mounted on two masts, one on Äspö and one at Plittorp in the western part of the regional model area. Personnel visit the monitoring installations for maintenance and service and to retrieve collected data. Some of monitoring and measurement equipment communicates via the GSM network, reducing the need to visit the sites.

Environmental impact

Construction of new roads, storage sites and stationary installations gives rise to noise, dust and exhaust emissions. Mobile machinery can leak hydraulic and lubricating oil. In some cases off-road operation may be required, which gives rise to ground damage.

The scope of the environmental impact in conjunction with roadbuilding can be compared to the damage caused by logging or the impact caused by the earlier building of logging roads in the area. The roads remain in the area throughout the site investigation phase, possibly even longer, and therefore occupy land. They also change the landscape to some extent. Additional roadbuilding increases accessibility in the area, which can affect sensitive landscapes and species.

Power and telephone lines will be run as underground cable or temporary overhead cables. The lines will be harmonized with the existing local network in the area. All-terrain vehicles will be used for the erection of temporary poles. Branches and some trees may need to be removed. Cable trenches will be dug for underground cable. Overhead line and underground cable will preferably be laid along existing and additional roads.

To permit monitoring of the groundwater level in soil wells in the wintertime as well, they will be provided with protective hoods to prevent freezing.

Measures

In planning roads, natural values and the landscape are taken into consideration in that an attempt is made to find routes that avoid streams, mires and swampy ground. All routes are cross-checked against the accessibility map and preceded by a field check of natural and cultural values. Routes are documented by photography before the roadbuilding begins.

In order to make it easy for vehicles to cross the road, and so that natural water flows will not be affected more than necessary, roads will if possible be built without open ditches. Where there is a risk of wash problems, plastic drums will be used. Arches will be used in permanent streams so that the aquatic fauna is not affected, but crossing streams will be avoided wherever possible.

After conclusion of the site investigation and if the area is then no longer being considered for a final repository, roads, drilling sites and other places where intrusions have been made will be remediated. Power and signal lines as well as other stationary installations will be removed. The remediation work will be done in consultation with the landowner. Certain roads and gravelled surfaces may be left in place if that is the wish of the landowner.

Construction of roads, drilling sites and stationary installations that can affect the natural environment will be preceded by supplementary consultation with the County Administrative Board.

B.3.2 Excavation in conjunction with mapping work

Description

The mapping work that requires some form of mechanized excavation is geological bedrock mapping to investigate fracture zones. This is planned on two or three sites. The trenches are 50–100 m long and three metres wide at the bottom, see Figure B-2. They are wider at ground level since the sides need to be sloped to avoid the risk of cave-in. For trench digging to be technically feasible, the soil depth may not exceed five metres.

The excavations will be done alongside the existing road network. It may be necessary to fell trees and move large boulders.

Compressed air or high-pressure water sprays are used to clean rock surfaces. Water is taken from a nearby stream or a tank. Small quantities of seepage water are pumped away by an electric drainage pump. A generator set may be needed to power the pump and any lighting needed on the site. Large groundwater inflows may necessitate interruption of the excavation work and relocation to another site.

When the soil is deep, stripping the soil gives rise to large quantities of excavation spoil. The excavation spoil is heaped up next to the pit or trench and later used for backfilling. In some cases, the spoil may need to be dumped at another place if the pit is dug near a sensitive natural area. The trenches are refilled after the survey.



Figure B-2. Trench for Quaternary deposit mapping before and after remediation.

Environmental impact

Excavators, compressors and power generators as well as vehicles for transport of personnel and equipment give rise to noise, dust and exhaust emissions. Excavators may leak hydraulic oil and lubricating oil.

The sites where excavation is done will occupy land for between several weeks and several months. The area immediately surrounding the excavation area is temporarily altered by the excavated spoil. There will be a local impact on the vegetation, and possibly a temporary lowering of the water table.

The soil stripping work emits noise from small machines and pumps, as well as from excavation and handling of excavated spoil. There may also be some vibration. The work is similar to the work involved in conjunction with small construction jobs. Any disturbances will be of short duration, about a week per excavation site.

Measures

Excavation sites must be approved by the site ecologist. The excavation site should be chosen to minimize the impact on the natural environment. All excavations are cross-checked against the accessibility map and preceded by a field check of natural and cultural values before they may be commenced. Selected sites are documented by photography before the excavation begins.

Pits and trenches are sloped to prevent the risk of cave-in. The excavation is cordoned off in the field. Arrangements are made so that spilled oil is collected wherever possible.

If possible, the excavations will be done in the autumn when the water table is at its lowest so that drainage effects are minimized. The autumn is also favourable because the sensitive nesting season is over.

After completion of the investigations the excavation spoil will be put back. The top soil layer with vegetation is separated so that it can be put back intact afterwards. The site is photographed once again, and remediation measures are documented.

Excavations that can cause impact to the natural environment will be preceded by supplementary consultation with the County Administrative Board.

B.3.3 Core drilling

Description

Approximately 13 new cored boreholes are planned in the Laxemar subarea during the remainder of the site investigation. Some boreholes reach a depth of about 1,000 m, while most will be between 300 and 600 m deep. Furthermore, some thirty or so short (about 100 m) cored boreholes will be drilled. What mainly determines the choice of drilling site is the geoscientific question which the borehole is intended to answer. Since the geoscientific goals can usually be achieved with inclined boreholes, the drilling sites can in most cases be chosen with consideration for the area's natural values as well. It is also possible to drill several boreholes from the same drilling site. SKB therefore estimates that seven new drilling sites will be sufficient to drill the remaining cored boreholes.

Core drilling entails that a cylindrical drill core is retrieved and evaluated along the entire length of the hole. Larger and heavier drilling machines are used for core drilling to great depth than for the more common types of boreholes. Core drilling of a 600-m deep hole normally takes two months, but may take up to 4–6 months if drilling is interrupted for measurements. When the position of a cored borehole has been determined, the transport road and drilling site are built. The drilling machine is transported – along with the drilling rig, compressors, cooling water pumps, hoses and containers etc – to the drilling site on a trailer. At the drilling site (see Figure B-3), a rest shed, toilet and temporary storage building for equipment are also built. The fenced-in drilling site occupies an area of about 30×30 m.



Figure B-3. Drilling site KLX03 in the Laxemar subarea.

During core drilling, clean groundwater (called flushing water) is pumped down into the hole to cool the drill bit and remove the drill cuttings. This water is taken from one of the nearby percussion boreholes; sometimes it has to be hauled to the drilling site by road tanker. The water is marked with the tracer uranine so that contamination with flushing water can later be determined by water sampling. Most of the flushing water is pumped up out of the borehole by compressed air (airlift pumping). Relatively large quantities of slurried drill cuttings are brought up with the return water, which therefore passes through settling tanks before being discharged to a receiving body, usually by soil infiltration.

The return water is normally discharged to the surrounding soil for infiltration. In cases where the return water has a chloride content in excess of 2,000 mg/l, it is discharged directly to the sea via a hose or hauled away in a container to a basin on the Simpevarp Peninsula with the sea as a receiving body.

