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Äspö Hard Rock Laboratory. Predictions prior to excavation and the process of their validation

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June 1991

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ÄSPÖ HARD ROCK LABORATORY.
PREDICTIONS PRIOR TO EXCAVATION AND THE PROCESS OF THEIR VALIDATION

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Information on SKB technical reports from 1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26), 1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77), 1984 (TR 85-01), 1985 (TR 85-20), 1986 (TR 86-31), 1987 (TR 87-33), 1988 (TR 88-32) and 1989 (TR 89-40) is available through SKB.

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INTRODUCTORY COMMENT

This report is No IV, of four summarizing the pre-investigation phase of the Äspö Hard Rock laboratory.

The reports are:

I	Stanfors R, Erlström M, Markström I. Äspö Hard Rock Laboratory Overview of the investigations 1986-1990. SKB TR 91-20.
II	Almén K- E, Zellman O. Äspö Hard Rock Laboratory Field investigation methodology and instruments used in the pre-investigation phase, 1986-1990. SKB TR 91-21.
III	Wikberg P, Gustafson G, Rhén I, Stanfors R. Äspö Hard Rock Laboratory Evaluation and conceptual modelling based on the pre-invegations 1986-1990. SKB TR 91-22.
IV	Gustafson G, Liedholm M, Rhén I, Stanfors R, Wikberg P. Äspö Hard Rock Laboratory Predictions prior to excavation and the process of their validation. SKB TR 91-23.

The background and objectives of the project are presented in a background report to SKB R&D programme 1989 (Hard Rock Laboratory) where a detailed description of the HRL project can be found.

ABSTRACT

In order to prepare for the siting and licensing of a spent fuel repository SKB decided to construct a new underground research laboratory.

The pre-investigations for the Äspö Hard Rock Laboratory started in late 1986. Intermediate reports on the investigations were published in 1988 and 1989. This report presents those predictions made prior to excavation of the laboratory. These predictions are based on data collected during the pre-investigations conducted between 1986 and 1990.

Comparisons between the predictions and observations will be made during excavation in order to verify the reliability of the pre-investigations.

The predictions concern five key questions: geological structures, groundwater flow, groundwater chemistry, transport of solutes and mechanical stability. These predictions are made in three scales: site scale (100-1000 m), block scale (10-100 m) and detailed scale (0-10 m).

ACKNOWLEDGEMENT

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We are also grateful to all the contractors, see list of progress reports, who have been involved in the investigations and thus contributed to this report. Special thanks to Ingemar Markström, Urban Svensson and Marcus Laaksoharju for their specific contribution to the report, and to Per Olsson and Håkan Stille for preparing the rock mechanics predictions.

Finally we wish to express our gratitude to our collegues for the interest they have shown regarding this work.

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APPENDICES

1. INTRODUCTION

1.1 Background

The Äspö Hard Rock Laboratory project is a rehearsal before the construction of a final repository for high level waste in Sweden.

The plans for the Äspö Hard Rock Laboratory were initially presented in the R & D programme 1986 /SKB, 1986/. In that report it was stated that the laboratory should be placed close to one of the nuclear power plants where existing services and the kind of infrastructure needed for research already existed. Therefore investigations were first carried out near the nuclear power facility at Simpevarp, Oskarshamn, Figure 1.1. SKB found the island of Äspö to be suitable. Permits pursuant to the Act on the Conservation of Natural Resources, the Planning and Building Code and the Act on Water Preservation were obtained from the concerned authorities and excavation of the laboratory started in October 1990.

The Äspö Hard Rock Laboratory is a continuation of the R&D effort developed during the study-site investigations, at Finnsjön and in the international STRIPA project.
The goals and objectives of the HRL are discussed in SKB's R&D Programme 89 /SKB 1989/. It should be noted that the site of the HRL will not be considered as a site for the final repository.

1.2 Overview of the project

The project is basically divided into three main phases. The first phase comprises the pre-investigations. The second phase is the excavation and construction of the laboratory and the third the operating phase, see SKB, 1989.

1.2.1 The pre-investigation phase

Site characterization is a multi- and interdisciplinary task that necessitates coordination of data acquisition, evaluation and presentation. In order to facilitate such coordination three basic decisions were made for the site characterization of the Äspö HRL, see Bäckblom et al /1991/.

The first decision was to divide the investigations into stages. Evaluations have been made and reported stage-by-stage. This provides an opportunity to record what has been achieved and allows the investigators to co-interpret all data at every stage.

The second decision was to make conceptualizations on different geometrical scales, as it was thought that this was appropriate for the planning of a real repository. The regional scale >> 1000 m forms a basis for later detailed investigations and for selection of suitable rock formations for a repository. The site scale, 100 - 1000 m will be used for lay-out of a repository and for the far field evaluations in a siting application. The block scale, 10 - 100 m, will be used for selection of canister positions and for near field performance assessment. The very near field, 0 - 10 m, defines the zone near to the buffer and canisters. It will also yield information on the so called "disturbed zone" that develops close to the excavated rock. By using several geometric scales it is possible to present both deterministically identified features and statistically defined properties in a meaningful way and in reasonable detail. Thus on the site scale, structures and

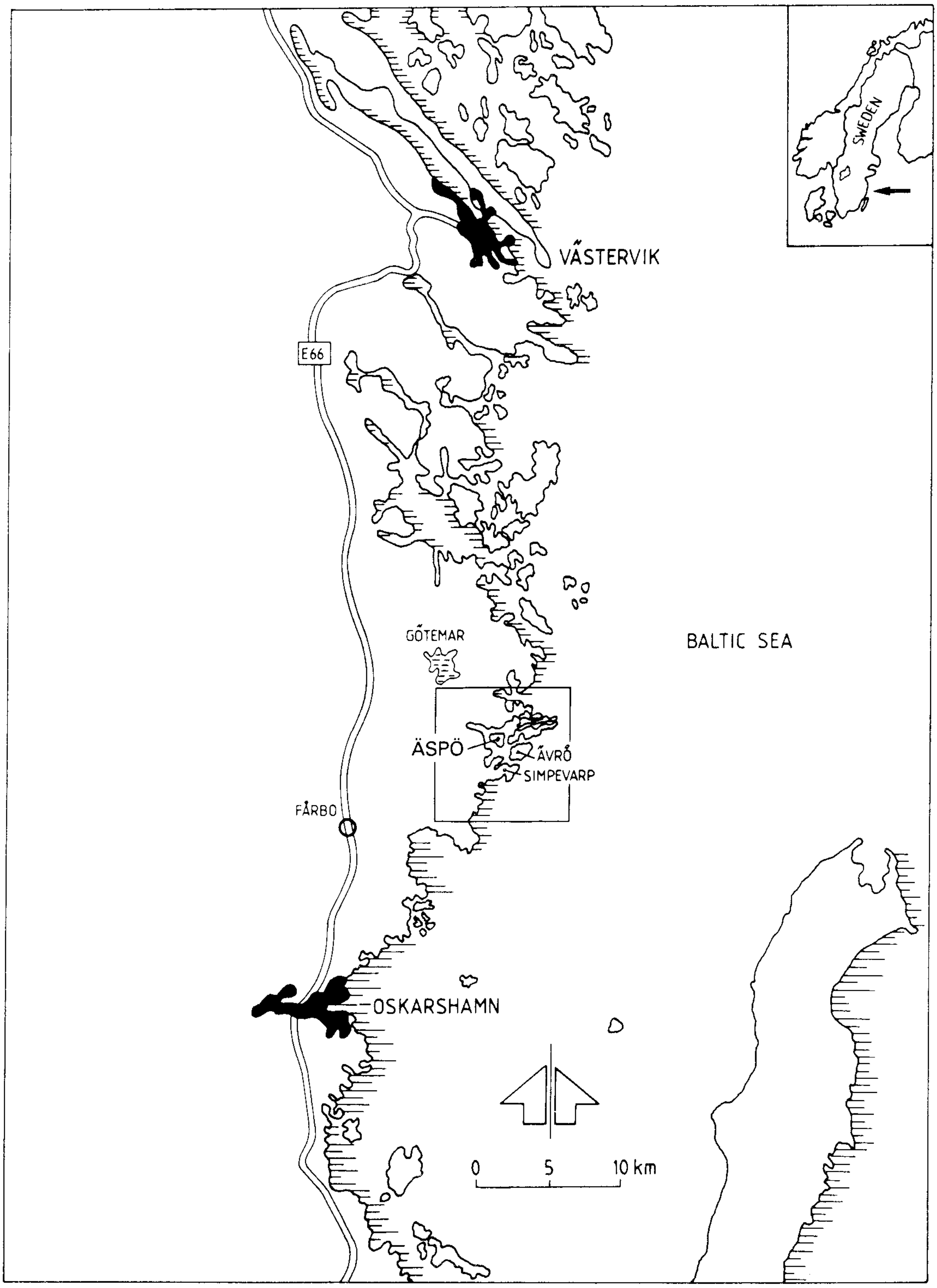

Figure 1.1 Äspö and environs

lithological bodies are localized whereas on the detailed scale, the properties of certain rock units and their ranges of variation are shown based on statistical analyses.

The third decision was to designate five key questions of relevance for design and/or performance assessment and/or safety assessment. The designated key questions are the geological-structural model, groundwater flow, groundwater chemistry, transport of solutes and mechanical stability.

The first evaluation /Gustafson et al 1988/ comprised the result of the regional investigations of geology, geohydrology and groundwater chemistry, a preliminary evaluation of several target areas and a regional conceptual model. An important part of the report was the initial geological prediction of Äspö made before results had been obtained from any cored boreholes.

The second evaluation /Gustafson et al 1989/ made use of the regional conceptual model in the above report to develop the first site-specific groundwater models. The report also presents the result of the first three deep boreholes and conceptual models based on the data. These conceptual models formed the basis of a new numerical groundwater flow model which was later used to predict the outcome of a long-term pumping test performed in 1989 and to calculate the impact the excavation of the laboratory will have on the ambient groundwater situation.

The second drilling programme commenced in parallel with the evaluation of the data from the first three cored holes. The objective of the drilling of four additional cored holes was to increase confidence in the existence and extention of indicated fracture zones. However, the third investigation stage was extended much further than was initially planned. This extension was required by the regulatory authorities for permits and for changing the layout of the laboratory. The government decided that the project should be reviewed under the Act on the Conservation of Natural Resources. In connection herewith, SKB decided to reduce the environmental impact at Äspö by starting the entrance tunnel from Simpevarp, see Figure 1.2. The extended target area required further drillings and evaluations.

Figure 1.2 Schematic design of the Äspö Hard Rock Laboratory.

Tables 1.1 and 1.2 give an overview of the different investigations within the project. A more detailed presentation of the investigation programme is given in the document I of this series; Overview of the investigations 1986-1990 /Stanfors et al, 1991/. The objectives of the different investigations are also presented in that report. The results are presented in document III of this series where the evaluation and conceptual modelling is also included /Wikberg et al, 1991/. The field investigation methods are presented in document II of this series /Almén and Zellman, 1991/.

Table 1.1 *Overview of investigations for the Äspö HRL - Regional scale*

Airborne geophysical survey (magnetic, EM, radiometric, VLF)
Gravity measurements (one station per km^2)
Petrophysical measurements (density, susceptibility, IP, etc)
Interpretation of lineaments (LANDSAT, digital terrain models)
Mapping of solid rock
Characterization of main tectonic zones (mapping, ground geophysics)
General hydrology of the area
Regional analysis of well data and water chemistry
Compilation of geohydrological data from construction works in the area

The results of the investigations on the regional scale formed the basis for the lithological-structural model of this scale. Inital models of hydraulic conductivity and groundwater chemistry in the region was obtained.

Table 1.2 Overview of investigations for the Äspö HRL - site scale

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Detailed mapping and petrographic studies along cleaned trenches (1 600 m)

Detailed geophysical studies (VLF, resistivity, magnetic, radiometric, seismic refraction, reflection)

Detailed study of ductile and brittle structures

Borehole investigations (20 percussion drilled holes, total length 2 200 m, 14 cored holes, total length 6 600 m)
- Lithology (detailed mapping, thin sections, modal and chemical analyses)
- Fractures (frequency, RQD, minerals, surface, relative and absolute orientation)
- Geophysics (up to 13 geophysical logs)
- Rock stresses (hydraulic fracturing, overcoring, mechanical properties)
- Head monitoring in packed-off sections
- Hydraulic tests (air-lift tests every 100 m, 72 h pumping test, flow-meter logging, packer tests in 3 m. Additional testing in 30 m sections in three cored holes
- Interference tests
- Long-term pumping test (one month pumping, two months recovery)
- Dilution tests to measure ambient flow in cored holes
- Tracer tests (non-sorbing)
- Sampling of groundwater chemistry during air-lift tests, pumping tests and sealed-off sections (full characterization in 10 points, including main constituents, trace elements, stable and radioactive isotopes, organics and gases).

The investigations on the site scale yielded in a first stage a preliminary 3-D lithological-structural model of the Äspö island. Some of the main hydraulic structures were identified and a model of the hydraulic conductivity distribution was presented. A preliminary model of groundwater chemistry was set up.

In a second stage a detailed 3-D lithological-structural model of the Äspö-Hålö site was constructed. Geological, geohydrological and geohydrochemical characterization of major fracture zones and the bedrock in between them formed the basis for the detailed conceptual models of the Äspö rock mass, see figure 1.3, including statistical distributions and test-scale dependence of hydraulic conductivity.

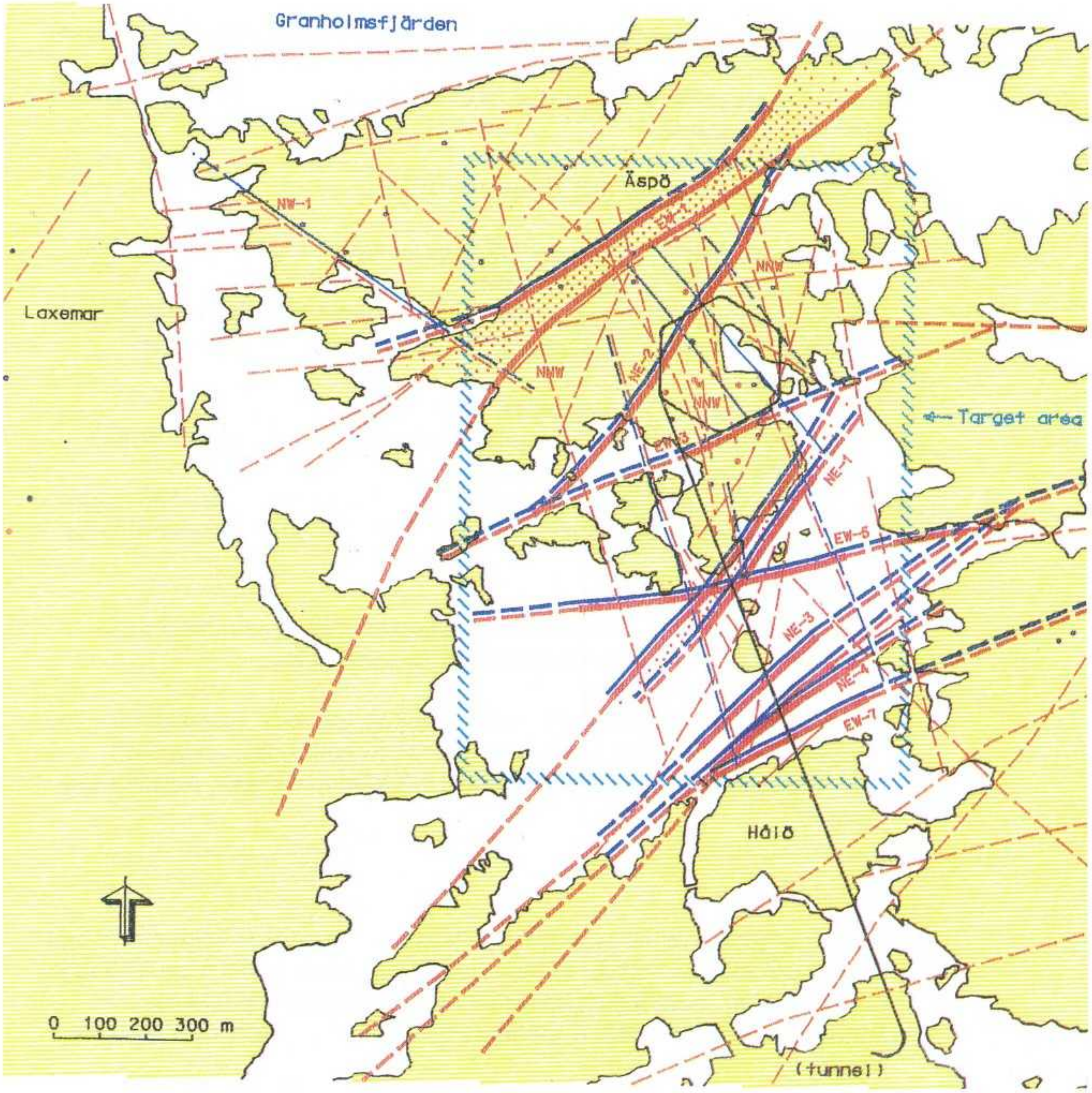

Figure 1.3 Target area for characterization. The full legend of the figure is found on page A8.

1.2.2 The construction and operating phase

Studies of alternative layouts of the underground portion of the laboratory were performed during 1987. An inclined ramp was selected, /SKB, 1989/. The main advantage of the ramp was good access to the rock to study the key aspects. It is also convenient to transport bulky equipment on a tunnel ramp.

The excavation work started in October 1990. The first stage comprises excavation to a depth of 330 m and raise-boring of shafts to the surface. Renewed predictions will be made in 1992. Excavations will then proceed to a depth of 500 m during 1993-1994.

The predictions will be checked continuously during the excavation of the access ramp. The comparison between the prediction and the outcome will be evaluated after 700 m, 1 475 m, 2 265 m, and 3 855 m of excavation.

An overview of activities during the Construction Phase and a preliminary programme for the Operating Phase is presented in the R&D programme /SKB, 1989/.

1.3 Overview of this report

Site characterization is a step-by-step procedure. Characterization can be done prior to construction, during construction and after construction.

The first stage goal of the Äspö HRL project is to "Verify pre-investigation methods" The approach adopted to reach this goal is to make predictions that can be checked and evaluated in the next investigation phase. This report summarizes the predictions that have been made prior to excavation of the ramp and the process of their validation. For obtaining the background and the basis for the predictions the reader is recommended to consult the other reports of this series especially Wikberg et al, 1991.

Chapter 2 discusses the process of validation. Chapter 3 describes the process of validation applied to this project. Chapter 4 gives the reader comments to the predictions presented in appendices, which are organized in accordance with a previous report /Bäckblom et al 1990/.

2. THE PROCESS OF VALIDATION

2.1 Basic definitions

According to U.S.NRC /U.S.NRC, 1987/: "Validation: The process of obtaining assurance that a model as embodied in a computer program is a correct representation of the process or system for which it is intended. Ideally, validation is a comparison between predictions derived from the model and empirical observation. However, as this is frequently impractical or impossible owing to the large length and time scales involved in HLW disposal, short term testing supported by other avenues of inquiry such as peer review is used to obtain such assurance".

According to IAEA /IAEA-TECDOC-264, 1982/: "a conceptual model and the computer code derived from it are validated when it is confirmed that the conceptual model and the computer code provide a good representation of the actual process occurring in the real system. Validation is thus carried out by comparison of calculations with field observations and experimental measurements".

According to the above definitions, validation comprises a comparison and a judgement. To this can be added an analysis of the underlying processes. In short the three elements of the process of validation are:

- A systematic comparison of prediction and outcome
- A scrutiny of the underlying structure and process
- A judgement whether the prediction is good enough.

Before validation is carried out, the accuracy of the predictions can be improved by calibration against known experiments or field measurements.

2.2 Modification and calibration

A computer model is a mathematical realisation of a conceptual model. In order to test the model and to improve it, a calibration is run.

When agreement between the model results and the system responses is deemed sufficiently good, the model is said to be calibrated against a certain set of data.

2.3 Prediction

Prediction produces a set of calculation results that can later be compared to the measured responses of the system. It should be noted, however, that predictions are not only made by means of computer models, since the structural model, for instance, is a descriptive, qualitative model of the rock.

2.4 Comparison of prediction and outcome

As a first step in the validation process a systematic comparison of predictions, with outcome shall be made.

2.5 Scrutiny of underlying structure and process

If prediction and outcome do not match, the reason for this may lie either in a poor description of the geological structure or in a poor description of the physical process or both. Even if the outcome matches the prediction, both may have their flaws.

In a scrutiny of the geological structure, completeness is a critical aspect. Based on pre-investigations, a set of features compatible with the geological structure are defined.

In addition, the physical process model must be scrutinized in order to make sure that the applied processes accurately describe the significant responses to tests and experiments.

2.6 Peer review

The final judgement of whether a certain model is good enough follows normally from the scientific process; results are published and those results that stand the test of time are considered to represent some kind of scientific truth. In the long run the results of the HRL project must undergo this test as well.

A peer review is another method of obtaining a judgement of the goodness of a model when the judgement is required in a limited time. Reports, predictions and experimental results are submitted to a group of peers who, after thorough analysis, render a judgement as to whether the models used are good enough in terms of results and of what could reasonably be expected.

3. THE FRAMEWORK FOR VALIDATION WITHIN THE ÄSPÖ HRL-PROJECT

The Äspö HRL-project has been structured with respect to time, scale and key questions; a discretization of site investigations in distinct time-steps facilitates an integrated approach to calibration of structures and processes.

Evaluations of the site characterization on several geometric scales facilitates a local presentation of data, models and evaluations that enable both the general and detailed nature of a site to be outlined.

Data and models can be related to certain key questions that are relevant to design, performance assessment and safety assessment of a final repository for spent fuel, see Figure 3.1.

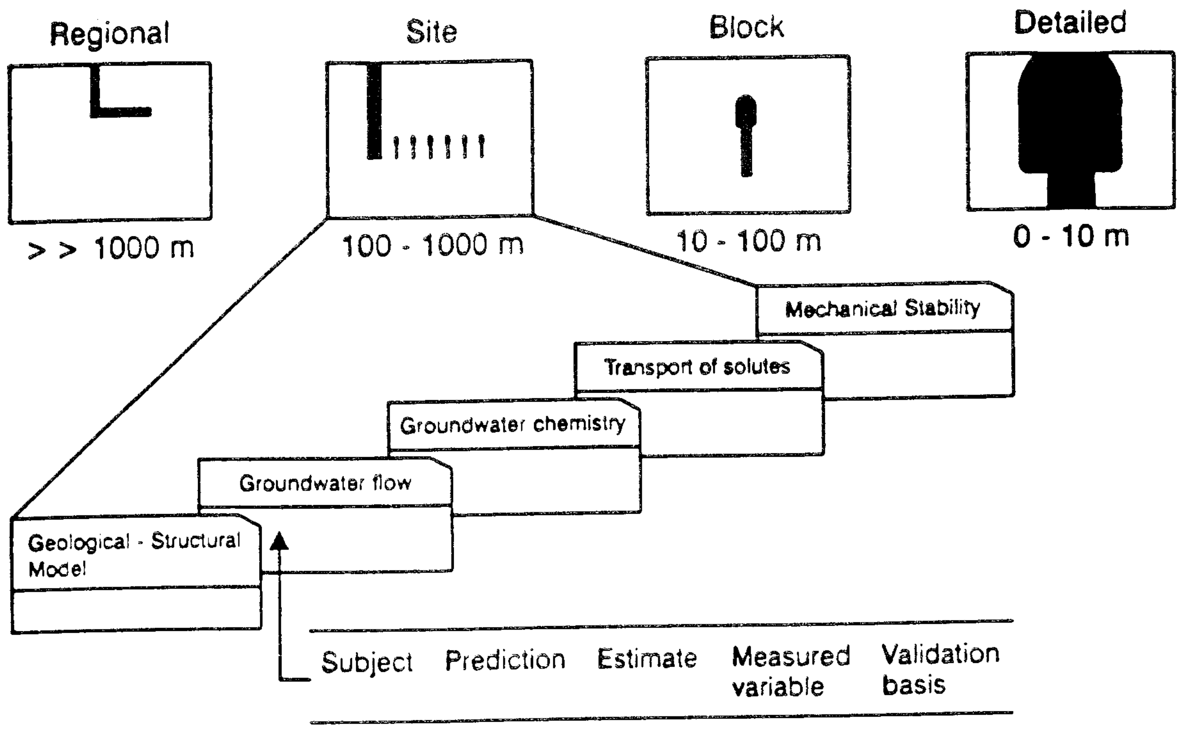

Figure 3.1 Overview of geometric scales and key questions

3.1 Investigation stages

Site characterization for a final repository can be divided into three parts:

- Pre-investigations from the surface and in boreholes prior to any construction activities

- Investigations during excavation of a tunnel/shaft to a potential repository level

- Investigations during construction of the repository.

These obvious stages are also applicable to the HRL project: pre-investigations, investigations during excavation and during the operating period of the HRL.

The pre-investigation period has also been divided into three phases. Each phase yields an integrated data set structured to different geometric scales. These evaluated data sets have later served as the basis for appropriate numerical models, mainly of groundwater flow. The first evaluation was based on surface investigations, mainly on a regional scale. The second integrated evaluation, on a 1 km^2 scale, was based on supplementary surface data and three deep cored holes. This data set was also the basis for detailed modelling of groundwater flow, including fracture network models, as well as predictive modelling of a long-term pumping test.

The last phase of the investigations utilizes data from several cored holes, interference tests and so on to establish the final predictions before construction.

3.2 Prediction scales and their rationale

One of the features of the programme for the Äspö HRL is that predictions are made on different scales for each step in the characterization. Appropriate numerical models are applied where possible. It will thus later be possible to determine how to assess the rock mass properties on different scales at various steps in the site characterization programme. These assessments are of importance as a basis for decisions on safety as well as for analysis of repository design.

Characterization on a <u>regional scale</u> >> 1000 m forms a basis for the detailed investigations. Assessment on a regional scale can be used to select a suitable rock volume for the repository. Areas of ground water recharge and discharge can be defined. The regional assessment will also provide a basis for long-term predictions of where the discharge area can be in the future as well as where potential zones of movement can be found.

The <u>site scale</u> characterization, 100-1000 m, can be used to locate major fracture zones and/or major flow paths. These investigations are essential as they will provide guidance in determining the depth the repository should be located at as well as the potential repository volume. Characterization on this scale also defines the far-field groundwater flow through the repository and to the biosphere.

Block scale assessment, 10-100 m, will be used to position deposition tunnels and later to position the canisters. Essential assessments include the transport of solutes from leaking canisters to major flow paths.

The detailed scale 0-10 m may be the most important scale, as properties on this scale define the geohydrological, chemical and mechanical near-field of the canisters. By proper selection of canister positions it will be possible to influence the service life of (copper) canisters and the dissolution of the spent fuel and transport and fixation of radionuclides.

This choice of geometric scales is, however, more or less subjective.

3.3 Key questions

The key questions in the predictions are - on every scale - geological-structural setting, groundwater flow, (groundwater) chemistry, transport of solutes and mechanical stability.

The principle is depicted in Figure 3.1.

The geological-structural model incorporating structures on different scales represents a simplification of the real physical medium. The geological model forms the basis of all conceptual models of the geosphere, regardless of processes. The geological model not only forms the basis of the conceptual models, but is also of vital importance as decisions on the design of the repository will be influenced by it. A repository volume will be selected to avoid major fracture zones. Deposition tunnels and canisters will be positioned to avoid the major flow paths, which may or may not be congruent with the major fracture zones.

Groundwater flow is a key question, as it influences the service life of the (copper) canisters and the dissolution of the spent fuel. The description of the groundwater flow provides a necessary, but not sufficient, basis for calculating the transport of nuclides from the repository to the biosphere should the canisters fail.

Groundwater chemistry is a key question as it reflects the chemical situation around a repository. The chemical situation influences the corrosion of the canisters and the dissolution of the waste and provides a necessary, but not sufficient, basis for calculating the transport of nuclides from the repository in case the canisters fail.

Transport of solutes is a key question as it provides a necessary, but not sufficient, basis for calculating radition doses, which represent the only hazard to the environment from a sealed final repository.

Mechanical stability is of interest both in a short- and a long-term perspective. Mechanical stability is a necessary condition during construction. The long-term issue is to identify potential zones of movement, so that the repository and canisters will not be intersected by movements that may be caused during e.g. a deglaciation. An assessment of the long-term mechanical stability is as well needed as the prime function of the rock basically is to provide a geohydrological and chemical stable environment.

3.4 Relevance

The predictions within the Äspö HRL project are made to test the quality of our ability to interpret surface and drill-hole data into a structural description of the bedrock and to use this structural information to describe eg the groundwater flow in the area. Obviously, a full knowledge of every detail of the bedrock or the movements of groundwater can never be gained. The objective must be to achieve sufficient quality in the prediction of parameters that are of relevance for the safety of a repository.

3.4.1 Demonstration of understanding

The safe disposal of radioactive waste requires that the protective capacity of the repository is predicted over many thousands of years. Thus, the long term performance can not be based solely on experiments or measurements over the relatively short period of investigations, construction and operations. Extrapolative methods must be used.

To ensure that good predictive methods are used, a thorough understanding of the properties of the crystalline rock and the processes involved must be achieved and demonstrated to the scientific community (eg in a peer review process). Both investigations and predictions in HRL must, consequently, be made in a broader context than just for the evaluation of repository performance alone.

3.4.2 Assessment of repository performance and safety

The objective of performance assessment is to evaluate the long term performance of barriers or subsystems that are of importance for confinement of the radionuclides in the repository. This is normally the main input in site comparison and design improvement.

In a safety assessment the integrated effect of the barriers is evaluated with respect to the external conditions that can be encountered. Also the confidence in (or uncertainty of) the predictions must be assessed. The results must be evaluated in terms given in the acceptance criteria of society.

3.4.3 Decision sequence

Several times in the siting and design of a repository the available information must be collected and decisions taken whether to continue the work at a site or to abondon it. Although, at every stage the information is incomplete, the database is successively expanded with every step.

During site reconnaissance potentially acceptable sites are selected on the basis of available information regarding rock type, topography, block size etc.

During the pre-investigations the available size of the site is established. The general acceptability of the rock quality down to repository depth with respect to homogeneity, fault spacing, geochemistry and water circulation is tested. Regional outflow areas of the groundwater are established. The data allows a conceptual layout of the repository to be defined, and large scale modelling of groundwater flow can be made. The decision to continue the investigations at the site is based on the predicted characteristics of the site and the potential safety as interpreted by performance and safety assessments.

In the detailed geologic investigations explorations are made from a shaft or an excavated drift to expected repository depth. If the general acceptability of the rock-mass is confirmed, this further information is used for defining the repository depth and identifying the areas in the site that are best suited for the repository. The modelling of the groundwater circulation can be refined with regard to fracture zones and hydraulic conductivities, and the large scale regional flow paths for groundwater can be defined. The chemistry of the rockmass, fracture filling materials and groundwater is verified. The decision to continue to the next investigation phase is based on the predicted quality of the rock mass, to serve as a suitable nearfield to deposition holes, as interpreted by performance evaluations. Important factors are the hydrochemical environment, the flow paths for the groundwater and the homogeneity of the rock mass in the 100 m scale.

The excavation of access tunnels will be a furhter check of the acceptability of the selected disposal-areas in the site. If good enough, the lay-out of the deposition tunnels can be made, including also a general plan for the construction of the repository, and for the ultimate plugging and sealing of the tunnels and shafts. After this stage only a little more information regarding the groundwater circulation can be expected, and the all-but final model of the far-field flowpaths for the radionuclides can be made. Information on the characteristics of the bedrock in contact with the canister positions will be substantially greater at this stage, and a realistic description of the coupling between the near field and the far field can be made.

Depending on the confidence in the description of the rockmass in the repository area, a formal commitment to the site in the form of an application of a siting license could be made at this stage or at the next one. Whenever the application is made it must be accompanied by a formal Preliminary Safety Report and an Environmental Impact Statement.

During the excavation of the disposal tunnels some adaption of the tunnel lay-out to encountered rock quality is possible. The excavation will successively provide better information of groundwater flow in the 10 m scale and detailed information regarding the quality of the rock available for selecting positions for the deposition holes. Hereby the hydraulic boundaries for the near field can be defined for the calculation of nearfield transport. The above excavations and long term monitoring of groundwater now allows a final revision of safety assessments to be done.

At no stage decisions regarding siting or safety can be based on full knowledge, and it is possible that sites regarded as suitable at an early phase must later be abondoned due to unexpected rock conditions, or a re-evaluation of the overall safety requirements.

3.5 Reliability

The reliability of a prediction is generally very difficult to assess. Estimates of reliability are based partly on statistics regarding measured parameters and their transformation into predicitions, and partly on experience; professional judgement. Nevertheless, an effort has been made to estimate the reliability of the predictions. A critical question is assessement of the degree of completeness of the geological-structural model.

3.6 Adopted process for validation

The validation process adopted for the Äspö HRL project follows the procedure described in section 2.

Predictions are presented in the appendices A, B and C. This report thus summarizes the structural model on different scales and the predictions of groundwater flow, groundwater chemistry, transport of solutes and mechanical stability. Additional detailed predictions, basically concerning borehole monitoring data is presented in a separate progress report /Rhén et al 1991/.

During construction, the geological structure will be mapped and the outcome of the different detailed predictions will be evaluated. Comparisons will be presented, as well as an analysis of the outcome.

Peer review will be used to judge whether the predictions are good enough.

Results will also be published in international journals, thereby providing an opportunity for achieving a broad scientific consensus.

4. COMMENTS ON THE PREDICTIONS

The predictions appended to the report are structured to scales and key questions. They are made in order to be easily checked from the tunnel during the excavation. The scientific background is presented in a separate report. /Wikberg et al, 1991/.

On the site scale (500-1000 m) the predictions are divided into four parts: 700 - 1475 m, 1475 - 2265 m, 2265 - 3064 m, 3064 - 3854 m.

On the block scale (10-100 m), predictions are made for 10 blocks situated at specified positions along the tunnel. The positions of the 10 blocks have been selected mainly in the vicinity of existing boreholes.

On the detailed scale (1-10 m) the positions of the four 5 m boxes have been selected on the basis of geological considerations as well.

4.1 Geological-structural model

The main purpose of the geological-structural prediction is to describe the rock mass in the target area as regards rock distribution and structural pattern and to estimate how different rock types and structures are likely to affect water inflow rates and excavation stability.

In the following geological predictions, point estimates and confidence intervals are deduced from sample data, but where samples are missing professional judgement has been used.

Predictions on a site scale are made in order to predict the position and character of major fracture zones and the average mineral composition of the main rock types.

The predicted positions of the major fracture zones (>5m wide) are based on geophysical measurements, geological field observations and borehole data. The character of the fracture zones is estimated mainly from drill core, mapping data and geophysical logging in boreholes. Confidence intervals are estimated

The estimated distribution of the main rock types and number of rock boundaries are based on a calculation of an average distribution of the different rock types in boreholes and on surface in the actual area.

Predictions on a block scale are made in order to describe and predict different kinds of rock volumes as regard to rock distribution, minor fracture zones and other structures.

The parameters predicted in the block scale are estimated mainly on data from at least one cored borehole penetrating the actual block or the rock volume close to the block.

Geological predictions on a detailed scale are made for the four most frequent rock types observed in the target area: Småland granite, Äspö diorite, Fine-grained granite and Greenstone. The predictions are concentrated to mineralogy, petrophysics and typical fracturing.

The blocks predicted on the detailed scale should mainly be regarded as typical examples of the four most frequent rock types based on calculation of the average mineralogical composition and fracture pattern of these rock types in boreholes and outcrops in the target area. The positions of the predicted blocks are based on information from boreholes which are penetrating the block volume.

4.2 Groundwater flow

The main purpose of the groundwater flow calculations is to describe the ambient groundwater flow in the bedrock and to predict its changes during excavation. Any deviations between prediction and observation may then be used to amend the description of the ambient situation.

Site scale (500m)

On the site scale, predictions are made of the hydraulic conductity of the rockmass and the transmissivity of major water bearing zones. The hydraulic conductivity for the tunnel section 700-1475 m is based on estimation of the rock composition in this section and the relation between the lithology and the hydraulic conductivity, see section 3.2 in Wikberg et al /1991/. The variables and parameters predicted in section 700-1475 m must therefore be considered to be more uncertain than those predicted on southern Äspö.

