P-02-03

# Execution programme for the initial site investigations at Forsmark

Svensk Kärnbränslehantering AB

May 2002

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# 1 Introduction

## 1.1 SKB's site investigation programme

In the feasibility studies that were completed in 2001, eight sites were identified as potentially suitable for hosting a repository. All the identified sites meet the safety requirements with respect to bedrock conditions that could be checked at that time /SKB, 2001a/. The feasibility studies have revealed good potential when it comes to the technical and environmental aspects as well. Summaries of results from the feasibility studies are presented in /SKB, 2001b/.

Based on an integrated evaluation SKB proposed to start site investigations with test drillings at three sites; Forsmark, Simpevarp and Tierp north /SKB, 2001a/. Site investigations have started at Forsmark and Simpevarp. The municipal council of Tierp voted no to a site investigation in April 2002.

The site investigations are divided into two main phases; *initial* and *complete* investigations. Initial site investigations are performed to identify the site within a specified area that is deemed to be most suitable for a deep repository and to determine whether the feasibility study's judgement of the suitability of the area holds up in the light of borehole data from repository depth. The initial site investigations are expected to take 1.5–2 years. If the assessment shows that the site has good potential to host a repository, complete site investigations will follow for an expected duration of 3.5–4 years. The purpose of the complete site investigations is to gather all information required to select one of the sites as the main alternative and to apply for a permit for construction of the deep repository at that site.

A general programme in which the results from feasibility studies are summarized, the candidate sites presented and the framework of programme for the site investigation phase presented has been published /SKB, 2001a/. The general programme, and main references to the programme, specifies which data are required in order to design the repository and carry out a safety assessment /SKB, 2000; Lindborg and Kautsky, 2000; Blomqvist et al, 2000; Blomqvist et al, 2001/, how the investigations should be carried out in order to provide these data /SKB, 2001c/, criteria with which the site must comply, as well as criteria for the discontinuation of the investigations /Andersson et al, 2000/.

A programme adapted for the site investigation at Forsmark based on /SKB, 2001c/ has been developed /SKB, 2001d/. The programme gives an overview of the whole site investigation phase as well as a detailed description of the initial stage, i.e. the first two years. The results of the initial investigations will determine whether Forsmark is appropriate for further investigation, i.e. the complete site investigations.

This document is a short summary of the investigations planned to be carried out at Forsmark during the initial site investigation. The plans will be successively updated as results from the investigations become available.

## 1.2 The Forsmark area

The Forsmark area lies between Forsmark's nuclear power station and the bay Kallrigafjärden. The bedrock in the area is part of a large rock block, known as a tectonic lens, which extends from Forsmarksverket to Öregrund, continuing to the Southeast. Towards the Northeast and Southwest, the area is delimited by bedrock with a high degree of deformation, and to the Southeast by a nature reserve, Kallriga reserve. Towards the Northwest, the rock block becomes progressively narrower, probably ending just to the north of the power station.

The boundaries of the study-area have been based on currently available information. The available geosphere data for the Forsmark area are derived mainly from relatively detailed geological mapping and from airborne geophysical measurements. In addition, information collected during the construction of Forsmark nuclear power plants and SFR (Final repository for low- and intermediate level operational waste), as well as studies of the Finnsjö study site (which lies 15 kilometres south-west of Forsmark), have contributed to the general knowledge of the area. Information about conditions at repository depth within the Forsmark area is not available at present.

The Forsmark area is about 10 square kilometres, which is relatively small for a candidate-area, but nevertheless by a good margin large enough for a deep repository, even if results from the investigations should indicate that parts of the area are in-appropriate. The bedrock map over the Forsmark area is found in Figures 1 and 2. The extension of the Forsmark area is illustrated in Figure 3.

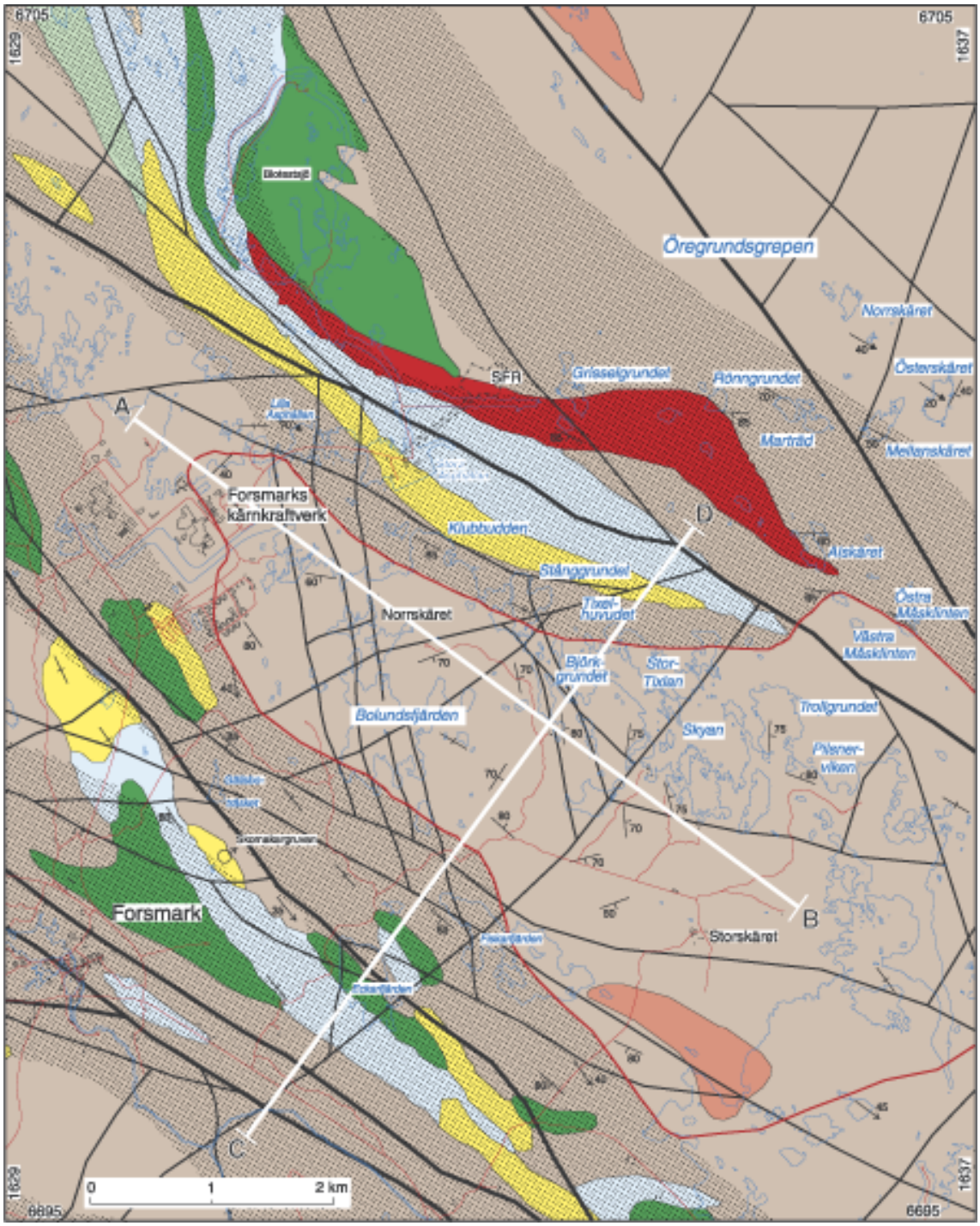


***Figure 1.*** *Bedrock map over the Forsmark area (se Figure 2 for explanations).*

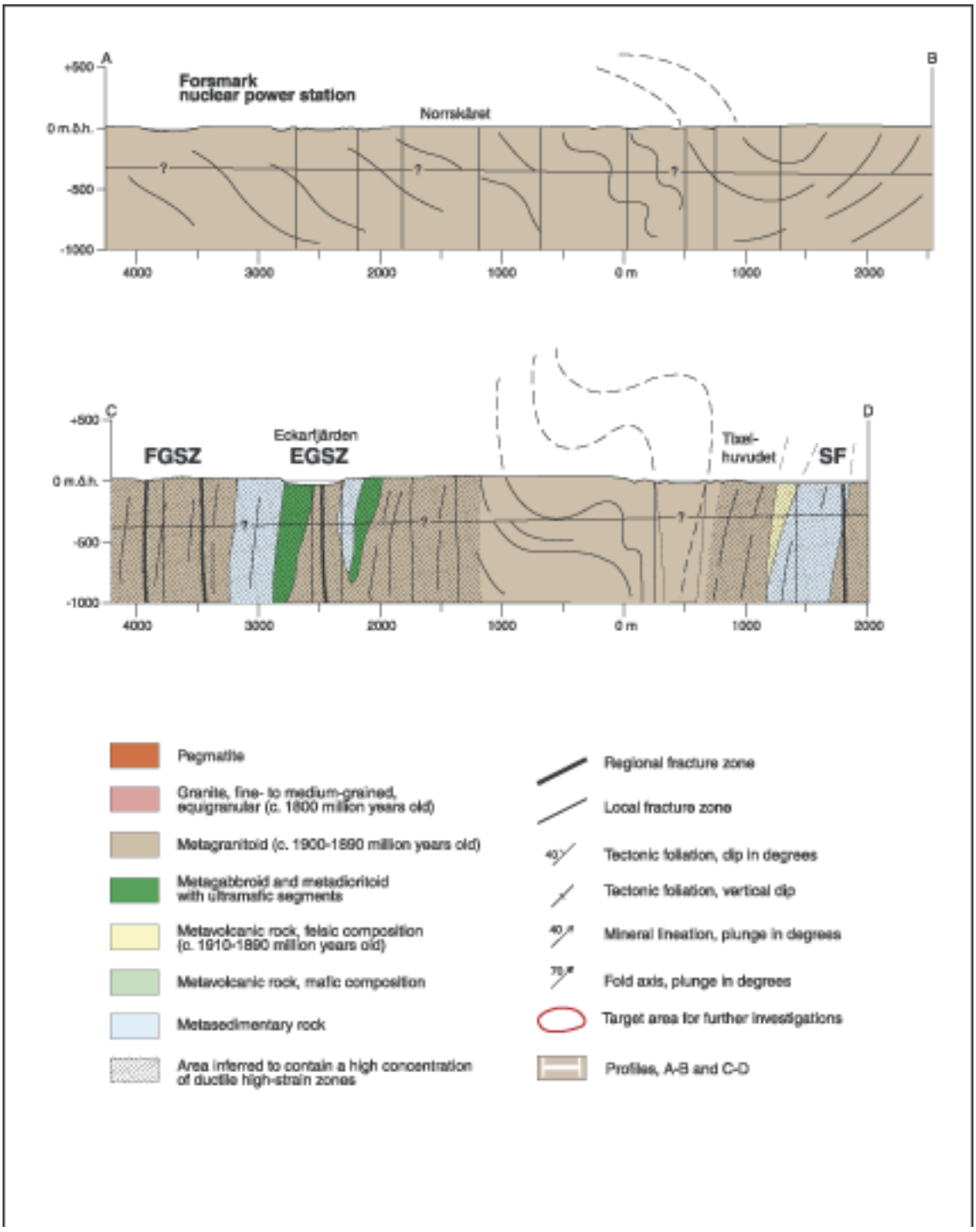


***Figure 2.*** *Vertical geological profiles. The positions of the profiles are found in Figure 1. It should be noted that the gently-dipping fracture zone in the figure (line with questions-marks) is hypothetical.*

