SKB

TECHNICAL REPORT

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General Siting Study 95

Siting of a deep repository for spent nuclear fuel

October 1995

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GENERAL SITING STUDY 95

— SITING OF A DEEP REPOSITORY FOR SPENT NUCLEAR FUEL

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FOREWORD

One of SKB's tasks is to compile the basis for the siting of a deep repository for Swedish spent nuclear fuel and other long-lived nuclear waste.

In the government decision of May 18, 1995, the government made the following statement: *"The Government finds, in agreement with most of the reviewing bodies, that SKB ought to present its general studies and site-specific feasibility studies collectively for the purpose of providing background and premises in the siting work. The Government believes that such collective accounts ought to be presented in future research and development programmes in accordance with Section 12 of the Act on Nuclear Activities."*

General Siting Study 95 is a detailed description of the work carried out to put the siting of a deep repository in a national and regional context. The report is based on SKB's siting factors, which have been applied on a national scale. Different factors of importance or of possible importance for the long-term radiological safety, technology, land and environment as well as society are described and evaluated.

This report is the overall description on general siting studies which the government considered that SKB should report in connection with RD&D Programme 95.

Stockholm, October 1995

SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

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SUMMARY

One of SKB's tasks is to compile a basis for the siting of a deep repository for Swedish spent nuclear fuel and other long-lived nuclear waste. The aim of the siting work is to compile all of the information which is necessary for a site to be selected and to obtain a siting permit in order to start construction of the deep repository through the detailed characterization of the selected site.

In the government decision of May 18, 1995, concerning SKB's programme, the government made the following statement with regard to the siting work:

"The Government finds, in agreement with most of the reviewing bodies, that SKB ought to present its general studies and site-specific feasibility studies collectively for the purpose of providing background and premises in the siting work. The Government believes that such collective accounts ought to be presented in future research and development programmes in accordance with Section 12 of the Act on Nuclear Activities."

General Siting Study 95, contains SKB's overall report on general siting studies carried out on a national scale in accordance with the government decision.

This report is mainly based on the extensive background material that SKB prepared as a part of the research and development work which has been conducted since the late 1970's.

The target group for this report is assumed to comprise experts within the different related areas as well as decision-makers and members of the general public who are particularly interested in these issues. For this reason, the report must contain information that is scientifically cogent and concise. At the same time the report must provide ample background information and easy-to-read background information. These requirements are not always compatible. Consequently, the reader, depending upon his/her specific background, may have to consult background technical reports or general material in order to obtain maximum benefit of the report.

In General Siting Study 95, important siting factors have been described and applied on a national scale. For each such siting factor, separate conclusions have been reported in detail.

All of the factors, of which the long-term radiological safety is the central factor, must be taken into account in the siting of the deep repository. However, to make an overall evaluation of this factor, site-specific data on the bedrock must be available. Such data can only be obtained by carrying out extensive investigations at sites which can only be selected on the basis of partially incomplete information. This is a characteristic which distinguishes the siting of underground facilities in general, and a deep repository in particular, from other types of industrial siting, where information on all of the vital factors is relatively easy to obtain.

An important part of the work on preparing General Siting Study 95 has been to explore the possibilities and limitations which are related to a general siting study on a national scale.

A general siting study on a national scale cannot provide information on scientific, technical and societal factors with the necessary level of detail in order to identify sites which are suitable for the siting of a deep repository. The information

presented in this study in general also covers conditions at the surface and not at the depths envisaged for the deep repository, 400-700 m below the surface. Thus, the suitability of a site is best evaluated through feasibility studies and site investigations and evaluations which must be carried out in connection with pertinent permitting of regulatory authorities.

However, General Siting Study 95 makes it possible to identify areas which are less suitable, or of less interest. However, areas which are of less interest, on a national scale, cannot be excluded since, on the local scale of a particular area, there may be many sites of interest which may be omitted when generalizations are made on the national scale. The general siting study also examines several scientific, technical and societal conditions in different parts of Sweden. These conditions provide a basis for assessing interest in, and for carrying out more detailed siting studies (feasibility studies).

A number of national databases which, in one way or another are, or may be significant for the siting factor of long-term radiological **Safety** have been described and evaluated. This includes rock types, topography, well data and the Highest Shoreline. Furthermore, geological deformation zones, lineaments, future ice ages and earthquakes have been included. The possibility of unintentional intrusion and the selection of discharge areas are also discussed.

The siting factor, **Technology**, describes how the feasibility may be affected by different conditions. After the waste is encapsulated, it must be transported to the deep repository. Various alternatives exist, depending on the location of the deep repository in relation to the encapsulation plant. There is no actual restriction on how the deep repository can be located in terms of the means of transportation. The preferred means of transportation would require railroads or harbours. It is easier to carry out investigations of the bedrock, facility design and safety assessment if the geoscientific conditions of the site are easy to understand and interpret. A number of attempts have been made to, on a national scale, assess possible regional differences in interpretability. Even if it is suitable to primarily seek out sites which are easy to interpret, a similar reliability in results might be obtained at a more complex site, although more extensive investigation of the site would be required. This is thus a question of optimization, among other issues. The deep repository, as an engineering and construction project, benefit from the same factors which benefit the long-term radiological safety. Thus, there is no conflict between safety and simplicity of implementation with regard to the actual construction work.

The factor, **Land and Environment**, must also be taken into account in the siting of the repository, bearing in mind the stipulations of the Act concerning the Management of Natural Resources etc. Furthermore, there are areas which are protected against exploitation by law, e.g. national parks, nature reserves etc.

With regard to the siting factor, **Society**, is concerned there are a large number of conditions which are treated in the report which can largely be evaluated on a more detailed scale in connection with feasibility studies and site investigations.

The goals of General Siting Study 95 have been described in the RD&D Programme 92 Supplement:

- *"In a general fashion (on a national scale), shed light on conditions of interest for determining which parts of the country are unsuitable, interesting or suitable for siting a deep repository.*
- *Yield data for determining SKB's interest in feasibility studies in different regions or municipalities.*

- *Provide indications of what must be particularly taken into account and studied in connection with continued more detailed studies within suitable or particularly interesting areas.*
- *Yield data for putting coming site selection in its national and regional context."*

The conclusions from this work is now related to the established goals.

"In a general fashion (on a national scale), shed light on conditions of interest for determining which parts of the country are unsuitable, interesting or suitable for siting a deep repository."

An overall evaluation of the applicable siting factors shows that it is unsuitable to locate the deep repository in the Scandinavian mountain range, Skåne and Gotland, primarily for geological reasons. Furthermore, the Scandinavian mountain range is an area of national interest with regard to nature conservation and outdoor activities. Siting of the repository in the bedrock below Öland is considered to be technically possible, although unsuitable in terms of the management regulations of the Act concerning the Management of Natural Resources etc.

Siting of the repository in areas which are directly protected by law is neither necessary or desirable and must be avoided.

Areas which are of national interest in other contexts cannot be simply excluded. However, work should not focus on siting the deep repository in such areas or should at least focus on siting and designing the deep repository so as not to negatively affect the aim of protecting areas which are of national interest.

The unnecessary use, or blocking of natural resources must, if possible, be avoided. Areas where unusual rock types occur or where there is a possibility of ore, especially bedrock consisting of acid volcanic rock types, are therefore of less interest. By avoiding these rock types, there is less possibility of future, unintentional intrusion into the deep repository as well.

The conclusion which was previously drawn by SKB that there are many areas in Sweden which appear to be suitable for the siting of a deep repository has not been altered by General Siting Study 95. In the future, siting should also focus on bedrock commonly found in Sweden, preferably more or less transformed granite-like rock types, or old, highly metamorphosised sedimentary bedrock. This type of "interesting" bedrock exists in large parts of Sweden.

It is not necessary to exclude areas containing gabbro, or areas where the bedrock is covered by sedimentary rock, in connection with siting. These areas can assessed especially if feasibility studies will be carried out in municipalities with this type of bedrock.

It is technically possible to locate the repository beneath large lakes or beneath the sea. However, there is no particular reason to seek out or avoid such a siting.

The long-term radiological safety is not the only factor taken into consideration in the siting of the deep repository but also the practical implementation of the work. Consequently, areas with bedrock that is easy to interpret as well as areas where the rock is relatively low-conductive are of interest. In general, there is no conflict between the factors which are favourable to the long-term safety and the simple, technical implementation of work. It is most suitable to evaluate the question of the variation of the bedrock and other properties in connection with more detailed studies.

As far as transportation and communication are concerned, the availability of harbours, railroads or airports is good. Thus, on the national scale, there is no real limitation of possible areas in terms of these factors.

"Yield data for determining SKB's interest in feasibility studies in different regions or municipalities."

The siting factors described in this report have already been largely applied in the feasibility study which was carried out in Storuman and in the ongoing (October 1995) feasibility study in Malå. These factors have also been applied to municipalities which have evinced interest in initiating feasibility studies but which have been considered to be less interesting by SKB.

In General Siting Study 95, it is emphasized that many of the siting factors should, above all, be applied on a local scale in connection with feasibility studies and site investigations. This study is one of the bases which can be used in connection with the planning of work to find a suitable site for the repository.

For general technical and societal reasons, it is of interest to conduct feasibility studies in municipalities with existing nuclear activities: Nyköping, Oskarshamn, Varberg and Östhammar, which has been previously reported.

Besides the already completed, ongoing or planned feasibility studies, it is suitable to carry out one additional or a few additional feasibility studies. It should be an advantage to further work and with regard to discussions with different communities that an overall report on the general siting studies which have been carried out now exists. The report makes it easier than before for all concerned to understand the background and general conditions that exist for siting work in different parts of the country.

As a basis for concrete discussions with different communities concerning feasibility studies, SKB intends to use regional general siting studies which are based on this study. In such regional general siting studies, it is of particular interest to preliminarily identify areas within one region which are expected to have suitable conditions with regard to industrial experience, availability of industrial land and proximity to harbours or railroads as well as where it is expected that there is bedrock with a good potential for fulfilling technical and safety-related requirements.

"Provide indications of what must be particularly taken into account and studied in connection with continued more detailed studies within suitable or particularly interesting areas."

General Siting Study 95 provides such indications, in several respects. Such factors include possible conflicts of interest in connection with land use in expansive areas of Sweden, the occurrence of ore mineralizations etc.

"Yield data for putting coming site selection in its national and regional context."

General Siting Study 95 contains background material and a description of general conditions in different parts of Sweden which make it possible to, in connection with site licensing (based on 5-10 feasibility studies and 2 site investigations), evaluate whether the selected site is acceptable from different aspects and whether it is based on a sufficiently broad basis of information.

The background material often contains large variations on a local scale, which cannot be specified on a national scale. Thus, in all probability, suitable areas can be found both in regions which, on a national scale, appear to be of greater interest, as well as in regions which, on a national scale, appear to be of lesser interest. This general approach can be applied to several of the databases or situations which are described in this report.

Regional and local conditions will have to be more closely investigated in feasibility studies and site investigations in each relevant case.

CONTENTS

1 INTRODUCTION

This chapter describes the aim of the report as well as the role of the general siting studies in the work on finding a suitable site for the deep repository. The structure and the contents of the report is also described for the reader's orientation.

1.1 BACKGROUND

One of SKB's tasks is to compile the basis for the siting of a deep repository for Swedish spent nuclear fuel and other long-lived nuclear waste. The aim of the siting work is to compile the information which are necessary for a site to be selected and for a siting permit to be obtained in order to start construction of the deep repository through the detailed characterization of the selected site. A schematic diagram of the main components of the siting work is provided in Figure 1-1. The structure of this work has been previously presented to the regulatory authorities and the government /1-1, 1-2/.

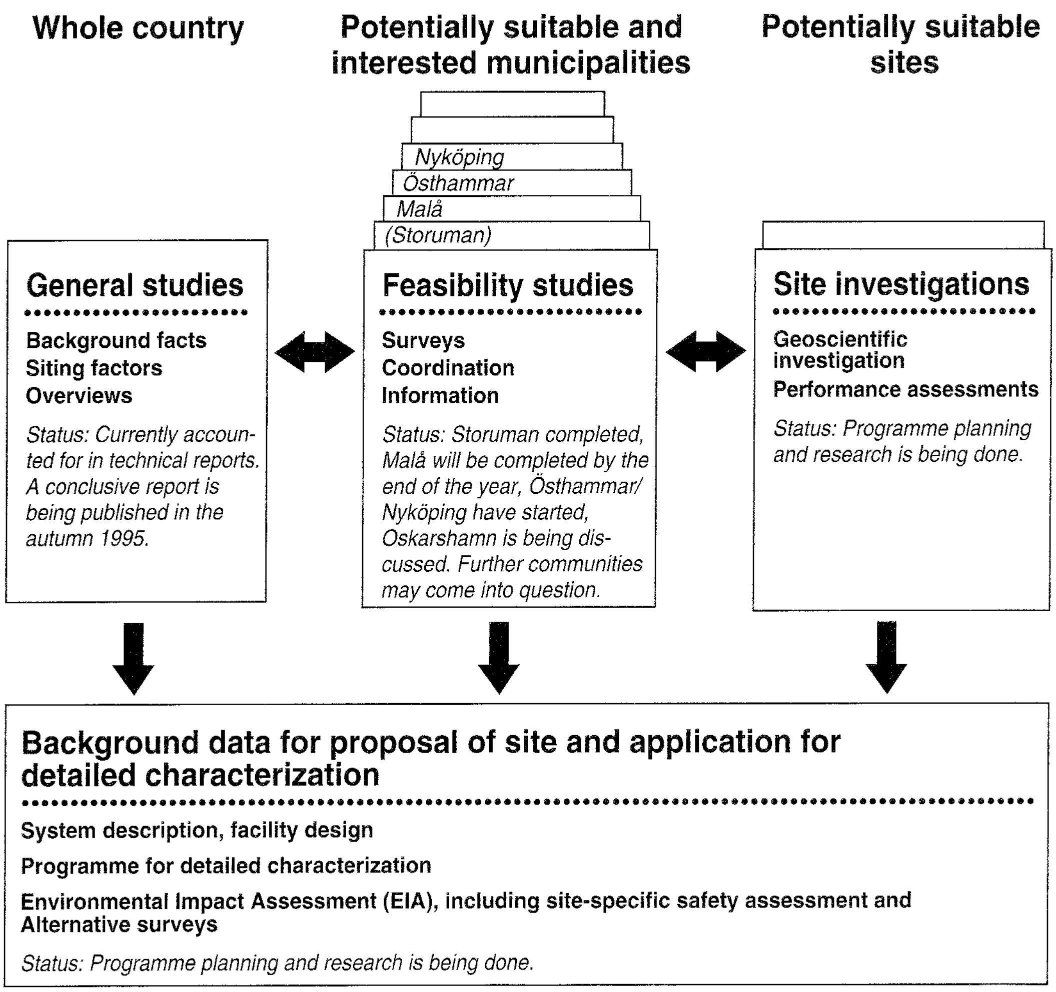

Figure 1-1. Main components of the siting work. From /1-5/.

The siting work will be based on the criteria which were previously specified in connection with the RD&D Programme 92 Supplement /1-2/. The most important criterion is the long-term radiological Safety at the site where the deep repository is constructed. Other siting factors are Technology, Land and Environment and Society.

In the government decision of May 18, 1995 /1-3/ concerning SKB's programme, the government made the following statement with regard to the siting work:

"SKB has, in a detailed manner, presented its view on the criteria and methods to locate a suitable site for the deep repository, from different standpoints. In the view of the government, the siting factors and criteria described by SKB should be a point of departure for further siting work."

Furthermore, the government states:

"The Government finds, in agreement with most of the reviewing bodies, that SKB ought to present its general studies and site-specific feasibility studies collectively for the purpose of providing background and premises in the siting work. The Government believes that such collective accounts ought to be presented in future research and development programmes in accordance with Section 12 of the Act on Nuclear Activities."

The applications for a permit, under Section 4 of the Act concerning the Management of Natural Resources etc. and 5 § of the Act on Nuclear Activities, to construct a repository for spent nuclear fuel and nuclear waste should contain material for comparative evaluations which shows that site-specific feasibility studies, in accordance with SKB's programme, have been carried out at between 5-10 sites in Sweden and that site investigations have been carried out at no less than two sites as well as the reasons for selecting these sites."

This report, General Siting Study 95, is SKB's compilation of general siting studies carried out on a national scale in accordance with the government decision. The final report on the feasibility study carried out in Storuman /1-4/ contains such an overall report of the first feasibility study which has been carried out. Similar reports will be compiled for other feasibility studies – a total of 5-10, as they are completed. Furthermore, prior to the starting of the site investigations, a report will be compiled which, with the help of the general siting studies, feasibility studies and other relevant material, will present the reasons why SKB considers it necessary to initiate site investigations in a certain area.

General Siting Study 95 is mainly based on the extensive background material that SKB has continuously prepared in the research and development work which has been conducted since the late 1970's. A survey of these reports is presented in Appendix 1.

Criteria, general premises and basic conclusions for the siting work have been previously reported. For more detailed information, see Chapter 4 of the RD&D Programme 92 Supplement /1-2/ as well as Chapters 8 and 9 of RD&D Programme 95 /1-5/.

It is assumed that the target group for this report will comprise experts within the different related areas as well as decision-makers and members of the general public who are particularly interested in these issues. For this reason, the report must contain information that is scientifically cogent and concise and at the same time provide ample and easy-to-read background information. These requirements are not always compatible. Consequently, the reader, depending upon his/her specific background, may have to consult background technical reports or general material in order to obtain maximum benefit of the report. The list of references and Appendix 1 may provide guidance in this respect.

1.2 AIM OF THE GENERAL SITING STUDY

In accordance with the government decision quoted above, this report shall help to "*... provide background and conditions for the siting work*". The report on a national scale will, of necessity, be less detailed in nature. The concrete identification of specific sites which may be of interest for field investigations will be made in connection with the 5-10 feasibility studies which are planned.

In the RD&D Programme 92 Supplement, the following goals were specified for the general siting studies:

- *" In a general fashion (on a national scale), shed light on conditions of interest for determining which parts of the country are unsuitable, interesting or suitable for siting a deep repository.*
- *Yield data for determining SKB's interest in feasibility studies in different regions or municipalities.*
- *Provide indications of what must be particularly taken into account and studied in connection with continued more detailed studies within suitable or particularly interesting areas.*
- *Yield data for putting coming site selection in its national and regional context."*

Work on the planning and implementation of this study has been guided by these goals. The summary and conclusions of the report (Chapter 8) describe the way in which and the extent to which these goals can be fulfilled.

1.3 STRUCTURE OF THE REPORT

The report is divided into a number of chapters. General background information is provided in Chapter 2. Radiation and radiation protection are examined as well as how the deep repository is designed for the long-term protection of human beings and the environment. The siting process is also described as well as the different factors which SKB has formulated for the siting. The long-term radiological safety and technical factors which are of significance for the implementation of the deep disposal system are described as well as the siting factors, Land and Environment, and Society.

The possibilities and limitations of a general siting study conducted on a national scale are described in Chapter 3, with an emphasis on scientific and technical factors. Many of the scientific and technical factors require extensive site investigations of the bedrock to be carried out before they can be fully evaluated. Other factors require that detailed studies should be carried out on a local scale.

Factors on a national scale which are of importance or of possible importance for the long-term radiological safety, technology, land and environment as well as society are described in the next few chapters, 4-7. A separate summary of each main chapter is provided.

The overall conclusions which have been drawn, taking into account the siting factors are presented in the final chapter, Chapter 8.

The general siting study was carried out as a project within SKB's Division Deep Repository, see Appendix 2.

2 GENERAL BACKGROUND

The nuclear waste will be disposed of according to the following principles:

- The waste must be isolated in such a way that it cannot harm human beings, animals or nature, neither today nor in the future.
- Our generation, which uses the electricity generated by nuclear power plants, is responsible for the safe disposal of the waste.
- To take responsibility means to ensure that the methods which now exist for the disposal of the waste can be evaluated and implemented in practice.
- Since we do not know anything about future societies, we must, as far as possible, minimise the measures which are required by future generations.
- The methods for the final disposal of waste must be compatible with the law of nature. Thus, these methods must be based on natural occurring materials and natural occurring chemical environments.
- It must be possible for future societies to retrieve the waste if they desire to do so.

These principles have been used to develop the current system for the management of radioactive waste that exist now. The principles will also be applied in the planning and construction of the remaining facilities, the encapsulation plant and the repository for the spent nuclear fuel. The work is being carried out in stages within the framework of the legislation which has been established in society for the disposal of the waste.

Up to year-end 1994, almost 2,100 tonnes of spent nuclear fuel is being stored at the central interim facility for spent nuclear fuel (CLAB) – a facility which is situated near to the nuclear power plant at Simpevarp. Furthermore, just over 700 tonnes of fuel were in temporary storage at the nuclear power plants, besides about 1,100 tonnes of uranium in the twelve reactor cores. The quantity of spent nuclear fuel is increasing by about 200 tonnes per year.

Several possible principles exist for the final disposal of the spent nuclear fuel/waste /2-1/. Examples include depositing the fuel and waste at great depths in geological formations or in deep sea sediment, dumping into the sea, expulsion into outer space etc.

In Sweden, work has focused on disposal in deep, geological formations. This is also the common, main alternative, seen from an international perspective. This alternative is considered to be both ethically and environmentally sound /2-2/.

There are many alternative designs for a geological repository. Different alternatives are constantly being evaluated and these evaluations were reported in connection with RD&D Programme 92 /2-3/. Both SKB and the competent authority, the Swedish Nuclear Power Inspectorate have found that the KBS-3 concept is a suitable reference. The Swedish Nuclear Power Inspectorate has stated that *"...no method appears to be essentially better from the standpoint of safety and possible to implement in Sweden without considerably lengthening the time frame, compared with SKB's plans."* /2-4/.

2.1 IONIZING RADIATION AND RADIATION PROTECTION

The requirements on the management of nuclear waste are, to a certain extent, unique since the nuclear industry must show that neither the present generation nor future generations will be harmed. The requirement is established by legislation and is mainly related to any damage which can be caused by the ionizing radiation released by the radioactive waste.

In relation to many other societal risks, ionizing radiation has "advantages" since:

- It is easy to measure the radiation.
- Considerable knowledge exists concerning protection from ionizing radiation.

The radioactive waste can be hazardous in two ways:

- It emits direct radiation (primarily, gamma radiation) which, upon contact, is harmful to human beings. In the light of this, protection can be obtained by surrounding the radioactive waste with sufficiently thick radiation shields which absorb the radiation. At nuclear power plants and within the medical services, there is extensive experience of such protective measures using shielding.
- It is possible that the radiation could be released into the air or water and, in that way, reach human beings. Protection can be obtained by ensuring that the waste is in solid form since this makes it difficult or impossible for radioactive substances to become vaporized in the air or to become dissolved in water. Furthermore, the waste is surrounded by several barriers, e.g. the canister, clay and rock, which prevent the waste from coming into any contact with the environment of human beings.

In a canister containing spent nuclear fuel, the same type of energy is not generated as that in a nuclear power reactor. Furthermore, it is not physically possible for the fuel to melt on account of the heat generated, much less explode. The radiation also decays rapidly with time. One year after removal from the reactor, the radioactivity decreases to 1%. After 40 years, the radioactivity is 0.1% of the original level. After about 1,000 years, the direct radiation will have largely decayed. However, the fuel will still be radioactive. After 100,000 years, the radiation from the fuel will correspond to the natural level of rich uranium ore and will entail the same risk as uranium ore if particles are ingested.

In general, the handling of encapsulated spent nuclear fuel at a deep repository is simpler than the handling of non-encapsulated fuel which currently occurs at the nuclear power plants and at CLAB. The total radioactive inventory and the level of radiation is considerably lower and the waste better protected through the fact that it is encapsulated.

Monitored storage of the spent fuel, which is carried out at CLAB, is an effective method of interim storage, but is not a permanent measure, because if monitoring should cease or become deficient, human beings and the environment must still be protected. For this reason, final disposal is required by Swedish law and, therefore, Sweden, like other countries, is working on carrying out final disposal in deep geological formations (deep repositories).

2.2 THE DEEP REPOSITORY

A deep repository is a nuclear industry with facilities above the surface as well as deep in the rock, at depths of 400 to 700 m. The purpose of the deep repository is to achieve an effective, long-term isolation of the waste to protect human beings and the environment.

The deep repository will be constructed in two stages. In the first stage, about 400 of a total of some 4,500 canisters containing spent nuclear fuel, will be deposited. This initial operating period is expected to start by the year 2008, at the earliest, and is expected to continue for about 5 years, after which the experiences will be evaluated.

There is a possibility of retrieving the canisters if, for any reason, this should be considered necessary.

If the outcome of the evaluation is positive, the rest of the repository will be constructed (stage 2) and work will continue until all of the waste is deposited, which will occur by the year 2040, at the earliest. The total quantity of spent nuclear fuel which will then be deposited is estimated at 8,000 tonnes, which is the quantity arising from the Swedish nuclear power programme up to the year 2010. During stage 2, other long-lived waste will also be deposited in a special part of the deep repository. This waste comprises reactor components which have been close to the core, research waste from Studsvik and certain decommissioning waste from CLAB and the encapsulation plant.

The central activity at the deep repository will be to receive canisters containing spent nuclear fuel and to deposit them at selected positions about 500 m deep in the rock. During the regular operation of the repository (stage 2), certain other types of radioactive waste will be deposited.

In order to achieve this, the following are required:

- preparations in the form of geoscientific investigations, access ramp excavation, excavation of repository, drilling of deposition holes etc.,
- transportation of canisters into the repository and emplacement of the canisters and the surrounding bentonite buffer in the deposition holes,
- transportation of other long-lived radioactive waste into the repository and emplacement,
- post-emplacement work in the form of instrumentation, backfilling of deposition tunnels and rock cavities as well as control etc.

As a support for these central activities, a number of technical support systems will also be needed at the deep repository.

The underground facilities consist of a central area with ventilation buildings, workshops, personnel facilities, offloading areas for transportation containers, tunnels for the transportation and deposition of canisters containing spent nuclear fuel as well as rock cavities and tunnels for other types of waste.

The repository will be located at a depth of about 500 m. From tunnels at this depth, holes, which are about 8 m deep and about 1.6 m in diameter, will be drilled. Canisters containing spent nuclear fuel will be placed in these holes and surrounded with bentonite clay. Each canister will be about 5 m long, with a diameter of about 0.9 m. The tunnels can be backfilled with, e.g. a mixture of bentonite and silica sand or crushed rock.

The waste will be deposited in three separate repository sections: a section for canisters deposited during the initial stage of operation (stage 1), a section for canisters deposited during regular operation (stage 2) as well as a section for other long-lived waste (stage 2). In total, these sections comprise an area of one or two km^2. A schematic drawing of the deep repository layout is provided in Figure 2-1. In reality, the positioning of the repository and the tunnels will be adapted to the local conditions of the rock, which will probably mean a more irregular layout than that shown in the figure.

A schematic drawing of the industrial area at the deep repository is provided in Figure 2-2. In this example, it is assumed that the facilities will be constructed on a flat industrial area. In reality, the facilities will be adapted to the conditions which exist at the specific site.

The industrial facilities will cover a certain surface area. In addition, there will be roads and railways to the deep repository. The land area will be used in connection with the start of the detailed characterizations. The total area needed is about 18 hectares (600 x 300 m) while about 15 hectares (500 x 300 m) are required for the reclamation area for waste rock which cannot be used for other purposes.

The industrial area is divided into four main areas, in principle:

- railway terminal,
- production area,
- service area,
- waste rock reclamation area.

If backfill material and transportation containers with the radioactive waste are transported by rail, they will be received at a railway terminal where there will be special facilities for offloading the transportation containers, sand and bentonite.

The production zone will contain a loading hall for transportation containers with waste, storage and production buildings for backfill material as well as buildings for ventilation, water and sewage. The access ramp/shaft to the repository will be located in the repository.

The service zone will contain areas for a large number of staff, such as offices, canteens, information buildings, maintenance and service workshops as well as garages and changing areas for the technicians working underground. This zone will face the access ramp and is a transition between the industrial area and the surrounding landscape.

Whenever excavated rock is not put to other uses, the waste rock will be stored near to the repository. The rock will be covered by moraine and trees will be planted. The exact design of the waste rock reclamation area will be determined by local conditions.

Transportation between the surface facilities and the repository level (about 500 m deep) can be designed according to three somewhat different alternatives:

- All transportation can take place via a long, sloping ramp. The lateral displacement between the surface section and the actual repository may amount to several kilometres.

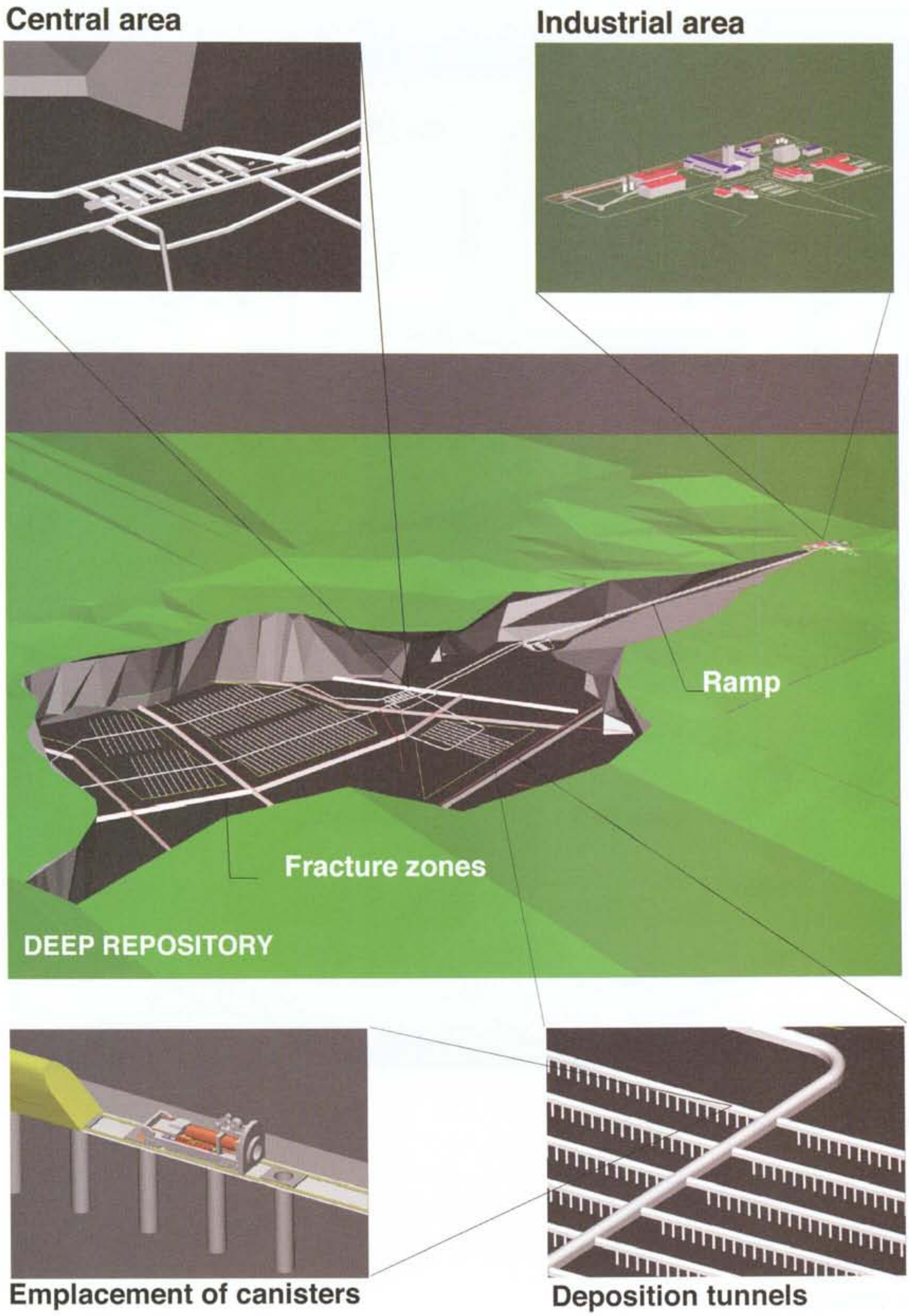

Figure 2-1. Schematic diagram of the layout of the deep repository.

Model of the industrial area

1. Operational building
2. Stores
3. Personnel areas
4. Offices
5. Information, canteen
6. Ventilation building

Figure 2-2. *Schematic diagram of the industrial area.*

- All transportation of heavy and unwieldy objects and materials can take place via a spiral ramp between the surface and the repository level. The shaft will be primarily used for personnel transportation and ventilation purposes.
- All transportation between the surface and the repository level can take place via a shaft.

In all three alternatives, the repository will be situated in an optimum position with regard to the long-term radiological safety and geological conditions. However, there may be good reasons to laterally offset the above-ground facilities in relation to the repository. For example, such a displacement may be required on account of nature conservation or other types of land use. It may also be required due to technical conditions such as land conditions, links with existing railways/roads etc.

During a site investigation, most of the site work will consist of rock drilling and borehole measurements as well as minor road construction.

During a detailed characterization, a ramp or shaft will be excavated to the repository level at a depth of about 500 m. The access route will be constructed and temporary buildings will be erected. Blasting will start with the central area of the underground area. Goods transported to and from the facility will consist of machinery, installation material and personnel as well as excavated rock.

After construction of the deep repository and waste deposition are completed, the extent of monitoring and control of the repository site can be individually decided by each generation. Closure of the repository entails the backfilling and sealing of tunnels and shafts. The repository will be designed to safeguard its security for a very long period of time even if monitoring and control ceases after closure. Before the repository is closed, it will have been possible to observe the first set of deposited canisters for a period of several decades. It will, therefore, be possible to ensure that the repository is performing as intended during the early stages. Before closure, it will be possible to retrieve the first set of deposited canisters and inspect them if additional verification is desired. After closure, the site will be restored, as far as is appropriate, to the conditions which existed before the repository was constructed. It is also possible that facilities for other kinds of activities can be constructed on the site. There will be no restrictions concerning use of the site for other purposes, with the exception of deep drilling or other types of deep rock engineering.

2.3 RESULTS FROM PREVIOUS SITE INVESTIGATIONS AND SITE SELECTION

In the background report to RD&D Programme 92, Siting of a deep repository /2-5/, SKB summarizes results from previous site investigations, see Figure 2-3. One statement which was made was: *"The reconnaissances for selecting the study sites which were conducted during 1979-1985 comprised general evaluations of almost 1,000 sites scattered all over Sweden. On the basis of geological and non-geological (landowner-related factors) siting factors, ten sites were selected as suitable for further investigation. Complete site investigations were carried out on eight of these sites. All the sites studied probably contain rock which is a suitable host for a repository. However, differences exist which make the sites more or less suitable."*

Some of the results from the site investigations have been applied within the KBS-3 project, where it was found that the Swedish nuclear fuel can be disposed

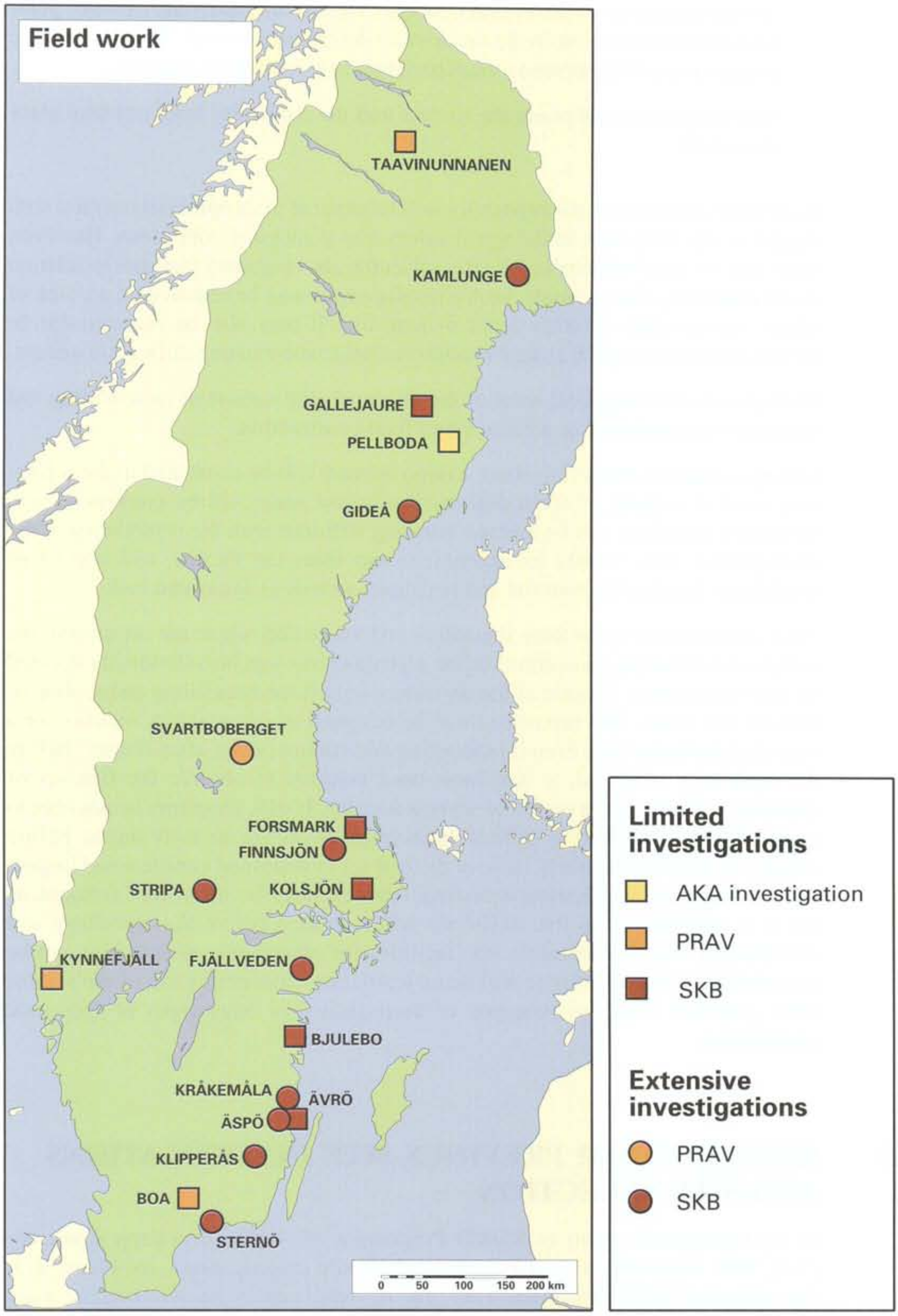

Figure 2-3. *Sites in Sweden where field work has been carried out within the Swedish nuclear waste programme to understand the properties of the Swedish bedrock and/or in order to evaluate and develop methodology.*

of in Sweden, in a way which satisfies high requirements on safety and radiation protection. Furthermore, it was stated that there were many sites in Sweden which are of the quality required for safe final disposal.

A similar conclusion is put forward by TVO, Finland which plans to construct a corresponding repository in bedrock which is similar to the Swedish bedrock. TVO has carried out site investigations at five sites and states /2-6/: *"In conclusion, it may be said that the bedrock properties of every one of the five sites investigated at this stage could provide suitable conditions for safe final disposal of the spent fuel and that there are no appreciable differences between them in this respect."*

In the background report to RD&D programme 92 /2-5/, SKB's experience from investigations and the siting of the Swedish interim storage facility for spent nuclear fuel (CLAB), the central repository for radioactive operational waste (SFR) and the Äspö Hard Rock Laboratory is reported.

SKB has also studied how site selection is carried out in other countries and has reached the following conclusions /2-5/:

- *"The siting process is heavily dependent upon the existing conditions in each country, especially those relating to the procedures for review by the authorities and the political decision-making process. Thus, great caution must be exercised when applying conclusions drawn from one country to another.*
- *If the focus of the siting work is flexible and pragmatic, starting from the fundamental criteria as regards safety, technology, environment, public opinion and local involvement, the possibilities of attaining good results are considerably greater than if detailed criteria and formal systems for, e.g. grading and screening sites, were used.*
- *Information to and cooperation with the municipalities and authorities concerned is important.*
- *Parallel detailed characterizations of several sites should be avoided. Instead, the investigations should be conducted sequentially, where the decision to continue or initiate investigations at a new site is taken on the basis of the results obtained."*

2.4 SITING WORK

A deep repository can, from the standpoint of siting, be considered to be a medium-sized industry with facilities above as well as below ground. This means that the site selection must take into consideration conditions above as well as below ground. The site must be selected so that a suitable site is found for the industrial facilities above ground and suitable bedrock for the facilities below ground. There must be a maximum of about 10 km between the two types of facilities so that they can be linked by an access ramp.

As far as conditions above ground are concerned, this type of siting is similar to the siting of conventional industrial facilities, which has to take into account nature conservation, land use, existing structure of industry etc.

Key issues for the underground facility are rock engineering conditions which affect the design and construction of the facility. This also includes collecting the necessary data so that the long-term function and radiological safety of the repository can be described. These data concern topics such as geology, groundwater flow, groundwater chemistry, rock stresses and rock strength.

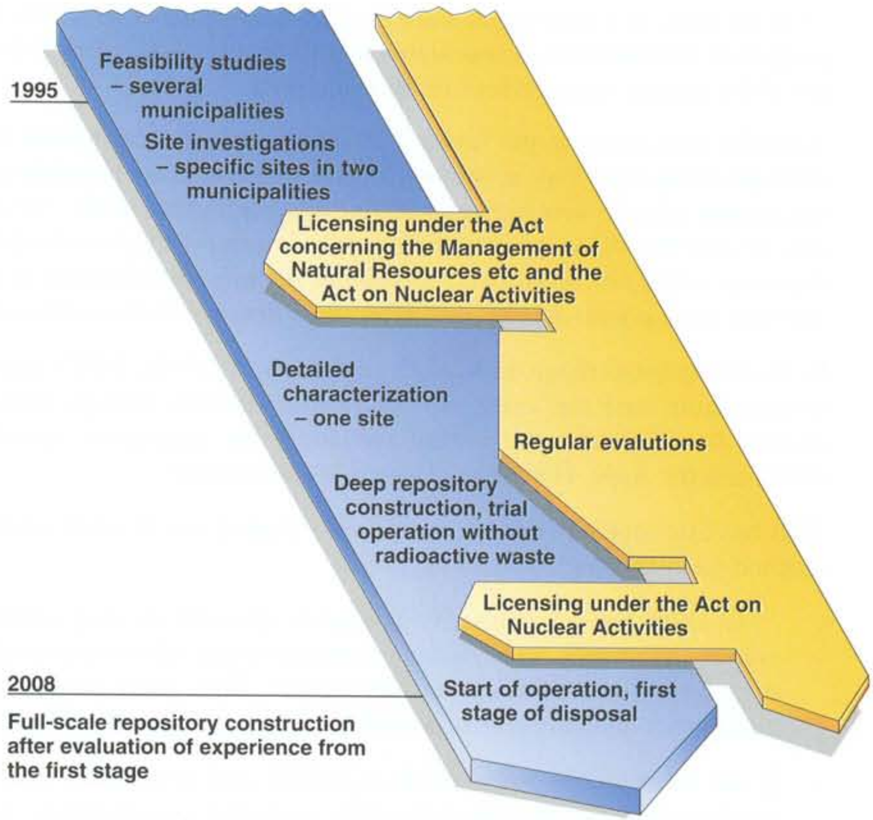

Figure 2-4. *Stages in the work on the siting, construction and commissioning of the deep repository.*

It is important to select a site where the safety-related conditions are very favourable. The structure of the siting work is based on the conviction that it is necessary and possible to identify a site which fulfils high environmental and safety-related requirements at the same time that the understanding of the local community which will host the repository is desirable. This approach is in good agreement with the intentions behind the applicable legislation in the Act concerning the Management of Natural Resources etc. and the Act on Nuclear Activities. The existing Swedish system with interim storage in CLAB also makes it possible to evaluate, in detail and without undue urgency, the possibilities of implementing deep disposal with the cooperation of the local community concerned.

The work on the siting, construction and operation of Sweden's deep repository will be accomplished in stages, see Figure 2-4. For further information on siting, see the RD&D Programme 92 Supplement /1-2/ and RD&D Programme 95 /1-5/.

The aim of the siting work is to prepare all of the information necessary in order to select a site and to obtain a permit in order to start detailed characterizations. This work will be carried out in several stages:

The general siting study. The results of the general siting study, general background information and general premises are compiled and presented in this report. The general siting study covers the whole of Sweden and large regions.

For a long time, SKB has compiled different kinds of factual information, including geoscientific factors. The geoscientific reports which, in broad terms, are parts of the background material for the general siting studies and which SKB has published within the framework of the R&D programme conducted since the mid-seventies, are summarized in Appendix 1.

One example of the general siting studies is as well the general siting study which has been carried out in municipalities with nuclear activities. In the siting work prior to the selection of a site for a deep repository for long-lived nuclear waste, it is reasonable that the premises for siting should also be studied in connection with the facilities where the waste was once generated. The infrastructure of these facilities and the extensive knowledge which is available at these facilities are positive factors for the siting of a deep repository. With regard to the survey which was compiled in the spring of 1995, the following statement was made, /2-7/:

"For Oskarshamn, Nyköping and Östhammar, the existing geological material is comprehensive and indicates that there is a possibility of good siting conditions. The material is also highly suitable to provide, in a feasibility study, a detailed evaluation of each municipality's geological conditions for the siting of a deep repository.

For these municipalities, SKB considers that it is of primary interest to carry out feasibility studies so that the basis for the siting of a deep repository is given the necessary breadth and additional information.

