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Äspö Hard Rock Laboratory Annual Report 1995

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ÄSPÖ HARD ROCK LABORATORY

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ABSTRACT

The Äspö Hard Rock Laboratory has been constructed as part of the preparations for the deep geological repository for spent nuclear fuel in Sweden. The Annual Report 1995 for the Äspö Hard Rock Laboratory contains an overview of the work conducted and important results.

The construction of the laboratory was completed during 1995 and the operating phase has now begun. The Äspö Research Village with office facilities, workshops, hoist and ventilation building was completed in June 1994.

During the construction phase data has been collected from the tunnel and boreholes drilled from the tunnel. These data have been compared to models of Äspö made before construction of the facility started. Results from these investigations have been reported and a comprehensive evaluation is in progress. The results will be used to design the site characterization programme for the deep repository.

The objective of the ZEDEX project has been to compare the mechanical disturbance to the rock for tunnel boring and blasting. The preliminary results show very little disturbance to the rock due to tunnel boring. The damage to the rock from blasting was also limited due to the special blast design applied. The damage in the wall was very limited while it reached an extent of 0.8 m in the floor of the blasted drift.

Ten organizations, including SKB; from nine countries are now participating in the work at the Äspö Hard Rock Laboratory and contribute to the results. An important part of the cooperative work is performed within the framework of the Task Force on groundwater flow and transport of solutes. An evaluation has been made of the Long Term Pumping test which was performed at Äspö some years ago. It showed that the modelling tools that exist today has the ability to give a three-dimensional description of groundwater flow at a site like Äspö. The Task Force will perform predictive modelling of the tracer experiments performed within the TRUE project. Characterization of the experimental site for TRUE and preparations for the tracer tests were completed during 1995.

Tests of the engineered barriers have been started with the test of technology for backfilling of deposition tunnels.

SAMMANFATTNING

Äspölaboratoriet har anlagts som en förberedelse för djupförvaret för det svenska använda kärnbränslet. Denna årsrapport för 1995 ger en översikt av genomförda arbeten och erhållna resultat.

Anläggnings- och byggnadsarbetet för Äspölaboratoriet slutfördes under året. Äspö forskarby stod klar redan i juni 1994 och där finns kontor, hiss- och ventilationsbyggnad, förråd m m.

I samband med bergarbetet har data samlats in från tunnel och omgivande borrhål. Insamlade data jämfördes löpande med de modeller av berggrunden som upprättades före byggstarten. Resultat från dessa undersökningar har rapporterats och en sammanfattande utvärdering pågår. Resultaten kommer att användas för att utforma ett väl avvägt platsundersökningsprogram för djupförvaret.

ZEDEX-projektet har genomförts för att jämföra mekaniska skador på berget vid TBM-borrning respektive sprängning. De preliminära resultaten visar på en mycket liten inverkan på berget vid TBM-borrning. Genom att använda försiktig sprängning blev inverkan på berget i den sprängda tunneln också liten, speciellt i tunnelväggen medan det blev uppsprickning av berget ned till ett djup av 0.8 m i tunnelns golv.

Tio organisationer, inklusive SKB, från nio länder deltar för närvarande i Äspölaboratoriets verksamhet och bidrar på olika sätt till resultaten. En betydande del av samarbetet rör modeller för grundvattenströmning och radionuklidmigration. En arbetsgrupp, s k Task Force, med medlemmar från de deltagande organisationerna jämför och utvärderar regelbundet resultat från olika försök med hjälp av olika beräkningsmodeller. En utvärdering har gjorts av det storskaliga pumptest som tidigare genomförts på Äspö. Den visade att de modelleringsverktyg som finns idag kan ge en god tredimensionell beskrivning av grundvattenströmningen på en plats som Äspö. Nästa uppgift för arbetsgruppen blir att genomföra prediktiv modellering av de spårförsök som skall genomföras inom ramen för TRUE-projektet. Karakterisering av experimentvolymen för TRUE och förberedelser för spårförsöken har genomförts under 1995.

Prov av ingenjörsbarriärerna har inletts med förberedande försök avseende teknik för återfyllnad av deponeringstunnlar.

EXECUTIVE SUMMARY

The Äspö Hard Rock Laboratory constitutes an important part of SKB's work to design and construct a deep geological repository for spent fuel and to develop and test methods for characterization of a suitable site. In the R&D Programme of 1986 SKB proposed to construct an underground laboratory. 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. Construction of the Äspö Hard Rock Laboratory started on October 1st, 1990 after approval had been obtained from the authorities concerned. Excavation work was completed in February 1995.

The work within the Äspö Hard Rock Laboratory, HRL, has ben divided into three phases; the pre-investigation, the construction, and the operating phase.

During the **Pre-investigation phase, 1986-1990**, studies were made to provide background material for the decision to locate the laboratory to a suitable site. The natural conditions of the bedrock were described and predictions made of geological, hydrogeological, geochemical etc. conditions to be observed during excavation of the laboratory. During the **Construction phase, 1990-1995**, comprehensive investigations and experiments were performed in parallel with construction of the laboratory. The excavation of the main access tunnel to a depth of 450 m and the construction of the Äspö Research Village were completed. The basis for the program for the **Operating phase**, which began in 1995, is described in SKB's RD&D Programme 1995.

Engineering and construction work

The Äspö Hard Rock Laboratory has been designed to meet the needs of the research, development, and demonstration projects that are planned for the Operating Phase. The underground part of the laboratory consists of a tunnel from the Simpevarp peninsula to the southern part of Äspö where the tunnel continues in a spiral down to a depth of 450 m. The total length of the tunnel is 3600 m where the last 400 m have been excavated by a tunnel boring machine (TBM) with a diameter of 5 m. The first part of the tunnel has been excavated by conventional drill and blast techniques. The underground tunnel is connected to the ground surface through a hoist shaft and two ventilation shafts. Äspö Research Village is located at the surface on the Äspö Island and it comprises office facilities, storage facilities, and machinery for hoist and ventilation. Construction of the facility was completed in the summer of 1995.

Stage goal 1 – Verification of pre-investigation methods

Work during the construction phase has focused on verification of pre-investigation methods and development of detailed investigation methodology which has been applied during tunnel construction. The comprehensive work on data collection for detailed characterization of the underground at Äspö was completed during 1995. These results are used for comparison of the predictions made of rock properties and groundwater flow and composition based on surface and borehole data with actual observations in the tunnel. Procedures for management of large quantities of data have now been developed to a point where SKB is in possession of a data production methodology that meets rigorous requirements on quality and overview. Results from investigations made during the construction phase are now reported.