The 3-m packer tests in KAS 02, KAS 04-08 have been used for the other site scale estimates. The calculated hydraulic conductivities for the packer tests were grouped in depth interval and analyzed separately. The intervals were:

Tunnel section (m)	Depth (m)
1475 - 2265	200 - 300
2265 - 3064	300 - 400
3064 - 3854	400 - 500

The hydraulic conductivitis were scaled up to 20 m blocks according to Liedholm /1991/.

Typical predictions are inflow into the tunnel and changes in pressure, flow and salinity in boreholes. These calculations were performed by the PHOENICS computer code /Spalding, 1981, Svensson, 1991/. Steady-state conditions are assumed for each calculated position along the tunnel. The estimation of the pressure distribution and the inflow to the tunnel under steady state conditions gives probably good approximations but the calculated salinity values are uncertain, because the redistribution of the salinity is probably a slow process compared to the excavation of the HRL. The salinity values should therefore be seen in a generic sense.

The following variables in the appendices A, B, C have been estimated by the numerical model boundary conditions; pressure and, flux distribution, flow, inflow to tunnel-zones, inflow to tunnel and salinity for tunnel legs, zone-salinity and position of saline interface. The calculations are presented in Svensson /1991/.

The distribution of the inflow of water along the tunnel is predicted. The inflow has, however, been limited to a maximum of 3 l/s in any zone, as it is anticipated that grouting will be performed at intersections with major waterbearing structures.

The detailed predictions for boreholes etc are published in a separate Progress Report /Rhén et al, 1991/.

Block scale (50 m).

The block scale predictions are based on the hydraulic conductivity distribution and the frequency distribution of conductive structures. The distance between conductive structures has been estimated from the 3-m packer tests in KAS 02-08. The general prediction is based on KAS02, KAS04-KAS08, see section 3.2 in Wikberg et al /1991/. Block P50-01 to P50-03 are based on averages of P50-04 to P50-10.

Block P50-04 to P50-10 are based on analyses of the following boreholes sections.

Block	Borehole	Section
P 50 - 04	KAS 05	200 - 250 m
P 50 - 05	KAS 05	307 - 357 m
P 50 - 06	Average of	P 50 - 06 and P 50 - 07
P 50 - 07	KAS 08	462 - 530 m
P 50 - 08	KAS 05	408 - 460 m
P 50 - 09	KAS 02	456 - 506 m
P 50 - 10	KAS 05	470 - 520 m

The hydraulic conductivity is based on the average of point estimates of the hydraulic conductivity calculated with different methods /Liedholm, 1991;32/ and it is scaled up to 20 m blocks according to Liedholm /1991;19/.

The flow distribution shown in flow in conductive structures have been estimated with scoping calculations with a finite element model /Liedholm, 1991; /.

The axial flow in the disturbed zone and the pressure around conductive structures have been estimated from scoping calculations. Axial flow is estimated as

$q_a = K \cdot a \cdot i = K_a \cdot i$

$K = 1 \cdot 10^{-9}$ m/s

K_a = effective hydraulic conductivity of the disturbed zone

a = 10 - 200

i = 0.1 - 1 gradient close to zone

The pressure is estimated from the pressure distribution around conductive structures crossing the tunnel as calculated in the numerical model. Scoping calculations have been made of the flux in these structures and for axial flux along the so called disturbed zone adjacent to the tunnel periphery.

Detailed scale (5 m).

The predictions on a detailed scale concern the hydraulic conductivity, leakage characteristics and some properties of the disturbed zone. They are made separately for the four rock types.

The hydraulic conductivity is estimated from the 3 m packer-tests in KAS 02-08 and are scaled up to 20 m blocks according to Liedholm /1991;19/. The results from the packer-tests were divided in separate litological groups before the analysis and the result is shown in detail in Liedholm /1991;29/.

Point leakage is based mainly on professional judgement but some indications of the flow distribution on the tunnel periphery was also found in Axelsson et al /1990/ (chapter 6, distribution of flux to individual panels) for Småland granite and fine-grained granite.

For the disturbed zone only scoping calculations have been possible to perfom. The pressure distribution outside the disturbed zone is estimated from the hydraulic conductivity (K_g) and the skinfactor (SK) with the formula below.

$$p = \frac{q}{2\pi K_g \cdot b} \left(\ln \frac{r_p}{r_t} + SK \right)$$

r_t = 3 m tunnel radius

r_p = 7 m radius to measurement point for the pressure

From the numerical model the average inflow q is estimated to be about $3 \cdot 10^{-7}$ m^2/s (no conductive zone) and the skin factor to be in the range of 0-10. The geometrical mean value K_g is scaled up to an effective hydraulic conductivity with the scale factor b = 15. /Liedholm, 1991:19/.

The conductivity changes are estimated from the assumption that the excavation of the tunnel increases the porosity of the rock around the tunnel periphery to a depth (d) of 1m. If the porosity is assumed to be 0,1%, the sum of the fracture width in one direction is 0,3 mm/m in a 3D case. The unloading of the rockmass causes expansion into the tunnel. An expansion of 1-2 mm the tunnel implies a porosity increase to about 0,2-0,3%. The fracture width perpendicular to the centre line of the tunnel sience increases 300-600%. As the hydraulic conductivity of a fracture is dependent of the square of the fracture width and the flow is dependent of cube of the fracture width the arithmetic mean of the hydraulic conductivity (K_a) in the disturbed zone is expected to increase 30-200 times. The porosity changes estimated above is however very uncertain and the professional judgement is that the increase may be in the range 10-200 times.

The conductivity change perpendicular to the tunnel axis (K_t) is calculated from the assumption that the skin factor is in the range of 0-10 and that the disturbed zone is 1 m.

Axial flow is estimated from K_a, K_t and the inflow to the tunnel. The inflowrate per m^2 tunnel wall area (q) was estimated from the inflow to legs, not intersected by a conductive zone, from the numerical model. Approximate values for the upper and lower quartile was used as maximum and minimum flowrates ($2 \cdot 10^{-9}$ - $2 \cdot 10^{-7}$ m/s).

The axial flow was estimated with the formula.

$$q_a = q\sqrt{K_a \cdot K_t}/K_g$$

K_t is assumed to be equal to K_g.

4.3 Groundwater chemistry

The predictions of the groundwater chemistry in the rock mass are focussed on the composition of the water in water-conducting fracture zones and in the different lithological units.

Site scale (500 m)

The chemical composition of the groundwater in the conductive fracture zones is predicted. The content of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} and Fe^{tot} is calculated by Principal Component Analyses, a multivariant procedure. The data base for these calculations consists of the results from analyses of groundwater in boreholes at Äspö, c.f. section 3.3 in Wikberg et al /1991/. The estimated range of variation is based on judgement.

The difference between the calculated concentration and an initially estimated one is equal to or smaller than the value of the variation. For sulphate and iron concentrations however, no estimates of the concentration could be made. Therefore the range of variation is estimated.

The pH is calculated on the basis of the concentrations of bicarbonate and calcite, assuming that the water is saturated with respect to calcite. The saturation index for calcite is generally slightly above unity for the Äspö groundwaters. This value is used for calculating the pH. The variation range of pH is based on the difference between the pH value calculated from the calcite system and a pH-value calculated from a relation between the pH and the potassium concentration /Eriksson, 1970/.

The Eh is calculated from the assumption that it is controlled by the concentration of dissolved ferrous iron and ferric oxy-hydroxide /Grenthe et al /1991/. Grenthe estimated the variation range to be ±59 mV. This was based on all the SKB-KBS measurements of Eh in deep groundwaters. The range of variation in the measured potentials can be given here. It was found to be ±25 mV.

Tunnel section 700 - 1475 m

The groundwater composition predicted for EW-7, NE-4 and NE-3 is based on the results of analyses from the borehole KBH02. The hole is parallel to the tunnel intersecting these fracture zones almost in the same position as the tunnel.

Tunnel section 1475 - 2265 m

The NNW fracture system is a recharge zone according to the pre-investigations, see 3.3 in Wikberg et al /1991/. Therefore the concentrations of main constituents are expected to be only half of the calculated ones.

Tunnel section 2265 - 3064 m

See section 1475 - 2265 m.

Tunnel section 3064 - 3854 m

See section 1475 - 2265 m.

Block scale (50 m)

No specific predictions relating to the ten different 50-m blocks can be made. A general prediction relating to the redox conditions is made, see page B9.

Detailed scale (5 m)

Specific characteristics of the groundwater in Småland granite and Äspö diorite are defined.

The discharge of water into the tunnel will influence the hydraulic situation and cause mixing of different types of water. Such mixing will cause dissolution and precipitation of fracture minerals in the vicinity of the tunnel. Furthermore, oxidation by the air in the tunnel will influence the narrow fracture systems intersecting the tunnel. These phenomena are predicted in a semi-quantitative manner.

4.4 Transport of solutes

The predictions of solute transport involve the variation in groundwater chemistry in combination with the geohydrological modelling. These predictions concern only the natural tracers in the groundwater, salinity and isotopes. The calculated saline interface with the numerical model should be seen as generic modelling.

On a site scale, predictions are mainly limited to the location of the interface between fresh and saline water. Scoping calculations of low flow and arrival times from borehole sections to tunnel are presented in a separate Progress Report. /Rhen, et al, 1991/.

4.5 Mechanical stability

The predictions of mechanical properties are based mainly on data from rock stress measurements in three boreholes and strength parameters obtained from laboratory tests on cores. Predictions of classifications of rock mass, rock support and likely location and direction of potential future movements in structures are based on the geological-structural model of the area.

5. ACCURACY AND CONFIDENCE IN THE PREDICTIONS

The predictions generally comprise both point estimates and a confidence interval of the point estimate at a certain confidence level. The confidence level is 95% unless otherwise stated. These point estimates and confidence intervals are generally obtained from analyses of sample properties. Sometimes subjective probability estimates are used to incorporate professional judgements into the prediction. In this case an attempt is made to identify and implement the probability distribution of the variable. Confidence levels and intervals are then based on professional judgement. Rather than obtaining an excessively wide interval for a 95% confidence level, the level of confidence is in these cased lowered, as indicated in the predictions.

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APPENDICES

PREDICTIONS PRIOR TO EXCAVATION OF THE ÄSPÖ HARD ROCK LABORATORY

TABLE OF NOTATIONS

C(t)	Concentration as function of time
D	Distance between conductive structures
dh/dn	Hydraulic gradient
E	Young's modulus
Eh	Redox potential
h	Groundwater head
JRC	Joint Roughness Coefficient
K	Hydraulic conductivity
L	Section in tunnel
Leg	A specified tunnel stretch
M_l	Mean fracture length
M_{logK}	Mean for logK
ν	Poisson's ratio
p	Groundwater pressure
q	Groundwater flux for specified parts
Q-system	NGI tunnelling quality index
Q_{FX}	Inflow of groundwater at certain zones
Q_T	Total inflow of groundwater to tunnel and raises from section 700 m to given position of tunnelfront
Q_L	Measured inflow to a tunnel section (leg)
RMR	Rock Mass Rating
RQD	Rock Quality Designation
ϱ	Density
$Sigma_c$	Uniaxial strength
σ	Rock stress
S_{BH}	Salinity of water in boreholes
S_{FX}	Salinity of water inflow to tunnel from zones
S_L	Salinity of water inflow to a tunnel leg
S_l	Standard deviation of fracture length
S_{logK}	Standard deviation for logK
t	Time
T	Transmissivity
x,y,z	Position in space
Index g	Geometric mean
Index a	Axial tunnel centre line
Index t	Transversal tunnel centre line

LEGEND FOR LITHOLOGY AND STEREO NETS

Småland granite ($\rho < 2.65$ g/cm^3) -postorogenic rocks of granite-granodiorite composition.

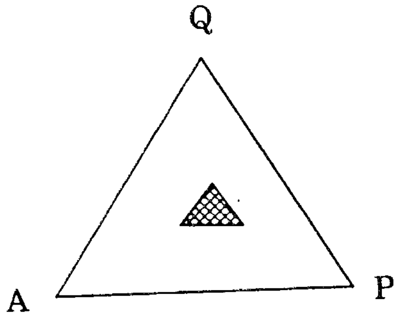
Äspö diorite (ρ ~2.65-2.75 g/cm^3) -postorogenic rocks of granodiorite-diorite composition.

Greenstone ($\rho > 2.75$ g/cm^3), fine-grained metavolcanic rocks of unknown age and more coarse-grained, basic variant of the Äspö diorite with a diorite-gabbroid composition.

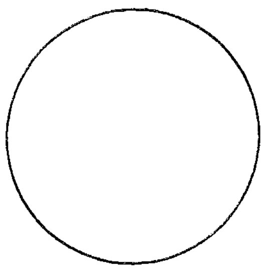
Fine-grained granite - rocks of anorogenic or postorogenic age.

Mylonite

Pegmatite



Triangle diagram for classification of the main rock types based on their content of: Q = quartz, A = alkali feldspars and P = plagioclase



Lower hemisphere equal area projection of fracture sets and dykes.

PREDICTIONS OF MECHANICAL STABILITY

Stability classes according to RMR (Rock Mass Rating)

Class	RMR	General stability conditions
A	> 72	Instability of single blocks.
B	60 - 72	Instability of single blocks which may progress to failure of the roof arch.
C	40 - 60	Instability in the roof. Both large and small blocks will be unstable.
D	< 40	General instability in walls and roof.
E	< 40	As class D.

APPENDIX A

PREDICTIONS IN SITE SCALE (500 m)

Appendix A presents the predictions made to site scale. The predicted items for the different key issues are presented on the next few pages, A3 - A7. The target area with fracture zones, and major water bearing zones are presented on maps, A8 - A10.

Predictions on tunnel section

PREDICTIONS OF GEOLOGICAL - STRUCTURAL MODEL - SITE SCALE (500 m)

SUBJECT	PREDICTION	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Logical units				
Different rock types	Position and extension of lithological bodies	Maps of 100 m slabs & in tunnel	Rock contacts	Lithological mapping
Rock boundaries				
Rock mass description	Number of positions of rock boundaries	Maps of 100 m slabs	Rock contacts	Lithological mapping
Major fracture zones	Position, strike, dip, extension.	L/leg ±%	Rock boundaries	Lithological mapping
	Width and character RQD for crossings	RMR for crossings RQD for crossings	RMR and RQD for crossings	Pilot tunnel investigations (crossings)
Fracture system	(See detailed scale, 5 m)			

PREDICTIONS OF GROUNDWATER FLOW - SITE SCALE (500 m)

SUBJECT	PREDICTION	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Hydraulic conductivity	Distribution of hydraulic conductivity in space	K (x,y,z)	K(x,y,z)	Pilot hole investigations
Water bearing zones	Positions and transmissivity of hydraulic conductors	T (x,y,z)	T, (x,y,z)	Hydrogeological mapping Pilot hole investigations
Boundary conditions	Head* or gradients at model boundaries	h (x,y,z) $\frac{dh}{dn}$ (x,y,z)	h (x,y,z) $\frac{dh}{dn}$ (x,y,z)	Groundwater level observations
Pressures	Pressures* in percussion and core boreholes under natural and disturbed conditions	p at x section for t timesteps	p	Pressure measured in boreholes during constructions
Flow	Total inflow to tunnel	Q_{tot}	Q_{tot}	Total pumpage from tunnel + vapour transport
Flux distribution	Groundwater fluxes* at natural and disturbed conditions	q at sections for t timesteps	C(t)	Dilution tracer tests at different borehole sections
Inflow to tunnel	Inflow from identified zones F_x--F_xN	Q_{FX} at x zones for t timesteps	Q_{FX}	Inflow measurements in sections
	Inflow to tunnel legs	Q_L for t timesteps	Q_L	Flow in sections
Salinity	Salinity* in boreholes and inflows to tunnels	Salinity for t sections S_{BH},S_L	S_{BH} S_L	Salinity in borehole sections and inflow sections

* Detailed predictions for boreholes are reported in a separate Progress Report, SKB PR 25-91-02.

PREDICTIONS OF GROUNDWATER CHEMISTRY - SITE SCALE (500 m)

SUBJECT	PREDICTION	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Zones	Chemical properties of groundwater in fracture zones	(Cl), (Eh), (pH), (Ca).. distribution	(Cl), (Eh), (pH), (Ca).. distribution	Measurement of groundwater in fracture zones

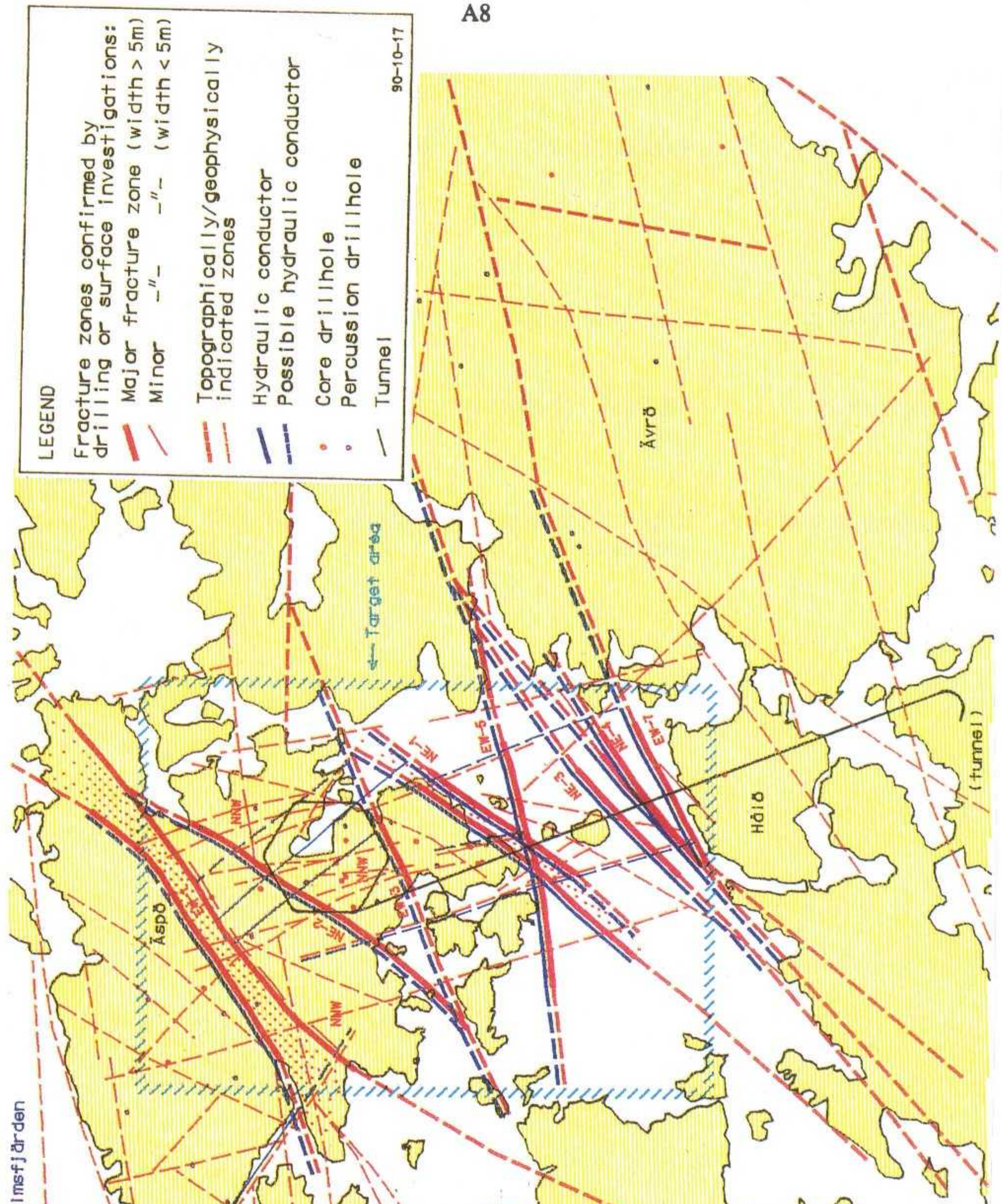
PREDICTIONS OF TRANSPORT OF SOLUTES - SITE SCALE (500 m)

SUBJECT	PREDICTION	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Flow paths	Flow trajectories* from x points to the tunnel	Input at x points give inflow of tracers at x^1	Points x^1	Tracer inflow to tunnel
Arrival time	(Scoping calculation)*	C(t)	C(t)	Tracer travel time measurements
Saline interface	(Scoping calculation)*	[Cl] at different positions (x,y,z) and time steps	[Cl], electric conductivity	Water samples in boreholes and tunnels
Natural tracers	(Scoping calculation)*	Isotopic signature at different positions and time steps	^{18}O, D, T HCO_3, SO_4, K, Ca, Mg, Na, Sr	Water samples in boreholes and tunnels

* Detailed predictions are presented in a separate Progress Report, SKB PR 25-91-02.

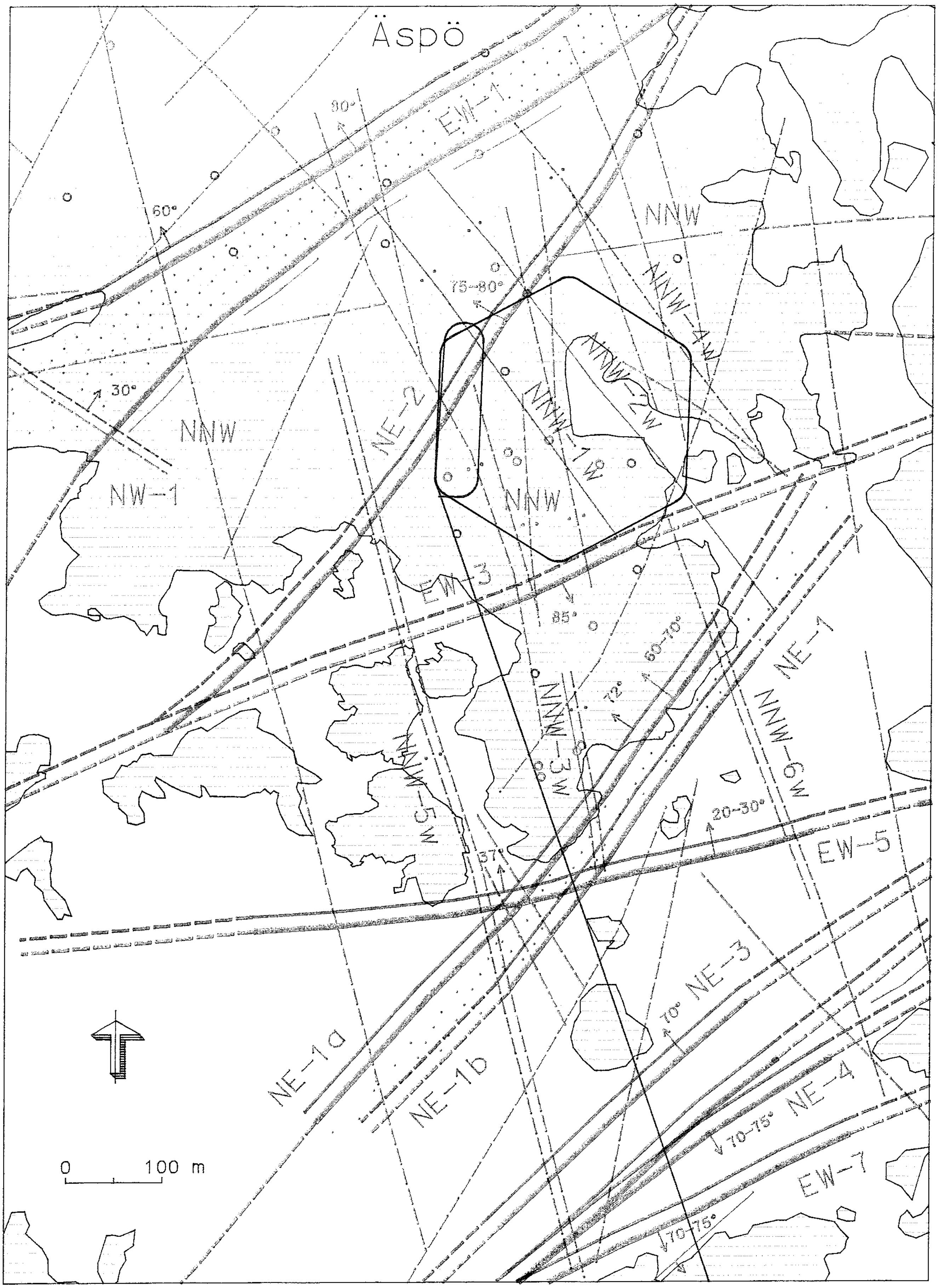
PREDICTIONS OF MECHANICAL STABILITY - SITE SCALE (500 m)

SUBJECT	PREDICTION	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Rock quality	Rock Mass Rating	RMR	±xRMR	Mapping
Rock stress	Vertical, horisontal stress	σ_{Hmin}, σ_{Hmax}, σ_v	σ_{Hmin}, σ_{Hmax}, σ_v	Stress measurement
Long term stability	Zones of potential movement	Zones	x,y,z x,y,z	- -

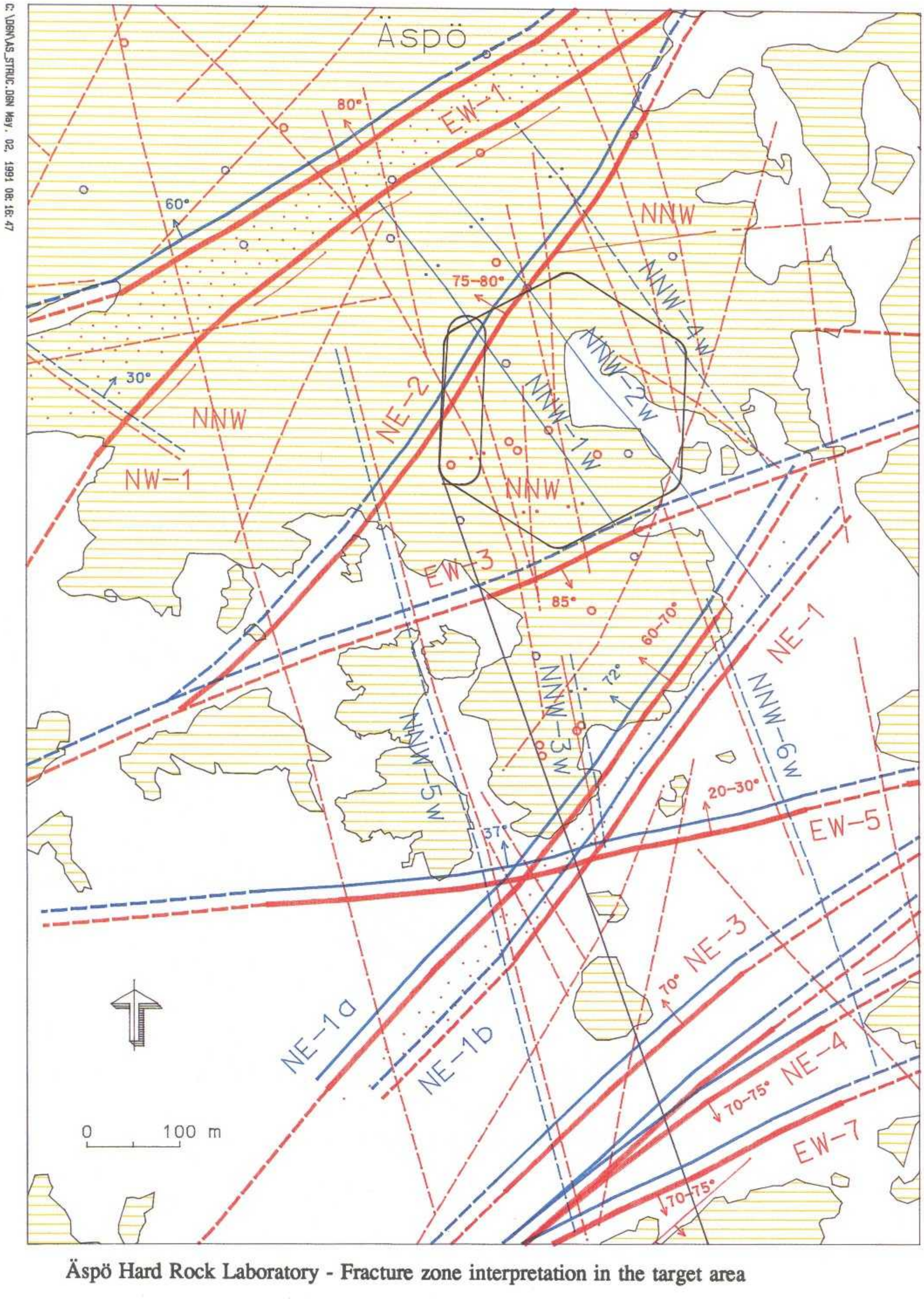


Fracture zone interpretation of the Simpevarp area

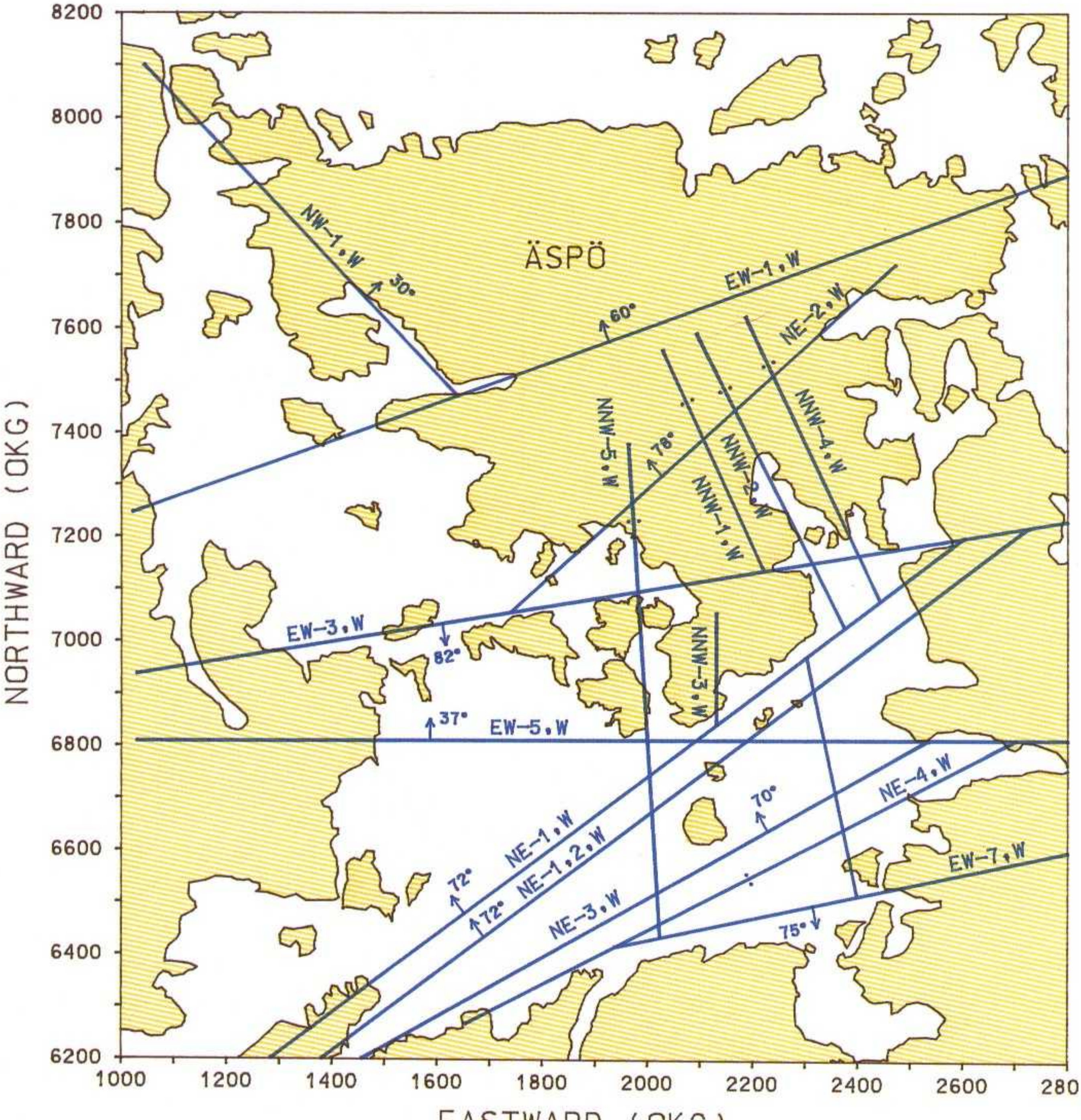
C:\DGN\AS_STRUC.DGN May. 02, 1991 08:16:47



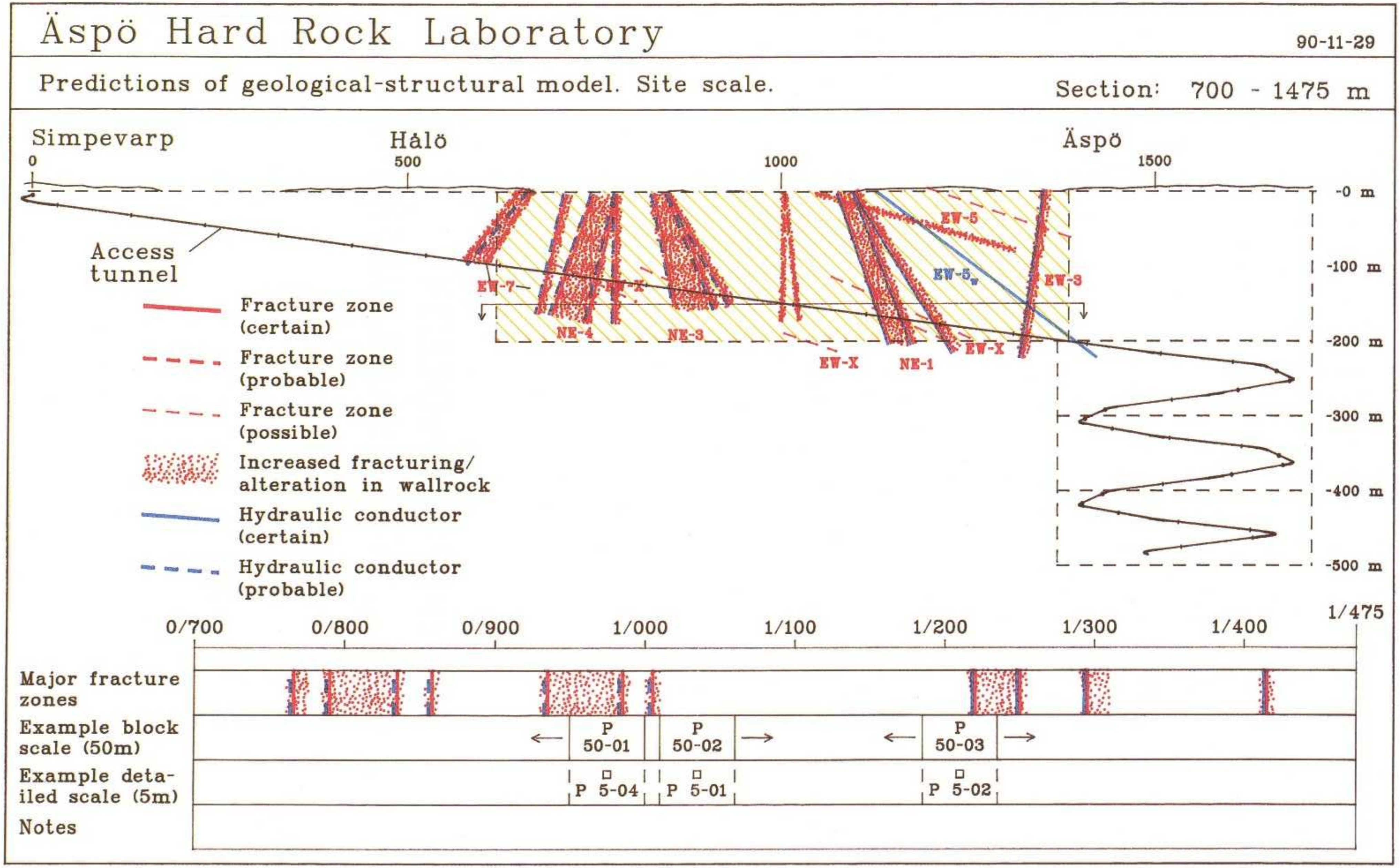
Äspö Hard Rock Laboratory - Fracture zone interpretation in the target area



Äspö Hard Rock Laboratory - Fracture zone interpretation in the target area



Major Water bearing zones in the target area as implemented into the numerical model


Äspö Hard Rock Laboratory
90-11-29
Predictions of geological-structural model. Site scale.
Section: 700 - 1475 m
Simpevarp
Hålö
Äspö
0
500
1000
1500
-0 m
-100 m
-200 m
-300 m
-400 m
-500 m
Access tunnel
EW-7
NE-4
EW-X
NE-3
NE-1
EW-5
EW-5w
EW-3
Fracture zone (certain)
Fracture zone (probable)
Fracture zone (possible)
Increased fracturing/ alteration in wallrock
Hydraulic conductor (certain)
Hydraulic conductor (probable)
0/700
0/800
0/900
1/000
1/100
1/200
1/300
1/400
1/475
Major fracture zones
Example block scale (50m)
Example detailed scale (5m)
Notes
P 50-01
P 50-02
P 50-03
P 5-04
P 5-01
P 5-02

PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL SITE SCALE (500 m) 700 - 1475 m

DISTRIBUTION (%) OF THE MAIN ROCK TYPES:

Småland granite	= 25(±5)60%*
Äspö diorite	= 50(±5)60%
Greenstone	= 8(±2)60%
Fine-grained granite	= 14(±3)65%
Mylonite-hybridized rock	= 3(±1)60%

ROCK BOUNDARIES ** (Nos/100 m):

10(±3)60%

MAJOR FRACTURE ZONES (Width >5 m):

ZONE	EW-7	NE-4	NE-3	NE-1	EW-3
Position (centre of zone)	755(±20 m)$_{60\%}$	810(±20 m)$_{60\%}$	920(±20 m)$_{60\%}$ 960(±20 m)$_{60\%}$	1230(±20 m)$_{60\%}$ 1290(±20 m)$_{60\%}$	1410(±20 m)$_{60\%}$
Strike	ENE	NE	NE	NE	ENE
Dip	65°S (±10)$_{60\%}$	65°SW (±5)$_{60\%}$	70°NW (±5)$_{75\%}$	65°NW (±5)$_{75\%}$	85°S (±5)$_{75\%}$
Extension (m)	<1000	>1000	>1000	>1000	<1000
Width (m)	10(±5)$_{60\%}$	50(±10)$_{75\%}$	10(±5)$_{75\%}$ 50(±10)$_{75\%}$	30(±5)$_{75\%}$ 15(±5)$_{75\%}$	10(±5)$_{75\%}$
RQD for crossings***					
0-25	25%	50%	25%	25%	50%
25-50	50%	25%	50%	50%	50%
50-100	25%	25%	25%	25%	-

* Estimated level of certainty.

