SKB

TECHNICAL REPORT

94-11

Äspö Hard Rock Laboratory Annual Report 1993

SKB

June 1994

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ÄSPÖ HARD ROCK LABORATORY

ANNUAL REPORT 1993

STOCKHOLM, JUNE 1994

Keywords: Äspö HRL, site characterization, geology, geohydrology, groundwater chemistry, rock mechanics, instruments, construction

ABSTRACT

The Äspö Hard Rock Laboratory is being constructed in preparation for the deep geological repository of spent fuel in Sweden. This Annual Report 1993 for the Äspö Hard Rock Laboratory contains an overview of the work conducted.

Present work is focused on verification of pre-investigation methods and development of the detailed investigation methodology. Construction of the facility and investigation of the bedrock are being carried out in parallel. As of December 1993, 2760 m of the tunnel had been excavated to a depth of 370 m below the surface.

An important and integral part of the work is further refinement of conceptual and numerical models for groundwater flow and radionuclide migration. Detailed plans have been prepared for several experiments to be conducted after the end of the construction work.

Eight organizations from seven countries are now participating in the work at the Äspö Hard Rock Laboratory and are contributing in different ways to the results being achieved.

SAMMANFATTNING

Äspölaboratoriet anläggs som en förberedelse för djupförvaret av det svenska använda kärnbränslet. Denna årsrapport för 1993 ger en översikt av det genomförda arbetet.

Nuvarande arbete är inriktat på att verifiera förundersökningsmetoder och att utveckla detaljundersökningsmetodik. Byggande och undersökningar av berggrunden sker parallellt. December 1993 var 2760 m tunnel utsprängd, motsvarande ett djup av 370 m under marknivån.

En viktig och integrerad del av arbetet är att förbättra metoder för att utveckla konceptuella och numeriska modeller för grundvattenströmning och radionuklidmigration. Detaljerade planer har utarbetats för ett flertal experiment som genomförs när byggnadsarbetena är avslutade.

Åtta organisationer från sju länder deltar nu i arbetet kring Äspölaboratoriet och medverkar på olika sätt till de uppnådda resultaten.

EXECUTIVE SUMMARY

The Äspö Hard Rock Laboratory is being constructed in preparation for the deep geological repository of spent fuel in Sweden.

The work with the Äspö Hard Rock Laboratory, HRL, has been divided into three phases: the pre-investigation, the construction and the operating phase.

The pre-investigaton phase was aimed at site selection for the laboratory, description of the natural conditions in the bedrock and predictions of changes that will occur during construction of the laboratory. The on-going construction of the access ramp to a depth of 450 m is being used to check the predictive models set up from the pre-investigation phase, to develop methodology for the integration of construction/testing and to increase the database on the bedrock in order to improve models of groundwater flow and radionuclide migration.

Stage goal 1 - Verification of pre-investigation methods

Some of the main results from the documentation of tunnel section 700 - 2245 m (depth 100 -300 m) are summarized in this report. Typical findings indicate e.g.:

- On the site scale (500 m) it seems possible to make a useful prediction of the distribution of the main rock types Småland granite, Äspö diorite and fine-grained granite, but it seems to be more difficult to predict the distribution of greenstone.
- -The outcome of the inflow to the tunnel section 1450 - 2245 m was approximately $12 \cdot 10^{-3}$ m^3/s and the predicted inflow was 150 % of the outcome.
- The results show that biological sulphate reduction is taking place in tunnel section 700 - 1475 m. The quite different data from this tunnel section indicate that this process is not occurring in tunnel section 1475 - 2265 m. The assumption that the sulphate reduction is related to the bottom sediments of the Baltic Sea therefore seems to be appropriate.
- The maximum principal stress at 300 m depth is 20-25 MPa, which is in the high range compared with background data from Scandinavia.

Evaluation of the predictions and outcomes will be used to assess the pre-investigation methodology prior to site characterization of the sites for the Swedish deep repository. A special experience report is also in preparation to evaluate all experiences gained so far.

Stage goal 2 - Finalize detailed investigation methodology

The detailed characterizations will encompass investigations during construction of shafts/tunnels to repository depth.

Management of the large quantities of data has been developed to the point where SKB is now in possession of a data production methodology that meets exacting

requirements on quality and overview. The methodology has been developed for conventional tunnelling.

When the deep repository is built a few years after the turn of the century, full face boring will undoubtedly be the dominant method for underground rock construction. In view of the above, c. 420 m of the facility will be excavated with a 5 m diameter tunnel boring machine (TBM) during 1994.

Testing of TBM is of considerable added value for achieving this stage goal of the project. The methodology of coordinating TBM tunnelling and investigations will be tested under realistic conditions, in addition to the methodology that has already been tested in conjunction with conventional blasting.

To obtain a better understanding of the properties of the disturbed zone and its dependence on the method of excavation, ANDRA, UK Nirex, and SKB have decided to perform a joint study of disturbed zone effects.

Stage goal 3 - Tests of models for groundwater flow and radionuclide migration

It is necessary to demonstrate the safety of the deep repository over long spans of time. Important phenomena that must be taken into account in the safety assessment are:

- transport of corrodants up to the canister
- possible transport of radioactive materials away from a defective canister.

These phenomena are in turn highly dependent on groundwater flow and chemistry.

A "Task Force" with representatives of the project's international participants has been formed for numerical modelling of groundwater flow and solute transport. This offers excellent opportunities for trying out alternative models in a way that would not have been possible without international cooperation. After remodelling the combined long-time pumping and radioactive tracer test LPT-2 several groups have performed scoping calculations for the Matrix Diffusion Experiment and the Multiple Well Tracer Experiment.

The planning for a Degassing/Two-Phase Flow Experiment has proceeded, as has he planning for a Radionuclide Retention Experiment.

The monitoring phase of the on-going Redox Experiment continued during 1993.

The objective of the Pore Volume Experiment is to provide data on the pore aperture distribution in selected fractures. Five 200 mm-diameter boreholes were drilled along the fracture plane to a depth of about 1 m and aperture distributions were collected.

Stage goals 4, 5 - Development of construction and handling methods, pilot test

The safety of a repository is determined by:

- the properties of the site
- the design of the barriers
- the quality of execution of the deep repository.

A KBS-3-type deep repository is supposed to hold about 4500 canisters in rock caverns at a depth of about 500 m. The different barriers (canister, buffer, rock) work together to isolate the waste. Backfilling/plugging of tunnels, shafts and boreholes limits the flow of groundwater via the potential flow paths opened up by the construction and investigation work, thereby making it more difficult for corrodants and any escaping radionuclides to be transported up to or away from the canisters/waste. All of this work with barriers, plugs etc. must be executed with a given minimum quality.

The Äspö HRL provides an opportunity for demonstrating technology that will provide this necessary quality. The need to integrate existing knowledge and build an (inactive) prototype of a deep repository is currently being discussed within SKB. The objectives include translating scientific knowledge into engineering practice, testing and demonstrating the feasibility of the various techniques, and demonstrating that it is possible to build with adequate quality. In conjunction with construction of the prototype proposed above, different types of models will be used to describe the performance of the prototype in conjunction with water absorption and restoration of groundwater pressures, etc. The prototype will then be monitored via a large number of measurement points for a period of 5-15 years. Following this there will be an opportunity to study in detail any chemical and physical changes in e.g. the bentonite surrounding the canisters.

Engineering and construction work

The Äspö HRL facility comprises several construction section and phases. A tunnel ramp has been excavated from the Simpevarp peninsula 1.5 km out under the Äspö island. The tunnel reaches Äspö at a depth of 200 m. The tunnel then continues in a hexagonal spiral under Äspö. The first turn of the spiral was completed in the summer of 1993. The tunnelling of this part was done by means of conventional drill and blast technique.

For the final part of the second spiral (from 420 to 450 m level), full-face boring with a 5 m diameter Tunnel Boring Machine, TBM, will be tested. The first part of the second spiral will follow a hexagonal shape and also be done by drilling and blasting. A rock cavern will be excavated at the end of this for assembly of the TBM. The tunnel will then go down to the 450 m level close to the shafts and continue horizontally westward to an experimental rock volume.

Office and storage buildings for the future research work are being constructed at Äspö over the tunnelspiral, along with buildings for ventilation equipment and machinery for the hoist. Together, these buildings form the "Äspö Research Village", which is designed to resemble other small villages in the surrounding archipelago. The village will be finished in the summer of 1994.

International participation

The construction of the Äspö Hard Rock Laboratory (HRL) has attracted significant international attention. Currently (April 1994) eight organizations from seven countries are participating. They are:

- Atomic Energy of Canada Limited (AECL), Canada
- The Power Reactor and Nuclear Fuel Development Co (PNC), Japan
- The Central Research Institute of the Electric Power Industry (CRIEPI), Japan
- Teollisuuden Voima Oy (TVO), Finland

- Commissariat à l'Energie Atomique - Agence Nationale pour la Gestion des Dechets Radioactifs (ANDRA), France
- United Kingdom Nirex Limited (NIREX), Great Britain
- National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland
- United States Department of Energy (USDOE), USA

An important part of the collaboration is groundwater flow modelling and radionuclide migration. The results of the work are reported in Äspö International Cooperation Reports.

CONTENTS

1 GENERAL

The scientific investigations within SKB's research programme are part of the work of designing a deep repository and identifying and investigating a suitable site. This requires extensive field studies of the interaction between different engineered barriers and the host rock.

A balanced appraisal of the facts, requirements and evaluations presented in connection with the preparation of R&D-programme 86 /1-1/ led to the proposal to construct an underground research laboratory. This proposal was presented in the aforementioned research programme and was very positively received by the reviewing bodies.

In the autumn of 1986, SKB initiated field work for the siting of an underground laboratory in the Simpevarp area in the municipality of Oskarshamn. At the end of 1988, SKB arrived at a decision in principle to site the facility on southern Äspö, about 2 km north of the Oskarshamn Nuclear Power Station (see Figure 1-1). After regulatory review, SKB ordered the excavation of the Äspö Hard Rock Laboratory facility to commence in the autumn of 1990. A number of investigations have been conducted in conjunction with the excavation of the facility. Up to December 31 1993, 2760 m of the access ramp had been excavated to a depth of 370 m below the surface.

The work on the Äspö Hard Rock Laboratory, HRL, has been divided into three phases: the Pre-investigation phase, and the Construction and the Operating phases (see Figure 1-2).

The Pre-investigation phase was aimed at selecting a site for the laboratory, describing the natural conditions in the bedrock and predicting changes that will occur

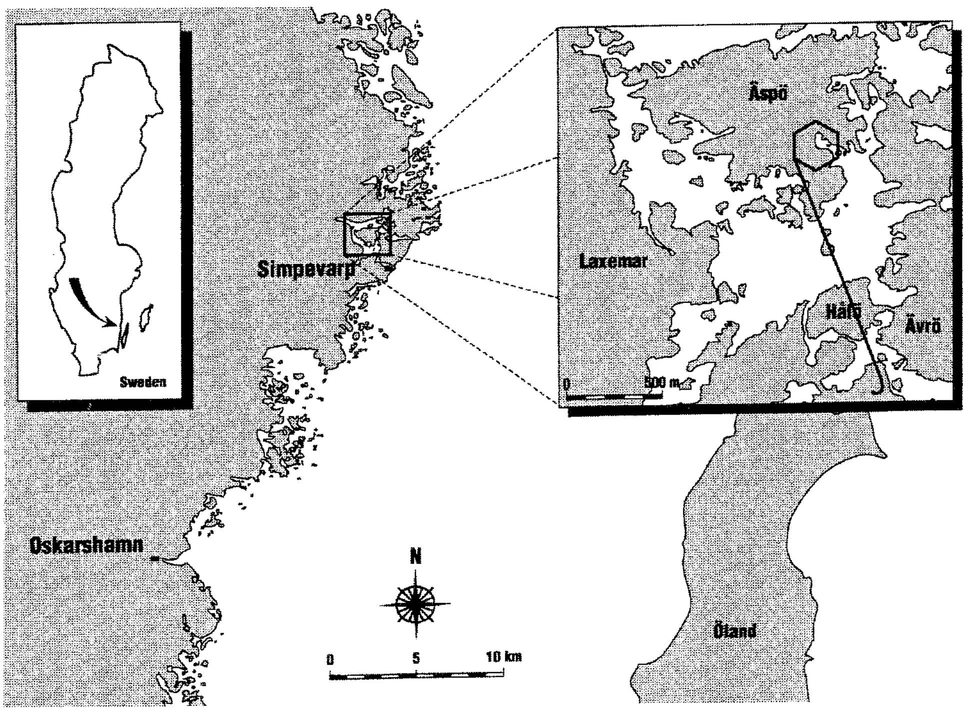


Figure 1-1. *Location of the Äspö HRL.*

during construction of the laboratory. The investigations have been summarized in eight Technical Reports /1-2--9/. The construction of the 3900 m long access ramp to a depth of c. 450 m (see Figure 1-3) will be used to check the prediction models set up from the pre-investigation phase, to develop methodology for detailed characterization underground, including integration of construction/testing, and to increase the database on the bedrock properties in order to improve models of groundwater flow and radionuclide migration. A preliminary programme for the Operating phase has been set up, /1-10/ as a part of the general SKB RD&D Programme 92 /1-11/. The Operating phase will focus on research and the development of models for groundwater flow and radionuclide migration, tests of construction and handling methods and pilot tests of important parts of a repository system.

The project has so far attracted considerable international interest. As of March 1993, eight international organizations were participating in the Äspö HRL. They are Atomic Energy of Canada Limited (AECL, Canada), Teollisuuden Voima Oy (TVO, Finland), Agence nationale pour de gestion des déchets radioactifs, (ANDRA, France), Power Reactor and Nuclear Fuel Development (PNC, Japan), the Central Research Institute of the Electric Power Industry, (CRIEPI, Japan), NAGRA (Switzerland) UK NIREX Ltd and the US Department of Energy.

A detailed outline of the project (goals, scope, schedules, organization, previous work) can be found in RD&D Programme 92 /1-10/.

A chart of the 1993 organization is shown in Figures 1-4 and 1-5.

This annual report describes activities during 1993.

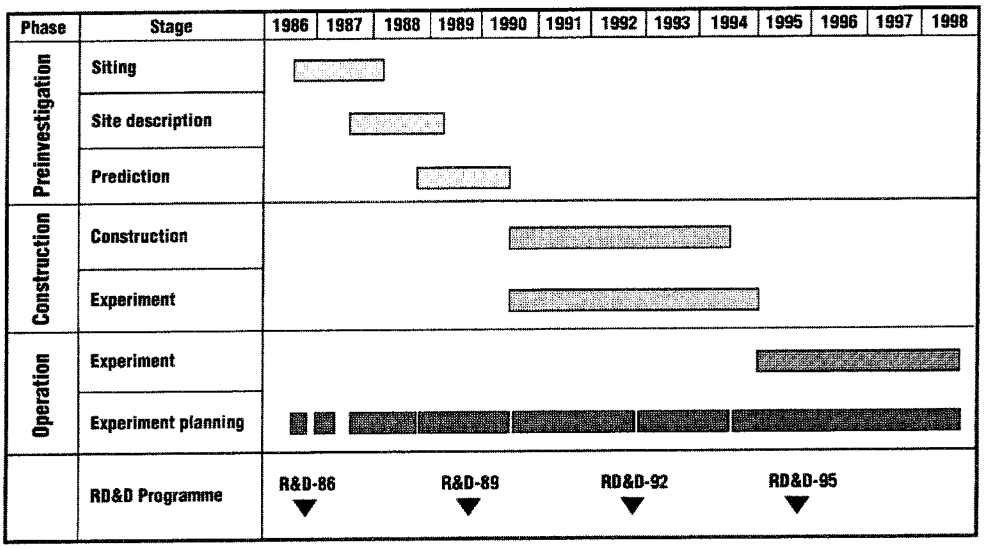


Figure 1-2. Master time schedule for the Äspö HRL.

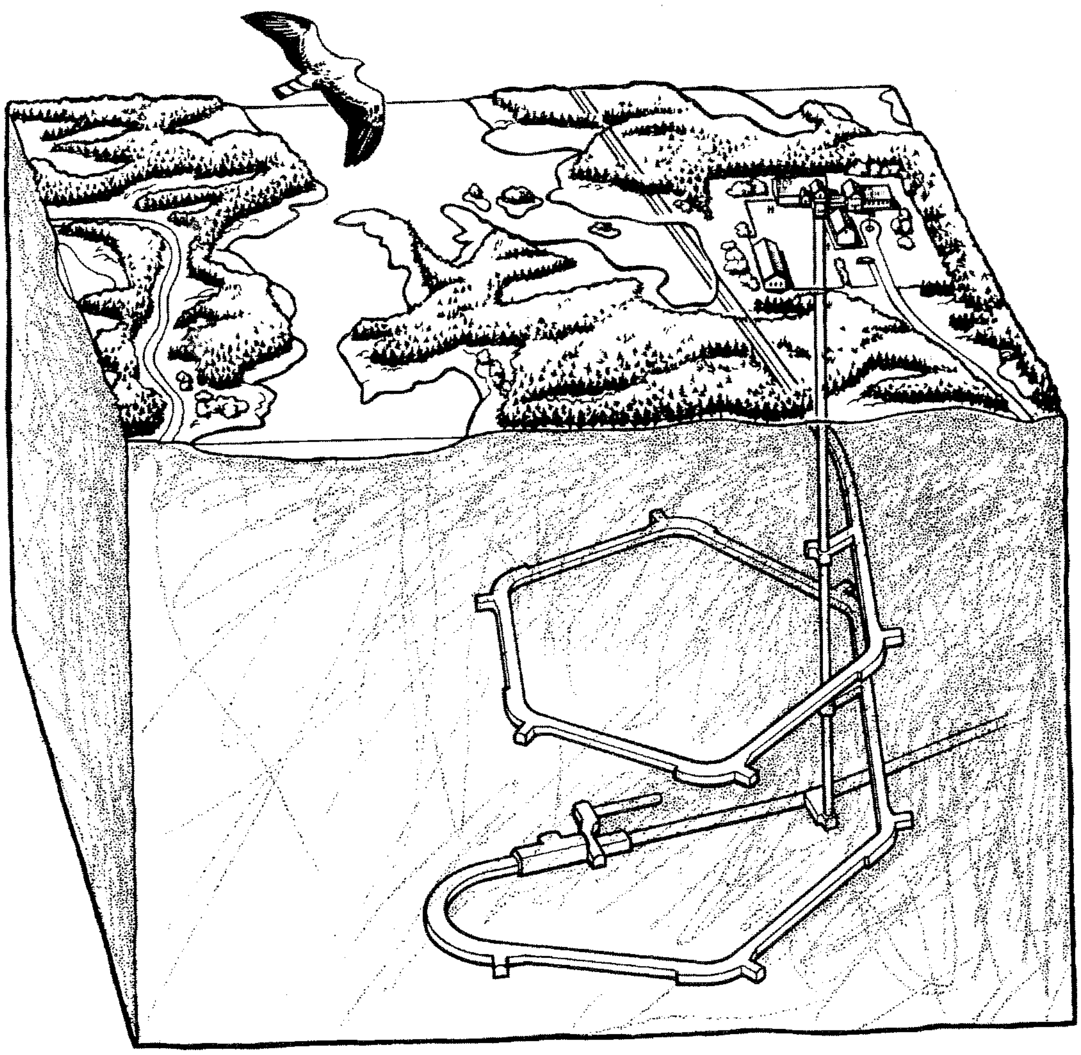


Figure 1-3. *Schematic design of the Äspö HRL. The lower part of the facility will be excavated by a 5 m diameter Tunnel Boring Machine.*