Environmental impact

The heavy core drilling equipment requires a gravelled surface and a road for transport of the drilling machine and measurement equipment. Trees need to be felled and the ground gravelled for the road and the drilling site. Land is occupied for a long time. The light core drilling machine (see Figure B-4), which is used for short (about 100 m) cored boreholes, is much less demanding of the access road and drilling site. In terms of the required infrastructure, environmental disturbances and intrusions, it is comparable to percussion drilling.



Figure B-4. Light drilling machine for drilling of short boreholes.

The drilling machine makes disturbing noise in the area around a drilling site. During the actual drilling, noise-sensitive and timid animals may be disturbed over a large area. Noise is also caused by vehicular traffic during the drilling work. Furthermore, some limited ground vibrations occur in the immediate environs of a drilling site. The light coming from the drilling site in the evening and at night is also of relatively limited intensity and range. Studies of breeding birds at the drilling sites suggest that there is no impact on the bird fauna /Green 2004/.

Some environmentally harmful substances are used during core drilling, such as hydraulic oil, lubricating oil, thread grease and diesel oil when diesel generators are used. Since the investigations of microorganisms in the bedrock are very sensitive to different types of disturbances, biodegradable oils cannot be used for equipment that is lowered into the boreholes. The drilling contractor is obligated to use as little oil and grease as possible. When it comes to other substances that do not come into contact with the borehole, environmentally friendly alternatives are preferred, such as biodegradable oils.

In all cored boreholes, stainless steel casing is installed through the soil layers and a short distance, no more than 100 m, into the rock. To prevent superficial water from leaking down and mixing with deeper-lying groundwater, the gap between the casing and the borehole wall is generally grouted with low-alkaline cement. No other grout is permitted. The total consumption is normally 400–700 kg per borehole. The grout also penetrates out into the fracture system around the borehole. Some pH change in the groundwater in the immediate vicinity of the borehole can therefore be expected as a result of grouting. Theoretically, the grout could also be transported to a stream, for example, where it could cause some pH increase.

During the drilling (as well as later during test pumping of boreholes), a temporary lowering of the groundwater level occurs due to the continuous pumping-out of flushing water and groundwater. The groundwater lowering or “drawdown” is normal measurable within several hundred metres of the drilling site. The size of the drawdown declines with the distance from the drilling site at a rate that is dependent on the hydraulic properties of the bedrock and the soil layers. The drawdown is recorded by equipment installed in both nearby and more faraway soil and percussion boreholes.

If slurried drill cuttings were released, this could have some environmental impact. Return water with a high salinity that is unintentionally released can also cause harm, mainly to animal and plant life. Unintentional releases of flushing water marked with uranine leave coloured stains in the surroundings for a short time. However, the dye is quickly broken down by sunlight. Passenger and equipment traffic, as well as haulage of e.g. flushing water and drill cuttings, may be substantial during the drilling work, along with visits to the drilling site.

Measures

Times and places for drilling are checked against the accessibility map and establishment of new drilling sites is preceded by a field check of natural and cultural values.

For each new drilling site, SKB’s site organization must approve location, transport roads to and from the site and the time of drilling. The site organization also judges whether there is a need for consultations with the County Administrative Board, landowners and other affected parties, as well as what consideration must be taken, for example under the Environmental Code and the Cultural Monuments Act. Prior to the construction work, the surface ecosystems at the drilling site must be documented.

Wherever technically and economically feasible – including at future drilling sites – underground cable will be laid for power supply of drilling rigs and air compressors.

Sedimented drill cuttings (about six cubic metres per cored borehole), as well as cuttings from the percussion boreholes (see below), have been used in the construction of drilling sites and branch roads. An attempt will be made to do this whenever possible during the complete site investigation as well. Otherwise the drill cuttings will be hauled to an approved landfill.

The groundwater level in nearby soil and percussion boreholes will be checked before, during and after core drilling. The water chemistry will also be checked.

When the gap between casing and hole wall is grouted, injection flows and pressures are carefully monitored.

In order to permit control of oil leakage (mainly hydraulic and lubricating oil), a concrete slab with a raised rim is cast on which the core drilling machine is placed. This keeps any fluids spilled by the drilling machine from running into the ground. It also enables the personnel to detect even small leakages of, for example, hydraulic oil very quickly. The drilling personnel also follow a special environmental control programme that includes daily inspection of hoses and couplings as well as replacement of worn equipment. Equipment for cleanup of oil spills is also available on the drilling site.

Waste will be collected and taken to environmental stations. Free-standing oil tanks will be dyked-in so that the whole volume is within the dyke, and also provided with a rain collar.

After completion of drilling, the work site is given a final cleaning and any ground damage outside the gravelled surface is remediated. When the site investigation is finished, SKB intends to remove the drilling sites and branch roads and remediate the land to its original condition to as great an extent as possible.

The placement of future drilling sites will be preceded by supplementary consultation with the County Administrative Board.

B.3.4 Percussion drilling

Description

Approximately 10 new percussion boreholes are planned in the Laxemar subarea During the remainder of the site investigation. The boreholes are normally 100–200 m long. Drilling of a percussion borehole takes about three days. Drilling can be carried out at any time during the year. Percussion boreholes are drilled to obtain flushing water for core drilling, to investigate fracture zones and to investigate the bedrock between fracture zones. Many of the percussion boreholes are furthermore intended for long-term monitoring of the groundwater level and groundwater chemistry.

Percussion boreholes are drilled with a pneumatic drilling rig similar to those used for drilling wells (see Figure B-5) and must comply with the same purity requirements as well bores for drinking water. The drill bit fragments the rock and the cuttings are blown up out of the hole by compressed air. A 200-m deep percussion borehole produces approximately three cubic metres of cuttings. Drill cuttings that are not collected for examination are used in the construction of drilling sites and branch roads or hauled to a landfill.



Figure B-5. Percussion drilling machine.

Except during setup and removal of the drilling equipment, virtually no vehicles are used for transport to and from the percussion drilling site. An exception is if heavy measurement equipment is needed on a later occasion. During the drilling work, the personnel can get around on foot. After completion of drilling, the drilling site is cleaned, the borehole is instrumented and a measurement hood is placed over it. After concluded geophysical and hydraulic borehole measurements, some (but not all) boreholes are instrumented for long-term monitoring of groundwater levels and groundwater chemistry, and the measurement instruments are covered by a lockable measurement hood. Signal cable is run to the measurement hood.

Environmental impact

The drilling machine and thereby the sound level are the same as during ordinary well drilling in rock. The diesel-powered compressors used to generate the compressed air, as well as the drilling machine's diesel engine, produce both noise and exhaust gas emissions. Percussion drilling makes more noise than core drilling and can be heard at a great distance (a kilometre or so), especially in the beginning of the drilling when the bit is near the ground surface. However, the noise does not last long (about three days). Noise is also created by vehicular traffic associated with the drilling. During the actual drilling, noise-sensitive and timid animals may temporarily be disturbed over a large area. Vibration is limited, as is the light from electric lighting in the evenings and at night.