** Veins less than approximately 0,5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

*** Some parts of the zones are probably rather fresh and less fractured.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
700 - 1475 m

HYDRAULIC CONDUCTIVITY*:

Scale: 20 m

Point estimate, geometric mean $K_g = 1.4 \cdot 10^{-9}$ m/s

95% confidence limits of geometric mean $= 7 \cdot 10^{-12} - 1 \cdot 10^{-7}$ m/s

Point estimate of sample standard deviation (logK) $S_{logK}=1.1$

WATER BEARING ZONES:

ZONE	TRANSMISSIVITY (m^2/s) Estimate $x\ 10^{-5}$	Possible range $x\ 10^{-5}$
EW-7	14	3-30
NE-4	35	5-50
NE-3	14	3-30
NE-1b**	15	4-40
NE-1a**	15	4-40
EW-3	0.05	0.01-0.1

* Based on rock composition estimate

** NE-1 is divided in two parts, a and b where NE-1b is the southern part

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
700-1475 m

BOUNDARY CONDITIONS:

Upper boundary

Sea - Constant head

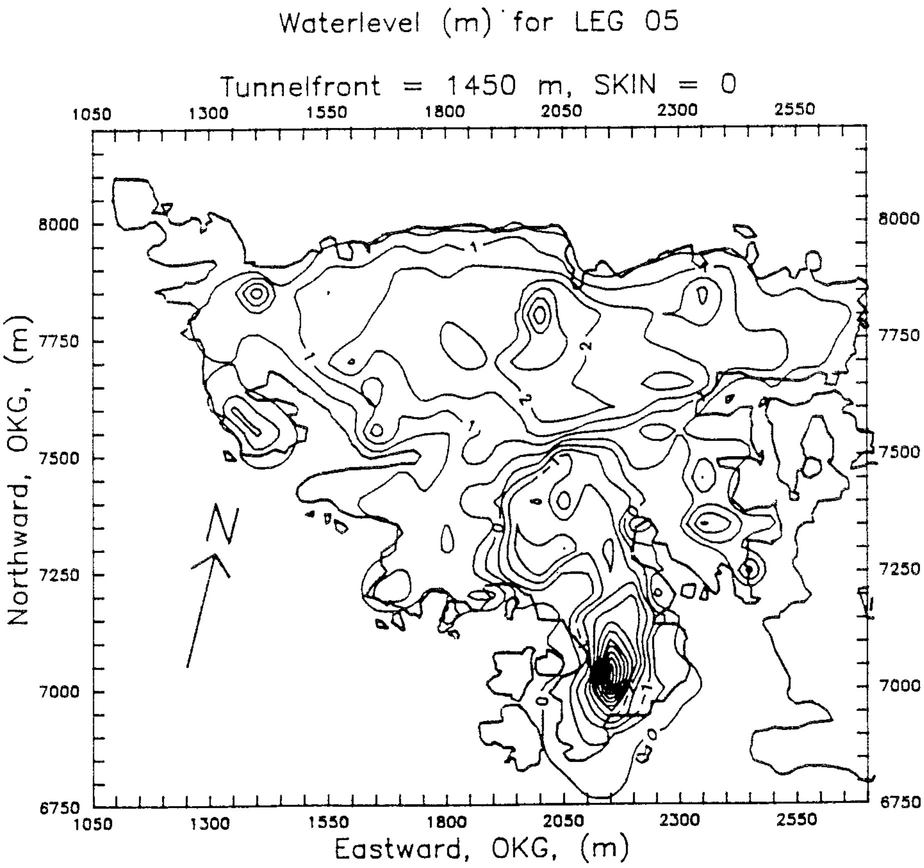
Äspö - Constant infiltration rate 3 mm/year except for a wetland in the centre of Äspö, which has a constant head of +2 m

Vertical boundaries

Hydrostatic pressure distribution based on a salinity of 0.7% at sea surface and 1.8% at a depth of 1 300 m.

Lower horizontal boundary

Zero flux.



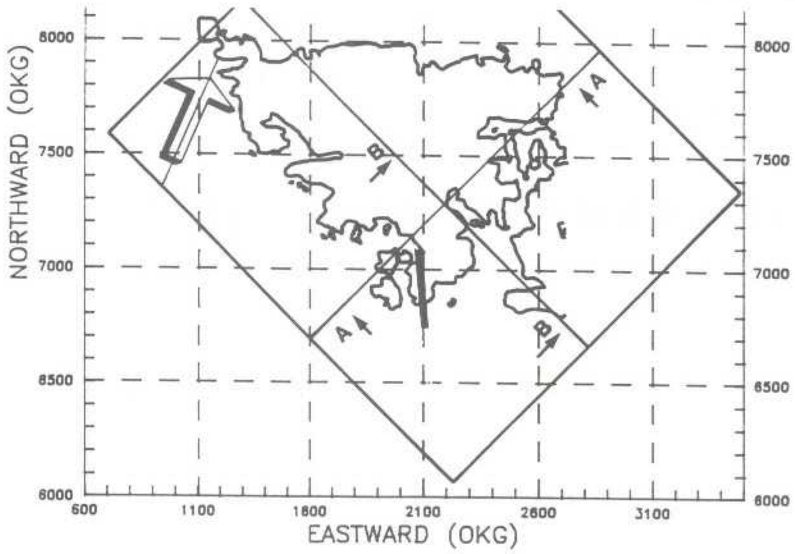
See SKB PR-25-91-03

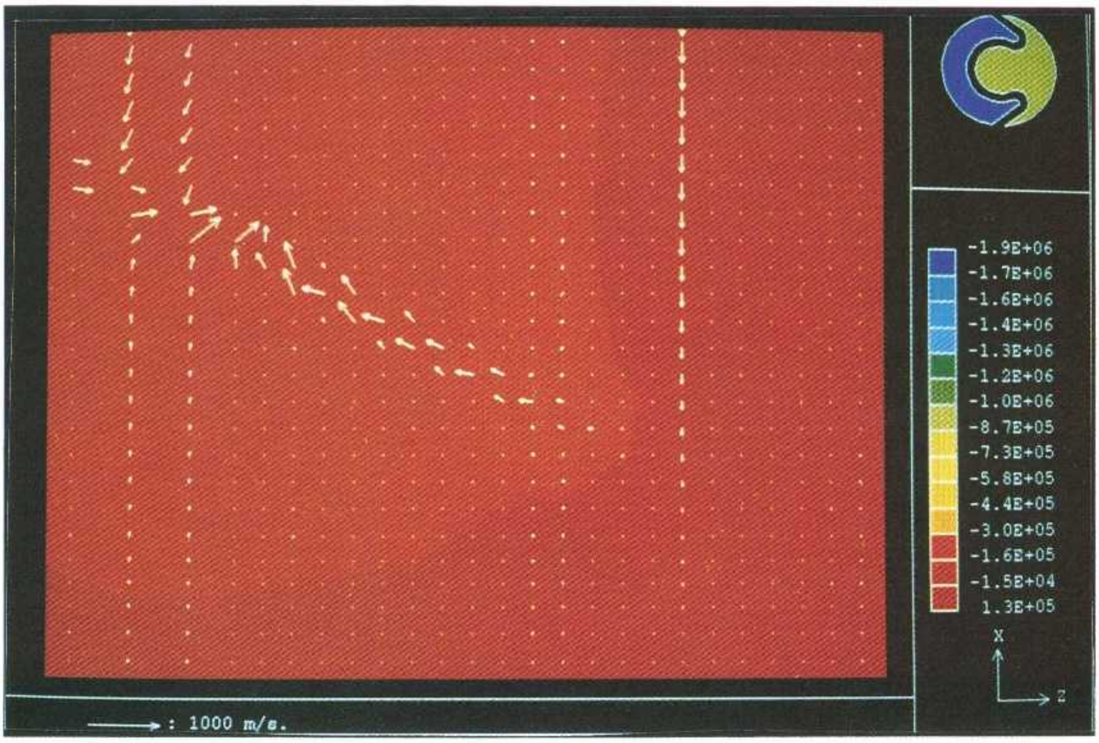
PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
700-1475 m

PRESSURE AND FLUX DISTRIBUTION:

In the pictures below the hydraulic head is shown (density of water = 1 000 kg/m^3). (See SKB PR 25-91-03).

Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). Vertical sections are shown in the figure below.

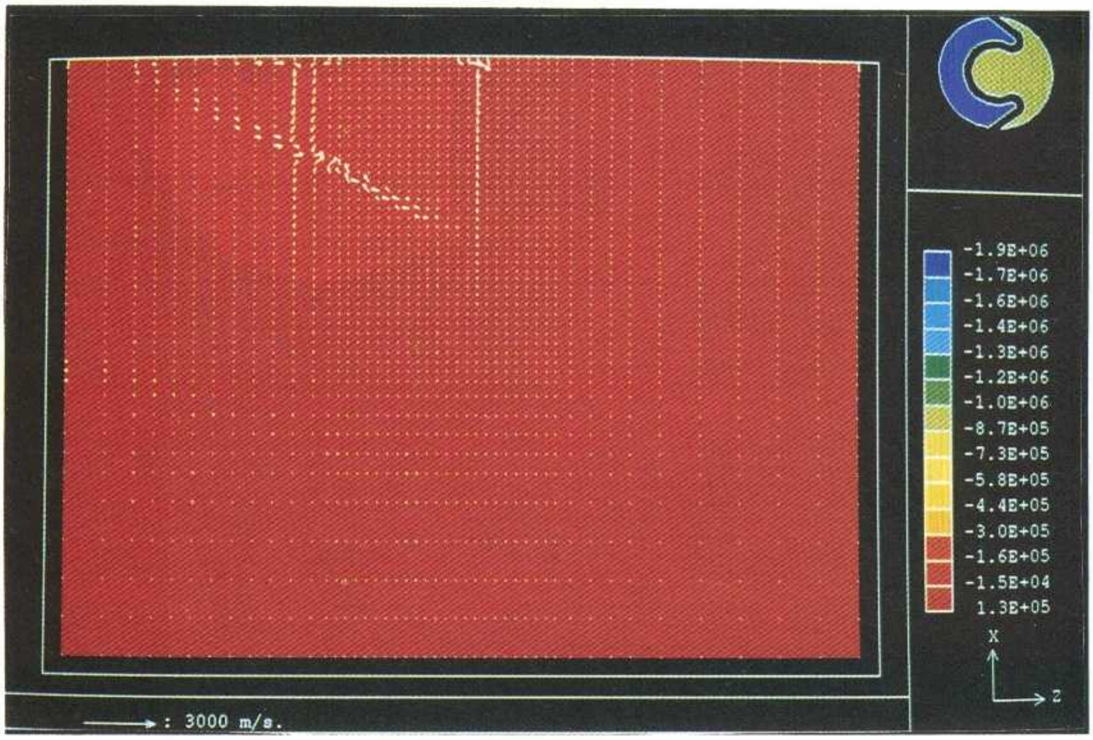




Vertical view of the section A (see above map for orientation). 1 cm in the picture refers to 36 m in the reality. Hydraulic head given in Pa is presented numerically in the legend. Tunnel in the centre of the figure.

PREDICTION OF GROUNDWATER FLOW SITE SCALE (500 m) 700 - 1475 m

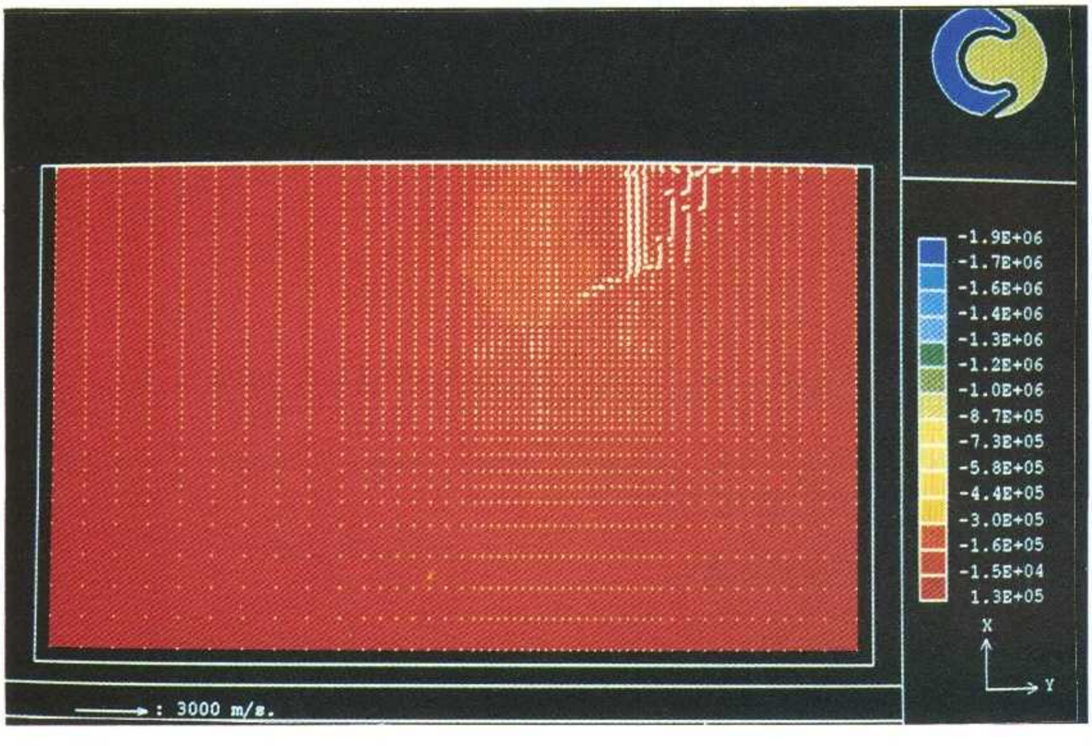
PRESSURE AND FLUX DISTRIBUTION:



Section A

Scale:
1 cm = 160 m

Hydraulic head in Pa



Section B

Scale:
1 cm = 200 m

Hydraulic head in Pa

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
700 - 1475 m

FLOW:

Total cumulative inflow to tunnel section 700-1475 m:

skin*** = 0, $Q_T = 15 \cdot 10^{-3}$ m^3/s
skin*** = 10, $Q_T = 14 \cdot 10^{-3}$ m^3/s

INFLOW TO TUNNEL: zones

ZONE	SECTION* (m)	$SKIN_{FX}$**	INFLOW Q_{FX} (m^3/s) x 10^{-3}	
			Skin*** = 0	Skin*** = 10
NE-4	900 - 950	120 }		
NE-3	950 - 990	0 }	3.2	3.2
NE-1b	1 170 - 1 200	80	2.4	2.3
NE-1a	1 230 - 1 270	80	2.3	2.3
EW-5	1 380 - 1 440	0	1.9	1.5
EW-3	1 450 - 1 480	0	0.2	0.048

* Approximate section for zone according to numerical model, SKB PR 25-91-03

** Skin for zones, skin in zone is substantially increased in order to simulate grouting. Q_{FX} maximized to approximatly 3.10^{-3} m^3/s

*** Skin for tunnel, zones excluded

PREDICTION OF GROUNDWATER FLOW SITE SCALE (500 m) 700 - 1475 m

INFLOW TO TUNNEL AND SALINITY: tunnel legs

LEG NO	SECTION (m)	INFLOW Q_L(m^3/s) x 10^{-3}		SALINITY S_L (‰)	
		Skin* = 0	Skin* = 10	Skin* = 0	Skin* = 10
1	700-850**	4.0	4.0	7.3	7.3
2	850-1000	4.1	4.0	7.2	7.2
3	1000-1150	0.06	0.03	7.2	7.2
4	1150-1300	4.7	4.7	7.3	7.3
5	1300-1450	1.9	1.5	7.5	7.5
6	1450-1600	0.07	0.02	7.8	7.4

* skin for tunnel, zones excluded
** outside model area, estimated inflow and salinity

PREDICTION OF GROUNDWATER CHEMISTRY
SITE SCALE (500 m)
700 - 1475 m

ZONES:

CONDUCTIVE ZONES	Na^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO^- mg/l	SO_4^{2-} mg/l	Fe^{tot} mg/l	pH --	Eh mV
EW-7	1700 ±100	36 ±10	410 ±300	190 ±30	2800 ±1400	250 ±10	130 ±50	0.6 ±0.6	7.6 ±0.6	-290 ±40
NE-4	1800 ±100	35 ±15	410 ±350	190 ±30	2800 ±1600	250 ±10	140 ±50	0.6 ±0.6	7.6 ±0.6	-290 ±40
NE-3	1800 ±100	34 ±10	680 ±250	170 ±15	4500 ±200	280 ±50	170 ±50	0.6 ±0.6	7.3 ±0.3	-240 ±25
EW-X	1800 ±200	33 ±20	990 ±150	150 ±70	4800 ±900	290 ±100	180 ±50	0.6 ±0.6	7.2 ±0.3	-230 ±25
NE-1	1900 ±200	31 ±20	1200 ±350	150 ±80	5300 ±400	290 ±100	210 ±50	0.6 ±0.6	7.2 ±0.3	-230 ±25

PREDICTION OF GROUNDWATER CHEMISTRY
SITE SCALE (500 m)
700 - 1475 m

ZONES: salinity

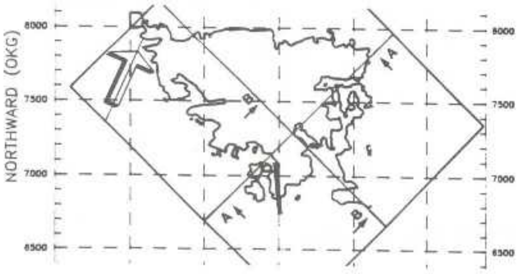
Salinity estimated with a numerical groundwater flow model, see SKB PR 25-91-03.

ZONE	SECTION * (m)	S_{FX} (‰) Skin** = 0	Skin** = 10
NE-4	900 - 950 }		
NE-3	950 - 990 }	7.3	7.3
NE-1b	1 170 - 1 200	7.3	7.3
NE-1a	1 230 - 1 270	7.3	7.3
EW-5	1 380 - 1 440	7.5	7.5
EW-3	1 450 - 1 480	7.9	7.5

* approximate section for zone according to numerical model

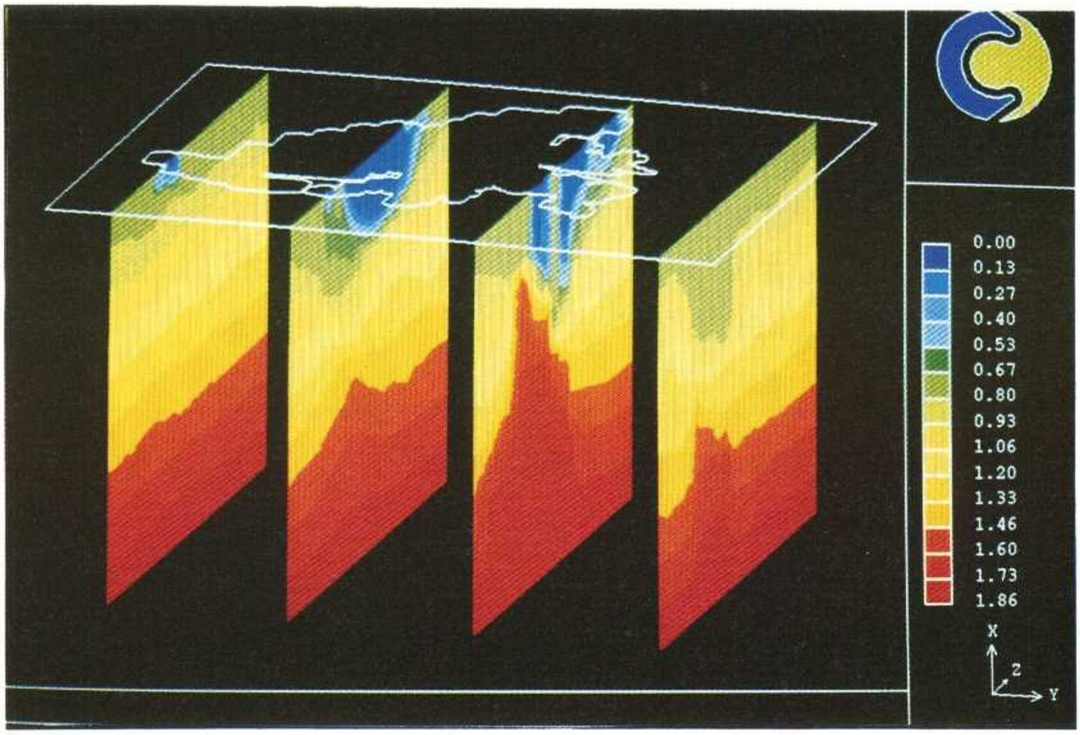
** skin for tunnel, zones excluded

PREDICTION OF TRANSPORT OF SOLUTES
SITE SCALE (500 m)
700 - 1475 m



SALINE INTERFACE:

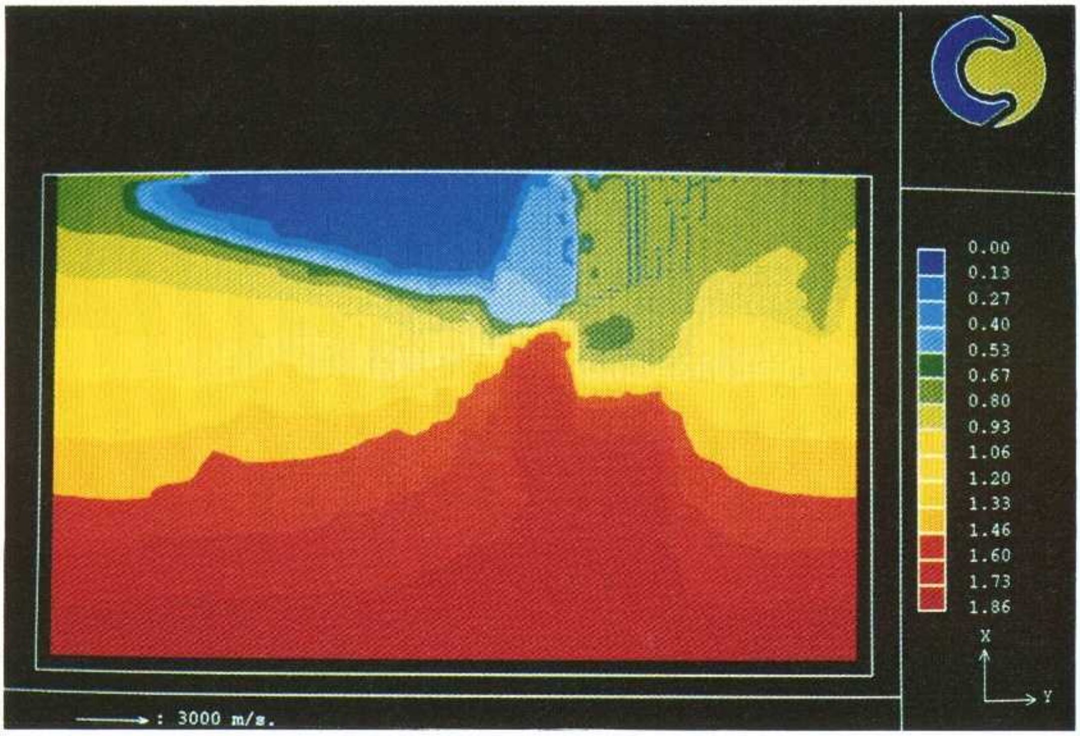
In the pictures below the salinity field and the water fluxes are shown (SKB PR 25-91-03). Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). See prediction of groundwater flow, site scale, pressures and flux distribution for definitions of sections.



Vertical

Scale
1 cm = 250 m

Salinity in %



Section B

Scale:
1 cm = 200 m

Salinity in %

PREDICTIONS OF MECHANICAL STABILITY SITE SCALE (500 m) 700 - 1475 m

ROCK QUALITY:

The rock can be classified as Class A, B, C, D or E according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the classes correspond to different values of Rock Mass Rating (RMR).

The Rock Mass Rating is predicated to have the following distribution in this 500 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
20%	45%	30%	-	5%

ROCK STRESS:

Predicted mean values for rock stresses along the tunnel.

Vertical stress σ_v = Depth x 0.0265 [MPa]

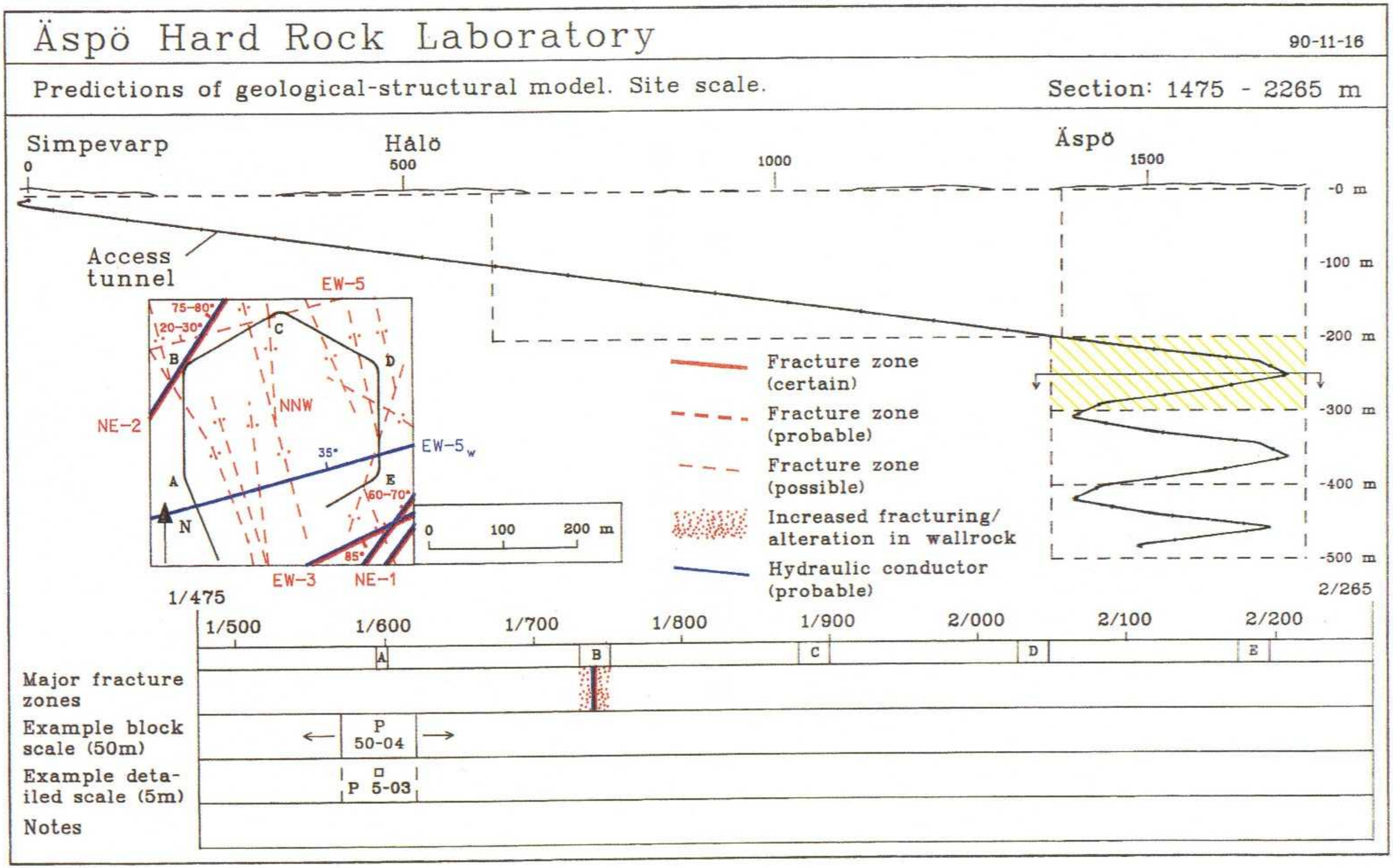
Maximum horizontal stress $\sigma_{H,max} = 1.7 - 2.0 \times \sigma_v$ [MPa]
orientation = N30°W ±15°

Minimum horizontal stress $\sigma_{H,min} = 1.1 - 1.5 \times \sigma_v$ [MPa]
orientation = N60°E ±15°

LONG TERM STABILITY:

Potential movements will be concentrated to existing clay filled fracture zones or major weakness zones. Small changes in magnitude or orientation of the present horizontal stress field will be sufficient for releasing movements in existing zones.

PREDICTIONS IN SITE SCALE
SECTION 1475 - 2265 m


Äspö Hard Rock Laboratory
90-11-16
Predictions of geological-structural model. Site scale.
Section: 1475 - 2265 m
Simpevarp
Hålö
Äspö
0
500
1000
1500
-0 m
-100 m
-200 m
-300 m
-400 m
-500 m
Access tunnel
EW-5
75-80°
20-30°
B
C
D
NNW
NE-2
35°
EW-5w
A
E
60-70°
N
85°
EW-3
NE-1
0
100
200 m
Fracture zone (certain)
Fracture zone (probable)
Fracture zone (possible)
Increased fracturing/ alteration in wallrock
Hydraulic conductor (probable)
1/475
2/265
1/500
1/600
1/700
1/800
1/900
2/000
2/100
2/200
A
B
C
D
E
Major fracture zones
Example block scale (50m)
P 50-04
Example detailed scale (5m)
P 5-03
Notes

PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL SITE SCALE (500 m) 1475 - 2265 m

DISTRIBUTION (%) OF THE MAIN ROCK TYPES:

Småland granite	= 25(±5)60%*
Äspö diorite	= 50(±5)60%
Greenstone	= 14(±3)60%
Fine-grained granite	= 12(±3)75%
Mylonite-hybridized rock	= 2(±1)60%

ROCK BOUNDARIES (Nos/100 m):**

9(±3)60%

MAJOR FRACTURE ZONES (Width >5 m):

ZONE	NE-2
Position (centre of zone)	1740(±30 m)$_{60\%}$
Strike	NE
Dip	75°(±5)$_{75\%}$
Extension (m)	<1000
Width (m)	15(±5)$_{60\%}$
RQD for crossings***	
0-25	50%
25-50	50%
50-100	

* Estimated level of certainty.
** Veins less than approximately 0,5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.
*** Some parts of the zones are probably rather fresh and less fractured.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
1475 - 2265 m

HYDRAULIC CONDUCTIVITY:

Scale: 20 m

Point estimate, geometric mean $K_g = 1.6 \cdot 10^{-9}$ m/s

95% confidence limits of geometric mean $= 8.5 \cdot 10^{-10} - 2.9 \cdot 10^{-9}$ m/s

Point estimate of sample standard deviation (logK) $S_{logK} = 0.8$

WATER BEARING ZONES:

ZONE	TRANSMISSIVITY (m^2/s)	
	Estimate $\times 10^{-5}$	Possible range $\times 10^{-5}$
EW-5*	2	0.2-4
NE-2	0.4	0.2-1
NNW-1**	1.5	0.5-2
NNW-2***	8	2-10

* The zone is complex and consists probably of several parts. It may be found between 1550-1700 m.

** The position of NNW-1 is uncertain and may consist of several zones. NNW-1 is expected to be found between 1750-1850 m and possibly between 2250-2350.

*** The position of NNW-2 is uncertain and may consist of several zones. NNW-2 is expected to be found between 1850-1900 m and 2150-2200 m.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
1475 - 2265 m

BOUNDARY CONDITIONS:

Upper boundary

Sea - Constant head

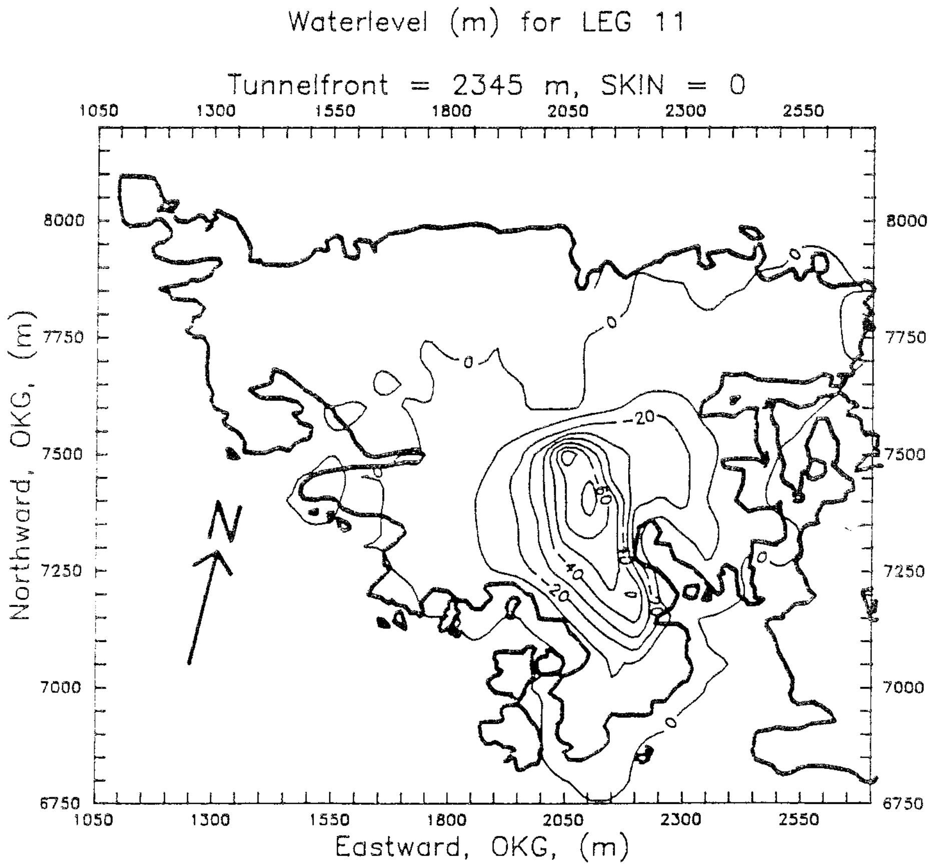
Äspö - Constant infiltration rate 3 mm/year except for a wetland in the centre of Äspö, which has a constant head of +2 m.