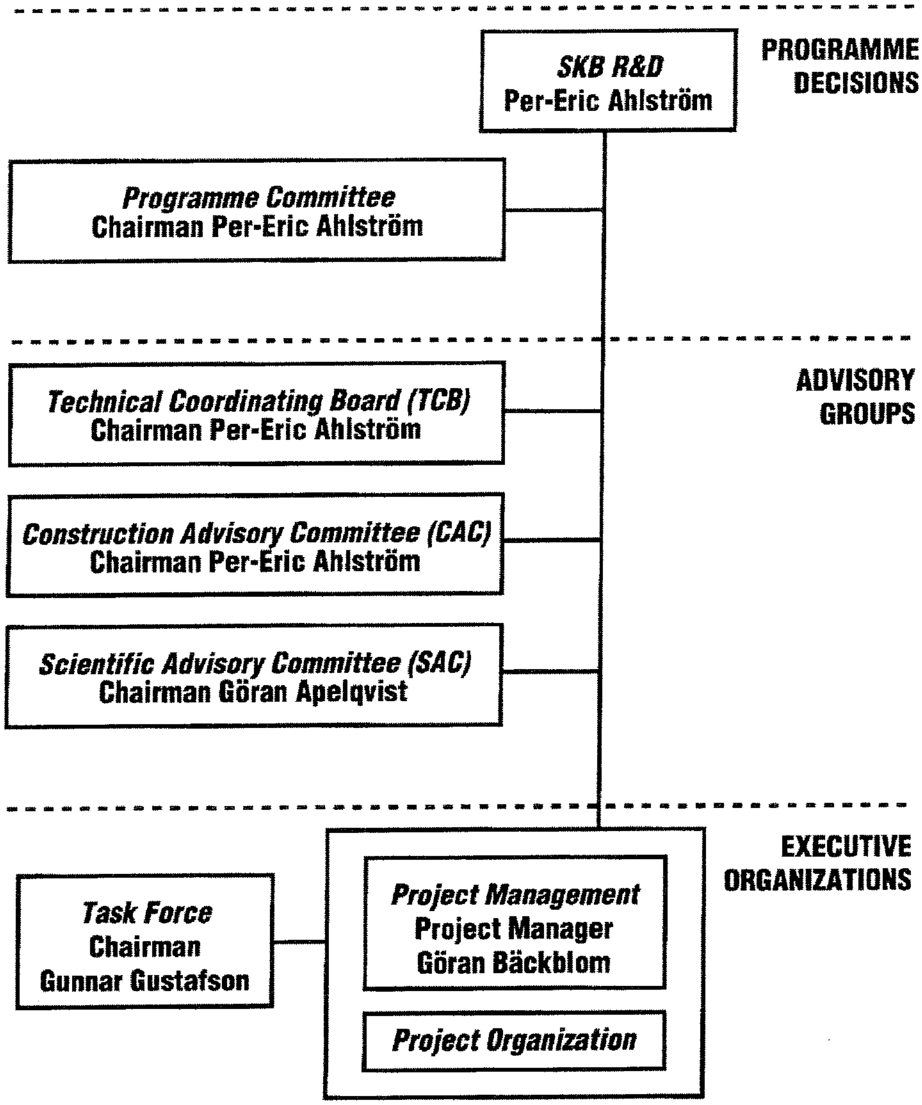


Figure 1-4. Äspö Hard Rock Laboratory - Overview of the organization 1993

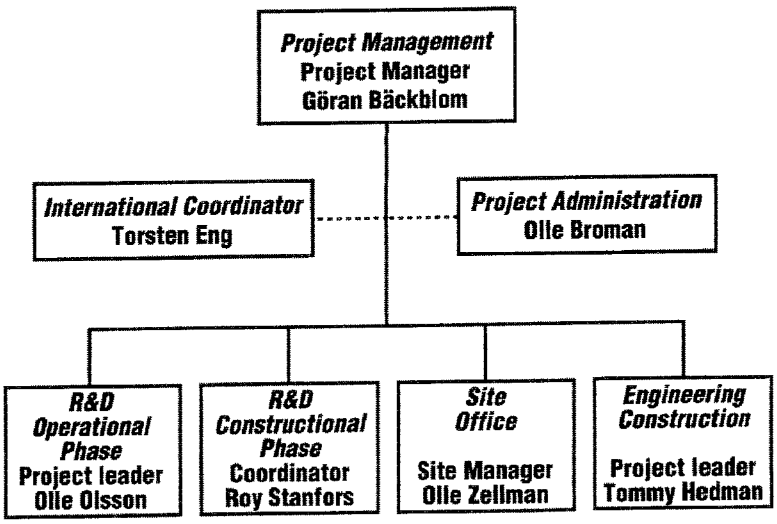


Figure 1-5. Äspö Hard Rock Laboratory - Project organisation 1993

2 VERIFICATION OF PRE-INVESTIGATION METHODS

2.1 GENERAL

The purpose of pre-investigations or site investigations is to:

- show whether a site has suitable geological properties
- provide data and knowledge concerning the bedrock on the site so that a preliminary emplacement of the repository in a suitable rock volume can be done as a basis for constructability analysis
- provide the necessary data for a preliminary safety assessment, which shall serve as support for an application under NRL (the Act Concerning the Management of Natural Resources) to carry out detailed site characterization
- provide data for planning of detailed site characterization.

It is thus important to show that pre-investigations provide reasonable and robust results.

In order to verify the pre-investigations methods, a strategy was set up, Figure 2-1.

This strategy entails predictive statements of certain rock properties. These statements have been structured to different geometrical scales for different key issues. The predictions have been reported in /2-1/. During construction of the facility these predictions of the bedrock are checked against the data collected during the construction work.

The evaluation of the models will be used to evaluate the methods used in the Pre-investigation phase. This evaluation covers strategy for the pre-investigation, methods for data collection, analyses, predictions and evaluations.

The knowledge will be applied in the planning for and execution of site investigations on the candidate sites for the deep repository.

2.2 DATA COLLECTION AT THE SITE OFFICE

Characterization in the tunnel is performed according to the established documentation manual by the Characterization Team at the Site Office. Overviews of the geological mapping, data on geohydrology, groundwater chemistry and bedrock stability and reinforcement/grouting are presented after every 150 metres of excavation in the tunnel in three different sheets. Sheets up to 2 526 metres have been compiled and distributed. An example is shown in Figure 2-2.

Separate tables on groundwater chemistry data (pH, Cl and HCO_3) are reported as well. Activities that have taken place in the tunnel, blasting, grouting, probe hole drilling, coring, packer settings and so on are reported in a Site Activity Data Base.

Ground water level data from all core-drilled and most of the percussion-drilled boreholes located on Äspö are transmitted to the Site Office by radio to the Hydro-monitoring system (HMS). Daily and weekly quality checking of preliminary data has been performed. Absolute calibration of groundwater levels in all sections in all boreholes was performed in mid-August, 1993. A measuring station positioned close to the shaft level at -220 metre, chainage 1650, collects data from boreholes located in the tunnel, from weirs positioned at regular intervals, see Figure 2-3, as well as values for velocity of ventilation air and tunnel air, humidity, amount of water pumped in to and out of the tunnel. This data are used for water balance determinations. All weirs in the tunnel have been calibrated to water inflow. Each metal sheet in the Thomson skiboard has been calibrated to three or four flow rates.

The personnel in the Characterization Team have been working during the year on compiling detailed manuals describing the work done to set up a formal Quality Assurance System.

2.3 EVALUATION OF MODELS AND METHODS

The first stage goal for Äspö HRL is:

1 Verify pre-investigation methods

- demonstrate that investigations on the ground surface and in boreholes provide sufficient data on essential safety-related properties of the rock at repository level.

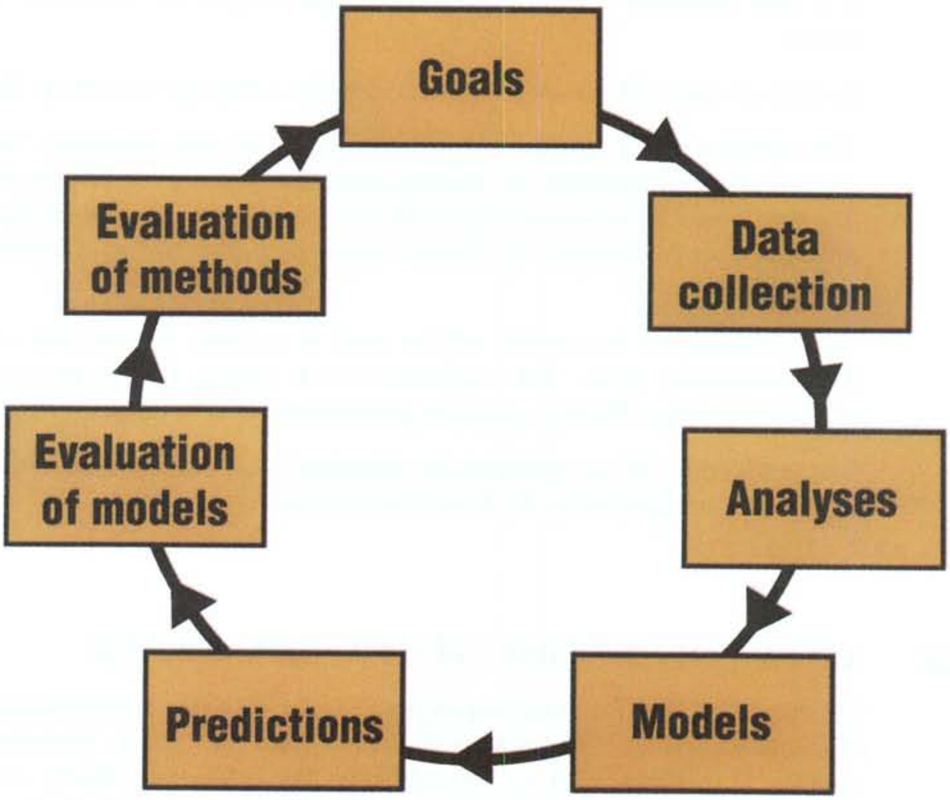


Figure 2-1. The strategy for the verification of the pre-investigation methods

Reporting on the evaluation of prediction models has been divided into four parts, related to the length coordinate along the tunnel.

An assessment of the agreement between prediction and outcome has been made for the first part, 0-700 m (depth 100 m), /2-2/. The comparison up to tunnel section 700-1475 m (depth 200 m) has been reported /2-3--6/.

The evaluation for tunnel section 1475 - 2265 was finished in early 1994 /2-7--10/. These results are discussed below.

The final reporting of experiences from the ongoing work started in the autumn of 1993. The outline of the report was presented at the Scientific Advising Committee (SAC) meeting in December 1993. The report is based on thirteen questions which are considered important for the planning and construction of a future deep repository. The report format for each chapter is generally as below:

X: Question:

Summary

X.1Background to question

X.2Experiences from Äspö

X.3Applicability to other sites.

Two examples of the questions are:

- How should the conditions (objectives, time, cost) for the pre-investigations be specified?
- What is needed to understand the site?

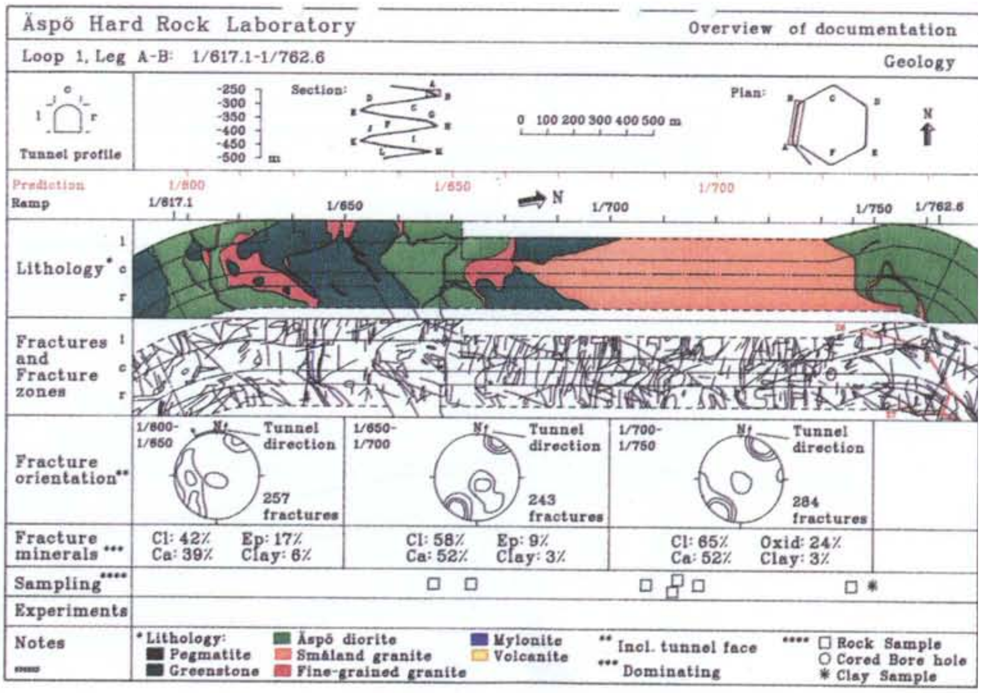


Figure 2-2. *Overview of documentation, geology sheet. Example from section 1617-1763 m.*

The report is not intended to give complete answers, but to highlight important experiences.

Geology:

An overview of the geological predictions and outcome for tunnel section 1475 - 2265 m is shown in Figure 2-4.

Some of the main results from the documentation of tunnel section 1475 - 2265 m are:

- On the site scale (500 m) it seems possible to make a useful prediction of the distribution of the main rock types Småland granite, Äspö diorite and fine-grained granite, but it seems to be more difficult to predict the distribution of greenstone.

- Based on general information about a rock mass and local cored boreholes it seems to be rather difficult to make useful predictions - on the block scale (50 m) - of the distribution of the main rock types at depth in a relatively inhomogeneous rock mass.

- It also seems possible to predict the distribution and mean number of rock boundaries to rock types.

- It seems possible to make a rather good fracture frequency and fracture density prediction, providing a general model of the structural geology is set up.

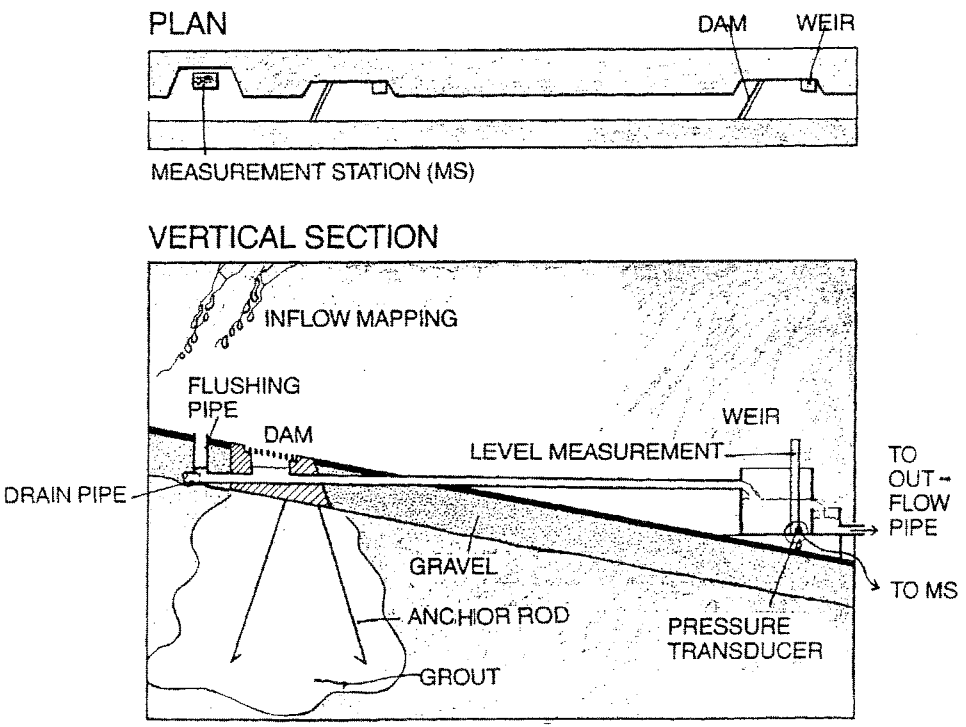


Figure 2-3. *Principal layout of dams and weirs used for determination of leakage into the tunnel at different intervals.*

During 1993 several coreholes (KA1751A, KA1754A, KA2084B and KA2162B) have been drilled from the tunnel for the main purpose of investigating fracture zones around the tunnel (see Figure 2-5 for borehole locations).

The major fracture zone NE-2 - which was predicted to be "major" - has been demonstrated underground as being 0.5 - 3 m wide strongly foliated mylonites in two sections in the tunnel. NE-2 probably consists of two instead of one zone.

The gently dipping zone EW-5 - which was predicted as "possible" - has not been confirmed underground.

A "swarm" of minor NNW-NNE striking fracture zones were predicted to be hydraulically important and penetrate the southern Äspö area and a number of narrow fracture zones - a few metres wide - have also been mapped in the tunnel and pre-grouted sections confirm hydraulic conductors.

Geohydrology:

The water levels on southern Äspö started to decrease autumn 1991 and continued decreasing during 1992 and 1993. In Figure 2-7 the water level is shown when the tunnel face was at chainage 2195 m. The groundwater levels have also decreased in boreholes on Hålö (close to the tunnel), Mjälen and in some boreholes on Ävrö (north-western part), see Figure 2-6. The levels on Laxemar seem to be undisturbed by the tunnel excavation.

As can be seen in Figure 2-7 there is good correspondence between prediction and outcome. However, the predicted level is lower than the outcome. This is due, at least partly, to the measured inflow rate being lower than the predicted rate for the spiral but higher for tunnel section 700 - 1475 m.

The outcome of the inflow to the tunnel section 1450 - 2345 m was approximately $12 \cdot 10^{-3}$ m^3/s and the predicted inflow was 150 % of the outcome. The outflow of

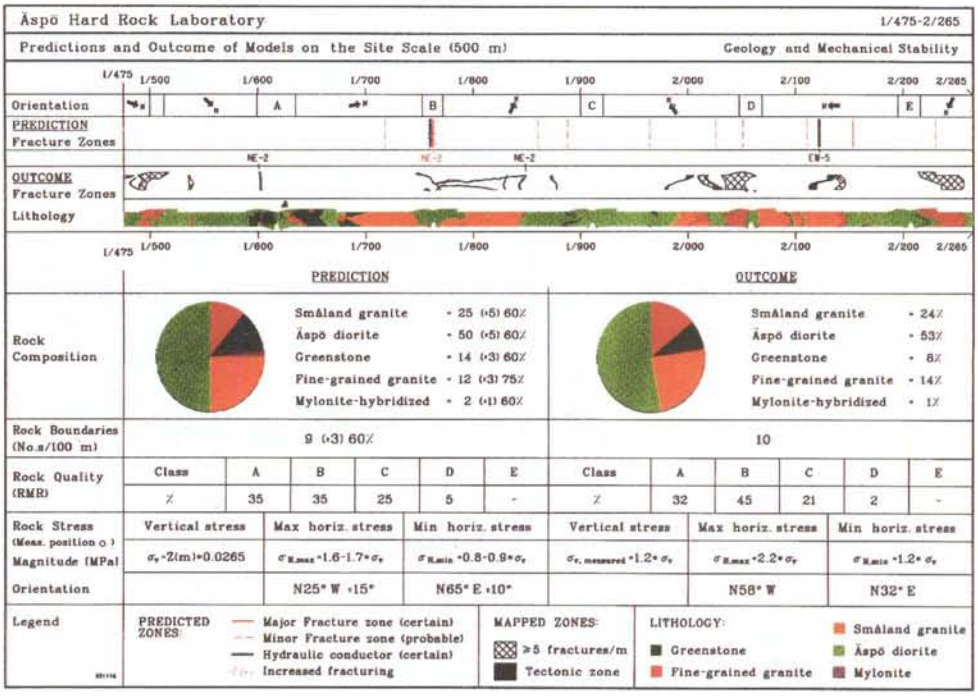


Figure 2-4. *Overview of geological predictions and outcome, tunnel section 1475 - 2265 m.*

water with the ventilation air is small, up to $0{,}1 \cdot 10^{-3}$ m^3/s but generally smaller. The total inflow to the tunnel is approximately $30 \cdot 10^{-3}$ m^3/s, see Figure 2-8.

During the supplementary investigations one very conductive structure (NNW-4), more or less vertical, striking N10°W was found between tunnel section 2020 and 2140 m - see Figure 2-5. The structure was confirmed by the results from the drilling of KA2048B, HA1060A, HA2025A-B and HA2074B.

During the drilling of KA2162B, pressure was monitored in some boreholes in the tunnel and the boreholes from the ground surface. The drilling through several structures intersecting KA2162B, several more or less vertical NNW striking structures (see Figure 2-5). Two of the structures may have been the predicted structures NNW-1 and NNW-2.

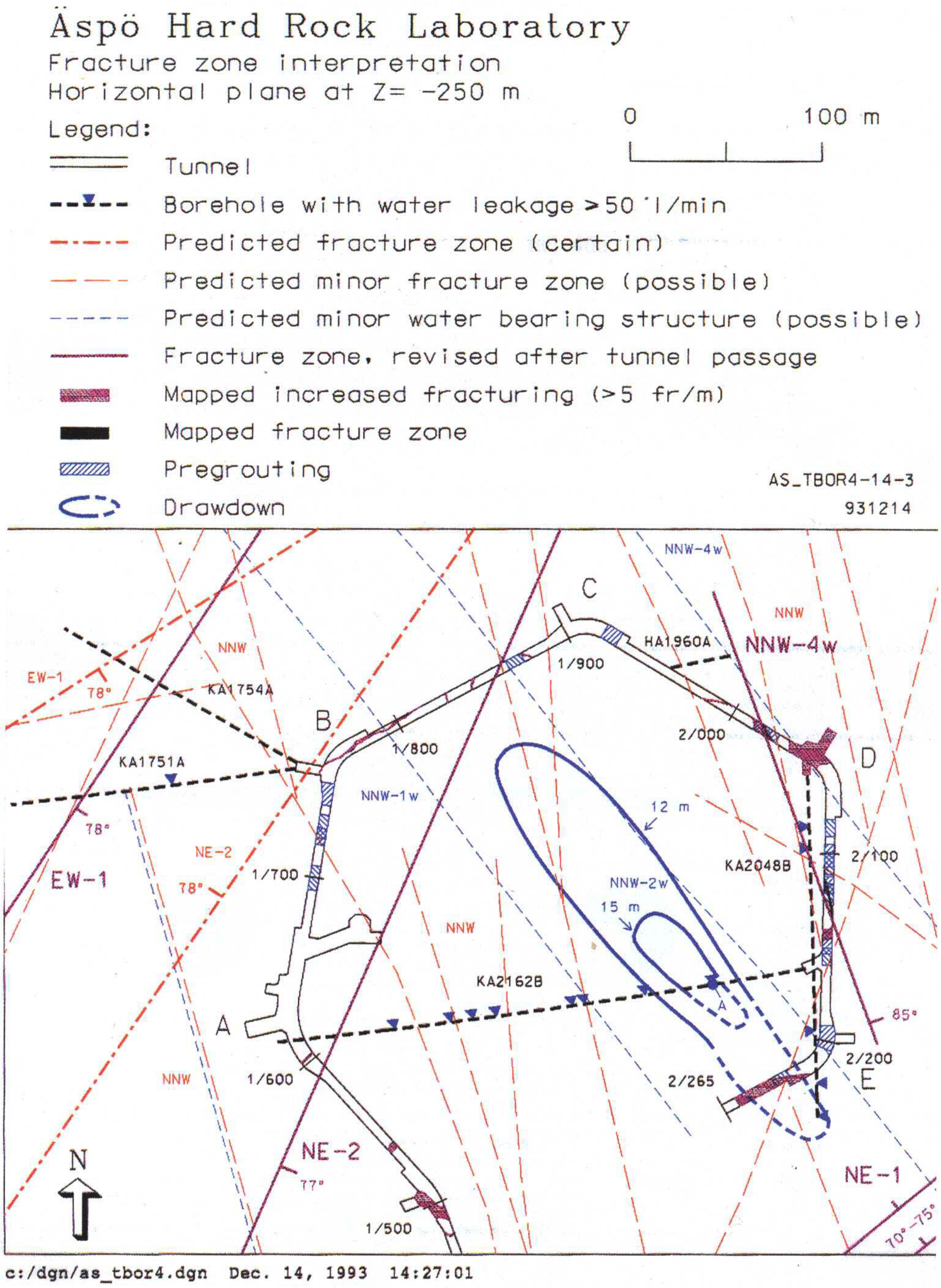


Figure 2-5. *Supplementary investigations in tunnel section 1400 - 2200 m. Drawdown ellipse during drilling through a water conductor at drill depth 49 - 53 m.*

Groundwater chemistry:

Hydrogeochemical documentation serves different purposes. Data are used to:

- Compare predictions of the groundwater composition with observations and thus test the reliability of the pre-investigation methods.