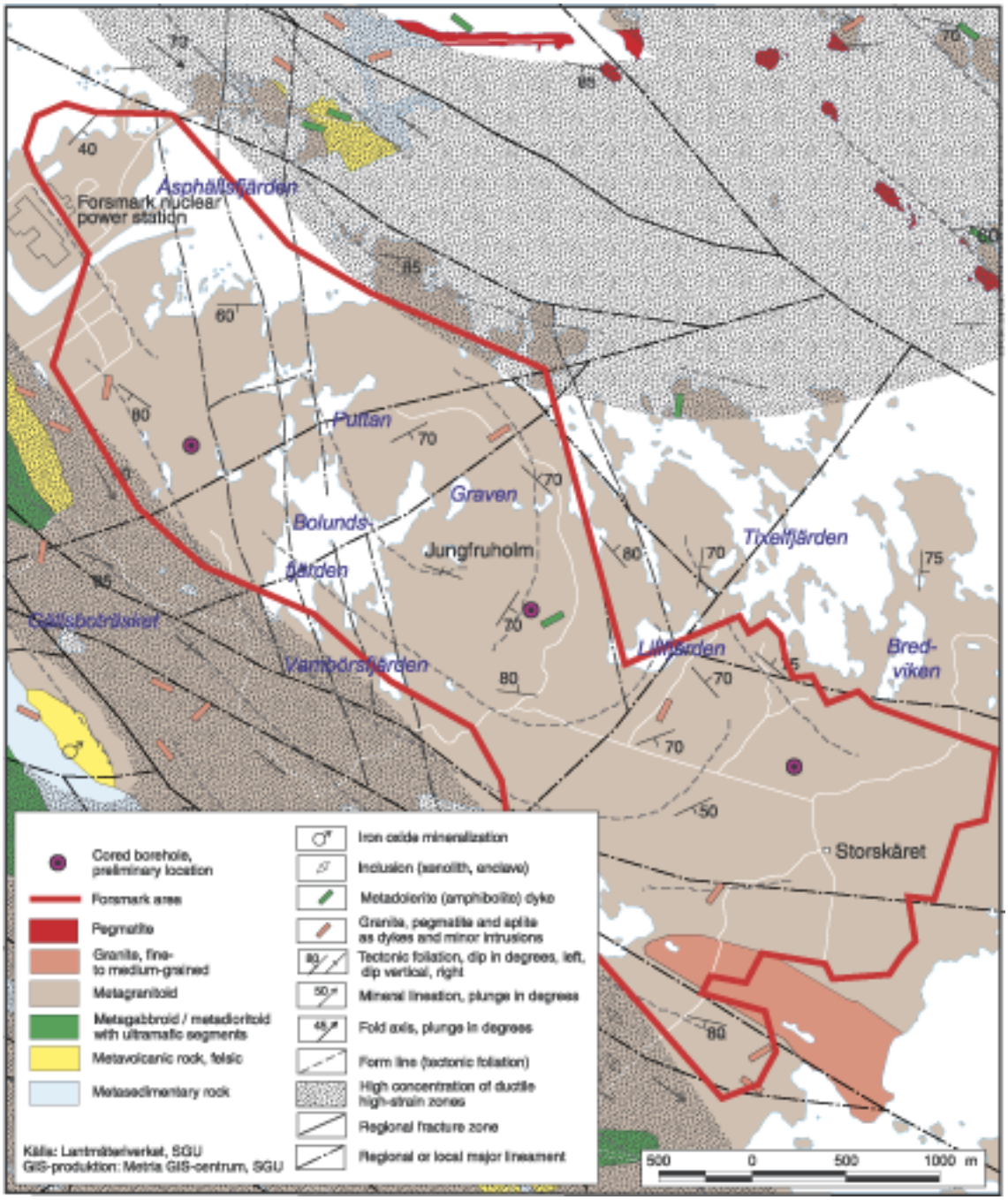


***Figure 3.*** *Preliminary positions for the first three cored boreholes. A further two cored boreholes will be drilled to study the boundary zone north-east and south-west of the rock lens.*

# 2 Site investigations

## 2.1 Aim – general

The main aim of the site investigation phase is to obtain permits to site and build the deep repository for spent nuclear fuel and the encapsulation plant.

The main task of a site investigation at Forsmark is to study the local bedrock and environment. This information is needed to evaluate the long-term safety of a repository for spent nuclear fuel at the studied site. Data is also needed to describe how the above- and underground parts of the deep repository can be designed and built with respect to the bedrock conditions and infrastructure. In addition, information is needed for the evaluation of the consequences of a repository for the environment during the construction and operating phases.

## 2.2 Aim for investigations in the Forsmark area

The bedrock in the Forsmark area is composed mainly of homogenous gneiss-granite with judged normal conditions regarding fracture frequency and local fracture zones, see Figure 1. Based on geological mapping of the area and experiences from the investigation and construction of the nuclear power plant and the SFR facility some important site-specific questions that must be addressed are:

- The three dimensional shape of the potential host rock (the tectonic lens). This question considers whether or not there is sufficient volume of suitable rock at repository depth (400–700 meters). Available information indicates almost vertical boundaries of the lens.
- Potential for metal-ore occurrence at depth. The Forsmark area lies in a region where the occurrence of metal-ores and mineralisations is fairly common. The surface bedrock is dominated by gneiss-granite, which is unlikely to contain metal ores, but the composition of the bedrock at depth must be investigated. Potential for ore-occurrence could render the site inappropriate.
- The possible occurrence of gently-dipping fracture zones. Near-horizontal, permeable fracture zones can have a great effect on where and how much groundwater can move through the rock and is therefore important with respect to long-term safety and to tunnel construction. Gently-dipping fracture zones can be both advantageous and disadvantageous for a repository, depending on their location.
- The occurrence of high rock stresses. These are important during the operational phase of the repository, as they, in combination with the rock strength and construction parameters, determine the stability of tunnels and thus the need for reinforcements. Rock stresses that are too high can make the site unsuitable for a deep repository.

Besides these site-specific questions, other general questions must also be considered. These are concerned for example with the occurrence and frequency of dikes and fracture zones, the hydraulic conductivity of the fracture zones and the surrounding bedrock, flow paths for groundwater and the chemical, thermal and rock-mechanical conditions. Long-term changes in surface runoff, groundwater flow and groundwater chemistry must also be assessed.

# 3 Execution of the work

## 3.1 General

Most of the investigation will be conducted within the Forsmark area, although a larger regional area surrounding the Forsmark area will also be studied. The regional modelling area roughly corresponds to the area that will be investigated by airborne geophysics, see Figure 4. It has been chosen to include likely inflow and outflow zones for a deep repository in the Forsmark area. In this area geological mapping and marine-geological studies will be carried out in addition to the airborne geophysics.

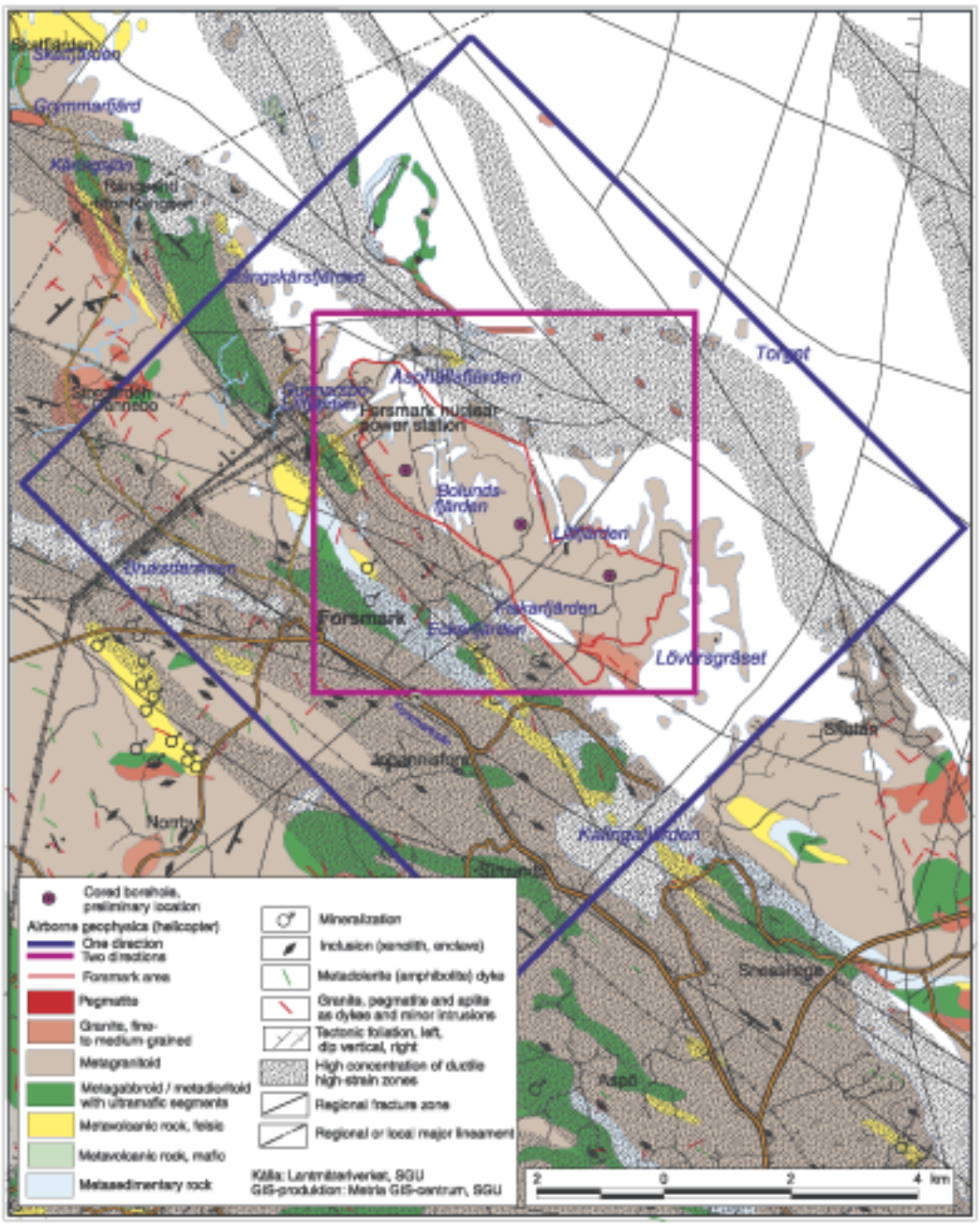


***Figure 4.*** *Area for airborne geophysics (helicopter).*

Boreholes will be placed mainly within the Forsmark area and in the fracture zones surrounding the area. However, should complete site investigations be carried out, one or more boreholes may be placed in the larger Forsmark region in order to obtain data relevant to the regional groundwater flow.

The overall strategy will be to carry out the investigations from a small scale to a larger scale, i.e. from the Forsmark area and outward. First, the candidate area for the repository, the Forsmark area (see Figure 3), will be investigated to assess if the rock properties motivates further investigations. Subsequently, the boundary zones of the Forsmark area will be investigated to assess if sufficient volume is available for the repository. Finally, the area outside the boundary zones will be investigated to obtain data on boundary conditions and other properties essential for a safety assessment. The strategy is illustrated in Figure 5.

The investigations of the Forsmark area and the boundary zones will be carried out during the initial and the complete site investigations. The area outside the boundary zones will be investigated in the complete site investigations.