Evaluation of obtained results for the final reporting of the Stage Goal "Verification of pre-investigation methods" has started. Three Technical Reports which summarize the results from the pre-investigation and construction phases will be published in 1996.

Stage goal 2 – Finalize detailed investigation methodology

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

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 experiment is performed in two test drifts near the TBM Assembly hall at an approximate depth of 420 m below the ground surface. The TBM test drift constitutes part of the main access tunnel of the Äspö HRL, the test section is 35 m long and located directly after the TBM assembly hall. The first four test rounds in the D&B test drift were used for testing the "smooth blasting technique" based on low-shock explosives and the remaining five rounds were used for testing the effects of "normal blasting". A number of boreholes were drilled axially and radially relative to the test drifts to assess the properties and extent of the EDZ.

The initial conditions in the rock mass have been characterized by several techniques including; tunnel mapping and core logging to determine geotechnical classification factors (Q, RMR), *in situ* seismic (P- and S-wave) velocity measurements and radar measurements. The rock mass response to excavation has been observed by mapping of induced fractures, multi point borehole extensometers (MPBX) and convergence measurements, laboratory testing on core samples, and by acceleration, vibration, seismic velocity, permeability and acoustic emission (AE) measurements.

Generally, the measurements in the far-field (more than 2 m from the drift perimeter) showed no evidence of damage to the rock for any of the excavation techniques in this generally good quality rock mass at Äspö. MPBX displacement measurements showed that deformation in the far-field was predominantly elastic. Seismic measurements showed no measurable change in the far-field due to excavation. The AE source locations showed that there was very sparse activity beyond about 2 m from the tunnel perimeter, but the distribution of events was similar for both TBM and D&B drifts at that distance.

From the measurements performed it is possible to conclude that the damaged zone formed by the excavation of the D&B drift was greater in degree and extent than that caused by excavating the TBM drift. This damaged zone is characterized by induced fracturing, increased permeability and reduced seismic velocities. It must, however, be borne in mind that relatively few measurements were made around the TBM drift to determine the extent of the damaged zone. The maximum measurable damage zone was approximately 80 cm in the floor of the D&B drift is probably a consequence of the larger charges used in the lifter holes for the rounds and the effect of the larger displacement caused by the flat shape of the floor. The extent of the damaged zone in the walls of the D&B drift was approximately 30 cm. The extent of the damaged zone was corroborated by AE data which showed that the majority of the AE events were located within a "thin skin", less than 1 m thick, around the drifts.

In general, the suite of methods employed in the ZEDEX Project has been effective in characterizing the extent and magnitude of property change in the EDZ. However, a significant problem in evaluating the results which have been obtained in a heterogeneous geologic setting is the relative scarcity of data points. To obtain a better statistical base to substantiate conclusions made above, the ZEDEX Project will be extended by another year. The project extension will include drilling and measurements in additional short radial holes, predictive modelling and extended data evaluations focused on understanding the crack initiation mechanisms and observed changes in hydraulic properties.

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 to the canister, and
- possible transport of radioactive materials away from a defective canister.

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

Several experiments are planned for the Operating Phase of the Äspö HRL. These experiments require sites which meet specific requirements with respect to rock conditions and groundwater properties. A separate project was carried out which provided base data and recommendations for locating experiments. Based on this work a provisional allocation was made of experimental sites for the experiments planned for the Operating Phase. Potential experimental sites were investigated by eight cored boreholes. The rock sampled by the boreholes has been characterized with different geological, geophysical and hydrogeological techniques. As a complement to conventional core logging, the new BIP borehole TV system was successfully utilized.

To gain a better understanding of radionuclide retention in the rock and create confidence that the radionuclide transport models that are intended to be used in the licensing of a deep repository for spent fuel are realistic, a programme has been devised for tracer tests on different scales. The programme has been given the name Tracer Retention Understanding Experiments (TRUE). The experimental programme is designed to generate data for conceptual and numerical modelling at regular intervals. Regular evaluation of the test results will provide a basis for planning of subsequent test cycles. This should ensure a close integration between experimental and model work.

The first tracer test cycle (TRUE-1) constitutes a training exercise for tracer testing technology on a detailed scale using non-reactive tracers in a simple test geometry. In addition, supporting technology development is performed for sampling and analysis techniques for matrix diffusion, and for understanding of tracer transport through detailed aperture distributions obtained from resin injection. The TRUE-1 cycle is expected to contribute data and experience which will constitute the necessary platform for subsequent more elaborate experiments within TRUE.

During 1995 work within the TRUE experiment has mainly been devoted to site characterization of the site where the tracer experiments during the First TRUE Stage will be conducted, and development of resin injection technology. One of the identified features at the selected site has been chosen for tracer testing. The selected feature is a reactivated mylonite with one major fracture plane and a few subparallel minor fractures. The characterization data have been provided to the Task Force on modelling of groundwater flow and transport of solutes which will use it for predictive modelling of tracer transport.

The project Degassing of groundwater and two phase flow has been initiated to improve our understanding of observations of hydraulic conditions made in drifts, interpretation of experiments performed close to drifts, and performance of buffer mass and backfill, particularly during emplacement and repository closure. The in-situ test program began with a pilot test with the objective to get data on the magnitude of degassing effects on permeability, time scales required for resaturation, and requirements on equipment for subsequent tests. The test showed no two-phase flow effects. Laboratory experiments have been carried out at Lawrence Berkeley National Laboratory (LBNL) during 1995 to investigate the effect of gas contents of similar low range as observed in the pilot hole field test on flow reductions due to degassing. Greater flowrate reductions were observed for greater gas contents, however, for relatively high gas contents, no further decrease in steady state flowrates and increase in gas saturations were observed for increasing gas contents. In addition to water gas contents, a number of parameters are of importance for the magnitude of flowrate reduction. Orders of magnitude differences in flowrate reduction were observed for fractures with different aperture distribution, aperture widths and inlet conditions.

The detailed scale experiment (REX) is planned to focus the question of oxygen and other redox active material that is trapped in the tunnels when the repository is closed. A test plan for the experiment has been prepared and the laboratory part of the experiment has started.