- Assess the role of the groundwater-rock chemical system in changes caused by the enhanced circulation of water with regard to redox conditions and biological processes.

- Improve knowledge of the important processes affecting the chemistry of the groundwater and possibilities for evaluating groundwater flow based on geochemical data.

Groundwater sampling is done in probe holes at the tunnel face, and repeated in packed off probe holes at Äspö.

Dilution tests are performed in monitoring boreholes at Äspö in order to evaluate predictions of groundwater flow. The results are analyzed together with changes in the chemical composition of the water and used to evaluate transport on the site scale. Isotope data from the probe holes are used.

Groundwater samples have been collected from 32 different locations in the tunnel between 1475 and 2265 m. The sampling points are 25 probe holes 20 m deep at an angle of 20 - 45 degree out from the tunnel, two cored investigation boreholes and two water conducting spots on the tunnel wall.

In most of these sampling points the composition has been stable without any systematic change. In those cases where there has been a change it has been towards more saline water, indicating a withdrawal of more saline water from deeper levels, Table 2-1.

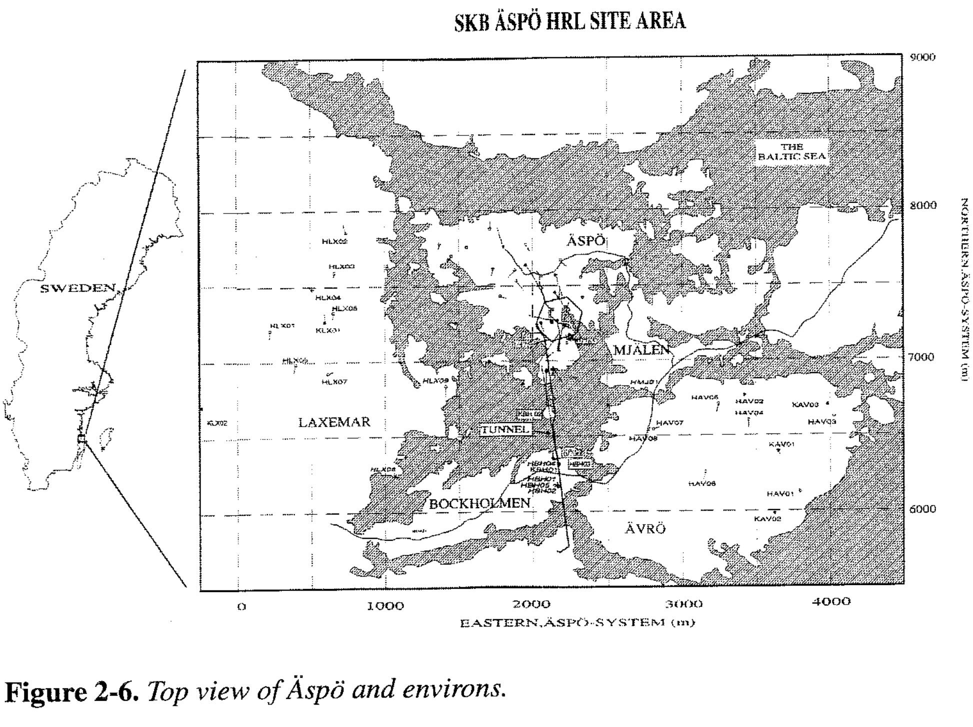


Figure 2-6. *Top view of Äspö and environs.*

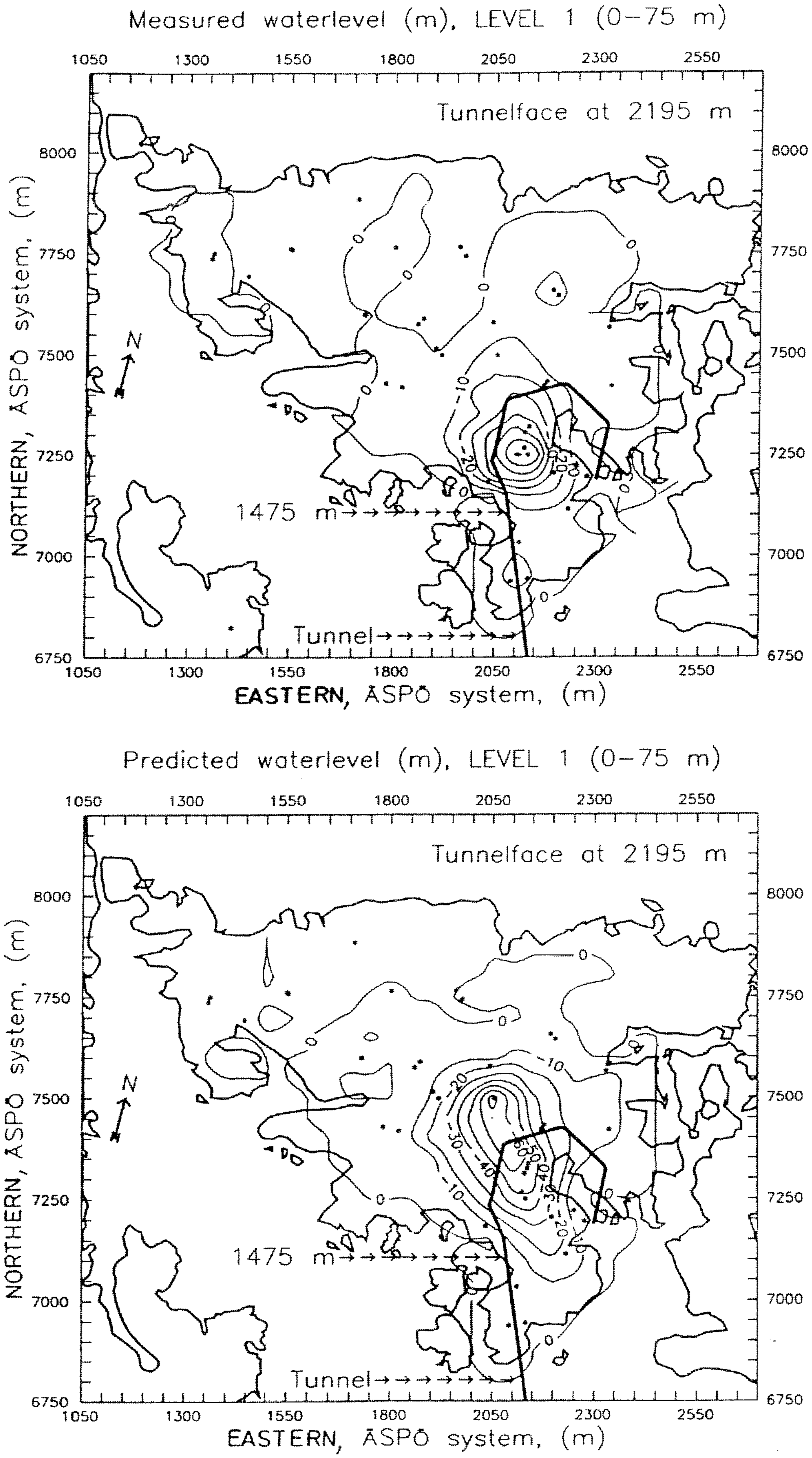


Figure 2-7. *Water levels on Äspö with the tunnel face at chainage 2195 m. Outcome above and prediction below.*

The grouting effects are seen in an increase in both pH and potassium concentration. It seems as if the pH effect is seen only shortly after the grouting, whereas the potassium effect persists for a longer time.

Only a few of the samples have been analyzed for ferrous and ferric iron. These samples clearly show that the iron is in ferrous form and that reducing conditions prevail.

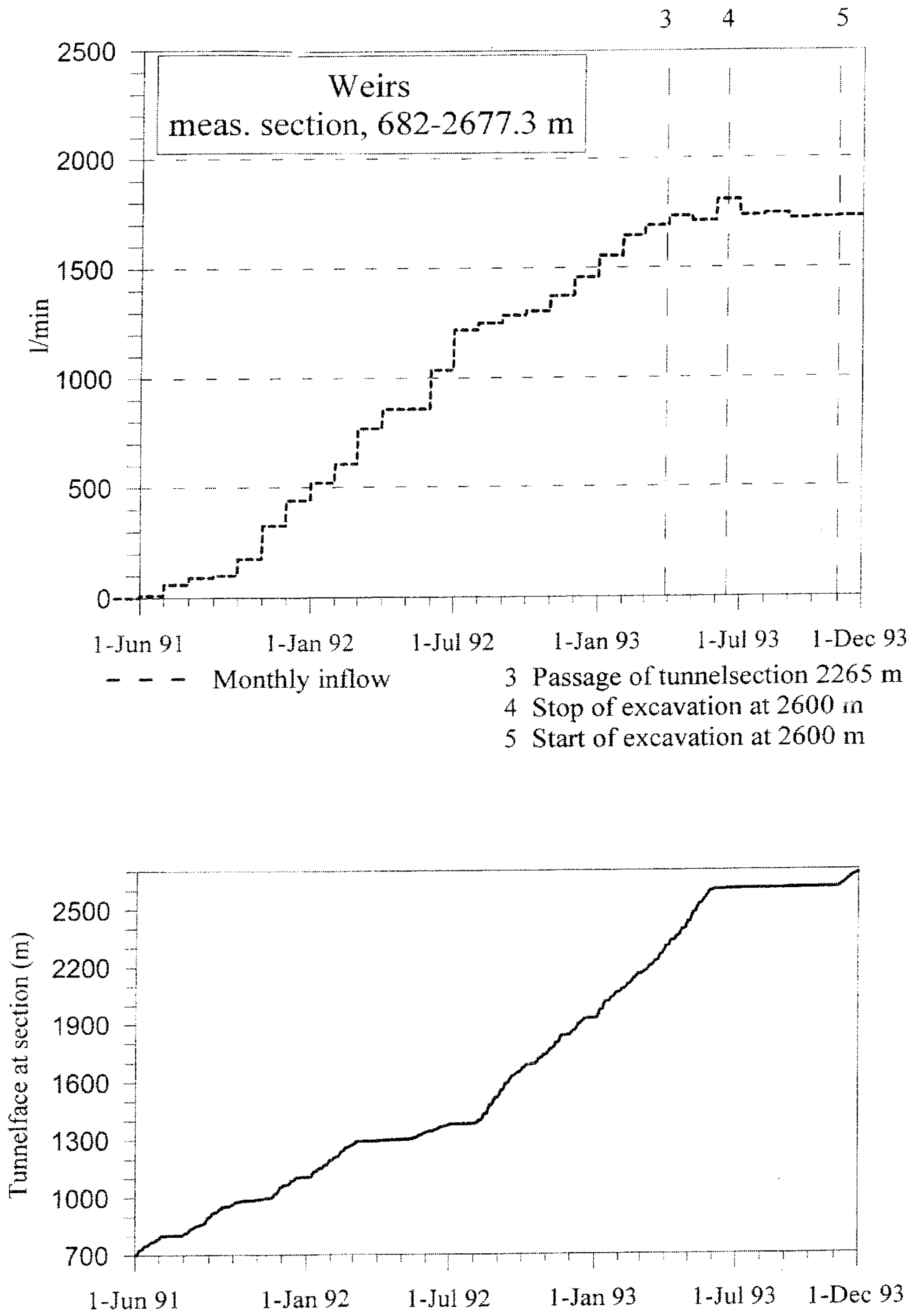


Figure 2-8. *Flow into the tunnel section 0 - 2677.3 m. The monthly flow into the tunnel is the sum of the monthly estimated or measured flows into the tunnel at each weir.*

Two thirds of all samples had a bicarbonate concentration of less than 80 mg/l and the maximum concentration was 237 mg/l. In tunnel section 700 - 1475 m half of the samples had more than 500 mg/l with a maximum value of 1200 mg/l. For sulphate the situation is the opposite. In this section the concentrations are above 150 mg/l, whereas only a few samples from the preceding section reached that high.

Biological sulphate reduction is taking place in tunnel section 700 – 1475 m. The quite different data from this tunnel section indicate that this process is not occurring in tunnels section 1475 – 2265 m. Therefore the assumption that the sulphate reduction is related to the bottom sediments of the Baltic Sea seems to be appropriate.

The predicted composition of the groundwater in major fracture zones and the salinity in the zones are different from the observed values. The reason for this is unknown. There are, however, different possible explanations, either a poor prediction method or incorrectly modelled groundwater conditions.

Therefore three different prediction methods were compared - i.e. predictions based on principal component analysis, linear regression and neural networks. The data from the boreholes close to the tunnel are used to predict the data in the tunnel. The accuracy of the predictions is then checked with the observed chemistry in the tunnel.

Principal components

The values to be predicted could be regarded as missing data in a matrix. The principal components are computed directly from the known data values.

Linear regression

The multiple linear regression model is based on the least-squares method that minimises the distance between the observed values and the model equation.

Table 2-1. *Observed and predicted concentrations of main and redox sensitive constituents in the groundwater collected from probing holes in the tunnel section 1 475-2 265 m. The predicted values are in italics.*

CONDUCTIVE ZONES	**Na^+ mg/l**	**K^+ mg/l**	**Ca^{2+} mg/l**	**Mg^{2+} mg/l**	**Cl^- mg/l**	**HCO^- mg/l**	**SO42 - mg/l**	**Fe^{tot} mg/l**	**pH -**	**Eh mV**
NE-2	*1200 ±300*	*5 ±5*	*1100 ±300*	*30 ±30*	*3800 ±1000*	*70 ±50*	*140 ±40*	*0.3 ±0.3*	*7.7 ±0.1*	*-290 ±40*
NE-2	1900 ±100	8 ±3	1500 ±300	65 ±15	6200 ±400	50 ±20	380 ±60	0.6 ±0.2	7.4 0.1	
EW-5	*1300 ±300*	*5 ±5*	*1200 ±300*	*30 ±30*	*4100 ±800*	*70 ±20*	*150 ±50*	*0.3 ±0.3*	*7.8 ±0.2*	*-300 ±25*
NNW-4	*500 ±200*	*5 ±5*	*400 ±200*	*30 ±30*	*1500 ±1000*	*150 ±50*	*150 ±50*	*0.3 ±0.3*	*7.8 ±0.2*	*300 ±25*
NNW-4	1700 ±100	3 ±2	1000 ±100	4 ±	4500 ±500	130 ±50	280 ±30	-	7.9 ±	-

Neural networks

Artificial neural networks contain artificial neurones organised in layers and connected to each other in a complicated way simulating the human brain. Each neurone in a layer is connected to all neurones in the previous and the following layers. The connections between the neurones have different strengths. The neurone computes its output signal as a weighted sum of its input signals. Neural networks learn by associations, from examples, by comparison, and by repetition.

The results of using principal components, linear regression and neural networks show the observed and predicted values made by the neural network to have a higher resolution. The natural element variation (except Ca) is well captured by the prediction. No other model seems to be able to predict the element changes with the same accuracy, see Figure 2-9 .

Groundwater flow rate and hydraulic head measurements were utilized in the study of five selected borehole sections straddling conductive fracture zones on Äspö. For the sake of comparison the electrical conductivities of all borehole sections are presented based on the measurements made at the time of installation of the packer system. In addition, changes in groundwater chemistry caused by drainage into the access tunnel are used as an indicator of solute transport. The natural tracers tritium and oxygen-18 are also used.

The access tunnel has a great impact on the flow conditions and groundwater chemistry at Äspö. Of the five studied borehole sections, three had been measured for groundwater flow rate under undisturbed, natural gradient conditions as well.

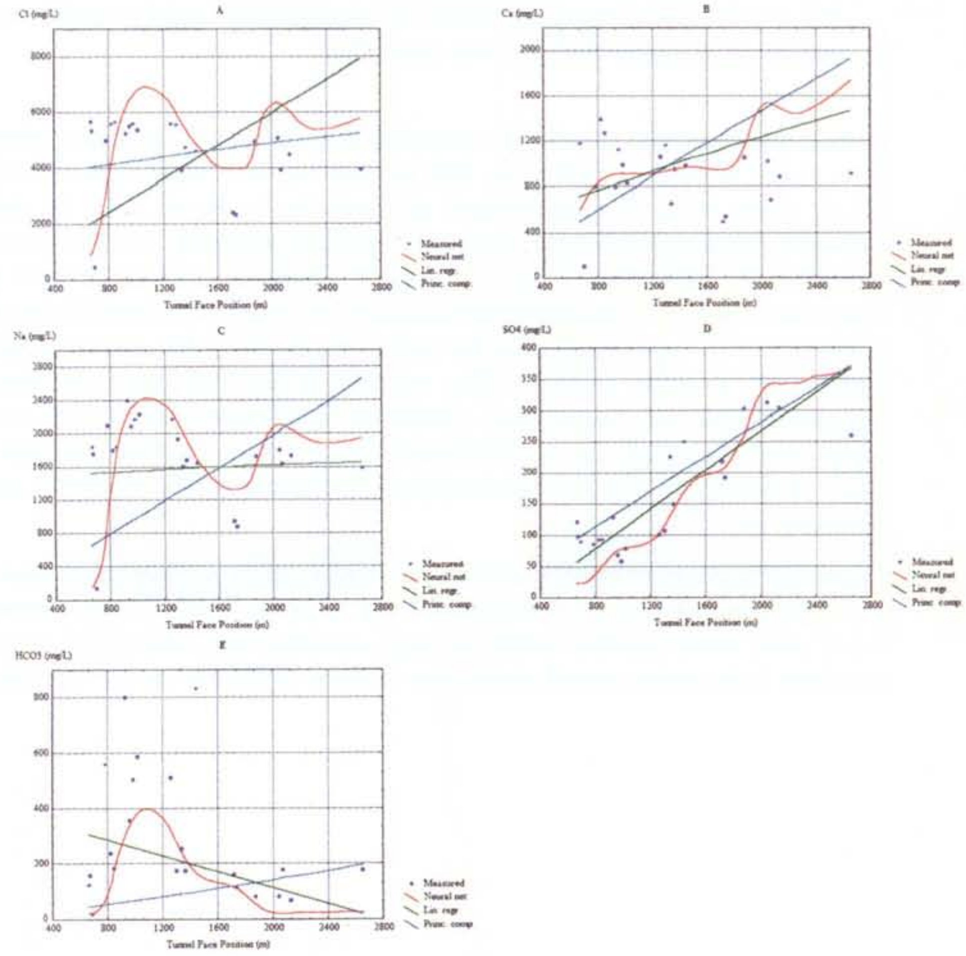


Figure 2-9. *Results of three different prediction methods compared with observed conditions for tunnel section 700 - 2500 m.*

Already when the tunnel face was close to the major fracture zone NE-1, groundwater flow rates through these borehole sections changed markedly. The chemical composition changes slower than do flow rates, and the impact on chemistry of the tunnel drainage is not clearly seen until the tunnel face has breached and passed zone NE-1 at position 1450 metres. The transport of solutes clearly increases in the system of interconnected fracture zones at Äspö when the access tunnel breaches the fracture zone NE-1.

Rock stress measurements:

During the Pre-investigation phase, stress measurements were conducted in some of the deep surface boreholes. Based on these early results, stress conditions at a number of locations along the access ramp were predicted.

Further stress measurements are being conducted in short holes drilled from selected locations along the access ramp. The CSIRO Hollow Inclusion overcoring technique is used, and 3-5 overcoring tests are performed in each borehole at a distance from the ramp sufficient to ensure that data are not influenced by excavation-induced stresses. The objectives are:

- To evaluate predictions made prior to excavation
- To provide background data required to establish stress conditions on a site scale. The overall state of stress determines the mechanical boundary conditions for the various experiments that are to be conducted.