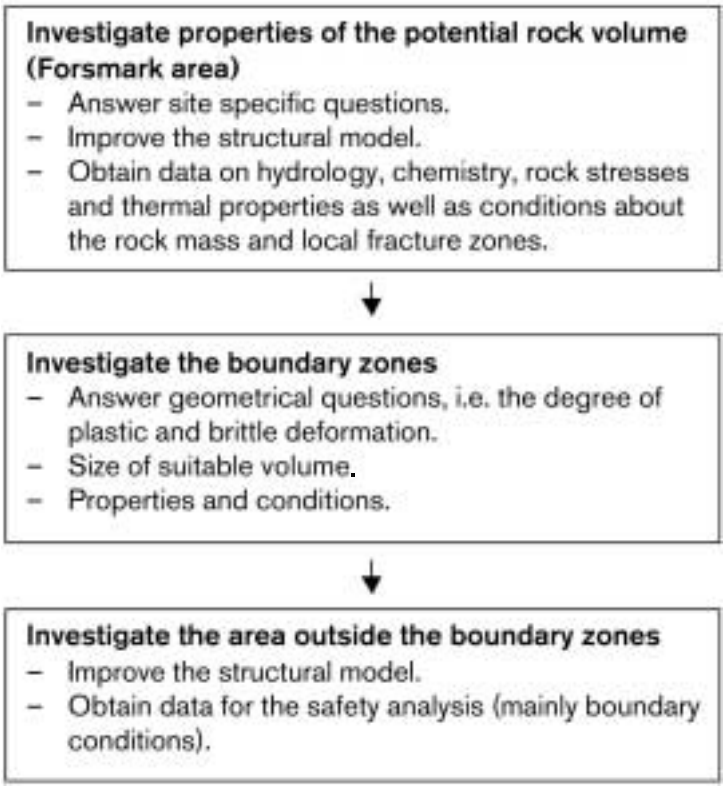


***Figure 5.*** *Schematic illustration of the investigation strategy.*

## 3.2 Initial site investigation

The aim of the initial site investigation phase is to answer the site-specific questions listed in section 2.2 and to assess if the judgement from the feasibility study regarding the suitability of the area still holds up in the light of borehole data from repository depth.

To answer the site-specific questions and to obtain a general knowledge of the properties at depth it is judged that five boreholes would be needed. The first three boreholes will reach a depth of approximately 1000 m and will be located within larger rock blocks in central part of the site, see Figure 3. If conditions are favourable, for example compared to criteria listed in /Andersson et al, 2000/, two additional boreholes will be drilled to investigate the boundaries of the tectonic lens. The drilling programme in conjunction with geological mapping and geophysical surveys, including a comprehensive reflection seismic survey, will also constitute a basis for refinement of the structural model of the site, including possible gently dipping zones.

The initial site investigation will take place over a period of about two years and includes the following main tasks:

- The properties of the bedrock will be investigated with three deep cored boreholes which will be drilled along the centre-line of the area.
- Fracture zones in the area and its surroundings will be studied by means of geological mapping, geophysical measurements from a helicopter and from the ground surface, and by means of percussion boreholes.
- The boundary zones of the area in the Northeast and Southwest will be investigated with two deep cored boreholes (the position of the boreholes can be decided first when the investigations in the previous point have been completed).
- The initial site investigation phase concludes with an overall evaluation and a decision whether to commence with complete site investigations or to terminate further work on the site.

In addition, a measurement programme will be initiated for those parameters that must be measured under undisturbed conditions and/or over long time periods. Examples of this type of parameter are those relevant to the area's hydrogeology and the surface ecosystem.

At the first hole to be core-drilled in the Forsmark area, investigations of the groundwater chemistry will be given priority. The aim of this is to obtain, at an early stage, information about the chemistry of undisturbed groundwater at depth in the bedrock.

Rock stress measurements will be given priority in the second cored borehole. The information from this borehole will form an important basis for further work, regarding design and construction of the underground facility.

The type of measurements that will be given priority in the third borehole will be decided based on results from measurements in the two first boreholes.

During the initial site investigation stage in the Forsmark area, percussion boreholes will be drilled to confirm and characterise steeply inclined fracture zones, as well as to study the bedrock's hydraulic conductivity down to a depth of approximately 150 meters.

The result of the initial site investigation will form a basis for a preliminary site description, which in its turn is used for a preliminary description of a possible outline of surface and subsurface repository facilities and a preliminary safety judgement.

As far as long-term safety is concerned, the body of material available after the initial site investigation is not expected to be sufficient to conduct a comprehensive safety assessment. The preliminary safety report will therefore mainly contain:

- A cross-check with the requirements and criteria that have been formulated in /Andersson et al, 2000/.
- Comparisons with the conditions on the three sites that were analysed in SR 97 and what can thereby be said about the expected outcome of a safety assessment based on data from a complete site investigation.
- Simple analytical nuclide transport calculations of the kind that were carried out in SR 97, with whatever new site-specific data are available.
- Presentation of data needs in the next stage of the site investigations, based on the results of the above-mentioned comparisons and calculations.

## 3.3 Complete site investigation

The aim of the complete site investigation is to provide the knowledge about the chosen site required for a safety assessment and the preparation of an application for permit for the deep repository.

If complete site investigations are to be undertaken, they will also be carried out in accordance with the general programme /SKB, 2001c/, but with adaptations to site-specific conditions. A complete site investigation will take approximately three years.

The scope of the investigations should be such that when it is finished, the underground parts of the repository can be designed and a safety assessment can be carried out. A geoscientific understanding of the site should also be obtained. The site-specific data required for a safety assessment can be divided into two categories:

- Data on properties that are expected to be similar at repository depth at all sites, for example, anaerobic groundwater, groundwater chemistry, thermal conductivity, etc. In most of these cases, a check must be made to ensure that these properties lie within the expected interval as specified for example in /Andersson et al, 2000/.
- Data that directly affect the repository design and the results of dose calculations for certain scenarios. For example, the position and properties of larger deformation-zones, the hydraulic conductivity of the bedrock and the transport resistance.

The number of boreholes in the drilling programmes and the scope of the measurements cannot be specified in advance, since they are dependent on the conditions on the site. A reasonable estimate is that 10–20 cored holes and roughly 20–40 percussion holes are required.

Drilling is carried out in campaigns, where 3–4 holes are drilled. This is followed by measurements and evaluation of the results. It takes several months to drill a deep hole, after which measurements are performed in the borehole for approximately six months. A preliminary estimate is that three drilling campaigns will be needed to obtain a good description of a site.

After each drilling campaign the rock models, the layout, and the evaluation of long-term safety are updated. The analysis of the uncertainties in the model descriptions is used to plan the next drilling campaign. The boreholes are positioned and aimed in order, for example, to verify the occurrence, location, orientation and properties of deformation zones and rock type boundaries. A number of holes are drilled to obtain data from potentially suitable repository volumes between the deformation zones. It is the properties and conditions in this bedrock that are most essential for the safety assessment. The results are evaluated in relation to the requirements and criteria discussed in /Andersson et al, 2000/ and with respect to remaining uncertainties in the description of the site. This evaluation serves as a basis for a decision as to whether the investigations should be continued with another drilling campaign or not. The investigations are discontinued when the reliability of the site description has reached such a level that the body of data for safety assessment and design is sufficient, or until the body of data shows that the rock does not satisfy the requirements.

## 3.4 General planning considerations

The generic site investigation programme /SKB, 2000 and SKB, 2001c/ provides a strategy and general specification of the investigations to be undertaken during the site investigation phase. The generic program does not specify the amount of investigations to be performed at a specific site nor where and when specific measurements should be undertaken. This is specified in the site specific programmes. However, the site specific programme has to be defined successively as it depends on results of future investigations and the integrated analyses of these results. The current programme is based on the information available after the completion of the feasibility studies. This information is compiled in Site descriptive model, version 0.

The basic idea in the continuous development of the site specific programme is that development of the site descriptive models is undertaken in parallel with the investigations activities. For each version of the site descriptive model a specific objective is defined. Based on the objective, it is possible to define the data required to meet the objective and the time when the objective has to be fulfilled. At an appropriate time a “data freeze” is made and the data set going into the next version of the model is defined. The site descriptive model, tentative repository layouts and preliminary evaluations of long-term safety are updated. The analysis of uncertainties in the model descriptions as well as feedback from design and safety assessment is used to plan the investigations following the presentation of the current model version. The time estimated from the “data freeze” to presentation of the model is expected to 3–4 months.

To make efficient use of the resources at the site, investigations have to proceed continuously. At each planning step a detailed investigation programme is planned for a time extending beyond the “data freeze” that includes the time estimated for completing the updated version of the Site descriptive model. Hence, investigations will proceed as the model is updated and the model will thus not include the latest data at the time of its presentation. This could imply that some investigations are undertaken in less than optimal locations, but this is a risk that SKB considers worth taking for making best use of available resources.

This procedure will also be followed when passing from the initial to the complete site investigation phase, i.e. investigations belonging to the complete site investigation phase will be started before the decision is taken to proceed with the complete site investigations.

## 3.5 Alternative plans

During the site investigation, boreholes will be drilled and used for various measurements. Measurements will also be carried out from the ground and by using a helicopter. The investigation programme is not planned in detail, but will be updated and revised due to results from early measurements. It is therefore not possible to draw up a complete alternative investigation plan to be used in cases where the investigations cannot be carried out as originally planned. It is however, necessary to be prepared for such cases, and therefore have some flexibility in the planning. It is important to ensure that the site investigations are carried out in such a way that the technical and scientific goals are fulfilled.

# 4 Work plan

A short description of the work plans for the initial site investigation in the Forsmark area is given below. More detailed descriptions of the aim and scope of the investigation are given in the appendix.

The initial site investigation will take place over a period of two years. The description in the attached table covers mainly the work that will be carried out during the first year. The second year's work plan will depend partly on the results of the first year's investigation.

## 4.1 Investigations

In the initial site investigation, information about the site and its surroundings will be derived mainly from:

- studies carried out to characterise the site and its surroundings,
- monitoring studies.

The studies carried out to characterise the site and its surroundings form the main part of the site investigations. They include:

- core drilling and measurements in the boreholes (see Figure 3),
- percussion drilling and measurements in the boreholes,
- geophysical measurements from helicopter (see Figure 4),
- geophysical measurements from ground level (see Figure 6 for reflection seismic),
- marine-geological investigations,
- mapping of the bedrock,
- studies of the transport properties, strength and thermal properties of the bedrock,
- mapping of soil types and soil thickness and hydrological tests in boreholes in the soil,
- hydrological and ecological studies,
- vegetation mapping and inventories of birds and mammals.