Most radionuclides have a strong affinity for adhering to different surfaces, i.e. a high K_d value. Numerical values that can be used in the safety assessments have been arrived at via laboratory measurements. However, it is difficult in the laboratory to simulate the natural groundwater conditions in the rock when it comes to redox status and concentrations of colloids, dissolved gases and organic matter. A special borehole probe, CHEMLAB, has been designed for different kinds of retention experiments where data can be obtained representative for the *in situ* properties of groundwater at repository depth. The results of experiments in the CHEMLAB probe will be used to validate models and check constants used to describe radionuclide dissolution in groundwater, the influence of radiolysis, fuel corrosion, sorption on mineral surfaces, diffusion in the rock matrix, diffusion in buffer material, transport out of a damaged canister and transport in an individual fracture. In addition, the influence of naturally reducing conditions on solubility and sorption of radionuclides will be tested. The CHEMLAB probe is currently being manufactured and will be put into use in 1996.

A "Task Force" with representatives of the project's international participants has been formed. The 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. The evaluation of Task No 1, the LPT2 pumping and tracer tests has been completed. A wide variety of conceptual as well as numerical models have been used to predict water flow and tracer breakthrough in this rather large scale. Eleven modelling groups participated in modelling of the LPT2 test. Evaluation has shown that all models, with respect to groundwater flow, represented the measured LPT2 data well. The hydraulic impact of the tunnel excavation at Äspö HRL was defined as the 3rd Modelling Task. The objective is to evaluate how the monitoring and the study of the hydraulic impact of the tunnel excavation may help for site characterization. This is an exercise in forward as well as inverse modelling which is currently in progress. Task 4 which includes predictive modelling of the TRUE radially converging and dipole tracer tests has recently been initiated. The Task Force has also produced an Issue Evaluation Table listing key issues related to the performance of the geological barrier.

Stage goal 4 – Demonstration of technology for and function of important parts of the repository system

The Äspö Hard Rock Laboratory provides an opportunity to test, investigate and demonstrate on full scale various components of the deep repository system that are of importance for long-term safety. It is also important to show that high quality can be achieved in design, construction and operation of a deep repository. Within this framework, a full-scale prototype of the deep repository will be built to simulate all steps in the deposition sequence. Different backfill materials and methods for backfilling of tunnels will be tested. In addition, detailed investigations of the interaction between the engineered barriers and the rock will be carried out, in some cases over long periods of time.

Preparatory tests of compaction techniques of different backfill materials were performed during the autumn of 1995. The *in situ* compaction tests, which were performed in the final part of the TBM tunnel, have been completed and the compacted back-fill has been excavated and removed from the tunnel. The compaction technique developed, where a vibrating plate is used on inclined layers, was successful and provided higher density than horizontal compaction. Laboratory measurements have been performed to provide data on properties of different mixtures of ballast material and bentonite.

Data management

One of the main objectives with the Äspö Hard Rock Laboratory is to test, develop and improve techniques before they are applied at the candidate sites. In this context efficient techniques are required to handle, interpret and archive the huge amount of data collected during a site characterization process.

A new database, based on combining the concepts of GEOTAB and SADB, has been developed. The first version of the new database, SICADA, was put into operation during 1995.

The experiences obtained from the investigations at Äspö Hard Rock Laboratory have shown that it is very important to have the possibility to test interactively in 3D different possible connections between observations in boreholes and on the ground surface. By effectively visualizing the rock model, based on available site data, it is possible to optimize new investigation efforts. To meet these needs SKB decided to develop a the Rock Visualization System (RVS) in November 1994. A detailed system specification was completed in December 1995. Realization of the system will be made during 1996.

International participation

The construction of the Äspö Hard Rock Laboratory (HRL) has attracted significant international attention. Presently (March 1996) nine organizations from eight countries participate. They are:

- Atomic Energy of Canada Limited (AECL), Canada.
- Teollisuuden Voima Oy (TVO), Finland.
- Agence National pour la Gestion des Dechets Radioactifs (ANDRA), France.
- The Power Reactor and Nuclear Fuel Development Co. (PNC), Japan.
- The Central Research Institute of the Electric Power Industry (CRIEPI), Japan.
- United Kingdom Nirex Limited (Nirex), United Kingdom.
- United States Department of Energy (USDOE), USA.
- National Cooperative for the Disposal of Radioactive Waste (NAGRA), Switzerland.
- Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF), Germany.

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1 GENERAL

1.1 BACKGROUND

The Äspö Hard Rock Laboratory constitutes an important part of SKB's work to design and construct a deep geological repository for spent fuel and to develop and test methods for characterization of a suitable site. In the R&D Programme of 1986 SKB proposed to construct an underground laboratory. A proposal that was 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 decided in principle to site the laboratory on southern Äspö about 2 km north of the Oskarshamn power station, see Figure 1-1. Construction of the Äspö Hard Rock Laboratory started on October 1st, 1990 after approval had been obtained from the authorities concerned. Excavation work was completed in February 1995.

The Äspö Hard Rock Laboratory has been designed to meet the needs of the research, development, and demonstration projects that are planned for the Operating Phase. The underground part of the laboratory consists of a tunnel from the Simpevarp peninsula to the southern part of Äspö where the tunnel continues in a spiral down to a depth of 450 m, see Figure 1-2. The total length of the tunnel is 3600 m where the last 400 m have been excavated by a tunnel boring machine (TBM) with a diameter of 5 m. The first part of the tunnel has been excavated by conventional drill and blast techniques. The underground tunnel is connected to the ground surface through a hoist shaft and two ventilation shafts. Äspö Research