To date, measurements have been completed in a total of nine boreholes distributed along tunnel section 1050-2510 m. This corresponds to vertical depths of 140 m to 330 m. Some of the results obtained are indicated in Figure 2-10. In summary, measured stresses are somewhat more scattered than predicted. Possible correlations between stress variations and local geological conditions have not yet been studied in any detail, however. Excluding the maximum principal stress, average magnitudes are as would be expected. As can be seen in Figure 2-10, the maximum principal stress at 300 m depth is 20-25 MPa, which is in the high range compared with background data from Scandinavia. Measured stress orientations show a very consistent, near-horizontal and NW-SE orientation of the maximum principal stress. This is in agreement with results from the surface boreholes and appears to apply for the entire site.

A programme has been established that stipulates remaining excavation-stage activities relating to rock stress investigations. Work to be done includes measurements at two or three more locations along the ramp, checking and compilation of all stress data from Äspö and an overall evaluation of stress conditions on the site scale.

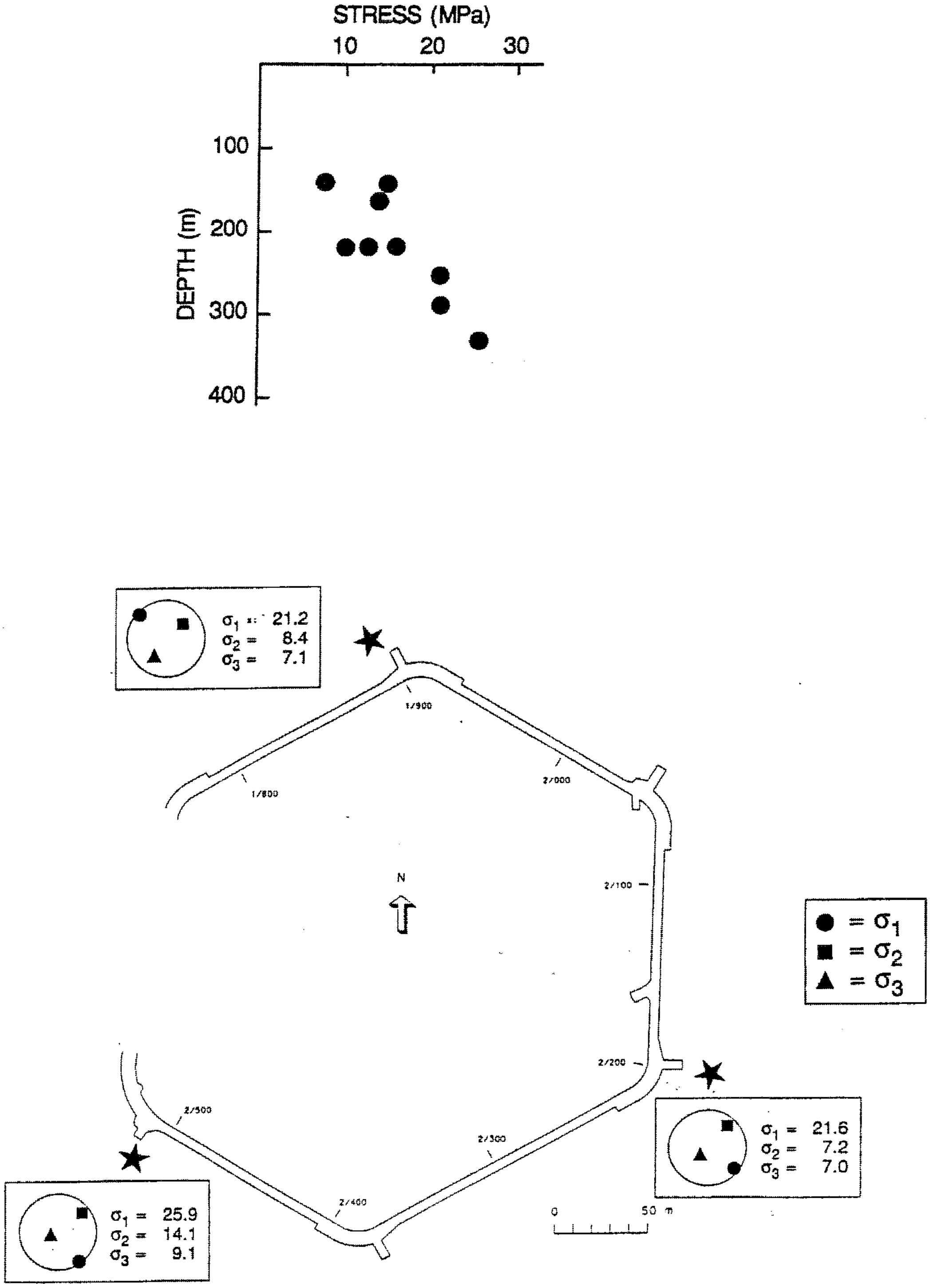


Figure 2-10. *Results from overcoring stress measurements in boreholes drilled from the access ramp.*
Upper: Maximum principal stress magnitude as a function of depth. Each data point represents an average of 3-5 overcoring tests.
Lower: Results from the three measurement locations, the deepest to date. Depths are 240-330 m. Principal stress orientations are shown in the lower hemisphere, equal area projections.

2.4 CODE DEVELOPMENT

At Äspö HRL several numerical models have been tested and are being tested and developed.

One of the program codes being used is called PHOENICS. This code was developed during 1993. It is now possible to generate non-planar fracture zones with stochastically distributed transmissivities.

There is also a need for effective visualization when you are modelling in 3D. As a part of code development, different visualization techniques (for example using the program Date Visualizer) have been tested and will be used for modelling during 1994. An example is shown in Figure 2-11. An example of code development is also shown in Figure 2-12.

As there has been a lot of development of sub-programs to the code PHOENICS, there has been a need to document this development so others can make use of it. This documentation project has just started and will be reported in 1994.

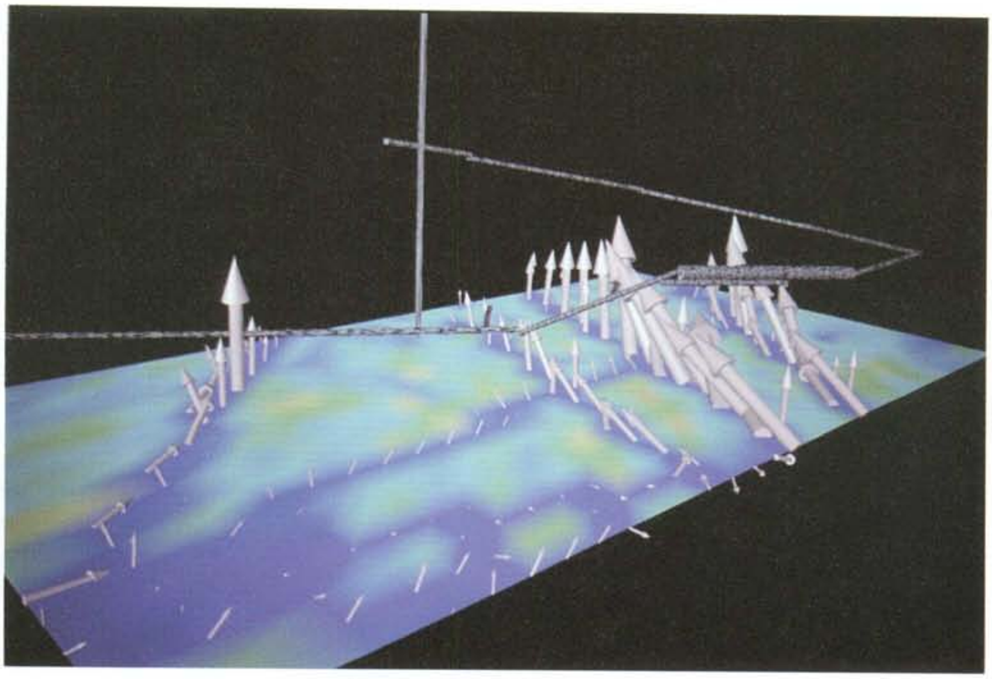


Figure 2-11. *Flow and conductivity fields at a depth of 480 m.*

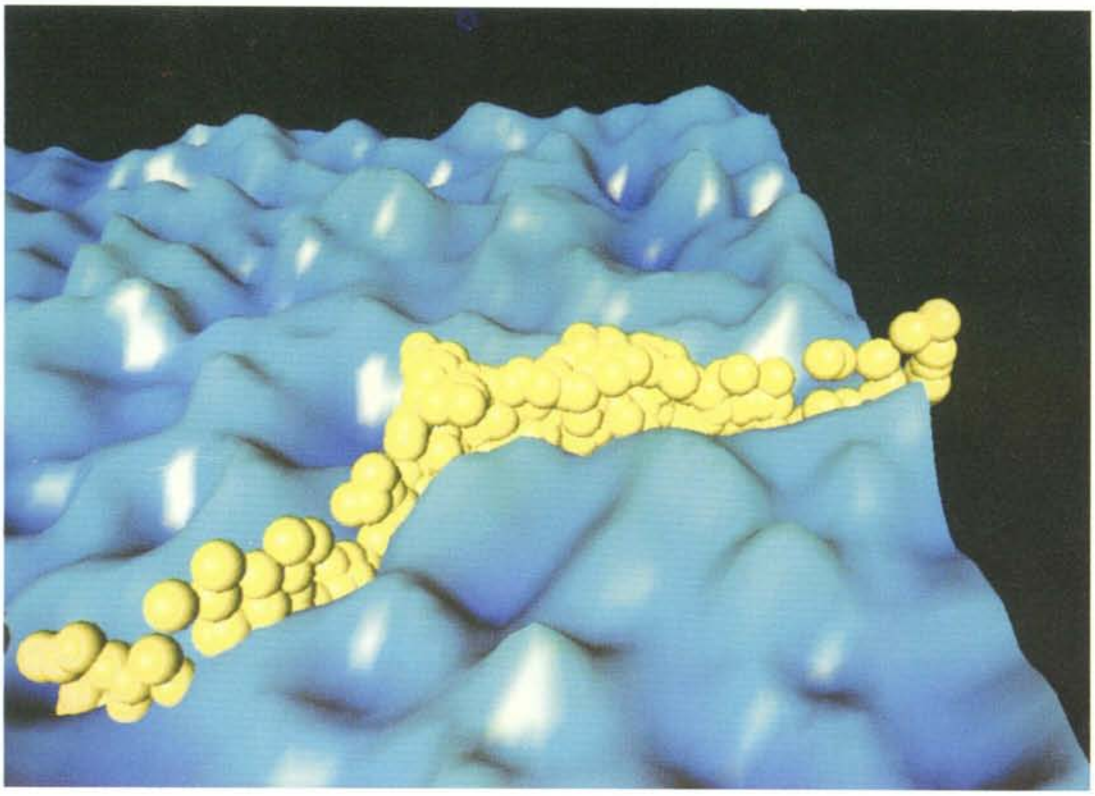


Figure 2-12. *Scoping calculations for the MWTE experiment. Particles are injected as a point source at the left boundary and transported and dispersed. The velocity field is calculated as a laminar three-dimensional flow in a fracture with a varying aperture. Taylor dispersion is thus not parameterized. Molucelar diffusion is considered by the particle tracking method used. The fracture is assumed to have a symmetry plane and hence only one boundary of the fracture is shown in the figure.*

3 METHODOLOGY FOR DETAILED CHARACTERIZATION OF ROCK UNDERGROUND

3.1 GENERAL

The selection of candidate sites for the deep repository will be based on the fundamental requirements that must be made on a deep repository site from safety-related, technical, societal and legal viewpoints. It must be possible to demonstrate that the safety requirements stipulated by the regulatory authorities are complied with, and to build the repository and carry out the disposal technically. Siting, the investigations and construction shall be carried out so that all legal and planning requirements are met. And last, but not least, it shall be possible to carry out the project in collaboration with the municipality and the local population.

The detailed characterizations will encompass investigations during construction of shafts/tunnels to repository depth. Finalizing the detailed investigation methodology is stage goal 2 of the Äspö project.

The purpose of detailed site characterization is to:

- finally confirm the suitability of the selected site and rock volume

- provide the necessary data for a safety assessment, which shall serve as support for an application under NRL (the Act Concerning the Management of Natural Resources) and KTL (the Act on Nuclear Activities) to construct a deep repository on the selected site

- provide data and knowledge concerning the bedrock on the site for planning and execution of the rock construction work for the deep repository.

Important skills are to be able to build in and investigate both the bad and the good rock with adequate personal safety. Data shall be collected and evaluated in parallel with the tunneling.

Experience from Äspö serves as a basis for planning of SKB's coming detailed characterization of a possible deep repository site. Methodology shall be available by not later than the time of the application under NRL in 1998.

The detailed characterization will give a refined picture of the conceptual models obtained from the pre-construction investigations. These conceptual models shall be used to up-date the layout of the repository. Due to the heterogeneity of the rock, the layout can and shall be adapted to the gradually refined conceptual models of the rock. This approach has a long tradition in underground construction and it should also be used for a deep geological repository.

The Äspö Hard Rock Laboratory will demonstrate the deepening of knowledge that is possible to achieve in relation to the evaluation made during the Pre-investigation phase. The Äspö Hard Rock Laboratory is also being used to test and develop the necessary techniques before they are applied at the candidate sites. Routines for data collection, documentation and reporting of results and evaluations can be tested under fairly realistic conditions at the Äspö HRL. The work described earlier in Chapter 2 constitutes the main bulk of the work needed to test underground characterization technology.

Management of the large quantities of data has been developed to the point where SKB is now in possession of a data production methodology that meets exacting requirements on quality and overview. This methodology is directly applicable to the planned detailed characterization work for a deep repository. The methodology has been developed for conventional tunnelling. Starting at a depth of about 430 m, the tunnel will be excavated using full-face boring - TBM. TBM adds considerable extra value to the project. The technology entails that the data collection methodology must be revised in certain respects.

When the deep repository is built a few years after the turn of the century, TBM will undoubtedly be the dominant method for underground rock construction. There are currently also technical means for boring downward-inclined tunnels. This means that the technology will also be of interest in connection with detailed characterization work, which is planned to start in 1998 at the earliest. In view of the above, it has been judged urgent to bore parts of the Äspö Hard Rock Laboratory facility right away.

Testing of TBM is of considerable added value for achieving this stage goal of the project. The methodology of coordinating TBM tunnelling and investigations will be tested under realistic conditions, in addition to the methodology that has already been tested in conjunction with conventional blasting.

3.2 LOCATION OF EXPERIMENTAL SITES AND LAYOUT OF TURN 2 OF THE FACILITY

3.2.1 Background

The layout of the underground excavations for the Äspö HRL was based on geological data obtained from surface and borehole investigations. The layout was designed to avoid major water-bearing fracture zones. The Operating Phase of the Äspö HRL will soon to commence and it was found essential that the layout of the laboratory be adapted to the experiments planned for the Operating Phase and that potential experimental sites be identified. During construction of the laboratory a decision was taken to change the excavation method from drill and blast to tunnel boring. This was made to test the feasibility of TBM excavation for a repository. Excavation by TBM was then planned to be used for excavation of the main laboratory tunnel below a depth of 400 m. The change of excavation method also prompted a reconsideration of the planned tunnel layout.

Starting in summer of 1993 an investigation programme was initiated with the following objectives:

- to provide data on rock properties to determine an appropriate tunnel layout below the 400 m level,

- to find suitable experimental sites within the Äspö HRL which meet the specific needs on the geological setting for each experiment, and

- to provide additional data to test the structural model of the Äspö site.

This investigation programme comprised drilling of four boreholes: KA2511A, KA2598A, KC0045F, and KA2050A. The location of these holes is shown in Figure 3-1. The investigation programme performed in these boreholes consisted of the following activities:

- borehole deviation measurements

- core logging with the Petrocore system (lithology, fracture mapping, RQD, alteration)

- borehole TV for orientation of fractures

- groundwater sampling for hydrochemical analysis

- directional radar

- cross-hole seismics (VSP)

- spinner to measure water inflow to the borehole

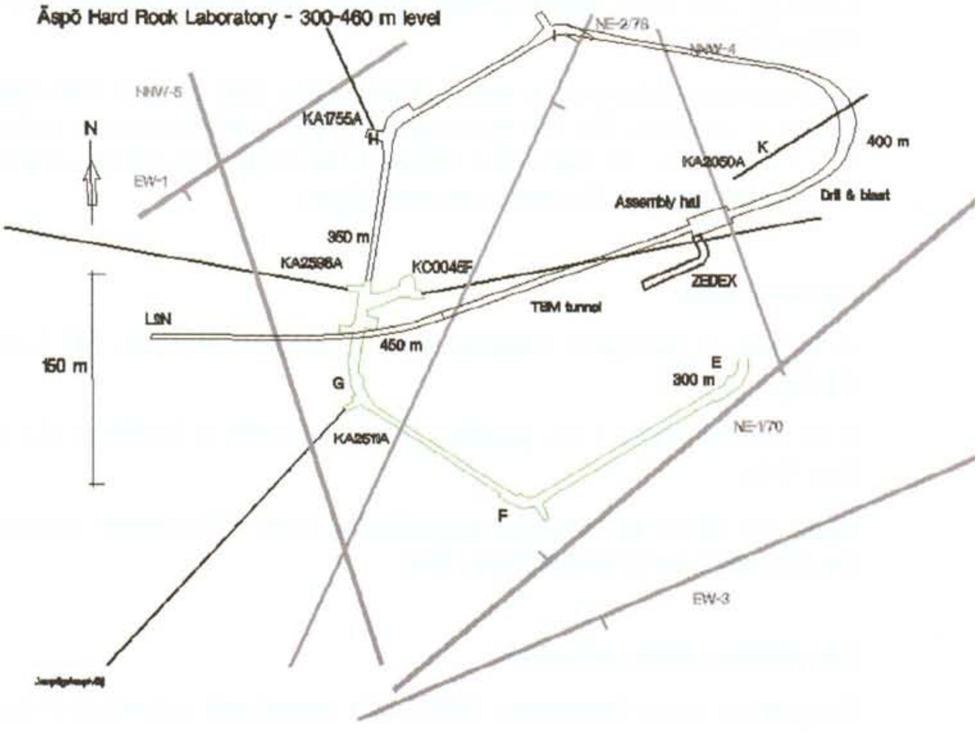


Figure 3-1. *Location of characterization boreholes and tentative tunnel layout for the second turn of the spiral.*

- hydraulic testing (pressure build-up tests at specified intervals during drilling and observation of hydraulic responses during drilling with the HMS system, injection tests at selected intervals)

3.2.2 New results

The drilling of the four boreholes was completed in late October 1993 and the measurements in these holes in late December 93.

Lithology and geohydrology

The new boreholes indicate that east of the spiral in the depth interval -400 to -500 m, the main rock type is Äspö diorite but Småland granite and fine-grained granite are also present. The rock quality around the planned location of the TBM assembly hall and the eastern curve is fairly good. However, a fracture zone called NNW-4, which probably intersects the TBM assembly hall, may pose some construction problems, mainly because of water. There may also be some conductive structures at the eastern curve.

Inside the spiral there is a large amount of fine-grained granite in addition to Äspö diorite and Småland granite. NNW conductive structures may be present inside the spiral at the experimental level. Borehole KC0045F indicates rather high transmissivities in the middle of the spiral and high at the eastern part, where NNW-4 is assumed to intersect the borehole.

West of the spiral the main rock types are Äspö diorite to the SW and Småland granite to the NW and the rock quality is mostly good. The initial hydraulic tests during drilling indicate that the rock mass has a rather low conductivity towards the NW and rather "normal" towards the SW.

Lithology and water inflows greater than 50 l/min in the boreholes are shown in Figure 3-2.

The total water inflow to the tunnel in December 1993 is about 1800 l/min (tunnel section 0 - 2 600 m). The first spiral has been rather dry. The average inflow for each leg (1.50 m) is 4 - 70 l/min. The inflow to two of the legs and the total inflow are shown in Figure 3-3. The results are preliminary.

Fracture zones

As a result of geological mapping of the tunnel and the shafts, NE-2 seems to be dipping to the SE.

A SE branch at EW-1 has probably been intersected in boreholes KA1751A and KA1754A.

Figure 3-4 shows the structural model for the level -340 m below sea level, i.e. the level the bottom of the tunnel has today.

The planned layout of turn 2

The planned layout (November 1993) of the second turn is shown in Figure 3-1.

The TBM assembly hall will probably be intersected by the structure NNW-4.

The TBM drift and the ZEDEX experiment are planned to be located west of the structure NNW-4.

From a position some metres west of the assembly hall the TBM tunnel will have an inclination of 140 ‰ down to about Z = -450 m. West of the shaft the TBM tunnel will have an inclination of about 20 ‰ upwards.

Numerical modelling of the groundwater flow situation around the planned tunnel and experimental sites has been done to predict the hydraulic gradients and the origin of the groundwater. The previous flow model of the Äspö site (based on the PHOENICS code) has been updated and used for this purpose. The results will be presented in a Progress Report which is currently being prepared.

An integrated evaluation will be made of the results obtained from measurements in these four boreholes and information available from other boreholes and documentation in the tunnel. The results will be documented in a Progress Report.

The selection of specific experimental sites and testing of their suitability will be based on additional investigations from the tunnel. These investigations are planned to start in the late autumn of 1994.

3.3 PLANNING FOR INTRODUCTION OF THE TBM

3.3.1 Background

The methodology of documentation and characterization work was originally developed for conventional drill-and-blast tunnelling.

Starting at a depth of about 420 m, the tunnel will be excavated using full-face boring - TBM. TBM adds considerable extra value to the project. The technology entails that the characterization and collection of methodology must be revised in certain respects.