With regard to Varberg municipality, there is general uncertainty concerning the suitability of the bedrock. No modern geological map data are available for parts of the municipality. Thus, in order to obtain data of similar value compared with other nuclear municipalities, the data must be supplemented at an early stage by geological mapping and geophysical measurements. However, SKB considers that it is desirable that Varberg should also be included in the data and that the conditions can be better investigated through a feasibility study."

With regard to Kävlinge municipality, the following has been stated: *"Geological as well as technical conditions show that a siting of the deep repository in the municipality would be complicated. Thus, SKB believes that it is not of interest to carry out a feasibility study in Kävlinge municipality."*

As far as general siting studies are concerned, General Siting Study 95 is an overall report on investigations carried out to date. It is expected that the studies will have to be supplemented, especially in connection with the practical siting work carried out in the feasibility studies.

Feasibility studies are conducted to establish the conditions in potentially suitable and interested communities. The general land and environmental factors as well as societal factors are identified in relative detail in the feasibility studies. Evaluations of siting factors for safety and technology are based on general knowledge and general material. The feasibility study provides the basis for evaluating if and where areas exist with potentially good possibilities in the municipality. Geoscientific conditions, transportation-related issues and the impact on the local industry and community are analyzed and described.

One example of a feasibility study report, carried out on Storuman municipality, is provided in /1-4/. The feasibility study in Storuman is, therefore, a part of comprehensive and gradual work to compile a basis for the siting of the deep repository. SKB is planning to conduct 5-10 feasibility studies in different places in Sweden. Besides the feasibility study completed in Storuman (October 1995), feasibility studies are being carried out in the municipalities of Malå, Nyköping and Östhammar.

Site investigations are scheduled to be carried out at a later stage at least two sites in Sweden, in areas which, on the basis of the feasibility studies and general siting studies, are evaluated to be of particular interest. A site investigation means more extensive studies, including bedrock investigations in boreholes, and is estimated to take about four years. The safety-related and technical siting factors will be identified as far as possible. Supplementary information concerning local land and environmental factors will also be obtained.

When at least two supplementary site investigations have been carried out, all of the relevant material from the siting work will be compiled and included in an application for a siting permit under the Act concerning the Management of Natural Resources and the Act on Nuclear Activity. A licence will also be required under the Planning and Building Act etc. After the licences are granted, detailed characterization will be initiated and will involve constructing a tunnel or shaft down to the planned repository depth. The properties of the rock will be identified in detail.

The decisive factor for the selection of a site is that the requirements on safety can be fulfilled. The basis for selecting a site for a detailed characterization will, therefore, be evaluated by the competent authorities and the municipalities concerned, as a basis for the government's decision. As stated in /1-3/, the government considers a detailed characterization to be a *"stage in the construction of a nuclear installation which is intended to be a repository for spent nuclear fuel and nuclear waste."* Thus, a permit both under the Act concerning the Management of Natural Resources and the Act on Nuclear Activities, is required to conduct the detailed characterization.

2.5 FACTORS TO TAKE INTO ACCOUNT IN CONNECTION WITH THE SITING OF A DEEP REPOSITORY

This section describes important factors which are being taken into account in the ongoing work on the siting of the deep repository.

2.5.1 General

In 1993, the Nordic radiation protection and nuclear safety authorities published the report entitled "Disposal of High-level Radioactive Waste, Consideration of Some Basic Criteria" /2-8/. The report describes the basic requirements for the final disposal of high-level waste and focuses on the long-term safety-related aspects of a deep geological repository. Recommendations and considerations published by the International Commission on Radiological Protection (ICRP), Nuclear Energy Agency in OECD (NEA) and International Atomic Energy Agency (IAEA) have been taken into account in the report, see references in /2-8/.

In the report, site selection is classified into three stages: area survey, preliminary site selection and the site confirmation through detailed characterizations.

The report presents, in general, different siting factors and classifies them into three main groups. The first group contains aspects which concern the geological medium, such as geology, hydrogeology, geochemistry and long-term stability. The second group contains environmental factors such as the aquatic and terrestrial environments, agricultural and transportation aspects. The third group contains social, economic and political aspects, landowner-related factors, natural assets and the risk of future intrusion.

In the RD&D Programme 92 Supplement /1-2/, SKB described siting factors which cover the three main groups in the radiation protection and safety authorities classification but which are also more strongly related to the functional requirements on the deep repository:

Safety	Siting factors of importance for the long-term safety of the deep repository.
Technology	Siting factors of importance for the construction, performance and safe operation of the deep repository.
Land and Environment	Siting factors of importance for land use and general environmental impact.
Societal factors	Siting factors connected to the development of society and impact on society.

The review statements submitted by several authorities to the government support a continued detailed analysis and application of these siting factors. The Swedish Nuclear Power Inspectorate states in /2-4/:

- *" SKB's siting factors and criteria are a suitable point of departure for further work. However, the requirements must be continuously defined and quantified.*
- *In the initial stage (general siting studies and feasibility studies), many factors which are important to an assessment of the long-term safety of the facility and the design of the facility cannot be determined.*
- *Whether a certain site fulfils all of the basic safety requirements cannot be completely determined until site investigations and detailed characterisations have been carried out."*

The following statement was made in the government decision of May 18, 1995, in response to the RD&D Programme 92 Supplement:

"SKB has, in a detailed manner, presented its view on the criteria and methods to locate a suitable site for the deep repository, from different standpoints. In the view of the government, the siting factors and criteria described by SKB should be a point of departure for further siting work. The views put forward by KASAM, SKI, SSI, the National Housing Board, the Swedish Environmental Protection Agency, the Central Board of National Antiquities and the National Association of Local Authorities should be taken into account in the siting work."

Certain basic requirements must be fulfilled by a deep repository. These requirements primarily concern the long-term radiological safety and any other environmental impact. These requirements are defined in legislation and regulations from the authorities. Whether or not the requirements for a deep repository are fulfilled at a specific site will be determined in connection with the authorities' evaluation of the safety assessments and environmental impact statements compiled by SKB. Regardless of how the site selection has taken place, it is the result of such broad and detailed analyses of safety and environmental impact which ultimately determine whether the deep repository can be constructed at the particular site.

An overall evaluation of the long-term radiological safety, in particular, requires access to site-specific data concerning the bedrock conditions. Such data can only be obtained through extensive investigations carried out at sites which must be selected on the basis of partially incomplete information. This situation distinguishes the siting of underground facilities, in general and a deep repository, in particular, from the siting of other industrial facilities (surface facilities), where knowledge of many important factors is relatively easily available.

The precision in the identification of siting factors varies considerably depending upon the scale on which the studies are conducted. A deep repository will occupy a surface area on the order of one or two km^2. The possibility of identifying siting factors on different scales must be considered in the light of this. A limited number of factors can be illustrated on a national scale (general siting studies) in order to, primarily, if possible, exclude certain areas. However, it is a rule that only in connection with studies carried out on a scale corresponding to a study area of 100 x 100 km or less (feasibility studies) can the geographical variation for different siting factors be identified with such a level of resolution that it can provide any guidance in the selection of a suitable site. Furthermore, many of the properties of the bedrock which are essential for the safety of the deep repository may vary by several orders of magnitude, even over short distances. Generalizations on the general siting study level should, therefore, be made with great caution or should be avoided, see Chapter 3.

Finally, it is important to note that detailed criteria for the properties of the bedrock at a site cannot be dealt with in isolation from the design of the deep repository at the specific site. An important principle is to optimize the layout of the repository, both above and below ground, to the conditions which exist at the particular site. Requirements on environmental protection and safety will determine how the repository is adapted to the properties of the site. For example, the relative positioning of the surface and the underground facilities, the length of shafts and access ramps, the geometry and depth of the repository as well as the locations of the deposition positions.

In this report, SKB has refined the siting factors in some details.

A simplified diagram of the siting factors is presented in Figure 2-5. A more detailed diagram is presented in Appendix 3. Certain general comments are provided below.

2.5.2 Long-term radiological safety

This group of siting factors describes, in particular, factors which are of importance for the long-term radiological safety.

The basic safety philosophy for the deep repository is to completely contain and **isolate** the spent nuclear fuel in tight canisters which will be deposited at a depth of about 500 metres at the selected repository site. This isolation will be achieved and sustained for very long time spans to allow the radioactive elements to decay inside the canister and, thereby, prevent their release. This means that the most important safety-related function of the rock is to safeguard the engineered barriers and, to as far as possible, provide:

- a long-term, stable chemical environment,
- low groundwater flow,
- mechanical stability.

The safety of a deep repository is based upon the multi-barrier system. This means that the safety may not be exclusively dependent on the intended performance of a single barrier or exclusively dependent on the intended performance of all of the engineered barriers.

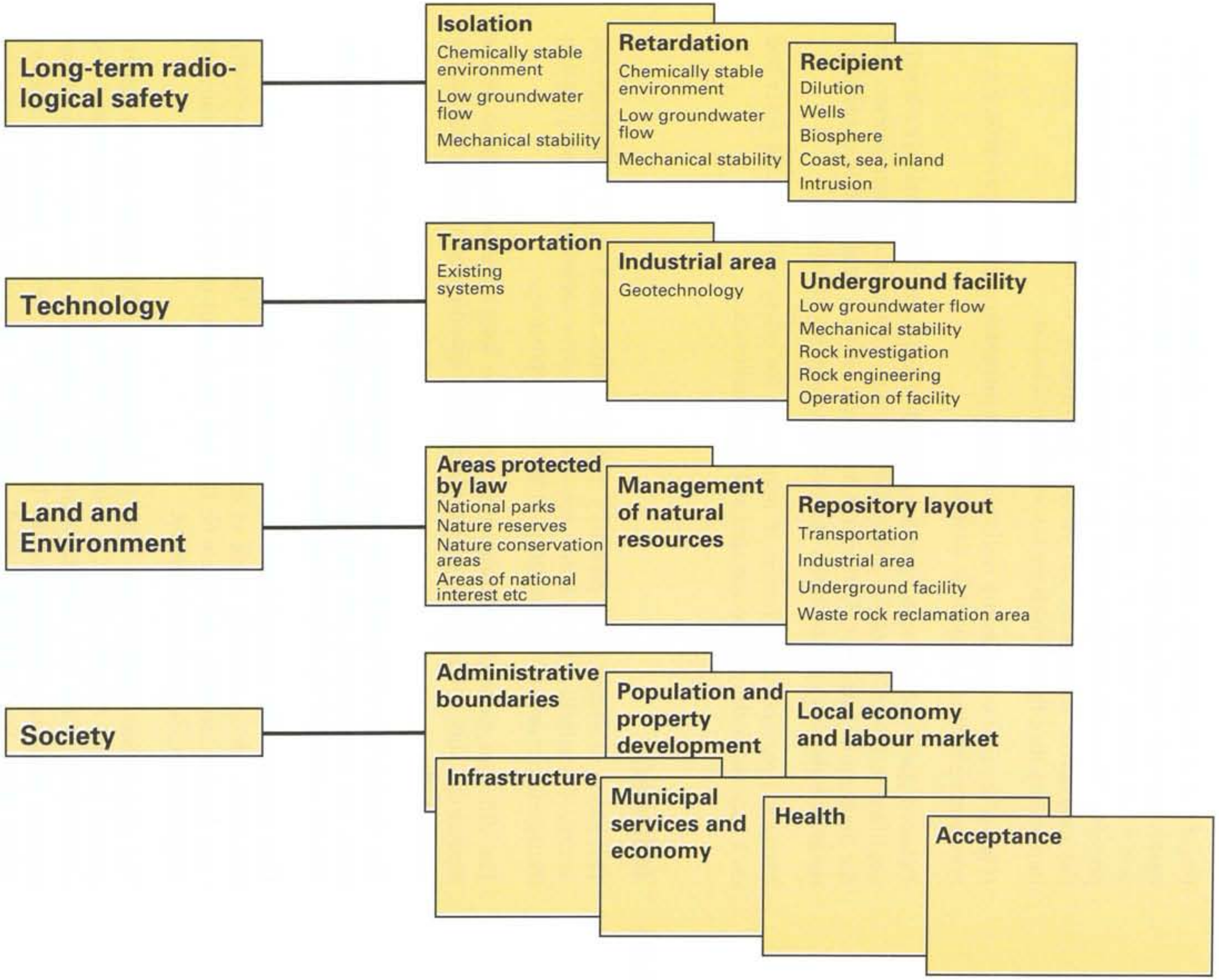

Figure 2-5. Diagram of siting factors.

An important safety-related function of the bedrock at a deep repository site is its ability to **retain** the radionuclides or **retard** radionuclide transport in the event of a failure of the engineered barriers.

The basic requirements on the rock are also, in this case, chemical stability, low groundwater flow and mechanical stability.

Finally, it is in principle, favourable to have **discharge area conditions** which ensure that only small quantities of any radioactive substances that may be released can reach human beings. It is desirable that the dilution should be as great as possible. Since the principle of the deep repository is based on the total isolation of the radioactive substances, the factors contributing to isolation are of greater importance than those which are favourable to dilution.

If possible, sites where future wells and future **intrusion** are more probable, e.g. in ore-bearing bedrock, should be avoided.

Detailed studies of isolation, retardation and discharge area conditions are a highly qualified technical-scientific undertaking. Several factors are of importance, see the diagram in Appendix 3, of which many can only be quantified in detail after measurements in deep boreholes at a possible deep repository site.

Chapter 4 presents a few factors of importance for safety which can be described on a national scale, such as ice ages and earthquakes etc.

2.5.3 Technology

This group of siting factors primarily includes issues which are of importance for technical feasibility. Part of this feasibility involves radiological safety during transportation and during operation of the deep repository.

The different technical solutions may affect the long-term performance of the repository. This is taken into account in the site-specific performance and safety assessments.

The alternatives which fulfil the basic requirements on safety, quality and feasibility can be compared with each other. This will occur at a stage when specific data are available for different alternatives.

With regard to the industrial and deposition area, no requirements are made other than those which normally occur at an industrial area. The land must have sufficient bearing capacity and must be flat and the layout of the facilities must be adapted to the external environment.

The underground facility must fulfil the elementary requirements for any underground facility. "Good rock", i.e. relatively low frequency of fractures and low conductivity of the rock, will facilitate the construction work and is also advantageous from the standpoint of the long-term safety of the repository. Factors which affect the construction work include the rock type, fracture frequency, position and character of the fracture zones, groundwater flow, the size and direction of rock stresses and mechanical properties of the host rock.

It is an advantage if the results of the bedrock investigations can be simply and unambiguously interpreted. This will facilitate the planning and implementation of the investigations, design, performance and safety assessment. No soil cover, or a very thin cover, simple and homogeneous bedrock conditions as well as a regular system of fractures/fracture zones will improve the level of reliability of the prognoses.

The technical solutions are flexible, as a rule, and they can be adapted to varying site conditions and bedrock properties.

The actual underground facility with tunnels, shafts and installations does not have to be directly connected to the industrial area, but can be located within a distance of about 10 km from the industrial area.

A schematic diagram is provided in Figure 2-6. Depending on the position of the deep repository site, it may also be necessary to construct a new road or railroad along a part of the stretch.

The different aspects of the transportation of the spent nuclear fuel must be taken into consideration when selecting the site of the deep repository. The requirement that the transportation of the spent fuel must be carried out in a safe manner can, as a rule, always be fulfilled, by adapting the technology and making the necessary investments. However, the costs may vary radically from site to site.

It is, of course, favourable, if the existing infrastructure for transportation by sea and on land can be utilized.

2.5.4 Land and environment

This group of siting factors describes issues of importance for land use and environmental adaptation.

Site selection and the layout of the facilities must be carried out so that any conflict with opposing interests is minimized. Nature, environment, cultural monuments, recreation, hunting, fishing and other outdoor activities, important natural resources, agriculture and forestry as well as existing and planned land use must be taken into account. Repository facilities and the transportation routes must blend in with the surrounding terrain. The environmental legislation requiring a comprehensive environmental impact statement with regard to construction projects also requires that, already during the siting work, the environmental impact of the facility should be balanced against the specific environmental conditions in the area.

Siting factors to be taken into account concerning land and environment are:

- Areas under legal protection such as national parks, nature reserves, nature conservation areas, etc.
- Management of natural resources, land, water, landscape, natural and cultural environments, agriculture and forestry, outdoor activities and tourism etc.
- The layout of the transportation system, industrial area, underground facilities and waste rock reclamation area which are adapted to the environment.

2.5.5 Society

This group of siting factors describes issues relating to the development of society and impact on society.

The societal conditions are important in the site selection process as well as in the layout of the facilities at the selected site. The establishment and operation of a deep repository will in several ways impacts on the community and the region. This includes the impact on employment, local economy and local services. In terms of politics and public opinion, it is also important that the repository should be viewed as an asset to society, also for the host community.

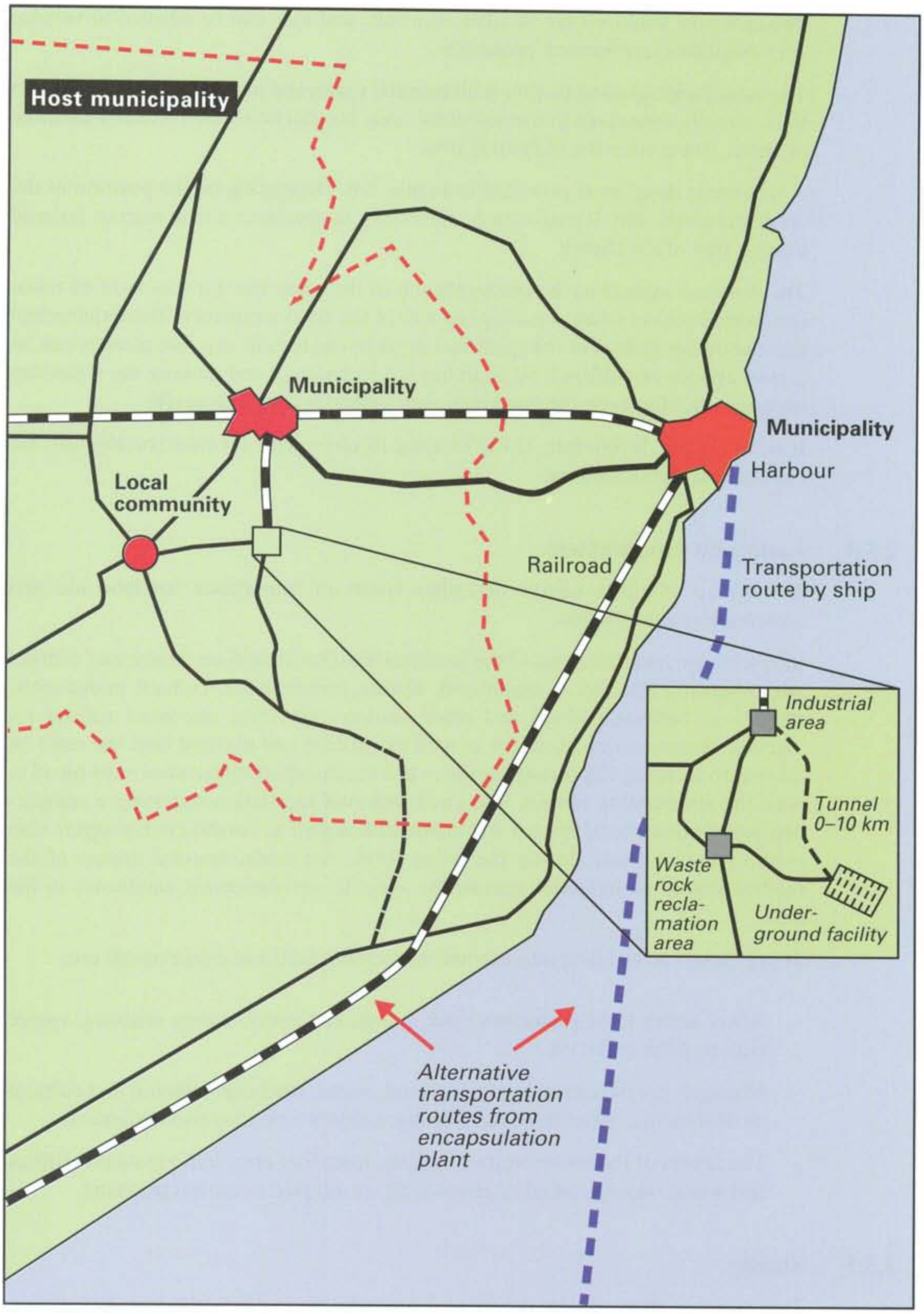

Figure 2-6. *Schematic diagram of the siting of the industrial area, underground facility and waste rock reclamation area. Not according to scale.*

The siting factors to be taken into account include:

- administrative boundaries,
- population and extent of property development,
- local economy and labour market,
- infrastructure,
- municipal services and economy,
- health,
- acceptance.

2.5.6 Application of siting factors

The factors and criteria discussed in the previous section must be weighed up in connection with the overall evaluation of a selected site. Many factors which are important in order to analyze, in detail, the long-term safety and factors relating to the design of the disposal system and rock engineering cannot be confirmed before extensive investigations have been carried out on site. Initially, assessments will have to be based on general knowledge of the region and bedrock as well as on general observations on the selected area. Since the identification of general land-related and environmental factors as well as societal factors is simpler to do at an early stage, these siting factors can be more completely clarified to begin with.

A description of how the siting factors can be applied in the initial siting stage is provided in the RD&D Programme 92 Supplement /1-2/, where it is stated that key questions to be considered in the initial siting stage are:

- *"Which sites have particularly good chances of meeting the requirement with regard to safety, technology, land and environment as well as societal aspects?*
- *Which of these sites offer good opportunities for later carrying out a reliable characterization of, above all, the important environmental and safety factors?*
- *How can these sites be identified based on existing material?*

The following conditions are thereby primarily favourable (give a "good prognosis") for the selection of study sites:

- *A common rock type without interest for other utilization of natural resources. This gives good prospects for obtaining a good understanding of safety-related bedrock conditions and it reduces the risk that the area will be of interest for other use in the future.*
- *A large site with few major fracture zones. This provides extra flexibility in connection with coming investigations and improves the prospects of being able to construct a repository with room for the necessary number of canister positions in sound rock with a high level of safety.*
- *Few opposing land-use and environmental interests. Good prospects for adapting the facilities so that the environmental requirements are met in a satisfactory fashion."*

In the initial siting stage, i.e. without any data from field investigations, the evaluation of the geoscientific data will focus on identifying unsuitable or unfavourable conditions on the basis of generally available information, cf /2-9/. In the final stage of the feasibility studies, areas will be identified which, on the basis of the overall criteria presented above, are considered to warrant closer investigation (site investigation).

In the subsequent stages, in connection with the site investigations and, gradually, also detailed characterizations, the work will gradually focus on identifying the conditions which will exist for the deep disposal system, as a whole, for the different parts of the deep disposal system and finally, for the individual canister positions.

3 POSSIBILITIES AND LIMITATIONS IN NATIONAL GENERAL SITING STUDIES

The extent to which conclusions can be drawn from general siting studies and how they can be applied to the siting of a deep repository are presented in this chapter.

3.1 GENERAL DESCRIPTION OF METHODOLOGY

Within the framework of the work on the siting of the deep repository, SKB has compiled geoscientific and societal data and conditions in databases which cover the whole of Sweden. These data can be processed, summarized and presented in a geographical information system – GIS. The system is used to store, present and analyze data for different siting factors. A list of commercially available databases which have currently been purchased and added to SKB's GIS is provided in Appendix 4. Several of the pictures in this report are based on this tool.

As far as possible, this report is based on information which is already available. Surveys are included in the new Swedish National Atlas, the volumes on Geology, Environment, Infrastructure and Population. Certain data are also included in SKB's technical reports which show results from the extensive research and development work which is being carried out at universities and institutes of technology, on behalf of SKB. This information has been further processed sometimes in order to be able to explore conditions which will be significant in connection with the siting of the deep repository.

This general siting study presents information on a national scale. It is, therefore, very important to remember that all details cannot be included. A hypothetical example is provided. For a certain siting factor, there may be regions which appear to be favourable, on the national scale, and others which appear to be less favourable, Figure 3-1.

Data, and in particular, geoscientific data, generally show considerable variations. This means that there may be favourable conditions due to a certain siting factor in areas within a region which, on a national scale, is considered to be unfavourable, taking into account the siting factor which has been studied. It may also be that there are areas with unfavourable conditions within regions which, on a national scale, are considered to be favourable.

A general conclusion is that, it is not obvious to completely exclude areas or regions which, on a national scale, appear to be less favourable.

A concrete example from an initial siting study in Laisvall illustrates this conclusion and is reported below:

3.2 EXAMPLES FROM THE LAISVALL MINE

The Laisvall mine is situated 34 km west of Arjeplog in the county of Norrbotten. The mine is located in the rock types of the mountain range, some kilometres from the margin with outcropping bedrock. The ore, which consists of galena (lead) and

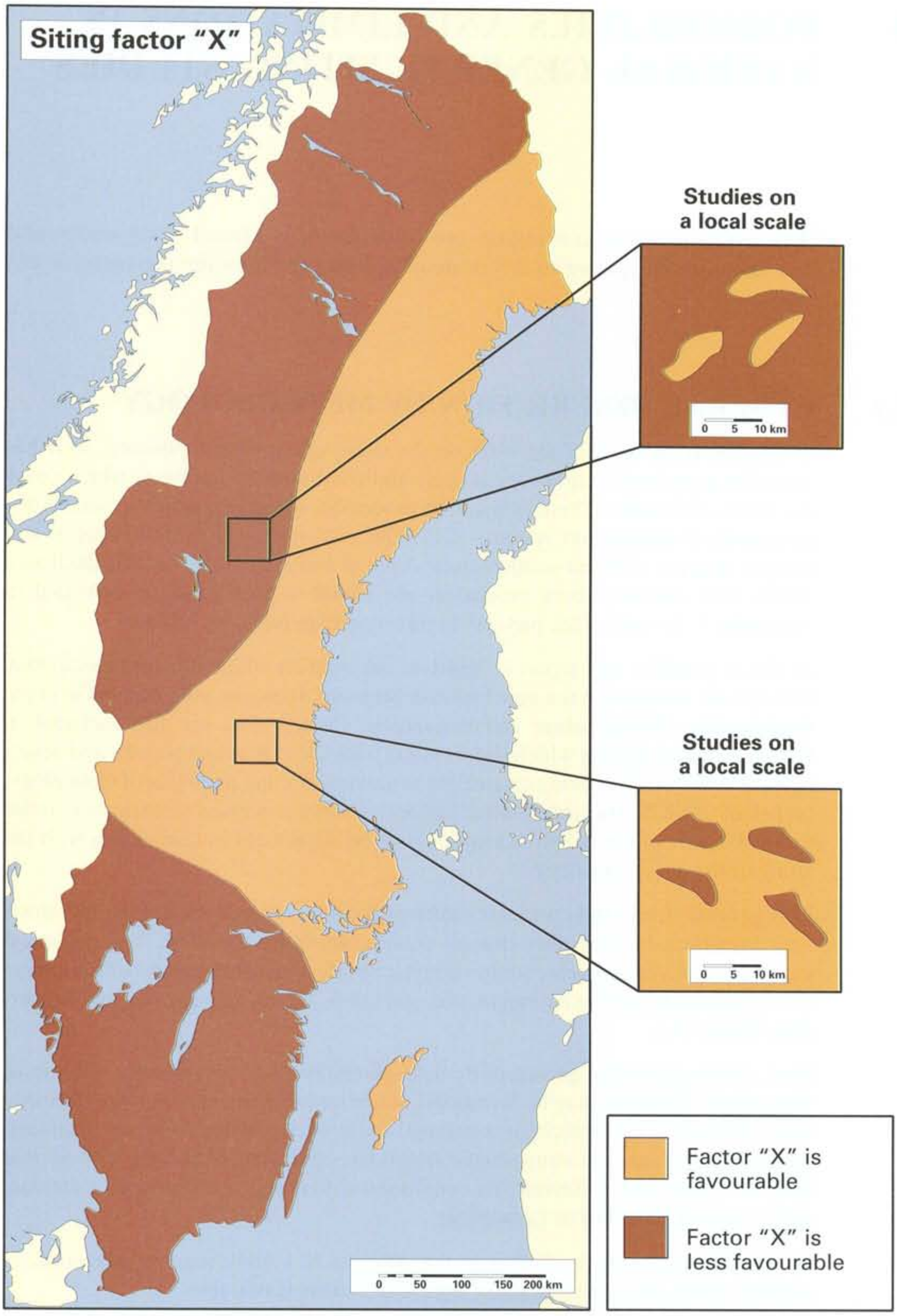

Figure 3-1. *Examples which illustrate that a siting factor "X" may be favourable in certain regions and less favourable in others. Studies on a more local scale may show that there are areas of interest in regions which, on the national scale, appear to be less interesting, and vice versa.*

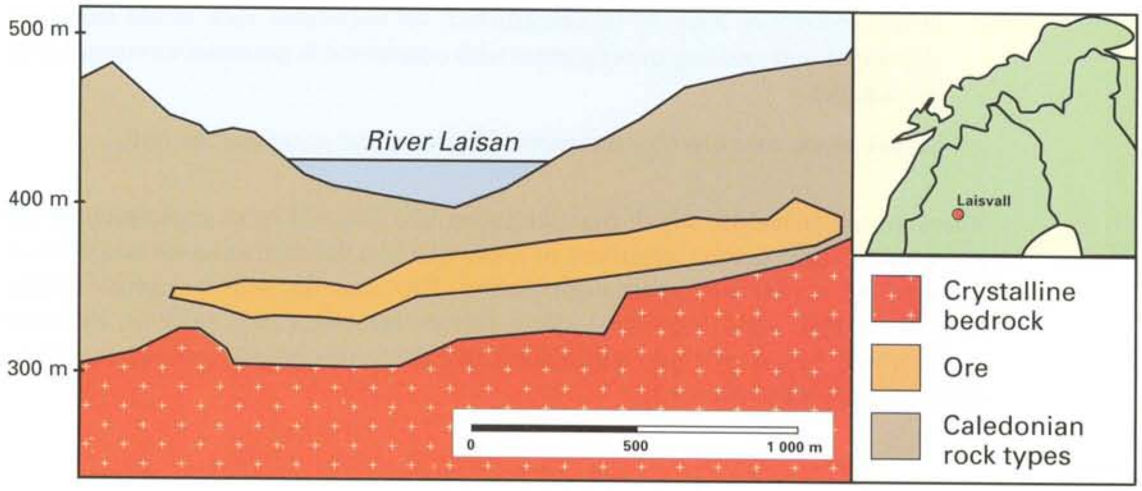

Figure 3-2. *Vertical profile through the ore area in Laisvall. Based on /3-1/.*

sphalerite (zinc), is located in an almost horizontal sequence of claystone and sandstone. The bedrock is located under these horizons. An east-west profile through the Laisvall area is shown in Figure 3-2.

When dissolved ore penetrated into the sandstone, the porosity of the sandstone was 25–30%. The pressure drop which occurred when the solution penetrated into the sandstone caused precipitation of the galena in pores and fractures.

On the basis of the knowledge currently available, a deep repository, 500 m deep in the underlying bedrock could be located in "ore-free" bedrock without any risk of presenting an obstacle to future ore mining or without any risk of human intrusion.

A superficial overall evaluation of Laisvall as a possible repository site reveals several obvious disadvantages:

- Laisvall is in an area with ore potential and with an established mine.
- It is located at the edge of the mountain range in an area where there is strong justification for nature conservation.
- The transportation distance to the site is lengthy.

The possibility of siting the repository at Laisvall was discussed with SKB by the mine management at the time and Arjeplogsgruppen during the spring of 1992. A closer evaluation also showed possibilities and obvious advantages:

- Bedrock without ore mineralizations can probably be found at greater depths, in accordance with the statement above.
- The existing mining area would provide a good opportunity to investigate the underlying bedrock.
- There is an established industrial area and an active mining community at the mine.

- If the repository were to be constructed, all excavated rock could easily be deposited into existing mining areas with considerable potential environmental advantages.
- Heavy loads are currently transported between the mine and the cost.

There are other factors which must be taken into account in an evaluation of the potential of siting a deep repository at Laisvall and a detailed analysis could result in a positive as well as a negative conclusion. The aim of the above example is only to indicate that when individual siting factors are taken into account, in many cases, it may be many local conditions which determine whether or not an area is suitable for a deep repository.

3.3 GENERALIZATION OF GEOSCIENTIFIC FACTORS ON DIFFERENT SCALES

Several of the siting factors concern geoscientific conditions. There are a few general problems which have to be paid particular attention in this context.

One problem is the scale on which the study has been conducted. A description on a national scale cannot describe the variations in the bedrock which exist for different geological factors.

Furthermore, the surface-based databases which can be described on a national scale primarily concern the conditions on the surface, while it is primarily the conditions at a depth of 500 m which are of interest.

A third problem is that specific data concerning, e.g. the chemical environment of the bedrock can only be obtained through field measurements. Data from great depths in Sweden are severely limited and originate primarily from the field investigations which were previously conducted within the nuclear waste management programme, see Figure 2-3. These data represent a certain position in a borehole and cannot simply be generalized to cover an entire site, much less an entire area or region.

A fourth problem is that results from different investigations often provide indications, i.e. indirect or incomplete information, concerning the factors about which information is required. This is often the case with, e.g. geophysical measurements.

Examples of generalizations of geoscientific factors are reported below.

3.3.1 Fracture zones and lineaments

The rock is intersected by fracture zones (i.e. areas where the frequency of fractures in the rock is greater than in the surrounding rock. These fracture zones can be found on all scales, from the local scale, with a longitudinal extension of a few hundred metres, to the regional scale, with an extension of 500 km or more.

In addition to the fact that fracture zones are mechanical planes of weakness in the bedrock, they may be water permeable and may become groundwater flowpaths. This means that data on these zones must be acquired for the repository design and safety assessment.

In order to establish the occurrence of fracture zones, lineament interpretations are used. A lineament is an interpreted line (straight or slightly curved) on a photographic, topographical, geological or geophysical map. Lineaments in landscape, e.g. valleys, bogs, scarps in the terrain and distinct straight shorelines often correspond to distinct fracture lines (faults and fracture zones) in the underlying bedrock. Experience from rock engineering largely supports these assumptions.

A few examples of lineament interpretations on different scales and based on different data are provided below.

Examples from the Baltic-Bothnian deformation zone

Parts of the Swedish bedrock have, during the pre-cambrian period (more than 570 million years ago) been exposed to very large rock movements during which wide and distinct deformation zones were formed. These deformation zones either consist of a single zone or a more complex zone where several smaller zones form a coherent network. One well-known example of a complex deformation zone is the Protogine Zone stretching from the region of Skåne via Vättern to Värmland. A map of complex deformation zones in Sweden is provided in Figure 3-3.

One of the more distinct zones which have been interpreted during the past stretches in a North-South direction from the Arctic Ocean through eastern Norrbotten and further south. This zone is called the Baltic-Bothnian deformation zone. The main activity occurred about 1,800 million years ago when lateral fault movements of up to 250 km could have occurred along this zone /3-2/. Within the zone, there are highly metamorphic sections and mylonites (fine-grained rock types formed through the deformation of the bedrock in the deformation zones) interspersed with large sections of unaffected rock.

Estimates of the width of the Baltic-Bothnian zone varies but, based on the geological mapping and the airborne magnetic maps, it can be estimated at between 5-10 km on the Kalix NW map sheet /3-4/.

Within the framework of study site investigations, SKB undertook drilling and investigations at Kamlunge from 1981–1983 /3-5/. The Kamlunge study site is located in the central part of the Baltic-Bothnian zone, Figure 3-4. At the time of the study site investigations, this zone was not known. The result from the investigation can now be used to study the impact that the zone has had on the bedrock at Kamlunge.

The study site is situated at Kamlungekölen, a rock area which is about 16 km^2 large and which rises above the surrounding region. The difference in elevation compared with the surrounding valleys is about 100 m. These valleys represent distinct lineaments where large rock movements have probably occurred /3-4, 3-6, 3-7/.

On Kamlungekölen, an extensive investigation programme was carried out which comprises 16 cored boreholes with a total borehole length of 7,800 m and a maximum depth of 670 m, Figure 3-5. The permeability of the bedrock has been studied in these holes. Apart from a minor, horizontal zone, 450 m in depth, the investigations have not been able to show any fracture zones within a rock volume of about 0.7 km^3 in the central part of the area. The fracture frequency was low, in general, below 200 metres deep. In this part, the permeability of the rock was also very low. Altogether, the investigations show that there are large rock volumes with little or no fractures and low-conductive bedrock. It has not been possible to prove any negative impact of the central position in the Baltic-Bothnian zone. On the contrary, from the hydrogeological standpoint, Kamlunge appears to be one of the better of SKB's study sites.

The example illustrates that an area which does not appear to be so favourable with regard to the factor "deformation zones" cannot directly be excluded in connection with a siting study on a national scale.

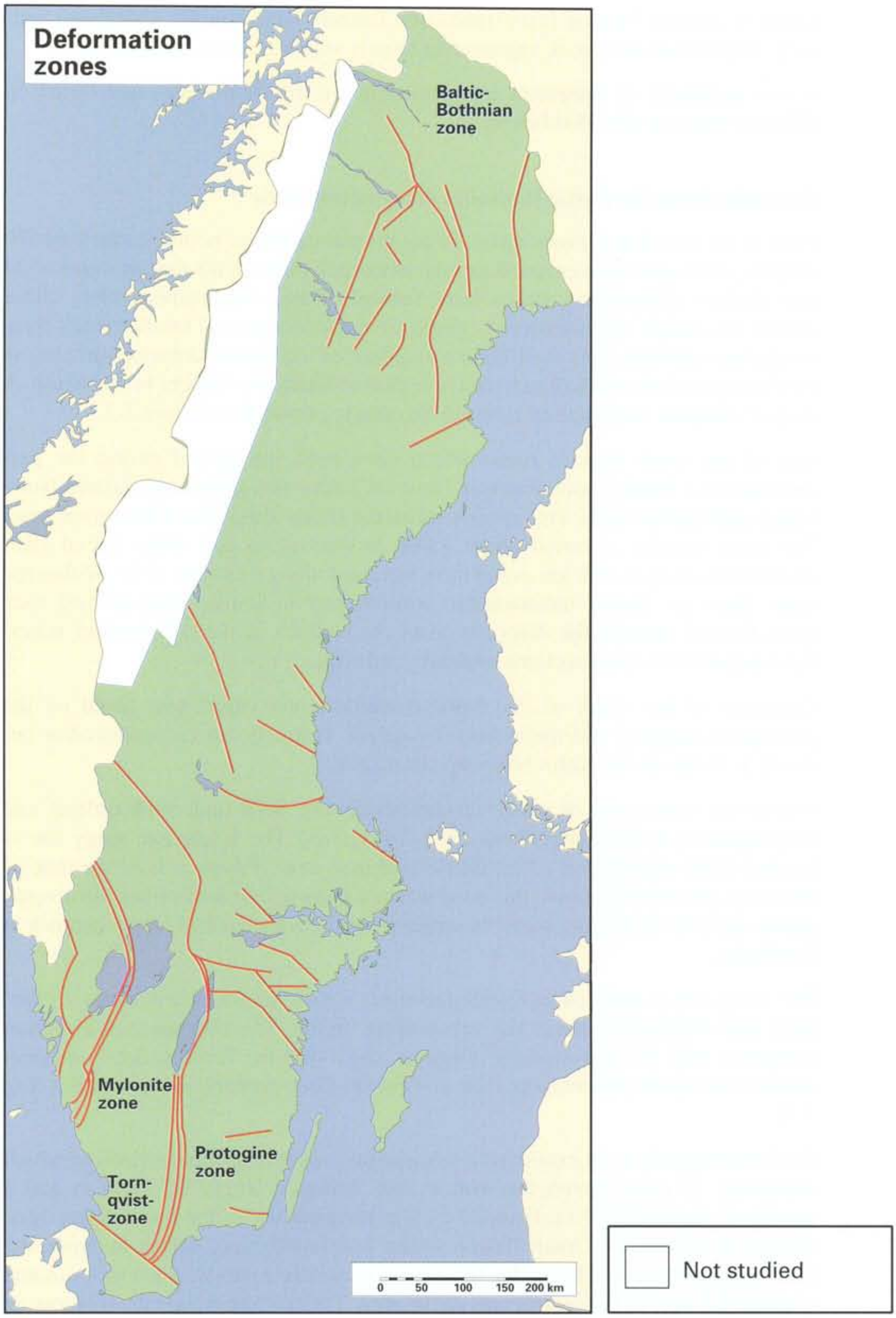

Figure 3-3. Map of complex deformation zones in Sweden. Based a map from the Swedish Geological Survey /3-3/.

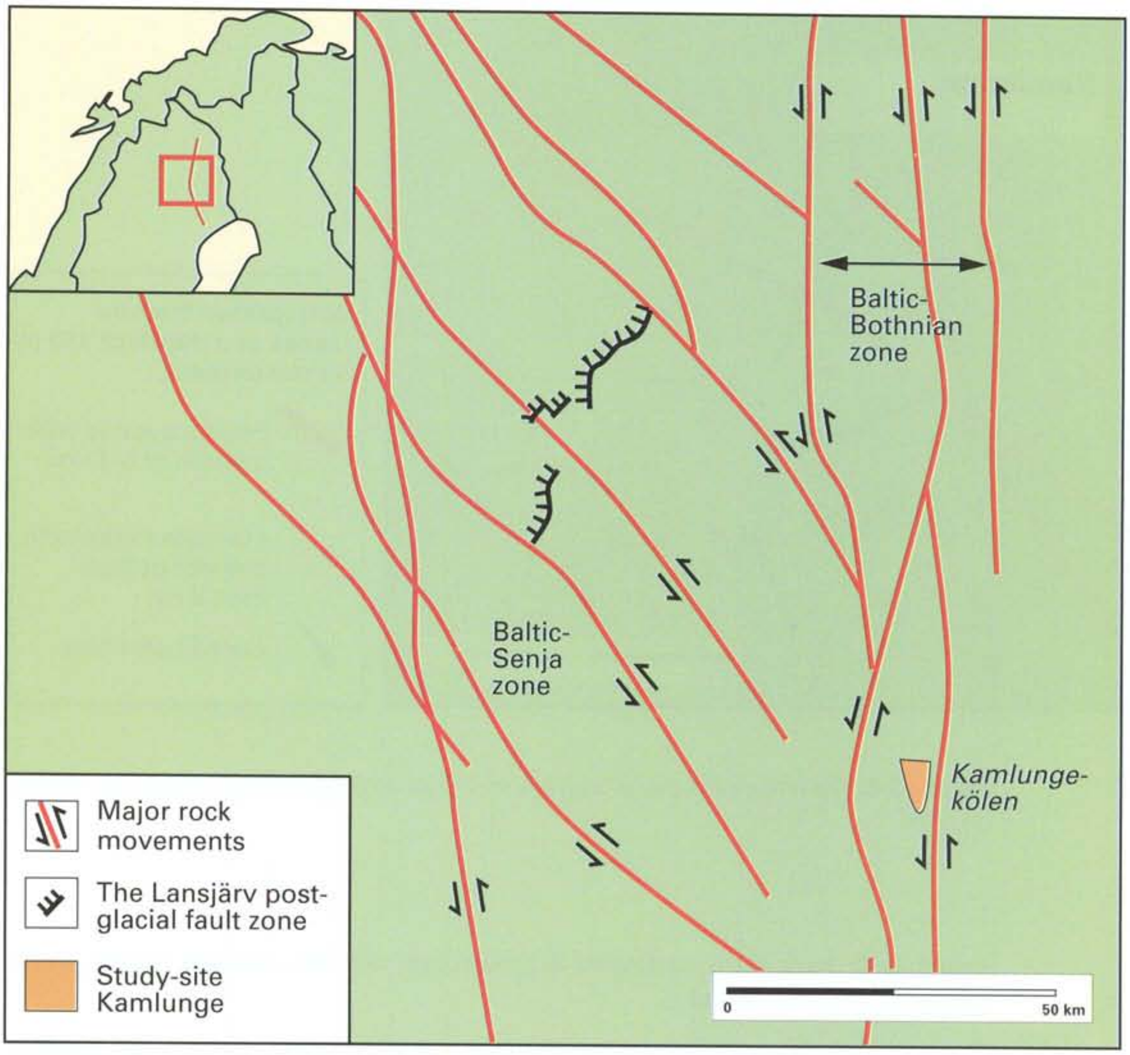

Figure 3-4. Location of the Kamlunge study site in relation to the Baltic-Bothnian deformation zone. Based on /3-6/.

Example from Äspö

Figure 3-6 shows an interpretation of lineaments in the region around Äspö, based on the National Land Survey's elevation database with 50 m grid. According to this interpretation, there are three fracture zones in an east-west direction on Äspö as well as a zone in a north-south direction.

Figure 3-7 shows a lineament interpretation of the airborne magnetic map from the above-mentioned region. There appear to be strong indications that Äspö is intersected by a regional northeastern fracture zone.

Through extensive studies involving ground geophysical measurements and borehole measurements, a considerably more detailed view has emerged concerning the locations of the fracture zones on Äspö and their water-bearing and mechanical properties. The resulting fracture zone map, after all land and borehole investigations were completed, is shown in Figure 3-8.