Vertical boundaries

Hydrostatic pressure distribution based on a salinity of 0.7% at sea surface and 1.8% at a depth of 1 300 m.

Lower horizontal boundary

Zero flux.



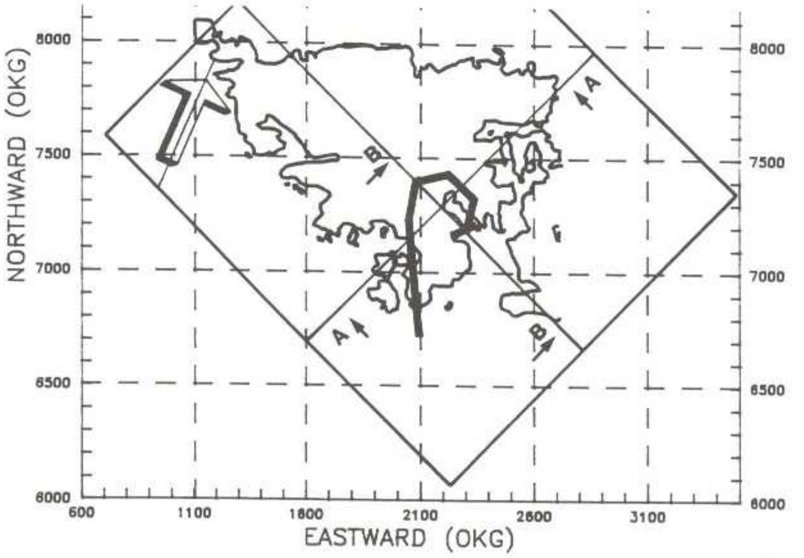
See SKB PR-25-91-03

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
1475 - 2265 m

PRESSURE AND FLUX DISTRIBUTION:

In the pictures below the hydraulic head is shown (density of water = 1 000 kg/m^3)

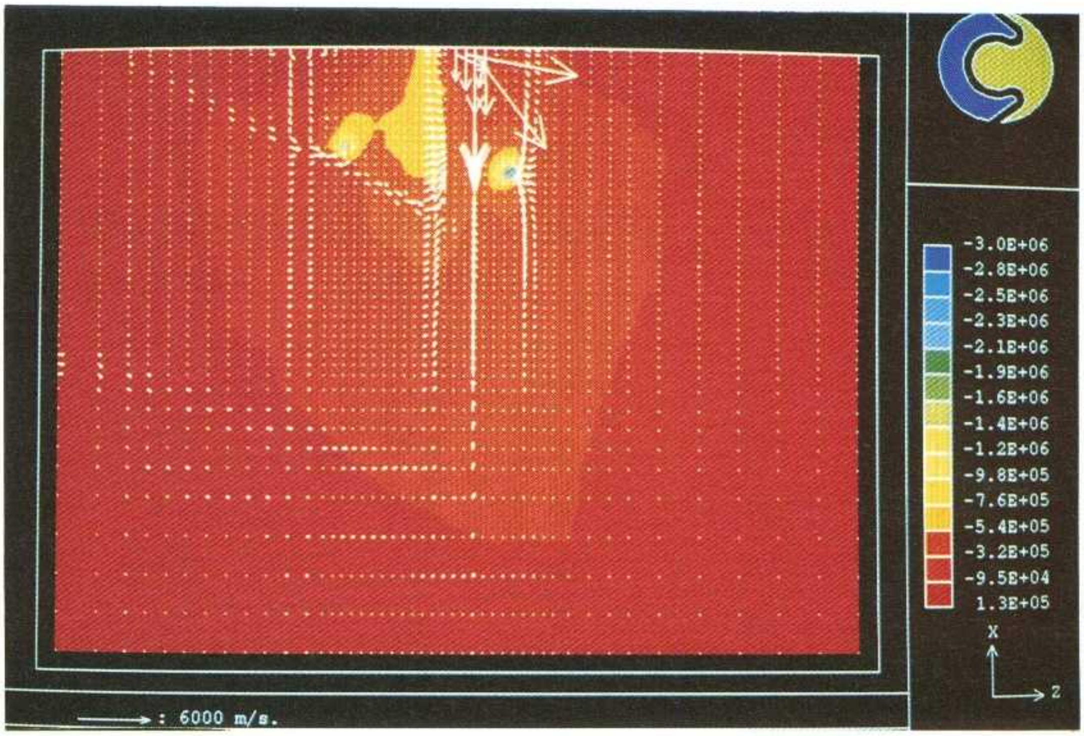
Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). Vertical sections are shown in the figure below.



Vertical view of the section B (see above map for orientation). 1 cm in the picture refers to 36 m in the reality. Hydraulic head given in Pa is presented numerically in the legend. Blue-spots are tunnel positions.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
1475 - 2265 m

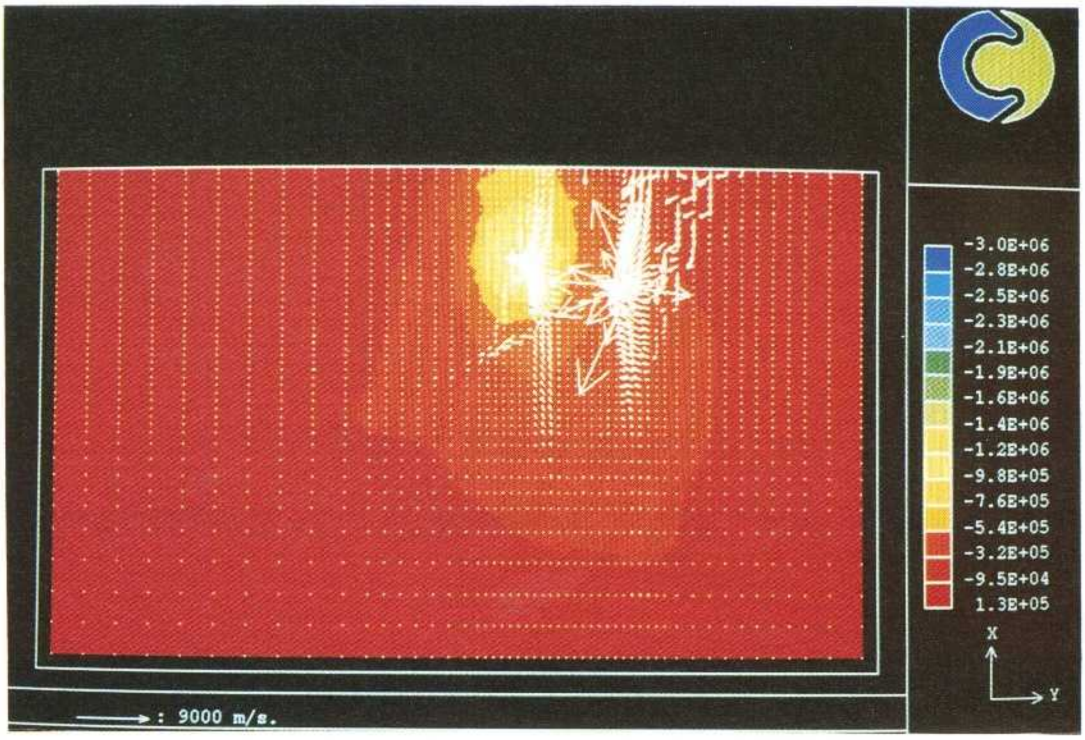
PRESSURE AND FLUX DISTRIBUTION:



Section A

Scale:
1 cm = 160 m

Hydraulic head
in Pa



Section B

Scale:
1 cm = 200 m

Hydraulic head
in Pa

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
1475 - 2265 m

FLOW:

Total cumulative inflow to tunnel section 700-2265 m: skin*** = 0, $Q_T = 27.5 \cdot 10^{-3}$ m³/s
skin*** = 10, $Q_T = 24.5 \cdot 10^{-3}$ m³/s

INFLOW TO TUNNEL: zones

ZONE	SECTION* (m)	$SKIN_{FX}$**	INFLOW Q_{FX} (m³/s) x 10^{-3} Skin***=0	Skin*** = 10
NE-4	900 - 950	120 }		
NE-3	950 - 990	0 }	3.2	3.2
NE-1b	1 170 - 1 200	80	2.4	2.3
NE-1a	1 230 - 1 270	80	2.3	2.3
EW-5	1 380 - 1 440	0	1.8	1.4
EW-3	1 450 - 1 480	0	0.19	0.05
NNW-1	1 770 - 1 800	0	4.2	1.4
NNW-2	1 860 - 1 880	30	3.4	3.4
NNW-4	2 030 - 2 050	30	2.1	2.1
NNW-2	2 190 - 2 210	30, 60	1.9	1.9
NNW-1	2 260 - 2 280	30	0.44	0.45

* approximate section for zone according to numerical model, SKB PR 25-91-03

** skin for zones. Skin in zone is substantially increased in order to simulate grouting. Q_{FX} maximized to approximatly $3 \cdot 10^{-3}$ m³/s

*** skin for tunnel, zones excluded

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
1475 - 2265 m

INFLOW TO TUNNEL AND SALINITY: tunnel legs

LEG NO	SECTION (m)	INFLOW Q_L(m^3/s) x 10^{-3}		SALINITY S_L (‰)	
		Skin* = 0	Skin* = 10	Skin* = 0	Skin* = 10
1	700-850**	4.0	4.0	7.3	7.3
2	850-1000	4.1	4.0	7.1	7.1
3	1000-1150	0.06	0.03	7.0	7.1
4	1150-1300	4.7	4.6	7.0	7.0
5	1300-1450	1.8	1.4	7.0	7.0
6	1450-1600	0.3	0.07	7.1	7.2
7	1600-1755	0.3	0.4	7.0	7.1
8	1755-1900	7.9	5.4	8.3	7.9
9	1900-2050	1.9	1.8	7.5	7.4
10	2050-2195	1.8	1.7	7.0	7.0
11	2195-2345	1.2	1.2	7.0	7.0

** outside model area, estimated inflow and salinity
* skin for tunnel, zones excluded

PREDICTION OF GROUNDWATER CHEMISTRY
SITE SCALE (500 m)
1475 - 2265 m

ZONES:

CONDUCTIVE ZONES	Na^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO^- mg/l	SO_4^{2-} mg/l	Fe^{tot} mg/l	pH --	Eh mV
NE-2	1200	5	1100	30	3800	70	140	0.3	7.7	-290
	±300	±5	±300	±30	±1000	±50	±40	±0.3	±0.1	±25
EW-5	1300	5	1200	30	4100	70	150	0.3	7.8	-300
	±300	±5	±300	±30	±800	±20	±50	±0.3	±0.2	±25
NNW	500	5	400	30	1500	150	150	0.3	7.8	-300
	±200	±5	±200	±30	±1000	±50	±50	±0.3	±0.2	±25

PREDICTION OF GROUNDWATER CHEMISTRY
SITE SCALE (500 m)
1475 - 2265 m

ZONES: salinity

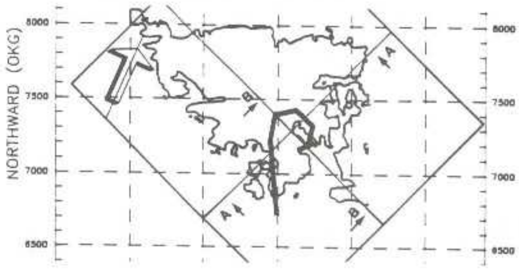
Salinity estimated with a numerical groundwater flow model.

ZONE	SECTION * (m)	S_{FX} (‰) Skin** = 0	Skin** = 10
NE-4	900 - 950 }		
NE-3	950 - 990 }	7.1	7.1
NE-1b	1 170 - 1 200	7.0	7.0
NE-1a	1 230 - 1 270	7.0	7.0
EW-5	1 380 - 1 440	7.0	7.0
EW-3	1 450 - 1 480	7.1	7.1
NNW-1	1 770 - 1 800	8.7	8.6
NNW-2	1 860 - 1 880	7.8	7.8
NNW-4	2 030 - 2 050	7.4	7.3
NNW-2	2 190 - 2 210	7.0	7.0
NNW-1	2 260 - 2 280	7.0	7.0

* approximate section for zone according to numerical model

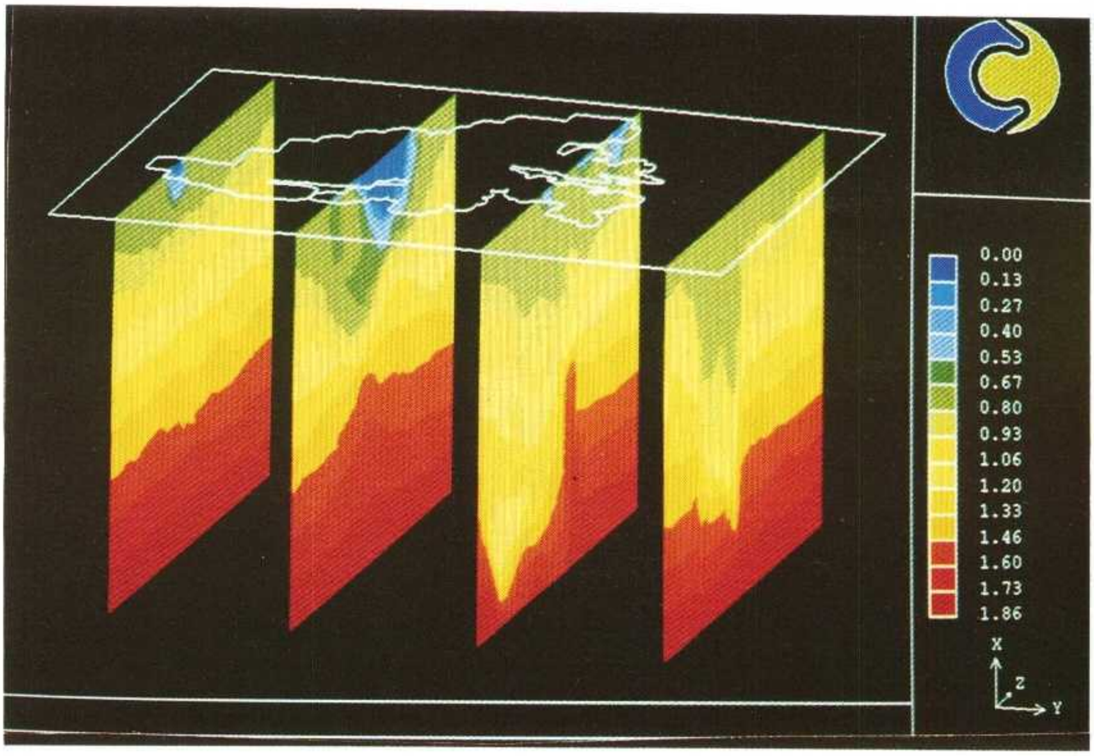
** skin for tunnel, zones excluded

PREDICTION OF TRANSPORT OF SOLUTES
SITE SCALE (500 m)
1475 - 2265 m



SALINE INTERFACE:

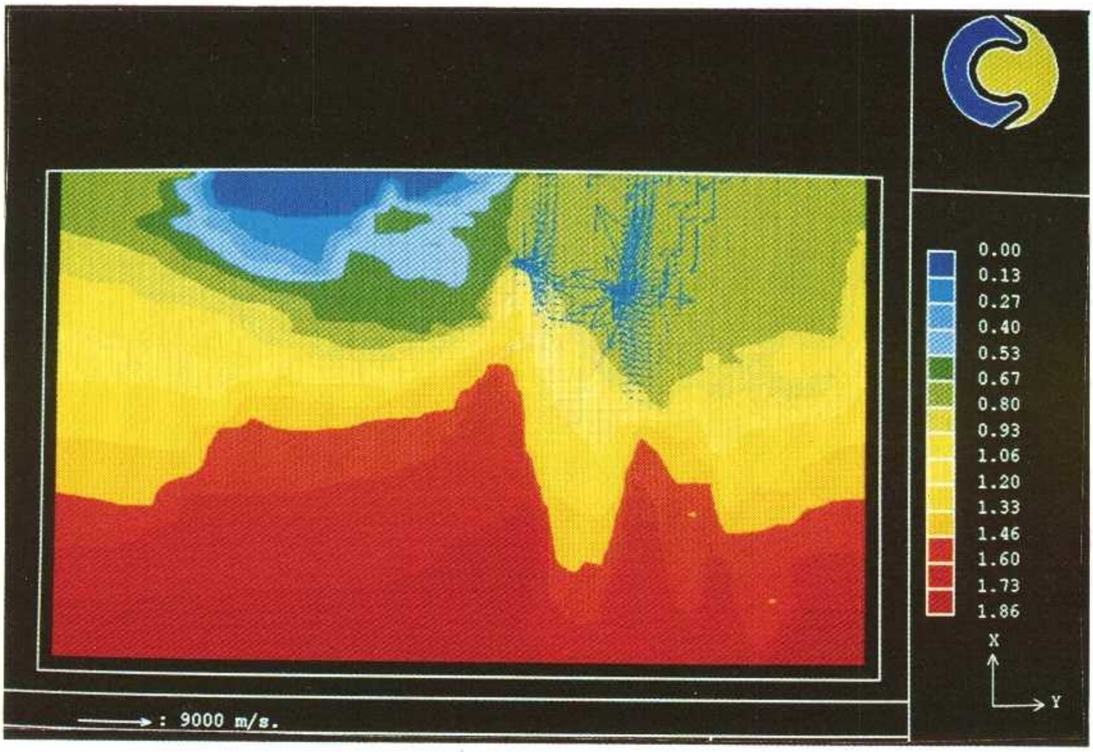
In the pictures below the salinity field and the water fluxes are shown. Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). See prediction of groundwater flow, site scale, pressures and flux distribution for definitions of sections.



Vertical

Scale
1 cm = 250 m

Salinity in %



Section B

Scale:
1 cm = 200 m

Salinity in %

PREDICTIONS OF MECHANICAL STABILITY
SITE SCALE (500 m)
1475 - 2265 m

ROCK QUALITY:

The rock can be classified as Class A, B, C, D or E according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the classes correspond to different values of Rock Mass Rating (RMR).

The Rock Mass Rating is predicated to have the following distribution in this 500 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
35%	35%	25%	5%	-

ROCK STRESS:

Predicted mean values for rock stresses along the tunnel.

Vertical stress σ_v = Depth x 0.0265 [MPa]

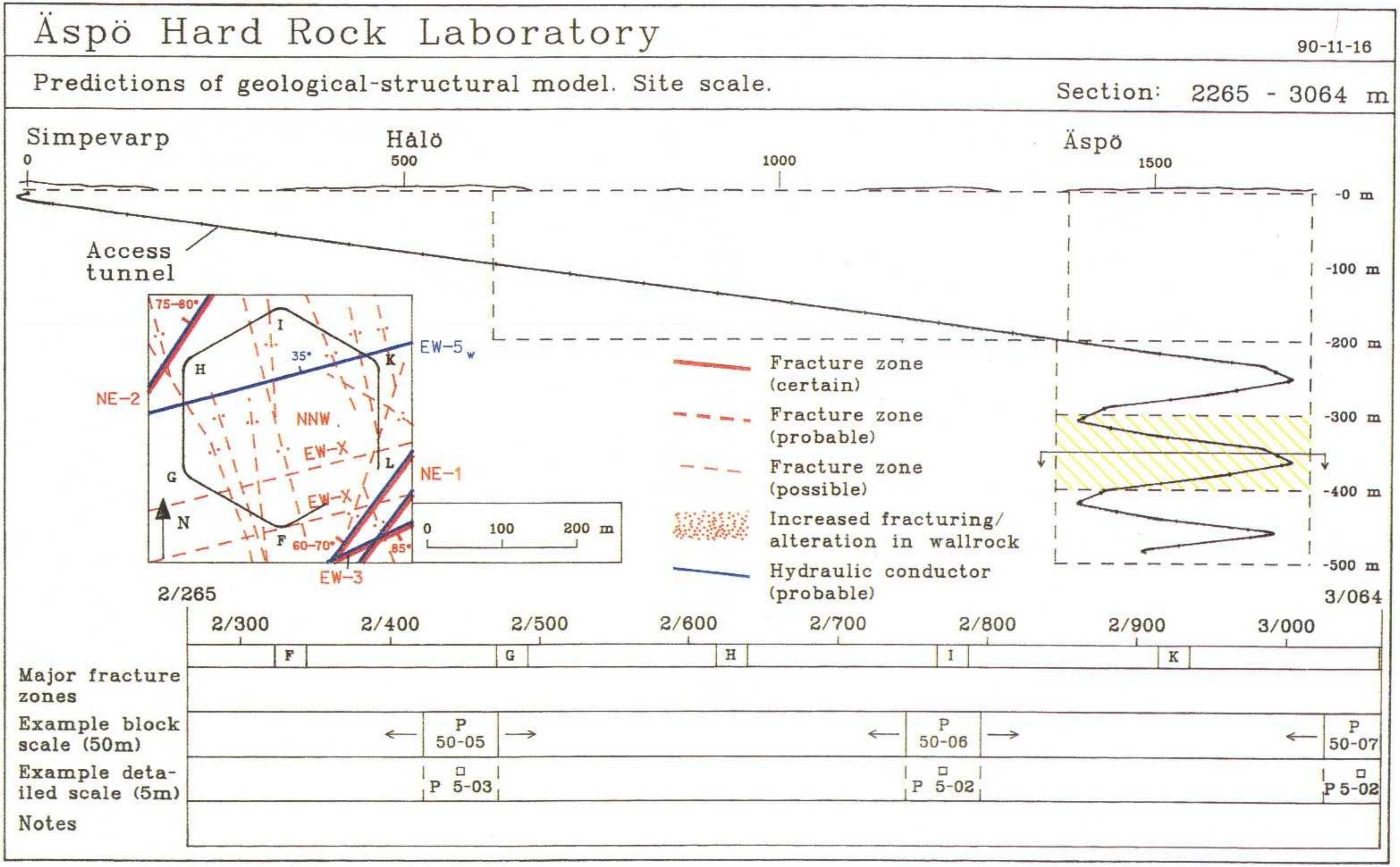
Maximum horizontal stress $\sigma_{H, max} = 1.6 - 1.7 \times \sigma_v$ [MPa]
orientation = N25°W ±15°

Minimum horizontal stress $\sigma_{H, min} = 0.8 - 0.9 \times \sigma_v$ [MPa]
orientation = N65°E ±10°

LONG TERM STABILITY:

Potential movements will be concentrated to existing clay filled fracture zones or major weakness zones. Small changes in magnitude or orientation of the present horizontal stress field will be sufficient for releasing movements in existing zones.

PREDICTIONS IN SITE SCALE
SECTION 2265 - 3064 m



Äspö Hard Rock Laboratory
90-11-16
Predictions of geological-structural model. Site scale.
Section: 2265 - 3064 m
Simpevarp
Hålö
Äspö
0
500
1000
1500
-0 m
-100 m
-200 m
-300 m
-400 m
-500 m
Access tunnel
75-80°
I
35°
H
K
EW-5 w
NE-2
NNW
EW-X
L
NE-1
G
EW-X
N
F
60-70°
85°
EW-3
0
100
200 m
Fracture zone (certain)
Fracture zone (probable)
Fracture zone (possible)
Increased fracturing/ alteration in wallrock
Hydraulic conductor (probable)
2/265
3/064
2/300
2/400
2/500
2/600
2/700
2/800
2/900
3/000
F
G
H
I
K
Major fracture zones
Example block scale (50m)
P 50-05
P 50-06
P 50-07
Example detailed scale (5m)
P 5-03
P 5-02
P 5-02
Notes

PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL SITE SCALE (500 m) 2265 - 3064 m

DISTRIBUTION (%) OF THE MAIN ROCK TYPES:

Småland granite	= 20(±5)60%
Äspö diorite	= 56(±5)60%
Greenstone	= 8(±3)60%
Fine-grained granite	= 14(±3)75%
Mylonite-hybridized rock	= 2(±1)60%

ROCK BOUNDARIES (Nos/100 m):**

12(±3)60%

MAJOR FRACTURE ZONES (Width >5 m):

No indications within this section

* Estimated level of certainty.

** Veins less than approximately 0,5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

*** Some parts of the zones are probably rather fresh and less fractured.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
2265 - 3064 m

HYDRAULIC CONDUCTIVITY:

Scale: 20 m

Point estimate, geometric mean $K_g = 2.0 \cdot 10^{-9}$ m/s

95% confidence limits of geometric mean $= 1.1 \cdot 10^{-9} - 3.7 \cdot 10^{-9}$ m/s

Point estimate of sample standard deviation (logK) $S_{logK} = 0.8$

WATER BEARING ZONES:

ZONE	TRANSMISSIVITY (m²/s) Estimate x 10^{-5}	Possible range x 10^{-5}
NNW-1*	1.5	0.5-2
NNW-2**	4	2-6
EW-5***	2	0.2-4

* The position of NNW-1 is uncertain and may consist of several zones. NNW-1 is expected to be found between 2620-2720 m and possibly between 2250-2350 m.

** The position of NNW-2 is uncertain and may consist of several zones. NNW-2 is expected to be found between 2720-2780 m and 3030-3080 m.

*** The zone is complex and consists probably of several parts. It may be found between 2500-2900 m.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
2265 - 3064 m

BOUNDARY CONDITIONS:

Upper boundary

Sea - Constant head

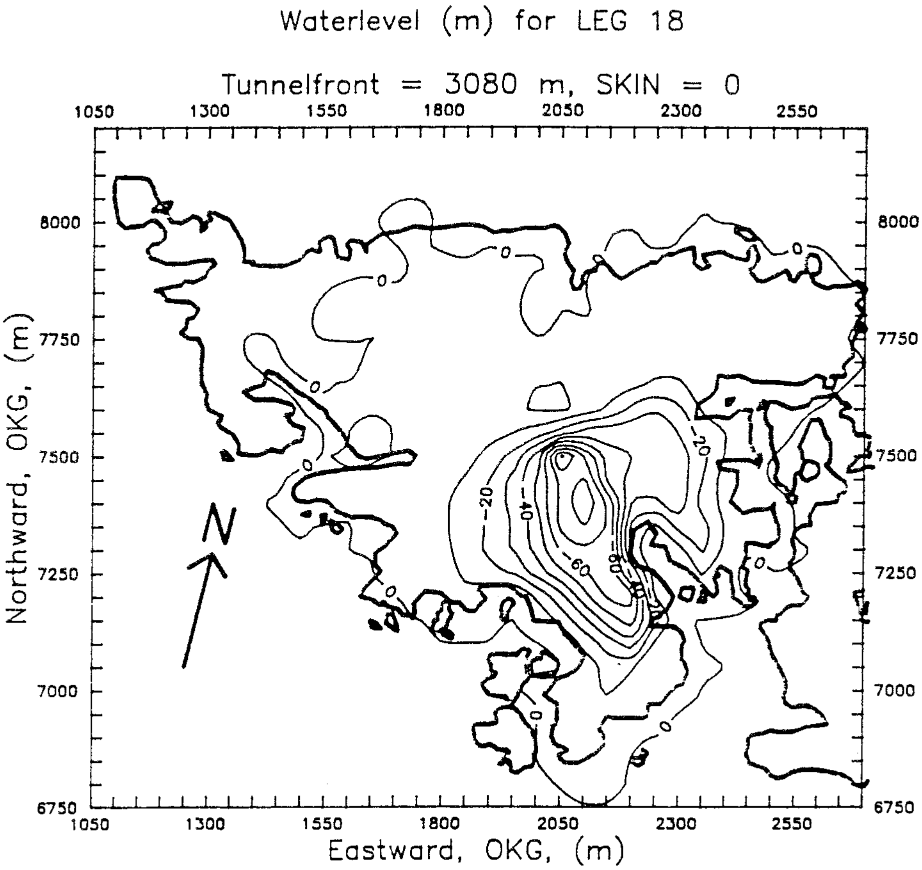
Äspö - Constant infiltration rate 3 mm/year except for a wetland in the centre of Äspö, which has a constant head of +2 m.

Vertical boundaries

Hydrostatic pressure distribution based on a salinity of 0.7% at sea surface and 1.8% at a depth of 1 300 m.

Lower horizontal boundary

Zero flux.



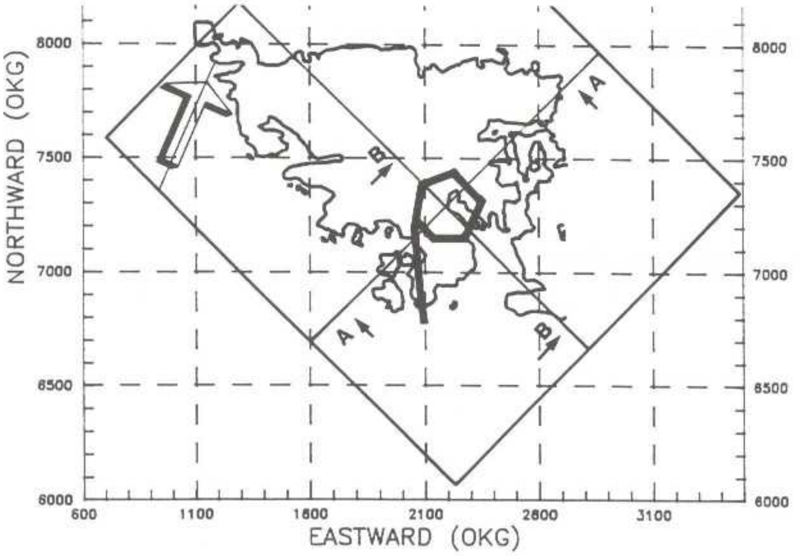
See SKB PR-25-91-03

PREDICTION OF GROUNDWATER FLOW SITE SCALE (500 m) 2265 - 3064

PRESSURE AND FLUX DISTRIBUTION:

In the pictures below the hydraulic head is shown (density of water = 1 000 kg/m^3)

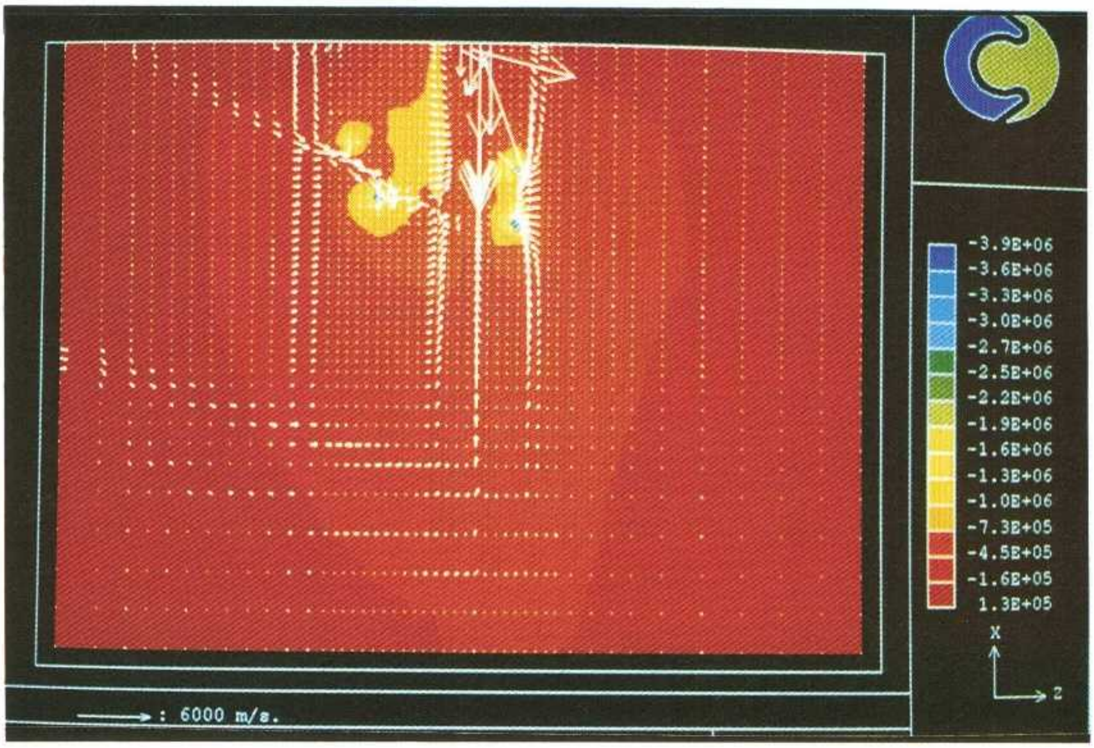
Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). Vertical sections are shown in the figure below.



Vertical view of the section A (see above map for orientation). 1 cm in the picture refers to 36 m in the reality. Hydraulic head given in Pa is presented numerically in the legend. Blue-spots are tunnel positions.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
2265 - 3064 m

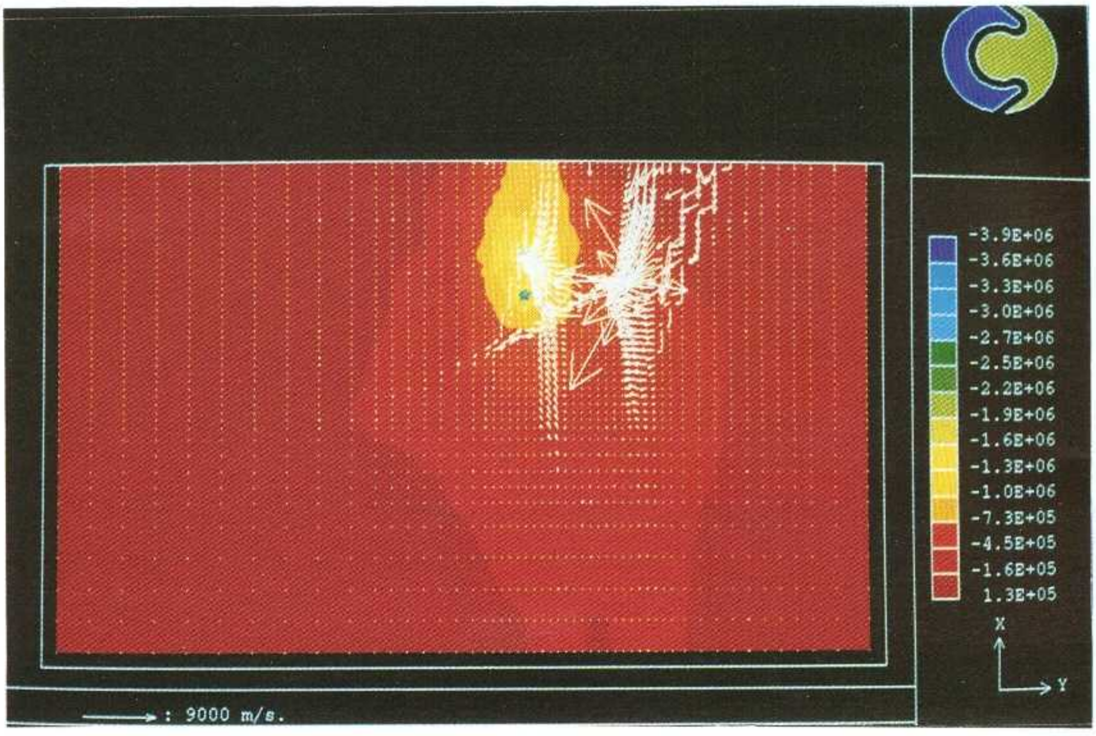
PRESSURE AND FLUX DISTRIBUTION:



Section A

Scale:
1 cm = 160 m

Hydraulic head
in Pa



Section B

Scale:
1 cm = 200 m

Hydraulic head
in Pa

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
2265 - 3064 m

FLOW:

Total cumulative inflow to tunnel section 700-3064 m + shaft: skin*** = 0, $Q_T = 39 \cdot 10^{-3}$ m³/s
skin*** = 10, $Q_T = 36 \cdot 10^{-3}$ m³/s

INFLOW TO TUNNEL: zones

ZONE	SECTION* (m)	$SKIN_{FX}$**	INFLOW Q_{FX} (m³/s) x 10^{-3} Skin*** = 0	Skin*** = 10
NE-4	900 - 950	120 }		
NE-3	950 - 990	0 }	3.2	3.2
NE-1b	1 170 - 1 200	80	2.3	2.3
NE-1a	1 230 - 1 270	80	2.3	2.3
EW-5	1 380 - 1 440	0	1.7	1.3
EW-3	1 450 - 1 480	0	0.2	0.04
NNW-1	1 770 - 1 800	0	3.6	1.2
NNW-2	1 860 - 1 880	30	3.1	3.1
NNW-4	2 030 - 2 050	30	1.9	1.9
NNW-2	2 190 - 2 210	30, 60	3.0	3.0
NNW-1	2 260 - 2 280	30	0.4	0.4
EW-5	2 450 - 2 510	0	3.1	3.2
NNW-1	2 640 - 2 660	30	0.8	0.8
NNW-2	2 720 - 2 750	80	2.0	1.9
NNW-4	2 860 - 2 940	30	2.8	2.8

* approximate section for zone according to numerical model
** skin for zones. Skin in zone is substantially increased in order to simulate grouting. Q_{FX} maximized to approximatly $3 \cdot 10^{-3}$ m³/s
*** skin for tunnel, zones excluded

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
2265 - 3064 m

INFLOW TO TUNNEL AND SALINITY: tunnel legs

LEG NO	SECTION (m)	INFLOW $Q_L (m^3/s) \times 10^{-5}$		SALINITY S_L (‰)	
		Skin* = 0	Skin* = 10	Skin* = 0	Skin* = 10
1	700-850**	4.0	4.0	7.3	7.3
2	850-1000	4.1	4.0	7.1	7.1
3	1000-1150	0.06	0.03	7.0	7.0
4	1150-1300	4.6	4.6	7.0	7.0
5	1300-1450	1.7	1.3	7.0	7.0
6	1450-1600	0.2	0.06	7.0	7.0
7	1600-1755	0.2	0.3	6.9	6.7
8	1755-1900	6.9	4.8	7.3	7.0
9	1900-2050	1.7	1.6	7.0	7.0
10	2050-2195	1.5	1.5	7.0	7.0
11	2195-2345	2.3	2.3	7.0	7.0
12	2345-2495	2.1	2.1	7.4	7.4
13	2495-2640	1.1	1.1	8.5	8.5
14 shaft	z=0-222	0.02	0.01	7.0	6.9
15 shaft	z=222-333	0.02	0.007	7.2	7.1
16	2640-2790	2.9	2.8	9.6	9.8
17	2790-2940	2.9	2.8	8.2	8.3
18	2940-3090	0.07	0.02	7.0	7.0

* skin for tunnel, zones excluded

** outside model area, estimated inflow and salinity

PREDICTION OF GROUNDWATER CHEMISTRY
SITE SCALE (500 m)
2265 - 3064 m

ZONES:

CONDUCTIVE ZONES	Na^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO^- mg/l	SO_4^{2-} mg/l	Fe^{tot} mg/l	pH --	Eh mV
NNW	800 ±300	7 ±5	800 ±300	40 ±30	2500 ±1000	170 ±70	120 ±80	0.3 ±0.3	7.7 ±0.3	-290 ±25
EW-5	1600 ±200	12 ±5	1600 ±200	150 ±20	5200 ±500	60 ±10	230 ±80	0.3 ±0.3	7.7 ±0.2	-290 ±25

PREDICTION OF GROUNDWATER CHEMISTRY
SITE SCALE (500 m)
2265 - 3064 m

ZONES: salinity

Salinity estimated with a numerical groundwater flow model.