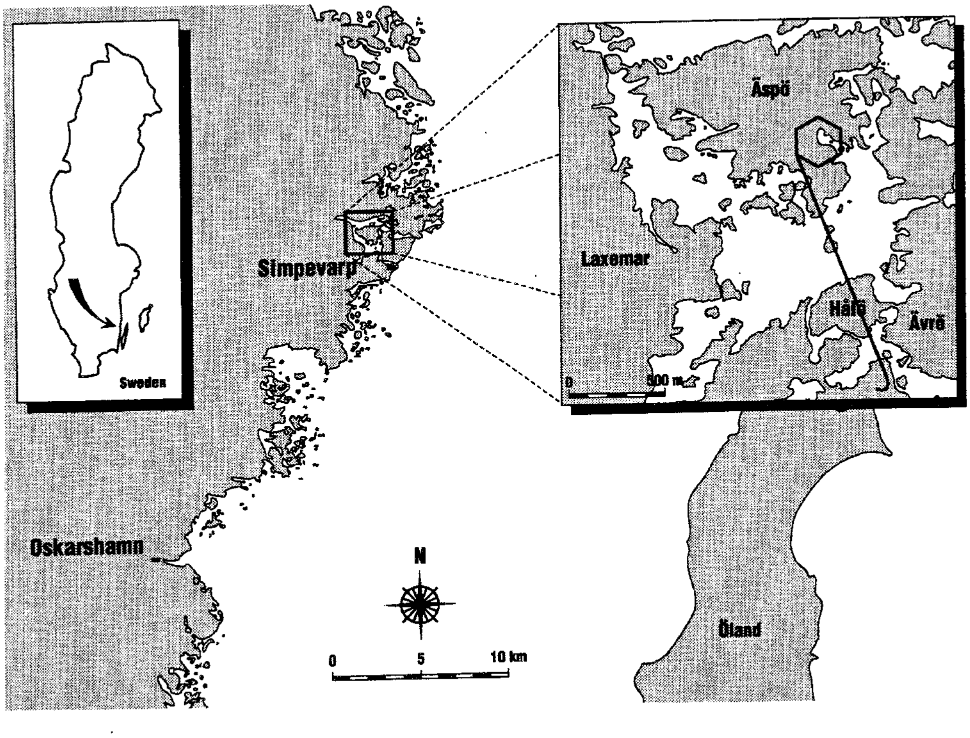


Figure 1-1. Location of the Äspö HRL.

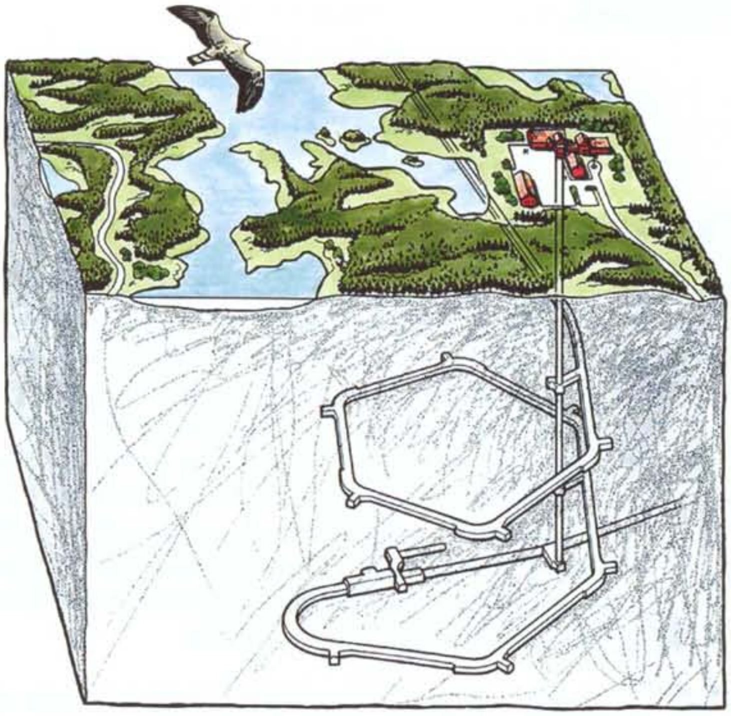


Figure 1-2. *Schematic design of the Äspö HRL. The lower part of the facility has been excavated by a 5 m diameter Tunnel Boring Machine.*

Figure 1-3. *Aerial view of the Äspö Research Village.*

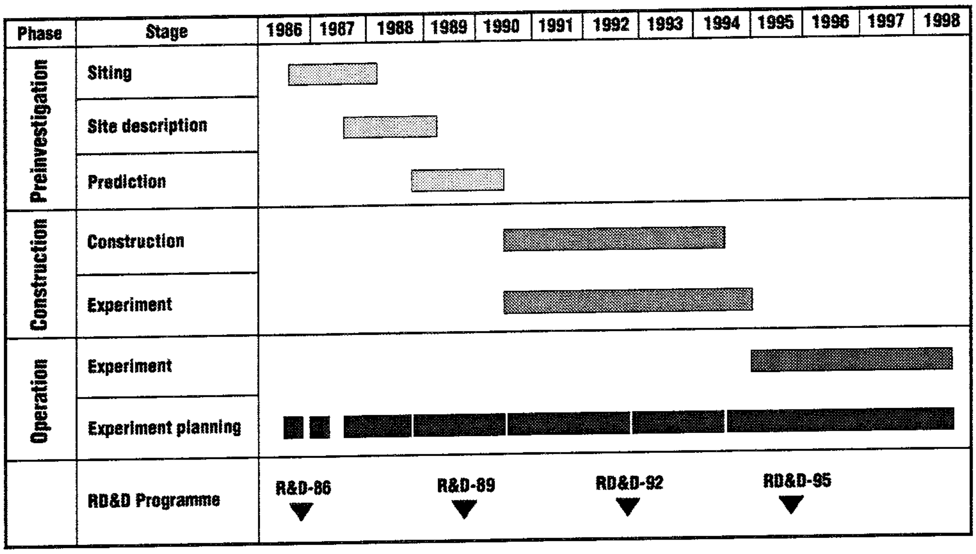


Figure 1-4. Master time schedule for the Äspö HRL.

Village is located at the surface on the Äspö Island and it comprises office facilities, storage facilities, and machinery for hoist and ventilation, see Figure 1-3.

The work with the Äspö Hard Rock Laboratory, Äspö HRL, has been divided into three phases: the pre-investigation phase, the construction phase, and the operating phase, see Figure 1-4.

During the **Pre-investigation phase, 1986–1990**, studies were made to provide background material for the decision to locate the laboratory to a suitable site. The natural conditions of the bedrock were described and predictions made of geological, hydrogeological, geochemical etc. conditions to be observed during excavation of the laboratory. This phase also included planning for the construction and operating phases.

During the **Construction phase, 1990–1995**, comprehensive investigations and experiments were performed in parallel with construction of the laboratory. The excavation of the main access tunnel to a depth of 450 m and the construction of the Äspö Research Village were completed.

The **Operating phase** began in 1995. A preliminary outline of the program for the Operating phase was given in SKB's Research, Development and Demonstration (RD&D) Programme 1992. Since then the program has been revised and the basis for the current program is described in SKB's RD&D-Programme 1995.