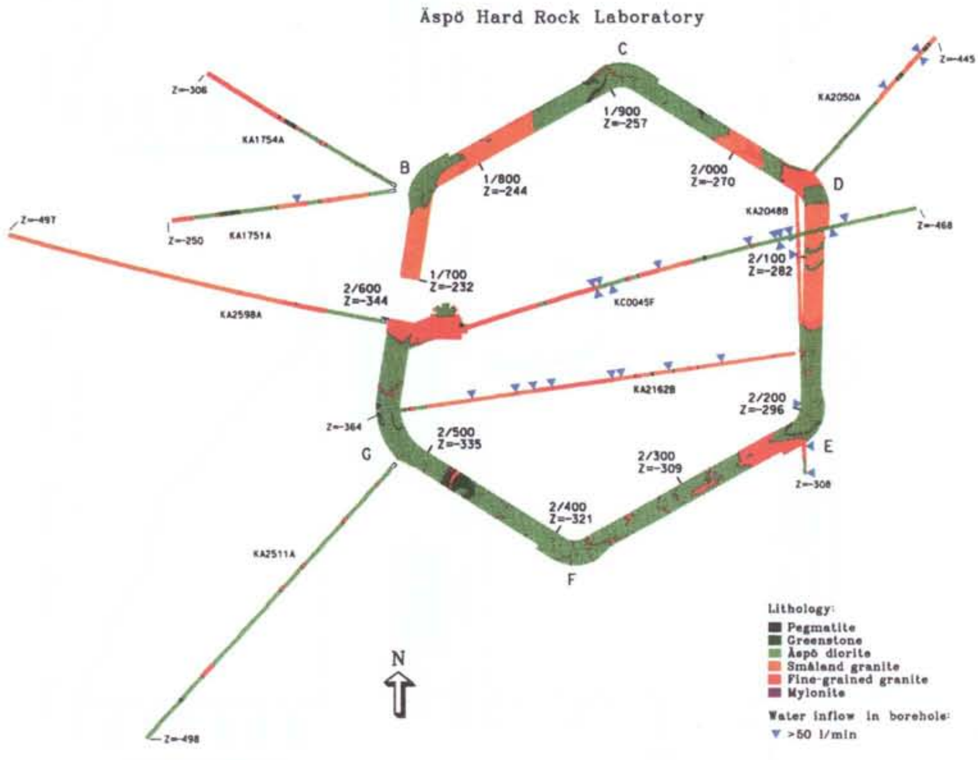


Figure 3-2. *Lithology and location of water inflows to boreholes greater than 50 l/min.*

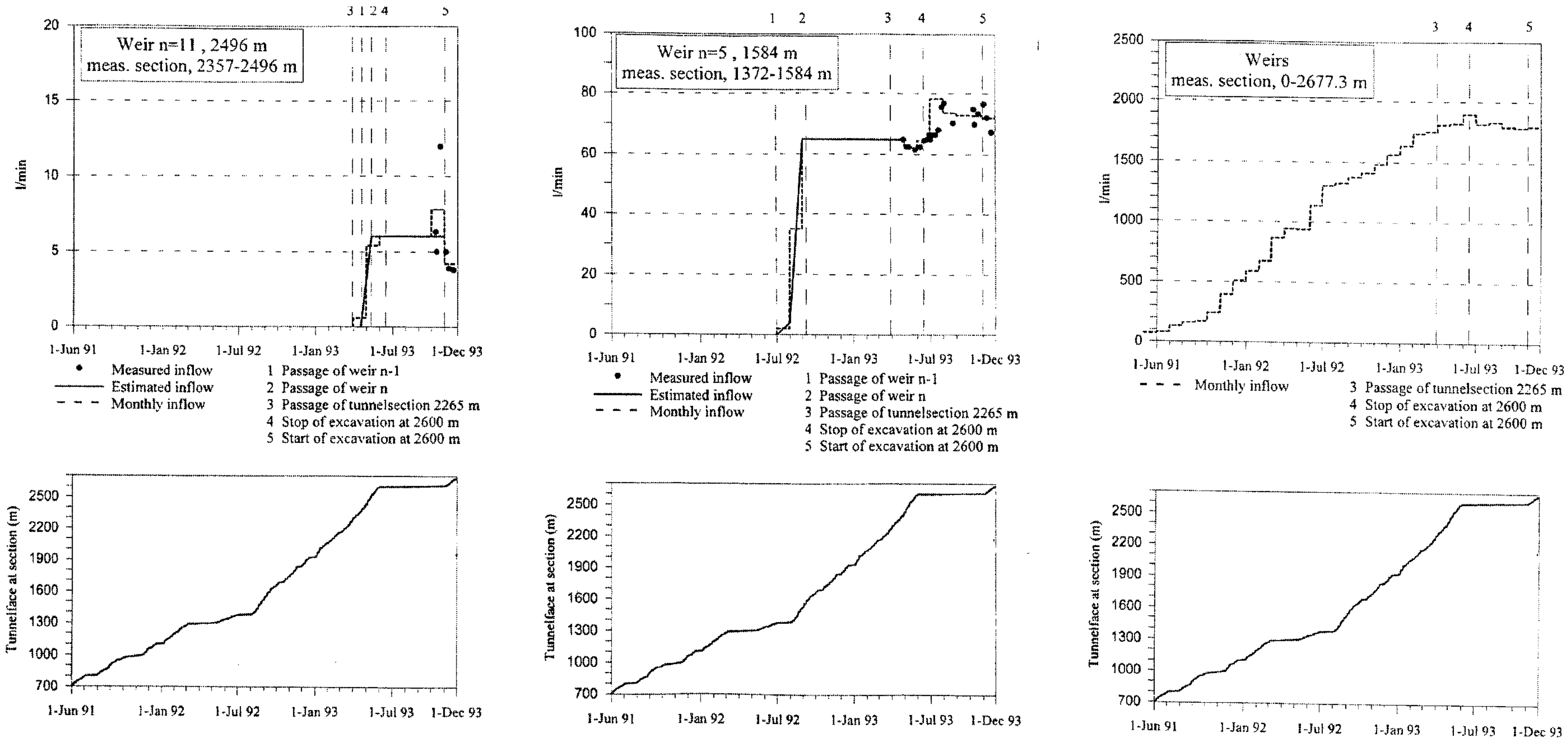


Figure 3-3. *Inflow to weirs as a function of time. The lower figures show the progress of tunnel excavation.*

The methodology of coordinating TBM tunnelling and investigations is planned to be tested under realistic conditions, in addition to the methodology that has already been tested in conjunction with conventional blasting.

3.3.2 Planned work

The characterization and documentation work for the TBM tunnel is planned to be tested in two different ways for the two parts of the tunnel - TBM-1 and TBM-2.

A new manual for field work in the tunnel has been updated on account of the new TBM routines.

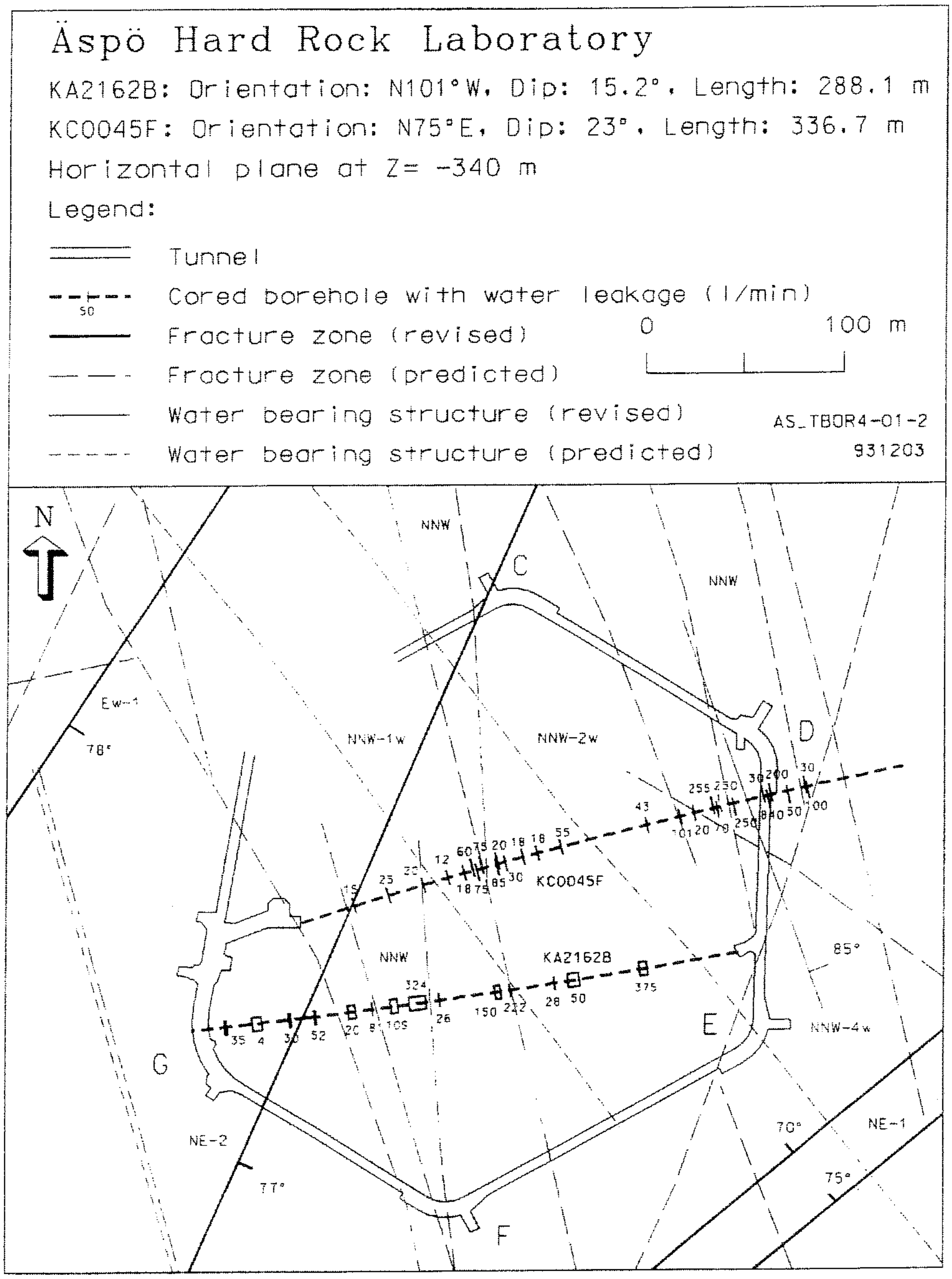


Figure 3-4. *Current model of the structural features at the 340 m level.*

TBM-1 (the first part of the tunnel, from the level approx. -420 m to the shaft)

A cored test borehole along the planned extension of the TBM tunnel will be drilled. The following investigations are proposed to be performed in the borehole before the start of TBM excavation:

- detailed investigations of the drillcore
- borehole deviation measurements
- borehole-TV for orientation of fractures
- directional radar
- spinner
- groundwater sampling for hydrochemical analysis
- pressure build-up measurements at 15 m intervals.

After TBM excavation the following investigations will be performed:

- geological mapping according to the new manual for field work in the TBM tunnel
- comparison of geological tunnel data against core mapping data
- evaluation of TV-logging data
- evaluation of radar data
- documentation of rock outfall, rock burst and Rock Mass Rating (RMR)
- mapping of seepage in the tunnel
- water pressure measurements in boreholes drilled in the TBM tunnel
- construction of measuring weirs.

TBM-2 (the second part of the tunnel from the shaft into the experimental volume)

- Probe drilling every 16 metres will be tried in the same manner and with the same objective as for the drilling and blasting technique. The probe holes will be drilled from the machinery section in the left and right walls 20 m in the forward direction with a relative angle of seven degrees to the tunnel axis. The drill penetration rate will be monitored automatically. Water inflow and colour of drill cuttings must, however, be monitored manually. Mechanical inflatable packers will be installed six metres inside the probe holes. Instruments for automatically setting packers will be developed.

- Pressure build-up measurements will tentatively be carried out every 16 m in the probing holes drilled on either side of the ramp. Measurements are performed in the same way as during drill and blast. The probe holes with installed packers must be kept undisturbed during tunnel boring.

- Sampling of groundwater for probe holes in the bored tunnel is done in the same manner and with the same objective as for the drilled and blasted tunnel.

After TBM excavation the following investigations will be performed:

- geological mapping according to the new manual for field work

- mapping of seepage in the tunnel

- documentation of rock outfall, rock burst and Rock Mass Rating (RMR) will be performed based on conditions along the tunnel walls. However, where rock is shotcreted, RMR will be measured before reinforcement

- furthermore, dams and measuring weirs will be installed every 150 metres in the same manner as for the drill and blasted tunnel.

3.4 ZEDEX - COMPARATIVE STUDY OF EXCAVATION INDUCED DISTURBANCE - TBM vs DRILL AND BLAST

3.4.1 Background

To obtain a better understanding of the properties of the disturbed zone and its dependence on the method of excavation ANDRA, UK Nirex, and SKB have decided to perform a joint study of disturbed zone effects. The project is named ZEDEX (Zone of Excavation Disturbance EXperiment). The objectives of ZEDEX are:

- to understand the mechanical behavior of the Excavation Disturbed Zone (EDZ) with respect to its origin, character, magnitude of property change, extent, and dependence on excavation method,

- to perform supporting studies to increase understanding of the hydraulic significance of the EDZ, and

- to test equipment and methodology for quantifying the EDZ.

The ZEDEX project will be performed in conjunction with the change of excavation method from drill & blast to tunnel boring that will take place during the summer of 1994. The experiment is expected to provide a better understanding of the EDZ that will contribute to the basis for selecting or optimizing construction methods for a deep repository and its subsequent sealing.

The experiment will be performed in two test drifts near the TBM Assembly hall at an approximate depth of 420 m below the ground surface. Measurements of rock properties will be made before, during, and after excavation. The investigation programme will include measurements of fracturing, rock stress, seismic velocities, displacements, and permeability. The experimental configuration is outlined in Figure 3-5.

3.4.2 Planned work

The ZEDEX Project is currently in an initial planning phase. Several meetings have been held during the autumn of 1993 between ANDRA, UK Nirex, and SKB to formulate the detailed plans for the experiment. A Test Plan and a detailed activity list have been produced.

Location and configuration of test drifts and investigation boreholes have been defined based on the detailed investigations for design of the facility described in Section 3.2.

The project is governed by a Steering Committee with one member from each participating organization (André Cournut, ANDRA, David Mellor, UK Nirex, and Göran Bäckblom, SKB). The project manager is Olle Olsson, Conterra AB/SKB.

Tests measurements in the TBM tunnel are planned to commence in June 1994. Excavation and testing in the drill and blast tunnel is expected to begin in October 1994.

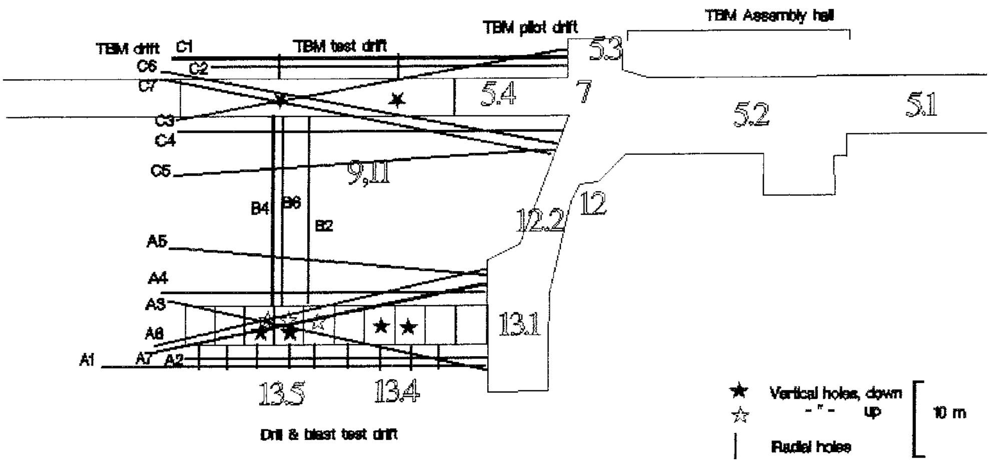


Figure 3-5. *Configuration of test drifts and investigation boreholes for the ZEDEX study.*

4 TEST OF MODELS FOR GROUNDWATER FLOW AND RADIONUCLIDE MIGRATION

4.1 GENERAL

It is necessary to demonstrate the safety of the deep repository over long spans of time. Important phenomena that must be taken into account in the safety assessment are:

- transport of corrodants up to the canister

- possible transport of radioactive materials away from a defective canister.

These phenomena are in turn highly dependent on groundwater flow and chemistry.

There are today several fundamentally different models for describing groundwater flow and radionuclide transport. Great uncertainty exists regarding the accuracy, precision and reliability of the models. This uncertainty includes the theory, the ability to collect realistic data over an entire repository area, and the ability to carry out realistic calculations. It is urgent to test and demonstrate different approaches in practice in preparation for the licensing process.

The results of ongoing investigations and planned experiments on Äspö are providing a better understanding of groundwater flow and radionuclide transport. This understanding will be utilized when an application under NRL and KTL is submitted. Here it is important to choose approaches that are robust and realistic and that meet the requirements of the authorities.

A "Task Force" with representatives of the project's international participants has been formed for numerical modelling of groundwater flow and solute transport. This offers excellent opportunities for trying out alternative models in a way that would not have been possible without international cooperation.

An outline of the research to be performed within this stage goal is presented in the SKB RD&D Programme 92 /4-1/. The planning draws on conclusions and experience from the Stripa Project, SKB 91, tracer tests at Finnsjön, URL, and previous experience from the Äspö Hard Rock Laboratory. Furthermore, experiences and suggestions made by the international participants will be considered in the planning process. In addition to research and development, relevant demonstration activities relating to design, construction and canister treatment will be carried out at Äspö.

4.2 THE BLOCK-SCALE REDOX EXPERIMENT

4.2.1 Background

During the Operating phase when a repository is kept open for the emplacement of the spent fuel canisters, the seepage of groundwater into the tunnels will cause an enhanced water circulation in the surrounding rock mass. This water circulation causes oxygenated surface water to be transported to great depth. Such a situation might cause an oxidation of the fracture minerals in the water-conducting fractures all the way from the surface down to the repository. The consequences of this would be that, in the post-closure phase, radionuclides oxidised by the radiolysis might be transported in oxidised form through the geosphere from a leaking canister up to the surface.

In the KBS-3 safety assessment a comparison was made between oxidising and reducing conditions. The calculations under otherwise identical conditions showed that the dose to man was two orders of magnitude higher in the oxidising than in the reducing conditions.

The geochemical data obtained from the site investigations made during the past ten year all over Sweden clearly indicate that the oxygen in the infiltrating surface water is reduced in the soil and in the uppermost part of the bedrock. At a depth of 100 metres the water is reducing with a typical iron concentration of 1 - 10 mg/l. Only in one borehole out of 30 - 40 has oxygen been measured in samples from more than 100 m depth. Evidence of the prevailing reducing conditions is also seen in mines and tunnels in the rock in the former iron precipitates on the walls where the reducing iron-rich water has flowed into the tunnel.

The objective is to observe the response of an undisturbed water-conducting fracture zone when opened during tunnel construction and operation of the Äspö HRL. The selected site for the experiment is at a depth of 70 m in a minor fracture zone which is intersected by the tunnel at 513 m.

The experiment started in 1991 and the results will be reported during 1994. The first year involved active planning and investigation, core drilling etc. The second included a monitoring phase to evaluate the changes that are due to the enhanced water circulation. The results of the first two years have been reported /4-2--3/.

4.2.2 New results

The monitoring phase continued during 1993. During this three-year period, an emphasis has been put on describing the chemical processes in the investigated fracture zone. The most important processes have been identified as microbial activity and mixing. No redox breakthrough has been observed and the chemical composition is fairly constant.

Final interpretation of hydrochemical data depends on knowing the hydrologic balance for the zone. A tracer test will be conducted in early 1994, with the purpose of verifying the assumptions of groundwater flow distribution and direction in the investigated fracture zone.

The results so far have indicated that the enhanced water circulation in the fracture zone has most likely not caused any significant penetration of oxidizing surface water. The explanation for this is that the high content of organic matter in the infiltrating surface water has been biologically oxidised at the same rate as the dissolved oxygen has been reduced. The population of bacteria has increased in order to be able to match the increased water circulation.

4.3 PLANNING OF EXPERIMENTS

The main experiments to be performed in the Operating Phase of the Äspö HRL are defined in the SKB RD&D Programme 1992. A test plan will be produced for each major experiment. Draft test plans will be prepared approximately one year before the experiment is planned to start. The draft test plan will then be sent to the Task Force on Modelling for review (SAC will at this stage receive a copy for information). Test plans will then be revised according to comments received and submitted to SAC and TCB for review. After a final revision the Test Plan will be published as a progress report and the formal decision to execute the work will be taken.

Test Plans for the following three experiments have been prepared:

- Flow and Transport in the Detailed Scale
- Flow and Transport in the Block Scale
- Disturbed Zone Effects - Two-Phase Flow

These Test Plans were distributed to SAC and the Task Force in January 1993.

The Detailed Scale experiments constitute a group of three experiments: the Multiple Well Tracer Experiment, the Matrix Diffusion Experiment, and the Pore Volume Characterization project. As detailed planning proceeds separate Test Plans will be prepared for these experiments. In addition, supporting laboratory experiments have been initiated for the purpose of developing and testing weakly sorbing tracers that can be used for these experiments.