Since new roads and gravelled areas are avoided at most percussion drilling sites, land needs are modest. Off-road driving in connection with drilling and subsequent measurements can cause damage to the ground and vegetation. The groundwater table is lowered (drawdown) during drilling. Groundwater of elevated salinity may be released to the environment during drilling.

Both percussion boreholes and cored boreholes are lined with stainless steel casing, and the casing-wall gap is grouted with white cement. The quantity of grout is generally much less than in the case of core drilling, but the potential environmental risks are of the same kind as for grouting of cored boreholes.

Measures

As in the case of core drilling, the choice of drilling site will be determined by the geo-scientific question which the borehole is intended to answer. Consideration can nevertheless be given to natural values by locating the investigation holes where the fracture zones to be studied intersect existing roads. Some holes may end up being located relatively far from the nearest road, however. Since the drilling is of short duration, and because an attempt is made to minimize the building of roads and drilling sites, the impact is judged to be limited. But off-road driving will be necessary during drilling, as well as later when measurements are made. Off-road driving must be approved by the site ecologist after the travel route is checked.

The drilling equipment is placed on a geotextile sheet so that any oil spilled by the drilling machine will be kept from reaching the ground immediately and so that the spill can be quickly discovered and remediated.

The air compressor's diesel engine must have a silencer that is approved for use in an urban environment.

The electrical conductivity of the water that is pumped up from the borehole is measured during drilling. If groundwater with elevated salinity comes up from the hole during drilling, no measures are taken since the impact is of short duration. Due to the very high water-generating capacity of the upper part of the bedrock, the flow rate during percussion drilling has generally been high, up to around 600 litres/minute.

B.3.5 Soil drilling

Description

During the complete site investigation, approximately 20 new soil drilled holes are planned in addition to those bored for the installation of soil wells next to new drilling sites. Soil drilling is done with a lightweight crawler-mounted machine (Geotech), see Figure 3-42. It takes two persons about one day per hole.

Environmental impact

Since light equipment is used for the majority of the soil boreholes, the environmental impact of the soil drilling is judged to be small. Only small amounts of cuttings or augured-up soil ends up on the ground and the groundwater is only affected to a limited extent. The main impact comes from off-road driving, some noise and minor exhaust emissions, passenger transport and a temporary increased presence in the area.

Measures

Off-road driving in sensitive areas will be limited and will be preceded by a cross-check against the accessibility map and a field check of natural and cultural values.

B.3.6 Investigations in boreholes

The group includes:

- Hydraulic tests, hydraulic fracturing and water sampling in wells and boreholes.
- Tracer tests.
- Other borehole tests.

Description

Heavier lifting and measuring equipment is used for hydraulic testing and water sampling. Equipment for hydraulic testing is often installed in freight containers or mobile work wagons that are positioned directly above the borehole. The investigations can be conducted year-round.

During water injection tests and pumping tests, water is handled in a way that resembles flushing and return water handling during drilling. Owing to the large water-conducting zones in the upper bedrock, the water quantities that are handled in test pumping can be relatively great if the pumping is of long duration. Most boreholes are test-pumped for one to several hours. In some boreholes, one or more tests are performed with a duration of around a week. But the water flows are much less than during core drilling and percussion drilling.

Hydraulic fracturing will be done in one or two cored boreholes to determine the magnitude and direction of the rock stresses. The equipment is very similar to that used for hydraulic injection tests. The water pressure used is higher, but on the other hand fewer measurements are made so the quantity of water is much less than in drilling.

Interference tests will probably be performed during the complete site investigation. This entails investigating the hydraulic contact between different boreholes by pumping water out of one hole and measuring responses in others. These tests will be of long duration (months) and be performed during the summer season. Depending on the amount of water flowing into the holes and depending on the nature of the soil layers and the contact between rock and soil, there may be some impact on the vegetation due to groundwater drawdown. The insignificant impact on the soil layers observed so far in conjunction with core drilling indicates that there is little risk of this, however.

In a dilution test, a tracer is injected into a borehole and the dilution of the tracer is then observed during pumping in a nearby hole. This provides an opportunity to evaluate the hydraulic properties and transport properties of the rock. Such tests or other types of tracer tests have not been conducted during the site investigation but are planned during the complete site investigation. Probable tracers are dyes (biodegradable) and some salts (NaI, NaBr, CsI). Some metal complexes (EDTA or DTPA) may also be used. If so, they must be used in extremely low concentrations, since they are rare earth metals (erbium, terbium, gadolinium and so on). The tracers are not expected to have any environmental impact in themselves, since they are harmless and the concentrations are so low. As in other borehole tests, some water will be pumped up. This will be handled in the manner described above.

Thermal borehole tests may be performed in deeper boreholes. Either a borehole instrument that emits heat very briefly is used, or a “pumping test” is performed with heat or cold.

Other borehole investigations (Figure B-6) such as geophysical logging, videotaping and borehole radar measurements are not expected to give rise to environmental disturbances.



Figure B-6. Borehole investigations in Simpevarp/Laxemar.

Environmental impact

Pumping tests lead to a lowering of the groundwater table (drawdown). The amount depends on the pump flow and the duration of the pumping. The groundwater level in the bedrock can be affected within a range of 200–400 m from a borehole. The drawdown is greatest (about 40–60 m) around the hole itself. The tests we have done so far have lasted several weeks, and as mentioned previously the groundwater table returns to its original level only a few hours after pumping has stopped.

The impact in overlying soil layers is entirely dependent on the composition of the soil layers and the nature of the interface between soil and rock. If the overburden deposits are non-permeable and the hydraulic connection between soil and rock is poor, the drawdown in the soil layers is reduced or eliminated entirely. Permeable overburden deposits such as gravel are affected more by pumping, but due to its brief duration, test pumping will probably not have any effect on the vegetation. On the other hand, the interference tests may have some impact on the vegetation depending on how sensitive the vegetation around the boreholes is. Areas that are wet in their natural state are most sensitive to drying-out. The effect will be temporary, however, so no effects are expected to persist into the next season.

The environmental impact of the heat in the thermal borehole investigations is assumed to be negligible. However, the use of the rig gives rise to exhaust and noise emissions.

Measures

The water that is pumped up is normally conducted a short distance away for soil infiltration. If there are large quantities or if the water is saline, however, it may have to be collected in a tank for transport to the sea or be pumped out to sea through a pipe.

As with other boreholes, the location of the thermal boreholes is determined by the geoscientific question the borehole is intended to answer. Consideration should nevertheless be given to natural values by locating the boreholes close to existing infrastructure so that off-road driving is avoided and power can be taken from the grid.

B.3.7 Measurement of stream discharge and water levels

Description

The stream discharge in a watercourse is measured either in naturally constricting sections where no artificial damming is necessary or in weirs. See Figure 3-45. Seven stream discharge stations have been prepared and put into operation during the site investigation. No further installations are planned.