ZONE	SECTION * (m)	S_{FX} (‰) Skin** = 0	Skin** = 10
NE-4	900 - 950 }		
NE-3	950 - 990 }	7.1	7.1
NE-1b	1 170 - 1 200	7.0	7.0
NE-1a	1 230 - 1 270	7.0	7.0
EW-5	1 380 - 1 440	7.0	7.0
EW-3	1 450 - 1 480	7.0	7.0
NNW-1	1 770 - 1 800	7.5	7.0
NNW-2	1 860 - 1 880	7.0	7.0
NNW-4	2 030 - 2 050	7.0	7.0
NNW-2	2 190 - 2 210	7.0	7.0
NNW-1	2 260 - 2 280	7.0	7.0
EW-5	2 450 - 2 510	7.7	7.8
NNW-1	2 640 - 2 660	11.3	11.0
NNW-2	2 720 - 2 750	8.9	9.2
NNW-4	2 860 - 2 940	8.2	8.3

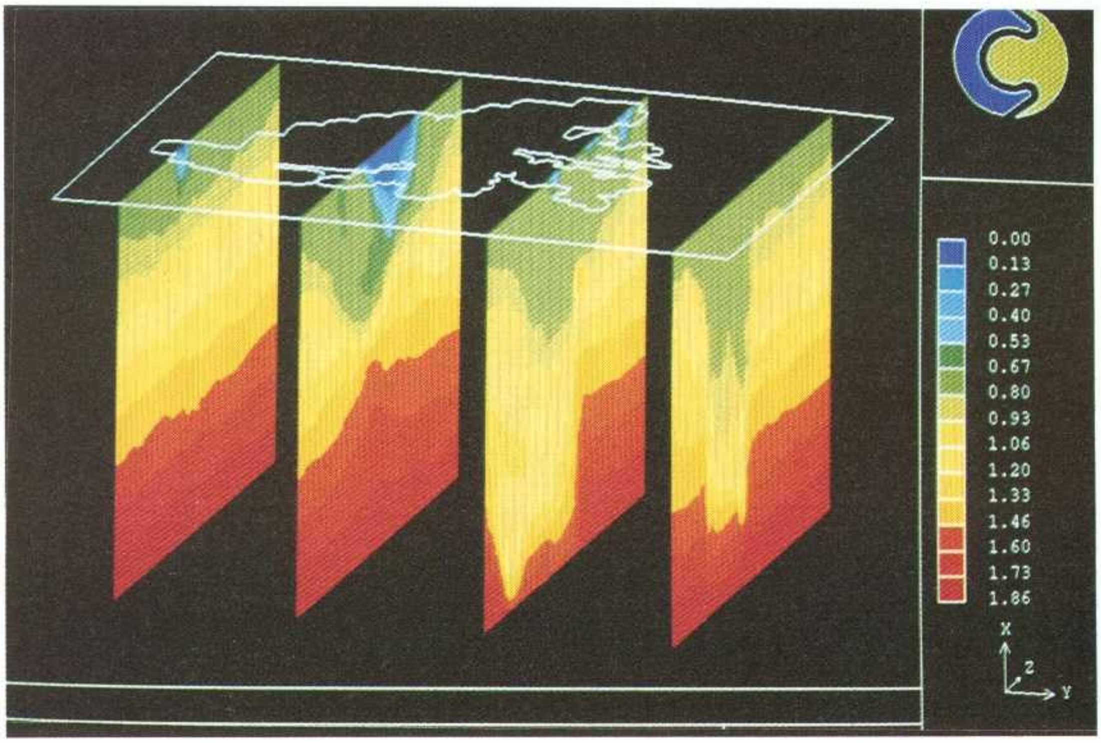
* approximate section for zone according to numerical model

** skin for tunnel, zones excluded

PREDICTION OF TRANSPORT OF SOLUTES SITE SCALE (500 m) 2265 - 3064 m

SALINE INTERFACE:

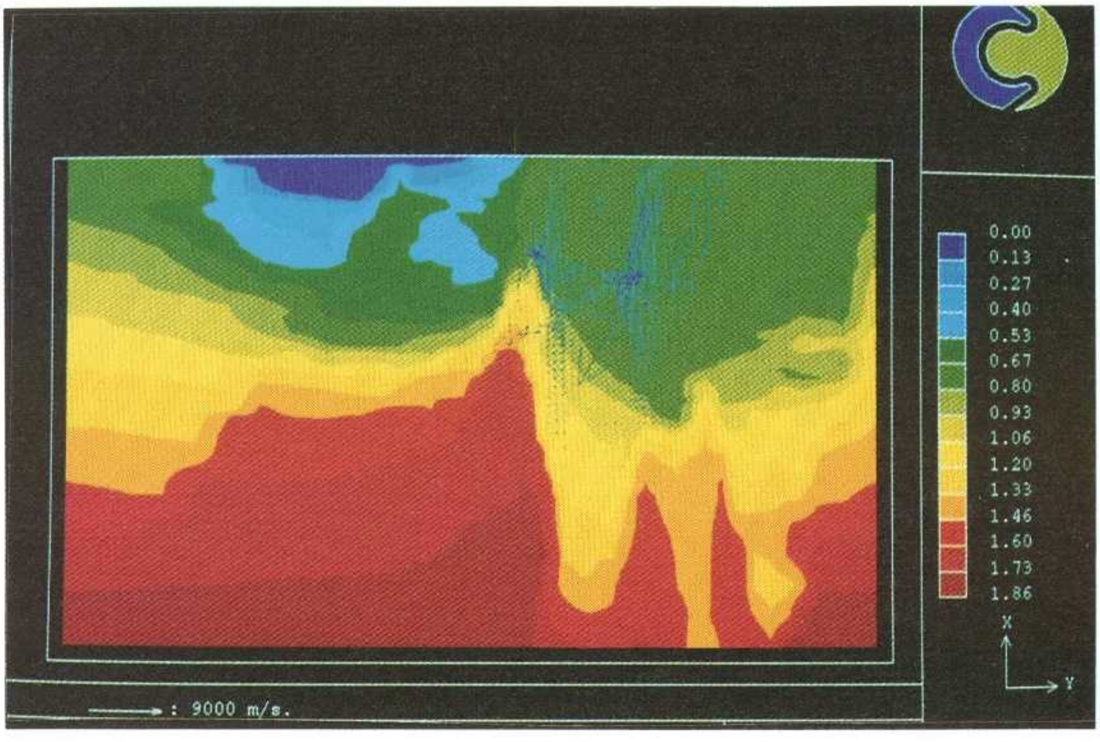
In the pictures below the salinity field and the water fluxes are shown (SKB PR 25-91-03). Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). See prediction of groundwater flow, site scale, pressures and flux distribution for definitions of sections.



Vertical

Scale
1 cm = 250 m

Salinity in %



Section B

Scale:
1 cm = 200 m

Salinity in %

PREDICTIONS OF MECHANICAL STABILITY
SITE SCALE (500 m)
2265 - 3064 m

ROCK QUALITY:

The rock can be classified as Class A, B, C, D or E according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the classes correspond to different values of Rock Mass Rating (RMR).

The Rock Mass Rating is predicated to have the following distribution in this 500 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
20%	50%	20%	10%	-

ROCK STRESS:

Predicted mean values for rock stresses along the tunnel.

Vertical stress σ_v = Depth x 0.0265 [MPa]

Maximum horizontal stress $\sigma_{H,max} = 1.2 - 1.4 \times \sigma_v$ [MPa]
orientation = N30°W ±10°

Minimum horizontal stress $\sigma_{H,min} = 0.6 - 0.8 \times \sigma_v$ [MPa]
orientation = N60°E ±10°

LONG TERM STABILITY:

Potential movements will be concentrated to existing clay filled fracture zones or major weakness zones. Small 3changes in magnitude or orientation of the present horizontal stress field will be sufficient for releasing movements in existing zones.

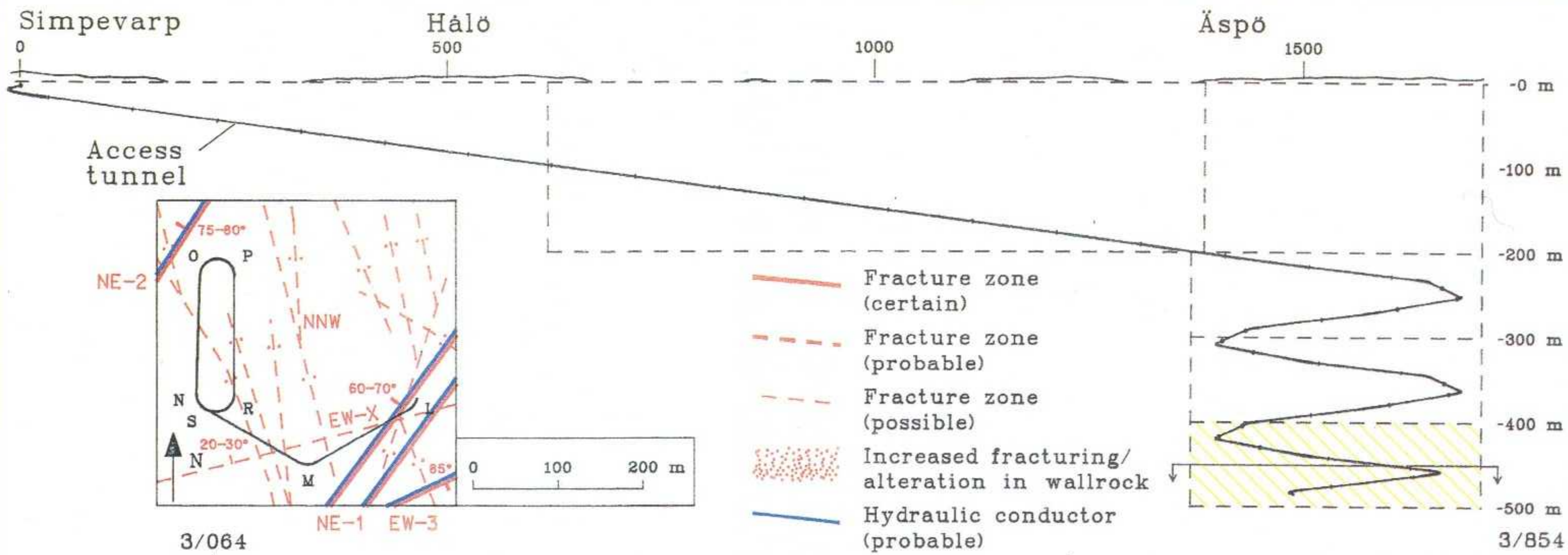
PREDICTIONS IN SITE SCALE SECTIONS 3064 - 3854 m

Äspö Hard Rock Laboratory

90-11-16

Predictions of geological-structural model. Site scale.

Section: 3064 - 3854 m



	3/064 – 3/100	3/100 – 3/200	3/200 – 3/300	3/300 – 3/400	3/400 – 3/500	3/500 – 3/600	3/600 – 3/700	3/700 – 3/800	3/800 – 3/854
	L		M	N		O P		R S	
Major fracture zones									
Example block scale (50m)			←	P 50-08 →			← P 50-09	– P 50-10 →	
Example detailed scale (5m)				□ P 5-02			□ P 5-02	□ P 5-02	
Notes									

PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL SITE SCALE (500 m) 3064 - 3854 m

DISTRIBUTION (%) OF THE MAIN ROCK TYPES:

Småland granite	= 15(±5)60%*
Äspö diorite	= 58(±5)60%
Greenstone	= 9(±2)60%
Fine-grained granite	= 16(±3)60%
Mylonite-hybridized rock	= 2(±1)60%

ROCK BOUNDARIES** (Nos/100 m):

8(±3)60%

MAJOR FRACTURE ZONES:

ZONE	NE-1
Position (centre of zone)	3985(±30 m)60%
Strike	NE
Dip	60°- 70°NW $(\pm 5)_{75\%}$
Extension (m)	>1000
Width (m)	$15(\pm 5)_{60\%}$
RQD for crossings***	
0-25	15%
25-50	20%
50-100	65%

* Estimated level of reliability.

** Veins less than approximately 0,5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

*** Some parts of the zones are probably rather fresh and less fractured.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
3064-3854 m

HYDRAULIC CONDUCTIVITY:

Scale: 20 m

Point estimate, geometric mean K_g $= 2.7 \cdot 10^{-9}$ m/s

95% confidence limits of geometric mean $= 1.3 \cdot 10^{-9} - 5.9 \cdot 10^{-9}$ m/s

Point estimate of sample standard deviation (logK) S_{logK} $= 1.0$

WATER BEARING ZONES:

ZONE	TRANSMISSIVITY (m^2/s)	
	Estimate x 10^{-5}	Possible range x 10^{-5}
NE-1	4	1-10
NNW-1*	1.5	0.5-2

* The position o NNW-1 is uncertain and may consist of several zones. NNW-1 is expected to be found between 3500-3600 m and possibly between 3150-3250.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
3064 - 3854 m

BOUNDARY CONDITIONS:

Upper boundary

Sea - Constant head

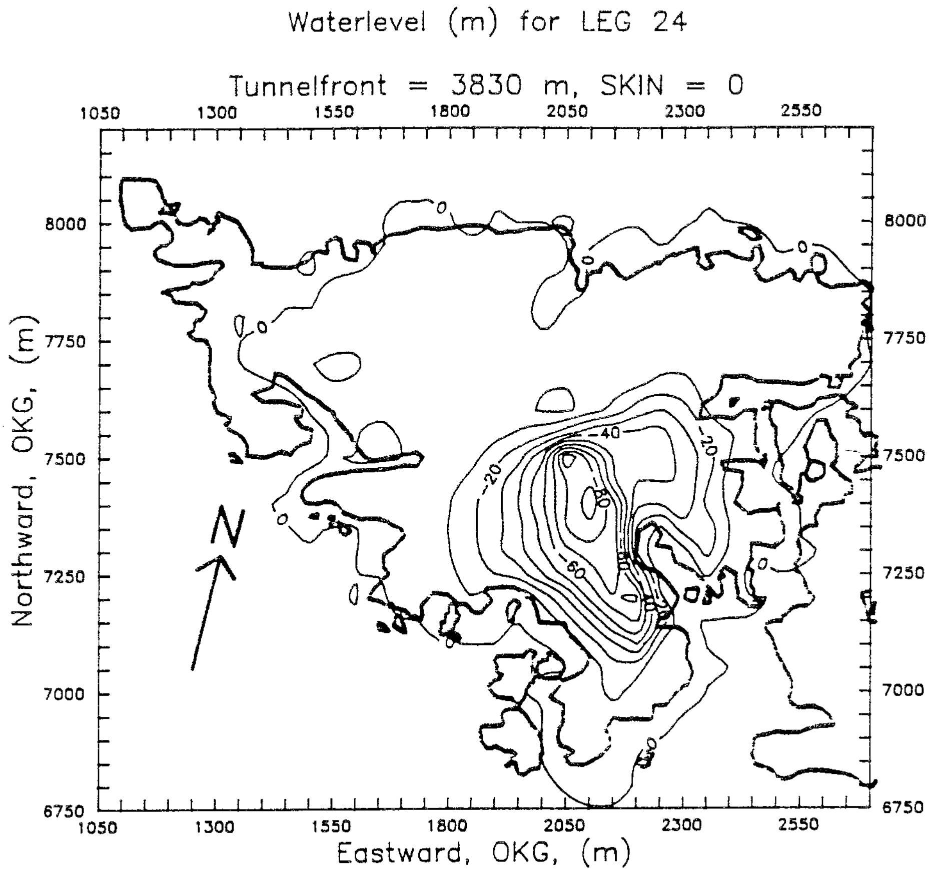
Äspö - Constant infiltration rate 3 mm/year except for a wetland in the centre of Äspö, which has a constant head of +2 m.

Vertical boundaries

Hydrostatic pressure distribution based on a salinity of 0.7% at sea surface and 1.8% at a depth of 1 300 m.

Lower horizontal boundary

Zero flux.



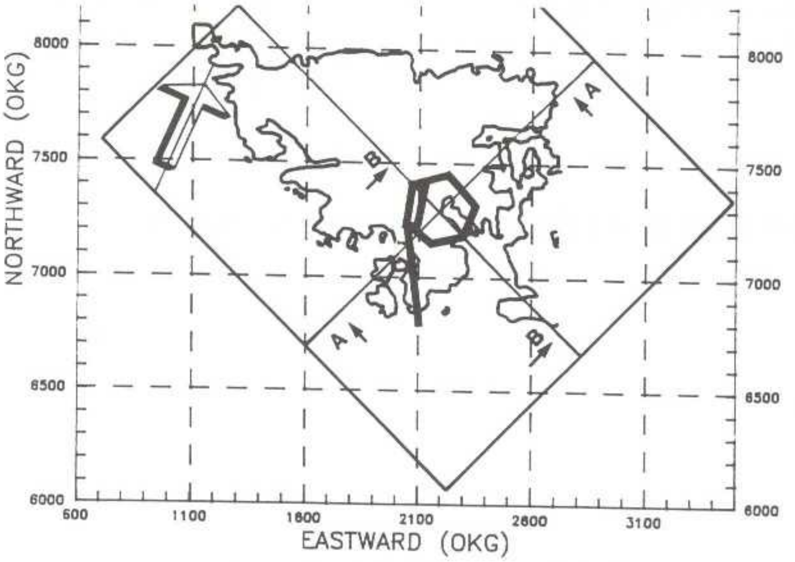
See SKB PR-25-91-03

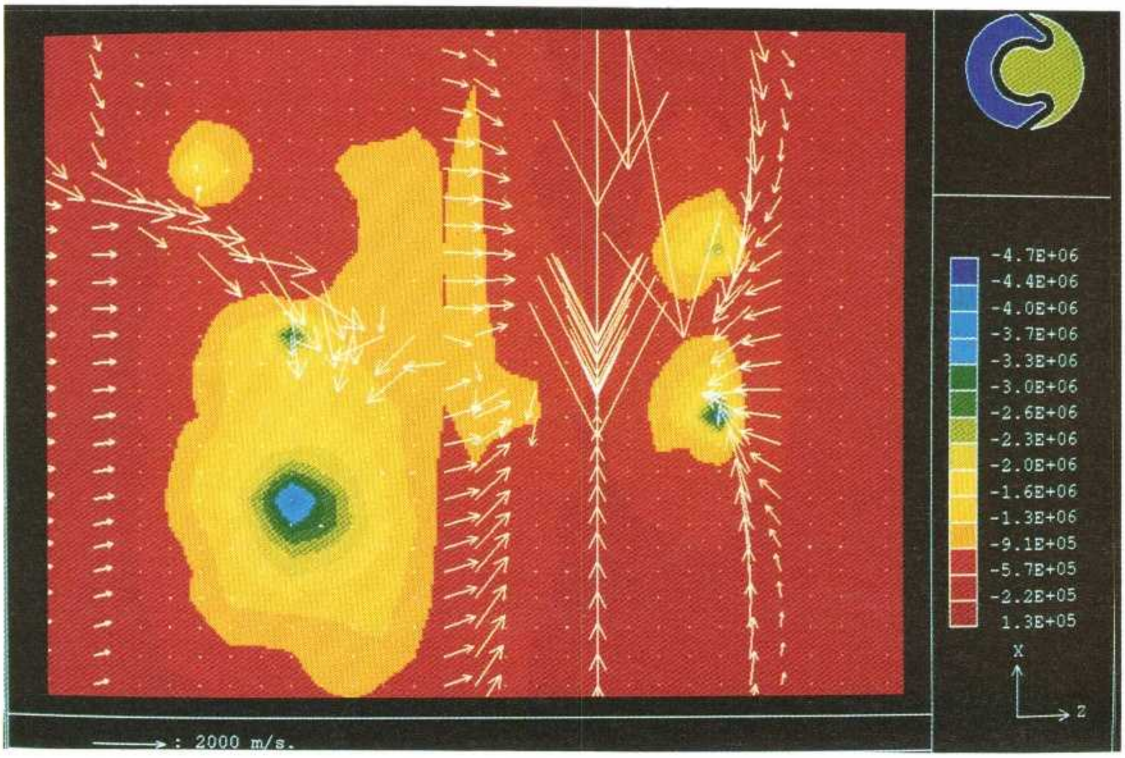
PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
3064 - 3854 m

PRESSURE AND FLUX DISTRIBUTION:

In the pictures below the hydraulic head is shown (density of water = 1 000 kg/m^3)

Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). Vertical sections are shown in the figure below.

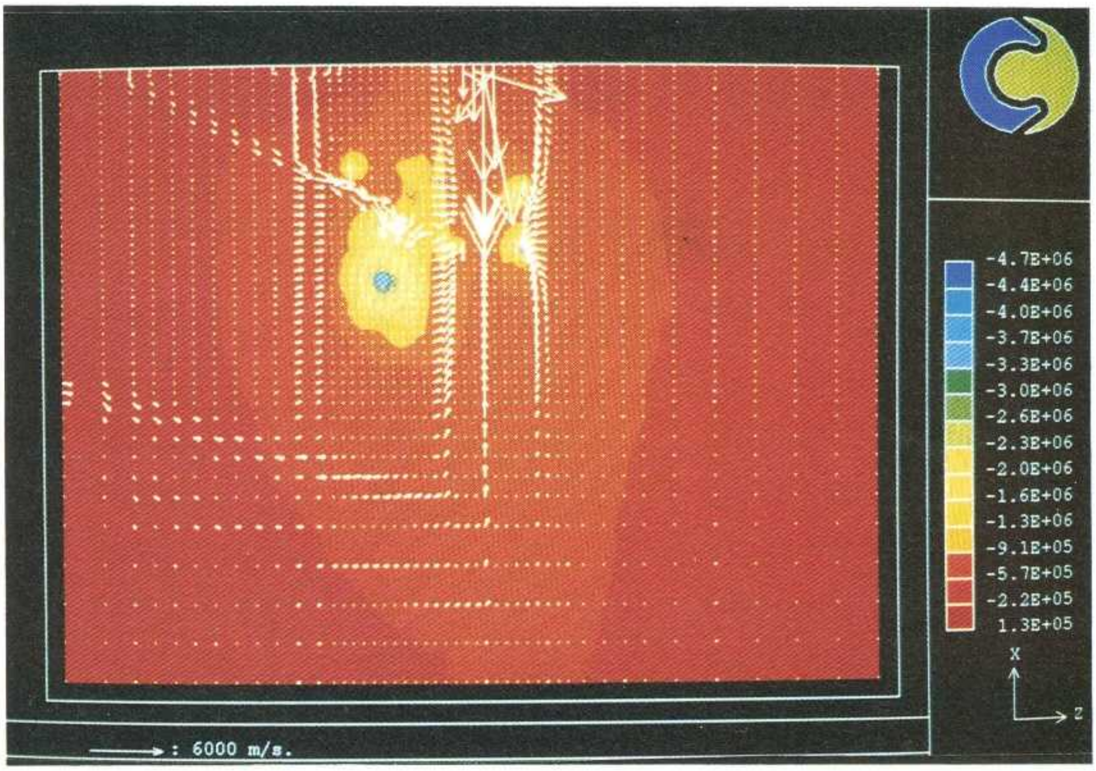




Vertical view of the section A (see above map for orientation). 1 cm in the picture refers to 36 m in the reality. Hydraulic head given in Pa is presented numerically in the legend. Blue-spots are tunnel positions.

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
3064 - 3854 m

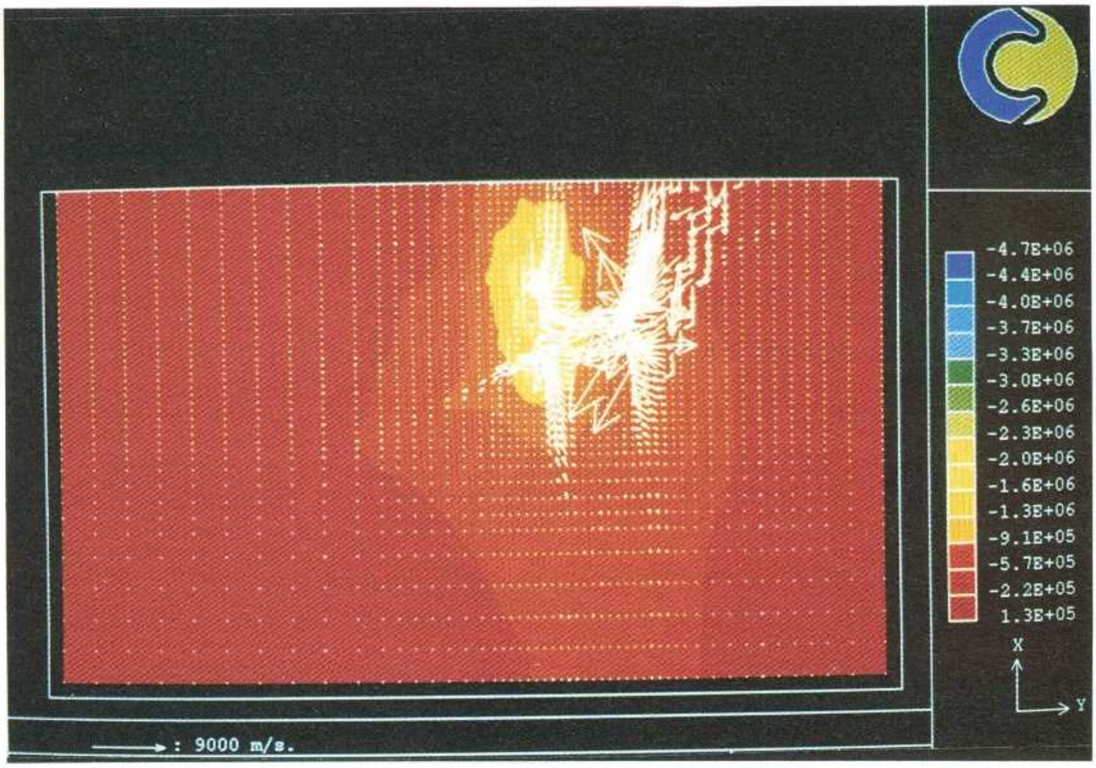
PRESSURE AND FLUX DISTRIBUTION:



Section A

Scale:
1 cm = 160 m

Hydraulic head
in Pa



Section B

Scale:
1 cm = 200 m

Hydraulic head
in Pa

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
3064 - 3854 m

FLOW:

Total cumulative inflow to tunnel section 700-3854 m + shaft: skin*** = 0, $Q_T = 41.0 \cdot 10^{-3}$ m³/s
skin*** = 10, $Q_T = 38.0 \cdot 10^{-3}$ m³/s

INFLOW TO TUNNEL: zones

ZONE	SECTION* (m)	$SKIN_{FX}$** (-)	INFLOW Q_{FX} (m³/s) x 10^{-3}	
			Skin*** = 0	Skin*** = 10
NE-4	900 - 950	120 }		
NE-3	950 - 990	0 }	3.2	3.2
NE-1b	1 170 - 1 200	80	2.3	2.3
NE-1a	1 230 - 1 270	80	2.2	2.3
EW-5	1 380 - 1 440	0	1.6	1.3
EW-3	1 450 - 1 480	0	0.16	0.04
NNW-1	1 770 - 1 800	0	3.2	1.1
NNW-2	1 860 - 1 880	30	3.0	3.0
NNW-4	2 030 - 2 050	30	1.9	1.9
NNW-2	2 190 - 2 210	30,60	2.9	2.9
NNW-1	2 260 - 2 280	30	0.4	0.4
EW-5	2 450 - 2 510	0	2.7	2.8
NNW-1	2 640 - 2 660	30	0.7	0.8
NNW-2	2 720 - 2 750	80	2.0	1.9
NNW-4	2 860 - 2 940	30	2.8	2.8
NNW-2	3 040 - 3 100	80	2.3	2.3
NNW-1	3 140 - 3 160	50	0.4	0.4
NNW-1	3 520 - 3 580	30	1.6	1.6
EW-5 shaft	Z = 350 - 390	20	1.4	1.5

* approximate section for zone according to numerical model
** skin for zones, skin in zone is substantially increased in order to simulate grouting. Q_{FX} maximized to approximatly $3 \cdot 10^{-3}$ m³/s
*** skin for tunnel, zones excluded

PREDICTION OF GROUNDWATER FLOW
SITE SCALE (500 m)
3064 - 3854 m

INFLOW TO TUNNEL AND SALINITY: tunnel legs

LEG NO	SECTION (m)	INFLOW Q_L(m^3/s) x 10^{-3}		SALINITY S_L (‰)	
		Skin* = 0	Skin* = 10	Skin* = 0	Skin* = 10
1	700-850**	4.0	4.0	7.3	7.3
2	850-1000	4.1	4.0	7.1	7.1
3	1000-1150	0.06	0.03	7.0	7.0
4	1150-1300	4.6	4.5	7.0	7.0
5	1300-1450	1.7	1.3	7.0	7.0
6	1450-1600	0.2	0.06	7.0	7.0
7	1600-1755	0.2	0.3	6.9	6.7
8	1755-1900	6.5	4.6	7.0	6.8
9	1900-2050	1.6	1.6	7.0	7.0
10	2050-2195	1.5	1.4	7.0	7.0
11	2195-2345	2.3	2.2	7.0	7.0
12	2345-2495	1.9	1.9	7.1	7.1
13	2495-2640	1.0	1.0	7.4	7.4
14 shaft	z=0-222	0.02	0.01	7.0	6.9
15 shaft	z=222-333	0.02	0.007	7.1	7.0
16	2640-2790	2.7	2.7	9.5	9.5
17	2790-2940	2.9	2.8	8.1	8.2
18	2940-3090	1.2	1.2	7.0	7.0
19	3090-3235	1.6	1.6	7.0	7.0
20	3235-3380	0.06	0.04	7.8	7.8
21	3380-3580	1.5	1.4	11.0	11.0
22 shaft	z=333-444	1.5	1.5	11.0	11.0
23	3580-3854	0.2	0.2	9.4	9.4
24 shaft	z=444-490	0.003	0.002	9.4	9.4

* skin for tunnel, zones excluded

** outside model area, estimated inflow and salinity

PREDICTION OF GROUNDWATER CHEMISTRY
SITE SCALE (500 m)
3064 - 3854 m

ZONES:

CONDUCTIVE ZONES	Na^+ mg/l	K^+ mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Cl^- mg/l	HCO^- mg/l	SO_4^{2-} mg/l	Fe^{tot} mg/l	pH --	Eh mV
NE-1	2000 ±500	8 ±5	2000 ±800	80 ±20	7000 ±2000	14 ±5	320 ±80	0.3 ±0.3	8.0 ±0.5	-340 ±25
NNW	1000 ±500	8 ±5	1000 ±500	50 20	3500 ±1000	120 ±20	160 ±80	0.3 ±0.3	7.6 ±0.2	-290 ±25

PREDICTION OF GROUNDWATER CHEMISTRY SITE SCALE (500 m) 3064 - 3854 m

ZONES: salinity

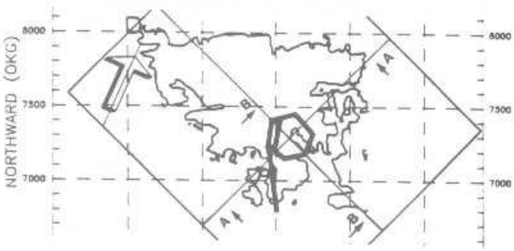
Salinity estimated with a numerical groundwater flow model.