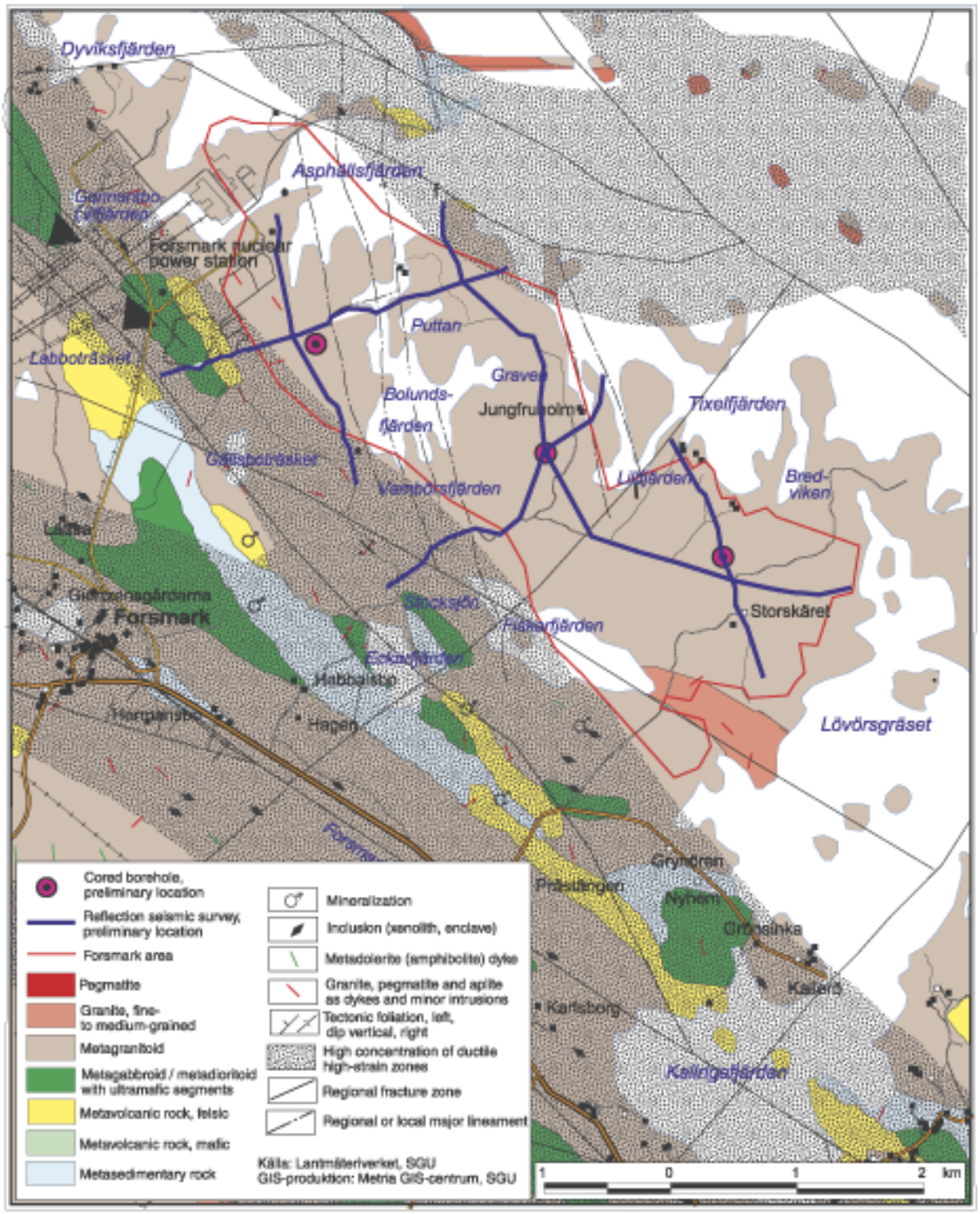


***Figure 6.*** *Preliminary locations for reflection seismic survey.*

Monitoring studies include studies and long-term documentation of different types of changes, for example, in the bedrock and in the natural environment. Monitoring is required partly to study changes, which can be caused by the site investigations, partly to study and understand natural variation and analyse which effects different dynamic processes have on the deep repository and thereby on its long-term safety. Monitoring covers mainly:

- meteorological and hydrological conditions,
- the natural environment,
- radionuclides and environmental contaminants,
- seismic activity,
- deformation of the bedrock.

## 4.2 Main decision-points

The initial site investigations will be carried out step by step and include several decision points. In short, the procedure will be to start from a site descriptive model, version X, carry out measurements on the ground and in boreholes, update the site specific model based on the results from the measurements, plan and design future measurements based on the updated site specific model. Hence, main decisions will be based on different versions of the site-specific models.

The procedure is illustrated in Figure 7. Detailed information about the measurements and the site descriptive models are found in the appendix.

### 4.2.1 Initial site investigations, the first year. Site descriptive model, version 0 → version 1.1

A regional site-descriptive model, version 0, has been developed on the basis of the feasibility study and associated inventories. This model has been used to determine the location of the first three cored boreholes, KFM01-03, as well as the location and scope for surface and airborne measurements.

Three cored boreholes, KFM01-03, will be drilled in the Forsmark area, see Figure 3. After completed drilling, each borehole will be characterized using a base programme followed by supplementary investigations. Finally, equipment will be installed in the boreholes for long-term sampling and monitoring of pressures.

Simultaneously to the drillings, airborne and surface measurements will be carried out, see Figure 7. These will include ground geophysics, airborne geophysics, geological mapping, marine geological investigations, surface ecosystems, hydrology, hydrochemistry and rock mechanics.

Long-term monitoring of hydrochemistry, hydrology, surface ecosystems, seismic events, creep movements will be initiated.

The work during the first year, including data from the first two deep cored boreholes, will be collated in a site-descriptive model of the site, version 1.1.

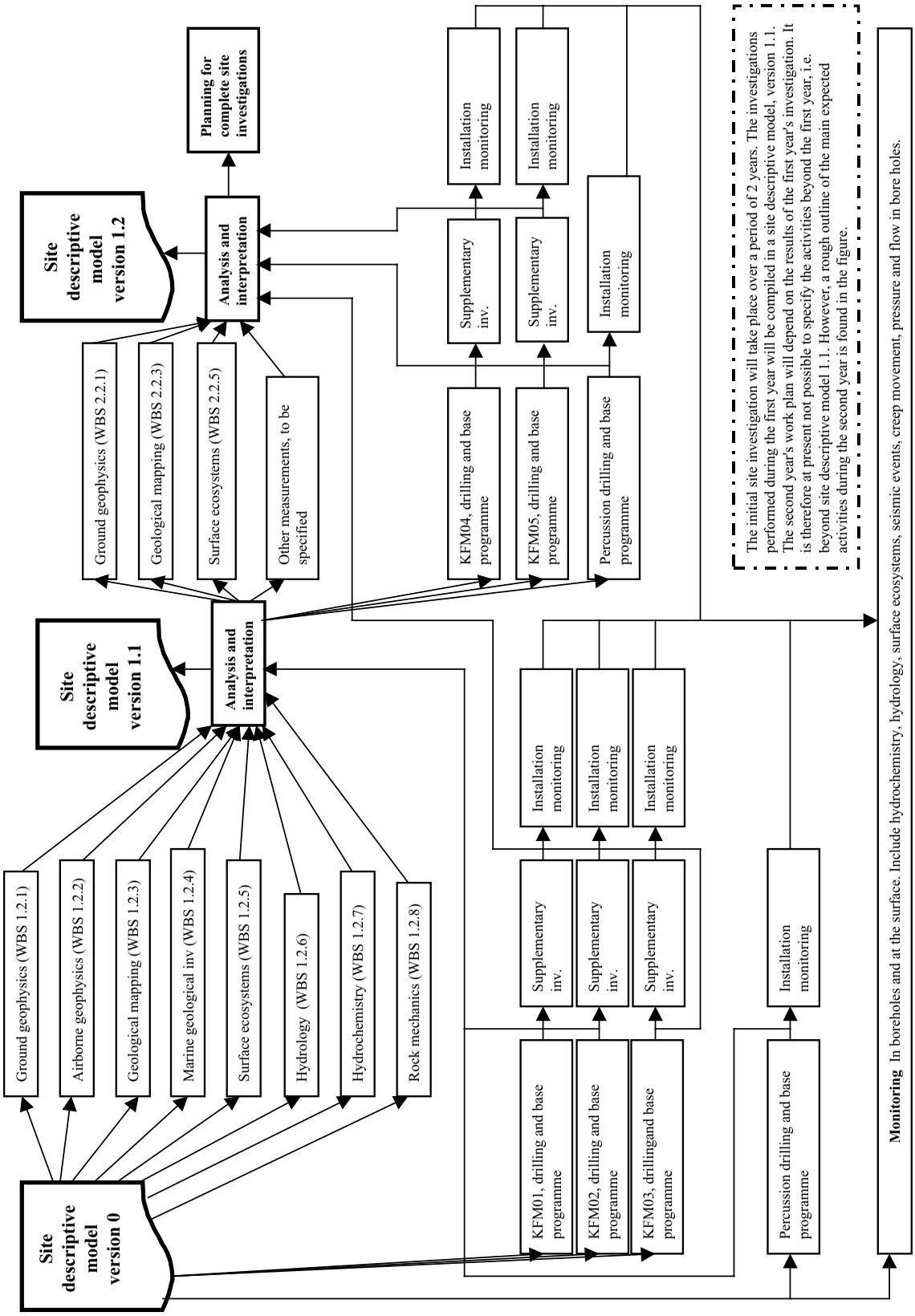


***Figure 7.*** *Forsmark – Initial site investigations.*

### 4.2.2 Site descriptive model v 1.1

The site-descriptive model, version 1.1, will be developed during 2003. It will be based on results from the surface and airborne measurements mentioned above as well as the results from the base measurements in boreholes KFM01-02 and the percussion boreholes, see Figure 7.

The site descriptive model v 1.1 will be used for planning of the measurements that will be carried out during the second year. It is therefore at present not possible to specify these activities in detail. However, a rough outline of expected main activities are found in Figure 7 and in the appendix.

One of the main objectives of the model is to provide a basis for positioning of boreholes KFM04 and KFM05. It is at present not possible to specify the position of these boreholes, but both boreholes will be drilled to study the boundary zones north-east and south-west of the rock lens. This is in accordance with the strategy to carry out the investigations from the Forsmark area and outward, see Figure 5.

### 4.2.3 Initial site investigations, the second year. Site descriptive model, version 1.1 → version 1.2

During the second year, supplementary investigations will be carried out in boreholes KFM01-03. Boreholes KFM04-05 will be drilled, base measurements and supplementary investigations will be carried out.

Simultaneously to the drillings, surface measurements will be carried out. It is at present not possible to specify these activities in detail, but geological mapping and ground geophysics will most likely be carried out.

Long-term monitoring of hydrochemistry, hydrology, surface ecosystems, seismic events, creep movements will continue.

The work during the second year will be collated in a site-descriptive model of the site, version 1.2.

### 4.2.4 Site descriptive model v 1.2

The basic objective of the Site descriptive model version 1.2 is to provide a basis for the preliminary safety judgement and the preliminary facility description and the decision to proceed with the complete site investigation phase.

The initial site investigation will finish in the development of version 1.2 of the site-descriptive model, which will be carried out during 2004. This version will result in a preliminary safety judgement and a first site-specific description of the facility.

### 4.2.5 Complete site investigations

The initial investigations of the complete site investigations will commence prior to the completion of model version 1.2. The programme for the initial investigations in this phase, e.g. boreholes KFM06-07, will be based on model version 1.1 and results obtained from investigations during the second year.

When model version 1.2 is completed and the preliminary safety judgement made a decision will be taken if investigations at the site should proceed. If the decision is to proceed, model version 1.2 and data needs identified by safety assessment and design form the basis for the placement of further boreholes and other work to be carried out during the complete site investigation.

The complete site investigation will also be carried out in stages. After each drilling campaign the rock models, the layout, and the evaluation of long-term safety are updated following the general planning strategy outlined in Section 3.4. Further boreholes will be located and orientated in order to, for example, confirm the occurrence, position, orientation and properties of deformation zones and boundaries between different types of rock.

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# Appendix

## Description of planned activities

A WBS-number of e.g. 1.2.x means that the activity involves several activities.