The Äspö Hard Rock Laboratory has so far attracted considerable international interest. As of March 1996 nine foreign organizations are participating in the Äspö HRL: Atomic Energy of Canada Limited (AECL); Power Reactor & Nuclear Fuel Development Corporation (PNC), Japan; Central Research Institute of Electric Power Industry (CRIEPI), Japan; Agence National Pur la Gestion des Dechets Radioactifs (ANDRA), France; Teollisuuden Voima Oy (TVO), Finland; Nirex, United Kingdom; United States Department of Energy (USDOE), USA; Nationale Genossenschaft für die lagerung von radioaktiver Abfälle (NAGRA), Switzerland; and Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF), Germany. The agreements with ANDRA has been prolonged for another year and with CRIEPI for another 4 year period. BMBF joined the Äspö HRL collaboration in July 1995.

1.2 OBJECTIVES

SKB has decided to construct the Äspö Hard Rock Laboratory for the main purpose of providing an opportunity for research, development and demonstration in a realistic and undisturbed underground rock environment down to the depth planned for the future deep repository. During the Operating phase priority will be given to projects which aim

- to increase scientific understanding of the safety margins of the deep repository,
- to test and verify technology that provide cost reductions and simplifies the repository concept without compromising safety, and
- to demonstrate technology that will be used in the deep repository.

To meet the overall time schedule for SKB's RD&D work, the stage goals for the activities at the Äspö Hard Rock Laboratory were defined in RD&D Programme 1989. The commencement of the Operating Phase has called for a revision of the Stage Goals based on experiences gained so far. For the Operating Phase the Stage Goals are defined as follows:

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, and

2 **Finalize detailed investigation methodology**

- refine and verify the methods and the technology needed for characterization of the rock in the detailed site investigations.

3 **Test models for description of the barrier function of the host rock**

- further develop and at repository depth test methods and models for description of groundwater flow, radionuclide migration, and chemical conditions during operation of a repository and after closure.

4 **Demonstrate technology for and function of important parts of the repository system**

- test, investigate and demonstrate on a full scale different components of importance for the long-term safety of a deep repository system and to show that high quality can be achieved in design, construction, and operation of system components.

1.3 ORGANIZATION

To meet the needs of the program for the Operating Phase which are quite different from those of the previous phases the organization of the Äspö HRL has been revised. A schematic chart of the organization of the Äspö HRL valid from January 1995 is shown in Figure 1-5.

1.3.1 The Program Committee for the Deep Repository

The committee is SKB's internal joint steering/advisory group for the deep repository project and the Äspö HRL. The Program Committee proposes and/or discusses changes in the technical/scientific program and changes in quality, schedule and cost frames. Coordination with SKB's other RD&D also takes place within the SKB Program Committee. Chairman of the Program Committee is Per-Eric Ahlström (March 1996).

1.3.2 Advisory Groups

The international partners and SKB reached a joint decision to form the Äspö International Joint Committee (IJC) to be convened in connection with Technical Evaluation Forum (TEF) meetings. The role of the IJC is to coordinate the contributions of organizations participating in the Äspö HRL. The TEF meetings are organized to facilitate a broad scientific discussion and review of results obtained and planned work. Technical experts from each participating organization and the IJC delegates participate in the TEF meetings. Chairman of IJC/TEF is Per-Eric Ahlström and secretary is Monica Hammarström (March 1996).

For each experiment the Äspö HRL management will establish a Peer Review Panel consisting of three to four Swedish or International experts in fields relevant to the experiment.

1.3.3 Project Groups

Project Group 1986–1995

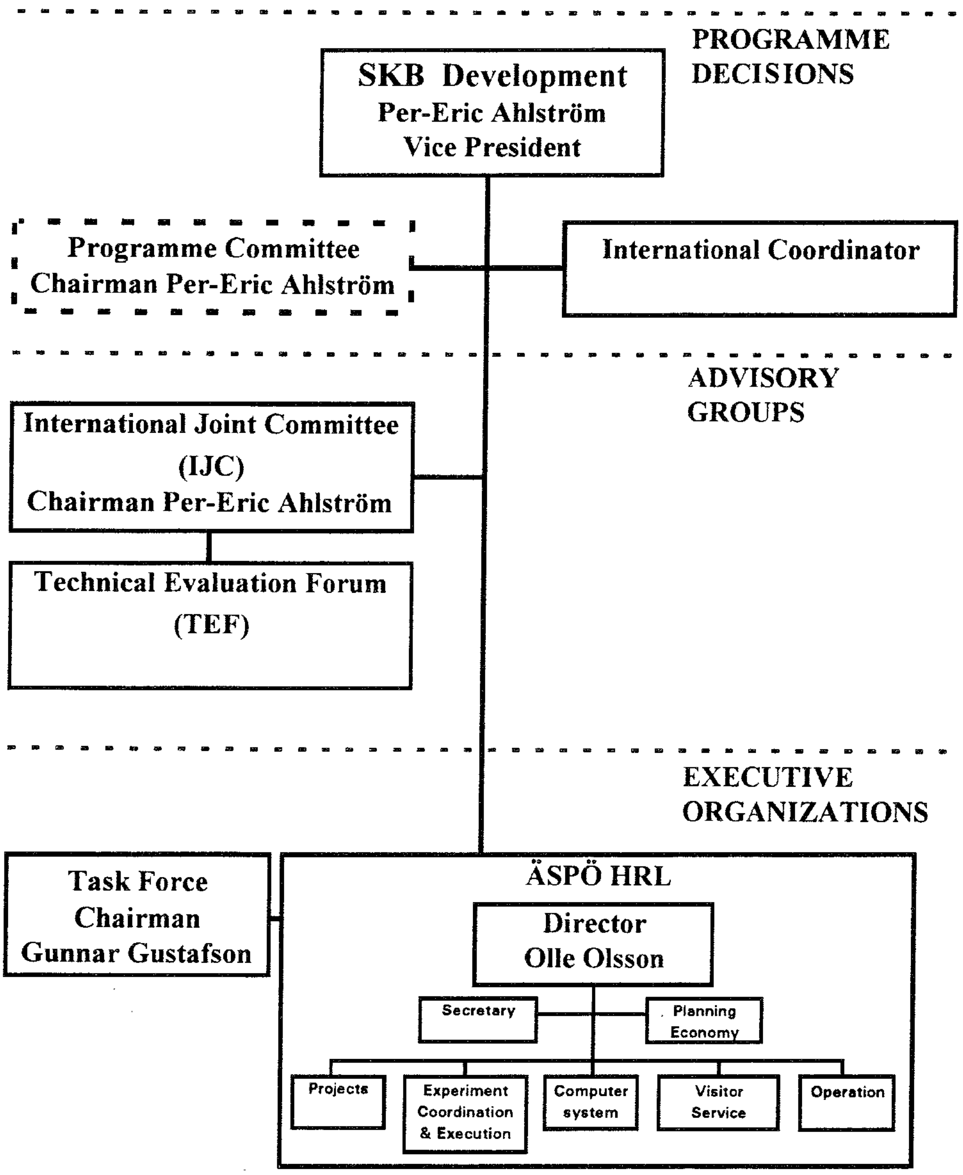
The Project Group that executed the Äspö Project during the period 1986–1995 will continue its efforts during 1996 to evaluate and publish the results and experience gained during the period 1986–1995.