It would appear that the picture is now different, compared to the findings of regional-scale studies. Some of the lineaments which were interpreted on a re-

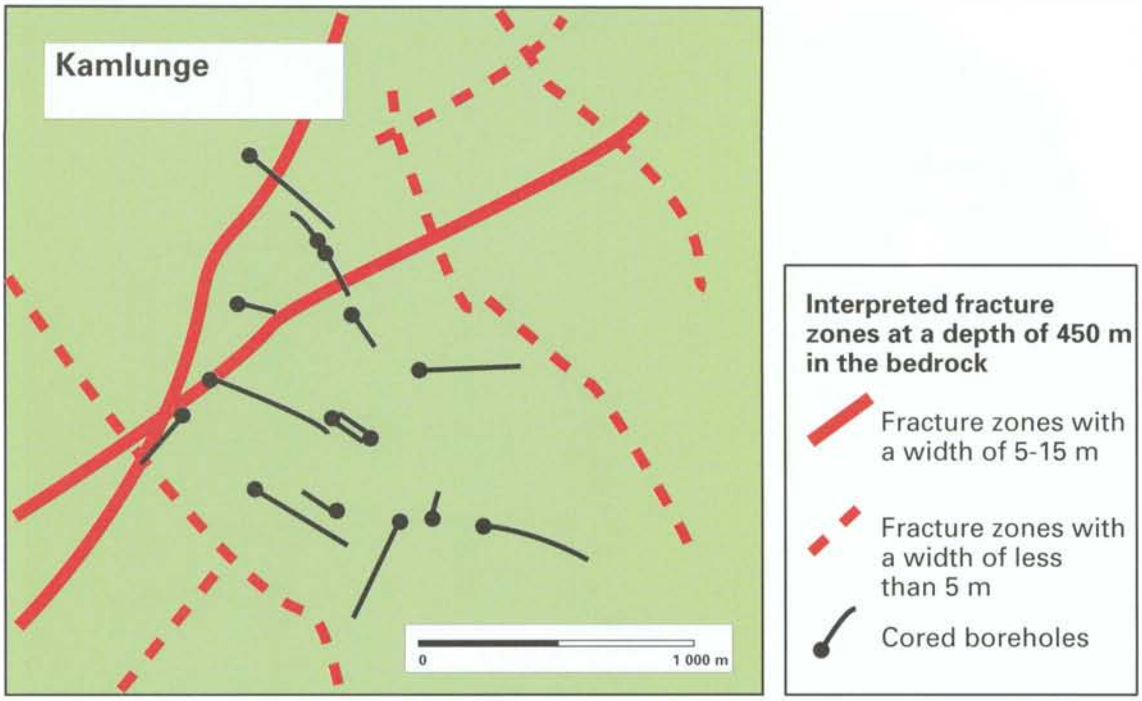

Figure 3-5. *Interpreted zones at a depth of 450 m at the Kamlunge study site. Based on /3-5/.*

gional scale have been confirmed in connection with the detailed studies while others have been rejected.

The very prominent EW-1 zone on the map, which is very visible in the regional interpretations, has been found, through further investigations at Äspö, to be a relatively low-conductive zone containing some mylonite. Several fracture ones have also been added, including several less marked but water-permeable fracture zones in a NNW direction. These zones are not marked on the map. They were identified, but the exact positions of each of these smaller zones were not established in the site investigations.

During the subsequent tunnel driving at Äspö, it was found that the fracture zone which posed the largest problems, from the standpoint of rock engineering, with considerable water inflow and clay metamorphic rock, was the fracture zone (NE-1) on the southern shore of Äspö. A hint of such a zone can be found on the airborne geophysical map.

The conclusion is that lineament studies on a regional scale are important in order to obtain an initial indication of the occurrence of fracture zones, and thereby, to also determine the locations of large blocks of bedrock which contain few or no fracture zones. At the same time, results from such studies must be considered in a cautious light, especially with regard to the correlation between how distinct a lineament is on topographical or geophysical maps and the actual importance of the lineament from the standpoint of constructability or safety.

The example illustrates the fact that it is only in connection with feasibility studies and site investigations that the significance of lineaments can be determined.

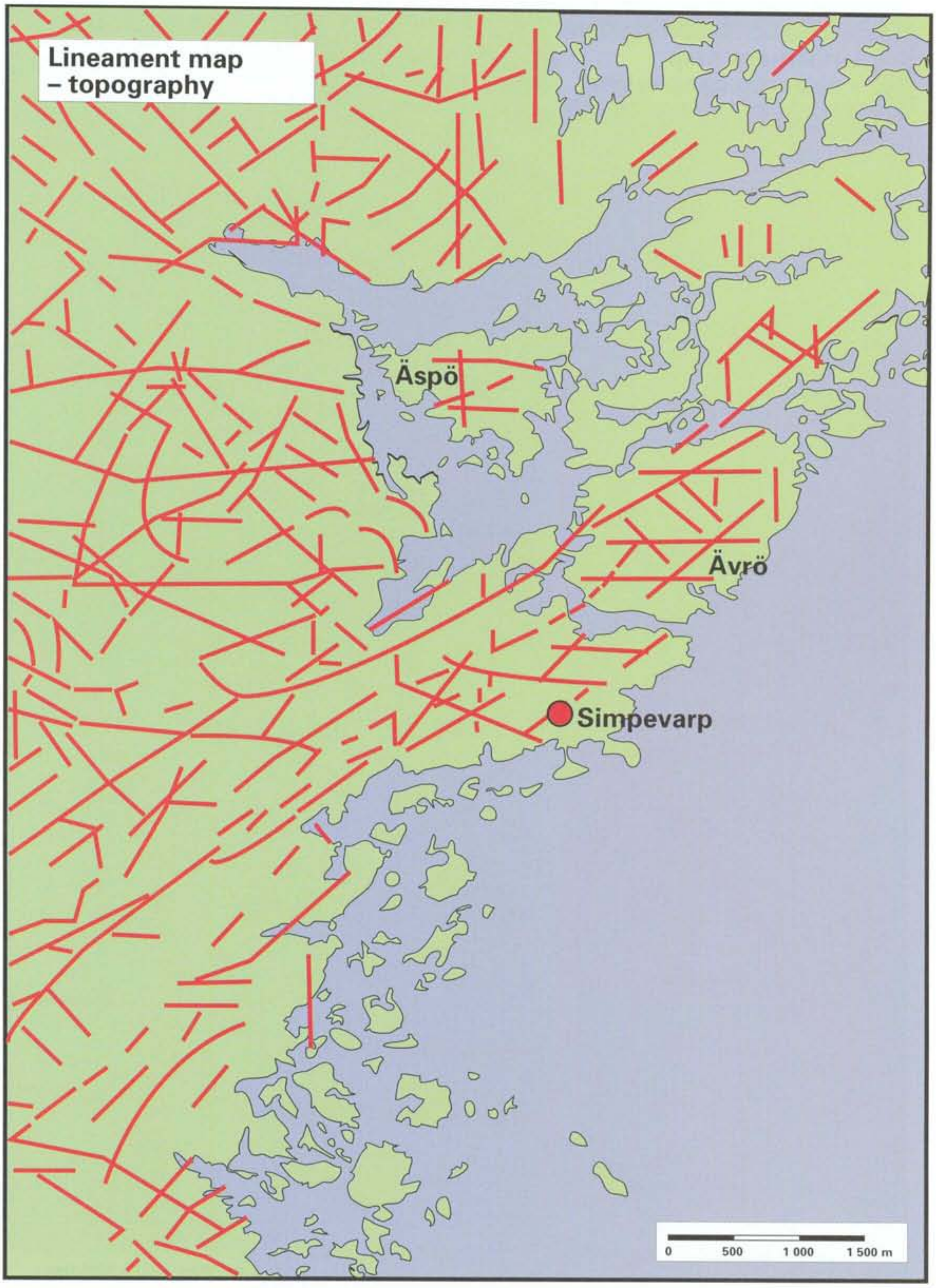

Figure 3-6. *Lineament interpretation based on topography. Based on /3-8/.*

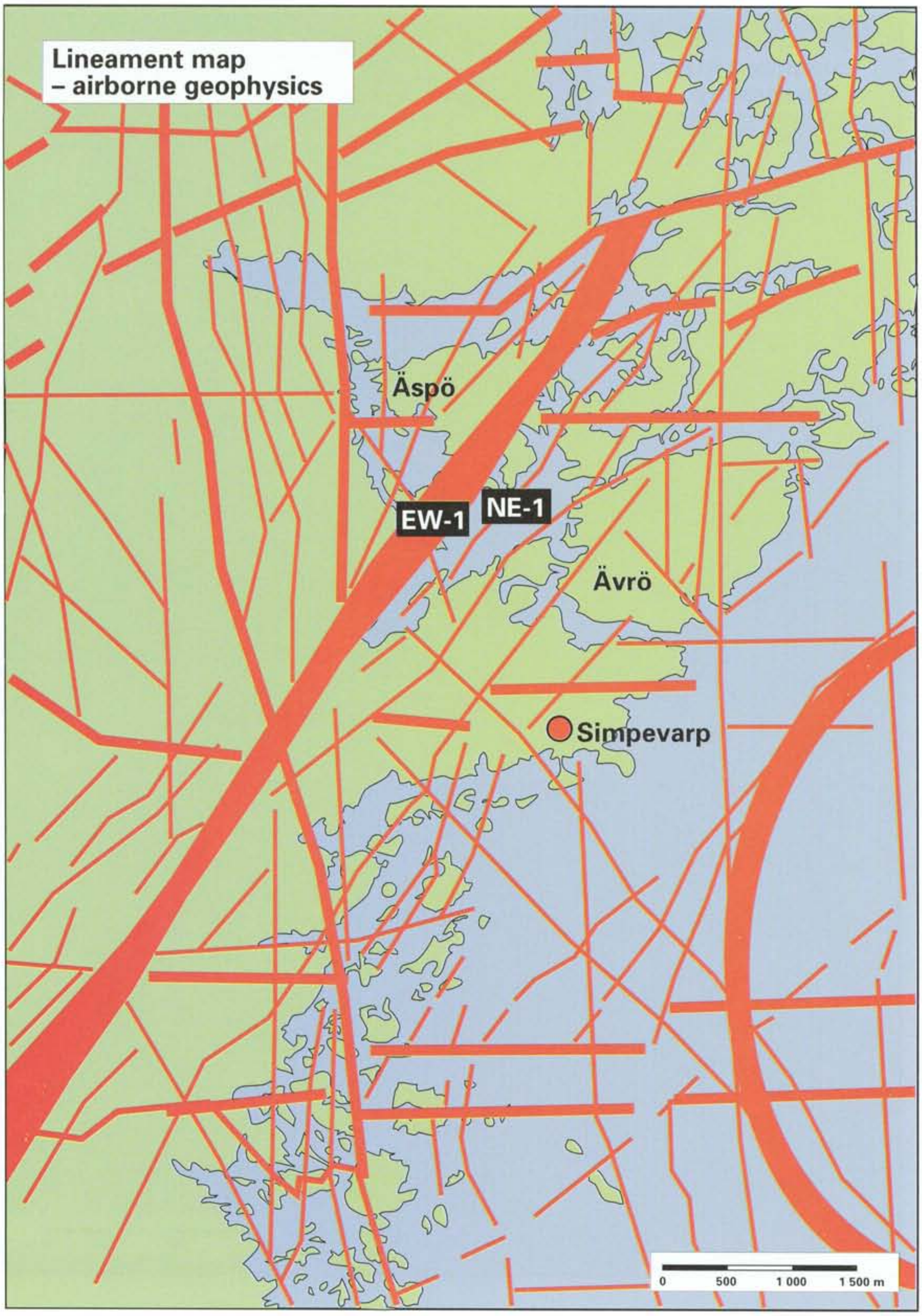

Figure 3-7. *Lineament interpretation based on airborne geophysics. Based on /3-9/.*

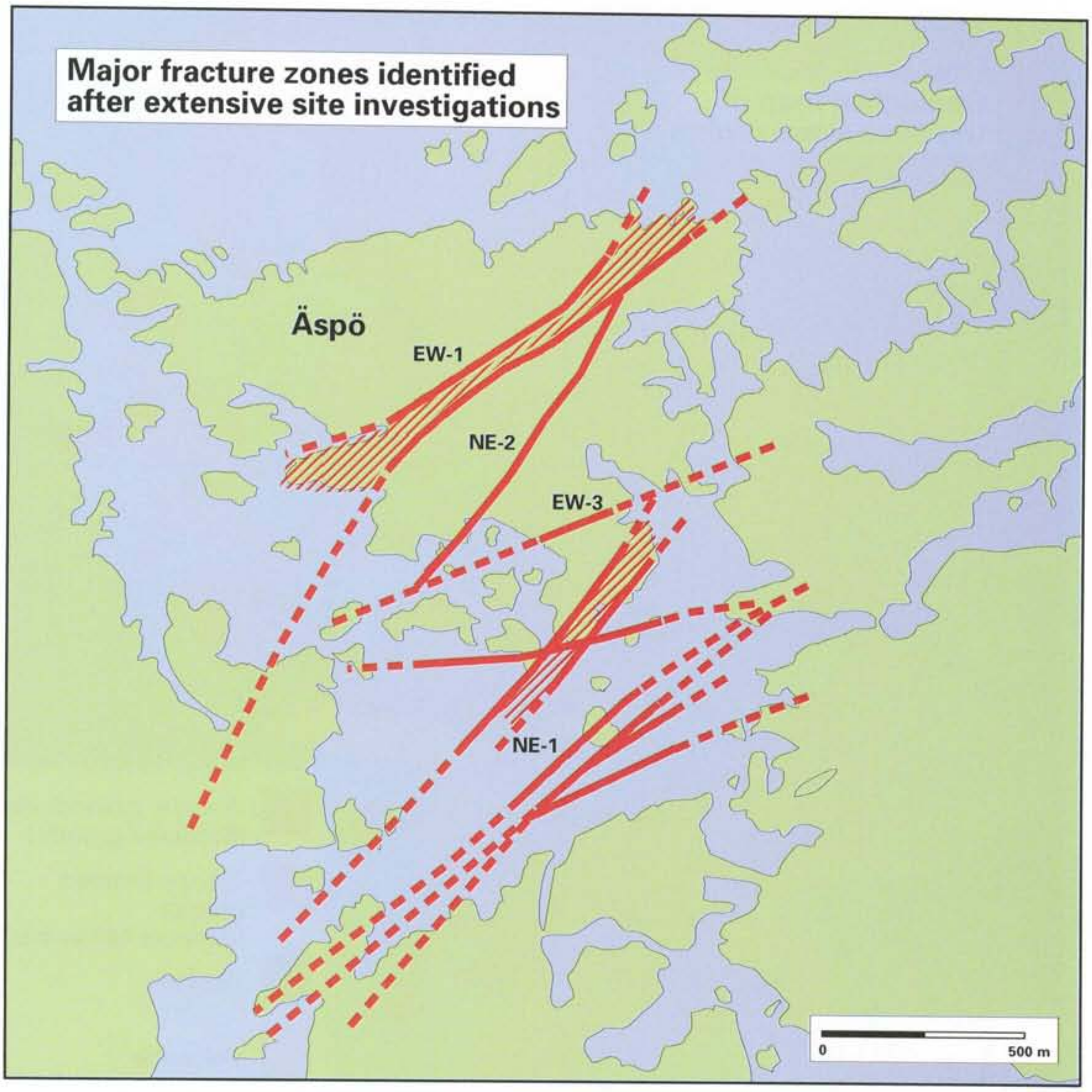

Figure 3-8. Interpretation of zones based on extensive site investigations. Based on /3-10/.

3.3.2 Rock types

Field observations of rock type distributions in outcrop surfaces are generalized in order to draw a geological map. A map of the bedrock, on a national scale, will have to be more generalized than a map on a local scale. Thus, it is difficult to estimate the variations of the bedrock, on the basis of general siting studies. The investigations for a deep repository are gradually being carried out and the level of detail is gradually increasing with each stage. The "dress-rehearsal" which was held in connection with the construction of the Äspö Hard Rock Laboratory can illustrate how the level of detail in the bedrock data has increased at different investigation stages.

The first figure, Figure 3-9, shows a detail from the bedrock map available at the start of the investigations in 1987. On this scale, it was possible to include a large section of greenstone in the northeastern corner of Äspö.

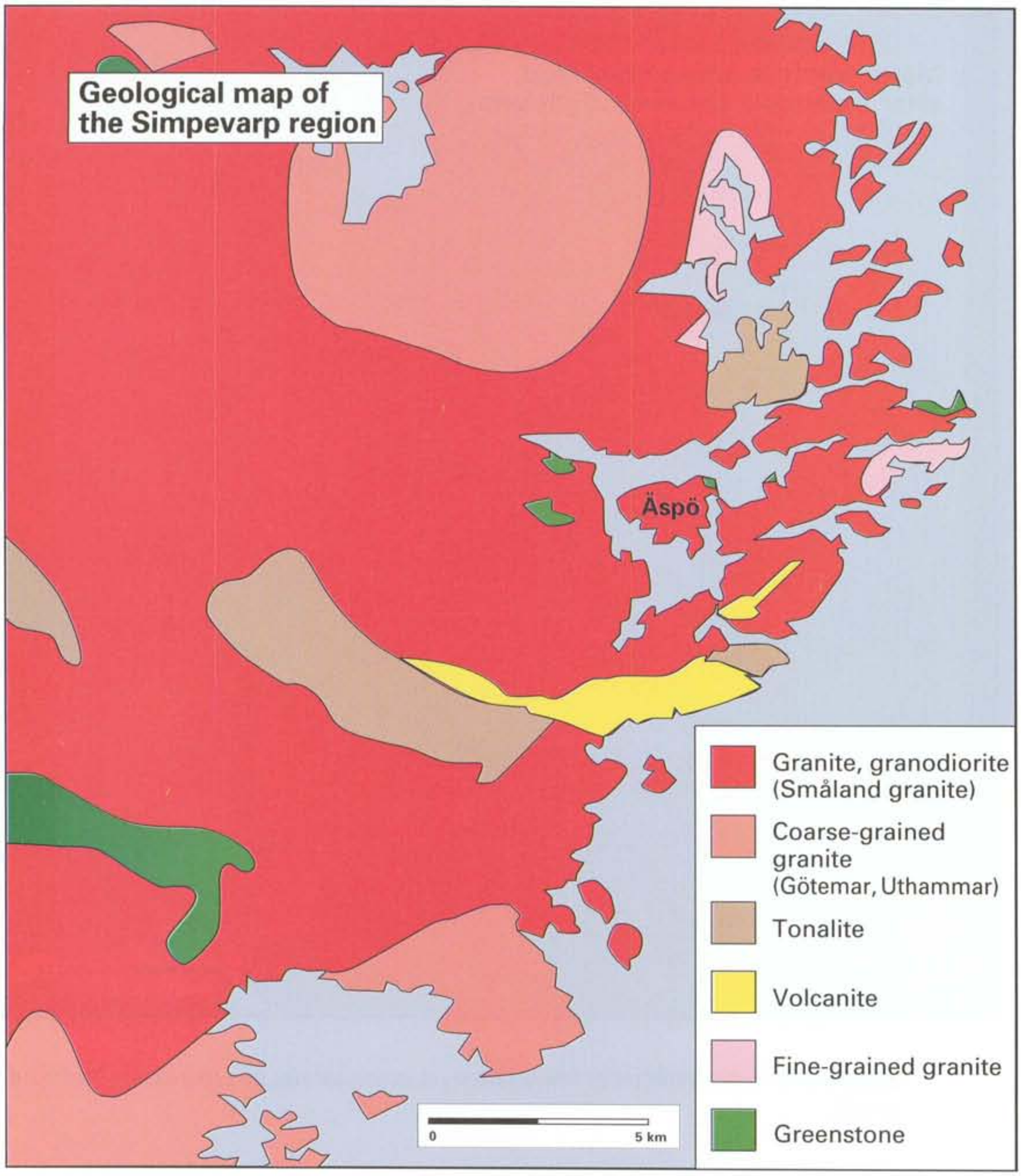

Figure 3-9. *Survey of the bedrock in the Simpevarp region. Based on /3-11/.*

The second figure, Figure 3-10, shows a more detailed map of Äspö, which was also drawn in 1987. On this scale, several narrow greenstone bands can be found on Äspö.

The third figure, Figure 3-11, shows the rock type distribution on Äspö after a very detailed mapping. On this scale, two different variations of granite as well as vulcanite and greenstone can be found.

The example shows that the description of the bedrock variation is partly dependent upon the scale on which the description is carried out as well as on the amount of work carried out to map the variations. The level of ambition which was used to prepare Figure 3-11 is exceptionally high.

The conclusion is that caution has to be exercised so that too definite conclusions are not drawn on the basis of the general maps. The areas which appear to be homogeneous on general maps are often significantly more heterogeneous in reality. Not until detailed studies are carried out can an evaluation be made, with any degree of certainty, of the variations in the bedrock.

3.3.3 Ore potential

Areas with ore potential should be avoided when selecting a site for a deep repository since constructing a deep repository near to an ore deposit may have the following consequences:

- A deep repository can block ore extraction.
- In the future, unintentional intrusion into a deep repository due to ore prospecting may occur if knowledge of the existence of the deep repository is not passed on to future generations.
- The hydraulic and hydrochemical conditions of a nearby deep repository may be changed in connection with mining activities.

Examples from Malå municipality

Figure 3-12 shows the areas with ore potential in the Skelleftefält ore province. On this scale, information is highly generalized.

On another scale, the information is more modulated. Figure 3-13 shows the areas within Malå municipality with ore potential. These areas are strongly linked to the occurrence of volcanic supracrustal rock. However, since there is no ore potential in several of the large granites, there are good possibilities of locating "ore-free" areas in the municipality.

The example is a further illustration of the fact that different results for studies carried out on different scales can be obtained for a given siting factor. Thus, the suitability of a repository site cannot be established before studies are conducted on more local scales, i.e. in connection with feasibility studies and site investigations.

3.4 OVERALL EVALUATION

How can SKB claim that, from a geoscientific standpoint, there are areas within large parts of Sweden which are suitable for the siting of a deep repository and at

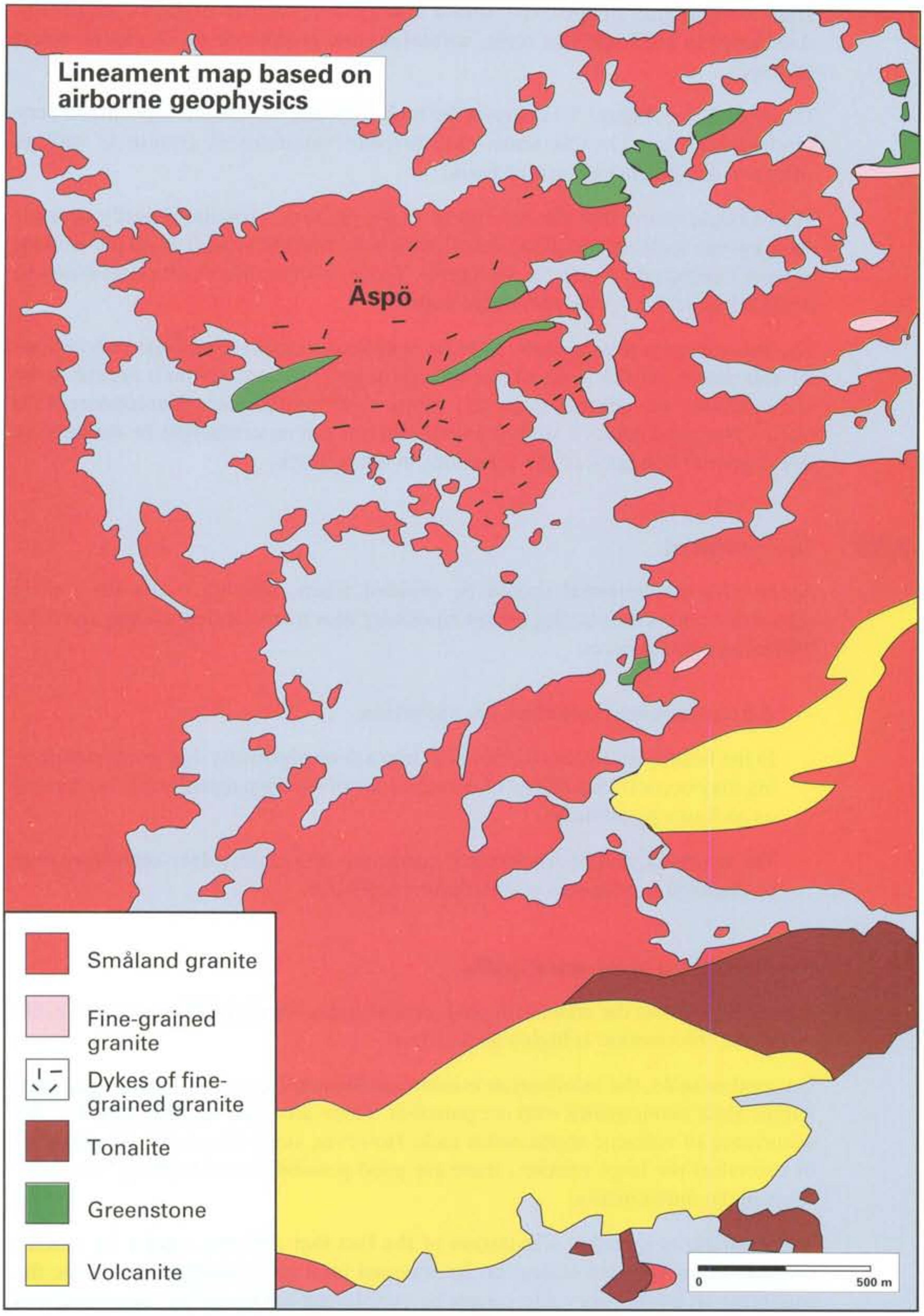

Figure 3-10. Detailed map of the bedrock in the Simpevarp area. Based on /3-11/.

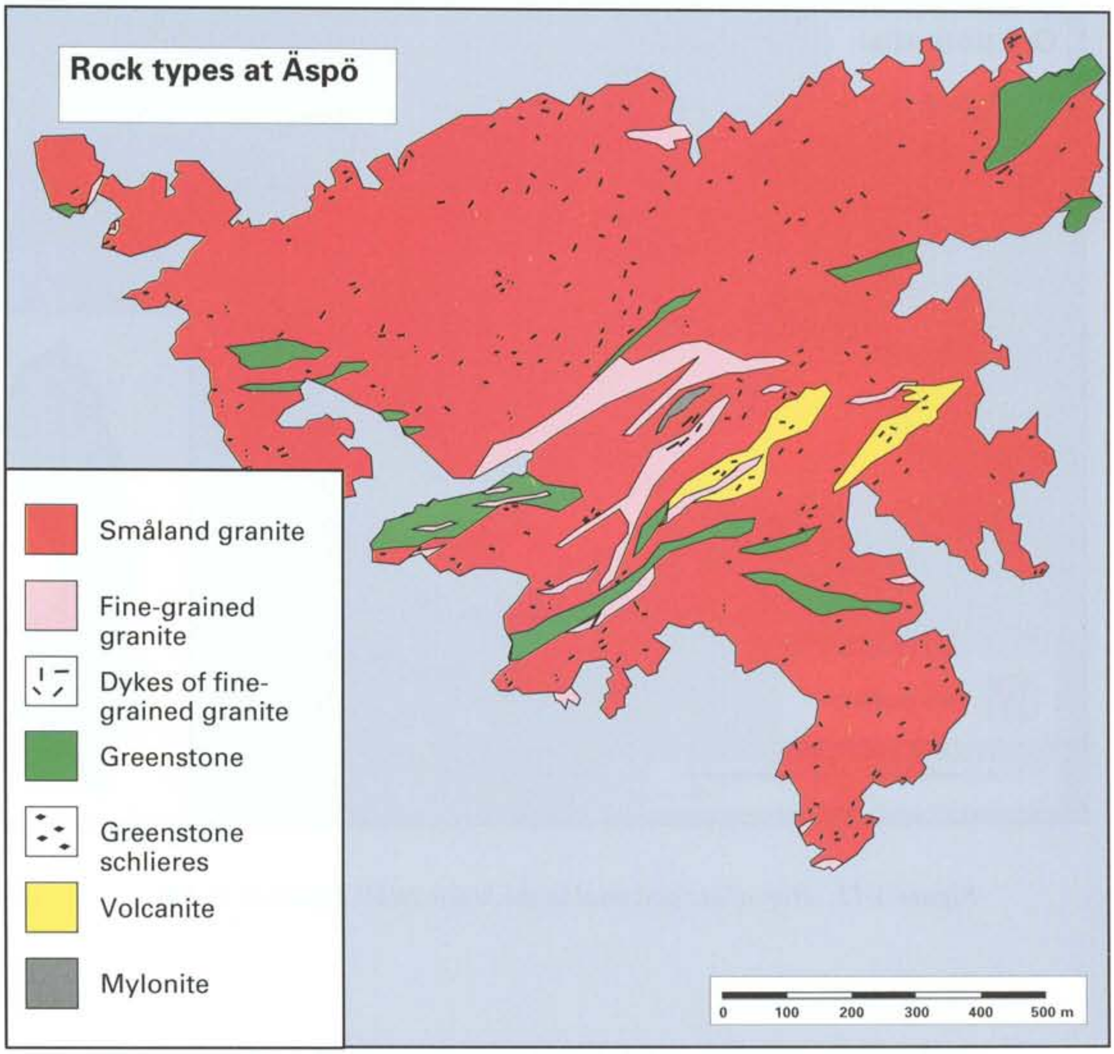

Figure 3-11. *Detailed map of the bedrock at Äspö. Based on /3-10/.*

the same time maintain that the suitability of a site in terms of the long-term safety of the repository must be assessed on the basis of site-specific data?

The structure of the bedrock is often found to be complex and the properties relating to the bedrock often show considerable variation, even within limited volumes. In national and regional inventories, the variation of the properties can mainly be commented upon, on the basis of previous experience and these generalizations are made with the help of the estimated mean values of the properties. As far as differences in the mean value of a particular property in bedrock in different places is concerned, this difference is often much smaller than the variation of the properties within a particular area. The site investigations provide information so that the design of the repository can be adapted to the actual geological environment and provide us with knowledge about the actual distribution in the rock of those properties which are important for the long-term safety.

Both SKB and the competent regulatory authorities are in agreement that a licence to construct the deep repository must be based on site-specific data, where the actual distributions from the site properties are included in the safety assessment.

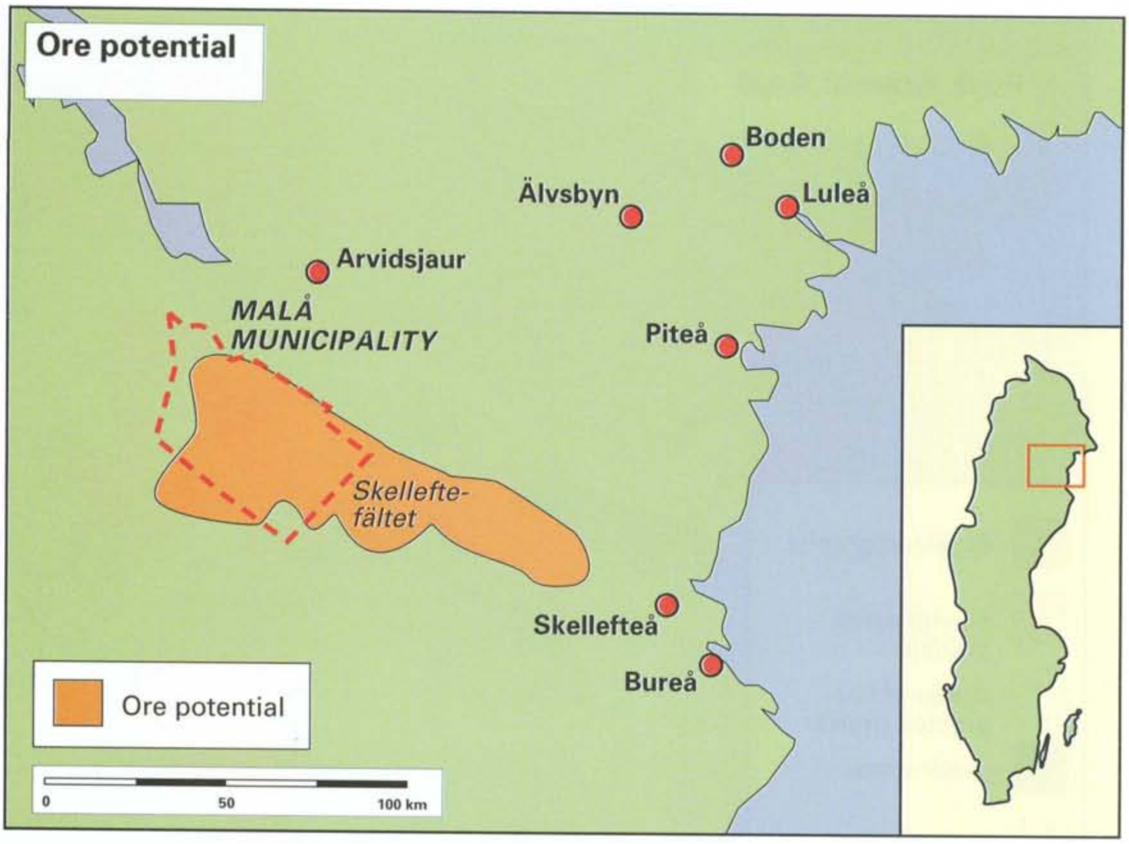

Figure 3-12. *Map of ore potential in the Skelleftefält. Based on /3-12/.*

On the whole, it can be said that a national general siting study has possibilities as well as limitations.

The scale in a national general siting study means limitations in terms of providing an adequate picture of technical/scientific as well as societal factors.

General conclusions are:

- **Whether an area is suitable or not, cannot be determined in a general siting study; more information are necessary for such an evaluation. The suitability is primarily determined in connection with feasibility studies and site investigations.**
- **The general siting study provides a good opportunity to identify factors which need to be taken up in more detailed studies.**
- **The general siting studies provide opportunities to identify areas which should be excluded from further siting work, or areas which may not be priority candidates for selection.**
- **The general siting study provides background information so that the site selection can be put in a regional and national perspective.**

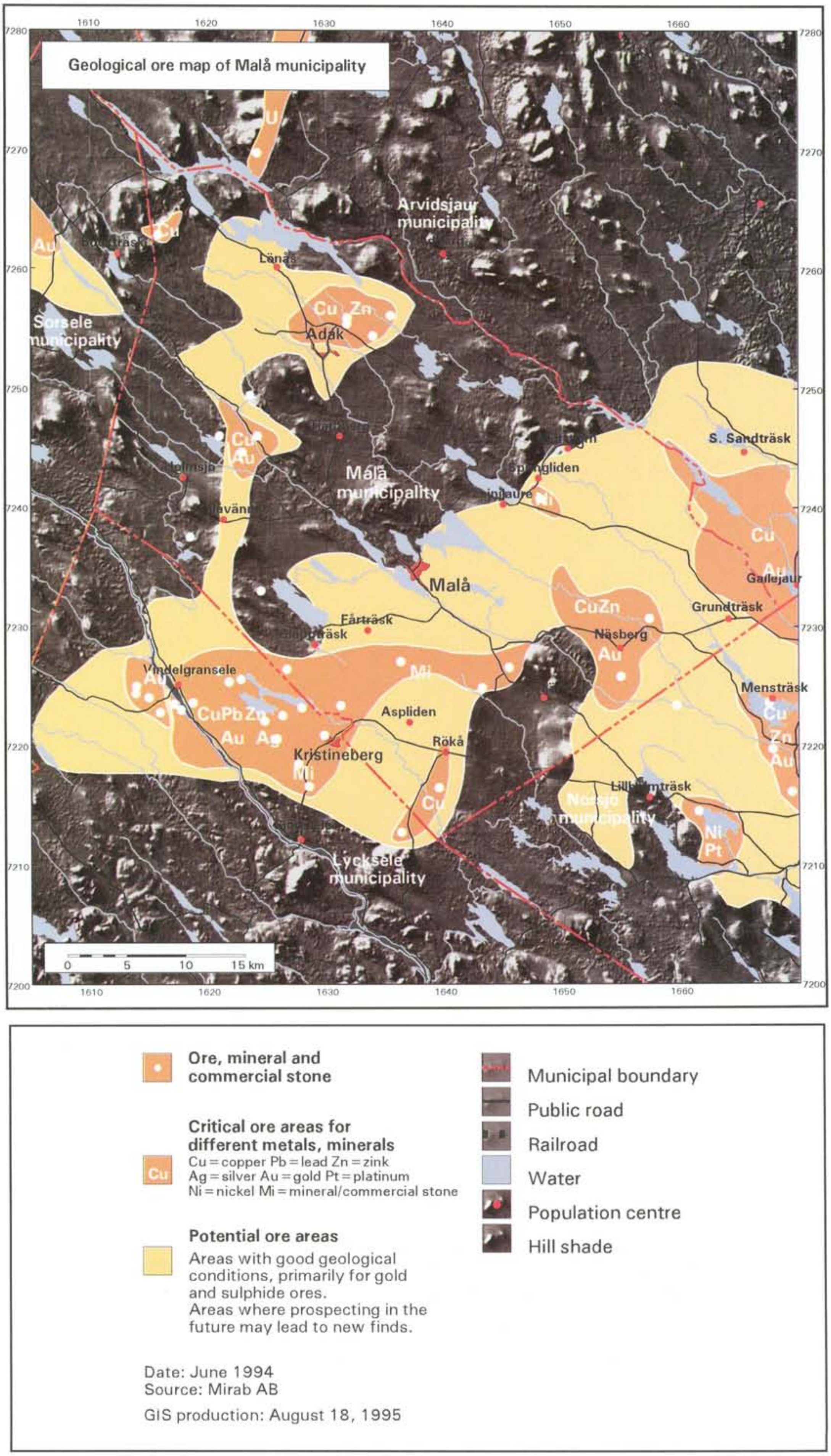

Figure 3-13. *Geological ore map of Malå municipality.*

4 LONG-TERM RADIOLOGICAL SAFETY – EVALUATIONS ON A NATIONAL SCALE

This chapter describes, on a national scale, different factors which may be of importance in connection with the siting of a deep repository, with regard to the long-term radiological safety. The chapter primarily focuses on the geoscientific factors.

4.1 GENERAL

As far as the final disposal of nuclear waste is concerned, society requires that the present generation as well as future generations should be protected. The method selected to fulfil this requirement is deep geological disposal of the waste surrounded by several engineered barriers. The aim is to fully isolate the waste within the engineered barriers. If these barriers fail, or became destroyed, the radionuclides must be retained or retarded, as far as possible, by the barriers or by the rock. The Swedish Radiation Protection Institute states /4-1/ that additional radiation doses to individual members of the general public shall not exceed 0.1 milliSievert per year, which roughly corresponds to one-tenth of the natural background radiation level. The absolutely most important period in terms of the hazard of the waste is the first 1,000 years. During that time, the fission products, Cesium-137 and Strontium-90 decay. Both of these fission products have a half-life of about 30 years. Furthermore, there is a reduced risk of a high level of external radiation, in the event of intrusion. However, radioactivity from the remaining long-lived elements is high enough to justify isolation of the waste from the environment for thousands of years more. An additional principle has been established for extreme long-term environmental protection, namely that radionuclides which can be released from the repository should not lead to any significant changes in the radioactive environment.

To show that the geological deep disposal method can fulfil these requirements, extensive analyses are made of different scenarios and the impact of these scenarios on the deep repository. Some of these scenarios would have a significantly greater impact on the entire Swedish society than that of a deep repository, even with very conservative assumptions. One such example is future ice ages, which would have a profound impact on future societies and nature.

A detailed analysis of the long-term radiological safety of the deep repository requires, besides credible models, extensive site-specific data, which can only be obtained after field measurements. Therefore, evaluations, on a national scale, of factors relating to the radiological long-term safety, focus on large-scale processes and on data which, in some specific way, are well represented throughout the entire country. These data are, above all, collected near to the surface and the evaluations are based on the fact that they are representative of the depths in the rock where the deep repository is to be constructed, about 400–700 m below the surface, see Chapter 3.

4.2 BEDROCK

This section deals with bedrock of interest as well as with bedrock which is of less interest for a Swedish deep repository. The section deals with issues related to the long-term radiological safety as well as issues relating to technology, land and environment. These factors are discussed in greater detail in Chapter 5 and Chapter 6.

For further information, see the geological volume of the Swedish National Atlas, Geology /4-2/, which provide an excellent and easy-to-read description of the bedrock in Sweden.

The bedrock in the Baltic Shield, to which most of the Swedish bedrock belongs, can be classified into different provinces. These are mainly related to the age of the bedrock and to important geological events.

The basic requirements on bedrock for a deep repository are suitable chemical environment, low groundwater flow and mechanical stability. These factors are treated later on in this chapter.

Most of the investigations which have been carried out for a deep repository have focused on more or less metamorphic granitoid bedrock and on highly metamorphic sedimentary bedrock. A large database on the bedrock at possible repository depths has previously been collected in connection with the study site investigations, see Figure 2-3. SKB's conclusion from the investigations was that, from a technical standpoint, suitable sites can be found in most parts of Sweden. The investigations of the bedrock which are being carried out in Finland, for a corresponding deep repository, are focusing on a similar type of bedrock /4-3/. These studies also indicate the general suitability of the bedrock in the Baltic Shield.

The highly schematic bedrock classification, provided in Figure 4-1, shows that about 65% of the Swedish bedrock is of general interest for further siting studies.

Thus, the prognosis for locating suitable bedrock is good, more or less throughout the whole of Sweden. If a common type of bedrock is selected, a deep repository in such bedrock will not result in a greater risk for future intrusion. Furthermore, this will not entail the blocking of any unique natural resources which future generations would want to use.

Another rock type which has also been discussed in this context is gabbro. Gabbro is also a deep seated rock type, but it has a lower content of silica than the granitoid rock types. Gabbro is a technically possible rock type which, in itself, has both advantages and disadvantages from the standpoint of deep disposal /4-4/. On the whole, it is not possible to find any decisive differences, on a national scale, with regard to the suitability of gabbro as opposed to granitoid/gneiss-like bedrock. However, the occurrence of large blocks of gabbro in Sweden is relatively limited (2% of Sweden's surface area), Figure 4-2.

There is no special reason to concentrate on finding a suitable site for the repository in gabbro. However, in connection with a feasibility study, it may, in individual cases, be possible and suitable to select siting in gabbro.

SKB is concentrating on finding a suitable site for the deep repository in crystalline bedrock. Some areas in Sweden where the crystalline bedrock is covered with ten to a few hundred metres of sedimentary bedrock are shown in Figure 4-2.

The following hypothetical examples from eastern Småland illustrate the possibility of finding a suitable site for a deep repository in bedrock which is covered by sedimentary bedrock.