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| **–** | **14** | **Regional site-descriptive model, v 0** | All site information regarding earth science and ecosystems gathered during the feasibility study will be presented in a regional site descriptive model, version 0, in a format that will be used during the site investigation. | | The regional site descriptive model covers an area that is larger than the regional investigation area (see figure 4) in order to cover future discharge areas. | A regional site-descriptive model, version 0, has been devised based mainly on the feasibility study, processing of existing data and field checks.<br><br>TR-01-29, Table 2-1. |
| **1.2** | **26** | **Initial site investigations, first phase (year)** | The main goal for the investigations during 2002 is to identify whether the 3-D extension of the tectonic lense is large enough and that the geological conditions seems to be feasible at depth. | | The investigations are focused on the Forsmark area. The investigations are described below, see ID 27-209. The main tasks are:<br>– baseline characterization of ecosystems,<br>– drilling of 2 deep cored holes (1:st - hydrochemical oriented, 2:nd - rock stress oriented),<br>– start of monitoring,<br>– airborne geophysics. | The information will be used for the site descriptive model, version 1.1, see ID 209. |
| ***1.2.5*** | ***27*** | ***Surface ecosystems*** | Main goals are:<br>– characterisation of the undisturbed ecosystem conditions in the candidate areas,<br>– collection of relevant data for safety assessment and design,<br>– obtaining a general understanding of the candidate area's surface ecosystems so as to be able to develop and justify models and make predictions of the area's future evolution,<br>– with the aid of collected data, present a framework for the further execution of the investigations with consideration for nature and the environment. | – Identification and characterisation of biologically sensitive areas in studied candidate areas,<br>– identification of the parameters in the surface ecosystems that are needed to achieve sufficient knowledge of the area,<br>– compilation of existing data on the areas,<br>– start of monitoring programmes for parameters that require long time series.<br><br>The obtained information will be presented in GIS. | Compilation of relevant parameters, for example:<br>– topography<br>– land uplift<br>– soil layers<br>– exposed rock<br>– recharge/discharge areas<br>– soil water and groundwater<br>– groundwater levels<br>– water turnover<br>– precipitation<br>– runoff. | TR-01-29.<br>General information in chapter 3.2.1 and 10.<br>Goals are found in chapter 10.1.2.<br>Compilation of parameters included in the model description of surface ecosystems are found in Table 10-1.<br>Flow plan and information needs are found in Figure 3-2.<br><br>See also R-00-38 (lakes) and R-01-20 (rivers). |
| 1.2.5.1 | 28 | Vegetation mapping | The general goals are described above, see ID 27. | An estimate will be made of the area's vegetation and biotopes and presented in GIS format with the aid of IR aerial photos, the key habitat inventory and digital satellite photos. | Vegetation mapping will be carried out on a regional scale.<br><br>In addition, more detailed mapping will be carried out in 6 circular sample plots, each with a diameter of about 1 km. The sample plots will be located within the Forsmark area. | Vegetation types are important features that characterise the landscape. Vegetation types are interesting also in a monitoring context, since they are, in contrast to most species, relatively easy to identify and thus to follow in a long term perspective.<br><br>TR-01-29, chapter 3.2.1 and 10.3.2. R-00-33, chapter 4.2. |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| 1.2.5.2 | 31 | Bird surveys | The general goals are described above, see ID 27. | Species and population. The character of the area with regard to birds will partly be based on survey of nesting birds as well as threatened and rare species. | Bird surveys will be carried out on a regional scale. | R-00-33, chapter 4.7. |
| 1.2.5.3 | 32 | Mammal survey | The general goals are described above, see ID 27. | Species and population. The survey will focus on an inventory of the game stock. | Mammal surveys will be carried out on a regional scale. | R-00-33, chapter 4.7. |
| 1.2.5.4 | 33 | Surface waters | The general goals are described above, see ID 27. | The surface waters will be characterized with respect to chemical, physical and biological parameters. | Sampling of surface waters will take place at about 20 different locations (mainly in lakes, watercources and the Baltic Sea) within the area illustrated in figure 9. Initially, samples will be taken about 20 times per year. | TR-01-29, chapter 3.2.7. See also R-01-20 and R-00-38. |
| 1.2.5.5 | – | Aquatic parameter collection | The general goals are described above, see ID 27. | Limnological parameters in **lakes** will be collected. Lake type and ecological functioning will be described with the aid of models based on the constituent lake parameters. A thorough inventory of the lake's abiotic parameters such as temperatur, stratification, light conditions, pH, buffering capacity, colour, nutrients and oxygen conditions will also be done during at least on annual cycle.<br><br>The properties of **water-courses** will be described in a manner similar to that for lakes.<br><br>**Seas.** Existing information as well as information from SMHI and other regular measure-ments of the sea's tempera-ture, salinity, currents and water level variations will be compiled. Based on this information, a preliminary assessment is made of what zonations of fauna and flora can be expected in depth. | | TR-01-29, chapter 3.2.1 and 10.3.10. R-00-33, chapter 5. |
| 1.2.5.6 | 34 | Soil mapping | The general goals are described above, see ID 27. | The soil mapping will provide information on soil chemistry, soil moisture content, supracrustal boulder frequency, soil depth, cultural impact etc.<br><br>The results will be used as input into the soil model. | Sampling will be carried out by digging sample pits. Most samples will be taken in the Forsmark area. A few samples will be taken on a regional scale. | By soil means here the upper levels of the soil that are affected by organisms, water, wind and climate and are thereby altered in one respect or another. This influence has often resulted in the formation of visible soil horizons. The soil here includes the humus layer but not the litter layer.<br><br>TR-01-29, chapter 10.3.7 and Table 4-3. |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| 1.2.5.7 | – | Biomass determination<br><br>Sampling of toxic pollutants and radionuclides in plants and animals | The general goals are described above, see ID 27. | Existing information on the total quantity (biomass) of the dominant species is compiled and calculated from vegetation maps and completed estimations, e.g. of agricultural yield or timber quantity.<br><br>Existing information from the Swedish Environmental Protection Agency's (EPA) and SSI's environmental monitoring will be compiled. In the chemistry programme, samples will be taken from water and soil. In the site investigation programme, a survey will be performed to obtain a good idea of the background levels in the area. | | TR-01-29, chapter 3.2.1, 10.3.4 (biomass) and 10.3.5 (toxic pollutants and radionuclides). R-00-33, chapters 4.4, 4.8 and 5.4. |
| ***1.2.6*** | ***35*** | ***Hydrology & surface ground water*** | The goals of the hydrogeological programme are in brief to:<br>– compile a hydrogeological description on a regional and local scale<br>– achieve a hydrogeological understanding on the regional scale that is sufficient to delimit and define properties and boundary conditions for regional groundwater flow models and achieve a hydrogeological understanding on the local scale that provides sufficient underpinning for the local hydrogeological description. | Data on precipitation, temperature and flows in watercourses as well as mapping of chiefly Quaternary and bedrock geology, plus springs, wetlands and streams. The investigations also include surveying of land use such as ditching and damming projects, water sources, etc., as well as areas of interest from a nature conservation viewpoint. | Normally it is possible to rely on enough meteorological and hydrological data being available in an area. If needed, supplementary data are obtained from newly-erected measurement stations for collection of meteorological and hydrological data.<br><br>Measurements locations and frequency to be specified. | TR-01-29, chapter 3.2.6, chapter 7 and table 10.1. |
| ***1.2.6*** | ***36*** | ***Hydrologic mapping*** | The general goals are described above, see ID 35.<br><br>The near-surface conditions influence the boundary conditions for the groundwater flow models and are essential for calculations of flow and dispersion in the biosphere. | The hydrological description includes discharge basins, runoff data, meteorological data, as well as interpreted recharge and discharge areas. Description of groundwater recharge and the natural variation of the groundwater level is also included. | The hydrologic mapping will cover the area illustrated in figure 9. | TR-01-29, chapter 3.2.6 and 7.3.1. |
| ***1.2.6*** | ***37*** | ***Runoff measurements*** | The general goals are described above, see ID 35. | The hydrogeological investigations will for example provide a general description of the hydraulic boundary conditions and the natural variation of the groundwater level. These data are obtained by establishing hydrological measurement stations (meteorology, runoff) and commencing groundwater level measurements for monitoring. | The hydrologic mapping will cover the area illustrated in figure 9. | TR-01-29, chapter 3.2.6 and 7.3.1. |
| ***1.3.6*** | ***38*** | ***Observation boreholes*** | The general goals are described above, see ID 35. | The observation boreholes will be used for measurements of groundwater levels and in some cases simple hydraulic tests will be performed. The groundwater level in some of the observation boreholes will be recorded continuously. | A total number of 20-40 observation boreholes are planned to be installed in the soil layers.<br><br>Groundwater levels will be measured approximately 6 times/year. | TR-01-29, chapter 3.2.6 and 7.3.2. |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| ***1.3.K1*** | ***39*** | ***Cored borehole KFM01 (Chemistry)*** | The aim is to obtain data on bedrock properties and groundwater chemical conditions at depth in an assumed block of "good" rock. As this hole will be the first deep borehole drilled, data on the chemistry of undisturbed groundwater is ensured.<br>Adress issues: rock type and rock structure, hydrogeochemical conditions, hydraulic properties, ore potential. | Data on rock properties in the northern part of the tectonic lens. Basis for correlation of reflection seismic data to provide for confidence in interpretation of structures based on seismic data. | KFM01 is the borehole in the north-west part of the Forsmark area, see Figure 3. The borehole will be drilled to a depth of about 1000 m. It will be semivertical, plunge 85 degrees. | General information about the drilling programme is found in TR-01-29, chapter 3.3.2 and 11. |
| 1.3.K1.1 | 50 | Drilling | | | | See AP PF400-02-03. |
| 1.3.K1.1 | 53 | Percussion drilling 0-100m | Provide a borehole geometry feasible for maintaining pumping out return water during further drilling and a borehole geometry adopted for investigations and monitoring installations after drilling is completed. | Percussion drilling technique applied in chemistry holes in order to not introduce flushing water into the upper part of the rock formation. In case of unstable rock and/or large inflow of shallow groundwater the borehole is lined with stainless stell casing tubes. The gap between the borehole wall and casing wall is sealed by grouting in order to protect the deeper parts of the borehole from shallow groundwater and/or surface water. | | See AP PF400-02-03. |
| 1.3.K1.1 | 56 | Core drilling 100-1000m, including measurements and supplementary drilling of a short 100 m deep cored hole after completion of the 1000 m hole. | The measurements that will take place in the borehole are described in ID 64-80 below.<br><br>Some main goals are to:<br>– provide access to the bedrock at depth for a characterization programme,<br>– provide a continuous sequence of rock samples down to 1000 m,<br>– get first strike water samples from conductive fractures,<br>– obtain hydraulic information at large depth in the rock. | Core samples.<br>Data on drilling and flushing water parameters recorded during drilling. Drilling parameters – some of the measuring results could directly or indirectly reflect properties of the drilled rock formation. Flushing water parameters – contribute to the hydrogeological and hydrochemical understanding of the bedrock. They also provide a method for understanding the impact on the aquifer of the injection/withdrawal of flushing water and formation water during the drilling process.<br><br>Obtain hydraulic and hydrochemical information. | The drilling parameters include feed pressure, torque, and drilling rate. The flushing water parameters include flow parameters, physical-chemical para-meters of the flushing water (tracer content, oxygen content) and physical-chemical parameters of the return water (tracer content, electrical conductivity).<br><br>The core drilling is interrupted at predetermined length intervals (preliminary 100 m) in order to carry out transient hydraulic tests of the most recently drilled interval.<br><br>The drilling process is also interrupted at presumed water-bearing fracture zones for water sampling. | TR-01-29, chapter 3.5.1, 3.5.2, 11.4 and 7.3.3.<br><br>Scope, see AP PF 400-02-03. |