ZONE	SECTION * (m)	S_{FX} (‰) Skin* = 0	Skin* = 10
NE-4	900 - 950 }		
NE-3	950 - 990 }	7.1	7.1
NE-1b	1 170 - 1 200	7.0	7.0
NE-1a	1 230 - 1 270	7.0	7.0
EW-5	1 380 - 1 440	7.0	7.0
EW-3	1 450 - 1 480	7.0	7.0
NNW-1	1 770 - 1 800	7.0	6.4
NNW-2	1 860 - 1 880	7.0	7.0
NNW-4	2 030 - 2 050	7.0	7.0
NNW-2	2 190 - 2 210	7.0	7.0
NNW-1	2 260 - 2 280	7.0	7.0
EW-5	2 450 - 2 510	7.2	7.2
NNW-1	2 640 - 2 660	10.4	9.6
NNW-2	2 720 - 2 750	9.2	9.4
NNW-4	2 860 - 2 940	8.1	8.2
NNW-2	3 040 - 3 100	7.0	7.0
NNW-1	3 140 - 3 100	7.0	7.0
NNW-1	3 520 - 3 580	10.8	10.7
EW-5 shaft	Z = 350 - 390	8.1	8.1

* approximate section for zone according to numerical model

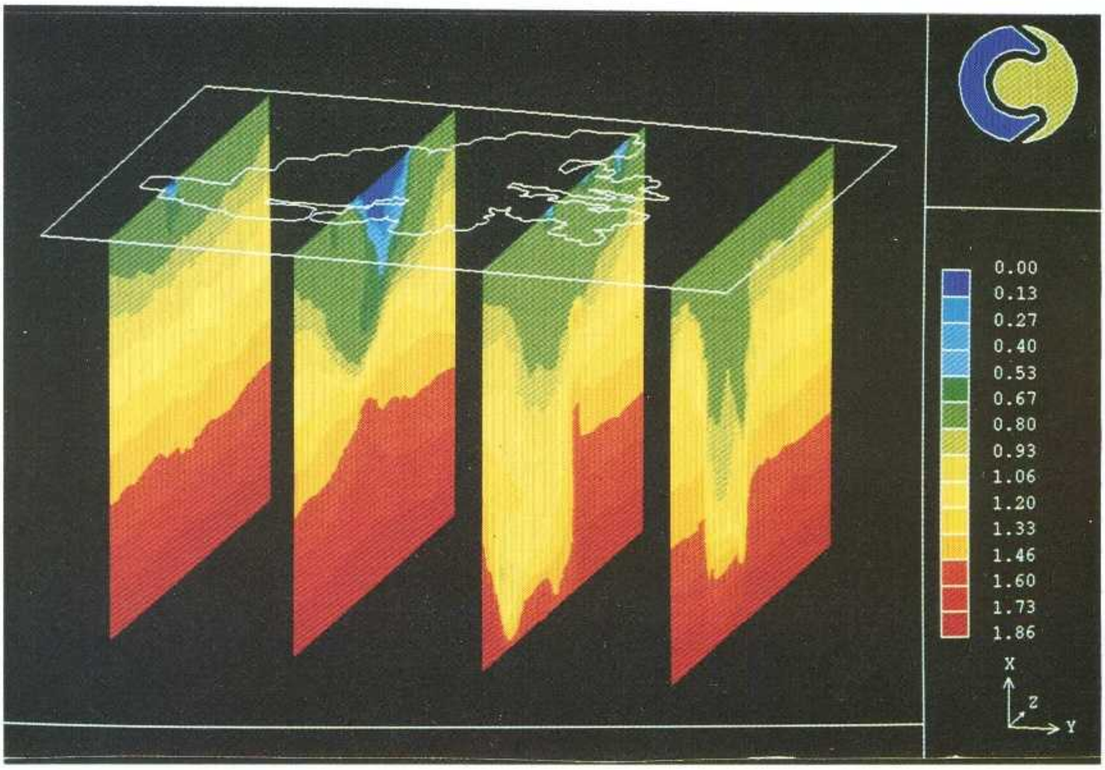
** skin for tunnel, zones excluded

PREDICTION OF TRANSPORT OF SOLUTES
SITE SCALE (500 m)
3064 - 3854 m



SALINE INTERFACE:

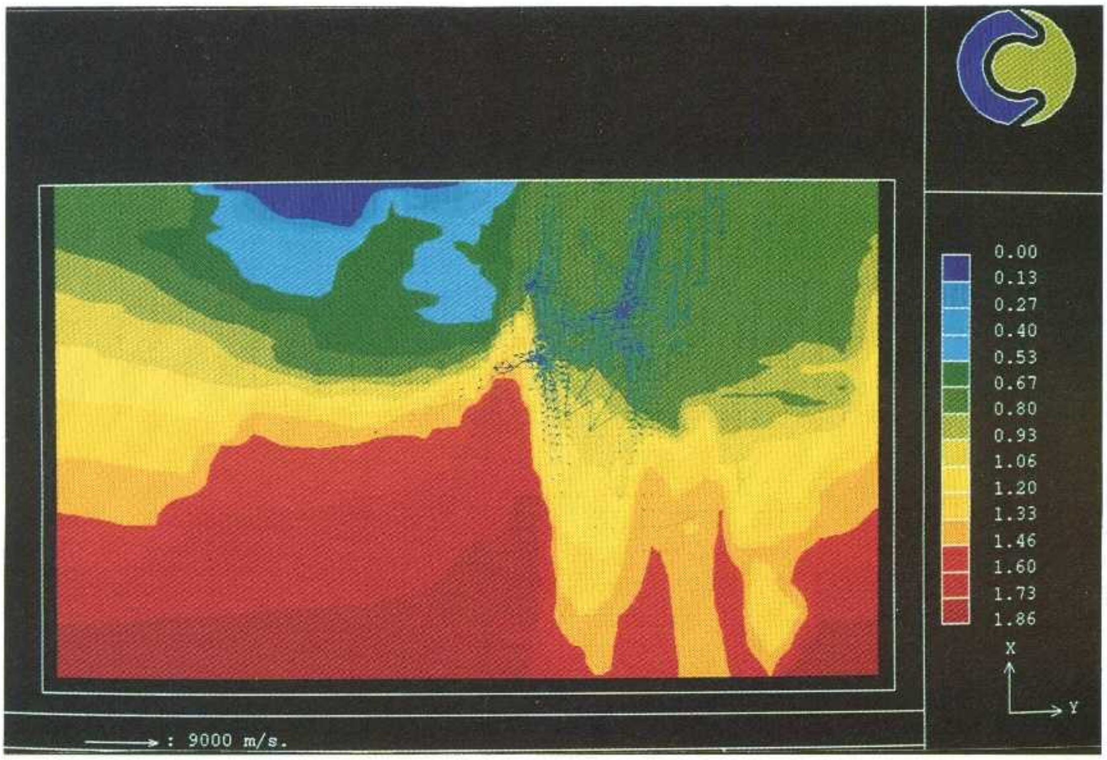
In the pictures below the salinity field and the water fluxes are shown (SKB PR 25-91-03). Flux vector scale shall be multiplied with 10^{-10} to give correct flux (m/s). See prediction of groundwater flow, site scale, pressures and flux distribution for definitions of sections.



Vertical

Scale
1 cm = 250 m

Salinity in %



Section B

Scale:
1 cm = 200 m

Salinity in %

PREDICTIONS OF MECHANICAL STABILITY
SITE SCALE (500 m)
3064 - 3854 m

ROCK QUALITY:

The rock can be classified as Class A, B, C, D or E according to the "Evaluation of Rock Mechanics" (Ref. 25-90-08), where the classes correspond to different values of Rock Mass Rating (RMR).

The Rock Mass Rating is predicated to have the following distribution in this 500 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
50%	30%	10%	10%	-

ROCK STRESS:

Predicted mean values for rock stresses along the tunnel.

Vertical stress σ_v = Depth x 0.0265 [MPa]

Maximum horizontal stress $\sigma_{H, max}$ = 1.7 - 1.9 x σ_v [MPa]
orientation = N40°W ±10°

Minimum horizontal stress $\sigma_{H, min}$ = 0.9 - 1.2 x σ_v [MPa]
orientation = N50°E ±10°

LONG TERM STABILITY:

Potential movements will be concentrated to existing clay filled fracture zones or major weakness zones. Small changes in magnitude or orientation of the present horizontal stress field will be sufficient for releasing movements in existing zones.

APPENDIX B

PREDICTIONS IN BLOCK SCALE (50 m)

Appendix B presents the predictions on block scale. The predicted items for the different key issues are presented on the next few pages, B3- B7.

Predicted blocks

PREDICTIONS OF GEOLOGICAL - STRUCTURAL MODEL BLOCK SCALE (50 m)

SUBJECT	PREDICTIONS	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
For approximately 10 blocks situated on specified tunnel legs				
Classification of zones and contacts within block, see site scale model				
Rock composition	Occurrence and extension of greenstone and finegrained granite in hostrock	%/50 m	%/50 m	Mapping
Rock boundaries	Number of rock boundaries	Nos/50 m	Nos	Mapping
Single open fractures	Occurence and orientation of single open fractures with water flow	Nos/50 m	Nos/50 m	Mapping
Mylonite	Occurence and extension of mylonites	Nos/50 m	Nos/50 m	Mapping
Minor fracture zones (width < 5 m)	Occurence and extension of fracture zones, orientation	Nos/50 m Width distr Strike and dip	Nos/50 m Width Strike and dip	Mapping
Fracture system	(See detailed scale, 5 m)			

PREDICTIONS OF GROUNDWATER FLOW BLOCK SCALE (50 m)

SUBJECT	PREDICTIONS	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Conductive structures	Frequency distribution of conductive structures	Expected distance between structures with trans-missivity greater than T	T-section	Pilot boreholes, pressure build up tests
Flow in conductive structures	Inflow distribution around identified conductive structures into side track drifts (scoping calculations)	q	q Q_w	Inflow mapping and weir flow
Axial flow in disturbed zone	Pressure around conductive structure close to drift Wall (scoping calculations)	p	p	Pressure measurements in pilote and core boreholes
	Axial flow (scoping calculations)	q	t_t travel time entry points	Tracer tests in h-holes

PREDICTIONS OF GROUNDWATER CHEMISTRY BLOCK SCALE (50 m)

(See also site scale)

SUBJECT	PREDICTIONS	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Quality changes	Redox front	-	Analyses of redox sensitive components	Measurement of components of groundwater in boreholes

PREDICTIONS OF TRANSPORT OF SOLUTES BLOCK SCALE (50 m)

(Efforts concentrated to operation period)

PREDICTIONS OF MECHANICAL STABILITY BLOCK SCALE (50 m)

SUBJECT	PREDICTION	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Rock quality	Rock Mass Rating	RMR	RMR	Mapping
Rock stress	In situ stresses - vertical stress	σ_v	σ_v	Stress measurements
	- max horizontal stress	$\sigma_{H,}$ max orientation	$\sigma_{H,}$max orientation	Stress measurements
	- min horizontal stress	$\sigma_{H,}$ min orientation	$\sigma_{H,}$ min orientation	Stress measurements
Stability	Block instability	Mechanism of failure	No. of blocks	Mapping

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 m) GENERAL PREDICTION

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for tunnel 700 - 3854 m. Confidence interval for point estimate given for a confidence level of 95 %.

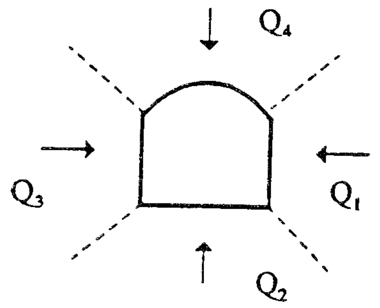
T **(m^2/s)**	**D_g** **(m)**
$> 3 \cdot 10^{-9}$	$3(1.6 - 4.4)_{95\%}$
$> 3 \cdot 10^{-7}$	$6(2.4 - 9.6)_{95\%}$
$> 3 \cdot 10^{-5}$	$55(0 - 350)_{95\%}$

FLOW IN CONDUCTIVE STRUCTURES:

Inflow distribution:

$Q_{FX} = \quad Q_i$

$Q_1/Q_{FX} = 0.25$
$Q_2/Q_{FX} = 0.3$
$Q_3/Q_{FX} = 0.25$
$Q_4/Q_{FX} = 0.2$



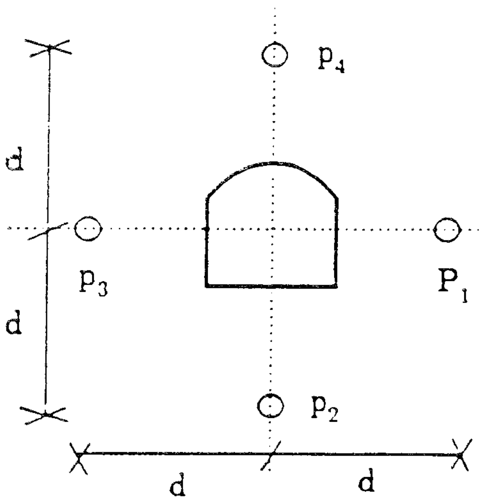
AXIAL FLOW IN DISTRUBED ZONE:

Axial flow:

Axial flow along tunnel close to zone 1 - 100 · 10^{-9} m/s

Pressure around conductive structure: D = 10 m

Zone-grouted	**Pressure (Pa), x 10^4**
No	5 - 50
Yes	50 - 200



PREDICTION OF GROUNDWATER CHEMISTRY
BLOCK SCALE (50 m)
GENERAL PREDICTION

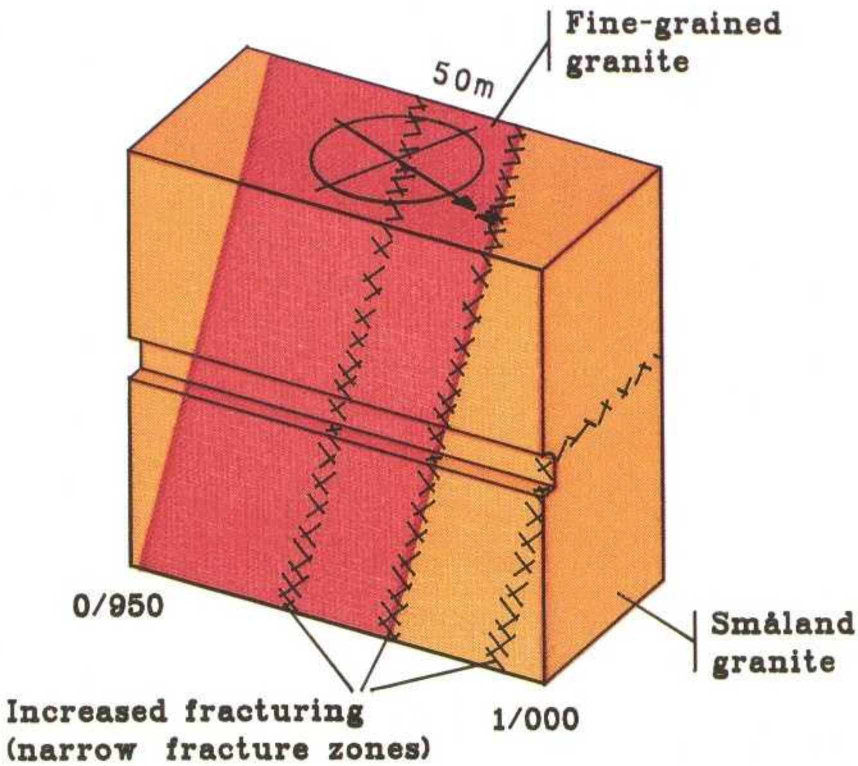
The entrance tunnel will reach Äspö at a depth of approximately 200 m. At that depth no penetration of an oxidizing surface water is expected. However, if oxidizing water enters the tunnel, it will be through the NNW fracture system.

At 500 m position of the entrance tunnel from Simpevarp the oxidation caused by the penetration of oxidising surface water will be studied. At this position the depth of the tunnel is approximately 70 m below the ground surface.

Äspö Hard Rock Laboratory

Geological prediction

50 m scale | P 50-01



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL
BLOCK SCALE (50 m)
P50-01

ROCK COMPOSITION:

Småland granite:	= 15% $(\pm 5)_{60\%}$ *)
Fine-grained granite:	= 80% $(\pm 5)_{60\%}$
Hybridized-mylonitized:	= 5% $(\pm 5)_{60\%}$

ROCK BOUNDARIES: **)

$7(\pm 2)_{75\%}$

SINGLE OPEN FRACTURES: ***)

$2(\pm 1)_{60\%}$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$3(\pm 1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$3(\pm 1)_{60\%}$

FRACTURE SYSTEM:

Orientation**** (main fracture sets based on surface mapping on Hålö and Äspö and KBH02)

1. N 5°E/90° (±10°) 100%
2. N 65°W/70°NE (±10°) 100%
   N 65°W/35°NE (±10°) 100%
3. N 45°E/70°SE (±10°) 100%
4. N 75°E/75°NNW (±10°) 100%
   N 75°E/25°SSE (±10°) 100%

*) Estimated level of certainty

**) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

***) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

****) Dominant peaks of the fracture sets.

PREDICTION OF GROUNDWATER FLOW BLOCK SCALE (50 m) P50-01

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater that T for block P50-01.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$3(0\text{-}35)_{95\%}$
$> 3 \cdot 10^{-7}$	$6(0\text{-}60)_{95\%}$

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50-01, scale 20 m and confidence limits on 95% level:

$K_g = 2 \cdot 10^{-9}(7.0 \cdot 10^{-10} - 4.4 \cdot 10^{-9})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-01

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
5%	35%	40%	10%	10%

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max} = 1.7\text{-}2.0 x \sigma_v$ [MPa] Orientation = N30°W±15°
Minimum horizontal stress	$\sigma_{H,min} = 1.1\text{-}1.5 x \sigma_v$ [MPa] Orientation = N60°E±15°

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-01

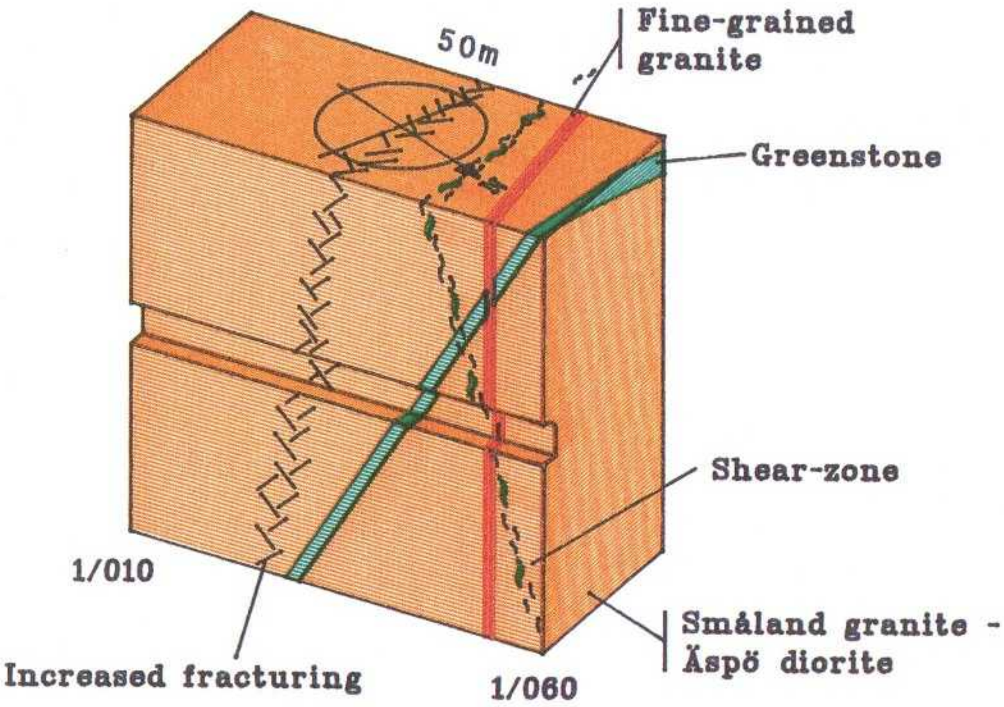
STABILITY:

Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

Geological prediction

50 m scale P 50-02



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL
BLOCK SCALE (50m)
P50-02

ROCK COMPOSITION:

Småland granite:	= 60% $(\pm 10)_{60\%}$
Äspö diorite:	= 30% $(\pm 10)_{60\%}$
Greenstone:	= 5% $(\pm 2)_{60\%}$
Fine-grained granite:	= 5% $(\pm 2)_{60\%}$

ROCK BOUNDARIES: *)

$4(\pm 2)_{75\%}$

SINGLE OPEN FRACTURES: **)

$2(\pm 1)_{60\%}$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$3(\pm 1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$1(\pm 1)_{60\%}$

FRACTURE SYSTEM:

<u>Orientation*** (main fracture sets based on surface mapping on Hålö and Äspö and KBH02)</u>

1. N 5°E/90° (±10°) 100%
2. N 65°W/70°NE (±10°) 100%
   N 65°W/35°NE (±10°) 100%
3. N 45°E/70°SE (±10°) 100%
4. N 75°E/75°NNW (±10°) 100%
   N 75°E/25°SSE (±10°) 100%

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

***) Dominant peaks of the fracture sets.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 m) P50-02

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 - 02.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$3(0\text{-}35)_{95\%}$
$> 3 \cdot 10^{-7}$	6(not available)

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50-02.
scale 20 m:

$K_g = 2 \cdot 10^{-9}\ (9.2 \cdot 10^{-10} - 5.6 \cdot 10^{-9})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-02

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
25%	35%	20%	20%	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max} = 1.7\text{-}2.0 x \sigma_v$ [MPa] Orientation = N30°W±15°
Minimum horizontal stress	$\sigma_{H,min} = 1.1\text{-}1.5 x \sigma_v$ [MPa] Orientation = N60°E±15°

PREDICTION OF MECHANICAL STABILITY
BLOCK SCALE (50 m)
P50-02

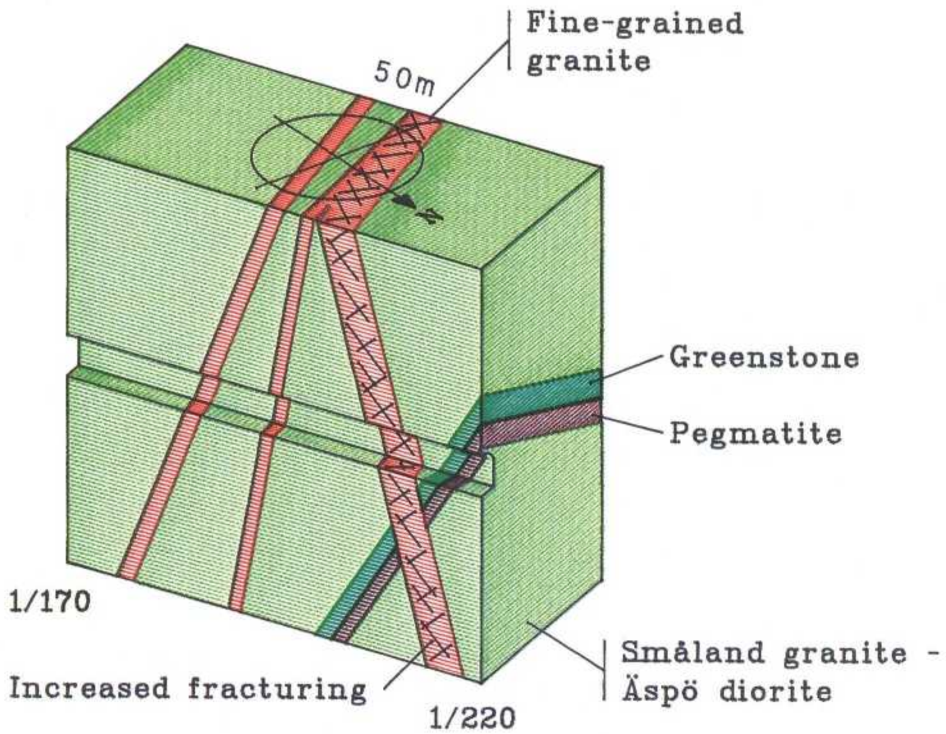
STABILITY:

Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak >30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak >30 cm if normal dillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

Geological prediction

50 m scale | P 50-03



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL BLOCK SCALE (50 m) P50-03

ROCK COMPOSITION:

Småland granite:	= 20% $(\pm 10)_{60\%}$
Äspö diorite:	= 60% $(\pm 10)_{60\%}$
Greenstone:	= 15% $(\pm 2)_{60\%}$
Fine-grained granite:	= 5% $(\pm 2)_{60\%}$

ROCK BOUNDARIES:*)

$8(\pm 2)_{75\%}$

SINGLE OPEN FRACTURES:**)

$3(\pm 1)_{60\%}$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$2(\pm 1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$2(\pm 1)_{60\%}$

FRACTURE SYSTEM:

Orientation***) (main fracture sets based on surface mapping on Hålö and Äspö and KBH02)

1. N 5°E/90° (±10°) 100%
2. N 65°W/70°NE (±10°) 100%
   N 65°W/35°NE (±10°) 100%
3. N 45°E/70°SE (±10°) 100%
4. N 75°E/75°NNW (±10°) 100%
   N 75°E/25°SSE (±10°) 100%

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

***) Dominant peaks of the fracture sets.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 m) P50-03

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 -03.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$3(0\text{-}35)_{95\%}$
$> 3 \cdot 10^{-7}$	6(not available)

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50-03.
scale 20 m:

$K_g = 2 \cdot 10^{-9}\ (1.1 \cdot 10^{-9} - 3.7 \cdot 10^{-9})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-03

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
30%	40%	20%	10%	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max}$ = 1.7-2.0xσ_v [MPa] Orientation = N30°W±15°
Minimum horizontal stress	$\sigma_{H,min}$ = 1.1-1.5xσ_v [MPa] Orientation = N60°E±15°

PREDICTION OF MECHANICAL STABILITY
BLOCK SCALE (50 m)
P50-03

STABILITY:

Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

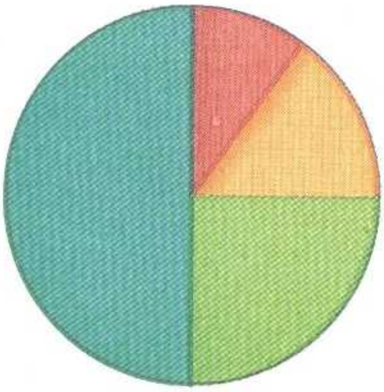
Äspö Hard Rock Laboratory

Geological prediction

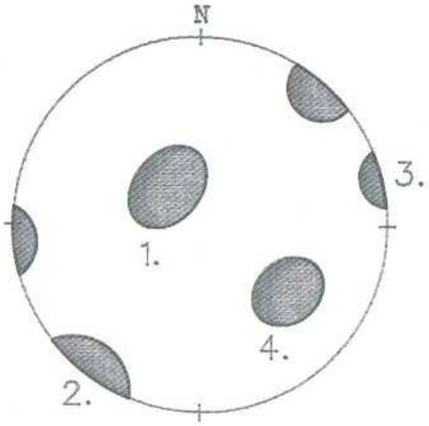
50 m scale

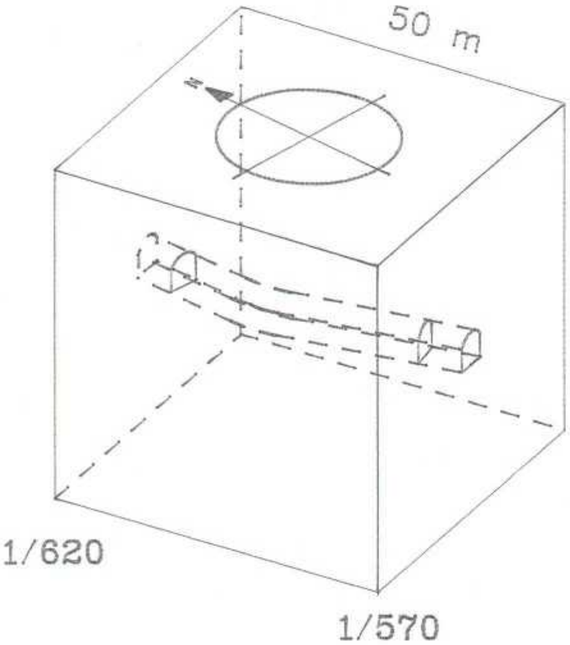
P 50-04

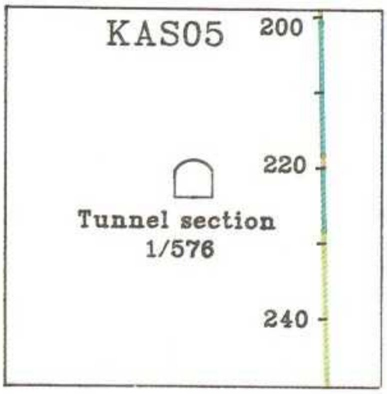
Rock distribution

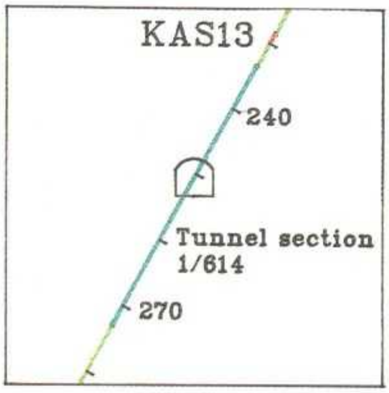


Main fracture set orientation

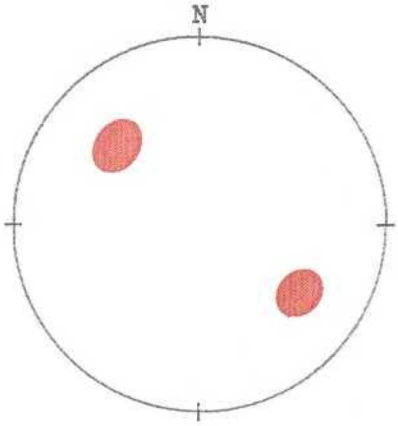




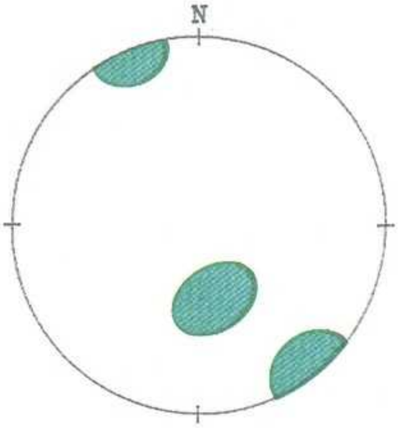




Fine-grained granite
Main orientation
of lenses and dykes



Main orientation
of greenstone dykes
and minor shear-zones



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL BLOCK SCALE (50 m) P50-04

ROCK COMPOSITION:

Småland granite:	= 15% $(\pm 5)_{60\%}$
Äspö diorite:	= 25% $(\pm 5)_{60\%}$
Greenstone:	= 50% $(\pm 10)_{60\%}$ (diorite-gabbro and fine-grained greenstone partly hybridized)
Fine-grained granite:	= 10% $(\pm 3)_{60\%}$

ROCK BOUNDARIES:*)

$6(\pm 1)_{60\%}$

SINGLE OPEN FRACTURES:)**

$2(\pm 1)_{60\%}$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$5(\pm 1)_{60\%}$

MINOR FRACTURE ZONES (width < 5 m):

3(±1)60%

FRACTURE SYSTEM:

<u>Dominating fracture infilling</u>

Chlorite	+++
Calcite	++
Epidote	+ (sealed)
Fe-oxyhydroxide (hematite)	++
Clay minerals	+

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 m) P50-04

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 - 04.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$16(0\text{-}35)_{95\%}$
$> 3 \cdot 10^{-7}$	$24(0\text{-}130)_{95\%}$

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50 - 04 scale 20 m:

$K_g = 4 \cdot 10^{-9}\ (2.0 \cdot 10^{-9} - 7.0 \cdot 10^{-9})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-04

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
-	20%	50%	20%	10%

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max}$ = 1.5-1.9xσ_v [MPa] Orientation = N25°W±15°
Minimum horizontal stress	$\sigma_{H,min}$ = 0.7-1.0xσ_v [MPa] Orientation = N65°E±15°

PREDICTION OF MECHANICAL STABILITY
BLOCK SCALE (50 m)
P50-04

STABILITY:

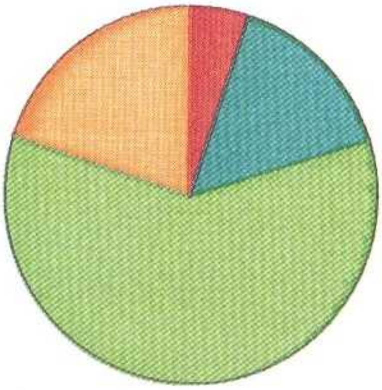
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

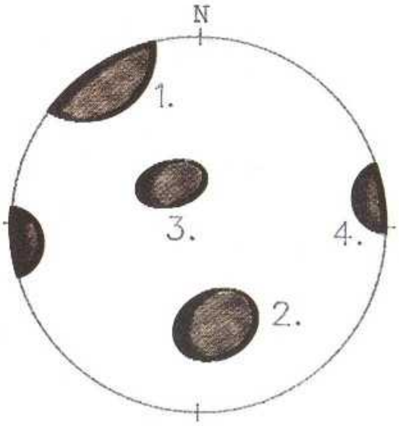
Geological prediction

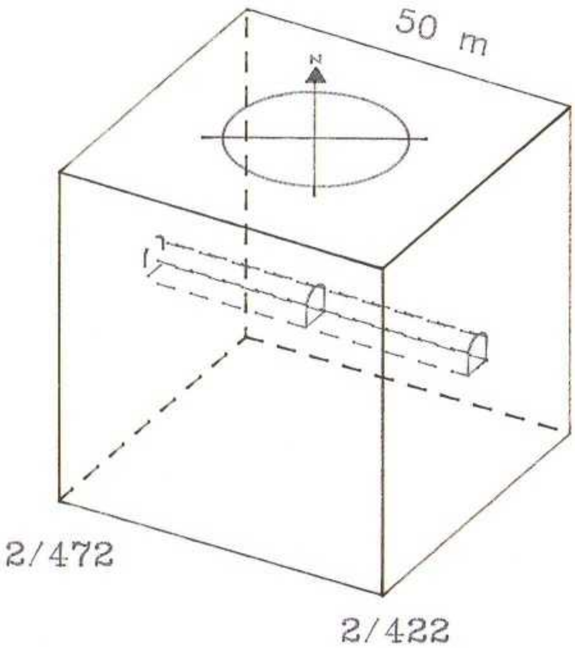
50 m scale | P 50-05

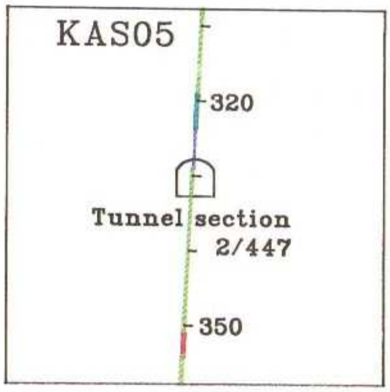
Rock distribution



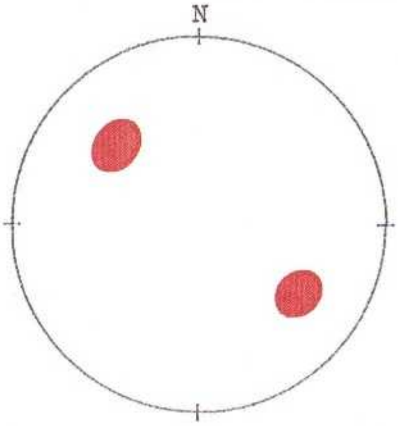
Main fracture set orientation



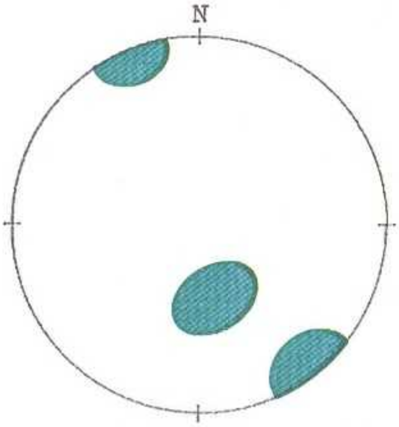




Fine-grained granite
Main orientation
of lenses and dykes



Main orientation
of greenstone dykes
and minor shear-zones



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL
BLOCK SCALE (50 m)
P50-05

ROCK COMPOSITION:

Småland granite:	= 20% $(\pm5)_{60\%}$
Äspö diorite:	= 60% $(\pm5)_{60\%}$
Greenstone:	= 15% $(\pm3)_{60\%}$ (fine-grained hybridized and coarse-grained diorite-gabbro with feldspar phenocrysts)
Fine-grained granite:	= 5% $(\pm1)_{60\%}$

ROCK BOUNDARIES:*)

$8(\pm2)_{60\%}$

SINGLE OPEN FRACTURES:**)

$2(\pm1)_{60}\%$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$3(\pm1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$3(\pm1)_{60\%}$

FRACTURE SYSTEM:

Dominating fracture infilling

Chlorite	+++
Calcite	++
Epidote	+ (sealed)
Fe-oxyhydroxide (hematite)	+
Clay minerals	+

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 M) P50-05

CONDUCTIVE STRUCTURES:

Point estimate of the geometric distance D_g between structures with a transmissivity greater than T for block P50 - 05.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$5(0\text{-}15)_{95\%}$
$> 3 \cdot 10^{-7}$	$7(0\text{-}15)_{95\%}$

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50 - 05 scale 20 m:

$K_g = 7 \cdot 10^{-9}\ (3.8 \cdot 10^{-9} - 1.3 \cdot 10^{-8})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-05