At the Task Force meeting in March 1993 scoping calculations for the Detailed Scale experiments were defined as Task Number 2. The results of the scoping calculations were presented and discussed at the Task Force meeting in September 1993. The results from the scoping calculations are summarized below and will form the basis for detailed planning of the experiments.

The updated Test Plans will be presented and discussed at review seminars (one for each experiment) where selected reviewers will be asked to comment on the proposed experiments. Based on discussions during the seminars and recommendations from the reviewers the Test Plans will be revised and the formal decision to perform the experiment will be taken by SKB.

4.4 THE MULTIPLE-WELL TRACER EXPERIMENT

4.4.1 Background

The objectives of the Multiple Well Tracer Experiment (MWTE) are:

- to improve understanding of transport processes and refine conceptualization of radionuclide transport in single fractures,
- to determine in-situ parameters for the processes that control transport of sorbing nuclides in single fractures, and
- to quantify variability in flow and transport parameters.

In the Multiple Well Tracer Experiment, a large number of boreholes will be drilled to intersect a "single" fracture. Cross-hole hydraulic and tracer tests will be made to characterize flow and transport parameters in the fracture plane for different tracers, different boundary conditions, different transport distances, different flow velocities, and different directions.

4.4.2 New results

Scoping calculations for the MWTE were defined as Task 2A by the Task Force on groundwater flow and transport of solutes. Scoping calculations for the MWTE were performed by the following organizations (the funding organization is also indicated):

- Geosigma/SKB by Nordqvist, Gustafsson, and Andersson
- CFE/SKB by Svensson
- KTH-Water Resources/SKB by Selroos, Winberg, and Cvetcovic
- KTH-Chemical Engineering/SKB by Moreno and Neretnieks
- LBL/US DoE by Gupta and Long
- CRIEPI/CRIEPI by Igarashi.

The results of these calculations were presented at the Task Force meeting in September 93. Since then draft reports have been compiled by five of the groups. These reports are currently being reviewed.

The scoping calculations performed by Geosigma were directed towards three objectives: 1) Model discrimination, 2) Parameter estimation, and 3) Influence of the experiment on natural hydraulic conditions. The main design ideas considered were: induced uniform gradient, repeated tracer tests with varying water velocities, sampling boreholes between injection and collection points, and combination of tracers with different transport properties. Three conceptual models were considered, formulated mathematically in their one-dimensional forms, representing different types of processes: advection-dispersion, transient solute storage, and matrix diffusion. The optimization calculations were aimed at investigating how the objectives of discrimination and estimation may benefit from the simultaneous evaluation of data from more than one sampling distance and from repeated tests with different water velocities. In addition, two-dimensional flow calculations were carried out to quantify some hydraulic effects on water velocities due to the presence of boreholes inside a flow field. For the models considered, the results indicate that both multiple sampling distances and using tracer tests with different velocities will significantly enhance the prospects for both parameter estimation and model discrimination. Specifically, the calculations indicate that an experiment involving two sampling distances, and two or three repeated tracer runs with different velocities, would provide data with a significantly increased interpretation potential, compared to traditional single-velocity, single-distance tracer tests.

Scoping calculations by KTH-Water Resources indicated that it may be difficult to distinguish between heterogeneity in transmissivity within the fracture plane and matrix diffusion in tests using a dipole flow field, as both are manifested by tailing in the tracer arrival. To distinguish between spatial variability in transmissivity and spreading resulting from mass transfer processes (e.g. matrix diffusion) they consider it necessary to work with several tracers with varying sorption properties.

Based on their calculations, KTH-Chemical Engineering also recommended simultaneous injection of several tracers with different sorption properties. They also pointed to the importance of appropriate selection of injection flow rates if radially converging tests are used. The natural flow rate should be determined before an injection hole is used, and if it is too low the hole should be discarded.

Work to produce a detailed Test Plan for the experiment has been initiated. The detailed plan should take into account what was learned from the scoping calculations and comments made by SAC and the Task Force. Anders Winberg, Conterra AB has been put in charge of producing the detailed Test Plan. He is assisted by Vladimir Cvetcovic, KTH-Water Resources, and Peter Anderson, Geosigma AB.

4.5 THE MATRIX DIFFUSION EXPERIMENT

4.5.1 Background

The objectives of the Matrix Diffusion Experiment (MDE) are:

- to show the significance of matrix diffusion as a retardation mechanism, and
- to estimate the flow-wetted surface area by direct observation.

In the Matrix Diffusion Experiment, sorbing tracers with different sorption capacity will be injected over a long period of time (years) into a permeable fracture. After injection has stopped, a dye or resin will be injected into the fracture to mark the flow paths. The fracture will be excavated to observe the distribution of flow paths and penetration of tracers into the rock matrix.

4.5.2 New results

Scoping calculations for the MDE were defined as Task 2B by the Task Force on groundwater flow and transport of solutes. Scoping calculations for the MDE were performed by the following organizations (the funding organization is also indicated):

- KTH-Water Resources/SKB by Selroos, Winberg, and Cvetcovic
- Kemakta-KTH/SKB by Birgersson, Widén, Ågren, Moreno, and Neretnieks

The results of these calculations were presented at the Task Force meeting in September 93. Since then draft reports have been compiled by five of the groups. These reports are currently being reviewed.

The scoping calculations performed by Kemakta-KTH comprised tracer migration calculations relevant to the proposed experiment and practical considerations for conducting the experiment. It was proposed that a mixture of tracers with different sorption capacities should be injected simultaneously. The tracers should have sorption capacities, $K_d\rho_p$, in the range 1 to 10 000 m^3/m^3. Most of the tracers should have sorption capacities in the range 1 to 100 m^3/m^3, since this is the range in which matrix diffusion effects can be observed as concentration profiles into the rock matrix.

Work to produce a detailed Test Plan for the experiment has been initiated. The detailed plan should take into account what was learned from the scoping calculations and comments made by SAC and the Task Force. Lars Birgersson, Kemakta AB, has been put in charge of producing the detailed Test Plan.

4.5.3 Planned work

To compile a detailed Test Plan for the experiment that will be basis for SKB's decision to proceed with the work.

Printing and distribution of scoping calculation reports in the Äspö ICR report series.

Design and construction of testing equipment is planned to start during the summer of 1994. A programme for selection of an experimental site will begin in the late autumn of 1994.

4.6 DEGASSING AND TWO-PHASE FLOW CONDITIONS

4.6.1 Background

The objectives of the project are:

- to understand and quantify the effects of air invasion and degassing ofgroundwater at low pressures on the hydraulic properties of fractured rock,

and

- to study the reversibility of desaturation and resaturation and their effect on the hydraulic properties of fractured rock.

The investigation of two-phase flow effects in fractured rock will commence with a literature review and laboratory experiments. In-situ tests of degassing will be performed by measuring the inflow to a number of boreholes at different pressures. Non-linearities in the flow-pressure relationship should be indicative of two-phase flow effects. The boreholes will be subject to air invasion and hydraulic properties during resaturation will be studied.

4.6.2 New results

A workshop on Two-phase flow in fractured rock was held in Berkeley, California, November 3-5, 1993. The workshop was sponsored by US DoE, SKB, and NAGRA and hosted by Lawrence Berkeley Laboratories. The workshop facilitated information exchange between the participants, it provided a review of the current state of understanding, and it identified the research needs. The outcome of the workshop is summarized in a report which will be distributed shortly.

A literature review and initial laboratory experiments on degassing in artificial fractures have been initiated.

A sample has been taken of the groundwater in borehole KA2598A and the gas content and composition measured. The gas content was 3.8 % by volume at STP.

4.6.3 Planned work

The current plan is to carry on a pilot study of degassing in a single borehole during 1994. The detailed plan for this study will be defined early 1994.

4.7 DEVELOPMENT OF TRACERS

4.7.1 Background

A number of in-situ tracer experiments are planned for the Operating Phase of the Äspö HRL. In these experiments the transport of weakly sorbing tracers will be studied. A project of supporting laboratory tests has been defined to develop and test such tracers before they are used in-situ. The objectives of this project are:

- to develop and test performance of new (or rarely used) tracers before they are employed in the in-situ experiments,
- to provide laboratory data on transport parameters (distribution coefficients and diffusivities) for comparison with in-situ derived parameters and/or for evaluation of in-situ results, and
- to show that the tracers do not sorb on equipment used in the in-situ experiments.

4.7.2 New results

A literature survey has been carried out to identify potential weakly sorbing tracers for use in the in-situ experiments. The literature survey and some basic considerations have been documented and published in a Progress Report /4-4/. The weakly sorbing tracers which have the greatest potential for use in the in-situ experiments are cations such as Na, Rb, Cs, Ca, Sr, Ba, and Tl.

4.7.3 Planned work

Laboratory studies to determine the distribution coefficients and diffusivities of these tracers will be initiated. The laboratory experiments will comprise batch tests and measurements in diffusion cells on rock material from the Äspö site.

4.8 PORE VOLUME CHARACTERIZATION

4.8.1 Background

The objective of this experiment is to provide data on the pore aperture distribution in selected fractures. The aperture distribution should provide insight on the heterogeneity and connectivity of flow paths within fractures. Such data are obtained by drilling core samples from a previously grouted fracture.

A fracture at a tunnel length of 1140 m was selected for the initial phase of this project. This fracture was filled with a red coloured grout when grouting was done ahead of the tunnel front during normal excavation of the Access Ramp. The rock type in the area is Äspö-diorite. The fracture is almost vertical, striking N-S, and is the major fracture (or minor fault) in this part of the tunnel.

In addition, a detailed study has been made of the grout spreading pattern in the fracture system adjacent to the "Method Tunnel" located approximately at the tunnel section 680 m.

4.8.2 New results

Five 200 mm-diameter boreholes were drilled along the fracture plane to a depth of about 1 m. The cores were taken to the Royal Institute of Technology in Stockholm. The samples were cast in cement and cut into 2 cm thick slices. The cut surface of the samples was recorded with a video camera and the thickness of the grout measured along the fracture trace. Figure 4-1 shows the location of the samples in the wall of a niche in the access ramp (Section 1140 m). The dashed lines show the intersections between the vertical fracture and the boreholes. Photographs have been taken along the boreholes using an ordinary camera placed inside the large boreholes (diameter 200 mm). Examples of the grout geometry traced from the photographs is shown in Figure 4-2.

The aperture data from the borehole photographs will be added to the data from sections of the core samples. The vertical lines in Figure 4-1 show the location of the sections. The data is collected in eight "samples" named "E1", "E2" etc. By using both the core sections and the boreholes for aperture data collection it will be possible to investigate the influence of sampling scale on the statistical parameters that are to be studied.

Figure 4-3a shows the distribution of the apertures, measured as the thickness of the grout layer, along fracture sections of sample F (see Figure 4-1). Average aperture, b, is 5 mm and standard deviation, %, is 2 mm. The accuracy of the measurements is about 0.1 mm. This means that this sample in general is very open. Figure 4-3b shows apertures measured in the photographs from borehole profiles F_{upper} and F_{lower} (b = 3.5 mm; %= 3.5 mm). The length of each profile is 40 cm and the accuracy of the measurement of aperture is about 0.3 mm.

A large spatial aperture variation in the fracture can be observed in the longer profiles from the boreholes. The large variation in aperture is also reflected in the difference in the ratio of average aperture to standard deviation between the smaller cores and the longer profiles. The diagram in Figure 4-4 shows the autocorrelaion coefficient for the measurements along F_{upper}. There is a strong correlation within 1 cm and a weaker correlation between points with about 8 cm separation. This is explained by the waviness of the fracture surfaces, which causes larger aperture areas at each wave in connection with shear displacement.

The study of the grout spreading pattern in the fracture system at the "Method tunnel" showed that one fracture was the main path for spreading of the grout. This fracture strikes approximately N-S. Two other minor fractures with grout were identified in the boreholes. These strike NE-SW and have a steep dip. The strike of these minor fractures is in agreement with fractures found from the radar measurements in KA0575A.

The possible maximum extension of grout spreading in the rock mass is at least 10 m. The data from pH inspection show that the grout has not penetrated to KM0013A

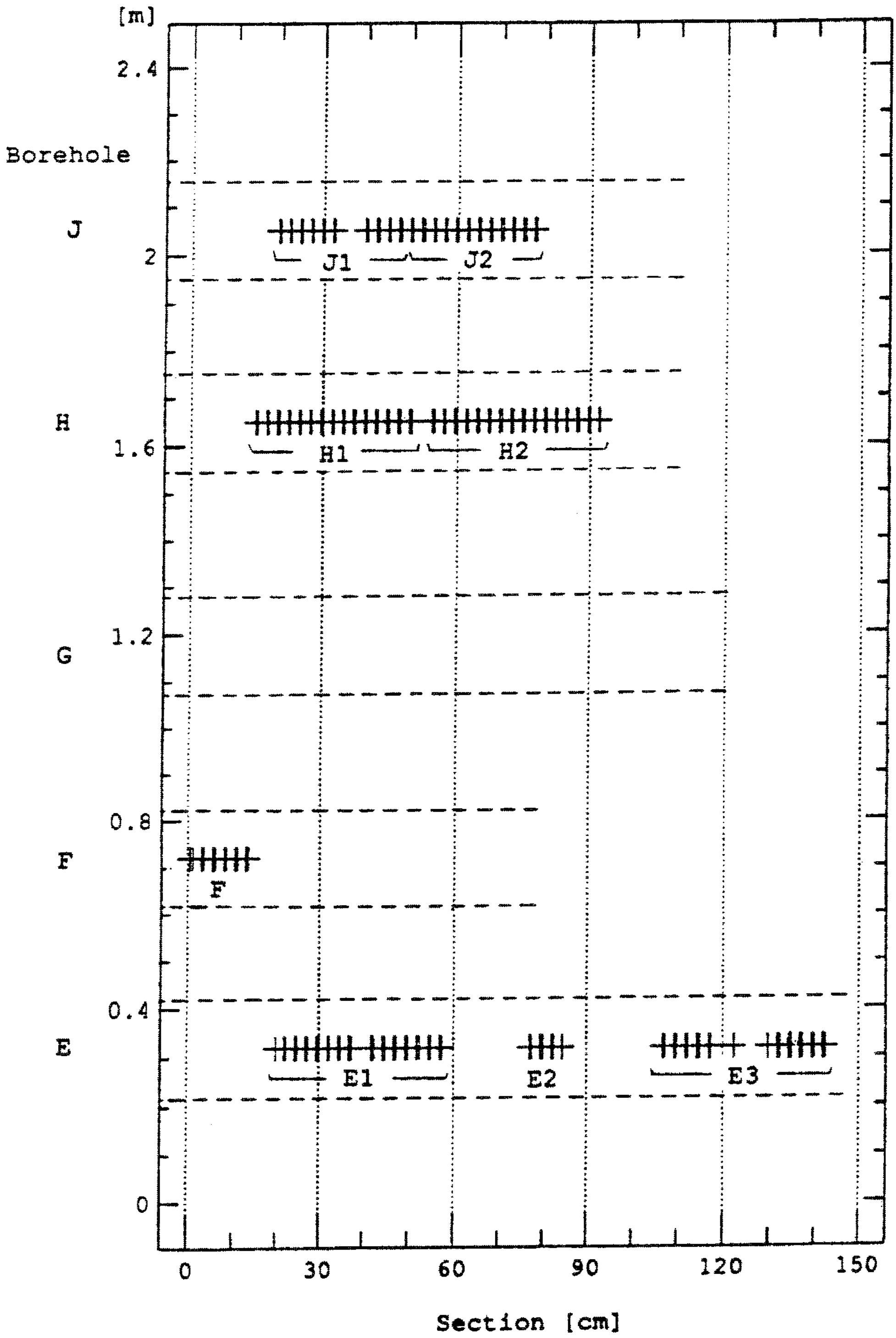
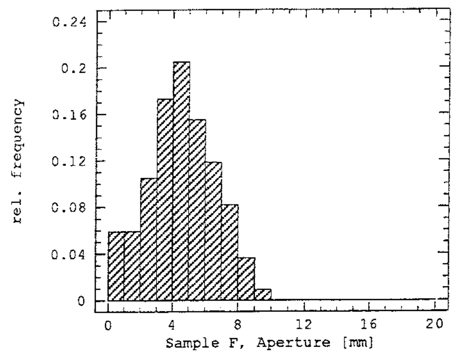


Figure 4-1. *Location of boreholes along the vertical fracture in the wall (for further explanation, see text).*

Figure 4-2. *Geometry of grout layer along fracture intersection in borehole.*



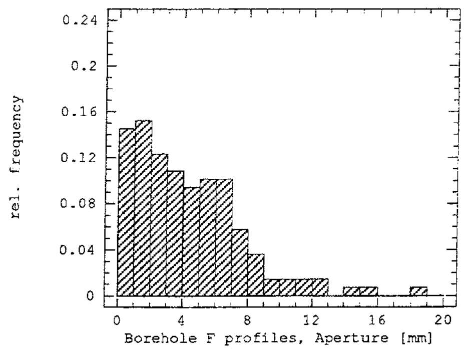


Figure 4-3a,b. *Frequency histograms of aperture measurements from sample F and borehole photographs in borehole F.*

or KA0747A located south and north of the "Method tunnel". On the other hand, grout penetration in the main fracture was confirmed about 6 m from the intersection point with the grouting hole.

As an aspect of this work a new procedure was developed to determine fracture orientation from Videoscope images without using an orientation device. The error in orientation was estimated to be less than 30 degrees.

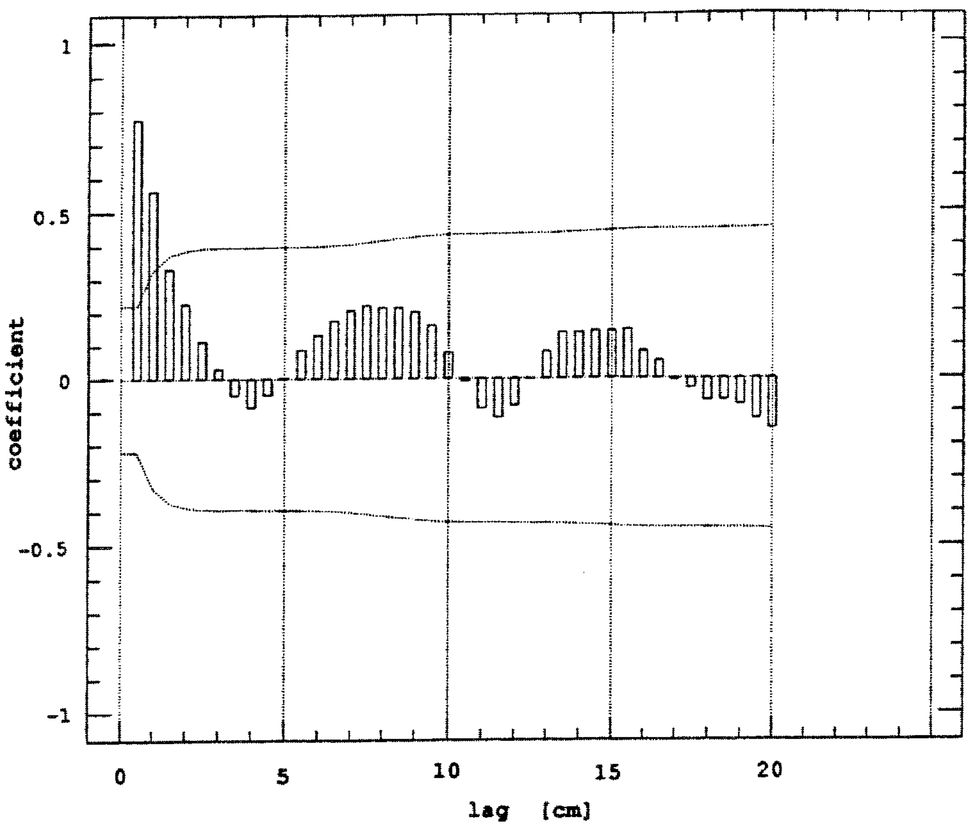


Figure 4-4. *Autocorrelation diagram of aperture measurements from photographs along F_{upper} profile. The dotted line indicates the standard deviation of the calculated coefficient.*

4.9 RESULTS OF WORK IN THE TASK FORCE ON MODELLING OF GROUNDWATER FLOW AND TRANSPORT OF SOLUTES

4.9.1 Background

The Äspö Task Force shall be a forum for the organizations supporting the Äspö Hard Rock Laboratory Project to interact in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock. In particular, the Task Force shall propose, review, evaluate and contribute to such work in the project.

4.9.2 New results

During 1993 the second and the third meetings of the Äspö Task Force were held at different locations in Sweden.

The main issue was the results of the modelling of the LPT-2 pumping and tracer experiment, defined as Task No 1. Eleven different groups have presented results regarding the LPT-2 test, see table 4-1. A wide variety of conceptual as well as numerical models have been used to predict water flow and tracer breakthrough on this rather large scale. The very large quantity of data available have been utilized to a differing extent and the calibration efforts vary. To facilitate further evaluation of Task No 1, a number of critical questions were selected and have been addressed to the modelling groups. Draft reports are expected in early 1994.

As Task No 2, the group initiated design calculations for some of the planned experiments at the Äspö site, for the Matrix Diffusion Experiment (MDE) and for the Multiple Well Test Experiment (MWTE).