Pressure probes positioned next to a soil well are used to measure the water level in lakes and the sea. The pressure levels are stored by a battery-powered logger mounted on the well. The loggers are connected to a GSM system that phones up and transmits data several times a week. The stations are visited roughly every fourth month when the batteries need to be changed. Seven water level stations have been prepared and put into operation. No further installations are planned.

Environmental impact

When the stream discharge stations with weirs were built, the stream was dredged with an excavator along a distance of about 30 m. Some trees had to be felled to clear a path for the excavator. During the excavation work the water in the creek was diverted past the construction section in a temporary side channel.

Measures

To prevent mobile machinery from having to be driven long distances off-road, the monitoring stations have been located close to existing roads. This location has been determined in consultation with the site ecologist and has been preceded by a cross-check against the accessibility map and a field check of natural and cultural values. The location and design of the stream discharge stations has furthermore been approved by the County Administrative Board. The location of the water level stations has been chosen in consultation with the site ecologist.

B.3.8 Seismic surveys

Description

Three different methods are used for seismic surveys: seismic refraction, seismic reflection and Vertical Seismic Profiling (VSP). During the remainder of the investigations only seismic refraction will be used. This method is used to determine soil depth and to study superficial structures in the rock, and to provide a basis for the lineament excavations that are planned.

In seismic refraction surveys small explosive charges (“shots”) of no more than a couple hundred grams are detonated in the ground and the wave’s propagation and refraction against structures in the soil or bedrock are recorded with geophones, which are similar to sensitive microphones.

The only environmental disturbance caused by other ground geophysical measurements that will be performed during the continued site investigation, for example magnetic or resistivity measurements, is the movement of people in the investigation area.

Environmental impact

A large area is often staked out for the investigations. Staking is often done along lines spaced at a distance of about 100 m with stakes spaced at about 10 m intervals. Sometimes visibility clearance is necessary, which means that small shrubs are removed to permit free visibility between the stakes. The initial site investigation has showed that few environmental intrusions are required and that they do not impair the experience of the wooded area.

The noise levels from the seismic refraction surveys are low to medium-high. They cause a report that can be perceived a couple of hundred metres away. The report from the shots located furthest from the geophones in seismic refraction is even louder. The noise is of short duration, but the shots can disturb birds and mammals.

A normal shot for seismic refraction on soil layers creates a mound in the ground surface with a diameter of about a half a metre, where the soil is loosened under the mound. The mound is levelled before the site is abandoned, so the impact is judged to be insignificant. Shots at greater distances from the geophones require larger charges, causing bigger pits and eruptions of soil and stones. The craters may be a metre in diameter, with a depth of a couple of decimetres. Off-road driving is not permitted during seismic surveys.

Measures

The route taken by all profiles is cross-checked against the accessibility map and in cases where the profiles do not follow existing roads but strike out into the countryside, field checks of natural and cultural values are sometimes also made. The purpose is to guide the placement of shot points so that the risk of damage to sensitive environments is minimized. Based on the accessibility map, the locations of the survey profiles can be adjusted and the time of the year can be chosen so that disturbances of animals and countryside are limited. Craters created in the ground are backfilled with debris and levelled off.

Guards are stationed to warn of ongoing blasting work. Storage, transport and handling of explosives complies with laws and regulations. For example, the seismic contractor must have a blasting licence and a permit for the blasting work.

B.3.9 Field inventories and other investigations in sensitive areas

Description

The big field investigations such as surface mapping of rock types, soil inventories, Quaternary deposit mapping and mapping of watercourses were carried out during the initial site investigation. But some field investigations will be carried out during the continued site investigation as well. Most respiration measurements on land and in water and continued monitoring of the bird fauna in the area entail minimal environmental impact. Bedrock geological mapping is being done on outcrops in the area. In detailed fracture mapping, outcrops are exposed by stripping the overburden and the rock surface is cleaned with a high-pressure spray. An investigation of fine roots will be conducted in the area, requiring digging of small pits. Furthermore, supplementary marine geological investigations will be conducted from a boat by taking sediment plugs from the bottom, where the water depth is less than 3 m.

Environmental impact

Most of the remaining field inventories and investigations have very little environmental impact, in principle only the disturbance caused by the presence of the personnel in the field.

Bedrock geological mapping of outcrops may require the temporary removal of moss and lichens within small areas. The areas, around 0.5–1 m in diameter, are remediated after completed mapping.

Detailed fracture mapping requires that the overburden be stripped down to the rock surface by an excavator. Outcrops at planned drilling sites or outcrops that are already bare or have little soil cover are preferred, however. The outcrops are then cleaned with a high-pressure spray or compressed air. Excavation gives rise to noise, dust and exhaust emissions, and excavators can leak lubricating and/or hydraulic oil. Compressors for powering high-pressure equipment also give rise to noise and exhaust emissions.

The animal and bird life is particularly sensitive during certain times of the year, and presence in the field may cause disturbances.

Measures

Field activities that only require personnel on foot in the field are not checked against the accessibility map. Other activities are checked against the accessibility map, and if necessary field checks are made of natural and cultural values. The investigations are scheduled to minimize disturbances of the animal life. This is particularly important during the breeding period (April to June), when SKB strives to have as few personnel as possible in the area.

Thanks to the monitoring of birds and game conducted by SKB, there are good opportunities to plan activities so that disturbances are minimized.

Field investigations that impact the natural environment will be preceded by supplementary consultation with the County Administrative Board.

B.3.10 Summary

The table below summarizes the investigations that are judged to have a possible impact on the environment and that in certain cases will be preceded by notification to the County Administrative Board of consultations according to Chapter 12 section 6 of the Environmental Code for further specification of dates, execution and siting.

Activities that can lead to environmental impact	Execution	Estimated scope	Comment
Construction of roads	2005–2007	New roads may have to be built in conjunction with the construction of new drilling sites, see below. Otherwise, however, no additional roads are planned in the area. The roads must be negotiable by cars and trucks with trailers and the loadbearing capacity of the road must permit heavy traffic year-round.	Will be preceded by notice of consultations with the County Administrative Board; construction of new roads will be minimized, however.
Construction of branch roads and drilling sites	2005–2007	Short roads may need to be built to new drilling sites. The road may need to be made wider at the drilling site. The extra width is used as a loading and unloading area and a parking place. The road can be widened on one or both sides. Core drilling sites require a gravelled surface of about 30x30 m and will be fenced in.	The notice of consultation regarding additional drilling sites will include an integrated account of roads, design and associated infrastructure.
Construction of other infrastructure	2005–2007	The need for additional power and signal lines is determined by the number of additional drilling sites and their location in relation to existing infrastructure. Lines are installed alongside roads, mainly underground in conduits. For infrastructure related to measurement and monitoring equipment, see below.	Power and signal lines have been laid to all core drilling sites.
Core drilling	2005–2007	Approximately 13 new cored boreholes, 3–6 months/borehole. Seven additional drilling sites. Approximately 30 short cored boreholes. Flushing water is supplied from nearby percussion boreholes. Return water is conducted via settling tanks to land situated downstream.	Construction of new drilling sites in the terrain and discharge of return water to alternative receiving bodies will be preceded by notice of consultation with the County Administrative Board.
Percussion drilling	2005–2006	Approximately eight new percussion boreholes, 100–200 m deep. Do not normally require construction of road or gravelled surface, which means that the land occupied will be insignificant. Drilling takes about 3 days/hole.	Information will be sent to the County Administrative Board.
Excavations for mapping of bedrock etc	2005–2006	Excavation of pits or trenches for examination of the rock surface at suspected fracture zones is planned at 3–6 places in the area.	The localities where excavations will be done will be notified for consultation with the County Administrative Board.
Seismic surveys	2005–2006	Several types of seismic surveys will be performed during the complete site investigation.	Information will be sent to the County Administrative Board.