Projects 1995–

For the Operating Phase the organization has been revised.

Each major research and development task is organized as a project which is led by a Project Manger. Each Project Manager will be assisted by an On-Site Coordinator from the Site Office with responsibility for coordination and execution of project tasks at the Äspö HRL.

The staff at the Site Office will be increased to ensure that efficient service and high quality work can be provided to the projects. It is estimated that a staff of around 13 members will constitute a suitable core of resources.



Äspö Hard Rock Laboratory Organization

Figure 1-5. *Organization of the Äspö Hard Rock Laboratory valid from January 1995.*

The Äspö Hard Rock Laboratory and the associated research, development, and demonstration tasks are managed by the Director of the Äspö Hard Rock Laboratory (Olle Olsson). The Operations Manager (Olle Zellman) is responsible for the operation and maintenance of the Äspö HRL facilities.

Work should be conducted according to the guidelines provided by the Äspö Handbook (in Swedish).

1.3.4 Task Force on modelling of groundwater flow and transport of solutes

The Technical Coordinating Board (TCB) which preceded the IJC established the Task Force on modelling of groundwater flow and transport of solutes. The Task Force reviews and or proposes detailed experimental and analytical approaches for investigations and experiments at Äspö HRL. The group convenes twice a year. More than ten different modelling groups are now actively involved in the work. Chairman (March 1996) is Gunnar Gustafson, CTH and secretary Anders Ström, SKB.

1.4 PLANNING OF EXPERIMENTS

The experiments to be performed in the Operating Phase will be described in a series of Test Plans, one for each major experiment. The Test Plans should give a detailed description of the experimental concept, scope, and organization of each project. The Test Plans are structured according to a common outline. In cases where experiments are planned to extend over long time periods (up to 10 years) it is not appropriate or even possible to plan the experiment in detail in advance. In such cases, Test Programmes will be prepared outlining the objectives and overall scope of the programmes, which will be divided into stages with a duration of 2-3 years. Detailed Test Plans will then be prepared for each stage, following an evaluation of results obtained to date. These evaluations may result in programme revisions.

Initially, draft Test Plans will be prepared which will be submitted for review by the Task Force and other bodies. After review, as well as scoping or design calculations, the Test Plans will be updated, detailed where appropriate, and published as Progress Reports or International Cooperation Reports. The general strategy is to begin preparation of the Draft Test Plans approximately one year before field work or some other significant preparation work is planned to start. The intention is also to actively engage the Task Force on modelling of groundwater flow and transport of solutes in the planning, design, and evaluation of the flow and transport experiments.

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) and KTL (the Act on Nuclear Activities) 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, see Figure 2-1.

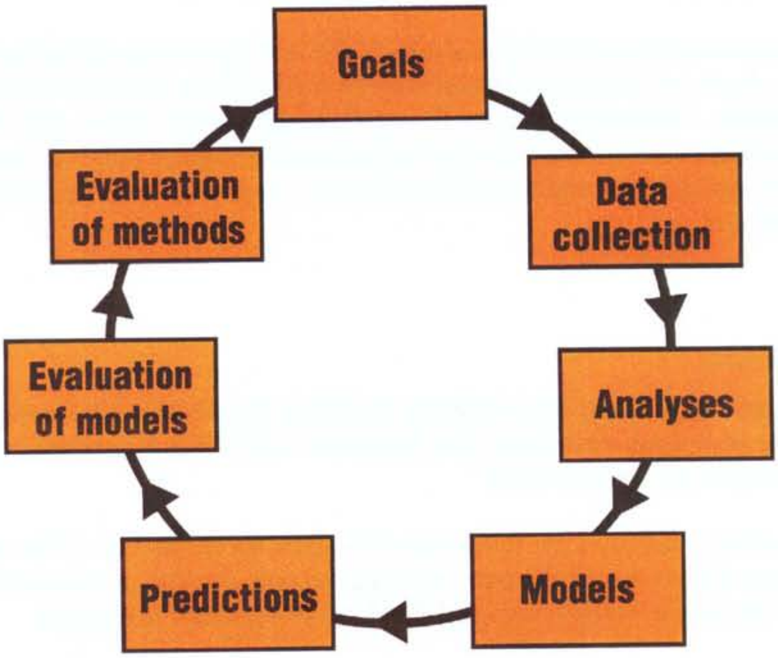


Figure 2-1. *The strategy for the verification of the pre-investigation methods.*

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 were checked against the data collected during the construction work.

The evaluation of the models will be used to evaluate the usefulness and reliability of 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

2.2.1 Background

Characterization in the tunnel is performed by the Characterization Team at the Site Office. Overview 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.

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 (SICADA).

Groundwater level data from core-drilled and percussion-drilled boreholes located on Äspö are transmitted to the Site Office by radio to the Hydro Monitoring system (HMS). Measuring centrals B and C in the tunnel collect data from boreholes located in the tunnel, from weirs positioned at regular intervals, measure velocity of ventilation air and tunnel air, humidity, amount of water pumped in to and out of the tunnel.

2.2.2 Results

Distribution of all data collected including the TBM-tunnel and parallel blasted tunnel at level -450 metres has been done. All niches have been mapped and data has been presented in /2-2/.

Packer installation for follow-up of the pressure around the TBM-tunnel has been done. Follow-up of pressures in all packed-off sections in most of the probe-holes in the access, spiral tunnel and TBM-tunnel has been performed.