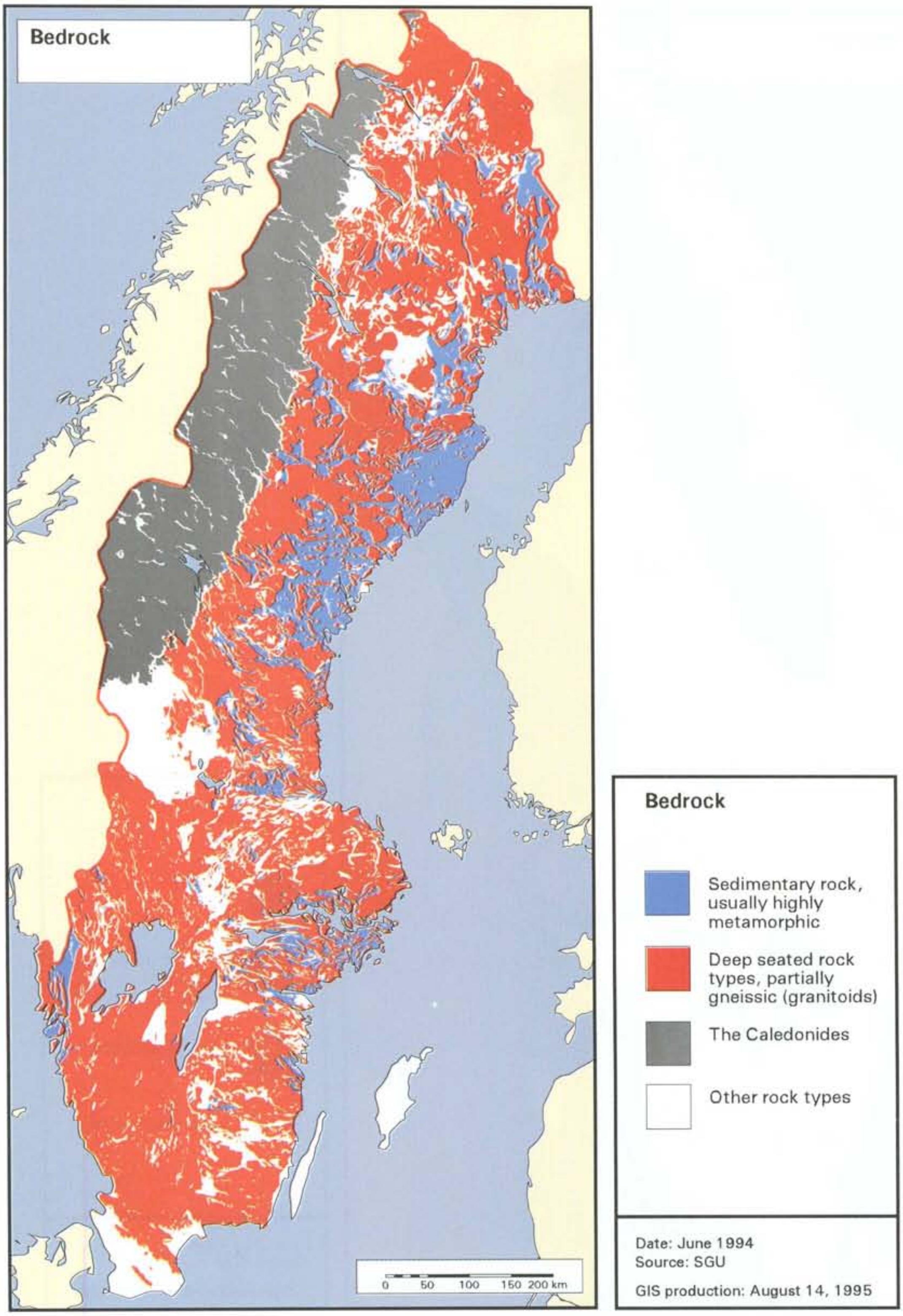

Figure 4-1. *Map of the bedrock (red and blue) which is of general interest for the siting of a deep repository. The bedrock of general interest consists of granitoid rock types with varying degress of metamorphosis and older, sedimentary rock, usually with a high degree of metamorphosis. Based on /4-2/.*

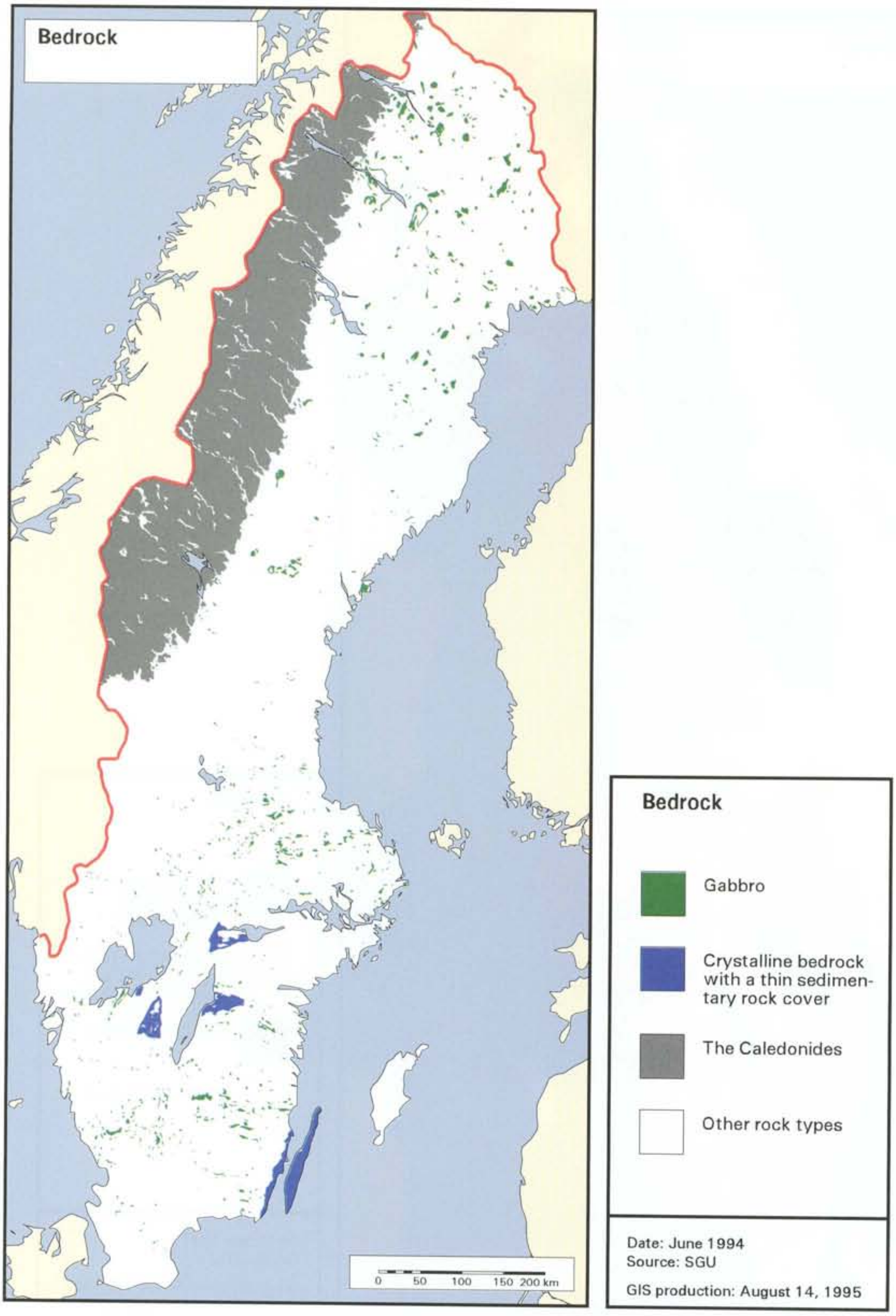

Figure 4-2. *Map of the bedrock (green and blue) which may be of interest for the siting of a deep repository, but where special conditions exist. The map shows the extension of gabbro and areas where the crystalline bedrock has been covered with a thin layer of sedimentary surface rock. In the latter case, it would also be possible to locate the repository in the crystalline bedrock. Based on /4-2/.*

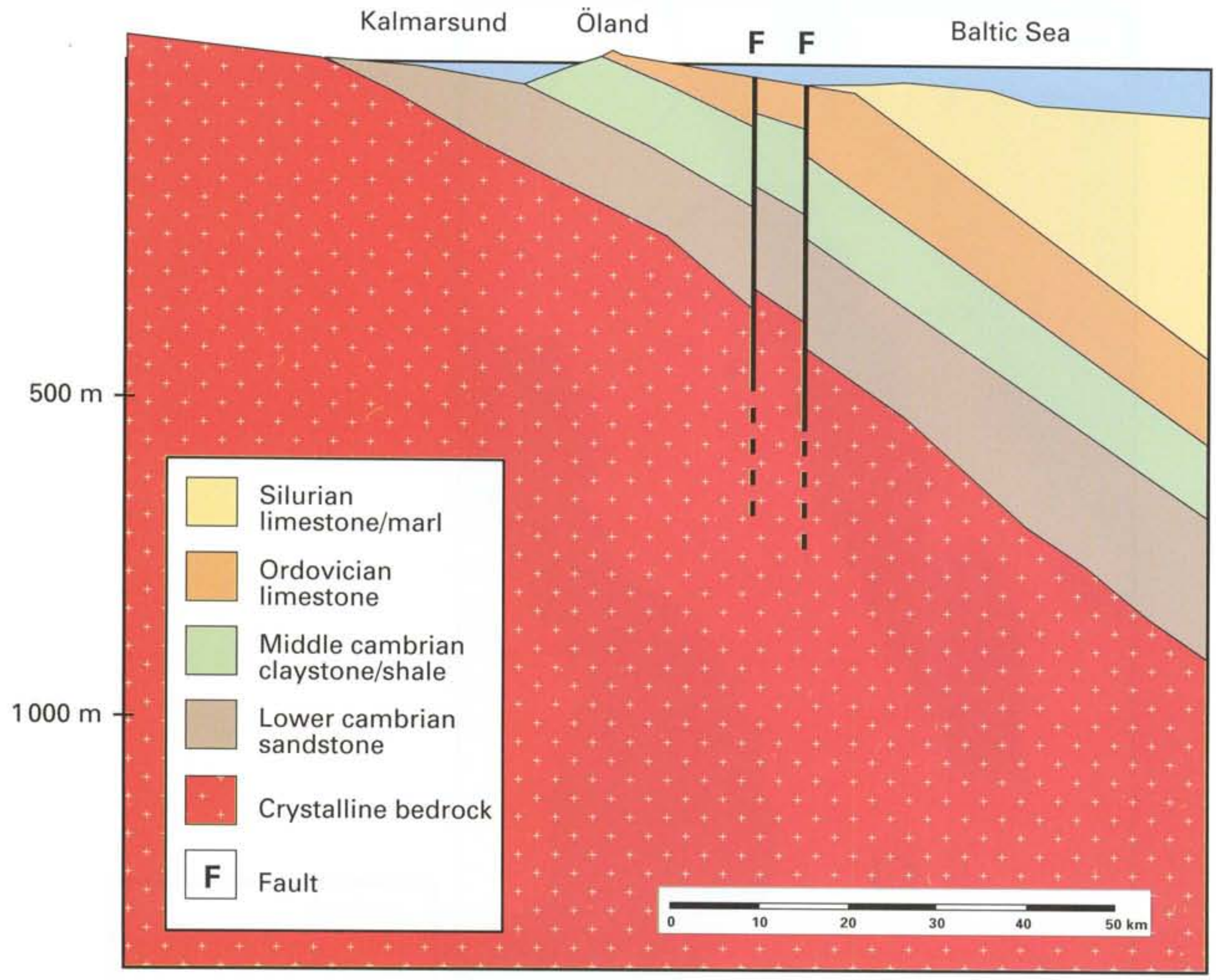

Figure 4-3. *East-west profile through the sedimentary bedrock in eastern Småland. Based on /4-6/.*

Figure 4-3 shows a profile from the highlands of Småland, via southern Öland and towards the east. The thickness of the sedimentary cover seems to increase towards the east. Note that the vertical scale is highly magnified (50 times). In reality, the crystalline bedrock and the sedimentary cover are almost horizontal. The thickness of the sedimentary cover on Öland is about 200 m.

Such a geological environment can offer certain advantages /4-5/. The most important advantage is that the groundwater in the underlying bedrock is probably more or less stagnant due to the low driving forces which can percolate the groundwater into the rock. Another advantage is that, in this geological environment, it is relatively easy to trace the vertical movements of the bedrock which have occurred in the sequence of strata when the sedimentary rock types were deposited, 570–440 million years ago. It will thereby be easier to design the deep repository to avoid possible movement zones.

The siting of the deep repository in the crystalline bedrock below a thin layer of sedimentary rock types is of possible interest. However, the suitability of such a site must be primarily taken into consideration in feasibility studies.

Finally, Figure 4-4 shows the bedrock on a national scale which, in general, is less suitable for the siting of a deep repository.

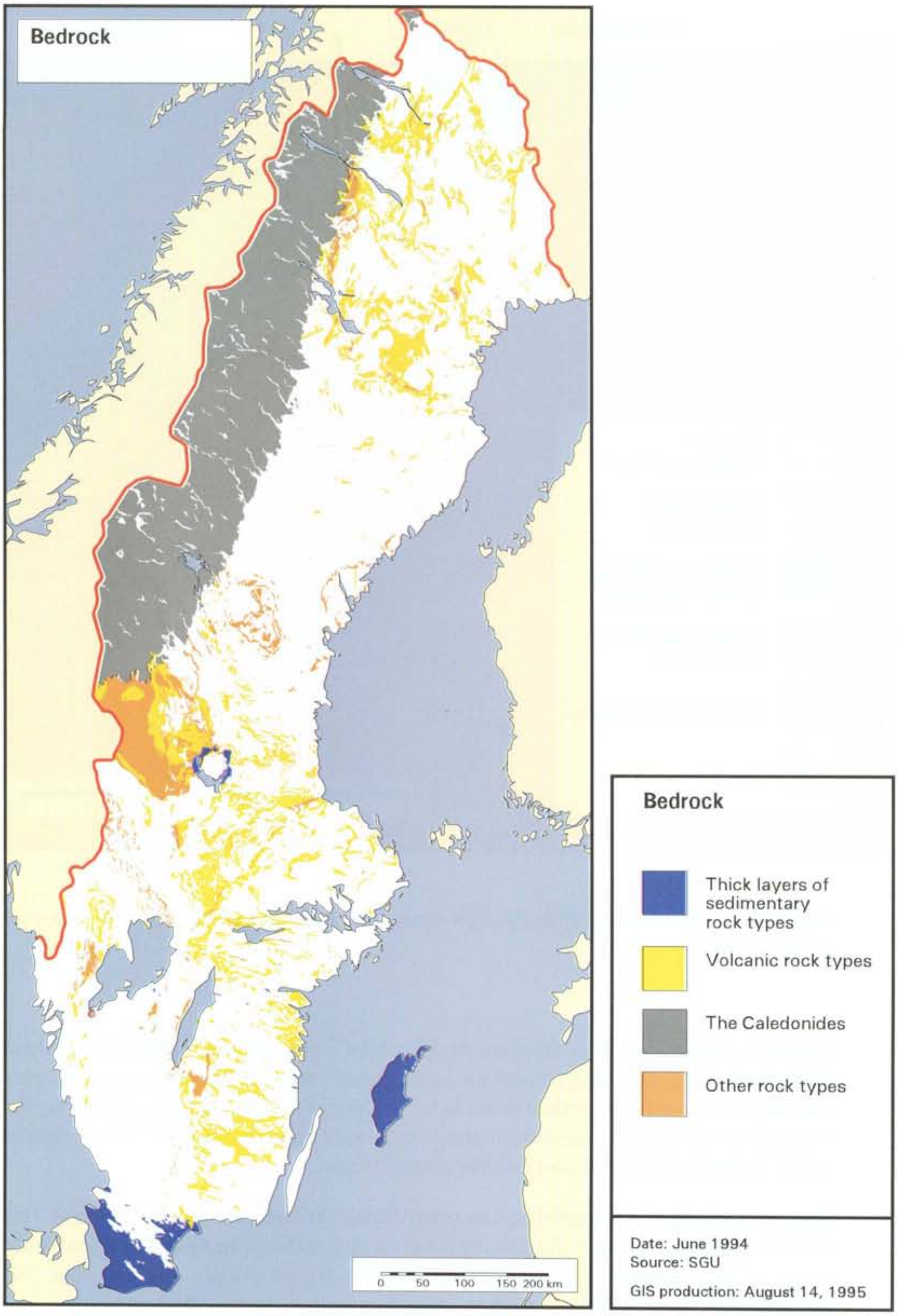

Figure 4-4. *Map of the bedrock (blue, yellow and orange) which is generally less suitable for siting, 32% of Sweden's surface area. This area includes the bedrock in the Caledonides, Skåne and Gotland. Acid volcanic rock is included on the map because they may be ore-bearing. Acid volcanic rock and volcanite with limited extensions (basic, intermediary) as well as other types of volcanite are classified in the same category in the figure. Unusual bedrock is classified under "Other rock types".*

The Scandinavian mountain range (Caledonides) was formed between 510 and 400 million years ago. It consists of large sheets of bedrock, called nappes, and flat overthrusts which separate them. The structure of the nappes is complex and they mainly consist of sedimentary rock types.

Skåne and Gotland are regions of sedimentary rock types which are not technically suitable for the deep repository. These rock types are usually highly water-permeable, with lower mechanical strength than the crystalline bedrock. They also often contain a higher content of organic material, which is not desirable from the standpoint of safety.

Acid volcanic rock are rock types with relatively high quartz contents, which are formed on the surface through volcanic processes. In the Swedish ore provinces of Bergslagen, Kiruna, Malmberget and Skelleftefältet, the ores are found in the acid volcanic rocks or in pre-cambrian (more than 570 million years old) sedimentary rock types. As far as the risk of intrusion and the possible blockage of future mineral extractions is concerned, these rock types are not suitable for the siting of a deep repository.

In Figure 4-4, basic volcanic rock with intermediate acidity, Dalaporphyry, – porphyrite and Venjans porphyrite have been shown together with the acid volcanic rocks. The extent of the basic and intermediary volcanic rocks is severely restricted and their suitability must be investigated during any feasibility studies carried out in these regions. More unique rock types are classified under "Other" in Figure 4-4.

Unusual rock types or bedrock which increases the possibility of unintentional intrusion due to prospecting for ore or industrial minerals must be avoided. In this way, possible advantages can be gained from the standpoint of safety, at the same time that the existing natural resources can be managed efficiently.

4.3 CHEMICAL ENVIRONMENT

The chemical environment is important to the barriers which isolate the waste or retard any radionuclides released.

The chemical environment is largely determined by the composition of the groundwater. The composition of the groundwater is a result of water from superficial and deeper parts of the bedrock interacting with the minerals in the bedrock. Since the composition of the minerals is stable, the chemical environment in the rock is, in general, stable over long periods of time.

Examples of important chemical parameters are dissolved oxygen and sulphide in the groundwater.

In the measurements carried out by SKB in deep boreholes, the groundwater was reducing, which indicates that the rock is capable of reducing the highly oxygen-rich groundwater which seeps out of the soil into underlying rock. Low sulphide contents are also important in order to ensure that the corrosion rate of the canister is slow which, in general, is the case with the Swedish groundwater.

The analysis of the chemical environment is facilitated if the quantity of foreign substances entering the repository during construction and operation is limited. The quantity of construction material in the rock will be limited by the criterion that the deep repository should be constructed in "good rock" which requires little use of concrete and steel reinforcements as well as sealing material.

Different chemical processes which are important for the isolation of the waste, for the limiting of the fuel dissolution and the retardation of the nuclide transport in the event of a canister failure are presented in the diagram of siting factors, see Appendix 3. See /1-2/ for detailed information.

In connection with, for example, the study site investigations, field and laboratory experiments, extensive knowledge of the processes which are important as well as relatively good knowledge of existing data ranges for important parameters have been obtained.

On the basis of almost 900 sampling points in deep groundwater, the chemical conditions of the groundwater are expected to be favourable at most sites which may be under consideration /4-7/. Almost all of the investigated groundwaters have been found to fulfil one important criterion, namely reducing conditions.

SKB's measurements in deep groundwater, 50–1,000 m, as well as measurements carried out in Finland and Canada, show that the groundwater may be saline and may sometimes also have a higher salinity than the Baltic Sea.

Both the range of concentrations and the median values are similar in both fresh and saline groundwater with regard to pH, potassium, carbonates, iron, sulphide and organic material. Only with regard to the components, chloride and calcium, is it expected that the variations in concentrations between different sites will be greater than within one site.

Changes in the distribution between fresh and saline groundwater can change in coastal areas, in connection with the ongoing isostatic land uplift and in connection with future glaciations.

The saline groundwater affects the groundwater flow in the bedrock. The lighter (fresh) surface water which seeps down from the surface can settle like a cushion on top of the more saline, heavier groundwater. The interface between the fresh and saline water is normally diffuse, but it may be of interest when interpreting the groundwater movements in the area.

Saline groundwater also affects the chemical environment and performance of the repository. However, only very high salinities, > 3% are of any real importance.

In this context, there is reason to study the concept of the Highest Shoreline, which has had some significance with regard to whether the groundwater is fresh or saline today.

4.3.1 The Highest Shoreline

The last ice age reached its maximum extent 20,000 years ago. The ice, which was up to 3 km thick depressed the Earth's crust about 800 m in relation to the current level. Most of the available water was bound in inland ice and the global seas were, thereby, about 120 m lower than at present. When the inland ice melted, the land rose. Certain parts were located below the seas of the time, other parts of the land were always above the highest sea level. The boundary which shows where land was always above sea level is called the Highest Shoreline, Figure 4-5. The heights of the Highest Shoreline are different in different parts of Sweden, depending on the extent of the downward pressure on the land when it was uncovered and how much of the sea's surface could rise. The Highest Shoreline is at its highest, 285 meter above sea level at the Ångermanland coast.

In a complex interactive process, the land uplift and the melting of the ice formed ice lakes and inland seas at different times, with water that was sometimes fresh, brackish and saline. The last phase, the Littorina Sea, was characterized by the fact that the seawater was significantly warmer and more saline than the Baltic Sea today.

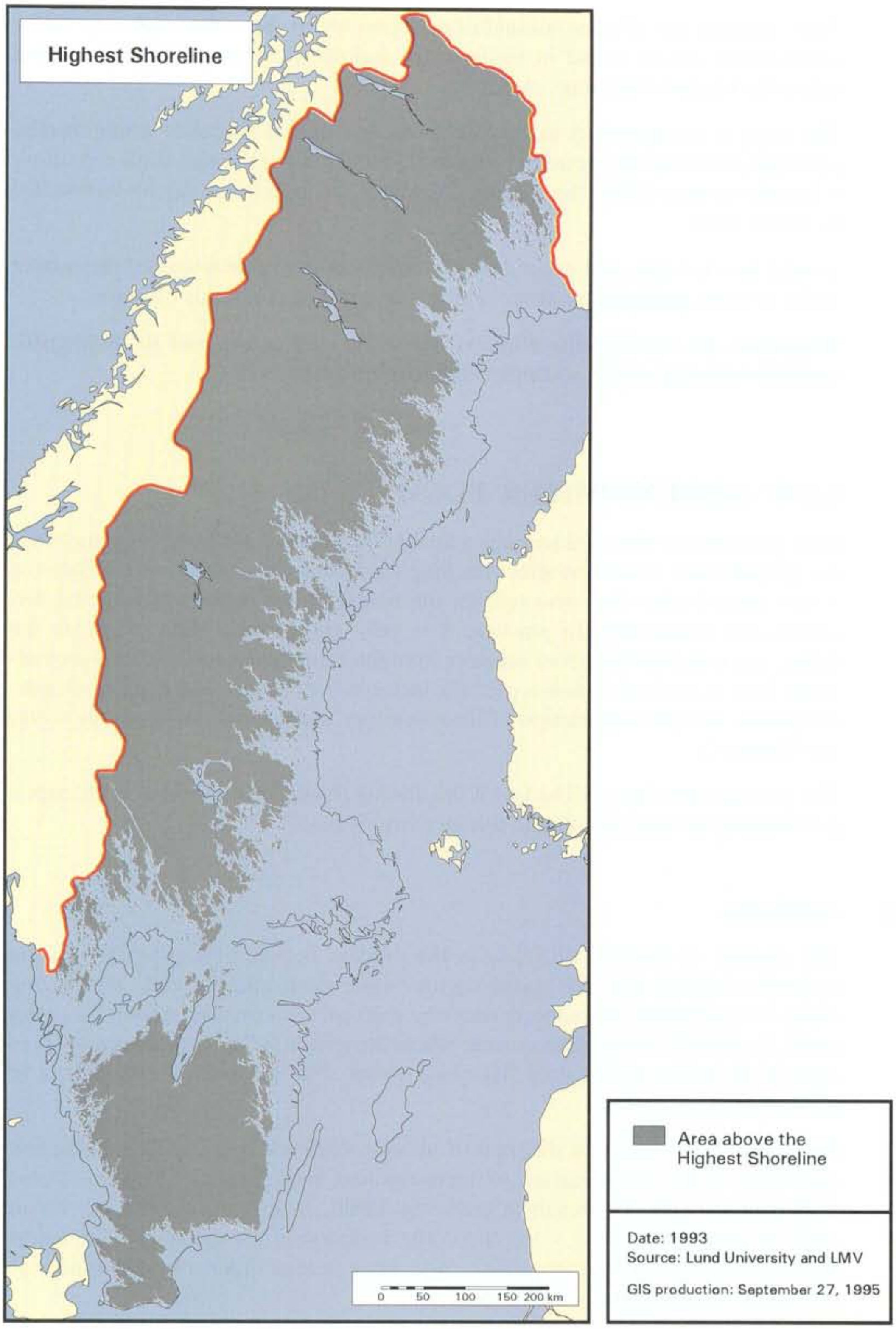

Figure 4-5. *Map of previous Highest Shorelines, i.e. areas not covered by sea after the last ice age. The groundwater above the Highest Shoreline is generally fresh. The position of the Highest Shoreline does not distinguish between suitable or less suitable regions.*

This situation has affected groundwater chemistry to the extent that, e.g. saline groundwater can be found in wells which supply water and which are located below the Highest Shoreline, /4-27/.

The siting of the repository in the area above the Highest Shoreline would thereby probably mean that the repository would be located in fresh water. If the repository is located in areas below the Highest Shoreline, the repository may be surrounded by saline water.

Several new ice ages will occur, and it is not possible to guarantee that the current saline or fresh groundwater environment will last over thousands of years.

Therefore, the level of the Highest Shoreline cannot be used to distinguish between suitable or less suitable regions in Sweden.

4.4 LOW GROUNDWATER FLOW

Low groundwater flow reduces any possible transport of chemical substances via the groundwater which can affect the long-term chemical stability of the barriers. A low groundwater flow also reduces the possibility of radionuclides being dissolved and transported. In practice, it is only groundwater flow which, in the future, can transport dissolved nuclides from the waste to the surface. Low groundwater flow in the rock is also a positive factor in connection with detailed characterizations and the construction of the repository, since it will facilitate the work, see Chapter 5.

The groundwater flow will be low if the driving forces are low and/or if the rock's permeability to water (hydraulic conductivity) is low.

4.4.1 Gradients

The amount of groundwater flow is the product between the gradient and the hydraulic conductivity. By depositing the waste deep into the rock, the driving forces will generally be reduced since the gradient is in reverse proportion to the depth. In general, low gradients occur where the terrain is flat. One alternative is to deposit the waste within very flat-lying terrain. The extreme case would be in bedrock beneath the sea.

Figure 4-6 is a simplified diagram of altitude differences in Sweden, described according to the classification of topographical map sheets in Sweden. These differences in elevation result in gradients which, at repository depth, are on an order of magnitude of 0.1 – 1% /1-5/. The variation of the gradient is limited in relation to many other factors which vary above several orders of magnitude, e.g. the hydraulic conductivity of the rock.

Therefore, there is no reason why regions should be excluded on the basis of regional differences in topography.

4.4.2 Hydraulic conductivity of the rock

Low hydraulic conductivity of the rock is a property relating to the material. It is primarily "defects" in the rock, fractures, crushed zones etc. which determine the permeability of the rock. Therefore, there are no simple relationships between conductivity and rock type. Experience from measurements show that the conductivity can vary by up to about eight orders of magnitude within a few metres and

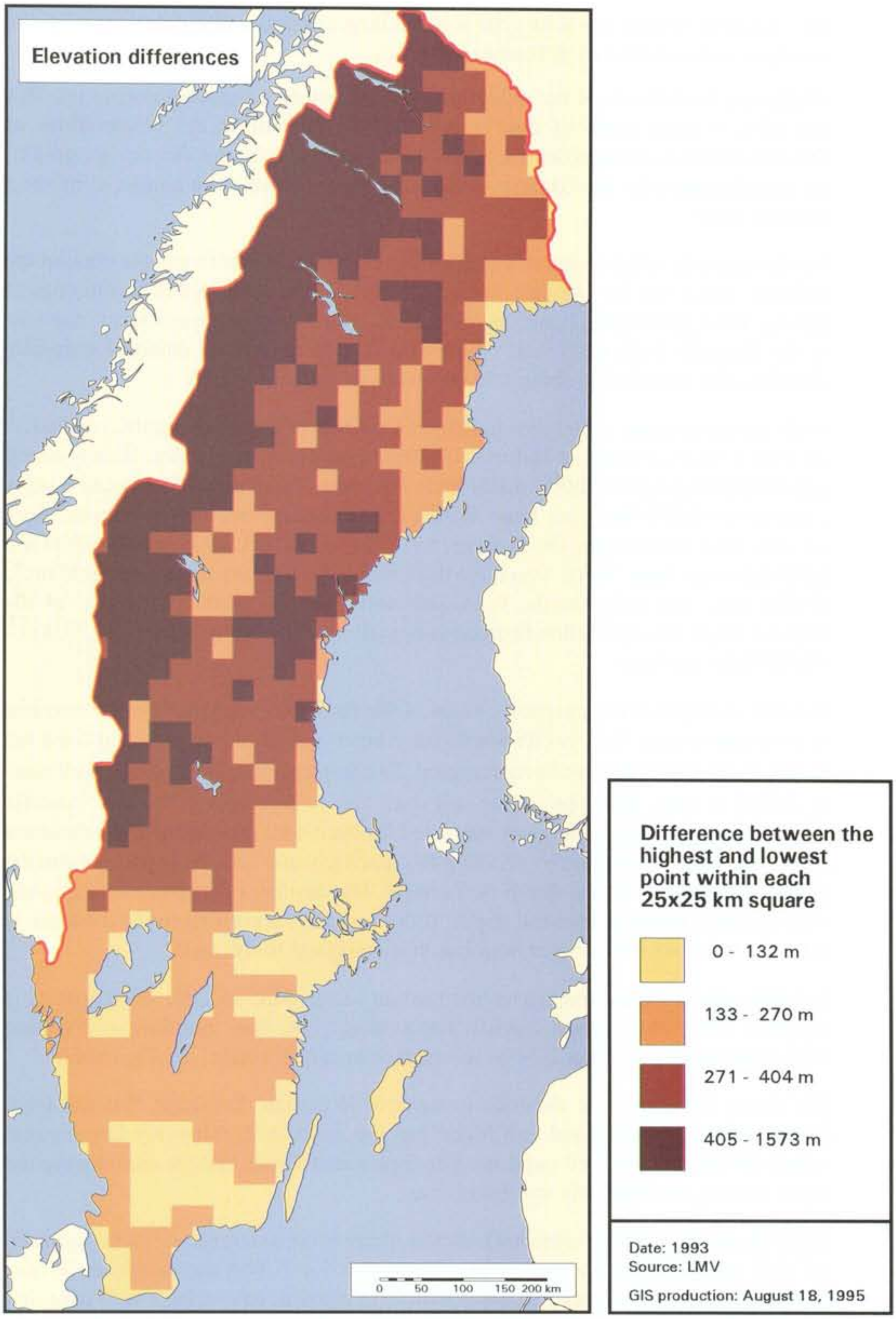

Figure 4-6. *The maximum difference in elevation on each topographical map sheet. The limits of each class have been determined so that each class corresponds to about 25% of the surface area of Sweden. Based on the Central Office of the National Land Survey's digital elevation database on a 500 grid.*

the variations within one rock type is often larger than the difference between the average conductivities of different rock types.

Within the framework of the study type investigations conducted during the 70's and 80's, a large body of data was collected concerning the conductivity of Swedish bedrock at large depths. Since these data are site-specific, the geographical distribution over the country is not sufficient to assess the conductivity on a national scale.

For this general siting study, it was considered to be relevant to use the data on the bedrock which can be obtained from the well archive at the Swedish Geological Survey. Data concerning position, soil depth, water volume capacity, etc. are sent to the database from each well which is drilled in rock. The database currently contains data concerning about 150,000 wells drilled after 1976.

Wells in sedimentary rock types generally have much greater hydraulic conductivity than wells in crystalline bedrock. Cambrian sandstones in Närke, Västergötland and Östergötland give 3,000 – 4,000 litres per hour; The chalk of Skåne can usually yield up to 60,000 litres per hour. Within the crystalline bedrock provinces, there are also local differences. On average, wells drilled in rock yield between 600 and 6,000 litres per hour. Wells which are drilled in large fracture zones can yield up to 50,000 litres per hour. On the Bjäre peninsula and the northwestern part of the Halland ridge, the crystalline bedrock is heavily fractured and wells yield 20,000 – 40,000 litres per hour.

In order to improve the prognosis value of the database, wells have been screened to a certain extent. Only wells which have been drilled to a depth of at least ten metres in the bedrock have been accepted. Furthermore, at least ¾ of the well must be drilled in rock. The depth of the soil must also be less than 20 m. The "specific well capacity" (m^3/m,s) has been estimated for each well remaining in the database (124,228). This is obtained by dividing the specific water volume capacity from the drilling of the well by the depth of the well. The number of metres of rock in the well has been taken as the well depth. If the capacity, according to the database is zero, the value of 10 litres per hour has been assigned to the well.

For each topographical map sheet, the median value of the specific well capacity is reported. This value is then classified according to the four quartiles so that each class corresponds to about 25% of the surface area of Sweden, see Figure 4-7.

The figure indicates that the rock in parts of Bohuslän, Dalsland, Östergötland, Södermanland, Hälsingland and Medelpad are areas with relatively low median values for the specific well capacity. The figure also shows that the medians for the lower classes are relatively similar in size.

Since the rock is a heterogeneous material, there is considerable variation between the well capacity in individual wells, see Section 5.4.1. This means that there may be wells with a low capacity in areas which, in general, have a high well capacity, and that there may be wells with a high capacity in areas which generally have a low well capacity.

At different times, SKB has analyzed well data in order to correlate, e.g. specific well capacity with rock types /4-8/. Five counties (Kalmar, Jönköping, Kronoberg, Älvsborg and Halland) were studied in detail to establish the correlation between rock types and the possibility of extraction, based on the well archive. Furthermore, small studies were carried out in a further ten counties. No rock type was found to be consistent with regard to the lowest or even the low specific capacity. More basic rock types such as (gabbro, diorite) were often found to have a relatively low specific capacity. However, the variation, expressed as the standard

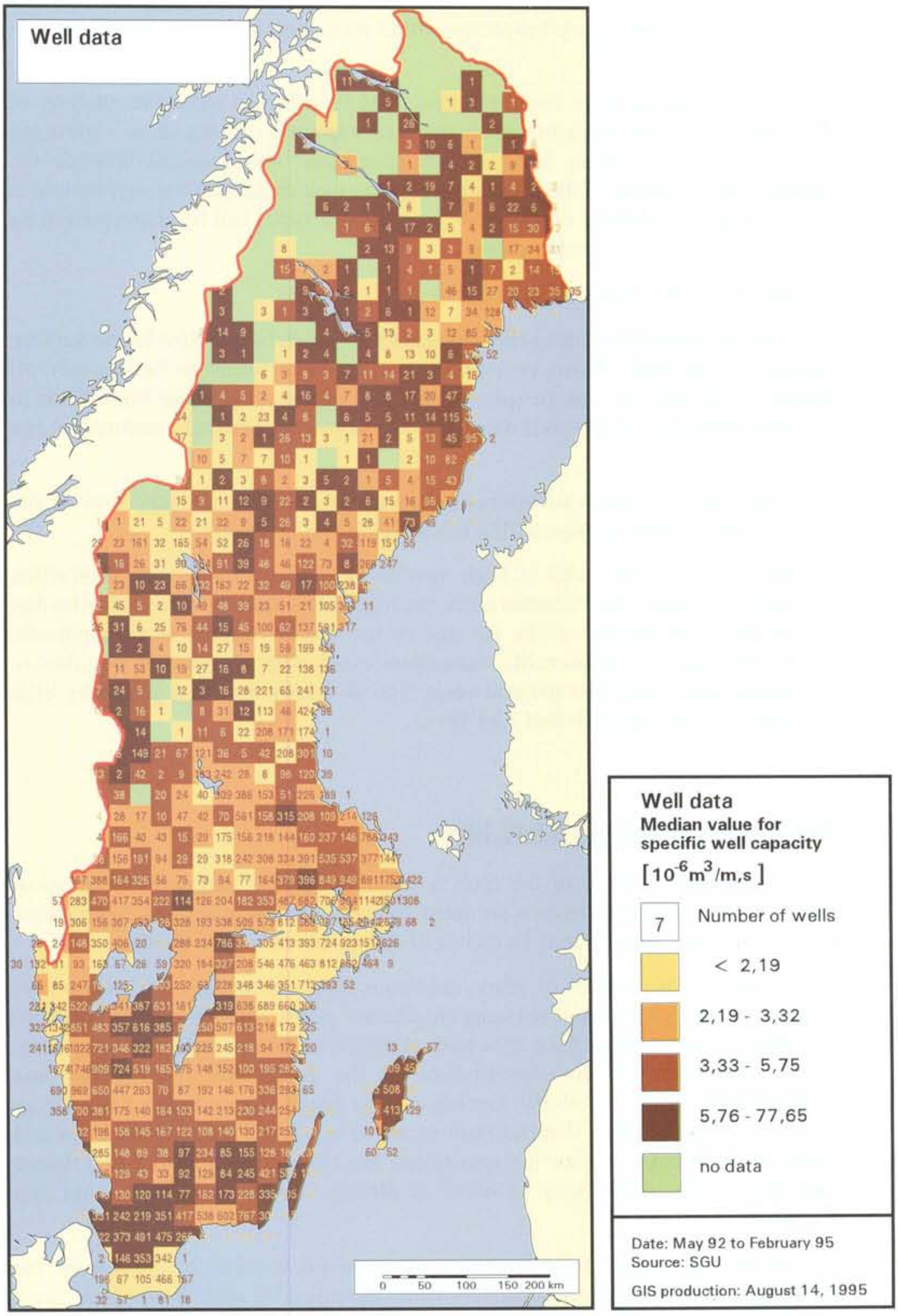

Figure 4-7. *The median values for the specific well capacity. The figure in each square refer to the number of wells included in the analysis. The class limits have been determined so that each class corresponds to about 25% of the surface area of Sweden.*

deviation of the specific well capacity, within these rock types is no longer significant.

Similar conclusions have been reported in /4-9/, where a variation analysis of different rock types, with regard to the well capacity, did not show significant differences. On the other hand, a high correlation was obtained between the ingoing silica content of the rock types and the well capacity. One explanation is that the higher hydraulic conductivity of acid rock types can be characterized by less sealing fracture mineralizations.

In conclusion, the following can be stated:

The well database provides general values for groundwater flow in the surface regions of the rock. These regions have often been found to be severely affected by the last ice age. In spite of this fact and several other limitations in the interpretation of the well database, the following general conclusions can be drawn:

- **There may be areas of interest in terms of low groundwater flow in the bedrock within regions with a low specific well capacity.**
- **However, regions with a high specific well capacity in the crystalline bedrock cannot be excluded since the high well capacity values may be due to the local impact of the ice age in the upper regions of the bedrock. Furthermore, considerable variations exist, which makes it possible to locate areas with low groundwater flow in a region with a generally high specific well capacity and vice versa.**

4.5 MECHANICAL STABILITY

The mechanical stability of the rock is important to the long-term radiological safety. It is important to position the spent fuel canisters in the bedrock to minimize the risk that the canisters may be damaged during any rock movements.

Over hundreds of millions of years, enormous forces have had an impact on the bedrock; orogeny, collisions between continental plates, kilometre-thick sedimentary deposits and recurrent ice ages have gradually deformed and eroded the rock. For a description of the development of the Baltic Shield over the past 1,200,000,000 years, see /4-10/. Geological and geochemical studies have shown that most of the bedrock displacement occurred in already existing fractures and zones. If earthquakes or new ice ages occur, any displacements between different rock blocks are more likely to occur in already formed weakness zones and fractures.

By making the layout of the repository so as to avoid zones of movement, the uncertainty of the engineered barriers being damaged by rock movements is reduced. An important part of the safety assessment will still be to estimate the consequences of damaged canisters or buffers.

In this section, some of the factors on the national scale are discussed, such as deformation zones, lineaments, ice ages, earthquakes and movements in the bedrock in connection with the last ice age.

4.5.1 Deformation zones

Deformation zones can either be a single zone or more complex zones containing minor zones which form a coherent network. Well-known Swedish examples of complex zones are, e.g. the Tornqvist Zone, the Mylonite Zone and the Protogine Zone.

Figure 4-8 shows the deformation zones in Sweden /4-11/, based on the Swedish Geological Survey's (SGU) general bedrock maps, unpublished surveys and supplementary information from several map sheets in SGU's Af and Ai series etc.

The large, complex deformation zones can be considered to be regional boundaries of tectonic blocks. The position and extent of deformation zones are based on extensive databases and interpretations, see Section 3.3.1.

New interpretations may mean that fracture patterns are connected in a different way, which may mean that already defined zones may have different extensions or that completely new zones are interpreted.

SKB is looking for rock with a stable chemical environment, low groundwater flow and mechanical stability. The fact that a geological area is in a deformation zone does not mean that the bedrock in the zone or in its vicinity must be of a poor quality. Instead, the position of the deformation zone indicates large movements in the, often smaller, zones included in the large, complex deformation zones. This is illustrated by the experience from several underground constructions and investigations. In the late 60's, a Swedish power utility carried out drilling and investigations for an energy project just south of Alvesta. The area is adjacent to the Protogine Zone but the rock is of very good quality and most of the cores which were taken from the boreholes were free from fractures and had to be broken for handling.

Even if the rock may be of excellent quality in a large deformation zone, it can generally be assumed that there will be a greater risk of large earthquakes with dynamic effects or deformations particularly in connection with these zones, due to the length of the zones, see Section 4.5.4.

Complex deformation zones are important from the standpoint of siting. Areas with such zones should not be the first priority when selecting a site for a repository. However, areas located at or near deformation zones cannot be excluded unless field studies have been carried out. The importance of deformation zones near to a repository must be taken into consideration and investigated in connection with feasibility studies and site investigations.

4.5.2 Lineaments

In different contexts, SKB has carried out lineament studies across Sweden. On behalf of SKB, the Swedish Geological Survey carried out a lineament interpretation based on the National Land Survey's relief map on the scale of 1:2,000,000, see Figure 4-9. Only a selection of more distinctive lines which, alone or in combination with others, have a length in excess of 30 km have been included.

Lineament maps do not provide a sufficient basis to prefer or exclude areas in Sweden, on the national scale. On the local scale, the repository must be designed to avoid zones where the barriers could be damaged in connection with bedrock movements.

4.5.3 Ice ages

Over the last few millions of years, the normal condition for Sweden was to be covered in ice /4-12/. The relatively warm period during which we now live will in all likelihood, as before, turn into another ice age. This will have major consequences for our society. A mass exodus of the population will probably occur.

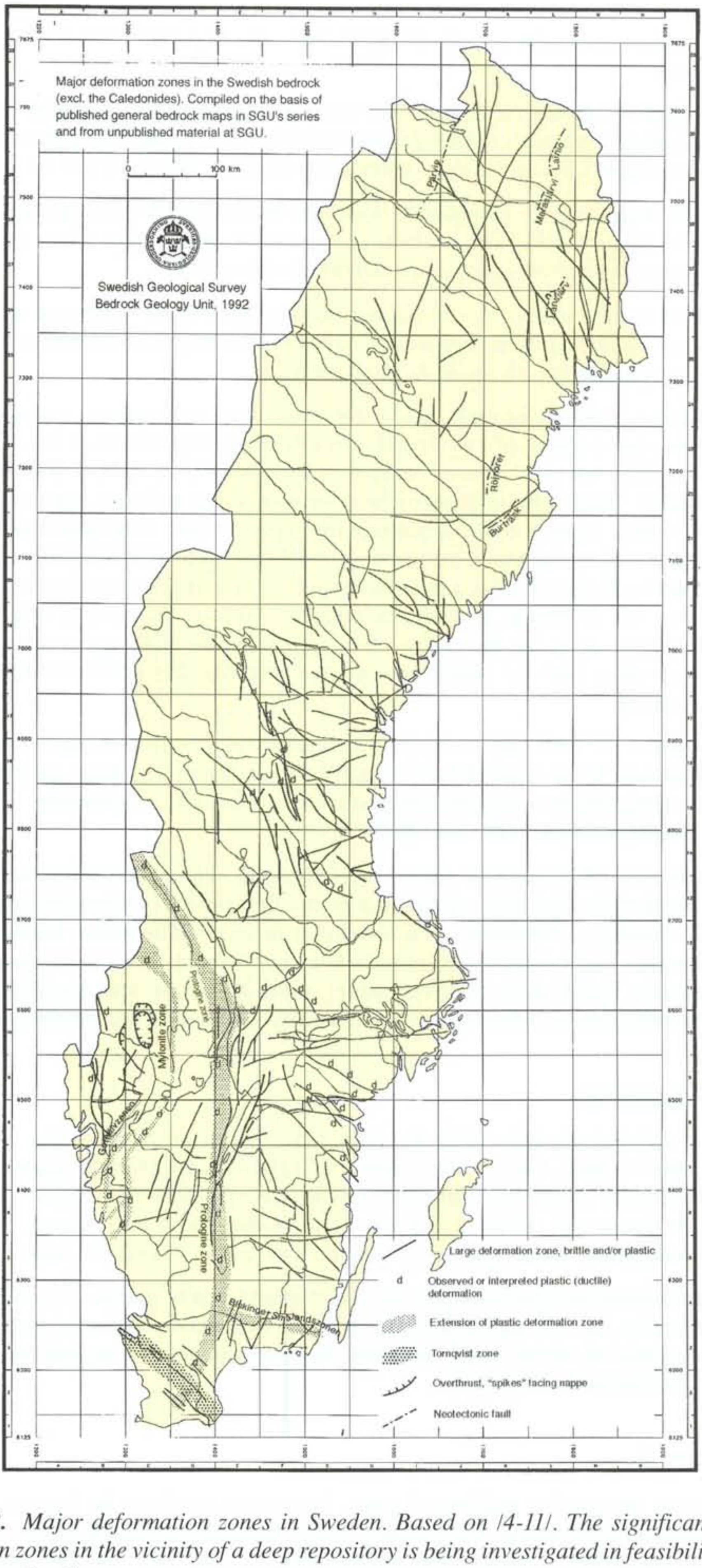

Figure 4-8. *Major deformation zones in Sweden. Based on /4-11/. The significance of the deformation zones in the vicinity of a deep repository is being investigated in feasibility studies and site investigations.*

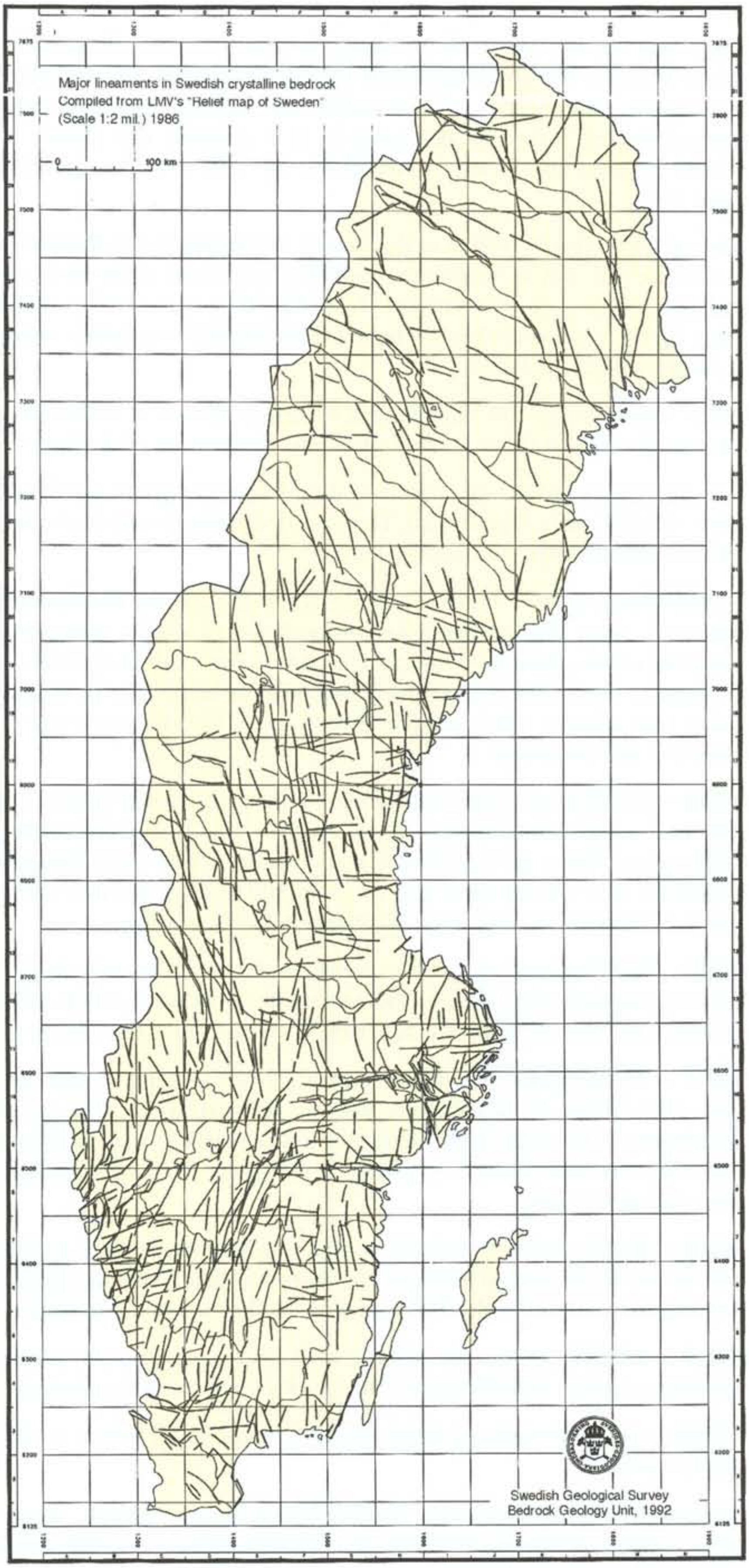

Figure 4-9. Major lineaments in Swedish crystalline bedrock. From /4-11/. The importance of lineaments near a repository is being investigated in feasibility studies and site investigations.