| 1.3.K1.2 | 64 | Base programme | Provide a fundamental characterization of the formation based on uniform methodology. | Data as specified below, see ID 65-72. | See below. | TR-01-29, chapter 3.5.3.<br><br>Downhole investigations will be performed according to base programmes in all completed rock boreholes.<br><br>The information from the base programme will constitute the base for the single hole interpretation (ID 80). |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| 1.3.K1.2 | 65 | Surveying | Obtain x-, y- and z-coordinates for the top edge of the casing.<br>Obtain direction and deviation of the borehole. | Borehole length.<br>X, Y, Z (RAK) versus borehole length.<br>Length-corrected measurement points. | Entire borehole. | TR-01-29, chapter 4.3.1 and 11.3.3. |
| 1.2.6.1 | 66 | Pumping & flow logging | Identify and characterise permeable features along the borehole. | Data on hydraulic properties of permeable features along the borehole.<br>Basis for locating test sections for hydrogeochemical sampling.<br>Pumping – determination of K-value for rock mass or T-value for dominant hydraulic features.<br>Flow logging – determination of position of structures and rough estimation regarding the properties of these structures. | Entire borehole. | TR-01-29, chapter 3.5.3, 7.3.3 and Table 7-6. |
| 1.2.7.3 | 67 | Hydrochemical logging | The purpose of the hydrochemical logging is to get a quick overview of the water composition along the borehole and detect any concentration anomalies. | The method provides an opportunity to identify the interface with saline groundwater.<br>Chemical composition of the groundwater. | One sample every 100 m. | TR-01-29, chapter 3.5.3 and 8.3.8. |
| ***1.2.1*** | ***68*** | ***BIP (Borehole Image Processing) system*** | To obtain information of rock type distribution and fracturing. | Image of borehole wall. Fold-out of the borehole. Fractures more than approx. 1 mm in width are detected by current equipment.<br>3D orientation of fractures. | Entire borehole. | BIPS consists of a digital TV camera that tapes the borehole wall while the camera is lowered into the borehole.<br><br>TR-01-29, chapter 3.3.3, 3.4.3 (section "Investigations of boreholes…"), 3.5.3 and 4.3.6. |
| ***1.2.1*** | ***69*** | ***Borehole radar*** | Interpretation support for Geological Borehole Documentation (GBD). | Borehole radar measurements provides information on the orientation of local minor and major structures. | Radar reflection measurements in the entire borehole. | TR-01-29, chapter 3.3.3, 3.4.3 (section "Investigations of boreholes…"), 3.5.3 and 4.3.6. |
| ***1.2.1*** | ***70*** | ***Geophysical logging*** | Interpretation support for Geological Borehole Documentation (GBD). | The measurements will give information regarding:<br>– Borehole status, geometry<br>– Lithological parameters<br>– Structures<br>– Groundwater salinity<br>– Hydraulic conductors<br>– Structures<br>– Rock temperature<br>– Water-bearing fractures. | The following measurements will be carried out along the entire borehole below 100 m:<br>– gamma-gamma<br>– magnetic susceptibility<br>– single-point resistance<br>– focused resistivity<br>– normal resistivity<br>– natural gamma<br>– sonic<br>– caliper<br>– temperature.<br><br>Full-wave sonic measurements might, at a later stage, be carried out in sections of the borehole. | TR-01-29, chapter 3.3.3, 3.4.3 (section "Investigations of boreholes…"), 3.5.3 and 4.3.5. |
| 1.2.3.1 | 71 | Boremap mapping (GBD) | Basis for Geological Borehole Documentation (GBD). | The measurements will give information regarding:<br>– Rock type distribution<br>– Rock type description<br>– Ductile structures<br>– Brittle structures (fractures, faults) and their location/orientation<br>– Properties of fracture surfaces. | Entire borehole. | TR-01-29, chapter 3.3.3, 3.4.3 (section "Investigations of boreholes…"), 3.5.3 and 4.3.5. |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| ***1.4.x*** | ***72*** | ***Sampling (geology, rock mechanics, geochemistry, transport)*** | Provide data on rock properties. | Data from measurement on core samples. | Sampling points and number of samles to be determined after GBD mapping and interpretation. | TR-01-29, chapter 3.5.3, 4.3.5, 5.3.2 and 6.3.2. |
| 1.3.K1.3, 1.2.x | 73 | Supplementary investigations | Additional testing dependent on the purpose of the borehole.<br>Focused on chemistry in this borehole. | Data as specified below, see ID 74-78. | See below. | TR-01-29, chapter 3.5.4. |
| 1.2.7.4 | 74 | Complete hydrochemical characterization | To get a complete "picture" of the groundwater chemistry in single fractures and local minor fracture zones. | Data on chemical composition of the groundwater at tested sections, class 5. | Information from methods in the disciplines of geology and hydrogeology is needed to select the borehole sections to be investigated (approximately five sections). | TR-01-29, chapter 3.5.4, 8.3.9 and Table 8-4. |
| 1.2.6.2 | 75 | Differential flow logging | To obtain information on location and properties of permeable features. | Data on transmissivity and undisturbed pressure of permeable features in the borehole. | Entire borehole below 100 m<br>Based on tests using two different pumping rates in order to obtain transmissivity and undisturbed pressure. | TR-01-29, chapter 3.5.4 and 7.3.3. |
| 1.2.6.3 | 76 | Hydraulic injection tests, 20 m sections | To obtain data on hydraulic properties in a scale relevant for the SC, Stochastic Continuum, model. | Hydraulic conductivity distribution for rock mass and deterministic features, flow dimension, groundwater pressure. | Entire borehole below 100 m. | TR-01-29, chapter 3.5.4 and 7.3.3. |
| 1.2.6.3 | 77 | Hydraulic injection tests, 5 m sections | To obtain data on hydraulic properties in a scale relevant for a canister. | Hydraulic conductivity distribution for rock mass and deterministic features, flow dimension, groundwater pressure. | To be determined after results of flow logging (ID 75) are available. | TR-01-29, chapter 3.5.4 and 7.3.3. |
| 1.2.6.4 | 78 | Groundwater flow measure-ments | To obtain information on groundwater flow under natural conditions. | Data on natural groundwater flow in major features. | To be determined after results of flow logging (ID 75) are available. | TR-01-29, chapter 3.5.4, 7.3.3 and 9.3.2. |
| ***1.4.3, 1.4.4*** | ***79*** | ***Installation for monitoring*** | Long-term monitoring of pressure and hydrochemistry. | Pressure and chemical composition in the borehole. | Permanent installations of packers etc are done in the cored boreholes for long-term measurements of pressure and for sampling within the long-term monitoring programme.<br>A preliminary estimate is that the pressure will be measured in up to 8 sections in each borehole.<br>The number of borehole sections for the groundwater flow measurements is much less than for groundwater pressure. In most cored boreholes, 1 to 2 sections are installed for groundwater flow measurements.<br>At least two borehole sections from each borehole will be included in long-term hydrochemical monitoring. | The long-term monitoring is decribed and illustrated in TR-01-29, chapter 7.3.4, 8.3.11, table 7.7 and figure 7-6. |
| 1.2.3.6 | 80 | Single hole interpretation, geology | To provide an integrated description of the geological structures along the borehole. | Identification and preliminary classification of fracture zones.<br>Properties and description of rock properties along the borehole. | Compilation of all availabe information. | The information from the base programme, see ID 64, will constitute the base for the single hole interpretation. |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
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| ***1.3.K2*** | ***81*** | ***Cored borehole KFM02 (rock mechanics)*** | The aim is to obtain data on bedrock properties with special focus on rock stress data. The information from this borehole will form an important basis for further work, above all for the planning of the design and construction of the underground facility. Adress issues: rock type and rock structures, potential for high rock stresses, hydraulic properties, ore potential. | Data on rock properties in the central part of the area of interest. Data on rock stress and mechanical properties of the rock. Basis for correlation of reflection seismic data to provide for confidence in interpretation of structures based on seismic data. | The borehole will be drilled to a depth of about 1000 meters. It will be semivertical, plunge 85 degrees. Location, see Figure 3. The two most common methods for direct rock stress measurement are overcoring and hydraulic fracturing. Rock stress measurements are carried out by means of the over-coring method down to about 500 m and by means of hydraulic fracturing down to about 700 m. The measurements (both methods) start at a depth of about 200 m. Rock stress measurements by means of overcoring give determination of orientation, dip and direction of dip of the prin-cipal stresses. Hydraulic fracturing is executed after the hydro-geological characterization of the borehole, see ID 120. Rock stress measurements are performed at 2–3 levels in order to provide an idea of fracture growth with depth. | General information about the drilling programme is found in TR-01-29, chapter 3.3.2 and 11.<br><br>Rock stress measurements are described in chapter 3.3.4 and chapter 5.3.1. |
| 1.3.K2.1 | 92 | Drilling | | | | See AP PF400-02-03. |
| 1.3.K2.1 | 95 | Core drilling and percussion reaming 0–100m | Provide a borehole geometry feasible for maintaining pumping out return water during further drilling and a borehole geometry adopted for further investigations and monitoring installations. | | | See AP PF400-02-03. |
| 1.3.K2.1 | 99 | Core drilling 100–1000m, including measurements | See ID 56. | | | See AP PF400-02-03. |
| 1.3.K2.2 | 108 | Base programme | See ID 64. | | | The information from the base programme will constitute the base for the single hole interpretation (ID 123). |
| 1.3.K2.2 | 109 | Surveying | See ID 65. | | | |
| 1.2.6.1 | 110 | Pumping & flow logging | See ID 66. | | | |
| 1.2.7.3 | 111 | Hydrochemical logging | See ID 67. | | | |
| ***1.2.1*** | ***112*** | ***BIP (Borehole Image Processing) system*** | See ID 68. | | | |
| ***1.2.1*** | ***113*** | ***Radar*** | See ID 69. | | | |
| ***1.2.1*** | ***114*** | ***Geophysical logging*** | See ID 70. | | | |
| 1.2.3.1 | 115 | Boremap mapping (GBD) | See ID 71. | | | |
| ***1.4.x*** | ***116*** | ***Sampling (geology, rock mechanics, geochemistry, transport)*** | See ID 72. | | | |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| 1.3.K2.3, 1.2.x | 117 | Supplementary investigations | Additional testing dependent on the purpose of the borehole. Focused on rock stress measurements in this borehole. | | | TR-01-29, chapter 3.5.4. |
| 1.2.6.2 | 118 | Differential flow logging | See ID 75. | | | |
| 1.2.6.3 | 119 | Hydraulic injection tests, 20 m sections | See ID 76. | | | |
| ***1.2.8*** | ***120*** | ***BSP-hydraulic fracturing*** | To determine the original state of stress in the rock mass. | Data on rock stresses at tested locations and mechanical properties of the tested rock. | Rock stress measurements by means of hydraulic fracturing give determination of the magnitude of the principal stresses. | TR-01-29, chapter 5.3.1 and Tables 5-5–5-6. |
| 1.2.1.2 | 121 | VSP (Vertical Seismic Profiling) | Identification and characterisation of features in the vicinity of the borehole. Identification of steeply dipping features to supplement information from seismic reflection survey (ID 174). | Will give information about structures (regional, local major and local minor) within up to 500 m from the borehole. | The entire borehole will be used for these measure-ments. A possible test layout is to have geophones every 5 m in the borehole and generate sound waves from about ten explosive charges placed on the ground. | TR-01-29, chapter 4.3.6 och Table 4-8. |
| ***1.4.3, 1.4.4*** | ***122*** | ***Installation for monitoring*** | See ID 79. | | | |
| 1.2.3.6 | 123 | Single hole interpretation, geology | To provide an integrated description of the geological structures along the borehole. | Identification and preliminary classification of fracture zones. Properties and description of rock properties along the borehole. | Compilation of all availabe information. | The information from the base programme, see ID 108, will constitute the base for the single hole interpretation. |
| 1.3.K3 | 124 | Cored borehole KFM03 | The aim is to obtain data on bedrock properties and groundwater conditions at depth in an assumed block of "good" rock. Adress issues: rock type and rock structures, hydrogeochemical conditions, hydraulic properties, ore potential.<br><br>The type of measurements that will be given priority in the third borehole will be decided based on results from measurements in the two first boreholes and surface investigations. | Data on rock properties in the southeastern part of the area of interest. Basis for correlat-ion of reflection seismic data to provide for confidence in interpretation of structures based on seismic data. | KFM03 is the borehole in the south-east part of the Fors-mark area, see Figure 3. The borehole will be drilled to a depth of about 1000 meters. It will be semivertical, plunge 85 degrees. | General information about the drilling programme is found in TR-01-29, chapter 3.3.2 and 11. |