Definitions

Abiotic	Used about non-living parts of our world, such as rock, air and water, and about processes not brought about by living creatures (antonym: biotic).
Acetogenic	Acetogenic bacteria produce acetic acid from carbon dioxide and hydrogen.
Alkalinity	The water's ability to neutralize acids, enabling it to better tolerate "acid rain" without the water becoming acidic.
Ancylus Lake	Fresh water stage in the evolutionary history of the Baltic Sea, about 9,500–8,000 years before present.
Anisotropy	Anisotropy means that a physical property of an object is different in different directions.
Anomaly	Deviation from the normal condition.
Aquatic	Relating to water (as opposed to terrestrial, relating to land).
Artesian	Term used about wells in a groundwater reservoir whose hydraulic head (groundwater table) is situated higher than the ground surface. Water will then flow freely out of the well if the well is open.
Autotrophic	Organism, for example plant or bacterium, that can synthesize organic compounds from inorganic carbon (carbon dioxide) using solar energy or the like (antonym: heterotroph).
Banding	Alternating, more or less parallel layers in a rock with different colours, grain sizes or mineral compositions.
Bathymetry	Measurement of depth, normally to the bottom of seas and lakes, usually by means of an echo sounder.
Benthal	The benthic zone, the biological bottom zone in seas and lakes. At great depths the only organisms are animals and bacteria, but in general benthal includes both plants and animals that are dependent for their existence on the bottom, even though some organisms spend parts of their life in the water above or live on plants attached to the bottom. The benthal is divided into the littoral, which includes most of the shore together with the wave-washed portion above the high-water level, the sublittoral, which extends down to the outer limit of the continental shelf, and the deep-sea zone thereunder.
Bentonite	Soft, plastic, light-coloured clay with high water absorbency. Swells when it absorbs water. Formed by chemical metamorphism of volcanic material, mainly ash and tuff. Transported and handled in powder form, can be compacted into blocks.
Biosphere	The parts of the earth and the atmosphere where living organisms are found. The biosphere can be divided into sea, fresh water, land and atmosphere.
Biota	Living fauna and flora.
Biotope	An ecological unit with uniform plant and animal life.
Bioturbation	The stirring and mixing of deposits (soil and sediments) by organisms such as worms and insects, especially by burrowing or boring.

BIPS logging	Borehole Image Processing System for video photography of the borehole wall.
Bladder wrack	<i>Fucus vesiculosus</i> , species of brown algae, a perennial marine alga, that can grow to great heights, around 1 m or more. It usually has air-filled bladders attached in pairs on the flattened, branching fronds, and male and female reproductive organs in swollen tips on separate individuals.
Borehole logging	Geophysical measurements in the borehole are used as a support for interpretation and determination of different rock types, deformation zones, fractures and the orientation of individual fractures.
Boremap mapping	Mapping by integrated interpretation of images from BIPS logging of a core borehole and the drill core.
Brittle deformation	Deformation in which the bedrock reacts by fracturing. In this kind of deformation, individual fractures and clusters of fractures form fracture zones.
C14	A radioactive isotope of carbon, valuable for dating (C14 method) of long-dead organisms and of water with carbon content.
Clab	Central interim storage facility for spent nuclear fuel. Spent nuclear fuel is stored at the facility, which is situated at the Oskarshamn Nuclear Power Plant, in water pools for about 30 years prior to encapsulation and final disposal. Clab was commissioned in 1985.
Colloids	Finely divided particles that do not sediment due to their small size but remain freely suspended in the water; they range in size from 1 nanometre (10^{-9} m) to 1 micrometre (10^{-6} m).
Conceptual understanding	Understanding of a process or condition that includes its geometric context, assignment of material properties and boundary conditions.
Conductivity	Can refer to electrical conductivity (ability to conduct electric current), thermal conductivity (ability to conduct heat) or hydraulic conductivity (permeability of a rock to water).
Confidence level	Degree of confidence, credibility (from the Latin <i>confido</i> “be sure of”, “rely on”). Cf confidence interval, statistical term, the most common form of uncertainty interval. If the answer cannot be determined exactly in an experiment or an investigation, two limits can be given instead which bracket the correct value with a predetermined probability, the confidence level. Common values are 95% and 99%.
Connectivity	Connection between two points. A hydraulic connectivity between two points that are ascribed to the same geological structure (for example a deformation zone) can be utilized to support the interpretation of the extent of the structure.
Core dinking	Phenomenon that occurs when a drill core is broken into a number of disks during drilling. Core dinking is an indication of high rock stresses. Core dinking in vertical boreholes is caused by high horizontal stresses.
CVES	Continuous Vertical Electrical Sounding is a method (also know as the Lund method) for determining the electrical properties of the soil layer and the rock. These properties are determined by the fractures' content of water and electrically conductive minerals, such as clay minerals. It is called continuous because measurements are made continuously after electrode deployment. Vertical sounding entails measuring so that a resistivity profile is obtained with information in relation to increased depth.

Deformation zone	Collective term for folding and faulting of rocks due to stresses in the bedrock. The rock volumes on either side of a deformation zone have moved in relation to each other.
Detailed characterization	Investigations of the bedrock in conjunction with the construction and commissioning of the final repository.
Deterministic	Elements in the descriptive model that are described as discrete bodies with a well-defined geometry. These deterministic elements (for example deformation zones) can be ascribed a varying degree of confidence depending on the underlying data. See also “Stochastic description”.
DFN model	Discrete Fracture Network model.
Diffusion	Transport (spreading) of one substance (for example salt) in another substance (for example water) due to concentration differences. Diffusion is substance-dependent and can take place in the rock via microfractures and pores.
Diorite	An intrusive igneous rock (a rock formed at great depth) consisting of the minerals plagioclase (a feldspar), hornblende and biotite. Relatively quartz-poor. Dark grey to greyish-black and coarse- to medium-grained.
Dioritoid	Collective term for dark grey to reddish-grey, diorite-like igneous rocks consisting mainly of plagioclase (a feldspar), biotite and hornblende. May also contain potassium feldspar and quartz in varying amounts.
Dip	Angle of inclination of a planar structure, such as a bedding, a fracture zone or a fault plane, with the horizontal. Measured perpendicular to the strike.
Dispersivity	Measure of dispersion of flow rates in an individual fracture or fracture network in rock or in a homogeneous porous medium such as sand.
Dolerite/diabase	Basaltic, usually black and fine-grained hypabyssal rock that forms more or less steeply-dipping strata in the bedrock.
Ductile deformation	Deformation where the bedrock reacts plastically, i.e. like a viscous mass. Ductile deformation, which takes place at great depth and high temperature, can give rise to folding and ductile shear zones, with strong schistosity and linear structures.
Ecological succession	Gradual process of change in an ecosystem where new plant and animal communities take the place of old ones.
Ecosystem	Biological community (organisms and their habitat) that is relatively self-sufficient with regard to energy flows, for example forest and grassland.
End member	(Ground)water with extreme but well-defined chemical composition. All other waters should be able to be described as a mixture with given proportions of end member waters.
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. The term is also used, somewhat freely, as a synonym for evaporation.
Evertebrates	Another name for invertebrates.
F factor	The accumulated ratio between flow-wetted surface and flow rate along an individual flow path. For a group of flow paths, a statistical distribution of the F factor is given.