Everything that has been built up during the course of a few thousand years will be buried under ice and gravel and much will be washed out to sea in connection with deglaciation. The ice age will also affect the bedrock, especially the uppermost hundred metres. After the deglaciation, it is possible that people will return. Society requires that the repository should be safe, even for these future generations /4-1/.

What will the climate be like in the future? According to the Milankovich theory, the climate will vary according to the cyclical variations of the earth's movements in relation to the sun, over the periods of 100,000 years, 41,000 years and 21,000 years. The theory has not been completely proven but is currently widely accepted by the scientific community.

If it is assumed that the Milankovich theory is correct, it would be possible to illustrate the impact of the climate variations on the basis of the theory.

The example provided here, concerns the forecasted climate for Stockholm over about 130,000 years, Figure 4-10. The specified times are not exact. However, this does not actually affect the conclusions.

0 – 10,000 years. The climate in Scandinavia will gradually become colder. An ice sheet will cover the Scandinavian mountain range with a maximum extension occurring within about 5,000 years. The earth's crust will be pressed down by the ice sheet by about 300 metres. Stockholm will not be covered by ice but will have a very cold climate with constant ground frost. The sea level will decrease by between 5 and 50 metres.

10,000 – 30,000 years. After a temporary, somewhat warmer period, a new ice age will occur within a maximum of about 20,000 years. At its thickest, the ice will be 1,500 metres. When the ice sheet is at its largest, it will reach Mälardalen. In the Stockholm area, the ice sheet will be about 800 m thick and this will depress the earth's crust in the area by about 60 metres before retreating.

30,000 – 50,000 years. An interim period with a dry and cold climate similar to that of Greenland today. Due to the land uplift, Stockholm will be elevated about 50 metres and the sea level will be about 50 metres below the current level.

50,000 – 70,000 years. The most intense ice age, peaking within about 60,000 years. The whole of Scandinavia will be covered in ice. The ice sheet over Stockholm will be about 2,500 metres thick which will press what is left of the city about 600 metres. When the ice gradually melts, the sea level will rise 100 metres above the current level.

70,000 – 80,000 years. A warmer period. Stockholm will have a climate which corresponds to the current climate in northern Sweden. The land uplift will restore the surface to current levels. The sea will be at the same level as today.

80,000 – 120,000 years. The climate will once again become colder within a maximum of about 100,000 years. The ice sheet will be very extensive.

120,000 – 130,000 years. A warm period with a climate which is similar to the present climate.

An ice age is estimated to have several effects on the bedrock, above all in the upper hundred metres. By locating the deep repository at a depth of 500 m, these surface effects can be avoided.

Studies have also indicated an increase in seismic activity and major movements in the bedrock (tens of metres) in connection with deglaciation. SKB has carried out extensive studies of this in northern Sweden, see e.g. /4-14/, which shows that

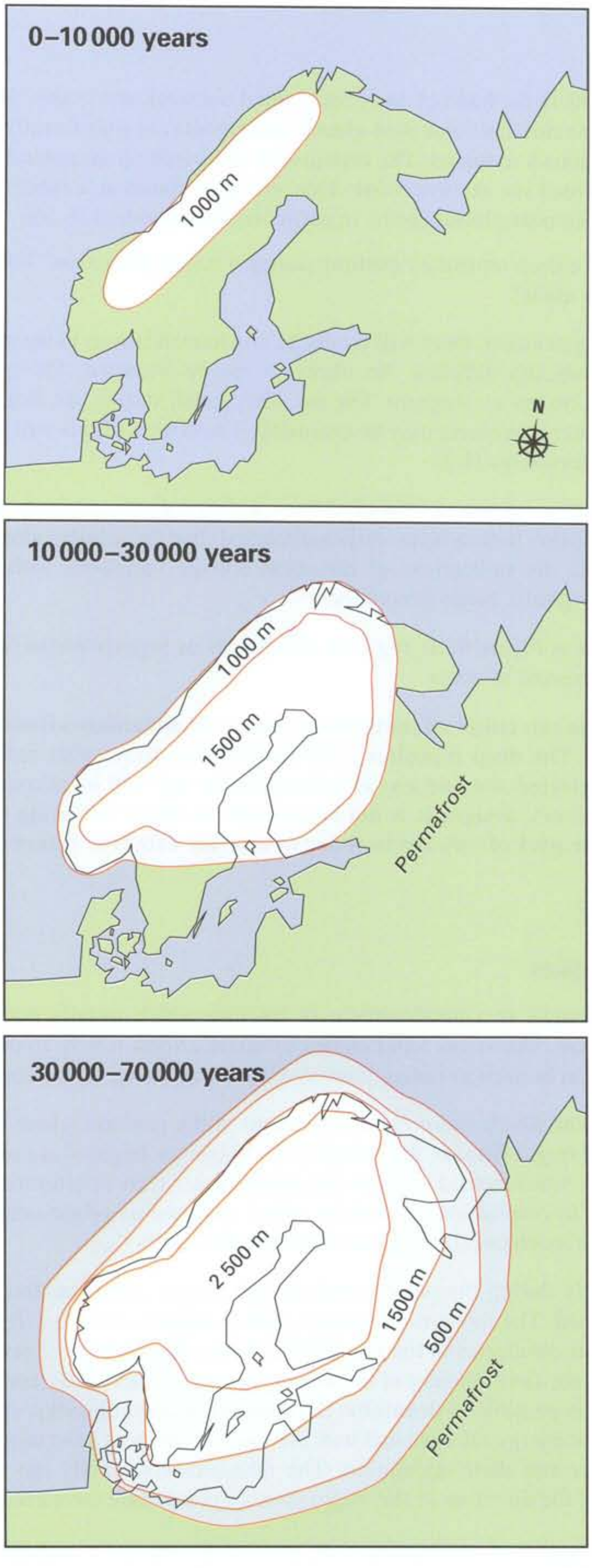

Figure 4-10. *Extension of ice sheet during future ice ages. The current shorelines have been kept as a reference, in spite of the fact that they will change due to variations in the sea level. Based on /4-13/. Regional differences in the location of glaciations should not be taken into account in the siting work.*

movements in the bedrock have reactivated old weakness zones. Some researchers /4-15/ maintain that these post-glacial movements are significantly more extensive than previously assumed. The conclusions are based on interpretations and methodology which are controversial. This was also found at a meeting of experts in 1991 where post-glacial faults, in particular, were studied /4-16/.

How will a deep repository perform during a future glaciation? What requirements should be made?

During a glaciation, there will hardly be any human beings in the area and land use will be radically different. No intrusion can be expected. The groundwater will either be frozen or stagnant. On the other hand, during the deglaciation phase, groundwater movement may be extensive. The effects of this will be studied in the safety assessments /4-1/.

From the perspective of geological time, a closed deep repository at a depth of 500 metres appears to be a better disposal method than "monitored storage", especially since there are indications of historical climate variations with radical climate changes within a single generation.

As shown in Figure 4-10, regional differences as regards where future glaciations can be expected to occur.

An ice age can entail advantages as well as disadvantages from the standpoint of safety. The deep repository will be designed to provide satisfactory safety for the selected site and any effects of the ice age will be taken into account in the repository design. It is not reasonable to allow the siting to focus on any particular part of Sweden in order to take the extent of future glaciations into account.

4.5.4 Earthquakes

An earthquake is a displacement or fracture which usually occurs deep in the earth's crust. The stress relief causes dynamic effects which, in the case of strong quakes, can be seen as noises, movements or fracturing, on the surface.

Earthquakes which cause fault movements at the position where the canisters are deposited might damage the canisters. Earthquakes might also cause new fracture formation which would increase the groundwater flow or alter the chemical environment. In connection with stress relief, movements might occur which would impair the mechanical interaction between the barriers.

It was only during the present century that a basic understanding of earthquakes was reached. The modern instrument used to register seismic activity, the seismograph, was developed in the late 1800's. It was the location of earthquakes which helped in the development of the theory of plate tectonics. By analyzing measurements, it is possible to determine the position of an earthquake, the depth and the quantity of energy released and how the fracture surfaces have moved in relation to each other and their orientation. The measurement results can also be used to determine the direction of the virgin stresses preceeding the earthquake.

The distribution of earthquakes over parts of the northern hemisphere is shown in Figure 4-11.

Several phenomena occur in connection with the release of energy:

- Seismic waves are produced. These lead to dynamic processes on land and in the sea (tsunamis) for earthquakes located below the sea.

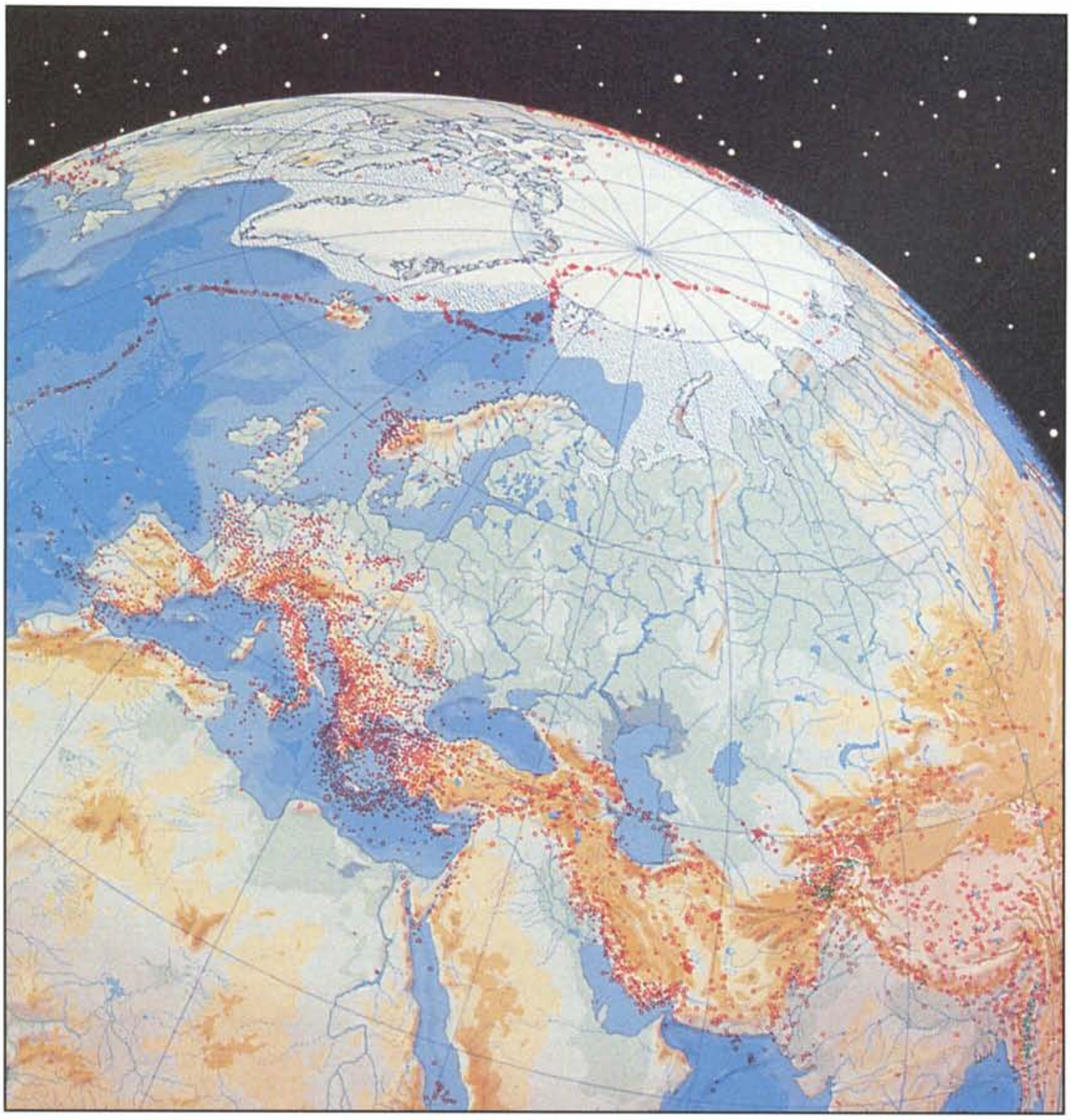

Figure 4-11. *Position of earthquakes registered between 1979 and 1988. Based on /4-17/.*

- The fault surface is displaced by a few millimetres up to several metres (depending on the size of the quake).
- The stresses between the blocks on both sides of the fault surface are reduced.
- The groundwater pressure and fluxes may change. In connection with this, the groundwater chemistry and the composition of the natural earth gases may be temporarily altered.

Earthquakes lead to dynamic processes, especially in the earth's surface. However, the seismic consequences are always less in the rock than on the ground surface, since the seismic movements are considerably lower in the rock than on the surface. From the seismic standpoint, underground facilities are considerably safer than surface facilities. There are many examples of major earthquakes, such as the earthquake in Alaska in 1964, where no underground facilities were damaged, but where the destruction on the surface was extreme, see /4-8/.

The size of the displacement which occurs and the active length of the fault is related to the strength and magnitude of the earthquake. Thus, a normal-sized earthquake for Fennoscandia (a magnitude of 2-3 on the regional scale) corresponds to an average displacement of about half a millimeter over a length of about 1 km; corresponding figures for a large Fennoscandic earthquake (magnitude of 5) are 1 cm and 2 km /4-19/.

For large, global earthquakes, a magnitude of 8 earthquakes corresponds to a maximum fracture length of more than 150 km /4-20/. The observed displacement amounts to more than 10 m for the largest earthquakes, e.g. the above-mentioned Alaska earthquake in 1964.

By reviewing historical documents such as old manuscripts and newspapers from the 1600's and onwards, seismologists have acquired some knowledge of large earthquakes during historical time. The Scandinavian earthquake catalogue starts with an earthquake which occurred in 1375 in Denmark.

Evidence of historical earthquakes (paleoseismicity) can also be found through studies of the soil; there are examples from Sweden where studies of the deglaciation which occurred about 8,000 – 10,000 years ago have shown severe earthquakes, with a magnitude greater than 8, in the northern regions of Sweden.

The most severe earthquake in modern time in Scandinavia originates from Oslo in 1904 with a magnitude of 5,4 on the local Swedish magnitude scale /4-21/. Earthquakes below a magnitude of 1 can, in special circumstances, be registered; normally, earthquakes are registered to a magnitude of 2. As shown in Figure 4-11, few earthquakes occur in Sweden. In Sweden, about 10 earthquakes occur per year, with this magnitude or greater. Figure 4-12 shows the geographical distribution of earthquakes in the proximity of Sweden during the period of 1375–1993, for magnitudes greater than 2.

In Sweden, earthquakes tend to be concentrated along a band from west Sweden and up towards the coast of Norrland.

Earthquakes in Sweden tend to occur at a depth of 5-25 km, with large variations, i.e. usually at much greater depths than the deep repository depth. Individual earthquakes occur at lesser depths, /4-23/. One exception is the mine earthquakes which occur at mines in active operation in connection with stress distributions in the rock. Damage to underground facilities is rare and of less importance in relation to the damage on the surface.

The impact of earthquakes on a deep repository is estimated to be minor, since the intention is to place canisters in rock of good quality. The large structures where earthquakes and displacements usually occur will be avoided. It can be assumed that any changes in flow patterns and groundwater chemistry will be temporary if the earthquakes occur near to the repository. However, the rock's ability to isolate and retard radionuclides will not be basically altered.

As in other areas with few and minor earthquakes, far from plate boundaries, the causes of the earthquakes have not been clearly identified. Two main processes have been specified with regard to earthquakes in Sweden. One is the ongoing land uplift after the last glaciation. The other is the plate tectonic forces with stress transport from the North Atlantic ridge. Both of these processes are probably significant.

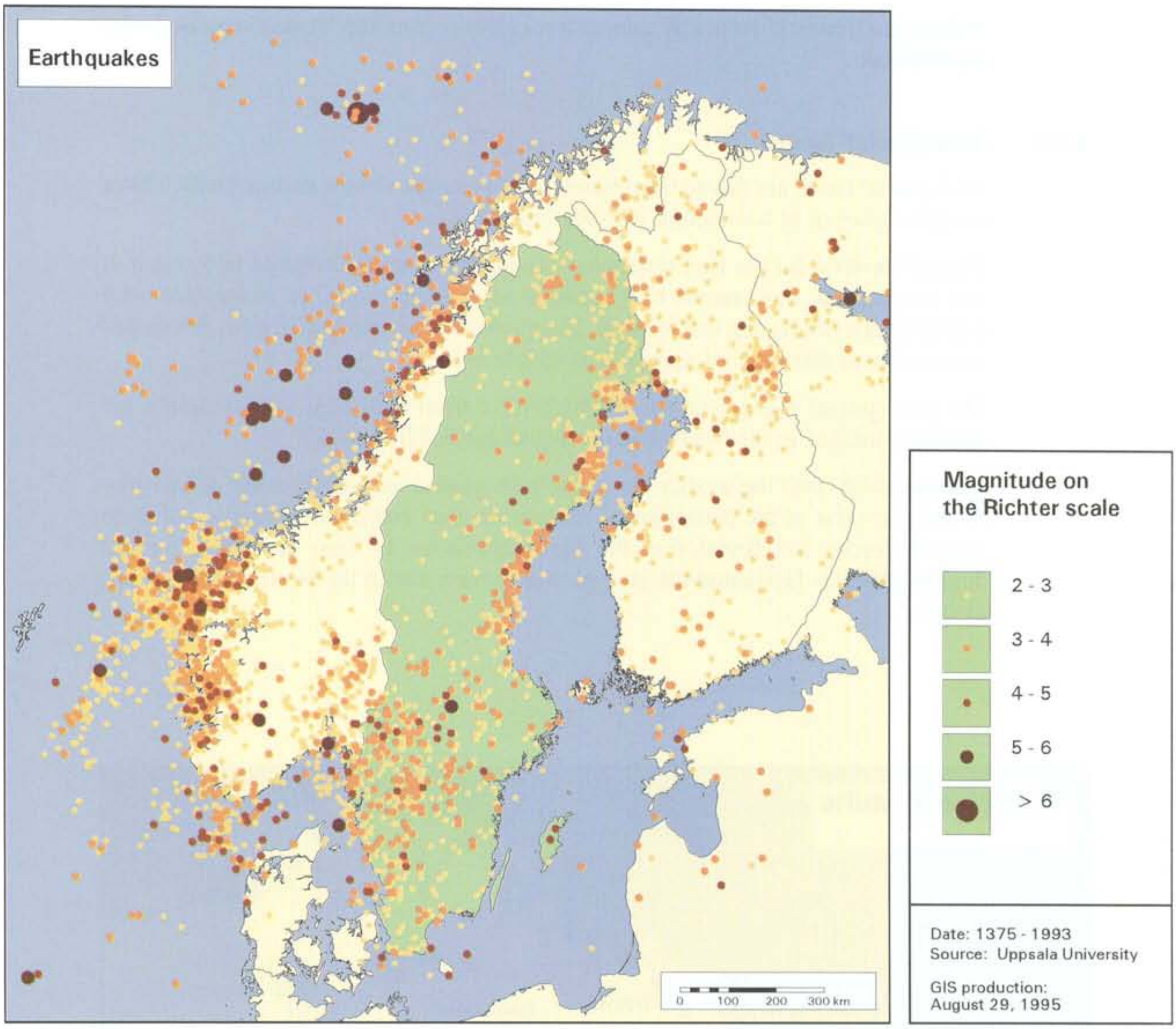

Figure 4-12. Position of earthquakes with a magnitude greater than 2 during the period of 1375-1994. Based on /4-21, 4-22/. The geographical distribution of the earthquakes should not be used as a basis for preferring regions or for excluding regions during the siting process.

Current statistics on earthquakes cover a short period of time, in terms of past geological history as well as in terms of the future timescales connected with a deep repository. The geographical position of the earthquakes in Sweden may alter in the future. The current location of earthquakes does not, therefore, comprise a basis for giving certain regions preference over others or for excluding regions in connection with the siting of the deep repository.

On the contrary, on the local scale, it is very important to avoid zones where possible future movements could occur. If the aim is to prevent the earthquake from damaging the waste, the safest alternative would be to construct an underground repository in good quality rock and to close it. A well-designed deep repository means that there will be a good possibility of protecting human beings and the environment from any radioactive releases from the waste associated with seismic risk.

4.5.5 Post-glacial faults

Post-glacial faults are distinct, permanent displacements in the bedrock which have occurred after or in connection with the last ice age.

During the 70's, for the first time, post-glacial faults were identified in Sweden. It was proven that movements had occurred in existing zones, in connection with deglaciations during the last ice age. The movements exceeded 10 m in places and occurred over distances of several tens of kilometres.

The post-glacial movement zones which have been identified with certainty are currently located in the Northernmost Scandinavia, Figure 4-13.

In connection with the evaluation of the post-glacial movement zone in Lansjärv /4-14/, the view of the participating researchers was that the combination of plate tectonic forces, the direction of the zones in relation to these as well as a rapid deglaciation has facilitated the post-glacial movements in the Northernmost Scandinavia.

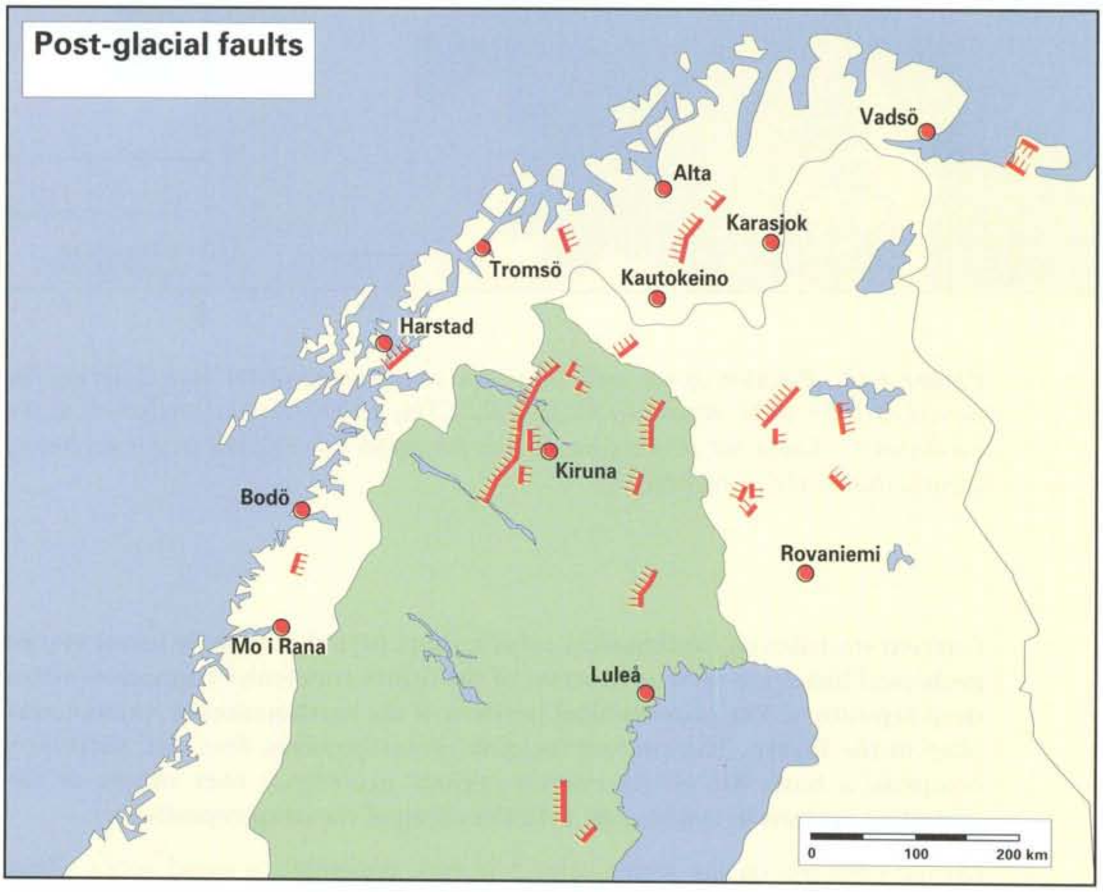

Figure 4-13. Position of post-glacial faults in Northern Europe. Based on /4-24/. The difference in the observed frequency of post-glacial faults between southern and northern Sweden should not be used as a basis for preferring or excluding regions during the siting process.

During the bedrock investigations for the siting of the repository, the possible movement zones of the rock will be located. Regional zones with widths from 50-100 m will be identified at an early stage in the investigations and after more extensive site investigations, zones from 5-50 m in size will be identified. The identification of the position and character of narrower zones can be carried out in connection with the detailed characterizations for a deep repository. SKB's design philosophy is to consider all, particularly distinct zones as possible movement zones which must be avoided in connection with repository design and canister emplacement.

The difference in the observed frequency of post-glacial faults between southern and northern Sweden is not a basis for preferring certain regions or excluding other regions.

4.6 INTRUSION

After the deep repository is closed, how can the knowledge that the repository is there be preserved, so as to avoid unintentional intrusion? Within the framework of the Nordic Council's nuclear safety programme, projects have been carried out to establish rational procedures for preserving such information for future generations, /4-5/. However, it cannot be guaranteed that future generations will be able to preserve the information regarding what has been deposited, how the repository has been constructed or where the repository is located. However, a site for the repository must be selected so that future generations do not run the unnecessary risk of unintentional intrusion 400 – 700 m deep in the bedrock.

An important point of departure in this context is the selection of a site where the conditions are not unique. The rock should be of a common type and not of interest in terms of ore, industrial mineral or groundwater prospecting. The risk of intrusion on account of groundwater prospecting can, in a short-term perspective, be prevented if the deep repository is located in an area with saline groundwater.

Mining and mineral rights in Sweden are shown in Figure 4-14. These indicate the occurrence of existing or assumed ore mineralizations. These deposits are often associated with acid volcanic rock types which are not of interest for hosting a deep repository.

A similar figure is shown in Figure 4-15. However, this concerns industrial minerals and rock types. These are minerals and rock types which are extracted for a purpose other than for their metallic content or value as fuel.

One possible type of intrusion which could occur in future societies is that the "good" rock which is suitable for hosting a deep repository may also be of interest for infrastructures, as yet unknown to us, which such a society may wish to construct deep in the bedrock. Consequently, information concerning the position, design and properties of the deep repository must be kept as efficiently as possible for the future. If future generations can construct advanced underground facilities, they will probably also have knowledge about radioactivity and about how to protect themselves from hazardous radiation.

The issue of future prospecting for groundwater must be assessed on a more local scale.

As was previously mentioned in Chapter 3, investigations on a local scale may provide another picture than that provided on a national scale. This applies to ore and industrial mineralizations as well as groundwater resources. By excluding the

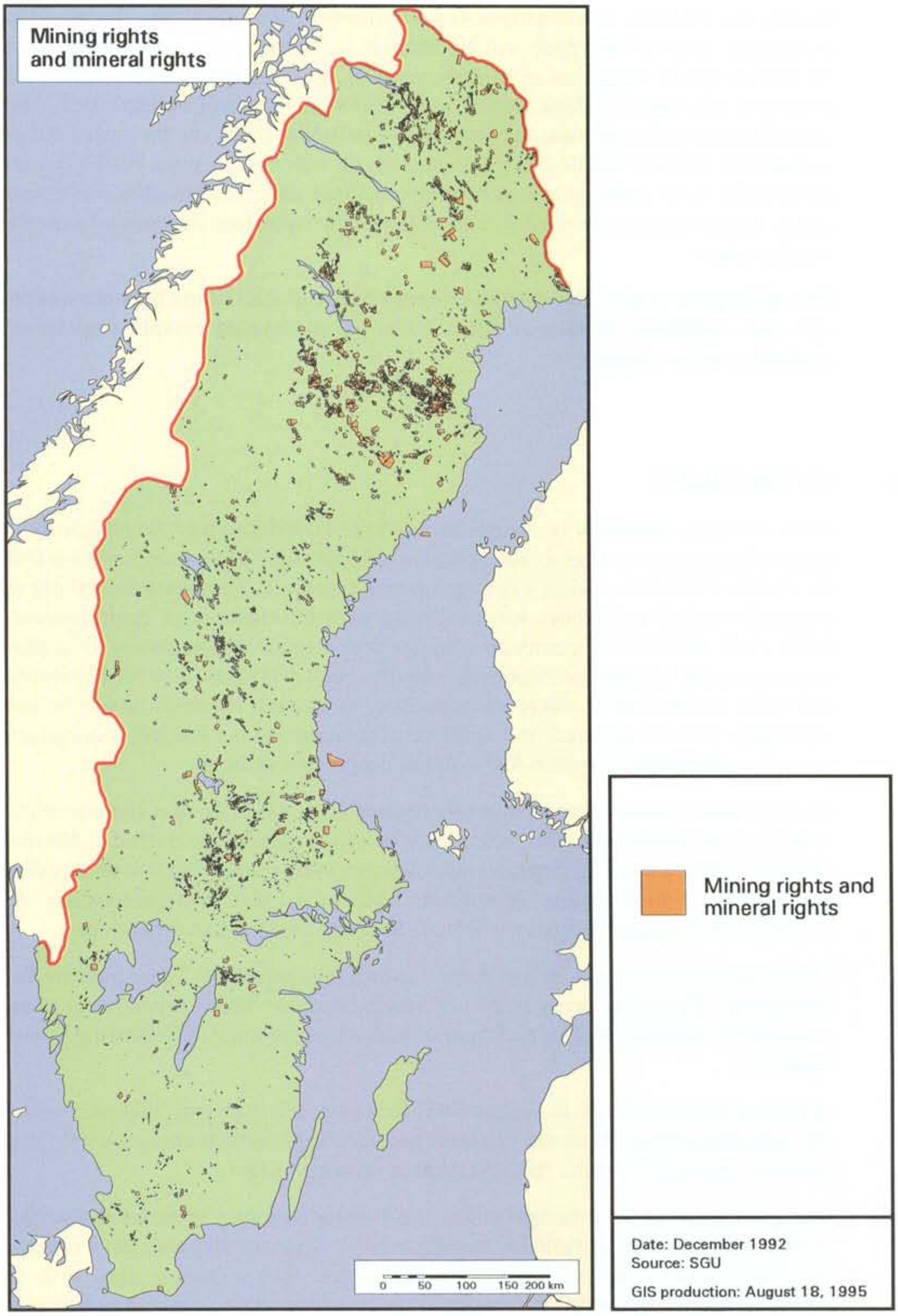

Figure 4-14. *Mining and mineral rights in Sweden. In the regions with extensive mineralizations, the probability of intrusion is a question which must be particularly taken into account.*

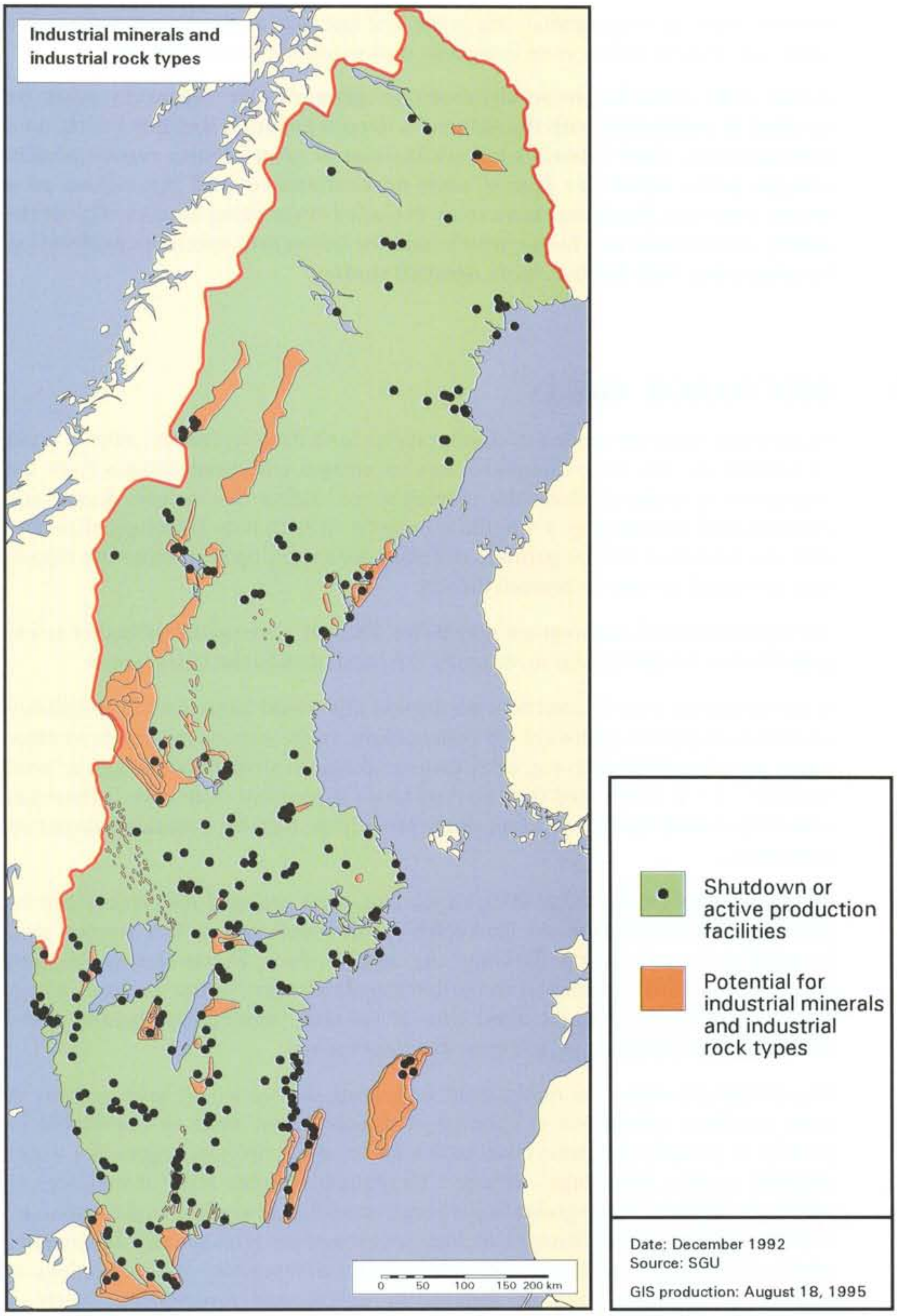

Figure 4-15. *Industrial minerals and rock types in Sweden. Based on /4-2/. In regions with extensive mineralizations, the probability of intrusion is a question which must be particularly taken into account.*

bedrock with e.g. ore potential, and in the first instance, acid volcanic rocks, many good sites may be found, even in regions with extensive mineralizations.

Areas with extensive mineralizations or groundwater resources must be avoided in connection with the siting of a deep repository. Regions which, on a national scale, show extensive mineralizations or groundwater resources may contain areas which are free of such mineralizations and the region, as a whole, does not, therefore, have to be excluded from siting studies. The probability of intrusion is a factor which must be taken into special consideration in connection with further, more detailed studies.

4.7 DISCHARGE AREAS

In principle, there are three possible locations for a deep repository: inland, coast or beneath the sea. Each alternative has advantages and disadvantages from the standpoint of transportation, site investigations, safety assessment, design and planning and construction. From the standpoint of long-term radiological protection, the scenarios will be partially different depending upon whether the repository is located on land or beneath the sea.

The hydrochemical environment may differ. There is a greater likelihood of saline groundwater occurring near to, or under the coast, than in the inland areas.

If the repository were located beneath the sea, this would minimize the probability of certain dispersion pathways for radionuclides in the ecosystem which, in other cases, are often dominant, e.g. early canister damage in combination with a "well scenario", i.e. it is assumed that the food chain is supplied from a well where the water has passed through the repository and which, thereby, contains radioactive substances.

With regard to the future position of the sea, clear regional differences can be distinguished. In Norrland, the land uplift is still significant, up to 9 mm per year. In southern Sweden, near to Blekinge, the land is sinking. However, these changes are relatively small in relation to the large-scale changes in the sea level which occur in connection with ice ages; what is sea now, may become land in a few thousand years and what is land now, may become sea.

The advantages that a site on the coast or beneath the sea would have in terms of extra isolation, retardation or dilution of radionuclides, must be considered in relation to possible problems connected with actually implementing such a waste disposal system. Advantages include a theoretically higher level of radiological safety, no decrease in the groundwater level, as well as fewer real land or environmental conflicts. Disadvantages include investigations with greater uncertainty, which can also affect safety through a more deficient repository design. Geological surface investigations must be replaced by geophysical investigations such as reflexion seismics which may be difficult to interpret for small depths of water. Since no drop in the groundwater surface level occurs beneath the sea, rock engineering and detailed characterizations will be carried out under higher water pressures than in the case of an inland siting. This will require development of technology in some details. However, the differences between inland siting and sub-seabed siting are minor and may be compensated for by locating the repository maybe a hundred metres deeper in the bedrock.

Moreover, the government in its decision concerning R&D Programme 89, /4-26/, states: *"The government wishes to maintain that, in its view, the alternatives with deep boreholes and long deposition tunnels beneath the Baltic seabed, which SKB* *is studying, appear to be less suitable."* After this statement was made by the government, SKB has not pursued its studies of sub-seabed deep disposal.

One general conclusion is that there is no reason to particularly seek or particularly avoid sub-seabed siting of the deep repository.

4.8 OVERALL EVALUATION

In many areas in Sweden, the bedrock is suitable for hosting a deep repository. However, in order for an overall evaluation of the long-term radiological to be made, site-specific data concerning the bedrock conditions must be available. Such data can only be obtained through extensive investigations being carried out at sites which must be selected on a the basis of partially incomplete data. This is a characteristic which distinguishes the siting of underground facilities in general, and a deep repository in particular, from other types of industrial siting (surface facilities), where information on all of the vital factors is relatively easy to obtain.

The survey and evaluation of processes and phenomena which has been made indicates that sufficiently detailed information will emerge, primarily within the framework of feasibility studies and site investigations.

The report provided in this chapter concerning certain geoscientific factors shows that:

- **Large parts of Sweden's crystalline bedrock are interesting for further siting.**
- **Occurrences of gabbro and bedrock covered with sedimentary rock may also be of interest in siting. However, there is no reason to particularly seek out this type of bedrock.**
- **The Scandinavian mountain range (Caledonides), Skåne and Gotland consist of sedimentary bedrock which is not of interest in siting.**
- **Acid volcanic rock and certain other types of rare rock types are not of interest in terms of intrusion or the management of natural resources.**
- **There is no reason to exclude regions on the basis of regional differences in topography.**
- **There may be many interesting areas in regions where the specific well capacity is low, in terms of low groundwater flow in the bedrock. However, regions where the well capacity is high in crystalline bedrock cannot be excluded, since high values may be due to the impact of local ice ages in the upper regions of the bedrock. Furthermore, the variations are considerable, which means that it is possible to find areas with low groundwater flow in a region with a generally high specific well capacity and vice versa.**
- **The position of the Highest Shoreline cannot be used to distinguish between suitable or less suitable regions in Sweden.**
- **Complex deformation zones are significant from the standpoint of siting. These areas should not be high priority areas for siting. However, areas located at or near deformation zones cannot be excluded until field investigations have been carried out.**
- **An ice age may entail advantages as well as disadvantages from the standpoint of safety. It is not reasonable to allow the siting work to focus on a**

particular part of Sweden, in order to take into account the extent of future glaciations.

- The known geographical distribution of historically known earthquakes is not a basis for preferring one region over another or for excluding regions in connection with the siting of a deep repository.
- The difference which exists with regard to the observed frequency of post-glacial faults between southern and northern Sweden is not a basis for preferring certain regions or for excluding other regions.
- Areas with extensive mineralizations or groundwater resources must be avoided in connection with the siting of a deep repository. Regions which, on a national scale, show extensive mineralizations or groundwater resources may contain areas which are free from these and the region, on the whole, does not have to be excluded from siting studies. The probability of intrusion is a factor which must be taken into special consideration in connection with further, more detailed studies.
- One general conclusion is that there is no reason to particularly seek or particularly avoid siting of the deep repository beneath the seabed.

5 TECHNOLOGY - EVALUATIONS ON A NATIONAL SCALE

Issues related to technical feasibility are primarily discussed in this chapter. Part of this feasibility is the maintenance of radiological safety in connection with transportation and the operation of the deep repository.

The properties of the site affect the possibility of interpreting site investigations, of conducting reliable performance and safety assessments and of designing and constructing the repository. The factor of technology cannot be disassociated from the issue of the long-term safety of the repository.

The aim of the siting of the deep repository is to locate a site where the technical feasibility is relatively straightforward and where the results of the site investigations are easy to interpret. However, for a more complex site, it may be possible to reach the same level of reliability, although with longer implementation times and at a higher cost. The technology is flexible and can be adapted to special requirements. The technology is optimized taking into account performance requirements, environment and cost.

In this study, how the selection of a site affects the cost of the deep repository is not discussed, since the cost is a complex parameter, composed of several factors which cannot be evaluated in this general siting study.

5.1 GENERAL

The long-term safety of the deep repository is determined by:

- the selected system of engineered barriers,
- the selected site,
- the selected method of locating and constructing the repository in the rock,
- the technology and quality selected for implementing the disposal system.

There is a clear link between the selected technology and the safety assessment; the safety assessment must analyze the long-term safety of the repository, as it will be constructed in practice. Coordination between the safety assessment and technology can thus mean that technology which is easier to evaluate is selected, or that technology and methods are avoided which make safety assessment difficult.

It is essential that known and tested technology should be used so that the feasibility of the selected technology can be predicted. The technology which will be needed for the deep repository will be evaluated at e.g. the Äspö Hard Rock Laboratory.

Specific technical issues concerning transportation, the industrial area and the actual deep repository will be evaluated in the general siting studies, where possible. Which factors are favourable to, or make the work of design, construction and operation of the deep repository difficult? Which factors can affect the performance of the deep repository?

5.2 TRANSPORTATION

The transportation system must handle two main types of goods, namely heavy units with encapsulated fuel and other long-lived waste as well as loose goods in the form of sand and bentonite clay which are necessary for the repository closure.

The heavy units are specially designed transportation containers for encapsulated fuel, moulds as well as similar containers for other types of waste. The total number of units which will be received at the repository is estimated at just over 300 per year. The transportation containers which are currently used for transportation between the nuclear power plants and CLAB are designed for the transportation of spent nuclear fuel which has been stored for a number of months after removal from the reactor. The transfers to the deep repository will consist of 30 to 40-year old fuel, of which the radioactivity will be about 10% of the level of radioactivity that the fuel had when it arrived at CLAB. Furthermore, during the transportation to the deep repository, the fuel will be encapsulated in a canister. Altogether, this means a lower level of radiation and a lower level of heat compared with the transfers made today. Consequently, the design of the transportation containers will be adapted to this situation. A transportation container with a copper canister is estimated to weigh about ca 55 tonnes.

Core components and other waste with long-lived radioactivity from the operation and decommissioning of the nuclear power plants, encapsulation plant and research reactors at Studsvik, will be deposited in the deep repository. Most of the waste will be cast in concrete moulds. Since this type of waste also requires some radiation shielding, it will be transported in containers made of steel, weighing 65 tonnes, including waste. The total quantity of other long-lived waste which is to be deposited in the deep repository is estimated at about 20,000 m^3.

The quantity of backfill material which will be transported to the deep repository will be a maximum of about 45,000 tonnes of sand and 15,000 tonnes of bentonite clay per year. The possibility of re-using the crushed rock which is produced in connection with tunnel excavation in the repository is currently being studied. This will eliminate the need for transporting sand over long distances as well as diminish the need for land for the waste rock reclamation area. Bentonite clay can be imported from many countries, including the USA and the Mediterranean area. The need corresponds to about 18 containers per week on average, for 40 weeks per year. Ordinary bulk ships can transport sand and bentonite to local harbours, about 10 shipments per year. Since the backfill material is shipped in large quantities, a buffer must be kept at the harbour.