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
20%	50%	20%	10%	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max}$ = 1.2-1.7xσ_v [MPa] Orientation = N35°W±15°
Minimum horizontal stress	$\sigma_{H,min}$ = 0.5-0.8xσ_v [MPa] Orientation = N55°E±15°

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-01

STABILITY:

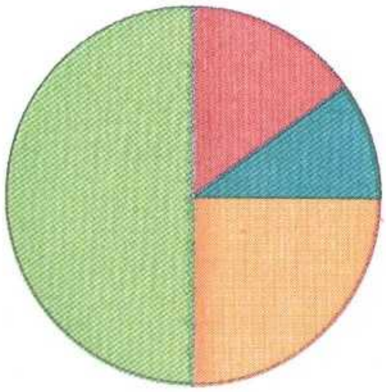
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

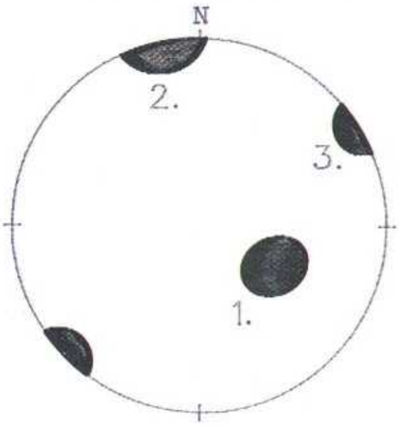
Geological prediction

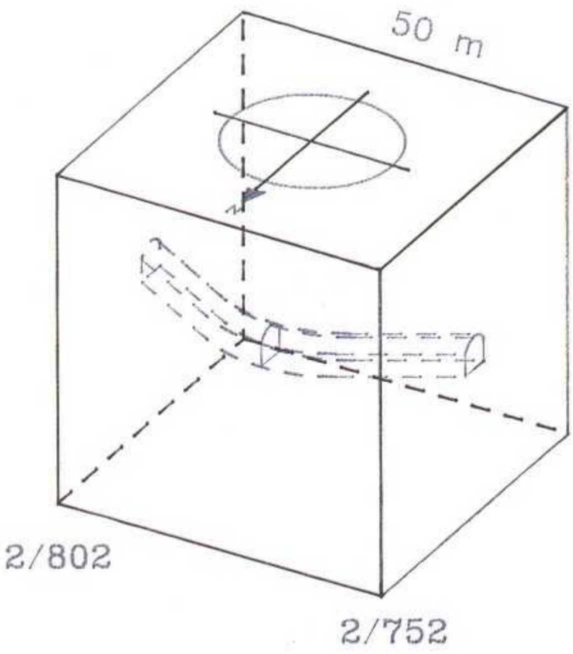
50 m scale   P 50-06

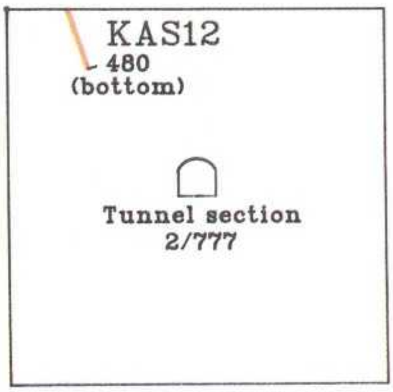
Rock distribution



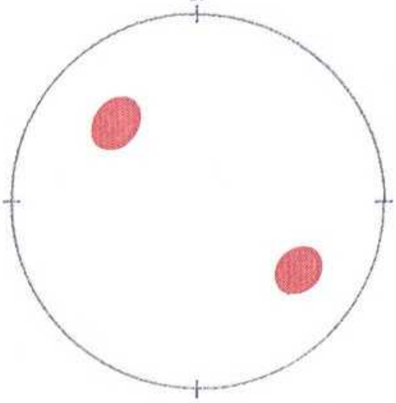
Main fracture set orientation



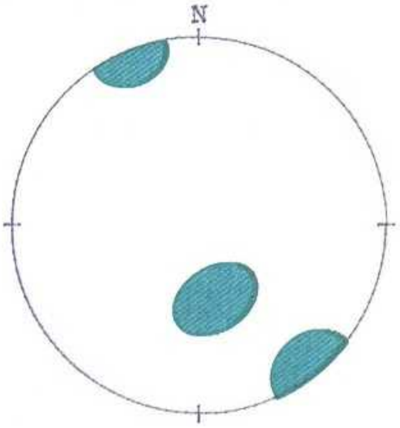




Fine-grained granite
Main orientation
of lenses and dykes



Main orientation
of greenstone dykes
and minor shear-zones



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL BLOCK SCALE (50 m) P50-06

ROCK COMPOSITION:

Småland granite:	= 25% $(\pm 10)_{60\%}$
Äspö diorite:	= 50% $(\pm 10)_{60\%}$
Greenstone:	= 10% $(\pm 3)_{60\%}$
Fine-grained granite:	= 15% $(\pm 3)_{60\%}$

ROCK BOUNDARIES:*)

$6(\pm 2)_{60\%}$

SINGLE OPEN FRACTURES:)**

$3(\pm 1)_{60}\%$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$3(\pm 1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$3(\pm 1)_{60\%}$

FRACTURE SYSTEM:

Dominating fracture infilling

Chlorite	+++
Calcite	++
Epidote	++
Fe-oxyhydroxide (hematite)	+
Clay minerals	+

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 m) P50-06

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 - 06.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$7(0\text{-}20)_{95\%}$
$> 3 \cdot 10^{-7}$	$18(0\text{-}435)_{95\%}$

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50 - 06 scale 20 m:

$K_g = 3 \cdot 10^{-9}\ (1.5 \cdot 10^{-9} - 5.0 \cdot 10^{-9})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-06

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
30%	40%	20%	10%	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max} = 1.2\text{-}1.7 x \sigma_v$ [MPa] Orientation = N35°W±15°
Minimum horizontal stress	$\sigma_{H,min} = 0.5\text{-}0.8 x \sigma_v$ [MPa] Orientation = N55°E±15°

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-06

STABILITY:

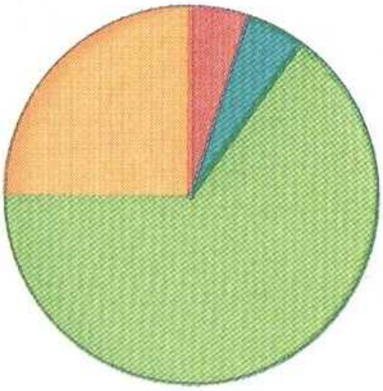
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

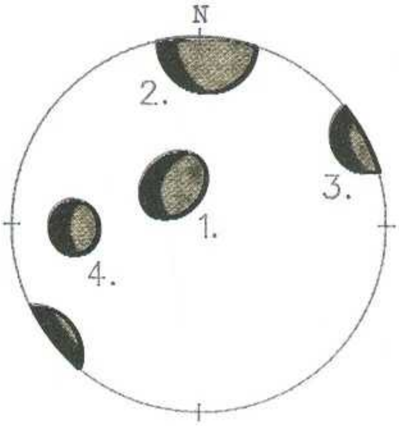
Geological prediction

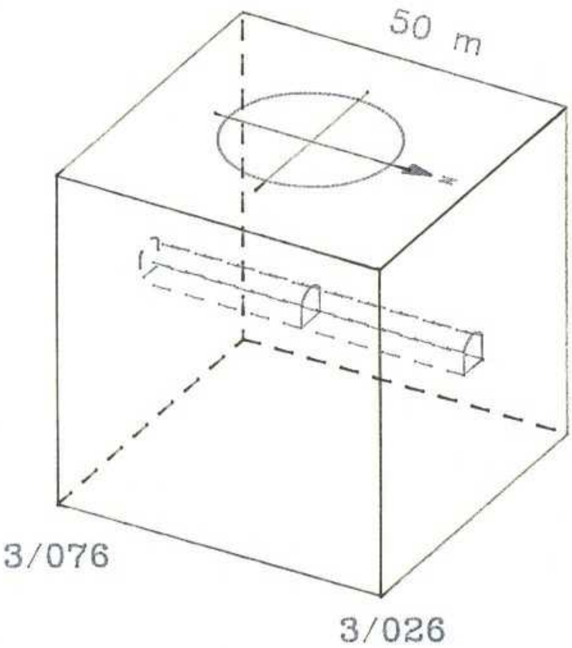
50 m scale — P 50-07

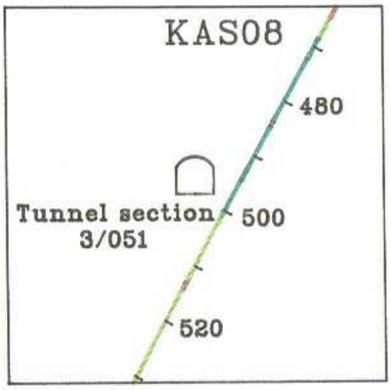
Rock distribution



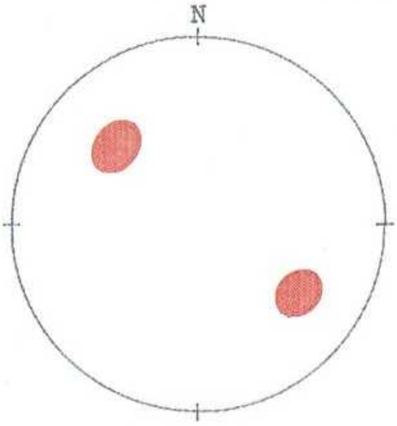
Main fracture set orientation



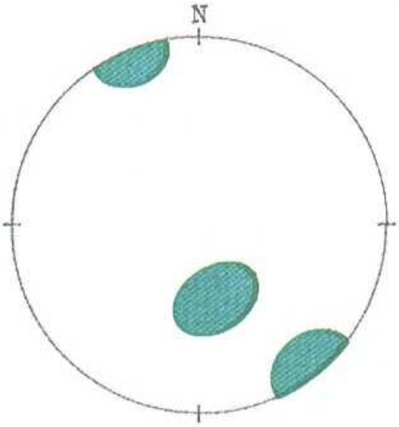




Fine-grained granite
Main orientation
of lenses and dykes



Main orientation
of greenstone dykes
and minor shear-zones



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL BLOCK SCALE (50 m) P50-07

ROCK COMPOSITION:

Småland granite:	= 25% $(\pm 5)_{60\%}$
Äspö diorite:	= 65% $(\pm 5)_{60\%}$
Greenstone:	= 5% $(\pm 1)_{60\%}$
Fine-grained granite:	= 5% $(\pm 1)_{60\%}$

ROCK BOUNDARIES:*)

$8(\pm 2)_{60\%}$

SINGLE OPEN FRACTURES:**)

$2(\pm 1)_{60}\%$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$4(\pm 1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$3(\pm 1)_{60\%}$

FRACTURE SYSTEM:

Dominating fracture infilling

Chlorite	+++
Calcite	++
Epidote	+
Fe-oxyhydroxide (hematite)	+
Clay minerals	+

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 m) P50-07

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 - 07.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$10(0\text{-}20)_{95\%}$
$> 3 \cdot 10^{-7}$	$30(0\text{-}435)_{95\%}$

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50 - 07 scale 20 m:

$K_g = 1 \cdot 10^{-9}\ (8.1 \cdot 10^{-10} - 2.7 \cdot 10^{-9})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY
BLOCK SCALE (50 m)
P50-07

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
40%	40%	10%	10%	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max}$ = 1.2-1.7xσ_v [MPa] Orientation = N35°W±15°
Minimum horizontal stress	$\sigma_{H,min}$ = 0.5-0.8xσ_v [MPa] Orientation = N55°E±15°

PREDICTION OF MECHANICAL STABILITY
BLOCK SCALE (50 m)
P50-07

STABILITY:

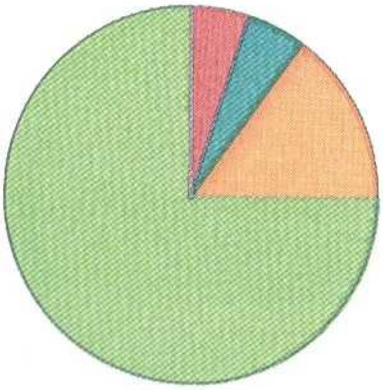
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

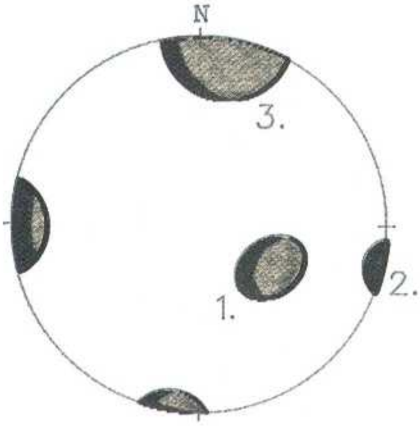
Geological prediction

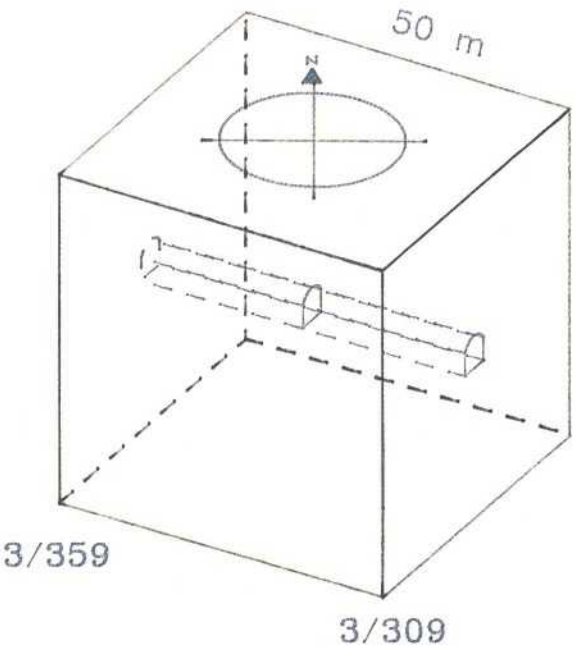
50 m scale — P 50-08

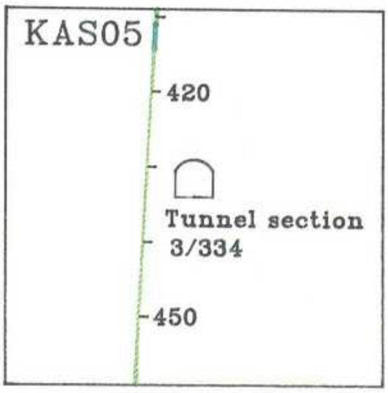
Rock distribution



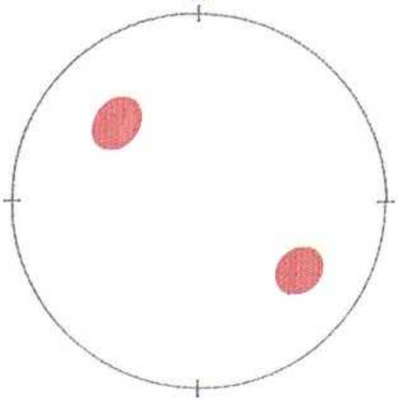
Main fracture set orientation



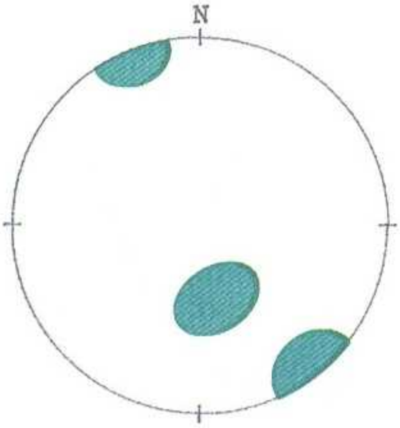




Fine-grained granite
Main orientation
of lenses and dykes



Main orientation
of greenstone dykes
and minor shear-zones



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL BLOCK SCALE (50 m) P50-08

ROCK COMPOSITION:

Småland granite:	= 15% $(\pm 10)_{60\%}$
Äspö diorite:	= 75% $(\pm 10)_{60\%}$
Greenstone:	= 5% $(\pm 2)_{60\%}$
Fine-grained granite:	= 5% $(\pm 1)_{60\%}$

ROCK BOUNDARIES:*)

$5(\pm 1)_{60\%}$

SINGLE OPEN FRACTURES:)**

$2(\pm 1)_{60}\%$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$2(\pm 1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$2(\pm 1)_{60\%}$

FRACTURE SYSTEM:

Dominating fracture infilling

Chlorite	+++
Calcite	++
Epidote	+
Fe-oxyhydroxide (hematite)	+
Clay minerals	+

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 M) P50-08

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 - 08.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$8(0\text{-}20)_{95\%}$
$> 3 \cdot 10^{-7}$	$8(0\text{-}20)_{95\%}$

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50 - 08 scale 20 m:

$K_g = 3 \cdot 10^{-9}\ (1.5 \cdot 10^{-9} - 6.6 \cdot 10^{-9})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-08

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
40%	60%	-	-	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max} = 1.6\text{-}2.0 x \sigma_v$ [MPa] Orientation = N40°W±15°
Minimum horizontal stress	$\sigma_{H,min} = 0.8\text{-}1.2 x \sigma_v$ [MPa] Orientation = N50°E±15°

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-08

STABILITY:

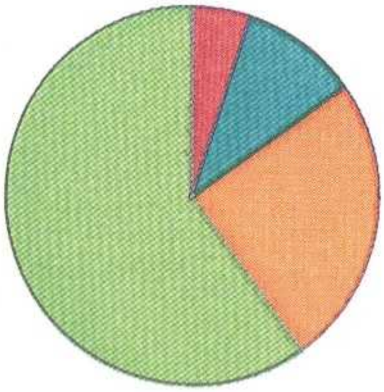
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

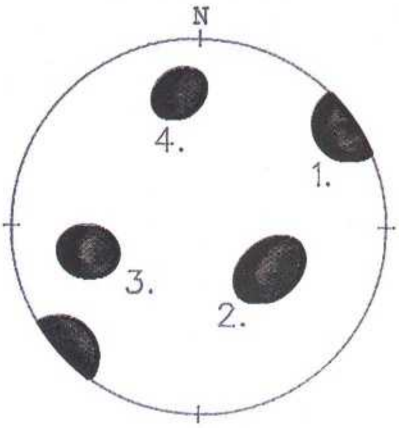
Geological prediction

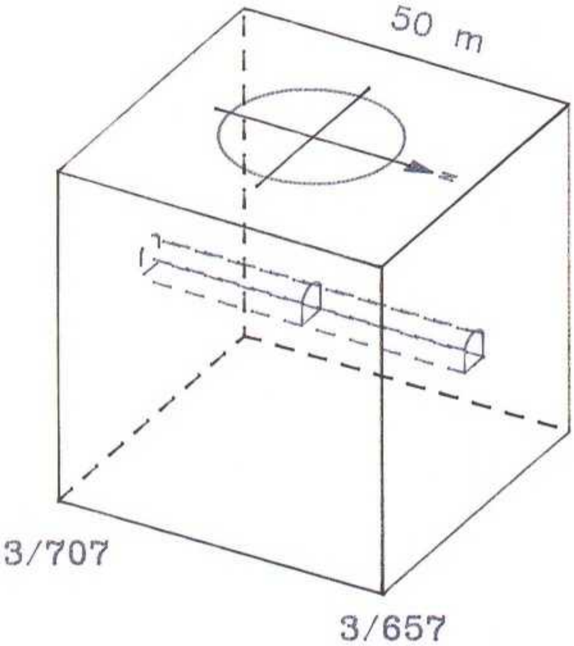
50 m scale | P 50-09

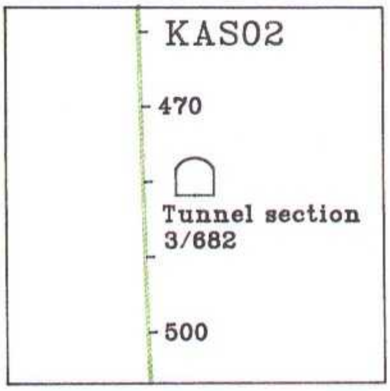
Rock distribution



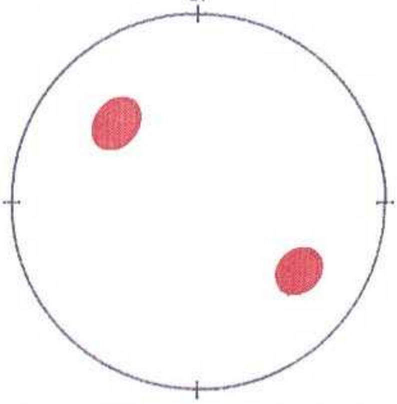
Main fracture set orientation



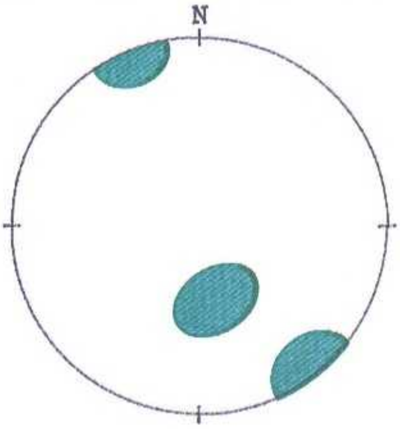




Fine-grained granite Main orientation of lenses and dykes



Main orientation of greenstone dykes and minor shear-zones



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL BLOCK SCALE (50 m) P50-09

ROCK COMPOSITION:

Småland granite:	= 25% $(\pm10)_{60\%}$
Äspö diorite:	= 60% $(\pm10)_{60\%}$
Greenstone:	= 10% $(\pm3)_{60\%}$
Fine-grained granite:	= 5% $(\pm1)_{60\%}$

ROCK BOUNDARIES:*)

$4(\pm1)_{60\%}$

SINGLE OPEN FRACTURES:)**

$2(\pm1)_{60}\%$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$8(\pm1)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$3(\pm1)_{60\%}$

FRACTURE SYSTEM:

Dominating fracture infilling

Chlorite	+++
Calcite	++
Epidote	+
Fe-oxyhydroxide (hematite)	+
Clay minerals	+

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 M) P50-09

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 - 09.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	25(not available)
$> 3 \cdot 10^{-7}$	25(not available)

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50-09 scale 20 m:

$K_g = 1.3 \cdot 10^{-8}\ (5.4 \cdot 10^{-9} - 3.1 \cdot 10^{-8})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-09

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
30%	50%	10%	10%	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max} = 1.6\text{-}2.0x\sigma_v$ [MPa] Orientation = N40°W±15°
Minimum horizontal stress	$\sigma_{H,min} = 0.8\text{-}1.2x\sigma_v$ [MPa] Orientation = N50°E±15°

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-09

STABILITY:

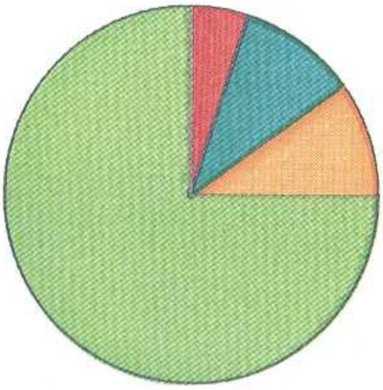
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

Äspö Hard Rock Laboratory

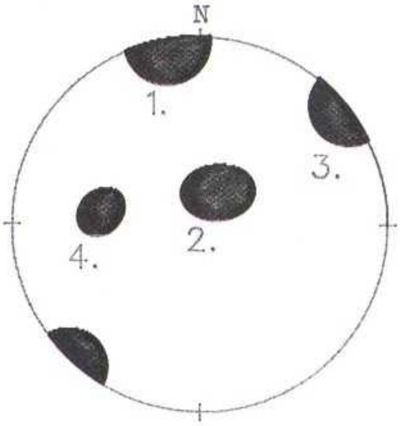
Geological prediction

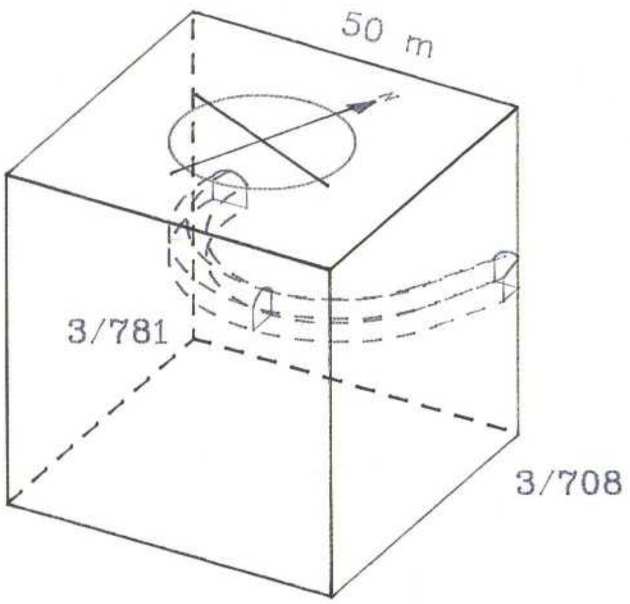
50 m scale | P 50-10

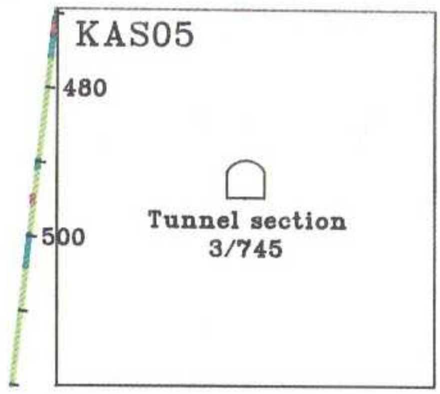
Rock distribution



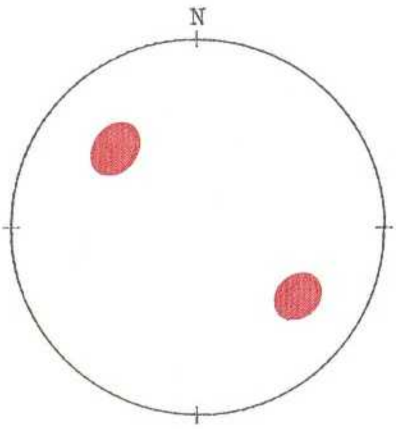
Main fracture set orientation



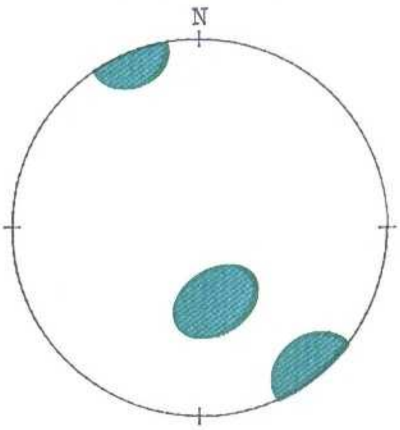




Fine-grained granite
Main orientation
of lenses and dykes



Main orientation
of greenstone dykes
and minor shear-zones



PREDICTION OF GEOLOGICAL-STRUCTURAL MODEL
BLOCK SCALE (50 m)
P50-10

ROCK COMPOSITION:

Småland granite:	= 10% $(\pm 3)_{60\%}$
Äspö diorite:	= 75% $(\pm 5)_{60\%}$
Greenstone:	= 10% $(\pm 3)_{60\%}$
Fine-grained granite:	= 5% $(\pm 1)_{60\%}$

ROCK BOUNDARIES:[*)]

$6(\pm 2)_{60\%}$

SINGLE OPEN FRACTURES:[**)]

$2(\pm 1)_{60}\%$

MYLONITE (incl narrow approx > 1 dm wide shear zones):

$8(\pm 2)_{60\%}$

MINOR FRACTURE ZONES (width <5 m):

$3(\pm 1)_{60\%}$

FRACTURE SYSTEM:

Dominating fracture infilling

Chlorite	+++
Calcite	++
Epidote	+ (sealed)
Fe-oxyhydroxide (hematite)	+
Clay minerals	+

*) Veins less than approximately 0.5 m and the normally very diffuse contacts between the different variants of the Småland granite - Äspö diorite excluded.

**) Persistent, several metres long fractures, mostly steep and estimated to be significant hydraulic conductors.

PREDICTION OF GEOHYDROLOGY BLOCK SCALE (50 m P50-10

CONDUCTIVE STRUCTURES:

Point estimate of the geometric mean distance D_g between structures with a transmissivity greater than T for block P50 - 10.

T (m^2/s)	D_g (m)
$> 3 \cdot 10^{-9}$	$7(0\text{-}35)_{95\%}$
$> 3 \cdot 10^{-7}$	$9(0\text{-}60)_{95\%}$

HYDRAULIC CONDUCTIVITY:

Point estimate of geometric mean of the hydraulic conductivity for P50-10 scale 20 m:

$K_g = 1.1 \cdot 10^{-8} \ (4.7 \cdot 10^{-9} - 2.7 \cdot 10^{-8})_{95\%}$ m/s

PREDICTION OF MECHANICAL STABILITY BLOCK SCALE (50 m) P50-10

GENERAL CONDITIONS:

The 50 m blocks consists of ten 5 m cubes with different mechanical characteristics. The 5 m cubes can be classified as Class A, B, C, D or E rock according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08), where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60
	D	RMR < 40
	E	RMR < 40

ROCK QUALITY:

Rock mass classification:

The Rock Mass Rating is predicted to have the following distribution in this 50 m block:

Class A	Class B	Class C	Class D	Class E
RMR >72	RMR 60-72	RMR 40-60	RMR <40	RMR <40
40%	60%	-	-	-

ROCK STRESS:

Predicted mean value for rock stresses in the 50 m block:

Vertical stress	σ_v = Depth x 0.0265 [MPa]
Maximum horizontal stress	$\sigma_{H,max} = 1.6\text{-}2.0 x \sigma_v$ [MPa] Orientation = N40°W±15°
Minimum horizontal stress	$\sigma_{H,min} = 0.8\text{-}1.2 x \sigma_v$ [MPa] Orientation = N50°E±15°

PREDICTION OF MECHANICAL STABILITY
BLOCK SCALE (50 m)
P50-10

STABILITY:

Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 blocks per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel
Class D	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)
Class E	General instability in roof and walls	Overbreak > 30 cm if normal drillpattern is used (geological overbreak)

APPENDIX C

PREDICTIONS IN DETAILED SCALE (5 m)

Appendix C presents the predictions on a detailed scale. Predicted items for the different key issues are presented on the next few pages, C3 - C7.

Predicted 5 x 5 x 5 m blocks

P5 - 01	C8 - C13
P5 - 02	C14 - C19
P5 - 03	C20 - C24
P5 - 04	C26 - C30

PREDICTIONS OF GEOLOGICAL - STRUCTURAL MODEL - DETAILED SCALE (5 m)

SUBJECT	PREDICTION	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
For 5 m-boxes in four major rock types				
Rock type characteristics	Mineralogical composition	IUGS-classification Petrographic description	Modal composition (volume %)	Sampling and analysis
	Alterations - Weathering - Hydrothermal	IUGS-classification (1-5)	Mineral alteration	Sampling and analysis
	Petrophysics - Density - Porosity	Density Porosity	Density Porosity	Sampling and analysis
Fracture system	For fracture sets			
	- Orientation	Strike and dip	Strike and dip	Fracture mapping
	- Length distribution	M_L, S_L	L>0.5 m	Tracelength mapping
	- Fracture spacing	(m^2/m^3)	(m/m^2)	Tracelength mapping
	- Fracture infilling minerals	Most frequent infilling minerals	Infilling minerals	Sampling and analysis

PREDICTIONS OF GROUNDWATER FLOW - DETAILED SCALE (5 m)

SUBJECT	PREDICTIONS	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Hydraulic conductivity	Conductivity distribution	M_{lnk}, S_{lnk}	Hydraulic conductivity	Pilot holes pressure build up tests
Point leakage	Flow distribution on tunnel periphery for four type rocks	q distribution	q (classes)	Geohydrologic
	Inflow characteristics	Spots (nos/m^2) Lines (m/m^2) Moist areas(m^2/m^2)	Spots Lines Areas	mapping + q_{leg} Mapping
Disturbed zone	Pressure distribution around tunnel	p distribution	p	Pilote holes an pressure measurements
	Conductivity changes (scoping calculations)			
	Axial flow (scoping calculations)			

PREDICTIONS OF GROUNDWATER CHEMISTRY - DETAILED SCALE (5 m)

(See also site scale)

SUBJECT	PREDICTIONS	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Redox conditions	Movement of oxidation zone from fresh tunnel surface	Weathered components and amount Precipitated and dissolved minerals	Fracture minerals	Mapping-sampling analysis
Weathering	Weathering and deposition of fracture minerals behind and on tunnel walls			

PREDICTIONS OF TRANSPORT OF SOLUTES - DETAILED SCALE (5 m)

(Operation period)

PREDICTIONS OF MECHANICAL STABILITY - DETAILED SCALE (5 m)

SUBJECT	PREDICTIONS	ESTIMATE	MEASURED VARIABLE	VALIDATION BASIS
Mechanical characteristics	- Rock strength - Elastic parameters - Ductility	$Sigma_c$ E, ν Ductility	$Sigma_c$ E,ν Ductility	Lab analysis " "
Fracture surface properties	For fracture sets - Roughness - Slickensides	JRC Direction	JRC Slickenside	Mapping "
Long term stability	Potential movements in fractures	Open fractures		Scoping calculations

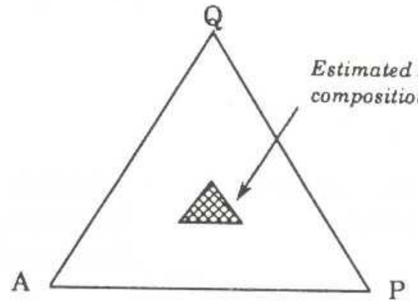
PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL DETAILED SCALE (5 m) P5 - 01 (P50-02) Småland granite

ROCK TYPE CHARACTERISTICS:

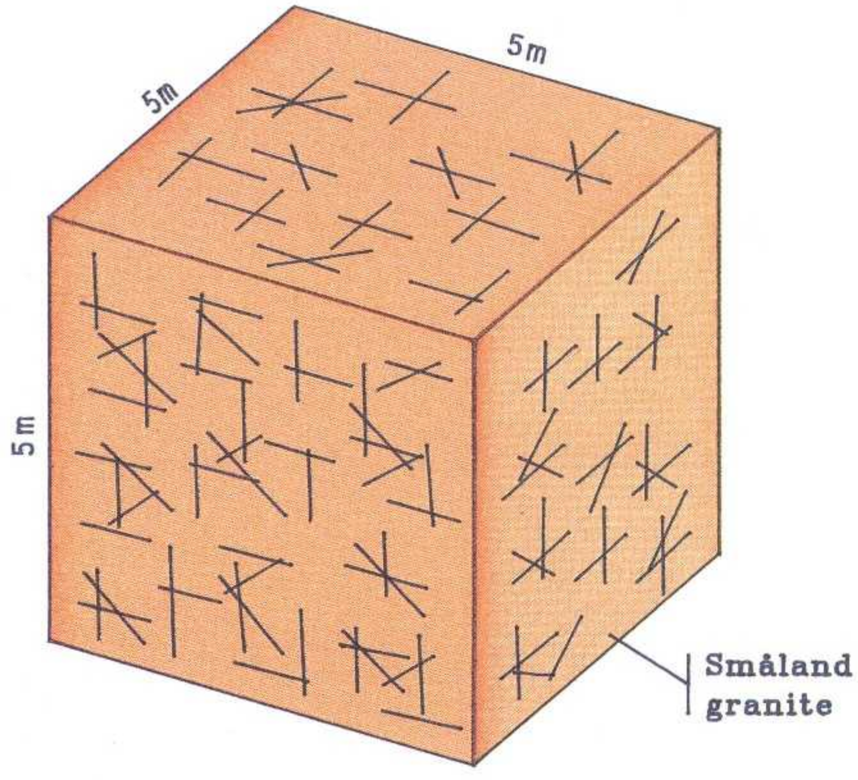
Mineral components (vol %)

(Q) Quartz	= 20 (±3) 60%
(A) K-feldspar	= 25 (±5) 60%
(P) Plagioclase	= 40 (±5) 60%
Biotite	= 10 (±3) 60%
Minor minerals	= 5 (±2) 60%

Modal classification according to IUGS (1973, 1980)



Alteration (IUGS-classification):	1-2
Density (g/cm^3):	2.62 (± 0.03) 90%
Porosity (%): (sum of kinematic and diffusion porosity)	0.24 (± 0.02) 90%



PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL DETAILED SCALE (5 m) P5 - 01 (P50-02) Småland granite

FRACTURE SYSTEM:

ORIENTATION* (estimated order of dominance)	Fracture infilling
1. N 55°W/70° NE (± 10°) 100% N 55°W/25° SW (± 10°) 100%	Chlorite, epidote, calcite, Fe-oxyhydroxide
2. N-S/steep (± 10°) 100%	Calcite, chlorite, Fe-oxyhydroxide
3. N85° E (± 5°) 100 %/75° NNE (± 10°)100% N85° E (± 5°) 100 %/30° SSE (± 10°) 100%	Chlorite, epidote, calcite
4. N55° E / 70° SE (± 10°) 100%	Chlorite, epidote, calcite

Fracture length (point estimate of geometric mean of all fractures > 0,5 m).