| 1.3.K3.1 | 135 | Drilling | | | | |
| 1.3.K3.1 | 138 | Core drilling 0–100m | | | | |
| 1.3.K3.1 | 142 | Core drilling 100–1000m, including measurements | See ID 56. | | | |
| 1.3.K3.2 | 151 | Base programme | See ID 64. | | | The information from the base programme will constitute the base for the single hole interpretation (ID 166). |
| 1.3.K3.2 | 152 | Surveying | See ID 65. | | | |
| 1.2.6.1 | 153 | Pumping & flow logging | See ID 66. | | | |
| 1.2.7.3 | 154 | Hydrochemical logging | See ID 67. | | | |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| ***1.2.1*** | ***155*** | ***BIP (Borehole Image Processing) system*** | See ID 68. | | | |
| ***1.2.1*** | ***156*** | ***Radar*** | See ID 69. | | | |
| ***1.2.1*** | ***157*** | ***Geophysical logging*** | See ID 70. | | | |
| 1.2.3.1 | 158 | Boremap mapping (GBD) | See ID 71. | | | |
| 1.4.x | 159 | Sampling (geology, rock mechanics, geochemistry, transport) | See ID 72. | | | |
| 1.3.K1.3, 1.2.x | 160 | Supplementary investigations | The focus for the supplementary investigations has not yet been decided. | | | TR-01-29, chapter 3.5.4. |
| ***1.4.3, 1.4.4*** | ***165*** | ***Installation for monitoring*** | See ID 79. | | | |
| 1.2.3.6 | 166 | Single hole interpretation, geology | To provide an integrated description of the geological structures along the borehole. | Identification and preliminary classification of fracture zones. Properties and description of rock properties along the borehole. | Compilation of all availabe information. | The information from the base programme, see ID 151, will constitute the base for the single hole interpretation. |
| ***1.2.3*** | ***167*** | ***Geological mapping*** | | | | TR-01-29, chapter 3.3.3 and 4.3.4. |
| 1.2.3.5 | 168 | Bedrock mapping | 1. Document key properties of lithological units, including mineralizations.<br>2. Document key properties of structures, including the frequency and orientation of fractures.<br>3. Provide 2D-model for the bedrock geology at the Earth's surface (lineaments, deformation zones, lithological units). | 1. Database of primary information at outcrop scale<br>2. Analyses of rock samples (modal, geochemical and petrophysical)<br>3. Analysis of measured structures<br>4. Geochronological data pertinent to the geological evolution<br>5. Bedrock geological map at the scale 1:10 000. | Rock outcrops, rock cuts, rock quarries and stripped rock surfaces are surveyed for description of lithology and bedrock structure. Regional and local major ductile and brittle structures are mapped. The rock surface is sampled as a basis for petrographical, geochemical, petrophysical, and geochronological determination. | TR-01-29, chapters 3.3.3 and 4.3.4, table 4-3 |
| 1.2.3.2 | – | Detailed fracture mapping | Provide input data for the statistical assessment of fractures at selected localities. | Database of measured fracture properties.<br>Surface-mapping: Detailed maps of studied outcrops showing the location and ID-number of all fractures exceeding the truncation level.<br>Line-mapping: Location and direction of the mapping-line, location and ID-number of fractures along the line exceeding the truncation level. | Detailed mapping of all fractures at a few (3-5) stripped outcrops. Mapping is performed either as surface or line mapping. | TR-01-29, chapters 3.3.3, 4.3.4, table 4-3. |
| 1.2.3.4 | 169 | Quaternary deposit mapping | Devise a model for the key properties and extent of the Quaternary deposits both at the Earth´s surface and down to the bedrock interface. | 1. Analyses of Quaternary deposit samples (e.g. grain-size variation, petrological, geochemical)<br>2. Documentation of ice-movement direction<br>3. Documentation of stratigraphy and structures (primary and tectonic) in key sections<br>4. Compilation of the variation in thickness of the Quaternary deposits<br>5. Quaternary geological map at the scale 1:10 000. | The Quaternary deposit mapping includes:<br>– aerial photo interpretations<br>– field mapping<br>– sampling (digging, drilling)<br>– investigation of lake sediments. | TR-01-29, chapters 3.3.3, 4.3.4, table 4-3. |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| 1.2.3.3 | – | Late- to post-glacial faulting | To determine whether late- to post-glacial faulting has occurred within the studied area. | Description of location and properties of late- to post-glacial faulting. | Interpretations of aerial photographs with negative-size of at least 1:30 000. Field checks of indications of late faulting from maps and aerial photographs. Superficial investigations in existing cuts and quarries outside the regional model area and investigation of new cuts along possible late faults. | TR-01-29, chapters 3.3.3, 4.3.4, table 4-3. |
| ***1.2.1*** | ***170*** | ***Ground geophysics*** | | | | Will be used for the site-descriptive model, version 1.1. |
| 1.2.1.1 | 171 | Gravimetry | Gravimetric measurements mainly provides information on the extent of the different rock types at depth and some information on soil depths where they vary widely. | Gravity data at measured points. | Some information is already available. Additional measurements will be conducted in order to obtain a point density of around 1 point/km2. Therefore, about 40-50 new point measure-ments are required. | TR-01-29, chapter 4.3.3, section "Ground geophysical survey". |
| 1.2.1.2 , 1.2.1.3 | 172 | Profile mats | Geophysical profile mea-surements, mainly magnetic and electromagnetic or electrical methods arranged in several parallel profiles (so-called profile mats) are carried out to augment the geological-structural characterization. The areas that will be measured are selected based on field observations, aerial photos or the results from the radar reflection measurements. | Location and strike of structures, depth of overburden. The results will be used in modells describing:<br>– structures<br>– rock types<br>– soil types. | Each mat will normally have 3-5 parallell profiles each with a with a length of 200– 1000 m. The spacing between the profiles are about 50 m. Measurements will take place in about 5 profile mats during the first year. In addition, measurements in profile mats with smaller extension will take place in the vicinity of each of the three cored boreholes.<br><br>Measurements at proposed locations for cored boreholes to aid in determining the exact locations of the boreholes. For KFM001-003 se AP PF400-02-01. | TR-01-29, chapter 3.3.3, section "Fracture zones and fractures". |
| 1.2.1.4 | 173 | Other geofysical measurements | The information from geophysical methods provide a basis for interpretation of:<br>– rock types<br>– structures<br>– deep saline groundwater. | | Several surface geophysical methods are available, for example:<br>– magnetic methods<br>– resistivity (CVES)<br>– electromagnetic methods (VLF, slingram)<br>– transient electromagnetic sounding (TEM)<br>– ground-penetrating radar.<br><br>Scope of investigations to be determined. | TR-01-29, chapter 4.3.3 and Table 4-5. |
| 1.2.1.2 | 174 | Seismic reflection | Seismic reflection investigations are carried out to discover large, gently-dipping fracture zones in the bedrock. | Data on location, orientation and mechanical properties of gently-dipping features. | The measurements are carried out along a profile that passes through the central part of the lens and some profiles perpendicular to the lens, see Figure 6. One of the profiles will pass one or a few northwest striking fracture zones.<br>The measurements will include about 15 kilometres in length. | TR-01-29, chapter 4.3.3, section "Ground geophysical survey". |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| ***1.3.H*** | ***175*** | ***Percussion drilling programme*** | Provide information on the location, orientation and properties of larger structural features at shallow depth (<200 m).<br>Provide a fundamental characterization of the formation based on uniform methodology. Some of the percussion drilled boreholes will serve as water wells for supplying flushing water during drilling of cored boreholes. | Verification of existence and extent of structural features detected from surface investigations at depth. Data on location, orientation and properties at tested locations. | A limited number of boreholes (preliminary 5-10) with a maximum depth of 200 m. Downhole investigations will be performed according to base programmes for percussion boreholes in all completed rock boreholes. | General information about the drilling programme is found in TR-01-29, chapter 3.3.2 and 11. |
| 1.3.Hx | 176 | Bore hole X (HFMXX) | | | | |
| 1.3.Hx.1 | 178 | Drilling | | | During percussion drilling the penetration rate is measured, the flow from the borehole estimated, the flushing water colour judged, the electrical conductivity of the flushing water measuredand and cutting samples are taken for rock type determination. | TR-01-29, chapter 7.3.3. |
| 1.3.Hx.2 | 187 | Base programme | | | | |
| ***1.2.1*** | ***188*** | ***BIP (Borehole Image Processing) system*** | See ID 68. | | | |
| ***1.2.1*** | ***189*** | ***Radar*** | See ID 69. | | | |
| ***1.2.1*** | ***190*** | ***Geophysical logging*** | See ID 70. | | | |
| 1.2.6.1 | 191 | Pumping, sampling & flow logging | Identify and characterise permeable features along the borehole. | Data on hydraulic and hydrogeochemical properties of permeable features along the borehole. | Entire borehole. | TR-01-29, chapter 7.3.3 and Table 7-6. |
| ***1.2.3*** | ***192*** | ***Boremap mapping (GBD)*** | See ID 71. | | | |
| ***1.4.3, 1.4.4*** | ***193*** | ***Installation for monitoring*** | Long-term monitoring of pressure, flow and hydrochemistry. | Pressure, groundwater flow and chemical composition in the borehole. | Long-term monitoring of pressure will be carried out in the percussion boreholes. However, only one packer is normally put in percussion boreholes, but 2 to 3 packers may occasionally be used.<br>A section may be installed for groundwater flow measurements in some percussion boreholes. Furthermore, some of the percussion boreholes will be equiped with permanent packer installations that can be utilized for hydrochemical sampling. | The long-term monitoring is decrribed and illustrated in TR-01-29, chapters 7.3.4, 8.3.11, table 7-7 and figure 7-6. |
| ***1.2.4*** | ***194*** | ***Marine geological investigations*** | Hydroacustic measurements and marine-geological sampling give information about sea bottom topography and depth to bedrock. | The information is primary used for the soil and structure models, but also as input to the ecological modelling of the area. | The measurements will take place in an area extending about 10 km along the coast line and about 2 km out from the coast line. The distance between the profiles are 200–400 m. | |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| ***1.2.2*** | ***197*** | ***Airborne geophysics from helicopter*** | The airborne gephysical maps are used for an assessment of the occurence of regional and local major fracture zones and various rock type volumes and their character. | Information on the location of regional and local major fracture zones. The results will be used in modells describing:<br>– structures<br>– rock types<br>– soil types | The airborne geophysical methods used are magnetic, electromagnetic and radiometric methods. Measurements along north-south lines separated by 50 m. The measurements will cover a about 110 km2 area. In addition, measurements along east-west lines are carried out in a smaller area, see Figure 4. | The information will be used for the limeament interpretation (ID 198).<br><br>TR-01-29, chapter 4.3.3, section "Airborne geophysics". |
| 1.2.1.3 | 198 | Lineament interpretation | Lineament interpretation of digital elevation data, aerial photos and airborne geophysical maps is used to obtain information on large-scale lineaments that may comprise regional or local fracture zones. | Lineament maps. | Area specified in Figure 8. | TR-01-29, chapter 4.3.4 (section "Lineament interpretations") and chapter 3.2.3 (section "Lineament interpretation – identification of regional fracture zones"). |
| **1.4** | **199** | **Monitoring 2002** | The long-term measure-ments, monitoring, will take place at the surface as well as in boreholes. The monitoring provide an under-standing of the area's natural evolution over an extended period of time. Long time series provide a good basis for documenting undisturbed conditions and for gaining an understanding of seasonal variations in the area. | The monitoring programme will include monitoring of hydro-chemistry, hydrology, surface ecosystems, seismic events, creep movements in the bed-rock (using GPS technology), pressure and flow in boreholes. | | Hydrogeological monitoring, see TR-01-29 chapter 7.3.4. Seismic events, creep movements, see chapter 3.2.3. Surface ecosystems, see chapter 3.3.1. Hydrogeology, see chapter 3.3.6. |
| **1.5** | **209** | **Site-descriptive model, version 1.1** | Version 1.1 of the site-descriptive model will be developed during 2003, and will form the basis for the placing of the next two cored boreholes, KFM04-05, and other activities. | | | TR-01-29, Table 2-1. |