Fold hinge	Line of maximum bending in a folded surface.
Folding	Deformation of the earth's crust due to compression by means of opposing forces.
Foliation	Refers to the planar structure of a rock that allows it to be cleaved along parallel planes. Most metamorphic rocks have a characteristic structure, foliation.
Formation factor	The ratio of effective diffusivity in a material to diffusivity in water. The formation factor can also be obtained from electrical measurements in the rock by an analogy between diffusion and conduction of current in the pore water in a porous material.
Fracture aperture	Fracture opening.
Fracture zone	Deformation zone formed as a result of brittle deformation, i.e. when the bedrock reacts by fracturing. See also brittle deformation.
Fucus	The scientific name of a genus of brown algae found in nearly all seas in the vegetation zone that starts directly beneath the higher green algae zone.
Gabbro	An intrusive igneous rock (a rock formed at great depth) consisting primarily of plagioclase and pyroxene. It is a coarse-grained, mafic (silica-poor) rock, normally dark grey to black in colour.
Gamma log	See natural gamma log.
Geochronology	Dating and sequencing of events in the earth's history. In a general sense, geochronology refers to the determination of ages, absolute as well as relative, on a geological time scale.
Geophone	Instrument that converts the shaking (vibration) of the earth caused by nearby earthquakes or blasts to electrical signals. Geophones are used for seismic measurements.
Geophysical	A method for measuring the physical properties of the rock in the borehole.
Geophysical surveys	Measurements of magnetic fields, electrical resistivity and other physical parameters. By surveying variations in the physical properties of the rock or the soil layers, it is possible to determine soil depth, rock type boundaries, deformation zones and other geological parameters.
Glacial	Formed in connection with (or otherwise associated with) a glacier or continental ice sheet.
Gneiss	Highly metamorphosed rock type, often banded with more or less parallel mineral grains.
Granite	An intrusive igneous rock (a rock formed at great depth) consisting primarily of the minerals quartz, feldspar, mica and/or hornblende. The colour is usually grey or red.
Granitoid	Collective term for quartz-rich granite-like intrusive igneous rocks, for example (besides granite) granodiorite and tonalite.
Granodiorite	Felsic intrusive igneous rock that outwardly resembles granite. Consists primarily of the minerals quartz, plagioclase, potassium feldspar and biotite (dark mica). It is medium- to coarse-grained and light to dark grey in colour.
Gravimetry	Gravity measurement. Used to determine density variations in rock.

Habitat	The setting in which a species normally lives; basically the same as its biotope.
Heterotroph	Organism, such as fungus or animal, that uses organic carbon as a carbon source (antonym: autotroph).
Histosols	Soils that consist primarily of organic matter. All peat soils in Sweden are histosols.
Hydraulic gradient	Difference in the level of the groundwater table (hydraulic head) per unit length. In its simplest form it is equal to the slope of the groundwater table.
Hydrothermal	A mineral deposit precipitated by a hot aqueous solution emanating from molten rock. Hydrothermal alteration, alteration of rocks or minerals caused by hot water or gas.
Hypabyssal rock	Igneous plutonic rock in the form of an intrusion formed when magma (molten rock) has penetrated and solidified in fractures, usually in the superficial parts of the bedrock.
Igneous rock	Rock crystallized from molten rock (magma).
In situ	In place. Used in geology about a fossil or mineral that is in its original location; used in biology when an organism (especially a small or sedentary one) is studied in its natural habitat.
Intrusive rock	A plutonic rock (a rock formed at great depth) that has penetrated into and solidified in the earth's crust as massifs or dykes.
Isotope	Atoms of the same element but with different atomic weights. Isotopes have identical electron shells and therefore almost identical chemical properties.
KBS-3 method	KBS is an abbreviation for KärnBränsleSäkerhet , which is Swedish for Nuclear Fuel Safety. Proposed method for final disposal of spent nuclear fuel based on the concept of encapsulation of the fuel in canisters and emplacement of the canisters in crystalline bedrock at a depth of about 500 m.
Kinematic	The field of mechanics that describes the motion of bodies regardless of the cause of the motion; The pattern of motion in ductile and brittle deformation zones.
K value	Hydraulic conductivity, a measure of the permeability of (in this case) a geological stratum (soil layer or bedrock).
Lacustrine	Pertaining to or living in fresh water (lakes).
Lateral moraine	Side moraine, low moraine ridge deposited on a slope along the side margin of a glacier. A lateral moraine has a gentle inclination that reflects the gradient of the glacier surface when the moraine was deposited.
Leptosols	Shallow mineral soils found in high, hilly terrain, can merge continuously with the broken-up surface layer of the bedrock. Leptosols generally have a thin A horizon.
Lineament	More or less linear feature on the ground surface. May be a topographical structure (elongated depression) or a geophysical property, such as variations in the magnetic field. A lineament indicates that there may be a fracture zone or a deformation zone in the underlying rock, but it may also be a ridge or a depression.
Lineation	Linear structure of a rock.