The transportation of radioactive material is currently regulated by three acts, in particular, the Act concerning the Transportation of Hazardous Goods, the Act on Nuclear Activities and the Radiation Protection Act. A large number of regulations are connected to these acts. The permits required and the safety requirements which must be fulfilled are stipulated in these acts. The regulations are largely based on rules which have been drawn up and agreed upon internationally.

The system for planning and implementing transportation which is currently used, has been found to work well. Thus, it is natural to assume that transportation to the deep repository will be organized in a similar manner. It is less important whether the transportation to the deep repository entails longer overland times than is currently the case, since the important factors from the standpoint of safety, both with regard to the organization of the transfers and the technical design, are the same regardless of the means of transportation. Even if radioactive goods are not currently transported by land or by rail to any great extent, the transportation of other hazardous goods occurs, and this is, therefore, nothing new for railway or road traffic.

With regard to transportation by road, restrictions exist with regard to weight. Larger roads are classified for a maximum of 60 tonnes. The goods which will be transported to the deep repository are up to 110 tonnes in weight, thus, transportation by road would require a waiver of existing restrictions or reinforcement of roads or bridges.

Transportation by ship or railway is a main alternative for long-distance transportation.

Figure 5-1 shows the railway network in Sweden in 1994. Furthermore, the picture also shows which areas can be accessed within a distance of 20 and 70 km from the network. Within a zone of 70 km, the whole of Sweden is covered, in practice. Within a distance of 20 km, there are parts, above all in the inland regions of Norrland which are not covered. Links between the existing railway network to the deep repository can be made by roads which are classified for the heavy loads in question, or by extending the railway network.

Transportation from an encapsulation plant to the deep repository can also occur by ship. Figure 5-2 shows harbours in Sweden with a depth of more than 6 m. From the figure, it can be seen that there are suitable harbours along large parts of the coast picture of Sweden.

In conclusion:

- **The goods must be transported so that the safety requirements are fulfilled. Transportation licences will be preceded by detailed assessments of the safety and environmental impact at the proposed repository site.**
- **It would be favourable if existing infrastructure for transportation by sea and land can be used.**
- **It would be unfavourable if extensive new investments are required and if new harbours, roads or railways are in conflict with other important land use interests.**
- **The current railway network and existing harbours do not lead to any essential limitations on a national scale for the siting of a deep repository. Consequences of minor extensions of harbours, railways, roads cannot be assessed on a national scale. Each individual component that is constructed can contribute to the development of society within an area, and this must be viewed against the perspective of environmental consequences and alternative land use.**

5.3 INDUSTRIAL AREA, WASTE ROCK RECLAMATION AREA

A general description of the components of the deep disposal system is provided in Section 2.2.

A schematic diagram of the industrial area at the deep repository is provided in Figure 2-2.

The detailed siting and design of the industrial area and waste rock reclamation area will be carried out in connection with feasibility studies and site investiga-

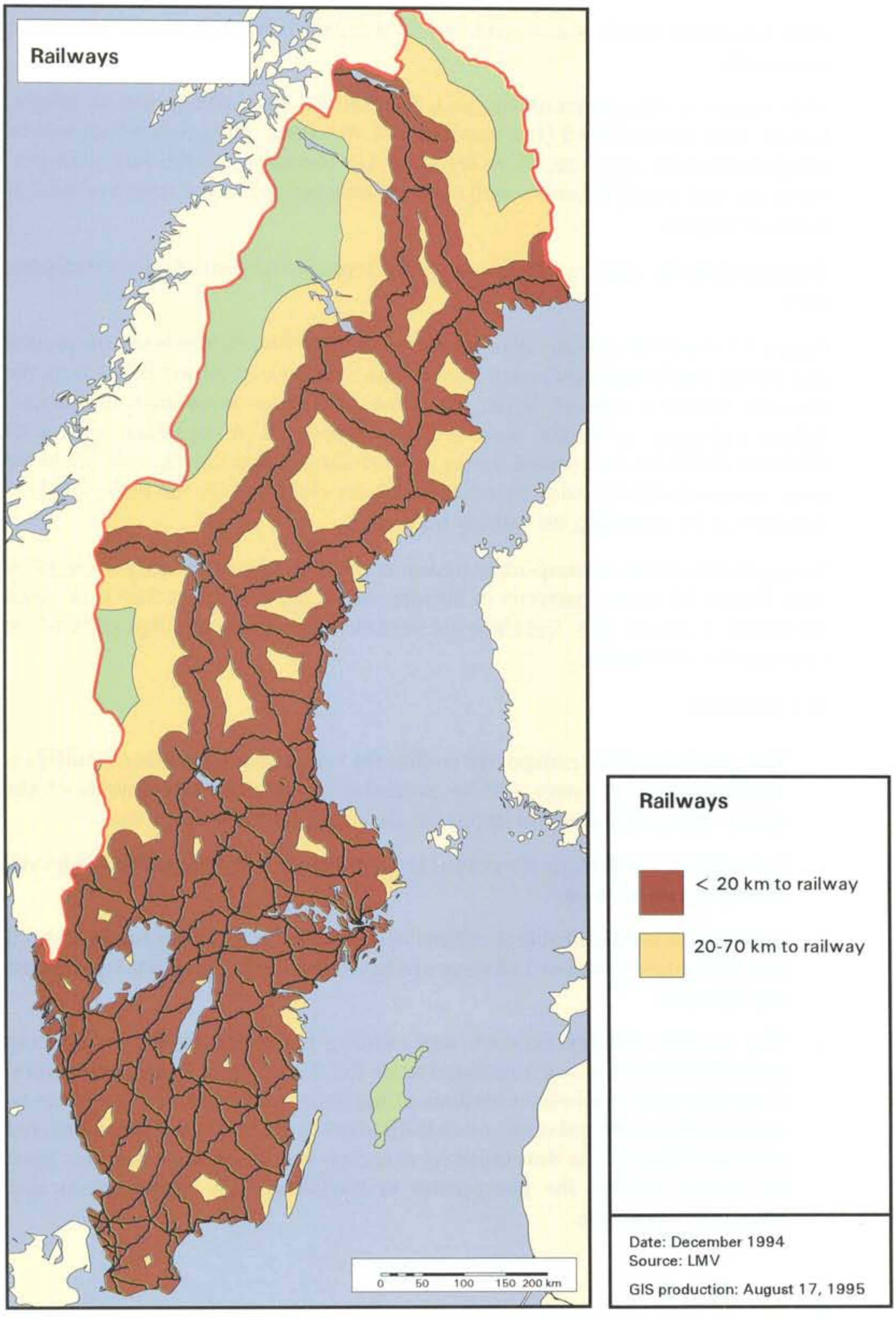

Figure 5-1. *Railway network in Sweden, 1994. On certain lines, there is no longer any traffic. The areas which can be reached within a distance of 20 and 70 km from the railway network are also shown. On the national scale, the railway network does not present any limitations with regard to siting.*

Figure 5-2. *Harbours in Sweden which are more than 6 metres deep. Based on /5-1/. The availability of harbours is good and, on a national scale, this does not present any limitations with regard to siting.*

tions. Specific requests from a technical standpoint are flat land with a sufficient bearing capacity. No evaluation is possible on a national scale.

5.4 UNDERGROUND FACILITY

The underground repository facilities consist of a central part with ventilation buildings, workshops, personnel rooms, offloading bays for transportation containers, tunnels for the transportation and deposition of canisters containing spent nuclear fuel as well as rock cavities and tunnels for other long-lived waste.

Safety assessment and repository design are carried out interactively with investigations of the bedrock at the site. From the standpoint of safety as well as implementation, it is advantageous if the rock is relatively low-conductive. The permeability of the rock is discussed in Section 4.4.2 and the conclusions there can also be applied to technical evaluations.

During construction and operation, it is important that the rock is mechanically stable. This factor cannot be evaluated on a national scale, since site-specific data on stresses and rock strength are required for stability assessments. Aggressive water will affect the selection of material for installations and is, above all, a question of cost.

The implementation of site investigations, detailed characterizations, repository design, performance and safety assessments is facilitated if the rock investigations at the site are easy to interpret. The aim of the next section is to investigate whether there may be regional differences in interpretability between different regions for certain properties.

5.4.1 Rock investigations

The design of the repository and implementation of the safety assessment are dependent upon the correct acquisition and interpretation of data concerning the properties of the site.

In general, there may be sites which enable interpretations to be rapidly made with certainty or sites which require very extensive investigations in order to attain a corresponding level of reliability in the interpretations. The aim is to find a site where the interpretation of data and the technical feasibility is simple, although even more complex sites can be accepted. Regardless of the extent of the investigations, there will always be properties in the rock which cannot be established by deterministic methods; in such cases, different statistical distributions of the variation of the properties must be determined.

Investigations of a site will be carried out in several stages, from initial investigations of the surface, to extensive drilling and borehole measurement programmes which will also be carried out in stages. After a basic understanding of the site has been obtained, SKB will apply for a permit to carry out detailed characterizations, if the site is found to be suitable. These characterizations will be carried out in connection with the construction of an access ramp or shaft to the intended repository depth.

As the detailed characterizations are carried out, a more detailed repository design will be developed, based on the data obtained. This is also the case with regard to the safety assessment where increasingly detailed models of the properties and conditions at the site will be successively analyzed.

If the site is complex, or difficult to investigate and interpret, the possibility of the interpretation being altered through additional data will increase. This will have an impact on the repository design and safety assessment which, to a certain extent, will then have to be reviewed.

The philosophy should be, in the first instance, to aim for sites which are easy to investigate and interpret.

The certainty of interpretation, at an early stage, can be facilitated by ensuring that:

- the bedrock is not covered by soil or sediment,
- the variations in the properties of the bedrock within the repository area are small,
- the frequency of discontinuities which determine repository design, i.e. possible zones of movement, fracture- and crush zones etc. is low,
- interpretations of the ground surface should be possible to extrapolate down to repository depth.

These factors are treated as follows:

Soil cover and soil depth

Figure 5-3 provides a simplified view of where in Sweden the bedrock is exposed or where the soil cover is thin or not coherent. Large local differences exist and even within areas where there is a low degree of exposure, there are areas with well-exposed bedrock.

Figure 5-4 is a supplementary picture showing wells with a greater depth than 20 m, on a national scale. The large soil depths exist particularly in ridges and in river valleys. For large soil depths, there will be practical problems in connection with rock drilling and the tunnel entrance construction. Since areas with large soil depths are of less interest for repository siting, this can be taken into consideration in connection with feasibility studies.

Areas with a good exposure of the bedrock may be advantageous. However, areas with a low degree of exposure cannot be excluded on account of local variations.

Homogeneity of the bedrock

As was previously mentioned in Chapter 3, there are large limitations with regard to the possibility of establishing homogeneity on the local scale. It may be the fact that the variations within one area are greater than the difference between the areas. In spite of this limitation, examples of variations for some available types of data are provided. These variations must be primarily considered to be illustrative. However, they are still expected to be of some interest in this connection.

Rock types

A map of the bedrock on a national scale shows regional differences in, e.g. the number of rock types within different regions, Figure 5-5. A deep repository which only takes up a surface area of a couple of square kilometres can probably with certainty be laid out so that the actual repository is located in one and not several different main rock types. On the local scale, there may be large variations in the

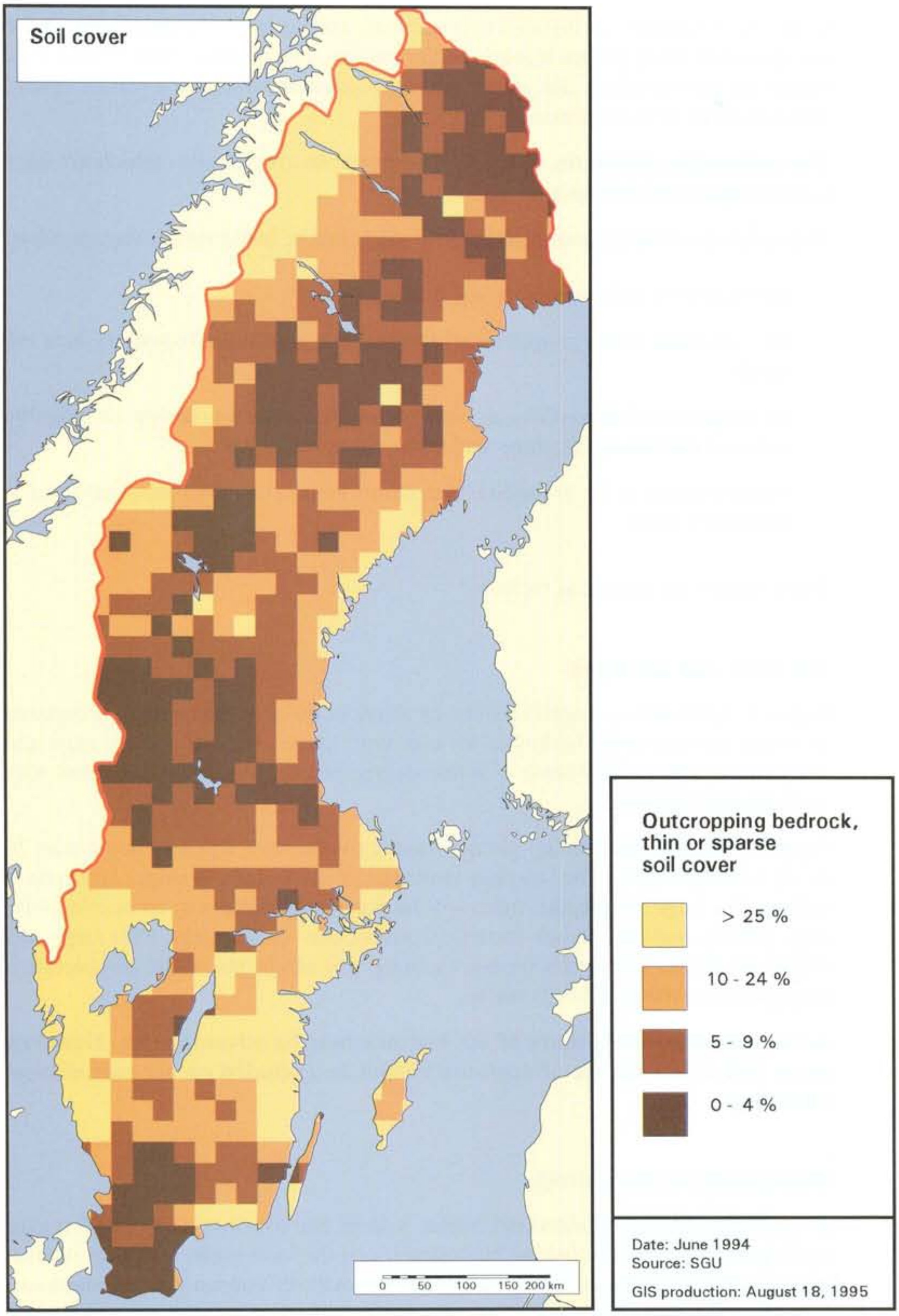

Figure 5-3. *The extent of areas with outcropping bedrock, thin or sparse soil cover. Based on /5-2/. The class limits have been determined so that each class corresponds to about 25% of the surface area of Sweden. The local variations are significant. Areas where soil-covered bedrock is common, cannot be excluded from the siting process.*

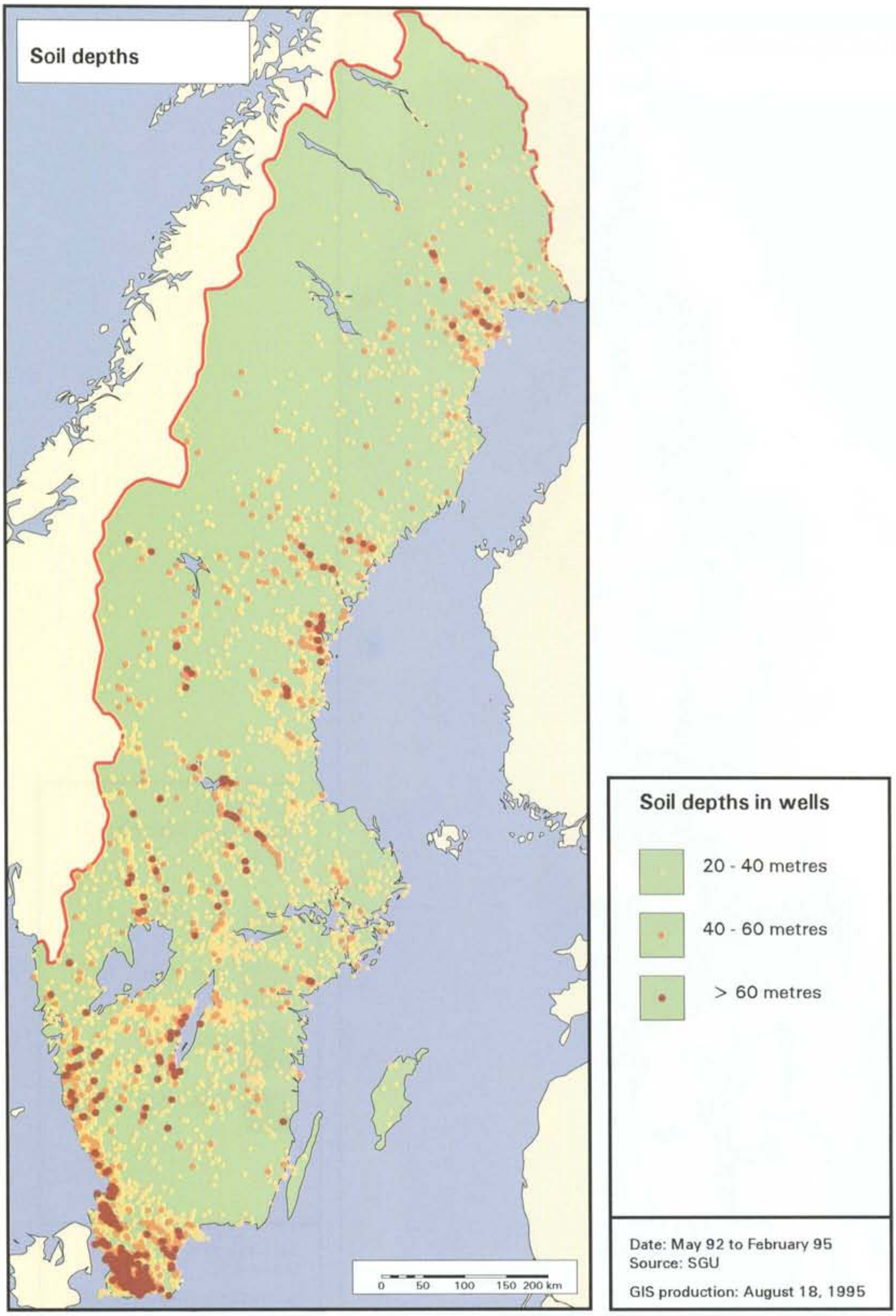

Figure 5-4. *The location of wells with soil depths greater than 20 m. Based on SGU's well archive.*

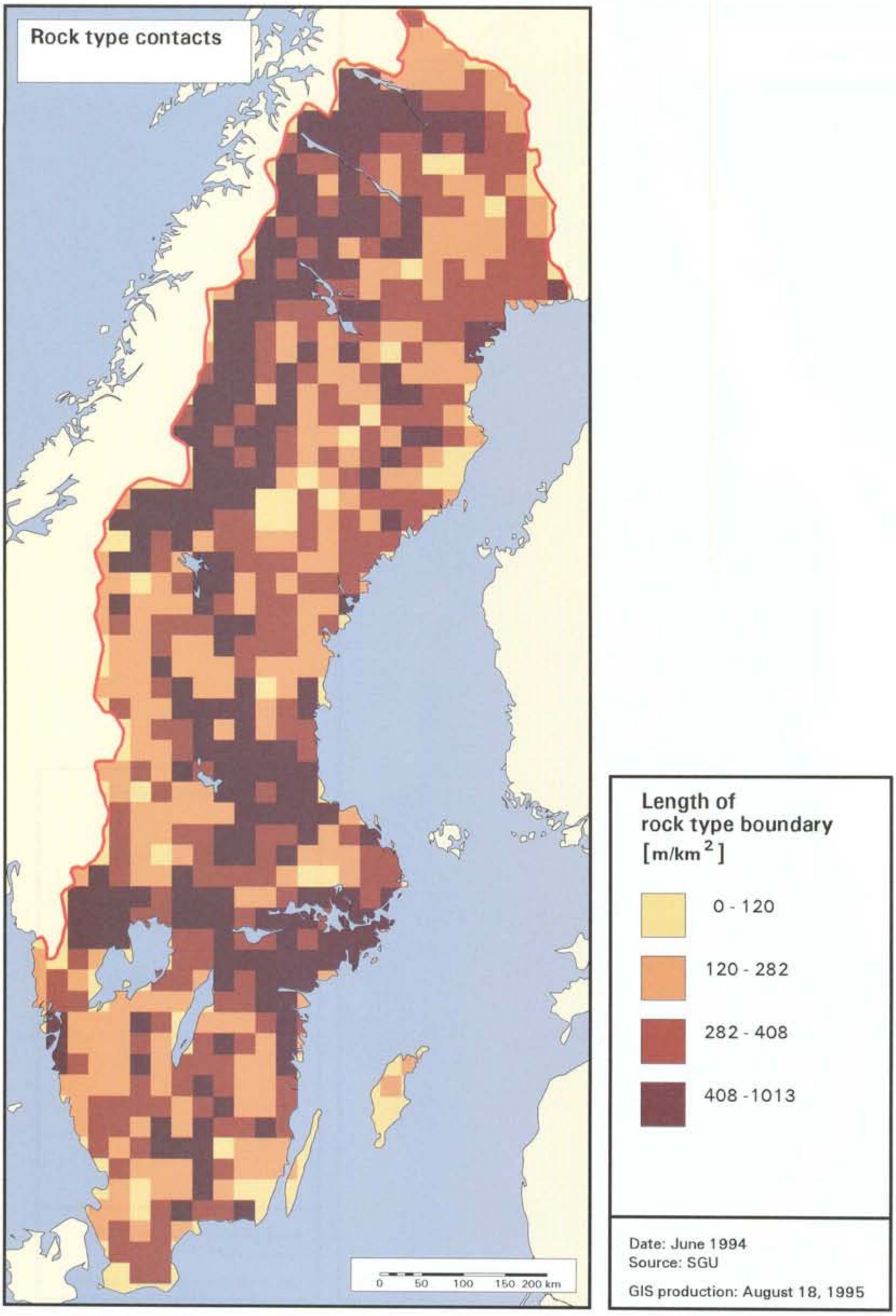

Figure 5-5. *Map of the length of the boundaries between different rock types per 25x25 km topographical sheet. Based on /5-2/. Regions which, on a national scale, contain many different main rock types do not have to be excluded.*

properties of the main rock types which are closely investigated during the site investigations.

There is no reason to exclude, on a national scale, areas with many different main rock types within a single region.

Airborne magnetic map

Through airborne measurements, a relatively complete picture has been obtained of magnetic variations caused by the bedrock. The magnetic variations often show lithological variations as well as variations which are due to fracture zones in the bedrock; it is often the case that the zones are low magnetic in relation to the environment.

The airborne magnetic map mainly consists of a grid with a pixel size of 40 m 200 m. The map has then been processed so that the "homogeneity" was estimated with the help of special mathematical texture filters /5-3/, Figure 5-6. It was then processed so that the mean value of the homogeneity was estimated for each topographical map sheet, Figure 5-7.

Regional differences exist with regard to magnetic homogeneity, with low homogeneity in the northernmost parts of Sweden and parts of Småland and Halland. A deep repository which only takes up a surface area of a few square kilometres can certainly be located so that the repository is situated in a relatively homogeneous formation. The magnetic conditions of the bedrock will be more closely investigated in connection with the site investigations.

There is no reason, on a national scale, to prefer or exclude areas on the basis of the magnetic homogeneity.

Well data

As was previously mentioned, the conductivity of the rock varies considerably and the variations are on several orders of magnitude within one site. Figure 5-8 shows how the standard deviation (^{10}log) for the specific well capacity varies over Sweden.

On a national scale, there are regional differences in the standard deviation of the specific well capacity.

On a national scale, there is no reason to prefer or exclude areas on account of the variation in the distribution of the well data.

Deformation zones, lineaments

From the standpoint of the repository, it is better to avoid areas with many zones. If the density of lineaments is a measure of the number of zones in the bedrock on different scales, it may be relevant, on a national scale, to compare the distribution of lineaments in Sweden. The lineament map in Figure 4-9 has therefore been processed so as to estimate the lengths of lineaments per topographical map sheet. As can be seen from Figure 5-9, the lineament density varies between different regions. It should be noted that areas with considerable soil depths and flat terrain may be underrepresented such as parts of upper Norrland.

The difference in lineament density which exists on the national scale is not a basis for excluding regions with a high lineament density or for classifying regions with a low lineament density as being of interest.

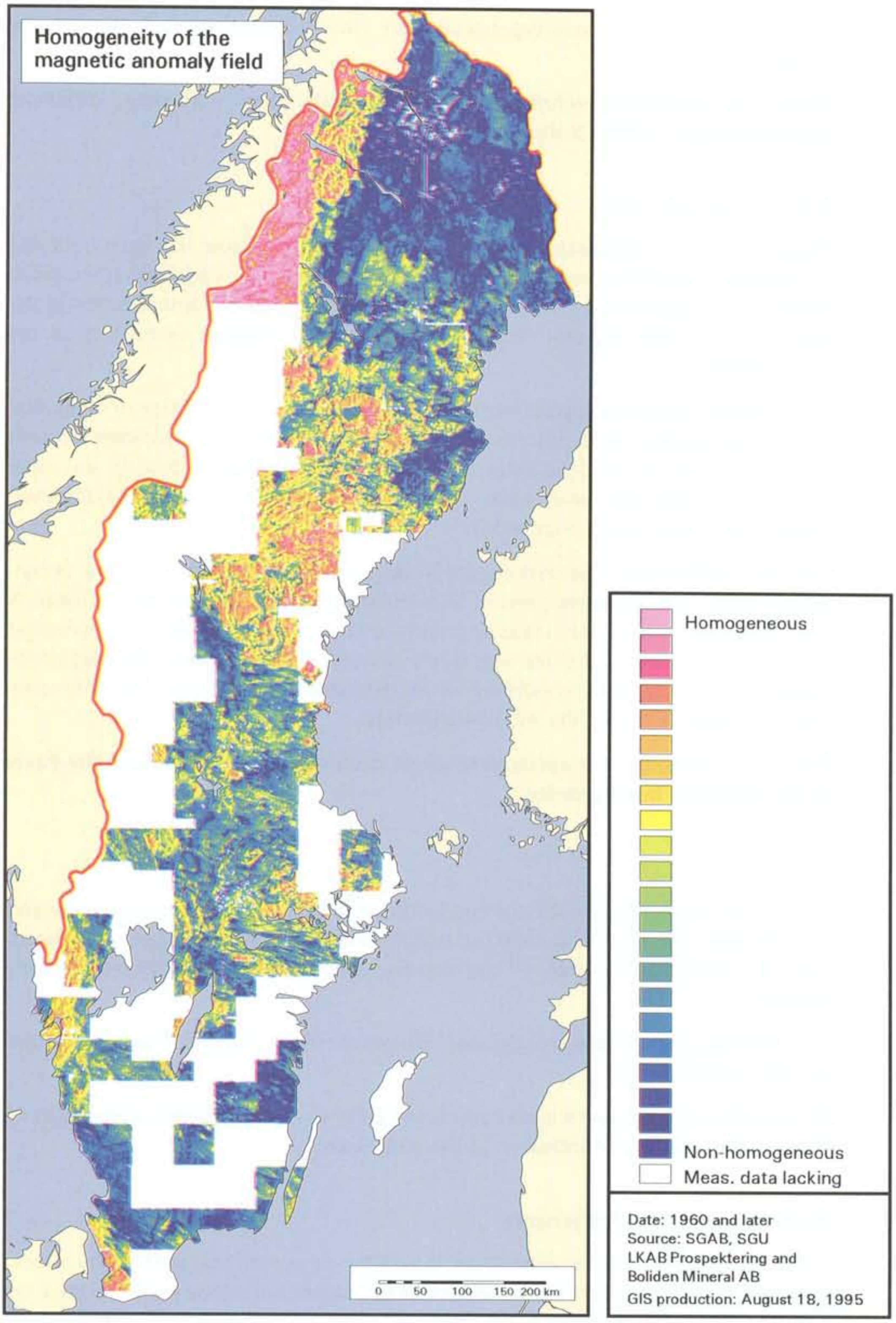

Figure 5-6. *"Homogeneity" on the basis of the airborne magnetic map. Parts of the Caledonides appear to be homogeneous, although this is dependent on the flying altitude over the terrain. From /5-3/.*

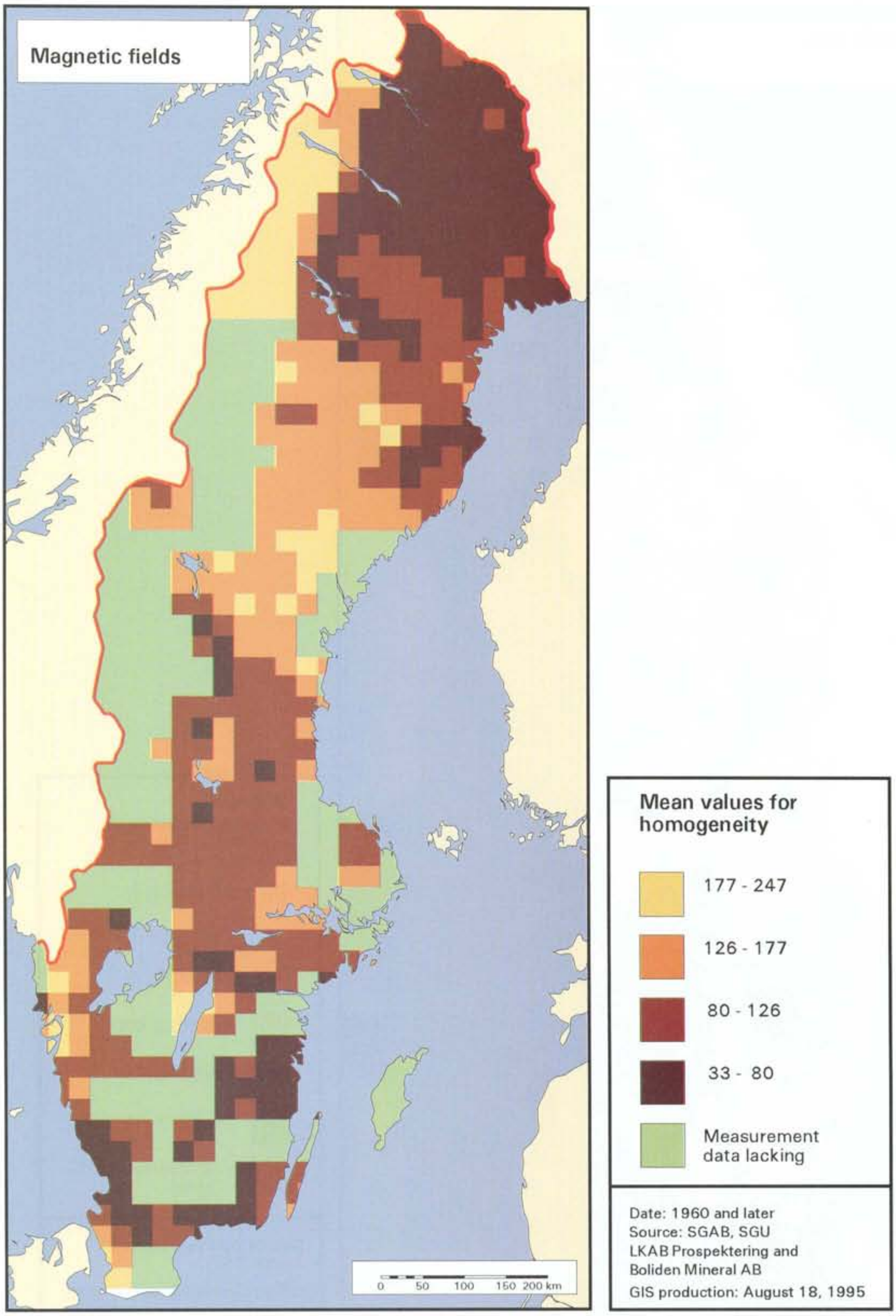

Figure 5-7. *Mean values of homogeneity based on the airborne magnetic map. The unit of the magnetic homogeneity is in inverse proportion to nano Tesla. Low values indicate low homogeneity, i.e. a large variation in the magnetic properities of the bedrock. Class limits are determined so that each class corresponds to about 25% of the surface area of Sweden. There is no reason to prefer or exclude areas on the basis of the magnetic homogeneity on a national scale. From /5-3/.*

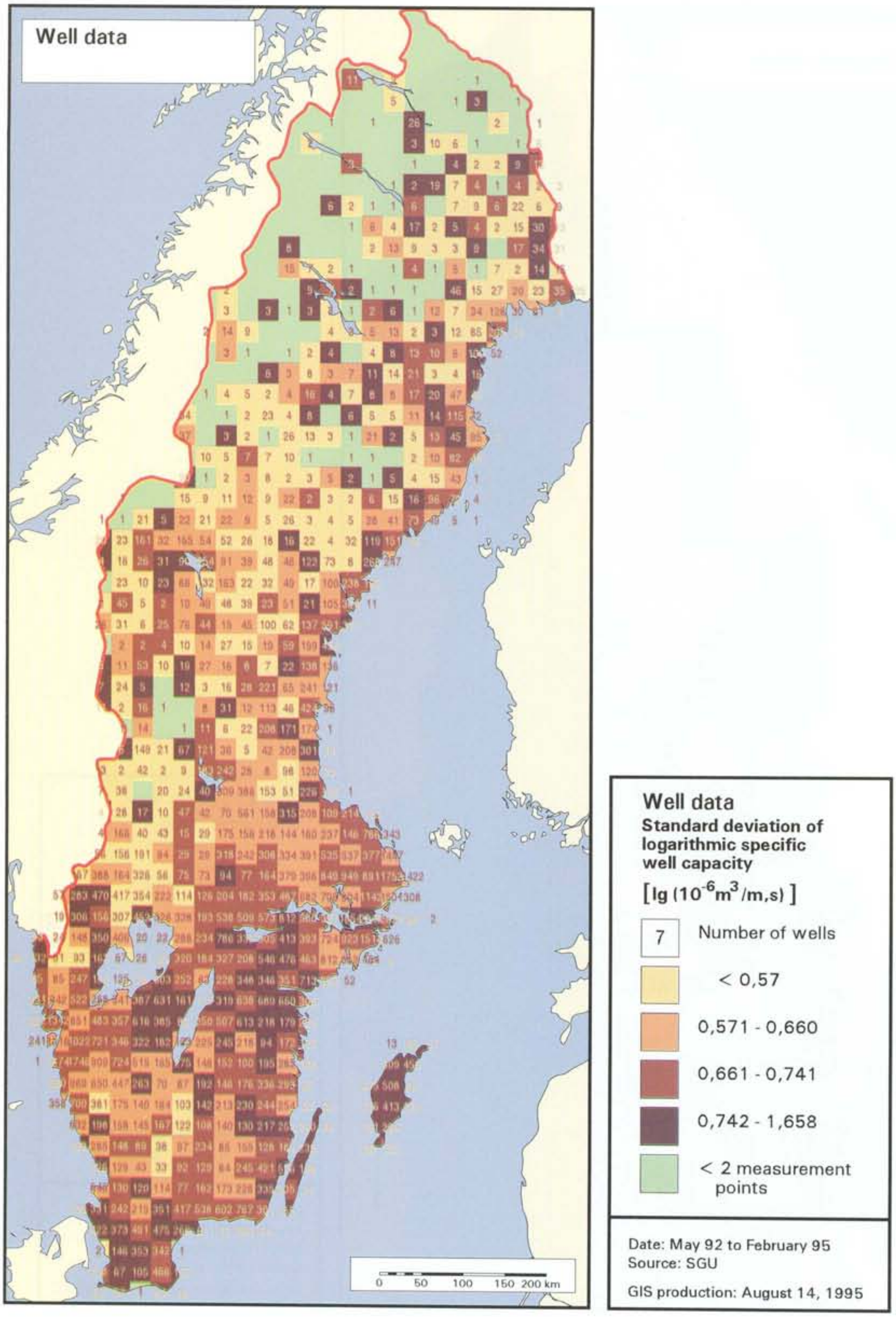

Figure 5-8. *Standard deviation (^{10}log) of the specific well capacity. Processing of SGU's well archive. Class limits are determined so that each class corresponds to about 25% of Sweden's surface area. There is no reason, on a national scale, to prefer or exclude regions on the basis of the variation in well data distribution.*

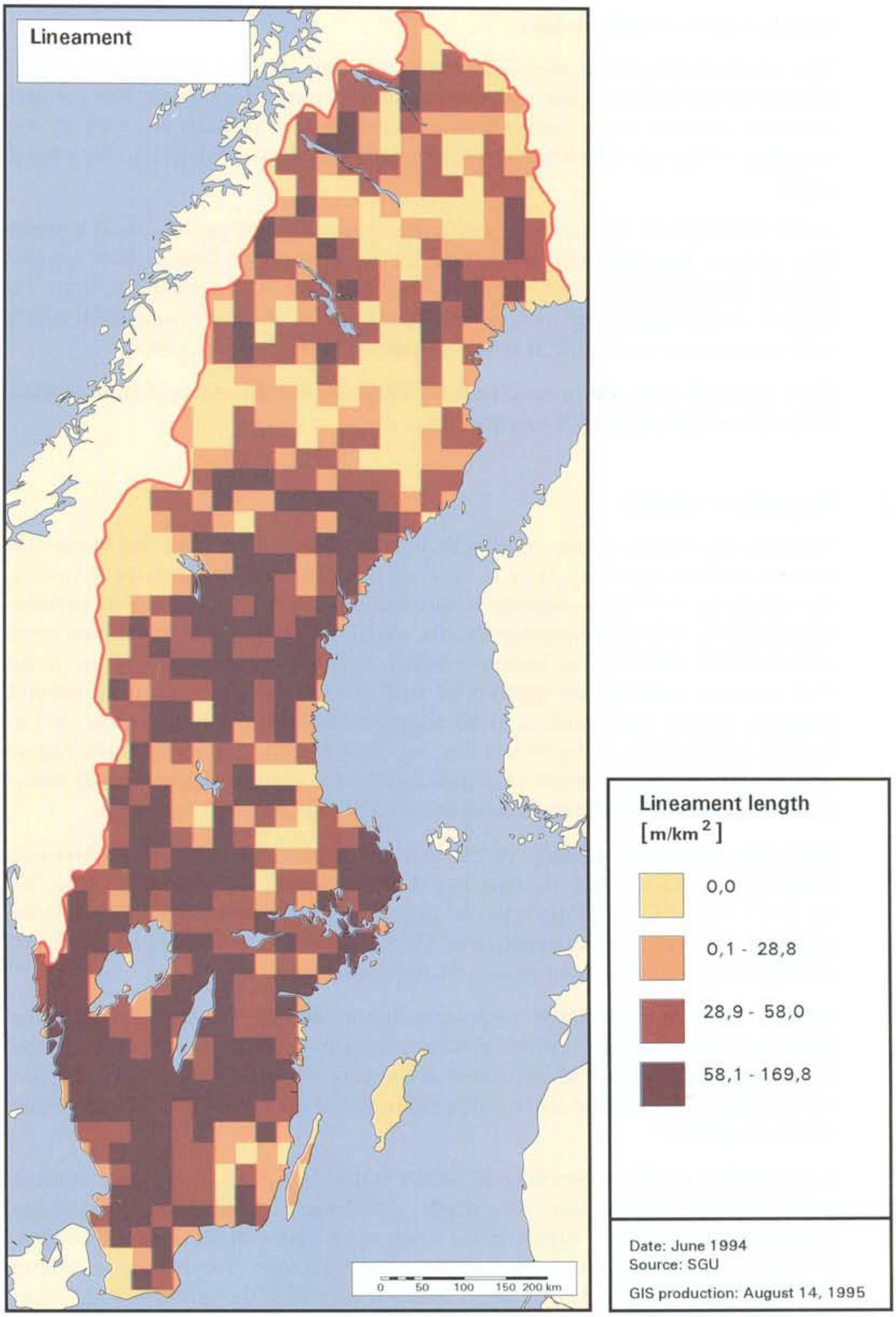

Figure 5-9. *Lineament density. Based on /5-4/. See Figure 4-9. Class limits are determined so that each class corresponds to about 25% of the surface area of Sweden. The variation shown on the national scale is not a basis for preferring or excluding regions from the siting process.*

Extrapolation of surface data

The interpretation of site investigations will be facilitated if what can be distinguished on the surface can be extrapolated down to repository depth. More or less vertically oriented zones, bedrock where lithological structures are vertical, are examples of factors which facilitate the reliability of extrapolation to repository depth.

A site investigation involves many different types of investigations. An important part of these investigations is to show the occurrence, or lack of both steeply dipping and flat-lying zones etc. The extent to which it is possible to, from the surface, extrapolate information to repository depth is, therefore, a question which will be taken into account in feasibility studies and site investigations.

On a national scale, there is no suitable database for the extrapolation of data from the surface to deep underground.

5.4.2 Repository design

Through the choice of the repository depth (site-specific), and the horizontal extension of the repository, there is, for each site, considerable scope for designing the repository. Few large zones at the site are, therefore, favourable. Furthermore, the repository will be designed so that the maximum temperature in the repository will be below 100°C in the bentonite buffer. This condition is fulfilled by, in the first instance, adapting the quantity of fuel in each canister and, in the second instance, placing the canisters at an adequate distance from each other. If the thermal conductivity of the rock is low, the canisters must be moved further apart which, will first and foremost be a question of cost; a larger repository will take a longer time to build and construction and backfilling costs will be higher.

SKB has carried out a study of the thermal conductivity etc. in the Swedish bedrock /5-4/. Basic rock types have low thermal conductivity values, 2.6 W/m, °C, up to 3.7 W/m, °C in certain types of gneisses. In its generic repository volume estimates, SKB uses the assumption of 3W/m, °C. With low thermal conductivity, the repository volume would have to increase somewhat.

Another question is the initial temperature in the bedrock. The temperature in the bedrock is determined by the annual mean temperature on the surface as well as by the temperature increase which occurs in the bedrock at greater depths (temperature gradient). The annual mean temperature varies between 7°C in Blekinge and -1°C in Lappland.

A description of the temperature at SKB's study sites /5-9/ shows that, in these areas, the initial temperature at a depth of 500 metres (before any heating has occurred) is about 5–6°C higher in the south compared with the north of Sweden. In order to compensate for such a temperature difference, a repository located in the south must be about 5–10% larger than one located in the south, with the same thermal conductivity.

The difference which exists in the capacity for thermal conductivity and the initial temperature between different types of bedrock and different parts of the country is not sufficient reason to give preference to some regions and exclude some regions from the repository siting process.

5.4.3 Implementation and experience from rock engineering in Sweden

The construction of the deep repository is a large and lengthy underground construction project. Sweden has had lengthy and sound experience of rock engineering. Mines, power plants, road and railway tunnels, access tunnels, storage facilities and many other types of facilities have been built for decades. Considerable knowledge and experience have been acquired and developed. Through special organizations, special research has also be carried out concerning underground facilities. Some of this research has to do with the possibility of predicting conditions in the bedrock before construction has been carried out. Recommendations have also been made concerning rock investigations /5-5/ for construction work.

The requirements which can be made on the deep repository with regard to technical feasibility are those which are normally required for any underground facility. "Good rock" which does not require additional sealing or reinforcement is advantageous to any type of underground construction. "Good rock" with a low groundwater flow and mechanical stability is also desirable with regard to repository performance; thus there is no basic conflict between the requirements of technical feasibility and the requirements of performance and safety.

In order to establish as far as possible whether there are any regional differences in technical feasibility, experience from rock engineering work has been documented in a recent report /5-6/.

The conclusions from the study are that the variations in the constructability of the facility within a certain region, or even within the same site, may be considerably greater than the difference in the "average constructability" between different regions. The facilities which have been evaluated in Figures 5-10 represent a certain geological-tectonic environment, which may vary on the local scale. The sites the facilities which have been evaluated have not been freely selected. Mines are established where there is ore, often in an metamorphic environment. Hydropower plants are located along stretches of valley, where tunnels are often constructed in connection with fracture zones.

The question of constructability is one of feasibility, and one which can be primarily evaluated in connection with feasibility studies and site investigations.

5.4.4 Repository operation

As far as the operation of the deep repository is concerned, it is favourable if the waste can be deposited with minor practical problems. Problems can also be avoided by selecting a canister position where the rock is dry or by sealing (grouting) the deposition hole so that it is dry.

If the repository is constructed in saline groundwater, the environment will be aggressive to installations etc. This can be corrected by increasing the corrosion protection.

For certain types of bedrock, high radon concentrations from the bedrock can be expected. This may lead to requirements on extensive ventilation during the construction and operation periods. Figure 5-11 shows bedrock which is particularly radioactive and where radon could be a problem during construction. This question should be particularly investigated in connection with feasibility studies and site investigations.

For construction and operation, it is important that the rock is mechanically stable.