Monitoring of water inflow into the tunnel to the weirs and maintenance of dams and weirs has been done. Results are presented in /2-2/.

Core logging and supervision of the core drilling has been done in connection with the first phase of TRUE-experiment, REX and RNR- experiment (SELECT).

Absolute calibration of ground water levels of all sections in all boreholes was performed in January, March/April and August.

2.3 EVALUATION OF MODELS AND METHODS

2.3.1 Background

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.

Reporting on the evaluation in order to evaluate the models of the predictions 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) /2-3/. The comparison up to tunnel section 700–2874 m (depth 200 m) has been reported /2-4 – 2-15/.

2.3.2 Results

Supplementary investigations of fracture zones

In order to get more detailed information of different kinds of fracture zones supplementary investigations have been performed in the Äspö tunnel after excavation during 1994–95.

The predicted sub-vertical "NNW-structures" are in some cases possible to identify as "minor fracture zones" at depth. In other cases they are rather forced to be built up as a more or less complex system of conductive "fractures" trending NW to NS.

A special study of gently dipping structures reveals only two narrow fracture zones. Gently dipping fractures occur as fracture swarms rather than zones.

All fracture zones mapped in the tunnel have been compiled in a "Fracture zone Catalogue". 43 fracture zones have been recorded and of these 12 are "major zones" (>5 m wide) and 31 "minor zones" (<5 m wide).

Supplementary investigations are reported in /2-16/.

Rock stress measurements

Rock stress measurements have been undertaken at several occasions during the site investigation- and construction phases of the Äspö Hard Rock Laboratory. Results have been reported successively in a number of reports. /2-17/ summarizes all stress data produced at Äspö to date.

Measurements reported comprise hydraulic fracturing and overcoring tests in three deep surface boreholes, and overcoring tests conducted in several short boreholes drilled from the ramp. Results show a rather consistent, NW-SE and sub-horizontal orientation of the maximum principal stress. In this direction, stress magnitudes are relatively high, reaching values of about 30 MPa at 499 meters depth. The intermediate- and minimum principal stresses are of considerably lower magnitudes, resulting in an anisotropic stress field and large shear stresses.

Data are commented briefly in the report, but no interpretation efforts are made. There is, however, clearly need for such work. Data reliability should be further analyzed. This may help in explaining some of the discrepancies observed when comparing different data sets. Furthermore, results should be studied in a geological perspective. Given the vast geological and geomechanical information available from Äspö, an opportunity is offered to explore the usefulness of point stress measurements in understanding stress conditions on a site scale.

Borehole radar measurements

Borehole radar measurements using directional antenna have been performed in the Äspö HRL. The investigation presented in /2-18/ was performed in four parts. The first part was correlation of oriented radar reflectors from three boreholes, calculate intersections with tunnel, and control of corresponding structures at the intersections. The second part was compilation of the radar measurements in form of stereograms and comparison with data from tunnel mapping before and after tunnel section 1/400. The third part was correlation of radar reflectors with core mapping in four boreholes. The fourth part included orientation of reflectors from three boreholes directed outward from the spiral ramp and comparison with data from tunnel mapping as well as the compiled radar data from boreholes in the spiral ramp.

The investigation shows that the dominating vertical WNW- to NW-striking fractures and waterbearing fractures have been detected by the borehole radar. The frequent sub-horizontal fractures and waterbearing fractures have also been detected by the radar as well as the vertical NNE- to NE-striking fractures. The result from the radar measurement also shows two subgroups of gently dipping WNW- and ENE-striking reflectors, which can not be considered as prominent fracture orientations. Correlation between reflectors in boreholes and structures in the tunnel were acceptable. Fractures, fracture zones and waterbearing fractures from tunnel mapping were correlated with radar reflectors. Correlation between radar reflectors and core mapping was considered good. The investigation shows that geological phenomena in the core were mainly indicated by radar reflectors and vice versa. Comparison of radar reflectors east and west of the spiral ramp to radar reflectors from boreholes and structures from tunnel mapping below tunnel section 1/400 was good. The orientation pattern, with a few exceptions, which was found east and west of the spiral ramp, could also be recognized within the spiral ramp. However, NS-striking radar reflectors are more common east and west of the spiral ramp, but this might be a result of borehole orientation.

Reporting

Several Progress Reports which compile investigations done during the construction phase of the Äspö HRL have been made 1995. For example: Compilation of groundwater chemistry data from Äspö 1990-1994 /2-19/ and lithology /2-20/ have been published.

A report on feasibility and use fullness of site investigation method was also published /2-21/ and the documentation of the last part of the tunnel, tunnel section 2374–3600 m, has been reported /2-22/.

2.3.3 Planned work

A few of the reports that are the base for the evaluation of pre-investigation methods are to be published during the spring. Evaluation for the final reporting have started and the final reporting of "*Verification of Pre-Investigation Methods*" will be made during 1996. Three Technical Reports will be made which summarize the results at Äspö HRL. The preliminary titles are:

1. An overview of investigations performed 1986–1995.
2. Evaluation of Äspö pre-investigation results and outcomes by comparison to the detailed characterizing results during construction of the Äspö HRL.
3. Final report – Äspö bedrock models based on site characterization and evaluation of results 1986-1995.

The purpose with the first report is to give a short information of what has been done and an easier access to data presented in different reports.

The second report will give a detailed description of the comparison between predictions and outcome for tunnel section 700–2875 m, which to a large extent have been presented in 12 Progress Reports. The evaluation will focus on the validity of conceptual models and evaluation methodology used and also the feasibility and robustness of methods and investigation strategy (sequence, amount etc).

The third report will give a short description of classification systems used, new results since the pre-investigation and a new integrated model over Äspö HRL, with comments of how some parts of the integrated model has developed.

2.4 CODE DEVELOPMENT / MODELLING

2.4.1 Background

As a basis for a good optimization of the repository system and for a safety assessment as a basis for the siting application, which is planned to be submitted a couple of years after 2000, it is necessary to:

"Test models for groundwater flow and radionuclide migration

- refine and test on a large scale at repository depth methods and models for describing groundwater flow and radionuclide migration in rock."

At Äspö HRL several numerical models have been tested and are tested and developed in order to meet this stage goal.

2.4.2 Results

Visualization

The developments of visualization and the coupling of the numerical groundwater flow model to the CAD-data base have been made /2-23/.