Table 4-1. *Äspö Task Force. Modelling groups for Task No 1, the LPT-2 experiment*

ORGANIZATION	MODELLING TEAM	REPRESENTATIVE
AECL	-	-
ANDRA	CEA/DMT BRGM ITASCA	Durin Sauty Billaux
CRIEPI	CRIEPI	Igarashi
PNC	PNC/Golder Hazama Corporation	Uchida Kobayashi
SKB	CFE Conterra/KTH KTH	Svensson Winberg Neretnieks
TVO	VTT	Taivassalo (flow) Hautojärvi (transport)
US DOE	-	-
UK Nirex	-	-

Regarding data delivered to the modelling groups, an updated geometric data set on a hydraulically active fracture zone was distributed in early 1993.

Furthermore, data have been delivered as a result of the discussions at the second Task Force meeting. Their content is summarized in two Technical Notes. The first is concerned with details regarding the injection and sampling of tracers during LPT-2. The second is a compilation from the Äspö area of undisturbed piezometric levels and their uncertainty.

Finally, a complementary set of fracture data was distributed to the modelling groups in late 1993. It contains core logging data from 14 boreholes in the Äspö area. Some information in previous data sets has been updated and/or corrected. New information has been added, for example oriented fractures for boreholes KAS02-KAS06.

The tunnel mapping data in GEOTAB will be further revised according to the discussions during the third Task Force meeting. A 3D representation in GEOTAB is desirable.

Task No 1, the LPT-2 experiment, will be preliminarily evaluated by the Secretariat in time for the next Task Force meeting, April 26-28 1994, at Äspö.

Task No 2, the scoping calculations, will also be summarized at the next Task Force meeting.

4.10 RADIONUCLIDE RETENTION

4.10.1 Background

Laboratory studies on solubility and migration of the long lived nuclides of Tc, Np, Pu and others indicate that these elements are so strongly sorbed on the fracture surfaces and into the rock matrix that they will not be transported to the biosphere until they have decayed. In many of these retardation processes the sorption may also be irreversible, and thus the propagation of the front will stop as soon as the source term has ended.

Laboratory studies under naturally reducing conditions are extremely difficult to conduct. Even though the results obtained by different scientists are in agreement, it is of great value to be able to demonstrate the results of the laboratory studies in situ. It is possible to include natural contents of colloids, organic matter, bacteria etc in the experiments.

4.10.2 New results

In order to prepare for radionuclide migration experiments during the operational phase of the project, a special piece of equipment, the CHEMLAB probe, is under development. The CHEMLAB probe is a borehole laboratory contained in a probe, in which migration experiments on core samples will be carried out under ambient conditions of pressure and temperature and using the formation groundwater surrounding the probe.

The first stage of the CHEMLAB development is now finished. The design work has been done and the drawings will now be studied before the manufacturing work starts.

A test plan for the CHEMLAB experiments will be prepared in parallel with the manufacture of the probe.

5 DEVELOPMENT OF CONSTRUCTION AND HANDLING METHODS, PILOT TEST

5.1 GENERAL

The safety of a repository is determined by:

- the properties of the site
- the design of the barriers
- the quality of execution of the deep repository.

A KBS-3-type deep repository is supposed to hold about 4500 canisters in rock caverns at a depth of about 500 m. The different barriers (canister, buffer, rock) combine to isolate the waste. Backfilling/plugging of tunnels, shafts and boreholes limits the flow of groundwater via the potential flow paths opened up by the construction and investigation work, thereby making it more difficult for corrodants and any escaping radionuclides to be transported up to or away from the canisters/waste. All of the work with barriers, plugs etc. must be executed with a given minimum quality.

The Äspö HRL provides an opportunity for demonstrating technology that will provide this necessary quality.

5.2 EVALUATION OF UNDERGROUND DESIGN AND CONSTRUCTION WORK

The experience from the first phase of the design and construction work (down to the 340 m level) has been compiled and evaluated. A Construction Methodology Report will be ready in the beginning of 1994. It will cover experience from conventional drilling and blasting of the tunnel and experience from full-face boring of the shafts to the 220 m level.

5.3 SITING FOR SUITABLE NEAR FIELDS

A very concrete question is how the canister positions will be chosen in a future final repository and how this can be predicted in the different phases from siting to final construction. The suitability of placing a canister in a certain position is governed by many factors, which are influenced by geology, stability and constructability, geohydrology and groundwater chemistry. A systematic description is required in order to predict and choose canister positions.

An important question is how many canisters can be emplaced in a given rock volume or in a given tunnel length. The maximum number is often determined by practical considerations such as dimensions of tunnels, machinery etc. We define

PPI as the probability at a certain level of confidence that a canister can be placed in a volume of rock.

Lars Rosén, CTH, will develop the PPI and test it on a selected portion of the TBM tunnel. A report will be ready by May 1994.

5.4 CONSTRUCTABILITY ANALYSIS

The design and construction of a repository must meet a number of requirements. A systematic analysis of constructability is essential to make sure that the requirements can be met.

An on-going study of constructability analysis will be completed in the spring 1994.

The proposed methodology will be tested on the TBM part of the facility.

5.5 DEVELOPMENT OF A PROTOTYPE REPOSITORY AT ÄSPÖ

5.5.1 Background

Plans for construction of an initial stage of a deep repository were presented in RD&D-92. By and large, these plans have been received positively by the reviewing bodies. The need to integrate existing knowledge and build an (inactive) prototype of a deep repository is currently being discussed within SKB. For example: A 100 m long deposition tunnel is built and backfilled on Äspö. In conjunction with planning, design and construction, work descriptions and quality plans are prepared which can later be used for the deep repository. The objectives include translating scientific knowledge into engineering practice, testing and demonstrating the feasibility of the various techniques, and demonstrating that it is possible to build with adequate quality. In conjunction with construction of the prototype proposed above, different types of models will be used to describe the performance of the prototype in conjunction with water absorption and restoration of groundwater pressures, etc. The prototype will then be monitored via a large number of measurement points for a period of 5-15 years. Following this there will be an opportunity to study in detail any chemical and physical changes in e.g. the bentonite surrounding the canisters.

Decision to execute, scope and time for such a prototype are important questions that will be considered during 1994.

5.5.2 New results/Planned work

The outline of the study has been scrutinized to prioritize science and design issues. A small working group plans to up-date the current test plan for review in summer 1994.

6 DEVELOPMENT AT THE SITE OFFICE

6.1 GENERAL

Collecting, compiling and distributing data is a main task at the Site Office. Most progress during 1993 has been made in the field of compilation and handling of data. This is where there is still room for efficiency improvements.

A new Site Activity Database (see section 6.2) has been developed which not only faciliates the ongoing work but will be of great benefit for the project and SKB in the future as well. The new database is extremely user friendly.

A Rock Visualization System (3D CAD) was initiated under 1993 and will be ready for use during 1994. This will not only faciliate the work with conceptual models, but will be of great value for planning of the experiments that are going to be performed during the operational phase of the project.

Documentation of the underground facility has proceeded smoothly and distribution of the datasheets has worked as planned. The three shafts connecting the tunnel with the surface on Äspö have been mapped down to the level -220 metres.

The Hydro Monitoring System has been extended underground and an alarm system has been installed.

6.2 DATA MANAGEMENT

6.2.1 Site Activity Database

An intensive effort has been made to realize the Site Activity Database. While development of a new database application is a very demanding process when conducted concurrently with investigations in progress, the application is extremely useful and user-friendly.

It is important to emphasize that the new database is a complement to the SKB Geotab Database. The relation between the Site Activity Database and Geotab is illustrated in Figure 6-1.

The first version of the database was ready to use on the 5th of October, when a short course was held for the Characterization Team at the Site Office. After some additional improvments the new database was classified as an operational tool and put into use on the 25th of October. Hence, the new database concept was ready some weeks before Skanska (the new contractor) started the excavation work from section 2 600 m onward, which was the first milestone in this database project.

The project has now advanced further and the database includes most of the data collected by the documentation group since the autumn of 1990. All data stored earlier in the Tunnel History are now available in the new database.

Figure 6-2 shows the latest version of the main menu of the Site Activity Database. In the lower left part of the menu you can see the different functions determining what information is to be seen in the *activity log* window located just under the logotypes. The three buttons (All,With and Without) under the text QC signature are worth describing in greater detail. By using these buttons the user(data collectors or managers) can get quick information about how far the different activities have progressed.

Raw data tables and result data tables are connected to the different activities/ events defined in the system. In Figure 6-3 the tables connected to the "buildup test" activity are shown. The "Buildup" and "Buildup Measurements" window in the figure was obtained by selecting a "buildup test" activity in the main menu and then pushing the button labelled "Show All Data".

The database project is still in progress and new improvements and extensions are being made daily. The next milestone is March 1994. At that time the system will cover most types of investigation activities in the Äspö area. The Site Activity Database will also be prepared for the ZEDEX experiment.

6.2.2 Pen-computer project

A first version of a pen-based tunnel mapping application has ben developed during the year. Data are loaded into the local mapping database by means of user-friendly forms on the screen. The final part of the pen-computer project, digitizing the geological structures directly on the pen-computer screen, has been delayed. Further development is dependent on the new version of MicroStation, MicroStation version 5.0, to be released in January 1994.

6.2.3 3D CAD project(RVS-Rock Visualization System)

A 3D CAD project was started in November 1993. The project is being executed in co-operation with the SKB Deep Repository project. The visualization system will be based on the Intergraphs MicroStation developed by Bently Systems Inc. Specifications describing the desired functions of the Rock Visualization System are now under preparation. The system will be developed during 1994.

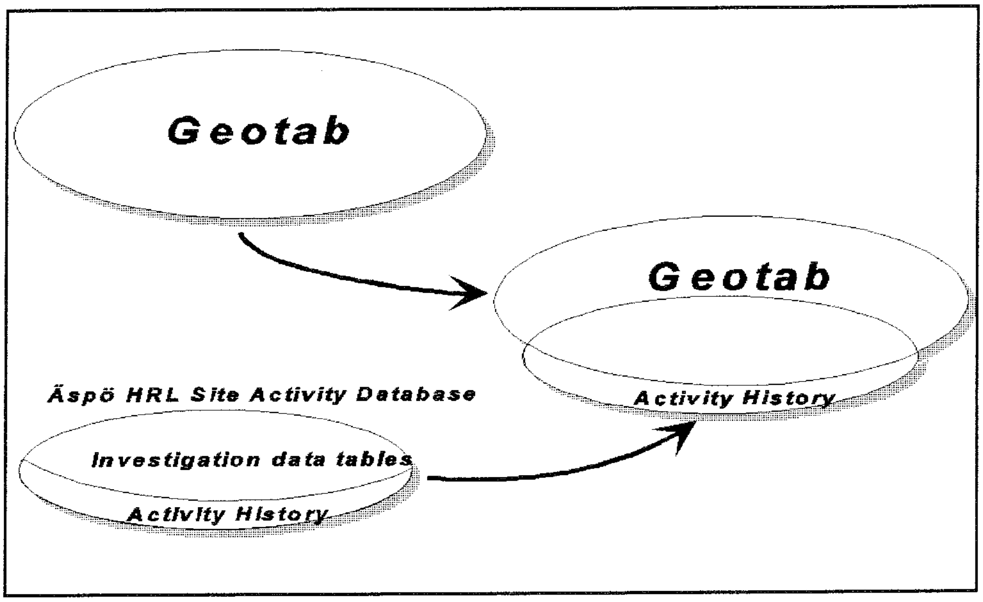


Figure 6-1. *The relation between Geotab and the Site Activity Database*

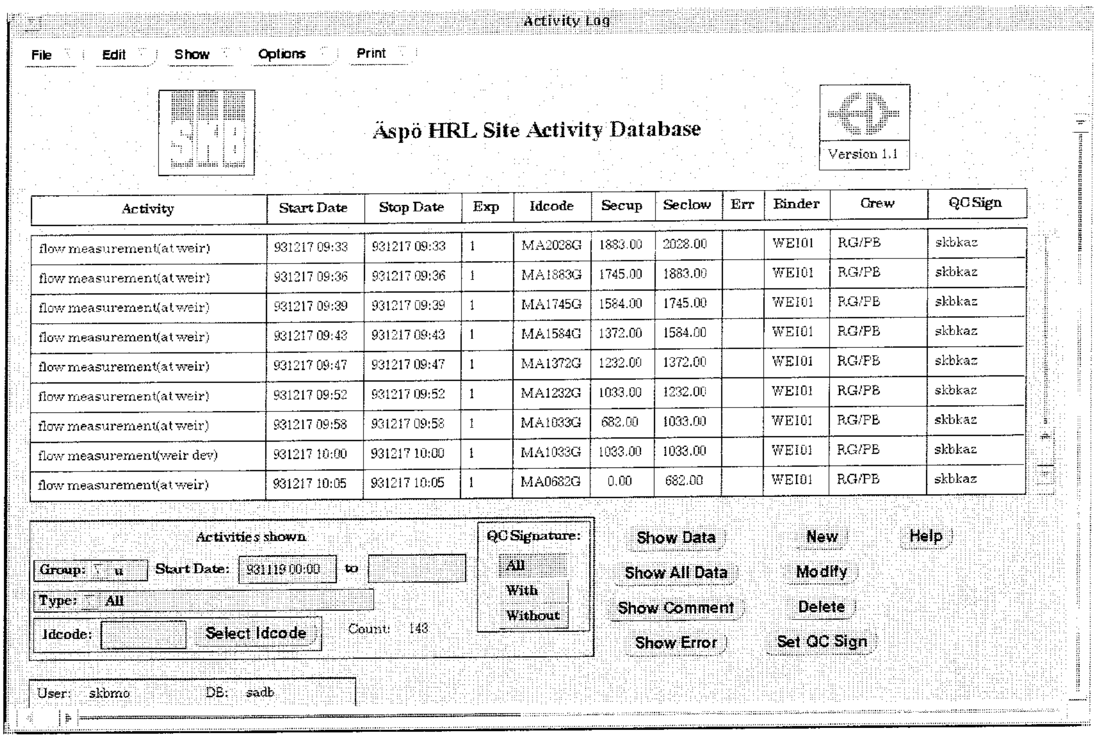


Figure 6-2. *The main menu of the Äspö HRL Site Activity Database.*

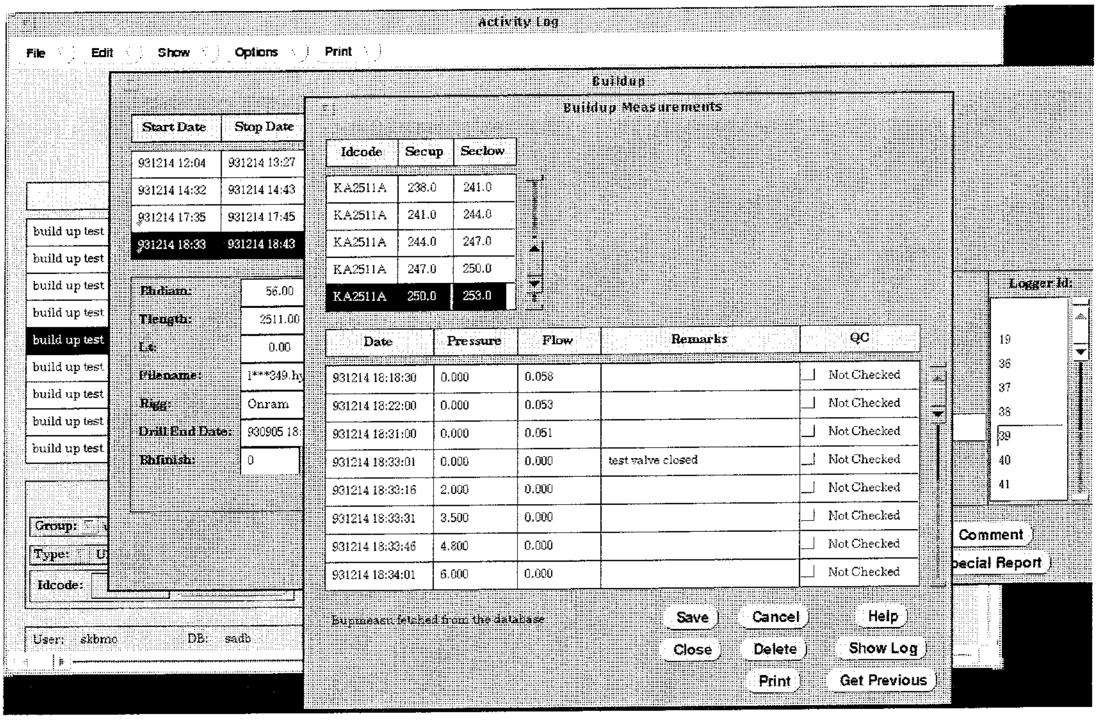


Figure 6-3. *Raw data tables and result data tables are connected to the different activities defined in the system.*

7 DEVELOPMENT OF INSTRUMENTS AND METHODS

The overall goal for development of instruments and methods during the Construction phase is to see to it that suitable and reliable measuring instruments and methods are available for the basic documentation and monitoring of the validation programme and for the detailed investigation work that will be carried out. Activities defined to achieve this goal are described below.

7.1 DRILLING- AND BOREHOLE-RELATED EQUIPMENT

7.1.1 Background

Inflows to boreholes from penetrated groundwater conductors sometimes cause problems for borehole measurements of various kinds, especially in boreholes from underground with high water pressures. This calls for grouting and re-drilling of highly conductive borehole sections only, while moderate and low-conductive sections remains unaffected by the grouting work.

With or without the above mentioned grouting the borehole has to be sealed off in order to prevent large water outflows to the tunnel and pressure draw down in and around the borehole. This effect is enhanced the deeper down in the tunnel the borehole is drilled. Also during drilling it sometimes is necessary to be able to seal off the hole when highly water conducting structures are penetrated.

7.1.2 New results

When the highly water-bearing zone NE-1 was passed through, a casing and valve system was developed to shut-in the borehole. After pre-drilling some 10 metres of the borehole, a casing is cemented and bolted to the rock wall. A ball valve is mounted on the casing and the drilling is then continued through the valve, enabling the borehole to be sealed off during drilling interruptions and after drilling is completed.

The sealing-off system has been refined so that the valve can be replaced with a sealing plate or a sealing device for use during hydraulic testing (see section 7.2).

When the outflow from the borehole during drilling exceeds about 100 l/min, the borehole normally has to be grouted in order to be able to use measurement instruments in the completed hole (the acceptable depends on the kind of measurement to be made). Preferably, only the conductive sections of the borehole are grouted by means of a single packer for cement grouting adapted to the drill string. Before grouting, the transmissivity of the borehole section can be measured. After grouting the packer element and the grouted section are redrilled, after which drilling of the borehole can be continued.

An alternative to grouting selected intervals of the borehole is to use a double packer for cement grouting, which has also been developed. The advantage of the double packer is that selected interval grouting can be done after drilling is completed. The technique has been used once, but without being able to drill out the bottom packer. The packer had to be pushed to the bottom of the borehole.

In summary, the easiest way to grout selected intervals of a borehole is to use single packer grouting technique during drilling. Double packer grouting can be a useful back-up if the remaining total outflow from the borehole exceeds an acceptable value. The double packer is therefore planned to be modified.

7.2 HYDRAULIC TESTING METHOD AT HIGH GROUNDWATER PRESSURES

7.2.1 Background

Hydraulic testing in boreholes drilled from underground is associated with special problems. The high water pressure in the borehole, relative to the tunnel, results in (sometimes very large) water out-flows from the boreholes. The pressure drawdown in the boreholes results in a prolonged pressure stabilization period during hydraulic testing (pressure build-up or injection test). The problems get worse the higher the groundwater pressure is.

7.2.2 New results

Normally, when the boreholes are not being used for testing etc, they are sealed off by means of a sealing plate or a valve (as described in 7.1). In order to keep the entire borehole sealed off during hydraulic testing and when the testing tool are moved in the borehole a special sealing device, replacing the sealing plate or valve at the casing top, has been designed. A rubber element with openings for the test pipe and tubing to the packer system seals off the borehole by tightening around the pipe and tubing. This keeps the borehole pressure almost constant, and therefore reduces the pressure stabilization time prior to testing.

In investigation holes, normally with lengths of couple of hundreds metres, injection tests or flow and pressure build-up tests are performed for hydraulic characterization. The testing tools are based on inflatable packers. The deeper down in the tunnel the borehole is drilled, the higher differential pressure the packers must withstand. At -330 m level (autumn 1993) some problems occurred when the packers did not seal sufficiently according to specifications. Before the next borehole investigation campaign in the spring of 1994, at approximately tunnel level -450 m, the packer system will be modified to withstand these pressures.

While investigation boreholes are drilled for certain specific purposes pilot holes are drilled more regularly as the tunnelling progresses. These shorter holes are only equipped with the special casing and sealing device when the holes are expected to penetrate highly conductive structures. Pressure build-up tests are performed with mechanically expanded packers, which are left in the hole for sealing-off and pressure monitoring.

7.3 THE HYDRO MONITORING SYSTEM (HMS)

7.3.1 Background

Monitoring of groundwater changes (hydraulic and chemical) during the construction of the laboratory is an essential part of the documentation work intended to verify pre-investigation methods. The large amount of data calls for an efficient data collection system and data management procedures. Hence, the Hydro Monitoring System (HMS) for on-line recording of these data was developed in 1991 and will be continuously expanded along as the tunnelling work progresses and the number of monitoring points increases.