The activities above (ID 1-209) will be carried out during the first phase (year) of the initial site investigations. The initial site investigation will take place over a period of approximately 2 years. The second phase (year) work plan will depend partly on the results of the first phase investigation. It is therefore at present not possible to specify the activities beyond the first phase (year). A rough outline of the main expected activities during the second phase (year) is found below.

| | | | | | | |
|---|---|---|---|---|---|---|
| **2.2** | **212** | **Initial site investigations, 2nd phase (year)** | | | | |
| ***2.2.5*** | ***213*** | ***Surface ecosystems*** | See ID 27. | | | |
| ***2.3.K4*** | ***218*** | ***Cored borehole KFM04*** | Boreholes KFM04 and 05 will be drilled to study the boundary zone north-east and south-west of the tectonic lens. The position and direction of these two boreholes will be determined from the results of aerial and ground-level measurements. | | | |
| 2.3.K4.2 | 245 | Base programme | See ID 64. | | | Will be used for planning the supplementary investigations (ID 254). |
| 2.3.K4.3 | 254 | Supplementary investigations | The focus for the supplementary investigations has not yet been decided. | | | |
| ***2.4.x*** | ***258*** | ***Installation for monitoring*** | See ID 79. | | | |

| WBS | ID | Activity | Goal | Expected results | Location and scope | Comments/ References |
|---|---|---|---|---|---|---|
| ***2.3.K5*** | ***260*** | ***Cored borehole KFM05*** | Boreholes KFM04 and 05 will be drilled to study the boundary zone north-east and south-west of the tectonic lens. The position and direction of these two boreholes will be determined from the results of aerial and ground-level measurements. | | | |
| 2.3.K5.2 | 287 | Base programme | See ID 64. | | | Will be used for planning the supplementary investigations (ID 296). |
| 2.3.K5.3 | 296 | Supplementary investigations | The focus for the supplementary investigations has not yet been decided. | | | |
| ***2.4.x*** | ***301*** | ***Installation for monitoring*** | See ID 79. | | | |
| ***2.2.3*** | ***303*** | ***Geological mapping*** | | | | |
| ***2.2.1*** | ***307*** | ***Ground geophysics*** | See ID 172. More information will however be available when the areas that will be measured are selected, for example the results from airborne geophysics from helicopter. | | | TR-01-29, chapter 4.3.3, section "Ground geophysical survey". |
| 2.3.H | 310 | Percussion drilling programme | | | | |
| 2.3.Hx | 311 | Bore hole X (HFMXX) | | | | |
| 2.3.Hx.1 | 322 | Base programme | | | | |
| ***2.4.x*** | ***328*** | ***Installation for monitoring*** | See ID 193. | | | |
| **2.4** | **329** | **Monitoring** | See ID 199. | | | |
| **2.5** | **339** | **Site-descriptive model, version 1.2** | The initial site investigation will finish in the development of version 1.2 of the site-descriptive model, which will be carried out during 2004. This version will result in a preliminary safety judgement and a first site-specific description of the facility, as well as form the basis for the placement of further boreholes and the other work to be carried out during the complete site investigation. | | | TR-01-29, Table 2-1. |
| **3** | **341** | **Planning for the complete site investigation** | The planning for the complete site investigations will be based on site specific model v 1.2, see ID 339. | | | |

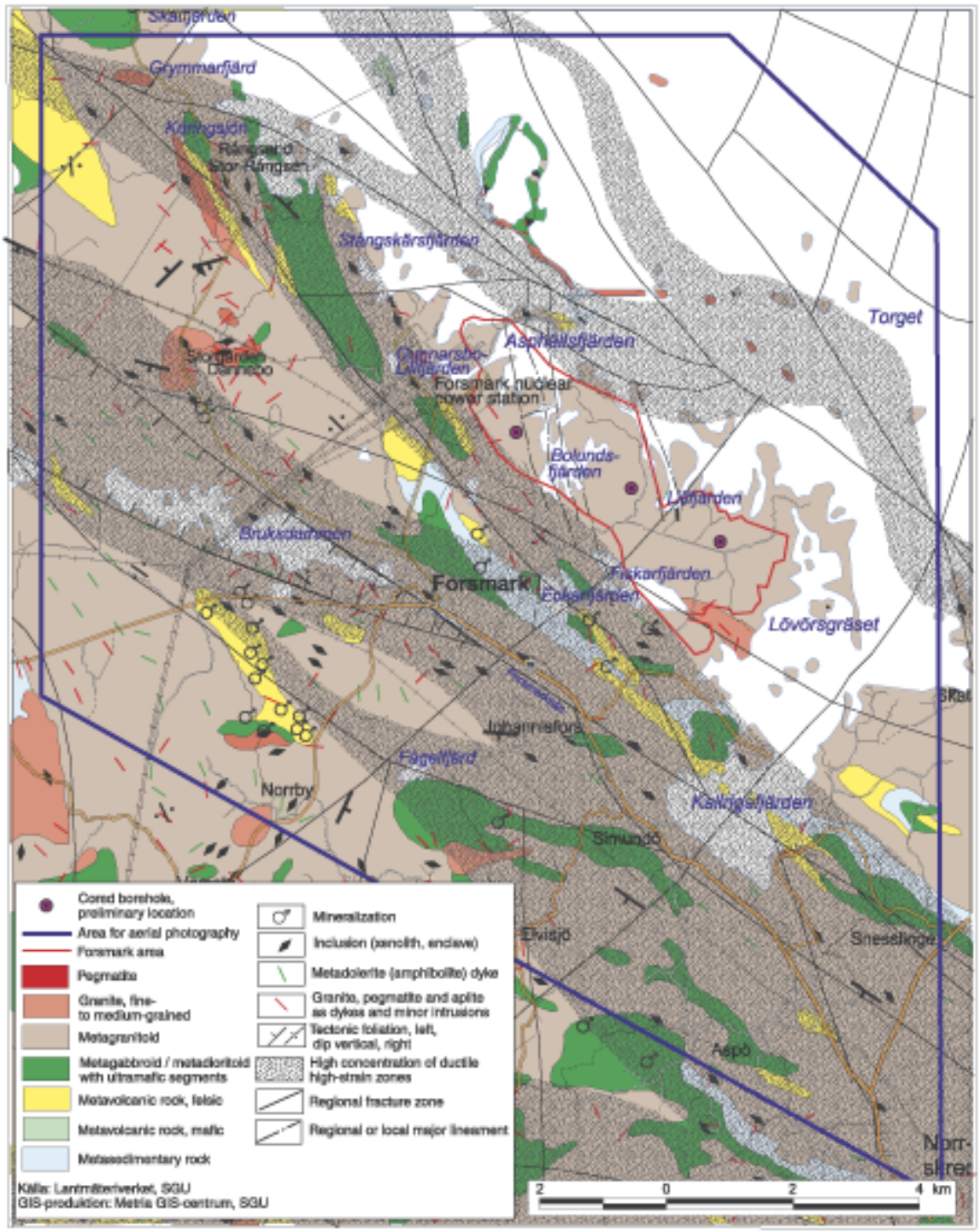


***Figure 8.*** *Area for aerial photography.*

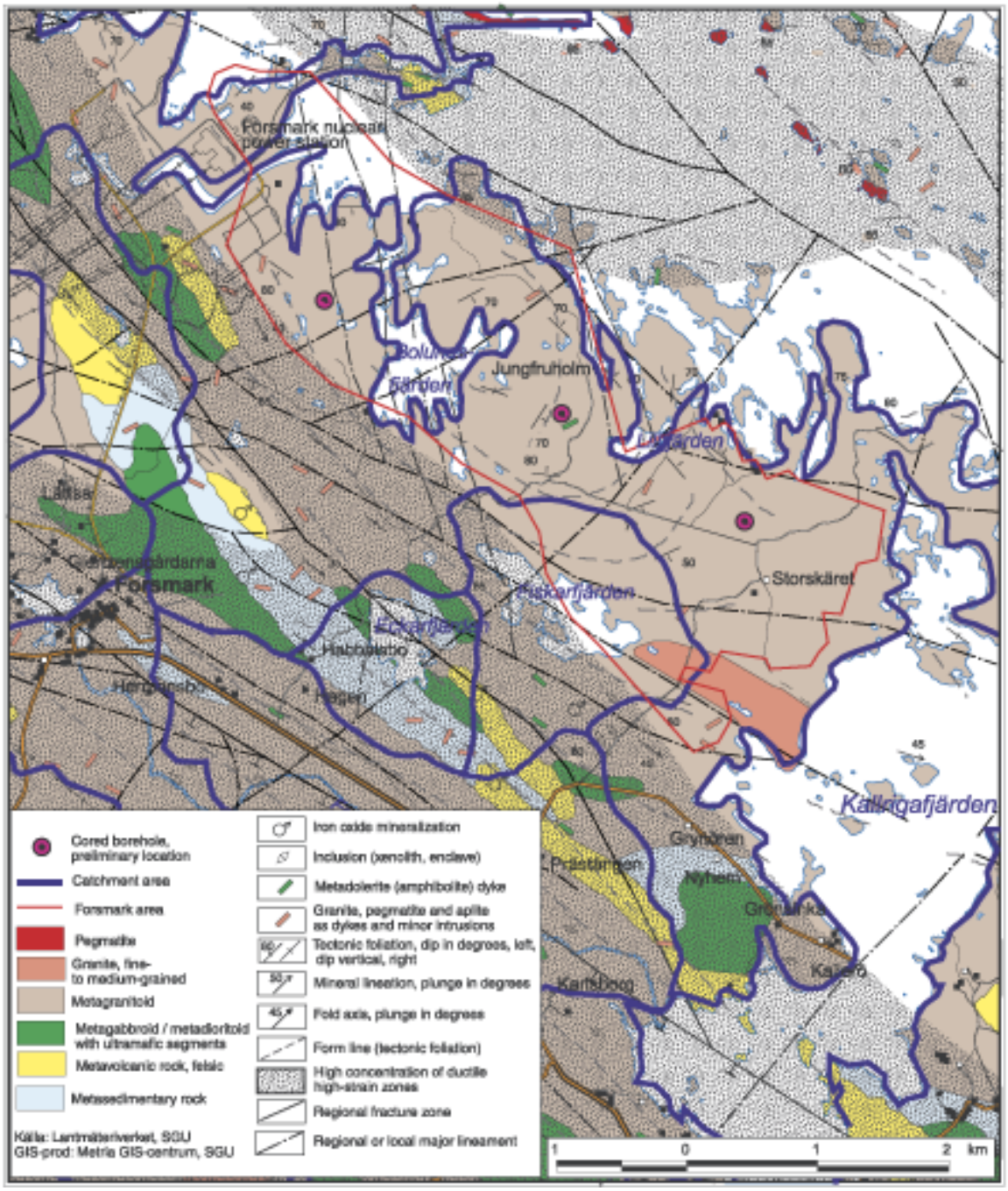


***Figure 9.*** *Catchment areas.*