Data concerning rock stresses in Sweden have been compiled, /5-8/. There are 145 measurement data from points at depths which are greater than 400 m, above all from mines, a few study sites, at SFR and Äspö. The horizontal main stresses are generally twice as large as the vertical stresses, but the variation is large. The direction of the largest main stress is often northwesterly. In order to establish the

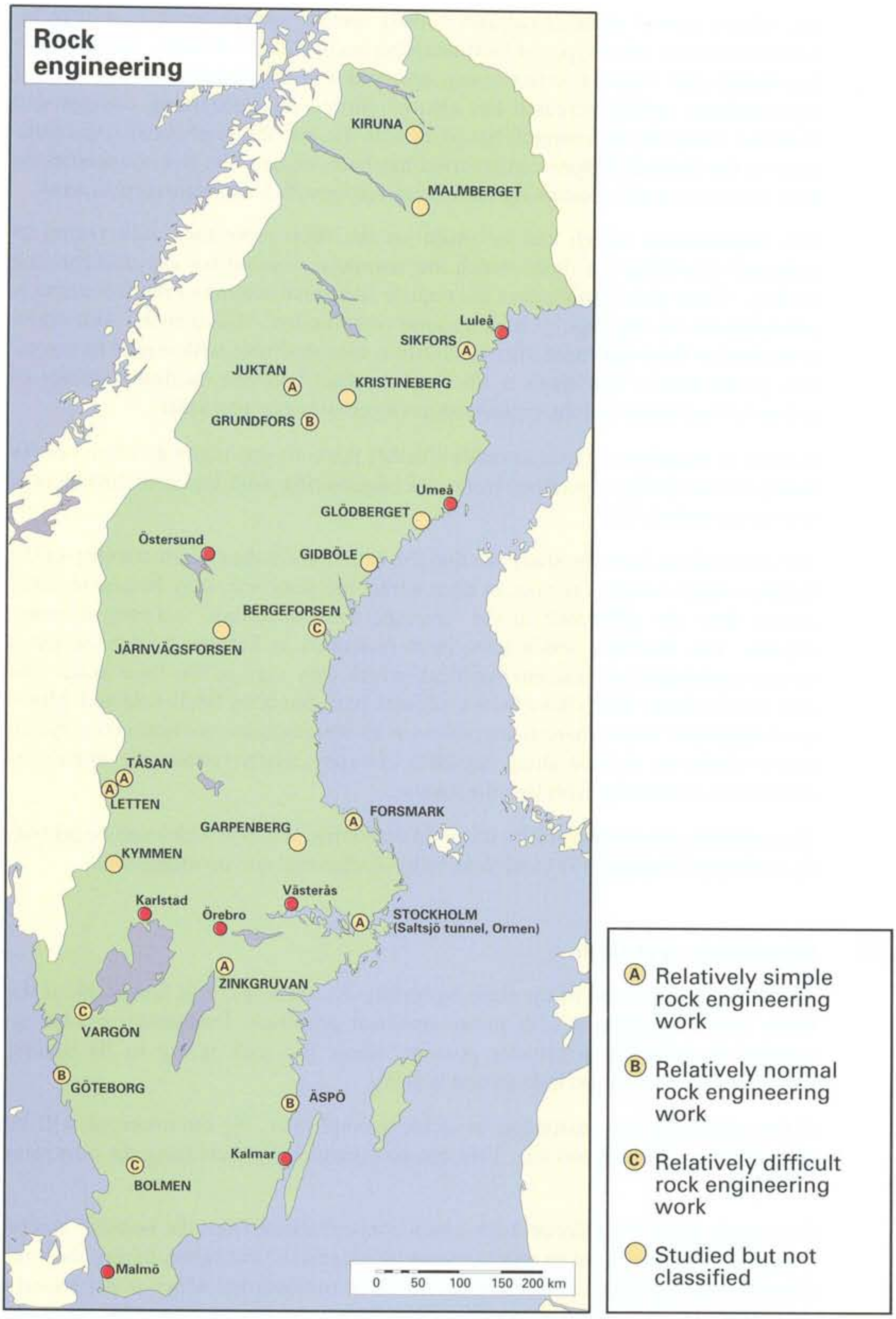

Figure 5-10. *Rock engineering evaluated according to constructability. Based on /5-6/. The rock engineering work is determined by local factors which are investigated in feasibility studies and site investigations.*

Figure 5-11. *Map of particularly radioactive bedrock. Based on /5-7/.*

mechanical stability, site-specific data are also required, such as the strength of the rock, which means that it is not possible to estimate, on a national or regional scale, whether different areas have different conditions for mechanical stability.

Altogether, it is an advantage if sites are selected which are also favourable to easy operation. This means that the rock must be relatively low-conductive and mechanically stable. The radon content must not be high. The suitability of a site is preferably studied in connection with feasibility studies and site investigations.

5.5 OVERALL EVALUATION

It is advantageous to select a site where the technical feasibility is relatively simple. Furthermore, there is, in general, no conflict between the favourable factors and the long-term safety as well as simplicity of technical implementation.

If there is a need to transport nuclear waste from an encapsulation plant over longer distances to the deep repository, there is a good possibility of using the existing railway network and harbours without any major additional investment.

On a national scale, there are no technical limitations on the siting of the industrial facility and the waste rock reclamation area. In connection with more detailed studies, the layout of the industrial facility and the waste rock reclamation area will be determined so that high requirements on environmental adaptations are met.

It will be easier to carry out site investigations, design and planning as well as performance and safety assessments if the interpretations of the rock investigations are reliable.

In summary:

- **Areas with good bedrock outcropping may be advantageous in terms of interpretation and implementation of characterization. However, areas with low outcropping cannot be excluded on a national scale, since the local variations may be considerable.**

- **There is no reason to exclude areas where there are many different main rock types within a single region.**

- **There is no reason to prefer or exclude regions which, on a national scale, show variations in well data distribution, lineament density or magnetic homogeneity. The factors can be investigated and evaluated in connection with feasibility studies and site investigations.**

- **The difference which exists, on a national scale, with regard to thermal conductivity and initial temperature between different types of bedrock and different parts of the country is not sufficient reason to give preference to certain regions or exclude certain regions from the siting of the deep repository.**

- **As far as the operation of the deep repository is concerned, it is an advantage if sites are selected which are favourable to the operation of the repository. This means that the rock must be relatively low-conductive and mechanically stable. The radon level should not be high.**

6 LAND AND ENVIRONMENT – EVALUATIONS ON A NATIONAL SCALE

In this chapter, basic conditions, factors and other important aspects relating to a deep repository are examined from the standpoint of land and environment. Factors which can be assessed on a national scale are analyzed, in particular. Areas protected by law as well as the society's requirements with regard to the management of natural resources are examples of such factors. In addition, the considerable possibilities which exist to adapt the repository to a particular site and its surrounding environment and land use are examined.

6.1 GENERAL

6.1.1 Legislation and system of regulations

The deep repository is a unique facility which does not have to be governed by any particular legislation but which is licensed in the same way as other nuclear installations in the existing system of regulations. Applications have to be submitted for licences under a number of legal acts. The important acts are the Act concerning the Management of Nuclear Resources etc. (NRL), the Act on Nuclear Activities (KTL), the Environment Protection Act (ML), the Planning and Building Act (PBL) and the Water Rights Act (VL). The basic requirements of the activity are established in connection with the application of these acts.

Current Swedish legislation which concerns the siting of a deep repository with regard to land and environmental facts can be classified into three different groups of acts.

1 Protective legislation, such as the Nature Conservation Act, the Environment Protection Act, the Radiation Protection Act, the Act on Nuclear Activities.

2 Legislation concerning the management or exploitation of natural resources, such as, for example, the Act concerning the Management of Natural Resources etc., the Water Rights Act, the Forestry Act, the Act for the Management of Agricultural Land.

3 Planning and land legislation, such as the Planning and Building Act.

The Act on Nuclear Activities and the Radiation Protection Act are naturally of central importance in this context. However, since these acts mainly deal with the actual activity at the deep repository and only deal with siting and site selection to a lesser extent, they are not examined in greater detail in this chapter. However, it should be noted that the Radiation Protection Act requires that an overall view of the deep repository system should be maintained with an optimization of the radiation protection for the entire chain of activities – encapsulation, transportation, handling at the deep repository and long-term storage – which must be taken into account in connection with the design of the system, including the selection.

Figure 6-1. *The Act concerning the Management of Natural Resources etc. (NRL) is a framework act for a series of different special acts.*

The Act concerning the Management of Natural Resources etc. contains overall guidelines for the use of land and water areas in Sweden for different purposes. It is a framework act and the real main function of the act is that it must be applied in connection with decision-making with regard to issues which concern a change in land use in accordance with other special acts. For example, this may relate to the evaluation of goals and proposed actions under the Planning and Building Act, the Water Rights Act, the Environment Protection Act, the Nature Conservation Act, the Road Act or the Minerals Act, see Figure 6-1.

6.1.2 Siting of a deep repository

Permission must be obtained from the government in order to select a specific site – a siting permit – in accordance with the Act concerning the Management of Natural Resources (NRL 4:1) and the Act on Nuclear Activities (KTL). The normal assumption is that the community which will be affected by the siting has granted its approval. Bearing in mind the fact that the repository is essential from the national standpoint, as well as the possibility that no other suitable community may be prepared to host the repository, under special circumstances, the government can rescind the municipal veto (NRL 4:3). This is a complex, difficult and undesirable alternative with regard to the siting of the deep repository. Consequently, the siting work is structured so as to achieve a solution which will be understood and accepted by the host community and which will fulfil high environmental and safety-related requirements, /6-1/.

The selection of a site and design of the facilities must be based on the intention to achieve a good management of natural resources as stipulated in the Act concerning the Management of Natural Resources etc. so as to minimize any conflict with opposing interests. Valuable natural and cultural environments, areas for tourism, recreation, hunting, fishing and other outdoor activities, agriculture and forestry, existing and planned land use as well as other natural resources must be taken into consideration. Particularly valuable or sensitive areas will be avoided. Facilities and communication systems will then be designed and adapted to suit the local conditions so that they can blend into the terrain and surrounding environment.

The legal requirements on comprehensive environmental impact statements for civil engineering projects also entail that the environmental impact must, at an early stage in the licensing process, be balanced against the specific environmental requirements in different parts of the countries and areas, each of which have highly varied terrain, landscapes etc.

The conclusion is thus that siting should be conducted so that there are:

- **Few opposing interests with regard to land use or land preservation.**
- **Good possibilities of constructing and operating the facilities so that all of the requirements with regard to environmental protection are fulfilled.**

Existing land use, valuable areas and significantly opposing interests are often compiled on the national or, at least, county administrative level through each sectorial body and county administrative board and documented in generally available maps and statistics. The data are often comprehensive, more or less easy to understand but still relatively extensive and uniform. In addition, there are many areas and properties which are of less significance, limited size or of such a nature that they can only be taken into account at a later stage in connection with comparisons on the local scale. The possibility of taking into account these properties is usually good, at that stage, through the adaptation of site selection and repository design. A more detailed report of the planned future land use is also provided in the municipal comprehensive plans which, in spite of their heterogeneity, are a very comprehensive and ambitious body of data which are of great value for subsequent analyses on the county, municipal and local levels.

In 1993–94, the National Housing Board completed, on behalf of the government, together with NUTEK and the Swedish Environmental Protection Agency, the first part of the work to put Swedish planning in an international future perspective /6-2/. In significant parts of the country, no extensive change in the current land use is expected. The largest and fastest changes have, in a historical perspective, mainly occurred in the already relatively densely built up and populated parts of the country. At present, there is nothing to indicate that any revolutionary break in trend is about to occur, in this sense.

Thus, it can be assumed that the changes, also in future, will primarily occur in and around the parts of the country, county and municipality where the pressures to develop property are already considerably high.

Terrain and topography, landowner conditions, available land for construction for the society and industry as well as the local environmental situation as a whole, are a few examples of other land and environmental factors which are of importance in connection with the siting of a deep repository. However, the local variations are so large that only individual, highly simplified conclusions can be drawn in connection with a general analysis on a national scale.

6.1.3 Impact of the repository on the land and environment

A deep repository is a facility which has little environmental impact compared with what can normally occur in industrial contexts. No industrial process will be carried out, chemicals will only be present in small quantities, the handling of excavated rock is not expected to lead to any specific problems, backfill material will not contain any environmentally hazardous substances and the actual waste will be well encapsulated and isolated. The repository can be compared to a medium-sized industry and even if the environmental impact is relatively small, the environment will still be affected.

The investigations and facilities will require land space. They will also affect the environment to a certain extent through transportation, drilling, rock blasting and construction. All of these factors must be described and discussed with the municipality, the local community and competent authorities.

The area needed for the underground facility is one to two square kilometres and for the surface industrial facility, about 0.3 km^2 or 30 hectares. Any necessary new road or railway links are also important from the standpoint of planning. These changes will have a visible impact on the land and may alter the landscape.

An environmental impact statement (EIS) will be included when an application is submitted for a licence, under the Act concerning the Management of Natural Resources etc. and the Act on Nuclear Activities, to start a detailed characterization at a site. The EIS includes an analysis of the long-term safety of the repository at the particular site. The EIS is prepared in cooperation with the communities concerned, competent authorities etc. (the process of environmental impact assessment). Prior to and during the site selection process, the submission of the licence application, the design and construction of the repository will be carried out in consultation with those most closely affected by the siting, i.e. those living in the vicinity, landowners as well as representatives of any other interests which may exist at the site in question.

The need for land for the construction of the deep repository is a possible source of conflict with other types of land use. However, the scope for freedom is relatively large in connection with the detailed siting of the industrial area, railway and road links, once the site of the underground facility has been selected. Unnecessary land conflicts can, thereby, be avoided.

It should largely be possible to avoid any conflict with outdoor activity areas through special consideration of, and undertaking special measures in connection with the design and operation of the repository. The impact on outdoor activities should, largely be limited to the areas which are in immediate proximity to the surface facility. Valuable cultural environments and cultural monuments are often geographically set apart or situated so that it is expected that they can be avoided in connection with siting. Thus, the repository does not have to lead to any unacceptable impact on cultural environments.

Activities at the deep repository and transportation to and from the repository will lead to a certain impact on the air and water. The operation of the deep repository will result in vehicle exhaust emissions to the air as a result of transportation activities. The estimated additional emissions around the deep repository as well as along the transportation routes must be considered to be insignificant in the context. During the detailed characterization and operation, the groundwater table level near to the repository will be lowered. This may result in the drying up of or lower capacity in neighbouring wells. Furthermore, the groundwater which is pumped up will be removed after contaminants are separated. Wells and water sources in the vicinity of the repository can be monitored for any contamination.

The surface buildings can be considered to be conventional industrial premises. When they are dismantled, the resulting waste should not be considered to be any different from regular construction waste. There is a considerable possibility of recovering the construction materials.

The handling of the excavated rock must be planned so that it can blend in with the existing landscape. It is best if left over rock can be used for other purposes, e.g. roadworks, harbour construction etc. The actual application will depend on local conditions.

The environmental impact of the deep repository may be minimized if the siting process is, already from the start, careful and considerate as well as if local environmental adaptation of facilities, communication systems and the actual activity are achieved.

6.2 AREAS PROTECTED BY LAW

This section describes the areas which are protected by law.

6.2.1 Nature conservation

Protected areas exist in Sweden in the form of

- national parks,
- nature reserves,
- nature conservation areas,
- natural monuments,
- animal sanctuaries,
- forest service reserves,
- protected shores,
- wetlands,
- protected biotopes,
- protected forests,
- private reserves.

Under the Act concerning the Management of Natural Resources etc., any property development project which essentially alters the natural environment must be discussed with the county administrative board. This may mean new roads, major excavations or new power lines. The county administrative board can request measures to limit the extent to which nature is affected.

The share of protected nature in the form of national parks, nature reserves, nature conservation areas, natural monuments, animal sanctuaries and forest service reserves are almost 10% of the surface area of Sweden, see Figure 6-2.

National parks are unaffected natural landscapes with unique nature. The level of protection is the highest. Only the Swedish parliament can grant permission for development. This has occurred in connection with the harnessing of rivers for hydropower production. There are currently 24 national parks with a total surface area of just over 6,000 km^2.

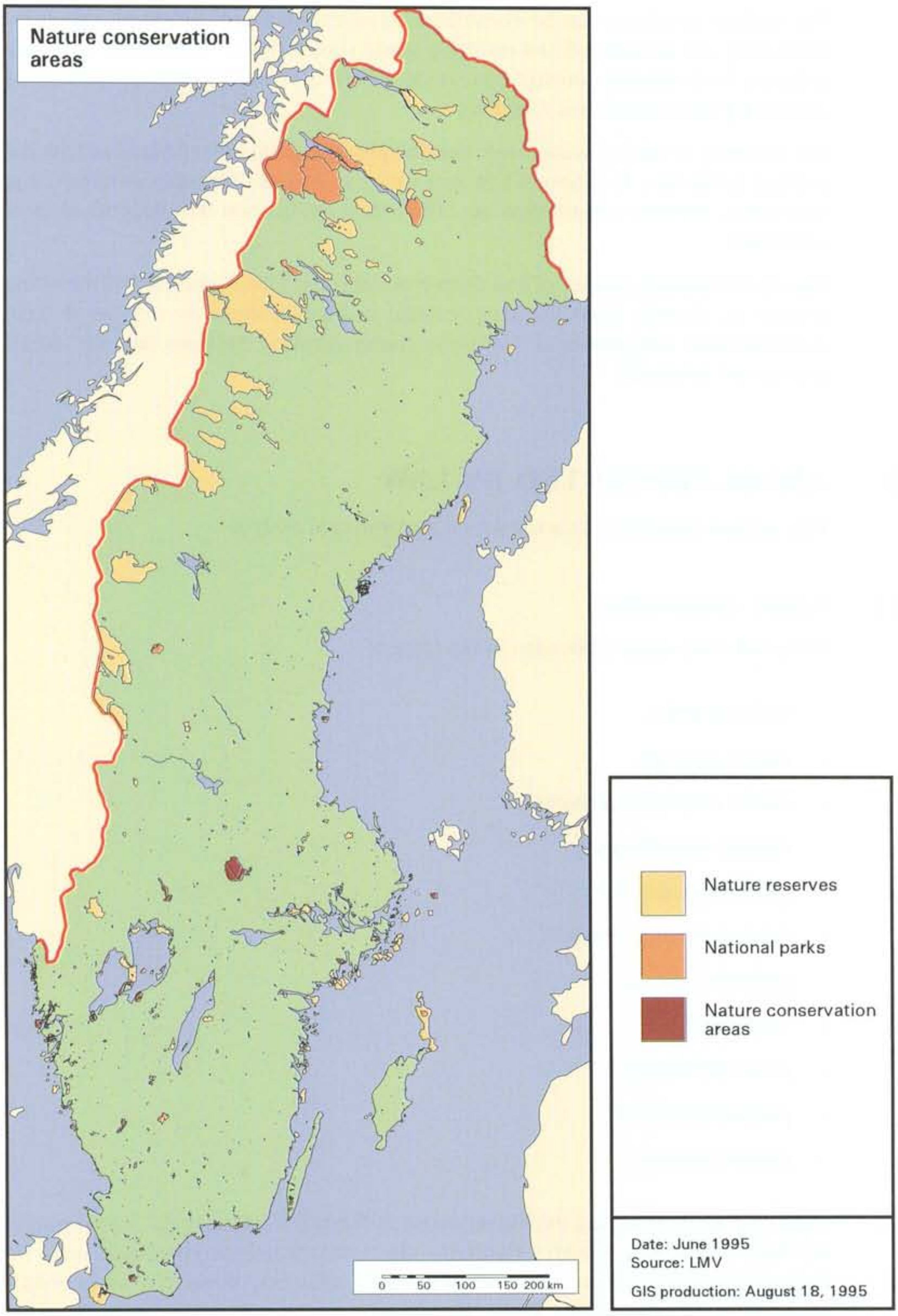

Figure 6-2. *The most important legally protected natural areas are national parks, nature reserves and nature conservation areas (6% of Sweden's surface area). It should be possible to avoid legally protected areas in connection with siting.*

Nature reserves are formally established by the county administrative board. Regulations are established for each specific case. At certain reserves, all types of land use for economic purposes is prohibited. At others, it may be permitted to carry out agricultural activity and forestry. About 1,400 reserves exist with a total surface area of 23,000 km^2.

Nature conservation areas are formally established by the county administrative board or municipality. The level of protection is relatively low. There are about 100 areas with a total surface area of almost 2,000 km^2.

Natural monuments consist of single objects or very small areas and are formally established by the county administrative board. There are about 1,400 natural monuments, most of which are botanical monuments.

Animal sanctuaries are established to protect the fauna, but not the land or water. Most of the some 900 areas are situated in lakes or archipelagos.

Forest service reserves are areas where the National Forest Enterprise (now Assi-Domän) has voluntarily refrained from forestry activities. Other forestry companies have also set aside similar reserves. However, these reserves can be reviewed at any time, since their establishment is not legally binding. The total surface area is around 12,000 km^2.

Shore protection exists so as not to limit the freedom of movement along coasts, inland lakes and watercourses. Shore protection means that all new construction or equipment is prohibited within a distance of 100 metres, or in certain cases, up to 300 metres, from the shoreline. Buildings for agricultural and forestry activities, fishing and reindeer herding are not affected by the regulations concerning shore protection.

Wetlands (fens, marshes, bogs etc.). About one-fifth of the surface of Sweden consists of wetlands. The Environment Protection Act and the Environment Protection Ordinance have been changed to give certain wetlands protection against draining. Prohibitions against drainage apply fully or partially in a number of counties and municipalities. However, the county administrative board can allow exceptions in the individual case. Furthermore, thirty areas have been marked as protected by Sweden in the Convention on Wetlands (primarily wetlands of importance to the bird population). The thirty areas occupy a total surface area of 3,800 km^2. About 60% of this surface area (24 of the areas) are protected as national parks, nature reserves or nature conservation areas.

Protected biotopes. The protection is provided on different levels and can be issued by different bodies. Certain types of biotopes are generally protected. No geographical areas are identified by law, only different types of protected biotopes.

Protected forests are forests or protected forests which are difficult to renew where no felling may be carried out without the permission of the Forestry Board. The government or competent authority in certain areas can decide that felling may not be carried out. Furthermore, felling in forests near to mountains may not be carried out if this is incompatible with nature conservation and cultural environmental interests. The Deciduous Forest Act was abolished in 1993 and such protection is now incorporated into the Forestry Act. The Forestry Act is also protected in a different way in national parks, nature reserves, nature protection areas, areas of national interest, forest service reserves, virgin forests, private reserves etc.

Information concerning protected areas can be obtained from the Environmental Protection Agency, the county administrative boards, the municipalities as well as other organizations. For example, the Central Office of the National Land Survey's

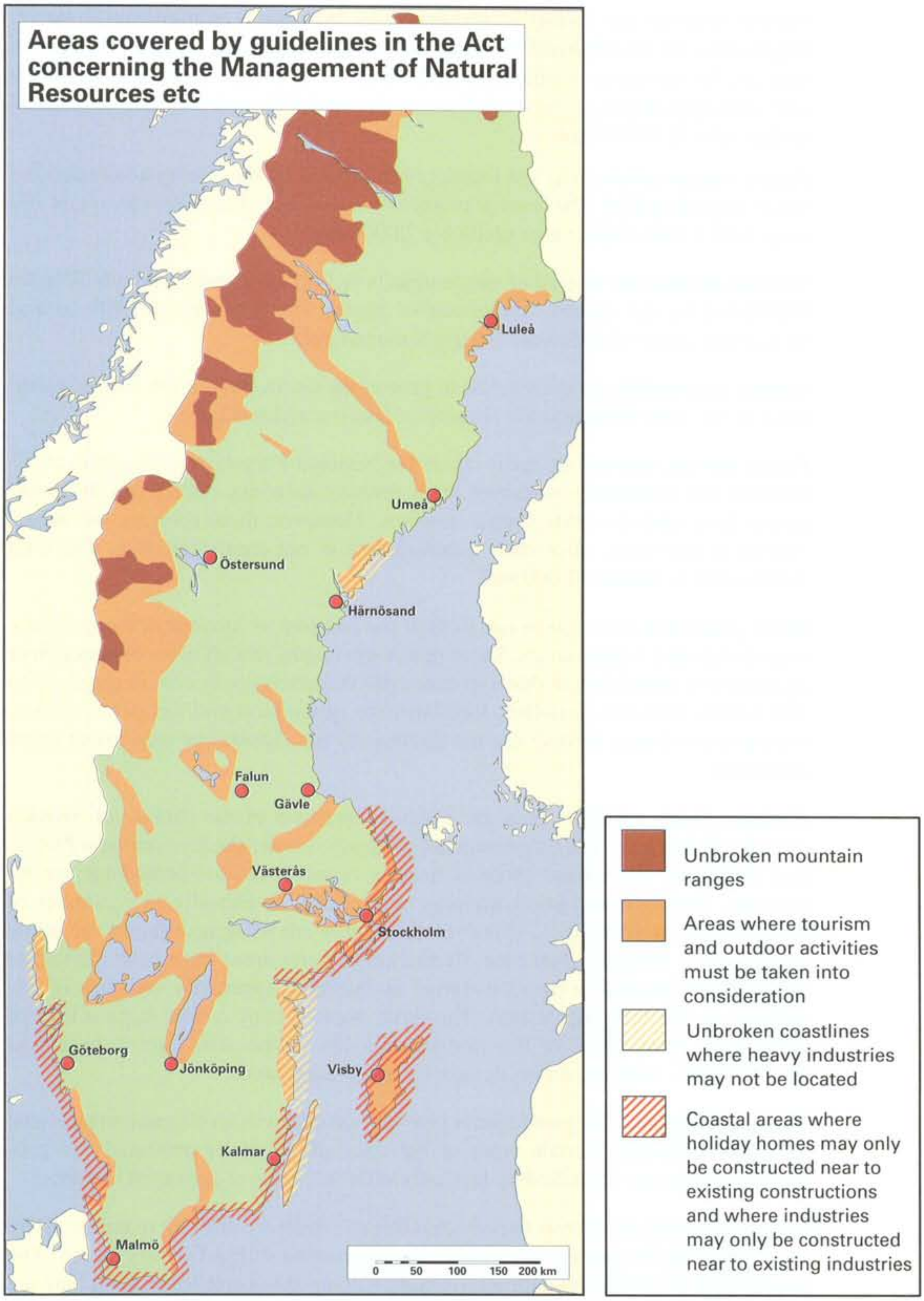

Figure 6-3. *Areas covered by special guidelines "geographical management regulations" in accordance with the Act concerning the Management of Natural Resources etc. Based on /6-4/.*

databases and the municipal comprehensive plans can provide adequate information.

Large coherent areas consisting of one or several national parks and nature reserves in certain parts of the country can be identified in general siting studies carried out on a national scale, see Figure 6-2.

It is important to avoid formally protected areas. Some examples include parts of the mountain range, parts of the coast and archipelago areas, areas surrounding certain large lakes and water courses as well as particularly valuable natural areas close to large, densely populated areas and population centres.

See Section 6.3 and Figures 6-2 and 6-3 as well.

6.2.2 Cultural protection

Formal protection for cultural purposes mainly applies to individual properties or groups of properties such as relics and buildings which are declared to be monuments. Coherent cultural environments which are considered to be particularly valuable have, in certain cases, been identified as areas of national interest under the Act concerning the Management of Natural Resources etc., although this does not necessarily mean that they are formally protected, in any case not on the national scale. On the contrary, they may be associated with restrictions and protection regulations on a regional or local scale through recommendations or regulations in connection with land legislation and planned land use.

Buildings, relics, cultural environments etc. Siting proposals which wholly or partially concern existing areas under cultural protection should be avoided. However, the size of areas protected in the national interest or local/regional interest for cultural purposes is often limited. Thus, there is a good possibility of taking these aspects into account in a satisfactory manner during the later stages of the siting process, i.e. in connection with feasibility studies and site investigations. Existing protection must be specified in the municipal comprehensive plans.

Buildings, relics and cultural environments must be taken into account in connection with feasibility studies and site investigations.

6.3 MANAGEMENT OF NATURAL RESOURCES

6.3.1 Background

Certain fundamental regulations and guidelines in the Act concerning the Management of Natural Resources etc. are examined in this section. Areas which are specially protected or which are considered to be especially valuable or worth protecting under the Nature Conservation Act and the Act concerning the Management of Natural Resources etc. are described here. Furthermore, comments are provided on the meaning of the protection regulations of the Act concerning Ancient Monuments and Finds and the Act concerning Monuments.

A large number of fairly extensive areas on the whole have been identified in the work on the conservation of nature and cultural monuments as being protected or particularly worth protecting.

Swedish legislation within the area of the conservation of nature and cultural monuments traditionally focuses on taking care of, maintaining and protecting in two different ways:

- Straightforward maintenance, through the setting aside of special, often relatively limited areas which are formally protected by law or area protection. Above all, this concerns the protection of nature conservation interests or interests related to outdoor activities through national parks, nature reserves, nature conservation areas, bird sanctuaries or the protection of certain species etc. as stipulated in the Nature Conservation Act, see Section 6.2.
- The planning of the use and management of Sweden's natural resources through overall guidelines in the Act concerning the Management of Natural Resources etc. as well as the identification of certain particularly important geographical areas (especially general management regulations) and areas of such value that they are considered to be areas of national interest. Such areas are thereby covered by an indirect form of protection, even if there is often no specific or formal protection. Such areas are considered to be worth protecting but are not covered by any form of formal protection. Such areas are dealt with in this section.

6.3.2 Act concerning the Management of Natural Resources etc.

In the general management regulations in Section 2 of the Act concerning the Management of Natural Resources etc., it is stipulated that: *"Land and water areas shall be used for that or those purposes for which they are most suited with regard to their nature and location as well as actual requirements. Precedence will be given to that use which encourages good management from the viewpoint of the public."*

Section 2 of the Act concerning the Management of Natural Resources etc. also contains general protection and consideration regulations for ecologically sensitive areas or large unaffected areas, agricultural and forest land of particular importance, reindeer husbandry, areas of natural and cultural value, outdoor activities, total defence, areas containing valuable substances or materials as well as areas which are particularly suitable for certain facilities such as a deep repository (NRL 2:2-10).

The Act concerning the Management of Natural Resources etc. stipulates:

- areas of national interest within different sectors of the society,
- protection for areas of national interest,
- geographical management regulations,
- requirements concerning licensing by the government for the siting of large, environmentally hazardous facilities, such as a deep repository.

The areas in Sweden which are of national interest are specified by each sectorial authority, e.g. the Swedish Environmental Protection Agency, the Central Board of National Antiquities and NUTEK together with the National Housing Board.

The government has stated /6-3/ that the Swedish Nuclear Power Inspectorate (SKI) should be responsible, after consulting with the Swedish Radiation Protection Institute (SSI), the Swedish Environmental Protection Agency and the county administrative boards concerned, for ensuring that the county administrative boards submit information on the areas which the authorities have established to be of national interest for the final disposal of spent nuclear fuel and nuclear waste.

In their comprehensive plans, the municipalities must report, interpret and limit all of the national interests as well as provide a framework for how they are to be protected against unacceptable actions. Areas of national interest must be protected against actions which tangibly render difficult or counteract maintenance or use for the specified purpose. However, the national interest does not mean that all change is prohibited.

In the special management regulations for Sweden, as stipulated in Section 3 of the Act concerning the Management of Natural Resources etc., a number of areas are named and generally set aside, in terms of their natural and cultural worth. On the whole, these areas are of national interest, see Figure 6-3.

Other areas which have been identified by the Swedish Environmental Protection Agency and the Central Board of National Antiquities as being of national interest for nature conservation and/or outdoor activities are presented in Figure 6-4.

The possibility of, without entering into conflict with the management of natural resources, finding suitable sites for new development activities such as large environmentally hazardous facilities, which require a siting permit from the government, is thereby limited in many different ways, especially in the following parts of the country:

- along the coast, especially in the archipelago,
- in the mountain ranges,
- on Öland and Gotland,
- around the large inland lakes,
- along the four harnessed Norrland rivers,
- as well as around a number of specific stretches of rivers, water courses and discharge areas.

The areas of national interest as stipulated under the Act concerning the Management of Natural Resources etc. comprise considerable parts of Sweden and are provided with a form of indirect protection but this does not include a prohibition against development activities. The significance of an area from the standpoint of nature conservation, for example, must be balanced against the value of managing the waste in the most suitable manner, which is also in the national interest. The areas which are protected by law are somewhat more limited but they can be expected to increase in number and size, in the future.

Areas protected by law must be avoided in the siting work. Areas of national interest should be avoided, if possible.

6.3.3 Impact of the deep repository on the management of natural resources

The impact of the repository on the management of natural resources can be considered from two aspects. Natural resources may be used or blocked.

The siting of the deep repository does not involve the use of any natural resources (substances, materials etc.) for which the regional or global resources are expected to be scarce. The siting of a deep repository can affect the management of the natural resources which exist within the municipality and region, by blocking the

Figure 6-4. *Areas of national interest with regard to nature conservation and outdoor activities. Areas of national interest should be avoided, if possible.*

resources for any alternative use. Such natural resources are primarily, the natural environment, mineral resources, groundwater and peat. On the other hand, if a suitable site is selected in an area which is not formally protected or identified as being particularly worth protecting, any impact of the repository will be on a natural environment which is common in Sweden and not particularly worth protecting. Such a siting will not be considered to have any impact on the management of the natural environment. On the other hand, if a suitable site is selected in an area with special value from the standpoint of natural environment, cultural environment, future construction, outdoor activities or reindeer husbandry, such a siting will be in conflict with the management of natural resources. It should be possible to minimize the conflict through special considerations in connection with the detailed siting work and repository design. In certain cases – e.g. where the value of the area lies in the fact that it is undisturbed – a deep repository would be in conflict with the management of natural resources.

Areas where there are ore or mineral deposits which may be of interest for future prospecting (see Section 4.6 and Figures 4-14 and 4-15) will be avoided in the siting of the deep repository. There is no reason to generally exclude all, or some of them at this stage. The possibility of adapting the deep repository to the site and environment, so that any actions undertaken in the area are not unacceptable, is expected to be good.

6.4 LAND USE AND SOCIETAL PLANNING

In connection with siting, it is naturally desirable, if possible, to avoid conflicts not only with the natural environment and cultural interests but also with current and ongoing land use and planned or other possible future land use.

6.4.1 Current land use

How different land and water areas are used today is relatively easy to determine. A large quantity of information can already be obtained from the generally available general plans of the country or counties, with regard to the type of nature, topography, population, infrastructure and communications. In addition, the availability of different thematic maps of Sweden is good, /6-4, 6-5/.

Above all, it is the large-scale general maps of Sweden and the counties which, together with maps of, for example, the population density, give a rough impression of demography and infrastructure.

A certain distance to population centres, built-up areas and areas regulated by detailed development plans should be desirable in order to avoid unnecessary conflict in the form of expropriation and compulsory acquisition of land or other disturbances such as the blocking of the possibility of future expansion. Furthermore, population centre recreation areas are often located on the fringes of population centres and these are assigned an increasingly higher value. This question is best examined in connection with feasibility studies and site investigations.

Health and safety as well as impact on the environment are central concepts in the Planning and Building Act, the Environmental Protection Act and the Act concerning the Management of Natural Resources etc. The risk for health, safety and environmental impact in connection with the establishment of industry has been treated in /6-6/. Environmental problems and recommended no-access distances for different types of facilities are presented in that report. For example, normal no-access distances of 200–1,000 m may be established depending on the type of facility and the local conditions. In practice, it has been proven to be difficult to apply the recommended safe distances to existing industries as well as to new industrial establishment /6-7/. A no-access distance for a deep repository has not been determined.

Information on landowners can be obtained from the Central Property Register and the landowner database. The latter is compiled on the scale of 1:1 million and may be used, to some extent, for very general evaluations. Access to government land, municipal land or commercial land can simplify the compulsory acquisition of the necessary land. Information concerning the classification of property and the type of ownership for the land concerned can also give an indication of possible conflicts. An extremely divided property and landowner situation, such as in Dalarna and parts of Värmland could render the implementation of the final disposal system more difficult. However, this does not have anything to do with the suitability of an area and furthermore, it is not a decisive siting factor, at this stage or at a later stage when it may be possible to take this aspect into consideration.

Other thematic maps which may be of interest concern, e.g. the location of good agriculture and forest land. However, the maps on a national scale are much too general for any in-depth analysis. Furthermore, the themes represented should not be of decisive importance in connection with the siting of a deep repository. The greatest possibility of also taking into account these aspects is probably through the environmental adaptation of site selection and repository design.

6.4.2 Planned or possible future land use

The establishment of a deep repository primarily involves a 50-year period during which the construction, operation and closure of the repository will be carried out. After these 50 years, the intention is to be able to close the deep repository and dismantle the industrial facilities, thereby restoring the site to a condition which is as close as possible to the original condition. Since no restrictions for land use, with the exception of a ban on deep drilling, are actually needed after restoration, the impact on the long-term future land use of the site and its surrounding environment can be very limited.

Using the areas near to existing or decommissioned industries or areas which have been identified in the municipal plans as land set aside for heavy or environmentally hazardous industry is one possibility which should be taken into account. This could contribute to reducing and minimizing the different types of disturbances which a deep repository could cause as well as possibly lead to technical and infrastructural advantages in terms of coordination. The only industrial facilities where in a general evaluation on a national scale, any kind of co-siting with a repository, e.g. in one and the same municipality, would entail certain obvious and significant advantages are already existing nuclear installations. Concrete, favourable conditions are short transportation distances, as well as the availability of competent and experienced personnel within the municipality.

6.5 OVERALL EVALUATION

The possibility of siting new facilities is limited in several different ways by society's framework and rules. In certain cases, this may involve restrictions which cannot be affected even if this does not always have to mean an absolute prohibition on new industrial establishment.

Siting in areas that are directly protected by law is not necessary or desirable and must be avoided.

General management, protection and consideration rules in the Act concerning the Management of Natural Resources etc., the Nature Conservation Act and the Forestry Act etc. also impose restrictions even if no direct protection is involved. As far as possible, areas of national interest must be protected against actions which tangibly render difficult or counteract maintenance or use for the specified purpose. However, the national interest does not mean that all change is prohibited. Several national interests can be coordinated or may compete with each other within one and the same area. Finding a suitable site for the deep repository is, in itself, a matter of national interest.

Areas which are of national interest in other contexts cannot simply be excluded. However, the siting work should focus on avoiding the siting of the deep repository's industrial area in such areas, or at least siting and designing the repository in such a way that the purpose of the national interest is not negatively affected. Unnecessary use or blocking of natural resources must, if possible, be avoided.

Factors concerning land use and societal planning are studied in closer detail in connection with feasibility studies and site investigations.

In connection with the siting of the deep repository, it is desirable to avoid conflicts with existing or ongoing land use as well as with planned or other possible future land use.

7 SOCIETY – EVALUATIONS ON A NATIONAL SCALE

A number of factors which are important for the siting of a repository or siting aspects which are societal and social in nature are dealt with in this chapter. Together, these factors comprise a basis for the society's or municipality's description of the general conditions and possible consequences of a siting. On a national scale, the number of factors and the aspects which can be studied and assessed in a meaningful manner is limited. The following factors are described: administrative limits, demography, local economy and labour market, infrastructure, municipal services and economy, acceptance and health.

7.1 GENERAL

The establishment and operation of a deep repository will have different impacts on the locality and region. Such impacts relate to employment, local businesses, local services and demographic development as well as the environment and conditions in general. The detailed environmental impact statement which, during the continued siting work will be prepared through an open environmental impact assessment process with the participation of local communities, competent authorities and other interested parties is a central part of the description of the assessed impact of the repository on the land and environment, see Chapter 6.

The siting of a deep repository must be achieved so that /7-1/:

- *Investigation work at different stages, construction and commissioning and operation are carried out on the basis of a democratic process of decision-making.*
- *Social and socioeconomic consequences are taken into consideration.*

Besides SKB, authorities and politicians, a number of different participants with different roles are affected by the siting process in different ways. The municipality, the local community and especially those living near to the repository as well as other parties concerned will play a central role. The Planning and Building Act gives the municipality the primary responsibility for providing information to those living in the vicinity and to other parties concerned. It is also common for different interest organizations, both on the national and local level, to participate with regard to controversial issues. Sometimes, special opinion groups or action groups are formed to oppose the establishment of an industry and, in certain cases, to support the establishment of an industry. Since the development of a municipality is to a great extent affected by politics and the state of the economy, cause-effect relationships will be difficult to understand and will depend on the time-scale concerned.

7.2 IMPORTANT CONDITIONS AND DEVELOPMENT TRENDS

It is difficult to assess and compare, in a general siting study, the consequences of the establishment of a deep repository on different parts of the country, regions, counties or municipalities. It is only possible to identify certain significant characteristics which furthermore tend, in many cases, to be variable and dependent upon the current state of the economy, politics etc. These questions are more suitably studied on a local scale in feasibility studies.

In a general siting study on a national scale, the number of factors must be limited and some generalizations and simplifications must be made. The following siting factors are discussed below:

- administrative boundaries,
- demography,
- local economy and labour market,
- infrastructure,
- municipal services and economy,
- acceptance,
- health.

7.2.1 Administrative boundaries

The socioeconomic impact does not simply stop at the municipal border. Neighbouring municipalities and the region, as a whole, will also be affected, to a certain extent.

Areas near to national boundaries or which cross municipal and county borders are expected to be more difficult to handle, in terms of planning, than other areas, see Figure 7-1.

Areas in the immediate vicinity of administrative boundaries may require special consideration, especially as far as the national boundary is concerned.

7.2.2 Demography

A deep repository is not associated with such risks, requirements or conditions that it is necessary to locate the repository in remote or sparsely populated areas. On the other hand, low population density can minimize the risk of conflicts with opposing land use interests. The risk of conflicts with other land use and maintenance interests is often especially relevant with regard to slightly larger communities. The land is needed for property development as well as for easy access to recreational areas and facilities, see Figure 7-2.

In a historical perspective, the demographic distribution as well as the distribution of property development and siting in Sweden change very slowly. There is strong commitment to the original agricultural and coastal areas as well as existing localities and infrastructure. Changes mainly occur on the fringes of the existing localities and there is nothing to indicate that this will change to any great extent in the future.

The construction of a deep repository is beneficial to society from the national as well as the local perspective. If benefit is to be gained on the local scale, the deep

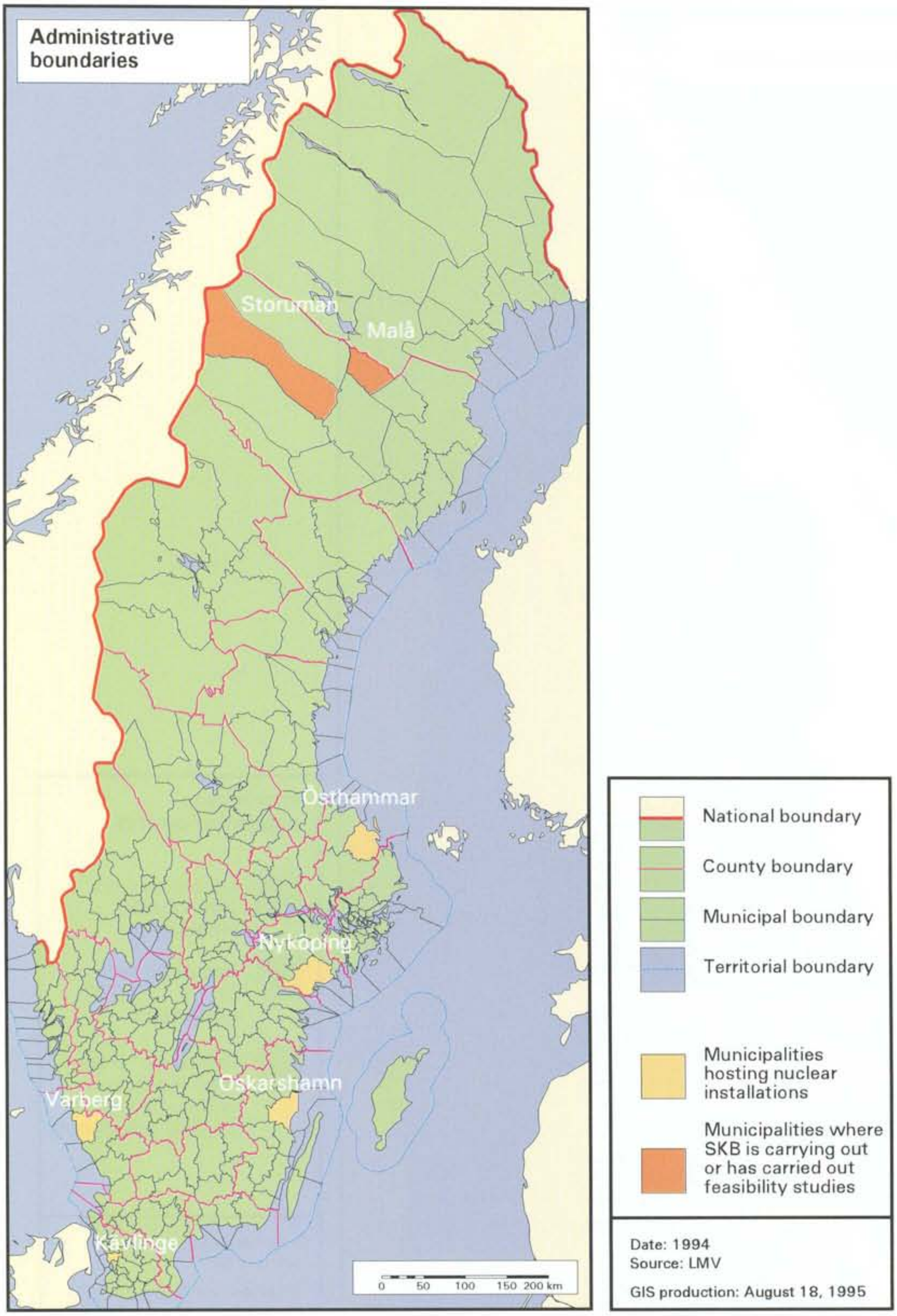

Figure 7-1. *Administrative limits as well as municipalities hosting nuclear installations and municipalities where SKB is carrying out or has carried out feasibility studies.*

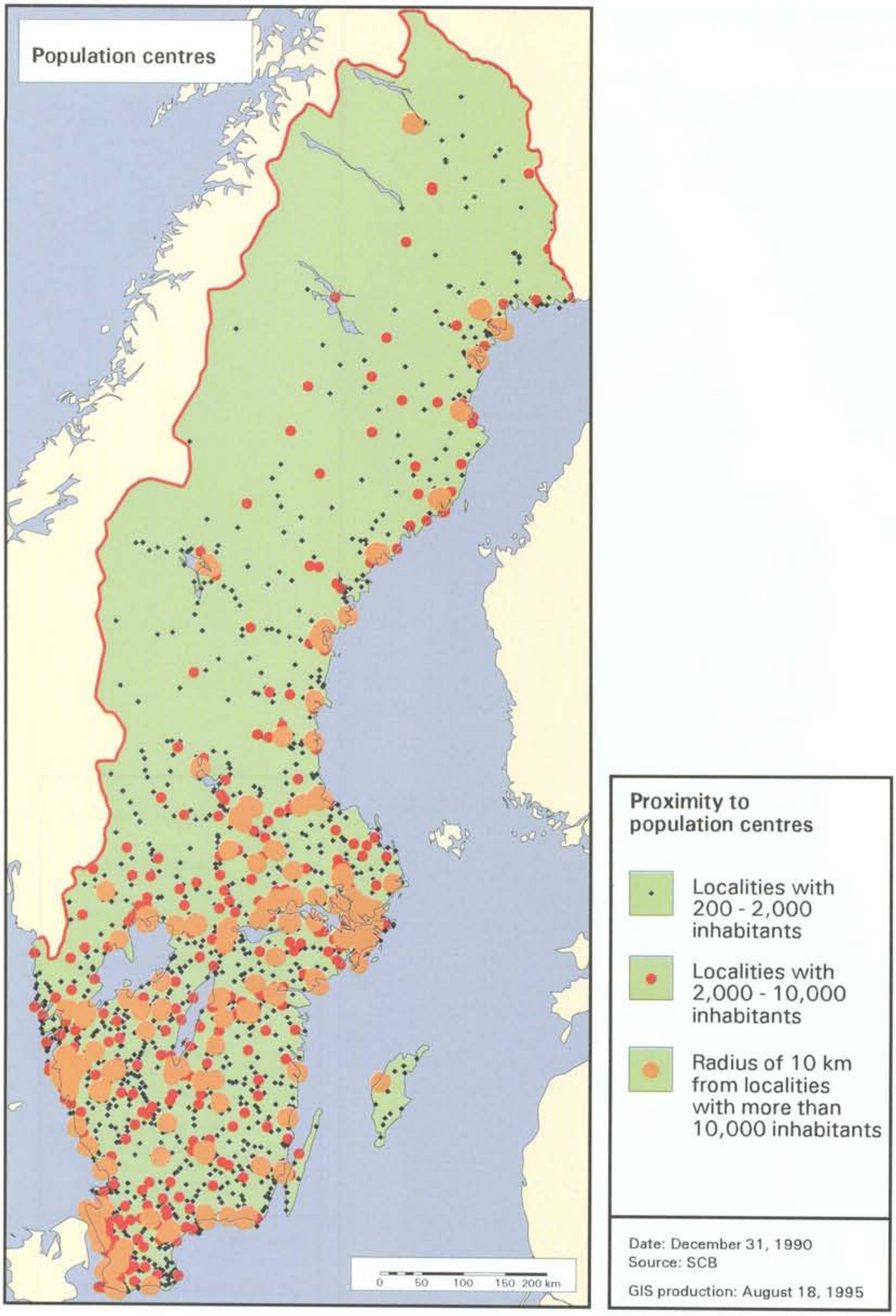

Figure 7-2. *Population centres. The distribution of the population and a 10 km zone around localities with more than 10,000 inhabitants.*

repository should be located near to an existing community. If the community or settlement is expansive, a deep repository can, on the other hand, block use of the land etc.