7.3.2 New results

By the end of 1992 the HMS had been expanded to tunnel section 1400 m. A new expansion step of the HMS was done during the spring and summer of 1993, covering the tunnel from 1400 m to 2360 m and including most of the first spiral turn. The computer network was expanded to 1600 m (the first shaft level at -220 m), to which point Measurement Station B was moved from 700 m. The datalogger network supported by this Station was expanded to 2360 m with new dataloggers at 1600 m and 2160 m. Water inflows for every tunnel leg, collected at water-dams crossing the tunnel floor in the corners of the spiral, are monitored in Thomson weirs. Electrical conductivity of the water is monitored at strategic points of the seepage water pumping system. Groundwater pressures are monitored in some selected boreholes.

By the end of 1993 the planning for another new expansion step of the HMS, covering 2360 m to 3200 m, was started. This expansion will be made during the spring 1994.

A programme for testing new components, ie water standpipes etc, for the base installation at surface boreholes is in progress, aimed at carrying out the measuring programme in boreholes with large groundwater drawdown as well.

7.4 THE CHEMLAB PROBE

7.4.1 Background

In order to prepare for radionuclide migration experiments during the operational phase of the project, a special piece of equipment, the CHEMLAB, is under development. The CHEMLAB will be a laboratory contained in a borehole probe, in which migration experiments on core samples will be carried out under ambient conditions of pressure and temperature and using the formation groundwater surrounding the probe.

7.4.2 New results

The first stage of the development work, the design of the CHEMLAB system, for which CEA in Chadarache, France, was contracted, is now finished. The design work, also including construction and testing of components of vital importance for the function of the equipment, has undergone a critical review with respect to how the system can fulfil the demands of the planned radionuclide experiments. The review has resulted in minor modifications to the final design report. The contracting of the manufacture of the CHEMLAB system will be based on the design report.

8 CONSTRUCTION AND ENGINEERING WORK

8.1 OVERVIEW OF GOALS AND MAIN TASKS

The Äspö HRL facility comprises several construction sections and phases. A tunnel ramp has been excavated from the Simpevarp peninsula 1.5 km out under the Äspö island. The tunnel reaches Äspö at a depth of 200 m. The tunnel then continues in a hexagonal spiral under Äspö. The first turn of the spiral was completed in the summer of 1993. The tunnelling of this part was done by means of conventional drill and blast technique.

For the final part of the second spiral (from 430 to 450 m level), full-face boring with a Tunnel Boring Machine, TBM, will be tested. The first part of the second spiral will follow a hexagonal shape and also be done by drilling and blasting. A rock cavern will be excavated at the end of this section for assembly of the TBM. The tunnel will then go down to the 450 m level close to the shafts and continue horizontally westward to an experimental rock volume.

Three shafts are being built for communication and supply to the experimental levels. Two shafts are being built for ventilation, one for fresh air and one for exhaust air. The diameter of these shafts is 1.5 m. A bigger cylindrical shaft (3.8 m) is being built for the hoist. The shafts are being excavated by means of the raise-boring technique.

Office and storage buildings for the future research work are being constructed at Äspö over the tunnelspiral, along with buildings for ventilation equipment and machinery for the hoist. Together, these buildings form the "Äspö Research Village", which is designed to resemble other small villages in the surrounding archipelago.

The ventilation system for the underground facilities is being installed in one of the buildings. The system is designed to supply up to 20 m^3 of fresh air per second to the tunnels and caverns. The hoist is designed to take 20 persons or 2000 kg and will operate at a maximum speed of 5 m/s.

8.2 EXCAVATION AND CONSTRUCTION BELOW GROUND

During September 1993 the first phase of the tunnelling work was completed by the contractor, Siab AB. Final inspection was carried out on the 1st of October and the contractual work was approved.

Excavation of tunnel phase 2 started at section 2600 m on level -340m at the end of October. The Contractor for the second phase is Skanska AB. Full-face drilling with a TBM is also included in the contract for the second phase. The first section is being excavated by means of the drill-and-blast technique in the same way as the first spiral turn. At the end of the year the tunnel had reached 370 m below sea level. The total length was then 2760 m from the tunnel entrance. On the east side of the next turn a TBM will be set up, Figure 8-1. It will be assembled in a rock cavern 30 long, 10 m wide and 10.5 m high. The full-face boring of a tunnel 5 m in diameter with start from this cavern. The total length of the TBM tunnel is planned to be 420 m.

The three shafts have been excavated down to the 220 m level. The remaining sections of the shafts down to the 450 m level will be excavated by raise boring in the same manner. In the first part, pregrouting was done in the pilot holes. Experience showed that the grouting work after the raise-boring became very extensive and difficult to perform. An alternative method for pre-grouting has been tested for the second section.

The work with shafts from the 220 m level to the 340 m level started in October with pregrouting in core-drilled holes around the three shafts. The pilot hole for raise-boring of the elevator shaft has also been drilled with good results. The deviation was less then the requirements for the installations. The water seepage was very small and indicated that the pregrouting has been successful. The following reaming up to full section (3.8 m) gave a very good result, the shaft was almost dry.

The pump sump at the 220 m level has been constructed and used as a basin for drilling water for the raise-boring.

8.3 INSTALLATIONS

The manufacture of equipment for the ventilation and hoist installations has commenced on schedule.

Figure 8-1. *The TBM is a 5 m diameter ATLAS COPCO JARVA MK15.*

Installation of the machinery for the hoist will start in January 1994. Installation of the hoist in the shaft will start. A provisional platform will be used for the installation work in the shaft. Installation of pipes and cable trays will be carried out at the same time. A plan for installations in the hoist shaft has been worked out. The plan also includes safety regulations for the contractors involved in the installation work.

The equipment for ventilation of the tunnels and caverns will be installed in the surface building during the spring of 1994. The total system will not be commissioned until the beginning of 1995 when the excavation work is finished.

The power supply to the research village will be installed and commissioned during 1994.

8.4 ÄSPÖ RESEARCH VILLAGE

Construction of the buildings at Äspö has followed the schedule. The roofs of the various buildings had almost been completed in December and a traditional "roofing party" was held for the construction workers.

The construction work for the village will be completed in June 1994, Figure 8-2.

Figure 8-2. *Äspö Research Village.*

9 INTERNATIONAL COOPERATION

9.1 CURRENT INTERNATIONAL PARTICIPATION IN THE ÄSPÖ HARD ROCK LABORATORY

Eight organizations from seven countries are currently (April 1994) participating in the Äspö Hard Rock Laboratory.

In each case, cooperation is based on a separate agreement between SKB and the organization in question. Table 9-1 shows the scope of each organization's participation under the agreements.

Most of the organizations are interested in groundwater flow and transport and characterization. This is also reflected in the great interest for participating in the Äspö Task Force on groundwater flow and radionuclide migration, which is a forum for cooperation in the area of conceptual and numerical modelling of groundwater flow and solute transport in fractured rock.

9.2 NEWS RELATED TO THE PARTICIPATING ORGANIZATIONS' WORK

Documentation

The Äspö International Cooperation Report series currently consists of six reports, four of which were issued in 1993. A list of the reports is given in Appendix A.

Agreements

The agreement with NAGRA concerning joint studies in the Äspö Hard Rock Laboratory and the Grimsel underground rock laboratory was signed on March 16, 1994.

The scope of participation for the different organizations cooperating in the Äspö HRL can be seen in Table 9-1.

Negotiations concerning extension of the present agreements are currently being conducted with PNC, CRIEPI and ANDRA.

The agreement with NIREX and ANDRA concerning the Zone of Excavation Disturbance Experiment, ZEDEX, in the Äspö HRL was signed on March 29, 1994. According to the present schedule for excavation the in-situ will take place during the period May 1994-March 1995. The final report on the project is planned to be ready in March 1996.

9.3 MISCELLANEOUS

During 1993, both CRIEPI and PNC have had one scientist stationed at the Äspö Site Office.

The scientists have worked in close cooperation with the project.

ANDRA started a specific experiment called "Hydromechanical Behaviour of a Joint" during 1993. The project aims of an understanding of the response of a fracture in a rock mass to block movements and deformations. The results will later be reported in the Äspö International Cooperation Report series.

Table 9-1. *Scope of international cooperation.*

Organization	**Scope of participation**
Atomic Energy of Canada Limited, **AECL**, Canada	General information exchange on site characterization and in-situ experiments at underground facilities
Teollisuuden Voima Oy, **TVO**, Finland	Groundwater flow modelling. Measurement of flow in-situ. Hydrogeochemistry.
Agence Nationale pour la Gestion des Dechets Radioactifs, **ANDRA**, France	Groundwater flow modelling. Characterization of fracture zones. Instrumentation development
The Power Reactor and Nuclear Fuel Development Co, **PNC**, Japan	Improved understanding of specific key processes relevant to repository performance. Validation of specific models for data collection procedures. Optimization of site characterization methods. Numerical modelling of groundwater flow and tracer transport.
The Central Research Institute of the Electric Power Industry, **CRIEPI**, Japan	Improved understanding of specific key processes relevant to repository performance. Validation of specific models for data collection procedures. Optimization of site characterization methods. Numerical modelling of groundwater flow and tracer transport.
United Kingdom Nirex Limited, **NIREX**, Great Britain	Development and validation of flow and transport models. Design of experiments. Development of geotechnical logging procedures.

United States Department of Energy, **USDOE**, USA	Flow and transport characterization in fractured rock. Disturbed zone effects. Geochemical investigations using radiogenic isotope methods. Geochemical modelling. Integration of construction and testing activities.
Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, **NAGRA**, Switzerland	Groundwater flow and radionuclide migration. Disturbed zone effects (Degassing of groundwater and 2-phase flow, drift excavation effects). Construction/testing integration, TBM technique. Data flow management, documentation.

10 OTHER MATTERS

10.1 QUALITY ASSURANCE

SKB is required, and recognizes the need, to implement formal Quality Assurance (QA) programmes for a number of its areas of management, such as repository site investigations. Quality Management for the Äspö Hard Rock Laboratory project is a system of documents that will be developed and refined as the activities of the HRL develop. The system being developed at HRL consists of a Quality Assurance Handbook, Project Handbook and detailed Manuals. The handbooks will be tested, reviewed and updated based on experience from the HRL project.

The purpose and scope of the Quality Assurance Programme is to determine formats for the procedures needed to meet the goals of the HRL. This includes formats for;

- Organizational and administrative procedures, quality system principles
- Procurement procedures
- Scheduling and cost control
- Identification and traceability
- Changes, Nonconformances and Corrective actions
- Document control
- Quality audit

The QA Handbook defines in general terms the requirements for the project. The next handbook in the quality system is the Project Handbook, which is the instrument of project management and describes in greater detail routines, formats and responsibility. The activity process is described in Manuals for the different disciplines and tasks for investigations and rock work, Figure 10-1.

The QA Programme is described by the programme formats, each of which is described as a procedure in the Manual. The programme formats provide a framework for managing all activities and projects for the HRL that come under the QA Programme and must be complied with, except as otherwise specifically described by project leaders in their project plans and approved by the Project Manager.

The final products of the HRL will be various kinds of instruments and techniques as well as documents, including descriptions of techniques, methods and computer codes. The ultimate goals of the Quality Assurance Programme are to minimize the risk of mistakes, achieve proven correctness and traceability of data used and increase confidence in the final products.

10.2 PUBLIC RELATIONS AND INFORMATOIN ACTIVITIES

Communicating information on the Äspö Hard Rock Laboratory is an important and integral part of the project. This information must be formulated in accordance with SKB's overall communication policy, which means that the information shall be accurate, comprehensible, candid and up to date.

The Äspö day is now a tradition when the public is invited to see the facilities and meet some of the researhers involved in the project. This year, the interim storage facility for spent fuel (CLAB) was incorporated in the Äspö Open House, and information was also given about the planned incapsulation plant. Around 600 people visited HRL this day. Altogehter during the year, more than 2200 people have been brought underground.

Several programmes on radio and television have dealt with the project from points of view. The local newspapers frequently write about what is going on at the project.

Several papers have been presented and published, see Appendix A.

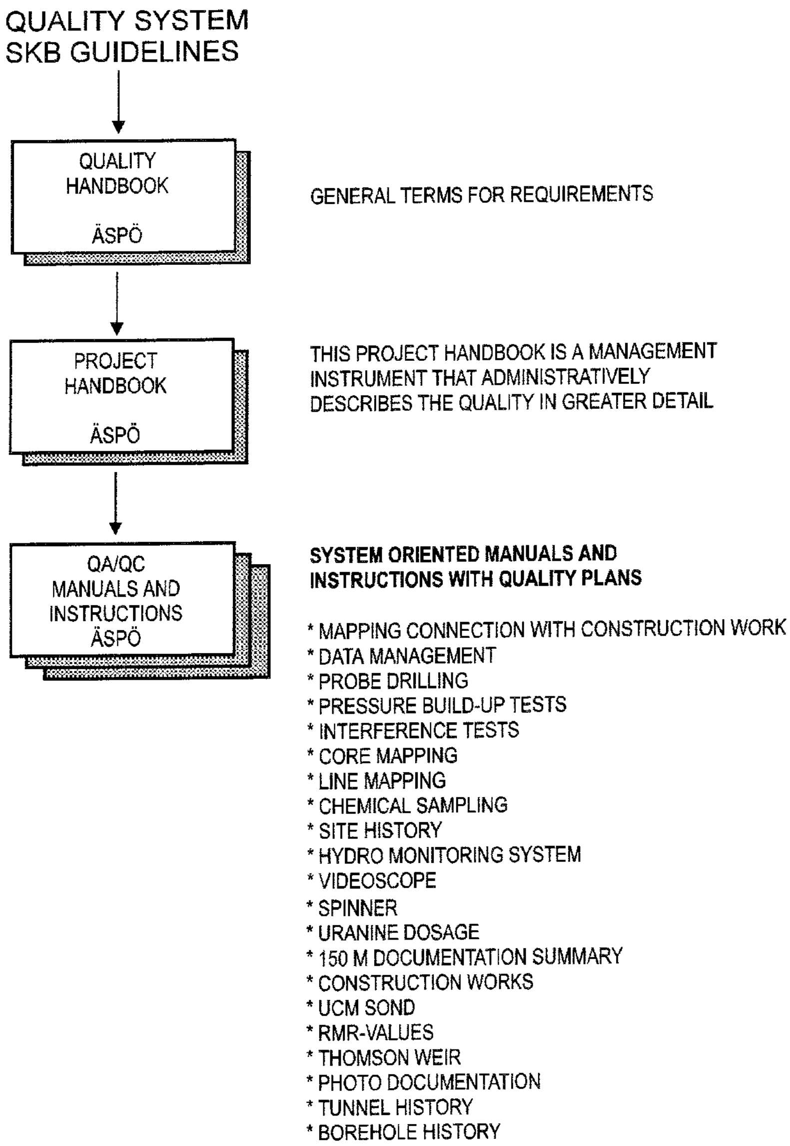


Figure 10-1. *The Quality System of the Äspö Hard Rock Laboratory.*

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/1-4/ **Stanfors R, Erlström M, Markström I (1991).** Äspö Hard Rock Laboratory. Overview of the investigations 1986-1990. SKB Technical Report, TR 91-20.

/1-5/ **Almén K-E, Zellman O (1991).** Äspö Hard Rock Laboratory. Field investigation methodology and instruments used in the pre-investigation phase, 1986-1990. SKB Technical Report, TR 91-21.

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/2-3/ **Stanfors R (ed), Liedholm M, Munier R, Olsson P, Stille H, 1993** a. Geological structural evaluation of data from tunnel section 700 - 1475. SKB Progress Report, PR 25-93-05.

/2-4/ **Rhén I, Danielsson P, Forsmark T, Gustafson G, Liedholm M, 1993 a.** Äspö Hard Rock Laboratory. Geohydrological evaluation of the data from section 700-1475 m, SKB Progress Report, PR 25-93-06

/2-5/ **Wikberg P, Gustafsson E, 1993**. Groundwater chemistry and transport of solutes. Evaluation of data from tunnel section 700 - 1475 m. SKB Progress Report, PR 25-93-07.

/2-6/ **Rhén I, Forsmark T, Danielsson P, 1993 b.** Piezometric levels. Evaluation of the data from section 700 - 1475 m. SKB Progress Report, PR 25-93-08.

/2-7/ **Stanfors R, Liedholm M, Munier R, Olsson P, Stille H, 1993 b.** Äspö Hard Rock Laboratory. Geological-structural evaluation of data from tunnel section 1475-2265 m, SKB Progress Report, PR 25-93-10.

/2-8/ **Rhén I, Danielsson P, Forsmark T, Gustafson G, Liedholm M, 1993 c.** Äspö Hard Rock Laboratory. Geohydrological evaluation of the data from section 1475-2265 m, SKB Progress Report, PR 25-93-11.

/2-9/ **Wikberg P, Skårman C, Laaksoharju M, Ittner T, 1993.** Äspö Hard Rock Laboratory. Groundwater chemistry and transport of solutes. Evaluation of data from tunnel section 1475-2265 m, SKB Progress Report, PR 25-93-12.

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/4-2/ **Banwart S, Laaksoharju M, Nilsson A-C, Tullborg E-L, Wallin B, 1992.** The large scale redox experiment. Initial characterization of the fracture zone. SKB Progress Report, PR 25-92-04.

/4-3/ **Banwart S, Gustafsson E, Laaksoharju M, Nilsson A-C, Tullborg E-L, Wallin B, 1993.** Redox processes in granitic coastal aquifer: Characterization of the large scale experimental site and some initial results. SKB Progress Report, PR 25-93-03.

/4-4/ **Byegård J, 1993.** The possibility for using slightly sorbing cations in tracer experiments in the Äspö Hard Rock Laboratory. A literature survey and some basic considerations. SKB Progress Preport, PR 25-93-14.

APPENDIX A

ÄSPÖ HARD ROCK LABORATORY

LIST OF PAPERS AND ARTICLES PUBLISHED IN 1993

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Stenberg L, Stanfors R. Äspö Hard Rock Laboratory - Evaluation of predictions in the access ramp. Part 1 Geology. FOCUS '93. Site Characterization and Model Validation. Las Vegas, September 26-29, 1993.

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APPENDIX B

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During 1993 the following reports and documents have been published.

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SKB Progress Report PR 25-93-13.

Byegård J. 1993. The possibility of using slightly sorbing cations in tracer experiments in the Äspö Hard Rock Laboratory.
PR 25-93-14

Technical Documents

Seven Technical Documents were produced during 1993.

Technical Notes

24 Technical Notes were produced during 1993.

List of SKB reports

Annual Reports

1977-78
TR 121
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Stockholm, May 1979

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Stockholm, May 1986

1986
TR 86-31
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TR 88-32
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TR 89-40
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SKB Annual Report 1991
Including Summaries of Technical Reports Issued during 1991
Stockholm, April 1992

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Technical Reports

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TR 94-01
Anaerobic oxidation of carbon steel in granitic groundwaters: A review of the relevant literature
N Platts, D J Blackwood, C C Naish
AEA Technology, UK
February 1994

TR 94-02
Time evolution of dissolved oxygen and redox conditions in a HLW repository
Paul Wersin, Kastriot Spahiu, Jordi Bruno
MBT Technología Ambiental, Cerdanyola, Spain
February 1994

TR 94-03
Reassessment of seismic reflection data from the Finnsjön study site and prospectives for future surveys
Calin Cosma[1], Christopher Juhlin[2], Olle Olsson[3]
[1] Vibrometric Oy, Helsinki, Finland
[2] Section for Solid Earth Physics, Department of Geophysics, Uppsala University, Sweden
[3] Conterra AB, Uppsala, Sweden
February 1994

TR 94-04
Final report of the AECL/SKB Cigar Lake Analog Study
Jan Cramer (ed.)[1], John Smellie (ed.)[2]
[1] AECL, Canada
[2] Conterra AB, Uppsala, Sweden
May 1994

TR 94-05
Tectonic regimes in the Baltic Shield during the last 1200 Ma - A review
Sven Åke Larsson[1,2], Eva-Lena Tullborg[2]
[1] Department of Geology, Chalmers University of Technology/Göteborg University
[2] Terralogica AB
November 1993

TR 94-06
First workshop on design and construction of deep repositories - Theme: Excavation through water-conducting major fracture zones Såstaholm Sweden, March 30-31 1993
Göran Bäckblom (ed.), Christer Svemar (ed.)
Swedish Nuclear Fuel & Waste Management Co, SKB
January 1994

TR 94-07
INTRAVAL Working Group 2 summary report on Phase 2 analysis of the Finnsjön test case
Peter Andersson (ed.)[1], Anders Winberg (ed.)[2]
[1] GEOSIGMA, Uppsala, Sweden
[2] Conterra, Göteborg, Sweden
January 1994

TR 94-08
The structure of conceptual models with application to the Äspö HRL Project
Olle Olsson[1], Göran Bäckblom[2], Gunnar Gustafson[3], Ingvar Rhén[4], Roy Stanfors[5], Peter Wikberg[2]
1 Conterra AB
2 SKB
3 CTH
4 VBB/VIAK
5 RS Consulting
May 1994

TR 94-09
Tectonic framework of the Hanö Bay area, southern Baltic Sea
Kjell O Wannäs, Tom Flodén
Institutionen för geologi och geokemi, Stockholms universitet
June 1994

TR 94-10
Project Caesium–An ion exchange model for the prediction of distribution coefficients of caesium in bentonite
Hans Wanner[1], Yngve Albinsson[2], Erich Wieland[1]
[1] MBT Umwelttechnik AG, Zürich, Switzerland
[2] Chalmers University of Technology, Gothenburg, Sweden
June 1994