Lithology	The description of Quaternary deposits or rocks with respect to characteristics visible to the naked eye, such as colour, mineral composition and grain size.
Littorina Sea	Salt water stage in the evolutionary history of the Baltic Sea, between about 8,000 and 3,000 years before present. It is named for the gastropod genus <i>Littorina</i> , periwinkles, which are found in the Littorina Sea's shore deposits up to the Stockholm region.
Lund method	See CVES measurements.
Mafic rocks	Igneous rock consisting mainly of dark-coloured, ferromagnesian (containing iron and magnesium) minerals such as olivine, pyroxene, amphibole and biotite.
Macrophyte	From the Greek roots macro "large" and phyton "plant" – large plant in aquatic vegetation. Macrophytes include vascular plants (for example reeds, sedges, bulrushes, reed sweet-grass and club-rush) as well as aquatic mosses (such as willow moss) and large algae (especially brown algae).
Magnetic susceptibility	The ability of rocks to be magnetized by an externally applied magnetic field, for example the earth's magnetic field.
Magnetite	A black, strongly magnetic mineral (iron oxide). Important mineral for extraction of iron.
Magnetometer	Instrument for measurement of magnetic field or magnetic properties. The instrument is normally used to measure the earth's magnetic field.
Magnetometry	Method for determining the magnetic properties of the rock stemming from the magnetic susceptibility of its minerals; magnetic susceptibility is the rock's ability to be magnetized by an externally applied magnetic field (such as the earth's magnetic field). The Q value is the ratio between the magnetization that was "frozen" in the rock a very long time ago and the magnetization caused by the earth's present-day magnetic field.
Magnitude	Measure of the energy released by an earthquake. Usually refers to magnitude on the Richter scale. Magnitude on the Richter scale increases by a factor of about 32 with each increment; in other words, a quake with a magnitude of 4 is 32 times more powerful than a quake with a magnitude of 3.
Marine	Relating to the sea.
Matrix diffusivity	A measure of how quickly a substance can penetrate (diffuse) through the rock matrix.
Mesosopic shear zone	Ductile deformation zone on outcrop scale, in other words the total thickness of the zone can be observed.
Meta-	Prefix used in front of the name of a rock to indicate that the rock has been metamorphosed.
Metamorphic	A metamorphic rock is one that has been altered in the earth's crust due to changed pressure and temperature conditions.
Methanogenic	Methanogenic bacteria produce methane from carbon dioxide and hydrogen.
Metavolcanic rocks	Rocks formed by volcanic activity (lava or volcanic ash) that have subsequently undergone metamorphism.

Meteoric water	Water that originates from rain.
Modal analysis	Method for determination of the mineral composition of a rock by microscopy.
Monitoring	Continuous or repeated observations and measurements of parameters (groundwater level, barometric pressure, etc) that vary with time.
National interest	Area designated by a municipality, county administrative board, national agency or authority as being particularly suited for a given activity, for example outdoor recreation, professional fishing, extraction of mineral deposits, industrial production, energy production, waste management or water supply. According to the Environmental Code, areas of national interest shall be protected as far as possible against measures that may be prejudicial to their utilization for this interest.
Natural gamma log	The natural gamma log records the bedrock's content of radioactive isotopes of uranium, thorium and potassium.
Nuclear installation	Plant where nuclear materials are handled. The present-day nuclear installations in Sweden are the nuclear power plants in Ringhals, Barsebäck, Oskarshamn (including Clab) and Forsmark (including SFR), Studsvik, Westinghouse Atom's fuel factory and Ranstad Mineral.
Pegmatite	Coarse-grained igneous rock of granitic composition that usually forms dykes or small massifs.
Pelagial	Pelagic zone, the open water in seas and lakes (in lakes also called the lacustrine zone), but normally not the top and bottom levels of the water. The organisms of the pelagial include the bacteria, algae, plants and animals that spend their entire lives (holoplankton) or only a portion of their lives (meroplankton) in this zone. They also include active swimmers, such as fish.
Permeability	Capacity of porous media, such as soil or fractured rock, to transmit gas or water.
Petrophysics	Method for determining physical properties of rock such as density, magnetic susceptibility, electrical and thermal conductivity and radioactivity.
PFL	Posiva Flow Log. Equipment for flow logging in boreholes.
pH	Value that indicates how acidic or basic (alkaline) a solution is. It is often used in chemistry, biology and environmental science. At room temperature, pH=7.0 corresponds to a completely neutral solution (no excess of either hydrogen ions or hydroxide ions). A lower value indicates that the solution is acidic (excess of hydrogen ions) and a higher value that the solution is basic (excess of hydroxide ions).
Podzols	Soils with a well-developed illuvial horizon consisting of organic matter, aluminium, iron, manganese and above that a bleached horizon. This is the most common type of soil in Sweden. Podzols are principal soils within the boreal and temperate parts of the northern hemisphere.
Poisson's ratio	Ratio of transverse contraction to longitudinal extension, a material constant in elasticity theory. When an elastic test bar undergoes elongation, a transverse contraction is obtained that is proportional to the rod's longitudinal strain. This proportionality ratio is called Poisson's ratio.
Porosity	Porosity is defined as the volume of void space per unit volume of the entire material.

Porphyry	Igneous rock of volcanic origin characterized by porphyritic texture, in other words large mineral crystals (megacrysts) scattered in a fine-grained or glassy groundmass. Famous Swedish porphyries include the Älvdal porphyries in Dalarna and the hypabyssal porphyries in Småland.
Postglacial	Following the most recent ice age.
PSS	Pipe String System. Equipment for execution of hydraulic tests in cored boreholes (injection tests or pumping).
P-wave	P-wave (= primary wave) compressional wave during earthquake. The name derives from the fact that it is the first wave to arrive at a seismograph after an earthquake. Primary waves are longitudinal waves.
Quartz	Light and very hard, sometimes translucent mineral consisting of silica (SiO ₂). The more silica a rock contains, the more felsic it is. The less silica it contains, the more mafic it is. Next to feldspar, quartz is the most common rock-forming mineral.
Quartzite	Even-grained, usually white or grey, metamorphic rock that consists mainly of quartz.
Quartz monzodiorite	An intrusive igneous rock (a rock formed at great depth) consisting of plagioclase (a feldspar), potassium feldspar, quartz, hornblende and biotite.
Radar interferometry	Length measurement using radio waves.
RD&D-Programme	The programme of R esearch, D evelopment and D emonstration which SKB is required by the Nuclear Activities Act to present every third year.
Redox potential	Can be compared to a measure of “electron pressure”. At a negative redox potential and high “electron pressure”, oxygen-free conditions prevail. At a positive redox potential, oxygen is present. The redox potential determines which reactions can take place and which chemical components can occur in groundwater, for example.
Regolith	The layer of unconsolidated overburden covering the unweathered bedrock. In areas that have not been covered by ice sheets, it includes the weathered bedrock (saprolith) and transported material on top of it. In areas that have been glaciated, the regolith consists primarily of glacial and postglacial deposits, but also a small portion of deeply weathered bedrock.
Regosols	Group of immature soils formed in fine-grained unconsolidated minerogenic materials that have no other horizons than a weakly formed A horizon; found in high-lying, hilly terrain. Regosols are found in all climates all over the world; in Sweden, regosols may possibly phase into weakly formed podzols or cambisols.
Resistivity	Describes the rock’s electrical conductivity, which is in turn determined by the fractures’ content of water and electrically conductive minerals, such as clay minerals.
Respiration	Scientific term for breathing.
Seismic reflection	A method where a sound wave is created by an explosion or a vibrator. The sound waves are propagated in the rock and some of the wave bounces or reflects against a flat surface in the rock, often a fracture zone or a rock type contact. The returning sound waves are recorded by sensitive microphones called geophones.