1,2 m (± 0,3) 60%.

Fracture spacing (point estimate of geometric mean of spacing for all fractures > 0,5 m).

1.0 m (± 0.3) 60°.

* Dominant peaks of the fracture sets

PREDICTION OF GROUNDWATER FLOW
DETAILED SCALE (5 m)
P5-01 (P50-02) Småland granite

HYDRAULIC CONDUCTIVITY:

Scale 20 m:

Point estimate of hydraulic conductivity, geometric mean, K_g $= 1 \cdot 10^{-9}$ m/s

95% confidence limits of geometric mean $= 7.6 \cdot 10^{-10} - 2.6 \cdot 10^{-9}$ m/s

Standard deviation of logK $S_{logK} = 1.0$

POINT LEAKAGE:

Flow distribution on tunnel periphery:
90% of the area is expected to be dry

Inflow characteristics: Character = Mainly damp areas or drip
Type = Mainly point flows along horizontal fractures and fracture intersections

DISTURBED ZONE:

Pressure distribution: Average pressure 4 m from tunnel wall
$P = 2 \cdot 10^4 - 30 \cdot 10^4$ Pa
(Skin: 0-10)

Conductivity changes: Parallel tunnel axis $K_a = K_g(10\text{-}200)$
Perpendicular tunnel axis $K_t = K_g(1\text{-}0.03)$

Axial flow: 10^{-9} m/s $< q_a < 10^{-5}$ m/s

PREDICTION OF GROUNDWATER CHEMISTRY DETAILED SCALE (5 m) P5-01 (P50-02) Småland granite

Rocktype	Fe^{2+}(mg/l)	S^{2-}(mg/l)	pH	Eh(mV)
Småland granite	0.1 ± 0.1	0.5 ± 0.5	7.8 ± 0.2	-290 ± 50

The water in the rock mass of Äspö has a salt content which increases by depth. This indicates that the saline water at depth is slowly washed out by freshwater causing a continuous mixing of saline and freshwater. Both the freshwater and the saline water are saturated with respect to calcite. A mixing of the saline and the freshwater will always result in a supersaturation which can also be seen from the calculated saturation indecies. Consequently calcite is precipitating in the fracture system causing a decrease of inflow. The opposite situation might occur in the most shallow part of the tunnel crossing the NNW fracture system in case surface water is penetrating the fracture.

PREDICTION OF MECHANICAL STABILITY
DETAILED SCALE (5 m)
P5-01 (P50-02) Småland granite

GENERAL CONDITIONS:

Homogeneous rock within the 5 m block. Fracture frequency is uniform and the block is not intersected by fracture zones. The rock can be classified as Class A, B or C according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08) where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60

MECHANICAL CHARACTERISTICS:

Rock strength:	> 200 MPa	100-200 MPa	< 100 MPa
	25%	75%	---
Elastic moduli:	>60 MPa	50-60 MPa	< 50 MPa
	90%	10%	---
Poisson's ratio:	> 0.25	0.20-0.25	< 0.20
	10%	90%	10%
Brittleness:	Wu/Wk > 1	Wu/Wk < 1	
	25%	75%	

FRACTURE PROPERTIES:

Joint Roughness Coefficient (JRC)	> 14	14-6	< 6
	60%	30%	10%
Joint Wall Compresssion Strength (JCS)	> 75 MPa	75-40 MPa	< 40 MPa
	60%	30%	10%
Fracture frequency (dist. between joints)	1-3 m	0.3-1 m	< 0.3 m
	20%	60%	20%
Fracture density (RQD)	90-100%	75-90 %	50-75 %
	40%	40%	20%

PREDICTION OF MECHANICAL STABILITY
DETAILED SCALE (5m)
P5-01 (P50-02) Småland granite

ROCK STRESS. (above level -500 m):

Vertical stress	σ_v	= Depth x 0.0265 (MPa)
Maximum horizontal stress	$\sigma_{h, max}$	= (1.1-2.1 x σ_v) 100% (MPa)
	$\sigma_{h, max}$	= (1.3-1.8 x σ_v) 70% (MPa)
	Orientation	= (N12°W-N68°W) 100%
	Orientation	= (N25°W-N55°W) 70%
Minimum horizontal stress	$\sigma_{h, min}$	= (0.6-1.6 x σ_v) 100% (MPa)
	$\sigma_{h, min}$	= (0.7-1.1 x σ_v) 70% (MPa)
	Orientation	= (N22°E-N78°E) 100%
	Orientation	= (N35°E-N65°E) 70%

STABILITY:

Block instability:

	Mechanism of failure	Estimate
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 block per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel

ROCK BURST:

Some spalling is predicted to occur below -400 m in Class A or Class B rock.

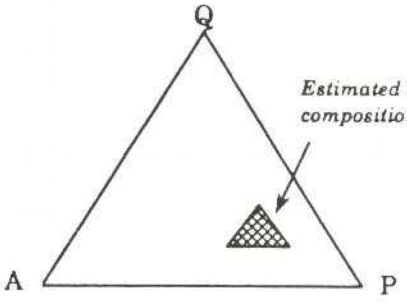
PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL
DETAILED SCALE (5 m)
P 5-02 (P50-03), Äspö diorite

ROCK TYPE CHARACTERISTICS:

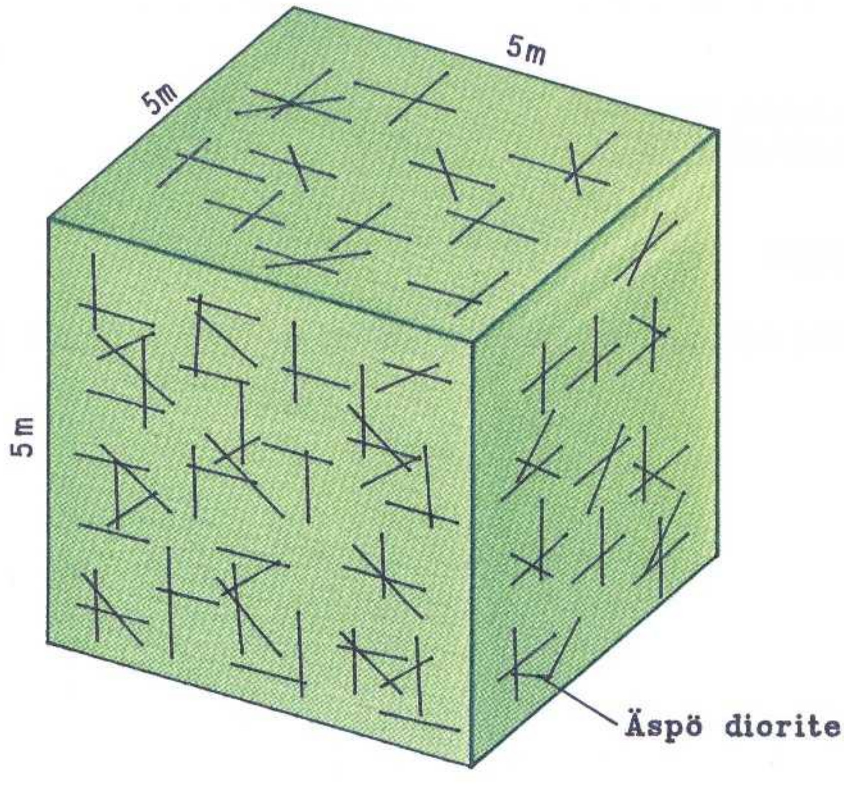
Mineral components (vol%)

(Q) Quartz	= 15 (±5) 60%
(A) K-feldspar	= 15 (±5) 60%
(P) Plagioclase	= 40 (±5) 60%
Biotite	= 20 (±5) 60%
Amphibole, pyroxene, epidote	= 10 (±3) 60%

Modal classification according to IUGS (1973, 1980)



Alteration (IUGS-classification):	1-2
Density (g/cm^3):	2.70 (±0.05) 90%
Porosity (%): (sum of kinematic and diffusion porosity)	0.32 (±0.02) 50%



PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL DETAILED SCALE (5m) P5-02 (P50-03) Äspö diorite

FRACTURE SYSTEM:

ORIENTATION* (estimated order of dominance)	Fracture infilling
1. N55°W/70° SE (± 10°) 100%	Chlorite, epidote, calcite, Fe-oxyhydroxide
" /35° NE (±10°) 100%	
2. N-S/Steep (±10°) 100%	Chlorite, calcite, Fe-oxyhydroxide
3. N85°E (±5°) 100%/75°NNE (±10°) 100%	Chlorite, epidote, calcite
" /30 SSE (±10°) 100%	
4. N55° E/70°SE (±10°) 100%	Chlorite, epidote, calcite

Fracture length (point estimate of geometric mean of all fractures > 0.5 m)
1.2 m (±0.3) 60%

Fracture spacing (point estimate of geometric mean of spacing for all fracturer > 0.5 m)

1.0 m (±0.3) 60%

* Dominant peaks of the fracture sets

PREDICTION OF GROUNDWATER FLOW
DETAILED SCALE (5 m)
P5-02 (P50-03) Äspö diorite

HYDRAULIC CONDUCTIVITY:

Scale 20 m:

Point estimate of hydraulic conductivity, geometric mean, K_g $= 3.7 \cdot 10^{-10}$ m/s *

95% confidence limits of geometric mean $= 2.1 \cdot 10^{-10} - 6.6 \cdot 10^{-10}$ m/s*

Standard deviation of logK $S_{logK} = 1.4$*

* These estimates probably overestimate the unbiased population properties.

POINT LEAKAGE:

Flow distribution on tunnel periphery:
90% of the area is expected to be dry

Inflow characteristics: Character = Mainly damp areas or drip
Type = Mainly point flows along horizontal fractures and fracture intersections

DISTURBED ZONE:

Pressure distribution: Average pressure 4 m from tunnel wall
$P = 5 \cdot 10^{-4} - 100 \cdot 10^{-4}$ Pa

Conductivity changes: Parallel tunnel axis $K_a = K_g(10\text{-}200)$
Perpendicular tunnel axis $K_t = K_g(1\text{-}0.03)$

Axial flow: 10^{-9} m/s $< q_a < 10^{-5}$ m/s

PREDICTION OF GROUNDWATER CHEMISTRY
DETAILED SCALE (5m)
P5-02 (P50-03) Äspö diorite

Rock type	Fe^{2+}(mg/l)	S^{2-}(mg/l)	pH	Eh (mV)
Äspö diorite	0.5 ± 0.3	0.5 ± 0.5	8.2 ± 0.3	-390 ± 50

The water in the rock mass of Äspö has a salt content which increases by depth. This indicates that the saline water at depth is slowly washed out by freshwater causing a continuous mixing of saline and freshwater. Both the freshwater and the saline water are saturated with respect to calcite. A mixing of the saline and the freshwater will always result in a supersaturation which can also be seen from the calculated saturation indecies. Consequently calcite is precipitating in the fracture system causing a decrease of inflow. The opposite situation might occur in the most shallow part of the tunnel crossing the NNW fracture system in case surface water is penetrating the fracture.

The walls of the tunnel is expected to be coated by iron hydroxide. In specially the dioritic rocks where the concentration of dissolved iron in the water is higher than in the water of the Småland and fine-grained granite.

PREDICTION OF MECHANICAL STABILITY
DETAILED SCALE (5 m)
P5-02 (P50-03) Äspö diorite

GENERAL CONDITIONS:

Homogeneous rock within the 5 m block. Fracture frequency is uniform and the block is not intersected by fracture zones. The rock can be classified as Class A, B or C according to the "Evaluation of Rock Mechanics" (SKB PR 25-90-08) where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60

MECHANICAL CHARACTERISTICS:

Rock strength:	> 200 MPa	100-200 MPa	< 100 MPa
	---	100%	---
Elastic moduli:	> 60 MPa	50-60 MPa	< 50 MPa
	50%	50%	---
Poisson's ratio:	> 0.25	0.20-0.25	< 0.20
	10%	80%	10%
Brittleness:	Wu/Wk > 1	Wu/Wk < 1	
	25%	75%	

FRACTURE PROPERTIES:

Joint Roughness Coefficient	> 14	14-6	< 6
(JRC)	60%	30%	10%
Joint Wall Compresssion	> 75 MPa	75-40 MPa	< 40 MPa
Strength (JCS)	60%	30%	10%
Fracture frequency	1-3 m	0.3-1 m	< 0.3 m
(dist. between joints)	20%	50%	30%
Fracture density	90-100%	75-90 %	50-75 %
(RQD)	40%	40%	20%

PREDICTION OF MECHANICAL STABILITY DETAILED SCALE (5m) P5-02 (P50-03) Äspö diorite

ROCK STRESS. (above level -500 m):

Vertical stress	σ_v	= Depth x 0.0265 (MPa)
Maximum horizontal stress	$\sigma_{h,max}$	= (1.1-2.1 x σ_v) 100% (MPa)
	$\sigma_{h,max}$	= (1.3-1.8 x σ_v) 70% (MPa)
	Orientation	= (N12°W-N68°W) 100%
	Orientation	= (N25°W-N55°W) 70%
Minimum horizontal stress	$\sigma_{h,min}$	= (0.6-1.6 x σ_v) 100% (MPa)
	$\sigma_{h,min}$	= (0.7-1.1 x σ_v) 70% (MPa)
	Orientation	= (N22°E-N78°E) 100%
	Orientation	= (N35°E-N65°E) 70%

STABILITY:

Block instability:

	Mechanism of failure	Estimate
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 block per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel

ROCK BURST:

Some spalling is predicted to occur below -400 m in Class A or Class B rock.

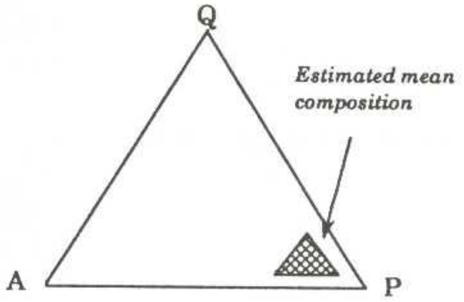
PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL DETAILED SCALE (5 m) P5-03 (P50-04) Greenstone

ROCK TYPE CHARACTERISTICS:

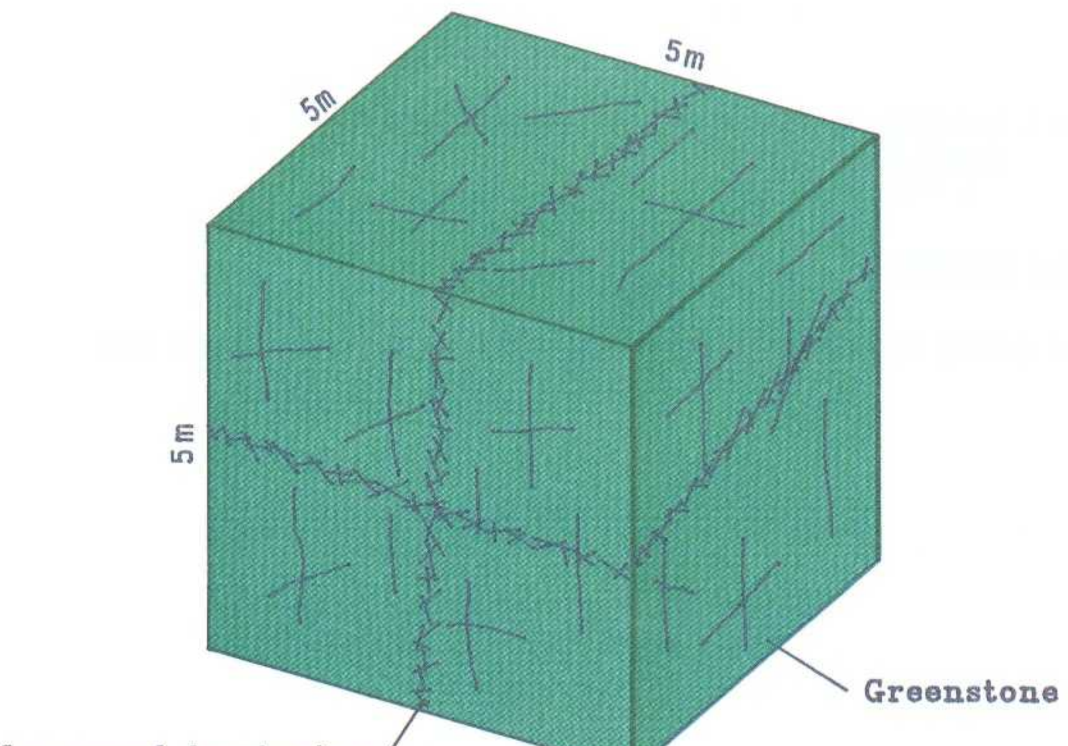
Mineral components (vol%)

(Q) Quartz	= 5 (±3) 60%
(P) Plagiclase	= 50 (±5) 60%
Amphibole	= 30 (±10) 60%
Biotite	= 20 (±5) 60%
Epidote, pyroxene	= 5 (±3) 60%

Modal classification according to IUGS (1973, 1980)



Alteration (IUGS-classification):	1-2
Density (g/cm^3):	2.80 (±0.05)90%
Porosity (%): (sum of kinematic and diffusion porosity)	0.16 (±0.02)90%



PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL DETAILED SCALE (5m) P5-03 (P50-04) Greenstone

FRACTURE SYSTEM:

ORIENTATION* (estimated order of dominance)	Fracture infilling
1. N55°W/70° SE (± 10°) 100%	Chlorite, epidote, calcite, Fe-oxyhydroxide
" /35° NE (±10°) 100%	
2. N-S/Steep (±10°) 100%	Chlorite, calcite, Fe-oxyhydroxide
3. N85°E (±5°) 100%/75°NN E (±10°) 100%	Chlorite, epidote, calcite
" /30 SSE (±10°) 100%	
4. N55° E/70°SE (±10°) 100%	Chlorite, epidote, calcite

Fracture length (point estimate of geometric mean of all fractures > 0.5 m)
1.2 m (±0.3) 60%

Fine-grained:	0.7 m (± 0.2) 60%
Diorite-gabbro:	1.5 m (± 0.3) 60%

Fracture spacing (point estimate of geometric mean of spacing for all fractures > 0.5 m)

1.0 m (±0.3) 60%

Fine-grained:	0.6 m (± 0.2) 60%
Diorite-gabbro:	1.2 m (± 0.3) 60%

* Dominant peaks of the fracture sets

PREDICTION OF GROUNDWATER FLOW
DETAILED SCALE (5 m)
P5-03 (P50-04) Greenstone

HYDRAULIC CONDUCTIVITY:

Scale 20 m:

Point estimate of hydraulic conductivity, geometric mean, $K_g = 3.7 \cdot 10^{-10}$ m/s*

95% confidence limits of geometric mean $= 6.3 \cdot 10^{-11} - 2.2 \cdot 10^{-9}$*

Standard deviation of logK $S_{logK} = 1.3$*

* These estimates probably overestimate the unbiased population properties.

POINT LEAKAGE:

Flow distribution on tunnel periphery:
90% of the area is expected to be dry

Inflow characteristics:

Character = Mainly damp areas (fine-grained)
Mainly damp areas and drip (diorite-gabbro)

Type = Mainly diffuse (fine-grained)
Mainly point flows along horizontal fractures and fracture intersections (diorite-gabbro)

DISTURBED ZONE:

Pressure distribution: Average pressure 4 m from tunnel wall

$$P = 5 \cdot 10^4 - 100 \cdot 10^4 \text{ Pa}$$

(Skin: 0-10)

Conductivity changes:

Parallel tunnel axis $K_a = K_g(10\text{-}200)$

Perpendicular tunnel axis $K_t = K_g(1\text{-}0.03)$

Axial flow: 10^{-9} m/s $< q_a < 10^{-5}$ m/s

PREDICTION OF MECHANICAL STABILITY
DETAILED SCALE (5 m)
P5-03 (P50-04) Greenstone

GENERAL CONDITIONS:

Homogeneous rock within the 5 m block. Fracture frequency is uniform and the block is not intersected by fracture zones. The rock can be classified as Class A, B or C according to the "Evaluation of Rock Mechanics" (Ref. PR 25-90-08) where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60

MECHANICAL CHARACTERISTICS:

Rock strength:	> 200 MPa	100-200 MPa	< 100 MPa
	---	75%	25%
Elastic moduli:	>60 MPa	50-60 MPa	< 50 MPa
	25%	50%	25%
Poisson's ratio:	> 0.25	0.20-0.25	< 0.20
	10%	80%	10%
Brittleness:	Wu/Wk > 1	Wu/Wk < 1	
	40%	60%	

FRACTURE PROPERTIES:

Joint Roughness Coefficient	> 14	14-6	< 6
(JRC)	30%	50%	20%
Joint Wall Compresssion	> 75 MPa	75-40 MPa	< 40 MPa
Strength (JCS)	30%	50%	20%
Fracture frequency	1-3 m	0.3-1 m	< 0.3 m
(dist. between joints)	20%	60%	20%
Fracture density	90-100%	75-90 %	50-75 %
(RQD)	20%	50%	30%

PREDICTION OF MECHANICAL STABILITY
DETAILED SCALE (5m)
P5-03 (P50-04) Greenstone

ROCK STRESS. (above level -500 m):

Vertical stress	σ_v	= Depth of overburden x 0.0265 (MPa)
Maximum horizontal stress	$\sigma_{h,max}$	= (1.1-2.1 x σ_v) 100% (MPa)
	$\sigma_{h,max}$	= (1.3-1.8 x σ_v) 70% (MPa)
	Orientation	= (N12°W-N68°W) 100%
	Orientation	= (N25°W-N55°W) 70%
Minimum horizontal stress	$\sigma_{h,min}$	= (0.6-1.6 x σ_v) 100% (MPa)
	$\sigma_{h,min}$	= (0.7-1.1 x σ_v) 70% (MPa)
	Orientation	= (N22°E-N78°E) 100%
	Orientation	= (N35°E-N65°E) 70%

STABILITY:

Block instability:

	Mechanism of failure	Estimate
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 block per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel

ROCK BURST:

Some spalling is predicted to occur below -300 m in Class A or Class B rock.

Moderate spalling is predicted to occur below -400 in Class A or Class B rock.

PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL DETAILED SCALE (5 m) P5-04 (P50-01) Fine-grained granite

ROCK TYPE CHARACTERISTICS:

Mineral components (vol %)

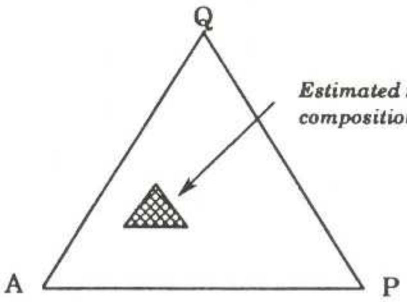
(A) Quartz = 30 (+5) 50%

(B) K-feldspar = 40 (±5) 50%

(C) Plagioclase = 23 (±5) 50%

(D) Biotite, epidote
and other minerals
small quantities = 7 (+2) 50%

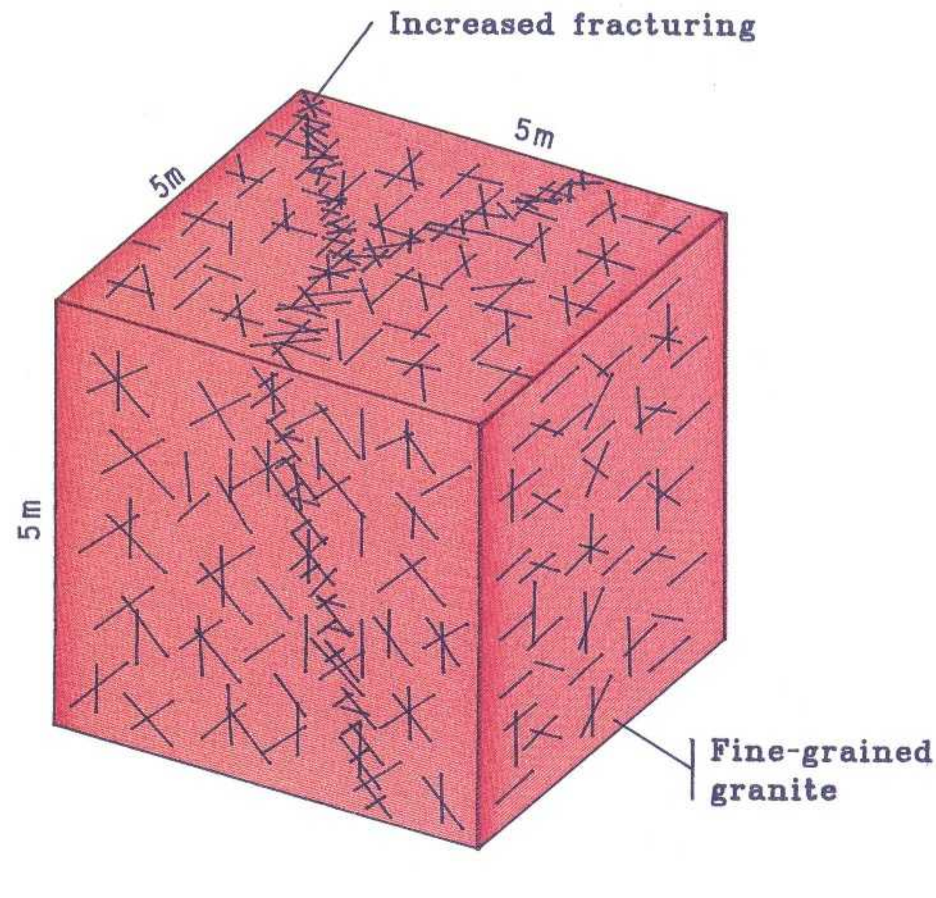
Modal classification according to IUGS (1973, 1980)



Alteration (IUGS-classification): 1-2

Density (g/cm^3): 2.56 (± 0.02) 90%

Porosity (%): 0.30 (± 0.01) 90%
(sum of kinematic and diffusion porosity)



PREDICTION OF GEOLOGICAL - STRUCTURAL MODEL DETAILED SCALE (5m) P5-04 (P50-01) Fine-grained granite

FRACTURE SYSTEM:

ORIENTATION* (estimated order of dominance)	Fracture infilling
1. N55°W/70° SE (± 10°) 100%	Chlorite, epidote, calcite, Fe-oxyhydroxide
" /35° NE (±10°) 100%	
2. N-S/Steep (±10°) 100%	Chlorite, calcite, Fe-oxyhydroxide
3. N85°E (±5°) 100%/75°NN E (±10°) 100%	Chlorite, epidote, calcite
" /30 SSE (±10°) 100%	
4. N55° E/70°SE (±10°) 100%	Chlorite, epidote, calcite

Fracture length (point estimate of geometric mean of all fractures > 0.5 m)
0.8 m (±0.1) 50%

Fracture spacing (point estimate of geometric mean of spacing for all fractures > 0.5 m)
0.5 m (±0.1) 50%

* Dominant peaks of the fracture sets

PREDICTION OF GROUNDWATER FLOW
DETAILED SCALE (5 m)
P5-04 (P50-01) Fine-grained granite

HYDRAULIC CONDUCTIVITY:

Scale 20 m:

Point estimate of hydraulic conductivity, geometric mean, K_g $= 9 \cdot 10^{-9}$ m/s

95% confidence limits of geometric mean $= 3.5 \cdot 10^{-9} - 2.2 \cdot 10^{-8}$ m/s

Standard deviation of logK $S_{logK} = 1.0$

POINT LEAKAGE:

Flow distribution on tunnel periphery:
60% of the area is expected to be dry

Inflow characteristics: Character = Mainly drip
Type = Mainly point flow

DISTURBED ZONE:

Pressure distribution: Average pressure 4 m from tunnel wall
$P = 0.2 \cdot 10^4 - 5 \cdot 10^4$ Pa
(Skin: 0-10)

Conductivity changes: Parallel tunnel axis $K_a = K_g(10\text{-}200)$
Perpendicular tunnel axis $K_t = K_g(1\text{-}0.03)$

Axial flow: 10^{-9} m/s $< q_a < 10^{-5}$ m/s

PREDICTION OF MECHANICAL STABILITY
DETAILED SCALE (5 m)
P5-04 (P50-01) Fine-grained granite

GENERAL CONDITIONS:

Homogeneous rock within the 5 m block. Fracture frequency is uniform and the block is not intersected by fracture zones. The rock can be classified as Class A, B or C according to the "Evaluation of Rock Mechanics" (Ref. PR 25-90-08) where the different rock classes correspond to the following RMR values:

Class	A	RMR > 72
	B	RMR 60-72
	C	RMR 40-60

MECHANICAL CHARACTERISTICS:

Rock strength:	> 200 MPa	100-200 MPa	< 100 MPa
	50%	50%	---
Elastic moduli:	> 60 MPa	50-60 MPa	< 50 MPa
	75%	25%	---
Poisson's ratio:	> 0.25	0.20-0.25	< 0.20
	10%	80%	10%
Brittleness:	Wu/Wk > 1	Wu/Wk < 1	
	25%	75%	

FRACTURE PROPERTIES:

Joint Roughness Coefficient	> 14	14-6	< 6
(JRC)	30%	50%	20%
Joint Wall Compresssion	> 75 MPa	75-40 MPa	< 40 MPa
Strength (JCS)	30%	50%	20%
Fracture frequency	1-3 m	0.3-1 m	< 0.3 m
(dist. between joints)	30%	50%	20%
Fracture density	90-100%	75-90 %	50-75 %
(RQD)	30%	40%	30%

PREDICTION OF MECHANICAL STABILITY
DETAILED SCALE (5m)
P5-04 (P50-01) Fine-grained granite

ROCK STRESS. (above level -500 m):

Vertical stress	σ_v	= Depth x 0.0265 (MPa)
Maximum horizontal stress	$\sigma_{h,max}$	= (1.1-2.1 x σ_v) 100% (MPa)
	$\sigma_{h,max}$	= (1.3-1.8 x σ_v) 70% (MPa)
	Orientation = (N12°W-N68°W) 100%	
	Orientation = (N25°W-N55°W) 70%	
Minimum horizontal stress	$\sigma_{h,min}$	= (0.6-1.6 x σ_v) 100% (MPa)
	$\sigma_{h,min}$	= (0.7-1.1 x σ_v) 70% (MPa)
	Orientation = (N22°E-N78°E) 100%	
	Orientation = (N35°E-N65°E) 70%	

STABILITY:

Block instability:

	Mechanism of failure	Estimate
Class A	Outfall of single block	1-2 block per meter of tunnel
Class B	Outfall of single block	2-3 block per meter of tunnel
Class C	Instability in the roof Outfall of blocks	Several blocks per meter of tunnel

ROCK BURST:

Some spalling is predicted to occur below -400 m in Class A or Class B rock.

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Annual Reports

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The KBS Annual Report 1979
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Annual Research and Development Report 1984
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Stockholm, May 1986

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SKB Annual Report 1986
Including Summaries of Technical Reports Issued during 1986
Stockholm, May 1987

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SKB Annual Report 1987
Including Summaries of Technical Reports Issued during 1987
Stockholm, May 1988

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Including Summaries of Technical Reports Issued during 1988
Stockholm, May 1989

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

Technical Reports
List of SKB Technical Reports 1991

TR 91-01
Description of geological data in SKB's database GEOTAB
Version 2
Stefan Sehlstedt, Tomas Stark
SGAB, Luleå
January 1991

TR 91-02
Description of geophysical data in SKB database GEOTAB
Version 2
Stefan Sehlstedt
SGAB, Luleå
January 1991

TR 91-03
1. The application of PIE techniques to the study of the corrosion of spent oxide fuel in deep-rock ground waters
2. Spent fuel degradation
R S Forsyth
Studsvik Nuclear
January 1991

TR 91-04
Plutonium solubilities
I Puigdomènech[1], J Bruno[2]
[1]Enviromental Services, Studsvik Nuclear, Nyköping, Sweden
[2]MBT Tecnologia Ambiental, CENT, Cerdanyola, Spain
February 1991

TR 91-05
Description of tracer data in the SKB database GEOTAB
SGAB, Luleå
April, 1991

TR 91-06
Description of background data in the SKB database GEOTAB Version 2
Ebbe Eriksson, Stefan Sehlstedt
SGAB, Luleå
March 1991

TR 91-07
Description of hydrogeological data in the SKB's database GEOTAB Version 2
Margareta Gerlach[1], Bengt Gentzschein[2]
[1]SGAB, Luleå
[2]SGAB, Uppsala
April 1991

TR 91-08
Overview of geologic and geohydrologic conditions at the Finnsjön site and its surroundings
Kaj Ahlbom[1], Sven Tirén[2]
[1]Conterra AB
[2]Sveriges Geologiska AB
January 1991

TR 91-09
Long term sampling and measuring program. Joint report for 1987, 1988 and 1989. Within the project: Fallout studies in the Gideå and Finnsjö areas after the Chernobyl accident in 1986
Thomas Ittner
SGAB, Uppsala
December 1990

TR 91-10
Sealing of rock joints by induced calcite precipitation. A case study from Bergeforsen hydro power plant
Eva Hakami[1], Anders Ekstav[2], Ulf Qvarfort[2]
[1]Vattenfall HydroPower AB
[2]Golder Geosystem AB
January 1991

TR 91-11
Impact from the disturbed zone on nuclide migration – a radioactive waste repository study
Akke Bengtsson[1], Bertil Grundfelt[1], Anders Markström[1], Anders Rasmuson[2]
[1]KEMAKTA Konsult AB
[2]Chalmers Institute of Technology
January 1991

TR 91-12
Numerical groundwater flow calculations at the Finnsjön site
Björn Lindbom, Anders Boghammar, Hans Lindberg, Jan Bjelkås
KEMAKTA Consultants Co, Stockholm
February 1991

TR 91-13
Discrete fracture modelling of the Finnsjön rock mass Phase 1 feasibility study
J E Geier, C-L Axelsson
Golder Geosystem AB, Uppsala
March 1991

TR 91-14
Channel widths
Kai Palmqvist, Marianne Lindström
BERGAB-Berggeologiska Undersökningar AB
February 1991

TR 91-15
Uraninite alteration in an oxidizing environment and its relevance to the disposal of spent nuclear fuel
Robert Finch, Rodney Ewing
Department of Geology, University of New Mexico
December 1990

TR 91-16
Porosity, sorption and diffusivity data compiled for the SKB 91 study
Fredrik Brandberg, Kristina Skagius
Kemakta Consultants Co, Stockholm
April 1991

TR 91-17
Seismically deformed sediments in the Lansjärv area, Northern Sweden
Robert Lagerbäck
May 1991

TR 91-18
Numerical inversion of Laplace transforms using integration and convergence acceleration
Sven-Åke Gustafson
Rogaland University, Stavanger, Norway
May 1991

TR 91-19
NEAR21 - A near field radionuclide migration code for use with the PROPER package
Sven Norman[1], Nils Kjellbert[2]
[1]Starprog AB
[2]SKB AB
April 1991

TR 91-20
Äspö Hard Rock Laboratory. Overview of the investigations 1986-1990
R Stanfors, M Erlström, I Markström
June 1991

TR 91-21
Äspö Hard Rock Laboratory. Field investigation methodology and instruments used in the pre-investigation phase, 1986-1990
K-E Almén, O Zellman
June 1991

TR 91-22
Äspö Hard Rock Laboratory. Evaluation and conceptual modelling based on the pre-investigations 1986-1990
P Wikberg, G Gustafson, I Rhén, R Stanfors
June 1991