The question of site selection within a municipality is to be studied in connection with feasibility studies and site investigations.

Investigations /7-2/ /7-3/ which have been carried out within the framework of the two ongoing feasibility studies in Storuman and Malå show that 400-500 more inhabitants can be expected to live in a municipality which hosts a deep repository than one without a repository. This assessment has been made in the light of a reference scenario without a deep repository which would entail a continued negative population trend for these communities as well as on the basis of direct as well as indirect employment impacts caused by the deep repository. The impact on the population is expected to subside after the repository has been closed and operations shut down, but it will probably be possible to trace such impacts for a considerably longer period than the 50-year period which results in direct impacts on employment. The effects on the population trend may, therefore, be more significant in small communities but are probably marginal in larger municipalities.

7.2.3 Local economy and labour market

There are advantages to the siting of a repository in areas where similar activities are already being conducted. The advantages are associated with the fact that professional expertise and experience will be available which should facilitate the recruitment of operational and maintenance personnel, access to relevant knowledge and experience among the public and politicians as well as advantages of coordination.

Apart from the fact that nuclear activities are involved, the deep repository has several large components which can be compared to those which can be found in connection with mining, rock engineering and at power plants as well as the transportation of heavy loads. Thus, it may be assumed that localities and regions with experience and expertise from such activities would be affected to a lesser extent than other localities.

The willingness of the community to expand the structure of local business may also be a significant factor in the siting of a repository. The structure of local business gives an indication of the nature of the community and of the possibility of finding competent labour.

The need for personnel will vary during the 50-year period when the deep repository will have a direct impact on employment. The largest impact on employment is expected to occur for a few years during the period from the year 2005–2009, i.e. during the initial construction and engineering stage and may create 500–600 employment opportunities. During the operational stage, i.e. most of the 50-year period, the deep repository is expected to employ 150–220 people.

The direct employment, an average of about 200 people per year for 50 years, with the subsequent impact on the population, caused by the repository, will also result in a number of indirect job opportunities in trade, the service industries etc. The size of the indirect impacts are largely dependent upon the local conditions for local businesses and the labour market. The feasibility studies carried out at Storuman and Malå indicate that there will be an average of 100 indirect man years during a period of 50 years /7-2/ and /7-3/.

7.2.4 Infrastructure

The links to population, local business and cultural centres as well as to the necessary infrastructure may be valuable, from the purely functional perspective of the deep repository and through the fact that it will make it possible to create an attractive workplace as well as recruit qualified personnel etc. In principle, roads and railways as well as airports are always located within a reasonable distance, see Figure 7-3. The map shows airports which have or could have regular passenger traffic. As can be seen, the possibility of reaching an airport within an hour's car drive is good over the entire country as a whole.

Depending on local conditions, the deep repository activities can, to a varying degree, contribute to maintaining, improving or even creating (e.g. through a new railway or new passenger line) the technical infrastructure, communication system and, thereby, the conditions for transportation and travel. Such impacts can, if they are exploited, be positive to local business, including tourism. Corresponding impacts can also be obtained within the "softer" parts of the society's infrastructure through greater motivation to establish new schools, educational opportunities, childcare and geriatric care, medical services, trade and other local services.

7.2.5 Municipal services and economy

The economic situation and range of available services within a municipality, such as housing, educational opportunities, medical services, childcare and geriatric care along with the situation with regard to population, local businesses, labour market and infrastructure provide a general indication of the nature and possible future development of the municipality. However, municipal services and economy and their importance from the standpoint of siting are difficult to assess on a general level on a national scale but are of interest mainly within feasibility studies carried out on a municipal level.

7.2.6 Acceptance

Positive and negative consequences of a deep repository are, to a certain extent, a question of subjective value judgements. Expressed in simple terms and somewhat provocatively, there are two decidedly different views on the deep repository.

- From one perspective, the deep repository is an important environmental protection facility for the nation, where the nuclear waste will be isolated so as to protect future generations. It is based on long-term planning and high quality requirements and will provide good jobs with advanced technology, will stimulate interest in Sweden and abroad and will be a positive contribution to the economic and societal life of the community and the region.
- From another perspective, the deep repository is an atomic garbage dump and a threat to the environment and the future. It will cause anxiety in the population and will scare away tourists and visitors.

Therefore, in order to examine all possible aspects, the work is not limited to geoscientific and technical issues but deals with questions relating to tourism, the future prospects of the municipality, local business and local economy. Facts must be compiled as well as analyses and forecasts. The views of local businessmen and members of the local community concerning different aspects of the issue must be obtained. Such surveys have been carried out in Storuman, where the socioeconomic impacts have been analyzed /7-5/.

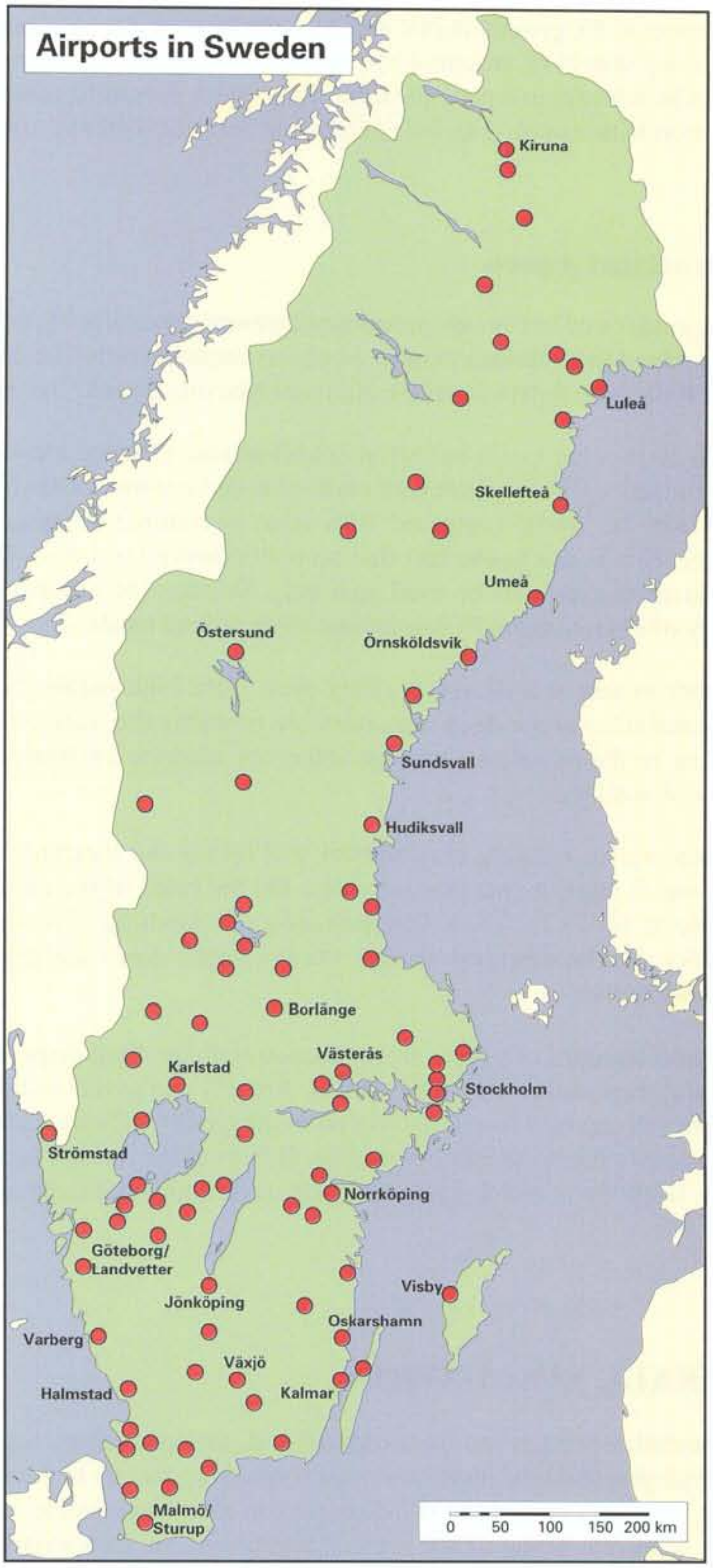

Figure 7-3. *Airports approved by the Board of Civil Aviation. From /7-4/.*

The opinion of the general public and decision-makers, i.e. that the planned facility and activity should be accepted by the local community, is an important factor. It may not be relevant in a general siting study, but it should be taken into account in connection with a more detailed comparison between different siting alternatives.

7.2.7 Health-related aspects

The importance of both medical and psychosocial aspects being taken into account and examined in a relevant manner has been emphasized by the Swedish Environmental Protection Agency and the National Housing Board /7-6/ and /7-7/.

As with every other major industrial establishment, the deep repository will have a certain impact on the environment at the site. Environmental studies show that the impact will be small, compared with what is commonly the case in industrial contexts. This is due to the fact that no real industrial process will be carried out and that chemicals will be used sparingly. Besides the encapsulated waste, the quantity of environmentally hazardous waste will be small.

The environment at a deep repository must fulfil high requirements. The underground activities at the deep repository are probably the feature that attracts most attention. In the initial construction stage, the working environment can be compared with a mine.

The radiological working environment will follow the standards and the requirements which apply to nuclear activities. On the basis of the experience which is available at SKB's facilities, transportation and handling of materials at the deep repository can be designed so that the personnel doses are kept far below the applicable norms.

Views and attitudes of people in connection with the final disposal of radioactive waste are often characterized by anxiety. Anxiety and psychosocial aspects which, it is believed can lead to a deterioration in the quality of human life, must be taken very seriously during feasibility studies. However, this cannot be considered to be a siting factor upon which siting alternatives on a national scale can be based.

7.3 OVERALL EVALUATION

The societal aspects in the form of local and, to some extent, regional conditions and developmental tendencies are not always siting factors in the real sense but are still an important part of the siting process so that the desirable overall evaluation can be achieved. Many of the societal aspects are of such a nature that they can only be considered on the local or possibly, regional scale in connection with feasibility studies.

- **Areas in the immediate vicinity of administrative boundaries may require special considerations to be made, especially with regard to national boundaries.**
- **Effects on local economy, labour market, infrastructure, municipal services and economy as well as acceptance and health are being specially investigated in connection with feasibility studies and site investigations.**

8 CONCLUSIONS

In General Siting Study 95, important siting factors have been described and applied on a national scale. For each such siting factor, separate conclusions have been reported in detail.

All of the factors, of which the long-term radiological safety is the central factor, must be taken into account in the siting of the deep repository. However, to make an overall evaluation of this factor, site-specific data on the bedrock must be available. Such data can only be obtained by carrying out extensive investigations at sites which can only be selected on the basis of partially incomplete information. This is a characteristic which distinguishes the siting of underground facilities in general, and a deep repository in particular, from other types of industrial siting, where information on all of the vital factors is relatively easy to obtain.

An important part of the work on preparing General Siting Study 95 has been to explore the possibilities and limitations which are related to a general siting study on a national scale.

A general siting study on a national scale cannot provide information on scientific, technical and societal factors with the necessary level of detail in order to identify sites which are suitable for the siting of a deep repository. The information presented in this study in general also covers conditions at the surface and not at the depths envisaged for the deep repository, 400-700 m below the surface. Thus, the suitability of a site is best evaluated through feasibility studies and site investigations and evaluations which must be carried out in connection with pertinent permitting of regulatory authorities.

However, General Siting Study 95 makes it possible to identify areas which are less suitable, or of less interest. However, areas which are of less interest, on a national scale, cannot be excluded since, on the local scale of a particular area, there may be many sites of interest which may be omitted when generalizations are made on the national scale. The general siting study also examines several scientific, technical and societal conditions in different parts of Sweden. These conditions provide a basis for assessing interest in, and for carrying out more detailed siting studies (feasibility studies.

The goals of General Siting Study 95 have been described in the RD&D Programme 92 Supplement:

- *"In a general fashion (on a national scale), shed light on conditions of interest for determining which parts of the country are unsuitable, interesting or suitable for siting a deep repository.*
- *Yield data for determining SKB's interest in feasibility studies in different regions or municipalities.*
- *Provide indications of what must be particularly taken into account and studied in connection with continued more detailed studies within suitable or particularly interesting areas.*
- *Yield data for putting coming site selection in its national and regional context."*

The conclusions from this work is now related to the established goals.

"In a general fashion (on a national scale), shed light on conditions of interest for determining which parts of the country are unsuitable, interesting or suitable for siting a deep repository."

An overall evaluation of the applicable siting factors shows that it is unsuitable to locate the deep repository in the Scandinavian mountain range, Skåne and Gotland, primarily for geological reasons. Furthermore, the Scandinavian mountain range is an area of national interest with regard to nature conservation and outdoor activities. Siting of the repository in the bedrock below Öland is considered to be technically possible, although unsuitable in terms of the management regulations of the Act concerning the Management of Natural Resources etc.

Siting of the repository in areas which are directly protected by law is neither necessary or desirable and must be avoided.

Areas which are of national interest in other contexts cannot be simply excluded. However, work should not focus on siting the deep repository in such areas or should at least focus on siting and designing the deep repository so as not to negatively affect the aim of protecting areas which are of national interest.

The unnecessary use, or blocking of natural resources must, if possible, be avoided. Areas where unusual rock types occur or where there is a possibility of ore, especially bedrock consisting of acid volcanic rock types, are therefore of less interest. By avoiding these rock types, there is less possibility of future, unintentional intrusion into the deep repository as well.

The conclusion which was previously drawn by SKB that there are many areas in Sweden which appear to be suitable for the siting of a deep repository has not been altered by General Siting Study 95. In the future, siting should also focus on bedrock commonly found in Sweden, preferably more or less transformed granite-like rock types, or old, highly metamorphosised sedimentary bedrock. This type of "interesting" bedrock exists in large parts of Sweden.

It is not necessary to exclude areas containing gabbro, or areas where the bedrock is covered by sedimentary rock, in connection with siting. These areas can assessed especially if feasibility studies will be carried out in municipalities with this type of bedrock.

It is technically possible to locate the repository beneath large lakes or beneath the sea. However, there is no particular reason to seek out or avoid such a siting.

The long-term radiological safety is not the only factor taken into consideration in the siting of the deep repository but also the practical implementation of the work. Consequently, areas with bedrock that is easy to interpret as well as areas where the rock is relatively low-conductive are of interest. In general, there is no conflict between the factors which are favourable to the long-term safety and the simple, technical implementation of work. It is most suitable to evaluate the question of the variation of the bedrock and other properties in connection with more detailed studies.

As far as transportation and communication are concerned, the availability of harbours, railroads or airports is good. Thus, on the national scale, there is no real limitation of possible areas in terms of these factors.

"Yield data for determining SKB's interest in feasibility studies in different regions or municipalities."

The siting factors described in this report have already been largely applied in the feasibility study which was carried out in Storuman and in the ongoing (October 1995) feasibility study in Malå. These factors have also been applied to municipalities which have evinced interest in initiating feasibility studies but which have been considered to be less interesting by SKB.

In General Siting Study 95, it is emphasized that many of the siting factors should, above all, be applied on a local scale in connection with feasibility studies and site investigations. This study is one of the bases which can be used in connection with the planning of work to find a suitable site for the repository.

For general technical and societal reasons, it is of interest to conduct feasibility studies in municipalities with existing nuclear activities: Nyköping, Oskarshamn, Varberg and Östhammar, which has been previously reported.

Besides the already completed, ongoing or planned feasibility studies, it is suitable to carry out one additional or a few additional feasibility studies. It should be an advantage to further work and with regard to discussions with different communities that an overall report on the general siting studies which have been carried out now exists. The report makes it easier than before for all concerned to understand the background and general conditions that exist for siting work in different parts of the country.

As a basis for concrete discussions with different communities concerning feasibility studies, SKB intends to use regional general siting studies which are based on this study. In such regional general siting studies, it is of particular interest to preliminarily identify areas within one region which are expected to have suitable conditions with regard to industrial experience, availability of industrial land and proximity to harbours or railroads as well as where it is expected that there is bedrock with a good potential for fulfilling technical and safety-related requirements.

"Provide indications of what must be particularly taken into account and studied in connection with continued more detailed studies within suitable or particularly interesting areas."

General Siting Study 95 provides such indications, in several respects. Such factors include possible conflicts of interest in connection with land use in expansive areas of Sweden, the occurrence of ore mineralizations etc.

"Yield data for putting coming site selection in its national and regional context."

General Siting Study 95 contains background material and a description of general conditions in different parts of Sweden which make it possible to, in connection with site licensing (based on 5–10 feasibility studies and 2 site investigations), evaluate whether the selected site is acceptable from different aspects and whether it is based on a sufficiently broad basis of information.

The background material often contains large variations on a local scale, which cannot be specified on a national scale. Thus, in all probability, suitable areas can be found both in regions which, on a national scale, appear to be of greater interest, as well as in regions which, on a national scale, appear to be of lesser interest. This general approach can be applied to several of the databases or situations which are described in this report.

Regional and local conditions will have to be more closely investigated in feasibility studies and site investigations in each relevant case.

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Appendix 1

GEOSCIENTIFIC BACKGROUND MATERIAL USED IN GENERAL SITING STUDIES

(Reports with Swedish titles are available in Swedish only.)

Report	Comments
The gravity field in Fennoscandia and postglacial crustal movements. KBS TR 17, 1977 A Bjerhammar	The report deals with tectonic and isostatic movements based on gravimetric measurements.
Studies of neotectonic activities in central and northern Sweden, review of aerial photos and geophysical interpretation of recent faults. KBS TR 19, 1977 R Lagerbäck, H Henkel	The report deals with postglacial structures and reactivation in a regional perspective.
Tectonic analysis of southern Sweden, Lake Vättern – Northern Skåne. KBS TR 20, 1977 K Röshoff, E Lagerlund	The report deals with lineament interpretations and neotectonics within the region.
Earthquakes of Sweden 1891–1957, 1963 –1972. KBS TR 21, 1977 O Kulhànek, R Wahlström	The report deals with seismic data in a national perspective.
The Blekinge coastal gneiss, Geology and hydrogeology. KBS TR 25, 1977 I Larsson et al.	The report deals with structure-geological units and their relation to groundwater occurrence for the region.
Seismotectonic risk modelling for nuclear waste disposal in the Swedish bedrock. KBS TR 51, 1977 F Ringdal et al.	The report deals with general geotectonic risks related to earthquakes and creep movements in Sweden.

Report	Comments
Stress measurements in Scandinavian bedrock – premises, results and interpretation. KBS TR 64, 1977 S G A Bergman	Rock stress measurements in a three-dimensional perspective are discussed.
Groundwater chemistry at depth in granites and gneisses. KBS TR 88, 1978 G Jacks	The report deals in general terms with groundwater chemistry in Swedish crystalline rock.
Hydrochemical investigations in crystalline bedrock in relation to existing hydraulic conditions. Experience from the SKB test sites in Sweden. SKB TR 85-11, 1985 J Smellie et al.	The report is a compilation of the comprehensive hydrochemical work carried out on SKB's study sites during the period 1982-1984.
A preliminary structural analysis of the pattern of post-glacial fault in northern Sweden. SKB TR 86-20, 1986 C Talbot	The report deals with the kinetics of postglacial faults.
Geological maps and cross-sections of Southern Sweden. SKB TR 87-24, 1987 K-A Kornfält et al.	Compilation of regional map material.
Earthquake measurements in southern Sweden, Oct 1, 1986 – Mar 31, 1987. SKB TR 87-27, 1987 R Slunga et al.	Regional compilation of earthquakes.
Swedish Hard Rock Laboratory. First evaluation of preinvestigations 1986-87 and target area characterization. SKB TR 88-16, 1988 G Gustafson et al.	Compilation of geoscientific premises for the Äspö project in a regional perspective.
Characterization of the morphology, basement rock and tectonics in Sweden. SKB TR 89-03, 1989 K Röshoff	Compilation of morphological terrain types in Sweden.

Report	Comments
Earthquake mechanisms in Northern Sweden Oct 1987 – Apr 1988. SKB TR 89-28, 1989 R Slunga	Regional compilation of earthquakes.
Interdisciplinary study of post-glacial faulting in the Lansjärv area Northern Sweden 1986 – 1988. SKB TR 89-31 G Bäckbom et al.	Summary of studies in the Lansjärv region.
Characterization of humic substances from deep groundwaters in granitic bedrock in Sweden. SKB TR 90-29, 1990 C Pettersson et al.	The report deals with the presence of fulvic acids in groundwaters from a number of study sites in Sweden.
The earthquakes of the Baltic Shield. SKB TR 90-30, 1990 R Slunga	Analysis of 200 earthquakes, ML 0.6-4.5, with emphasis on depth of focus, of focus dynamic outcrop parameters and fault plane.
SKB/TVO Ice age scenario. SKB TR 91-32, 1991 K Ahlbom et al.	Scope of hypothetical future glaciations.
Gideå study site. Scope of activities and main results. SKB TR 91-51, 1991. K Ahlbom et al.	Main report on Gideå study site.
Fjällveden study site. Scope of activities and main results. SKB TR 91-52, 1991 K Ahlbom et al.	Main report on Fjällveden study site.
Sternö study site. Scope of activities and main results. SKB TR 92-02, 1992 K Ahlbom et al.	Main report on Sternö study site.
Kamlunge study site. Scope of activities and main results. SKB TR 92-15, 1992 K Ahlbom et al.	Main report on Kamlunge study site.

Report	Comments
The Protogine Zone. Geology and mobility during the last 1.5 Ga. SKB TR 92-21, 1992 P Andreasson et al.	The report summarizes the Protogine Zone's geological and geophysical functions.
Klipperås study site. Scope of activities and main results. SKB TR 92-22, 1992 K Ahlbom et al.	Main report on Klipperås study site.
Bedrock stability in Southeastern Sweden. Evidence from fracturing in the Ordovician limestones of Northern Öland. SKB TR 92-23, 1992 A G Milnes & D Gee	Regional stability in the bedrock is reported on the basis of a fracture mapping.
Geologiska miljöer och faktorer sett i olika skalor att beakta vid planering av ett slutförvar för använt kärnbränsle. (In Swedish) SKB PR 44-92-101, 1992 Å Brunn et al.	The report includes nationwide maps of crystalline rock provinces, ore deposits, active mining and mineral rights, lineament interpretation and major deformation zones.
Gabbro as a host rock for a nuclear waste repository. SKB TR 92-25, 1992 K Ahlbom et al.	The report describes the location of gabbro formations in Sweden and the advantages and disadvantages of siting a deep repository in basic rock.
The Äspö Hard Rock Laboratory: Final evaluation of the hydrogeochemical pre-investigations in relation to existing geologic and hydraulic conditions. SKB TR 92-31, 1992 J Smellie & M Laaksoharju	The report compiles and interprets all hydrochemical analyses in the introductory phase of the Äspö project.
Finnsjön study site. Scope of activities and main results. SKB TR 92-33, 1992 K Ahlbom et al.	Main report on the Finnsjön study site.
Climatic changes and uplift patterns – past, present and future. SKB TR 92-38, 1992 S Björk & N-O Svensson	The report describes the climate changes of the past 2.5 million years and their effects in a global and Scandinavian perspective.

Report	Comments
Post-glacial faulting in the Lansjärv area, Northern Sweden. SKB TR 93-11, 1993 R Stanfors et al.	The report summarizes the second programme phase in the Lansjärv project, including comments from the 1991 excursion with international participation.
Possible strategies for geoscientific classification for high-level waste repository site selection SKB TR 93-12 L Rosén, G Gustafson	The report discusses and makes use of different classification systems using geostatistics methods.
A review of the seismotectonics of Sweden. SKB TR 93-13, 1993 R Muir Wood	The report deals with seismological aspects of tectonics in the Baltic Shield in a historical perspective.
Simulation of the European ice sheet through the last glacial cycle and prediction of future glaciation. SKB TR 93-14, 1993 G S Boulton & A Payne	The report presents the results and the structure of a coupled, time-dependent glaciation model which allows simulation of hydrogeological, thermal and rock-mechanical regional effects.
Tectonic regimes in the Baltic Shield during the last 1200 Ma – A review. SKB TR 94-05, 1994 S-Å Larsson & E-L Tullborg	The report summarizes the geological history of Scandinavia with an emphasis on plate tectonic movements and probable rock stress directions.
Storumans kommun i ett regional-geologiskt sammanhang. (In Swedish) SKB PR 44-94-003, 1994 T Eliasson & T Lundqvist	The report is part of the background material for the feasibility study of Storuman.
Reassessment of seismic reflection data from the Finnsjön study site and prospectives for future surveys. SKB TR 94-03 C Cosma, C Juhlin, O Olsson	An field investigation at Finnsjön 1987 is re-processed and the measurements now show subhorizontal fracture zones in the area.
Tectonic framework of the Hanö Bay area, southern Baltic Sea SKB TR 94-09, 1994 K O Wannäs, T Flodén	The bedrock tectonics of Hanö Bay have been interpreted via seismic reflection methods.

Report	Comments
Summary report of the experiences from TVO's site investigations SKB TR 94-17 A Öhberg, P Saksa, H Ahokas, P Ruotsalainen, M Snellman	General results and experiences from the Finnish programme.
A reconstruction of the tectonic history of Fennoscandia based on observations at the boundary areas. SKB TR 95-XX, 1995 R Muir Wood	The report deals with the past 100 million years in detail based on geophysical interpretations in the sedimentary basins surrounding the Baltic Shield. The interpretation is based on the large body of material from oil and gas prospecting that exists mainly in the North Sea.
Beskrivning till databas över bergspänningsmätningar i Sverige. SKB PR D-95-107 C Ljunggren, M Persson	An updated compilation of all available rock stress measurements in Sweden.
A catalogue of earthquakes in Sweden in 1375-1890. Geol. Fören. Stockholm, Förh 112 (1990), 215-225 R Wahlström	Databases in GIS format including reporting. The report deals with all available data in Fennoscandia. Special emphasis on superficial earthquakes.
Maps of the Seismicity of the Fennoscandia. SKB AR D-95-17 S Sundqvist	Compilation of database.

Appendix 2

PROJECT ORGANIZATION FOR GENERAL SITING STUDY 95

This report was prepared within the General Siting Studies Project carried out by SKB's Division of Deep Repository.

Göran Bäckblom was the project manager and author of the report. An informal reference group with Claes Thegerström (chairman) and Ingela Månson (secretary), Kaj Ahlbom, Torsten Eng and Lars O Ericsson have met on a regular basis to provide advice and recommendations.

Siting factors were studied in consultation with Tönis Papp, Lars O Ericsson, Christer Svemar, the whole of the SKB organization as well as Erik Setzman, Vattenfall Energisystem AB.

Data processing and production of GIS material was carried out in cooperation with Karin Fridstrand and Lennart Holmberg, GIS Centrum. The airborne data was also analyzed by Patrik Eriksson and Hans Isaksson, Geovista.

Studies were carried out by Erik Setzman (Vattenfall Energisystem AB) concerning land and environment. Kaj Ahlbom, Conterra AB, studied the possibilities and limitations of a general siting study on a national scale.

Jerker Tengman, (Vattenfall Energisystem AB) acted as project administrator and Ingela Månson as project secretary.

Pictures were compiled by Art-O-Matic, Inger Svendsen and Helene Ekman. The report was prepared for printing by Maj-Britt Danielsson, Correcta.

Appendix 3

DIAGRAM OF SITING FACTORS

LONG-TERM RADIOLOGICAL SAFETY

ISOLATION

Chemically stable environment
- low content of foreign material (organic, construction material)
- low content of corrosion agents (sulphides, acids)
- non-abnormal salt content
- non-abnormal pH
- stable groundwater chemistry

Low groundwater flow
- low gradient
- low transmissivity

Mechanical stability
- low deviator stress
- no large deformations over canister hole
- safe distance (zones, deformation zones, locations of major displacements, quakes)

RETARDATION

Chemically stable environment
- low fuel dissolution (reducing environment, pH, carbonates)
- stable buffer (calcium, potassium, chlorides)
- sorption, matrix diffusion, diffusion, (Kd, available surface, organic material, colloids, gas bubbles, reducing environment)
- non-abnormal salt contents
- non-abnormal pH
- stable groundwater chemistry

Low groundwater flow
- low gradient
- low transmissivity
- thermal convection
- density differences
- two-phase flows

Mechanical stability
- stable stress field

DISCHARGE AREA

Dilution
- dispersion
- mixing conditions
- flow stretch

Wells

Biosphere

Coast, sea, inland

Intrusion
- prospecting for ore, industrial minerals, groundwater
- infrastructure project

TECHNOLOGY

TRANSPORTATION

Existing facilities

INDUSTRIAL AREAS

Geotechnology
- flat land
- land with good bearing capacity

UNDERGROUND FACILITY

Low groundwater flow
- low transmissivity

Mechanical stability
- low deviator stresses
- high mechanical rock strength
- few fracture zones

Rock investigations
- homogeneous bedrock
- thin soil cover

Repository layout
- tunnel/shaft
- depth
- safe distance to zones
- thermal conductivity
- plugs
- interaction between barriers

Rock engineering
- few crushed sections
- low hydraulic conductivity
- rock conducive to grouting
- low transmissivity
- mechanically stable
- low radon content

Operation
- radon
- canister handling
- non-aggressive water

LAND AND ENVIRONMENT

LEGALLY PROTECTED AREAS

- national parks
- nature reserves
- nature conservation areas etc.
- areas of national interest
- other areas

MANAGEMENT OF NATURAL RESOURCES

- special management regulations with geographical guidelines (NRL)
- land and water
- landscape, natural and cultural environments
- agricultural and forestry, hunting, fishing, reindeer husbandry
- outdoor activities and tourism
- natural resources (e.g. ore, industrial, minerals, peat, gravel etc.)
- land for community development

REPOSITORY DESIGN

Transportation
- existing facilities

Industrial area
- adaption to local conditions
- design of buildings

Underground facility
- groundwater table lowering
- borehole installations
- discharge area
- long-term measurements

Waste rock reclamation area
- availability

SOCIETY

ADMINISTRATIVE BOUNDARIES

POPULATION AND PROPERTY DEVELOPMENT

LOCAL ECONOMY AND LABOUR MARKET

INFRASTRUCTURE

MUNICIPAL SERVICES AND ECONOMY

HEALTH

ACCEPTANCE

Appendix 4

SURVEY OF SKB's GIS DATABASES

GIS databases used in the report are printed in italics. Local databases added to the GIS databases in connection with the feasibility studies are not included.

INFRASTRUCTURE
Population centres
Administrative boundaries
Planning details
Power lines
Shooting ranges
Environmentally hazardous activities
Churches

NATURAL GEOGRAPHICAL DATA
Coast
Islands
Lakes
Watercourses

ELEVATION DATA
Elevation data, 500 metres

GEOLOGICAL DATA
Bedrock geology
Soil types
Mining and mineral rights
Industrial minerals and rock types
Highest shoreline and ice dammed lakes
Continental shelf bedrock and tectonics
Earthquakes
Ore deposits
Crystalline bedrock provinces and sedimentary bedrock
Large lineaments
Large deformation zones
Current land uplift

HYDROGEOLOGICAL DATA
Groundwater resources in the soil
Groundwater resources in the rock
SGU's well archive

CHEMICAL DATA
Groundwater composition – chloride and pH
Ground geochemistry
Moraine geochemistry

GEOPHYSICAL DATA
Airborne geophysical data
Gravity data

COASTAL DEVELOPMENT DATA
Highest Shoreline
Baltic Ice Lake
Yolida Sea
Ancylus Sea
Littorina Sea

NATURAL RESOURCES DATA
Nature conservation areas of national interest
Outdoor activity areas of national interest
Wetlands, protected
Wetlands, unprotected
CW areas
Virgin forest areas
National park plans
Natural geographical regions
National parks
Nature reserves
Nature conservation areas
Animal sanctuaries
Natural monuments
Natural monument points
Forest services reserves
Private reserves

LAND USE DATA AND LANDOWNERS
Land use and type of ownership
Major landowners in Sweden

SOCIOECONOMIC DATA
Population statistics

TRANSPORTATION DATA
Roads – red map
Railroads – red map

Appendix 5

ABBREVIATIONS USED

AKA	The final report of the AKA commission to study spent nuclear fuel and radioactive waste, SOU: 1976:30, 31, 41
CLAB	Central interim storage facility for spent nuclear fuel
EIS	Environmental Impact Statement
GIS	Geographical information system
KASAM	Swedish National Council for Nuclear Waste
KTL	Act on Nuclear Activities
NRL	Act concerning the Management of Natural Resources etc.
NVL	Nature Conservation Act
PRAV	Council for the Radioactive Waste Programme
RD&D	Research, development and demonstration
SFR	Repository for radioactive operational waste
SGU	Swedish Geological Survey
SKB	Swedish Nuclear Fuel and Waste Management Co
SKI	Swedish Nuclear Power Inspectorate
SKN	Swedish National Board for Spent Nuclear Fuel
SSI	Swedish Radiation Protection Institute

List of SKB reports

Annual Reports

1977-78
TR 121
KBS Technical Reports 1 – 120
Summaries
Stockholm, May 1979

1979
TR 79-28
The KBS Annual Report 1979
KBS Technical Reports 79-01 – 79-27
Summaries
Stockholm, March 1980

1980
TR 80-26
The KBS Annual Report 1980
KBS Technical Reports 80-01 – 80-25
Summaries
Stockholm, March 1981

1981
TR 81-17
The KBS Annual Report 1981
KBS Technical Reports 81-01 – 81-16
Summaries
Stockholm, April 1982

1982
TR 82-28
The KBS Annual Report 1982
KBS Technical Reports 82-01 – 82-27
Summaries
Stockholm, July 1983

1983
TR 83-77
The KBS Annual Report 1983
KBS Technical Reports 83-01 – 83-76
Summaries
Stockholm, June 1984

1984
TR 85-01
Annual Research and Development Report 1984
Including Summaries of Technical Reports Issued during 1984. (Technical Reports 84-01 – 84-19)
Stockholm, June 1985

1985
TR 85-20
Annual Research and Development Report 1985
Including Summaries of Technical Reports Issued during 1985. (Technical Reports 85-01 – 85-19)
Stockholm, May 1986

1986
TR 86-31
SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

1987
TR 87-33
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Including Summaries of Technical Reports Issued during 1987
Stockholm, May 1988

1988
TR 88-32
SKB Annual Report 1988
Including Summaries of Technical Reports Issued during 1988
Stockholm, May 1989

1989
TR 89-40
SKB Annual Report 1989
Including Summaries of Technical Reports Issued during 1989
Stockholm, May 1990

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1994
TR 94-33
SKB Annual Report 1994
Including Summaries of Technical Reports Issued during 1994.
Stockholm, May 1995

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Biotite and chlorite weathering at 25°C. The dependence of pH and (bi) carbonate on weathering kinetics, dissolution stoichiometry, and solubility; and the relation to redox conditions in granitic aquifers
Maria Malmström[1], Steven Banwart[1], Lara Duro[2], Paul Wersin[3], Jordi Bruno[3]
[1] Royal Institute of Technology, Department of Inorganic Chemistry, Stockholm, Sweden
[2] Universidad Politécnica de Cataluña, Departmento de Inginería Química, Barcelona, Spain
[3] MBT Tecnología Ambiental, Cerdanyola, Spain
January 1995

TR 95-02
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Lars Werme, Joachim Eriksson
Swedish Nuclear Fuel and Waste Management Co, Stockholm, Sweden
March 1995

TR 95-03
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Marie Wiborgh (ed.)
Kemakta Konsult AB, Stockholm, Sweden
January 1995

TR 95-04
Spent nuclear fuel corrosion: The application of ICP-MS to direct actinide analysis
R S Forsyth[1], U-B Eklund[2]
[1] Caledon-Consult AB, Nyköping, Sweden
[2] Studsvik Nuclear AB, Nyköping, Sweden
March 1995

TR 95-06
Palaeohydrological implications in the Baltic area and its relation to the groundwater at Äspö, south-eastern Sweden – A literature study
Bill Wallin
Geokema AB, Lidingö, Sweden
March, 1995

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Äspö Hard Rock Laboratory Annual Report 1994
SKB
April 1995

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Swedish Nuclear Fuel and Waste Management Co., Stockholm
January 1995

TR 95-09
A thermodynamic data base for Tc to calculate equilibrium solubilities at temperatures up to 300°C
Ignasi Puigdomènech[1], Jordi Bruno[2]
[1] Studsvik AB, Nyköping, Sweden
[2] Intera Information Technologies SL, Cerdanyola, Spain
April 1995

TR 95-10
Investigations of subterranean microorganisms. Their importance for performance assessment of radioactive waste disposal
Karsten Pedersen[1], Fred Karlsson[2]
[1] Göteborg University, General and Marine Microbiology, The Lundberg Institute, Göteborg, Sweden
[2] Swedish Nuclear Fuel and Waste Management Co., Stockholm, Sweden
June 1995

TR 95-11
Solute transport in fractured media – The important mechanisms for performance assessment
Luis Moreno, Björn Gylling, Ivars Neretnieks
Department of Chemical Engineering and Technology, Royal Institute of Technology, Stockholm, Sweden
June 1995

TR 95-12
Literature survey of matrix diffusion theory and of experiments and data including natural analogues
Yvonne Ohlsson, Ivars Neretnieks
Department of Chemical Engineering and Technology, Royal Institute of Technology, Stockholm, Sweden
August 1995

TR 95-13
Interactions of trace elements with fracture filling minerals from the Äspö Hard Rock Laboratory
Ove Landström[1], Eva-Lena Tullborg[2]
[1] Studsvik Eco & Safety AB
[2] Terralogica AB
June 1995

TR 95-14
Consequences of using crushed crystalline rock as ballast in KBS-3 tunnels instead of rounded quartz particles
Roland Pusch
Clay Technology AB
February 1995

TR 95-15
Estimation of effective block conductivities based on discrete network analyses using data from the Äspö site
Paul R La Pointe[1], Peter Wallmann[1], Sven Follin[2]
[1] Golder Associates Inc., Seattle, WA, USA
[2] Golder Associates AB, Lund, Sweden
September 1995

TR 95-16
Temperature conditions in the SKB study sites
Kaj Ahlbom[1], Olle Olsson[1], Stefan Sehlstedt[2]
[1] Conterra AB
[2] MRM Konsult AB
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TR 95-17
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Anna Ledin, Anders Düker, Stefan Karlsson, Bert Allard
Department of Water and Environmental Studies,Linköping University, Linköping, Sweden
June 1995

TR 95-18
Thermal evidence of caledonide foreland, molasse sedimentation in Fennoscandia
Eva-Lena Tullborg[1], Sven Åke Larsson[1], Lennart Björklund[1], Lennart Samuelsson[2], Jimmy Stigh[1]
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[2] Geological Survey of Sweden, Earth Sciences Centre, Göteborg, Sweden
November 1995

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Compaction of bentonite blocks. Development of technique for industrial production of blocks which are manageable by man
Lars-Erik Johannesson, Lennart Börgesson, Torbjörn Sandén
Clay Technology AB, Lund, Sweden
April 1995

TR 95-20
Modelling of the physical behaviour of water saturated clay barriers. Laboratory tests, material models and finite element application
Lennart Börgesson[1], Lars-Erik Johannesson[1], Torbjörn Sandén[1], Jan Hernelind[2]
[1] Clay Technology AB, Lund, Sweden
[2] FEM-Tech AB, Västerås, Sweden
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Conceptual model for concrete long time degradation in a deep nuclear waste repository
Björn Lagerblad, Jan Trägårdh
Swedish Cement and Concrete Research Institute
February 1994

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The use of interaction matrices for identification, structuring and ranking of FEPs in a repository system. Application on the far-field of a deep geological repository for spent fuel
Kristina Skagius[1], Anders Ström[2], Marie Wiborgh[1]
[1] Kemakta, Stockholm, Sweden
[2] Swedish Nuclear Fuel and Waste Management Co, Stockholm, Sweden
November 1995

TR 95-23
Spent nuclear fuel. A review of properties of possible relevance to corrosion processes
Roy Forsyth
Caledon Consult AB
April 1995

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Marcus Laaksoharju[1], Claude Degueldre[2], Christina Skårman[1]
[1] GeoPoint AB, Sollentuna, Sweden
[2] University of Geneva, Switzerland
December 1995

TR 95-25
Sulphate reduction in the Äspö HRL tunnel
Marcus Laaksoharju (ed.)
GeoPoint AB, Sollentuna, Sweden
December 1995

TR 95-26
The Äspö redox investigations in block scale. Project summary and implications for repository performance assessment
Steven Banwart (ed.)
Dept. of Civil and Environmental Engineering, University of Bradford, UK
November 1995

TR 95-27
Survival of bacteria in nuclear waste buffer materials. The influence of nutrients, temperature and water activity
Karsten Pedersen[1], Mehrdad Motamedi[1], Ola Karnland[2]
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[2] Clay Technology AB, Lund, Sweden
December 1995

TR 95-28
DECOVALEX I – Test Case 2: Calculation of the Fanay-Augéres THM Test – Thermomechanical modelling of a fractured rock volume
Lennart Börgesson[1], Jan Hernelind[2]
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December 1995

TR 95-29
DECOVALEX I – Test Case 3: Calculation of the Big Ben Experiment – Coupled modelling of the thermal, mechanical and hydraulic behaviour of water-unsaturated buffer material in a simulated deposition hole
Lennart Börgesson[1], Jan Hernelind[2]
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December 1995

TR 95-30
DECOVALEX I – Bench-Mark Test 3: Thermo-hydromechanical modelling
Jan Israelsson
Itasca Geomekanik AB
December 1995

TR 95-31
DECOVALEX I – Test Case 1: Coupled stress-flow model
Lars Rosengren[1], Mark Christianson[2]
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[2] Itasca Consulting Group Inc.
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Partitioning and transmutation (P&T) 1995. A review of the current state of the art
Mats Skålberg[1], Anders Landgren[1], Lena Spjuth[1], Jan-Olov Liljenzin[1], Waclaw Gudowski[2]
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December 1995

TR 95-33
Geohydrological simulation of a deep coastal repository
Sven Follin
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December 1995