Seismic refraction	A method where a sound wave is created by an explosion or a vibrator. The sound waves are propagated through overlying soil layers down into the rock. A portion of the wave is refracted against a flat surface in the rock and between soil and rock. Since the sound wave is propagated along the top surface of the rock, it will be slowed down when it passes sections of fracture rock, such as a fracture zone in the rock. The fracture zone may be filled with clay mineral, for example. The returning sound waves are recorded by sensitive microphones called geophones deployed on the ground.
SFR	Final repository for radioactive operational waste. SKB's facility for final disposal of low- and intermediate-level operational waste situated approximately 50 m down in the rock, beneath the seabed, at the Forsmark Nuclear Power Plant. The repository has been in operation since 1988.
Shear zone	Deformation zone formed as a result of ductile deformation, i.e. under high pressure and temperature. See also "Ductile deformation".
Sheeting	The structure near the surface of the bedrock in which fracturing has divided the rock into tabular bodies, or sheets, that are parallel or nearly parallel to the surface of the bedrock. Common in otherwise fracture-poor crystalline bedrock and can be seen in many road cuts around the country.
Single-hole interpretation	Method where results of geological and geophysical borehole investigations are weighed together to a subdivision of the borehole into rock units consisting of rock types with similar properties and possible deformation zones. Single-hole interpretation is mainly intended to serve as a basis and support for geological 3D modelling.
SKI	Statens kärnkraftinspektion (Swedish Nuclear Power Inspectorate). Authority whose mission is to exercise supervision of the safety of the nuclear installations according to the Nuclear Activities Act.
Slingram	A method where two coils are used, a transmitter and a receiver. An electromagnetic field is transmitted from the transmitter. If there is a fracture zone in the rock that conducts electric current, for example if it contains clay minerals or water, a new field is created due to electric currents generated by the transmitter field. The new field can then be detected in the receiver as a change.
Sorption	Physical and/or chemical bonding of atoms or molecules to a surface, includes both adsorption and absorption.
Sorption coefficient	Measure that indicates the ability of a rock to retain different substances on fracture surfaces and in pores.
Spatial	Having to do with extent in space, for example the shape of an object.
SSI	Statens strålskyddsinstitut (Swedish Radiation Protection Authority). Authority whose mission is to protect humans, animals and the environment against the harmful effects of radiation in accordance with the Radiation Protection Act.
Stochastic description	For elements in the descriptive model where the data does not allow a discrete description (i.e. a description of each individual element), a description of the object is instead used where both its location and its properties (including geometry) can be allowed to vary on the basis of statistical distributions.
Stoichiometry	Study of the proportions in which substances react chemically with each other.

Stratigraphy	Branch of geology that studies the sequence and interrelationship between different strata of rock in the earth's crust.
Strike	The direction taken by a planar structure, such as a bedding, foliation, a fracture zone or a fault plane, as it intersects the horizontal.
Subhorizontal	Close to horizontal.
Substrate	The surface or material (soil, water) on which plants, fungi, lichens, bacteria and certain invertebrate animals grow or live.
Supracrustal rock	Rock formed on or near the surface of the earth by sedimentary or volcanic processes.
S-wave	Elastic shear wave caused by earthquake, the same as secondary wave, i.e. the second wave that arrives at a seismograph after an earthquake. Secondary waves are transverse waves, which means the oscillations occur perpendicularly to the direction of propagation.
SWIW test	Single Well Injection Withdrawal test. Tracer test for investigation of the rock's transport properties. The test is performed in a single cored borehole.
Tectonics	The branch of geology that studies the large-scale regional structures in the earth's crust and the processes that have created them.
TEM	Transient electromagnetic sounding, a method for determining the electrical properties of the rock, which in turn are determined by the fractures' content of water, salt and electrically conductive minerals, such as clay minerals. In transient electromagnetic sounding, a transient magnetic field is created in a transmitter loop. TEM provides a resistivity profile with information in relation to increasing depth.
Terrestrial	Relating to land. Land-based as opposed to aquatic (in water). Habitat on the surface of the earth.
Thin section	Sample of a mineral or a rock consisting of a 0.02–0.03 thick slice glued to a thin glass slide. At this thickness, most rock types and minerals are transparent, which permits their optical properties to be studied in a polarization microscope.
Till	Unsorted, unconsolidated material deposited by glaciers and inland ice sheets, consisting of pulverized rock fragments of varying size from boulders to clay particles.
Tonalite	Intrusive igneous rock (a rock formed at great depth) related to granite. Tonalite is usually grey and consists primarily of the minerals quartz and plagioclase, plus biotite, hornblende and amphibole.
Transect	A (straight) line along which measurements, surveys and/or observations are performed.
Transient	A phenomenon (for example electrical, electromagnetic or hydraulic) that varies with time.
Transmissivity	Ability of a soil or rock layer to conduct water. Groundwater flow rate per unit width is given by the transmissivity (m^2/s) multiplied by the hydraulic gradient (which in its simplest form is equal to the slope of the groundwater table in m/m). Transmissivity can be determined by test pumping.
Transpiration	Loss of water vapour from plants by evaporation.

Trophic level	Level in ecological food web, for example as a primary or secondary producer or consumer.
Veined gneiss	A very common type of gneiss in Sweden, characterized by light and dark layers, parallel to the rock's plane of schistosity. The light layers are dominated by quartz and/or feldspar, while the dark layers contain dark mica and possibly amphibole.
VES	Vertical electrical sounding, a method for determining the electrical properties of the soil layer and the rock, which in turn are determined by the fractures' content of water and electrically conductive minerals, such as clay minerals. Sounding is done so that a resistivity profile is obtained with information in relation to increasing depth.
Volcanic rock	Rock formed by volcanic processes, i.e. extrusion of magma (molten rock) on the earth's surface, which forms lava or layers of volcanic ash.
Weathering	In geology, decomposition and disintegration of solid rock, stones and boulders to a gravelly, sandy or clayey mass by mechanical, chemical and biological processes.
Yoldia Sea	Stage in the evolutionary history of the Baltic Sea falling between the Baltic Ice Lake and the Ancylus Lake. The Yoldia Sea was named for the marine arctic bivalve <i>Yoldia arctica</i> (now <i>Portlandia arctica</i>), which has been found in deposits from this stage. The Yoldia Sea existed between approximately 10,300 and 9,500 carbon-14 years before present. According to the classical picture of the history of the Baltic Sea, the water in the Yoldia Sea was brackish, but more recent investigations show that the actual brackish water phase only spanned 100 years around 10,000 carbon-14 years before present (i.e. about 9,400 BC).
Younger granite	Granite that was formed after the most recent major ductile deformation of the bedrock. In Sweden, these granites are normally 1,800 million years old or younger.
Äspö HRL	SKB's underground Hard Rock Laboratory on the island of Äspö north of Simpevarp, intended for geological research and technical development and demonstration of methods for deposition and retrieval of canisters with spent nuclear fuel.
Ävrö granite	Collective term for porphyritic (megacryst-bearing) intrusive rocks in the Simpevarp area with a composition varying between granite and quartz monzodiorite.