Predicting piezometric levels at Äspö HRL

The drawdowns for tunnel face position 2 874 m have been calculated with the same model as was used 1990 for predicting the drawdown but with the measured flow into the tunnel. An updated structural model from 1994 has also been tested with the measured flow rates. A few Monte Carlo simulations were done with each model. The simulations indicate that in some cases the predicted level can vary considerably depending on distance to a deterministic feature and position in space. In several cases the standard deviation for predicted drawdown seem to have decreased. However, in some cases the mean predicted drawdowns are better for the 1990 model compared to the 1994 model. The results will be used when the new model is set up /2-24/.

Groundwater recharge under natural and disturbed conditions

To estimate the groundwater recharge under natural and disturbed conditions is very difficult. During the autumn a new method have been tested on the Äspö data in order to see if it is possible to define a more robust boundary condition, than for example constant rate, that can handle both natural conditions and large disturbances due to for example inflow to a tunnel system.

A schematic outline of the situation considered is given in Figure 2-2, P-E denotes precipitation minus evaporation and is set to 200 mm/year, which is relevant for the Äspö area. Capillary forces are not considered, which indicates that pressure in the unsaturated zone will be equal to the atmospheric pressure, here set to zero. It then follows that the vertical conductivity, K_Z, is equal to P-E close to the ground surface. This can be understood from the balance of forces:

$$0 = \frac{\delta p}{\delta z} - \frac{\rho g}{K_Z} w - \rho g,$$

where w is the vertical Darcy velocity, p density and g the gravitational constant. For the unsaturated zone close to the ground p = 0 and w = -(P - E) and hence K_Z = P - E.

This analysis is applicable to a porous medium, but some further considerations are needed for a fractured media. In Figure 2-2 some fracture zones in contact with a tunnel are indicated. The phreatic surface may be lowered in the fracture zone, due to the contact with the tunnel. In the unsaturated part of the zone we may have a

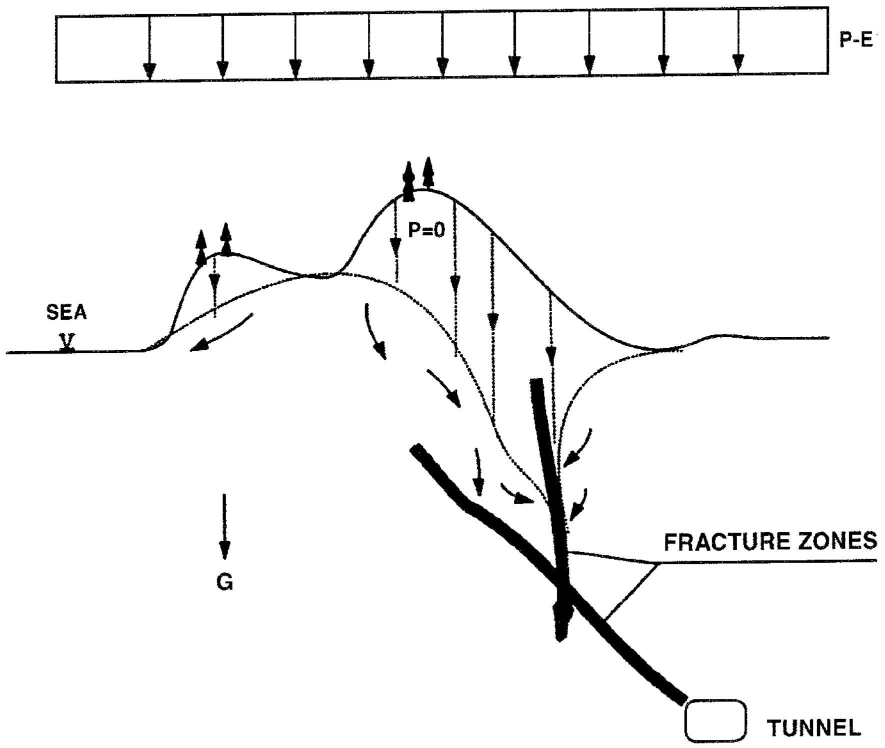


Figure 2-2. Schematic outline of the situations considered.

significantly higher vertical flow than P-E, due to horizontal inflows. We thus conclude that it is not relevant to assume that the vertical conductivity is always equal to P-E for the unsaturated zone.

The method suggested seems to perform quite well. A vertical flow under atmospheric pressure is resulting in the unsaturated zone. Good agreement is obtained in the comparison with the analytical solution and results for the Äspö site seem plausible.

The general conclusion from the work presented is that a simple and efficient method for the identification and prediction of the unsaturated zone has been found.

Regarding the deep infiltration rates it is perhaps too early to make any firm conclusions. The tentative results, i.e. 10 mm/year for natural conditions and 150 mm/year with tunnel present, do however seem realistic. See also Figure 2-3.

Results are reported in /2-25/.

2.4.3 Planned work

The re-modelling of Äspö HRL will start 1995 but will be finalized during 1996. The modelling will mainly be done in three steps.

- Scoping calculations/calibrations on natural tracers.
- Test importance of some hydraulic structures.
- Calculate flow-paths to water sampling points and draw-down due to Äspö HRL.

Figure 2-3. *Infiltration rates 5 metres below ground surface. Natural conditions. (top): isolines for 10–200 mm/year. Tunnels present (below): isolines for 200–2000 mm/year.*

The modelling is intended to give a better model realization of the Äspö site compared to the one used earlier in the project and to give results for the final reporting mentioned in section 2.3.3.

3 METHODOLOGY FOR DETAILED CHARACTERIZATION OF ROCK UNDERGROUND

3.1 GENERAL

Detailed characterization includes construction of access tunnels or shafts to a potential repository and investigations made from the tunnels and boreholes drilled from the tunnels.

The purpose of detailed characterization of a repository site is:

- to confirm the existence of a sufficiently large rock volume suitable for use as a repository at a selected site,
- to provide the data needed for the safety assessment required for obtaining the permit to construct the deep repository, and
- to provide data on bedrock conditions in order to optimize repository design with respect to engineered barriers and repository layout.

Detailed characterization will facilitate refinement of models based on data from the ground surface and surface boreholes. The refined models will provide the basis for updating the layout of the repository and adapting it to local conditions. Due to the heterogeneity of the rock, the layout of the repository needs to be adapted to the gradually refined model of rock conditions. This approach has a long tradition in underground construction and it should be used also for a deep repository.

Important skills are to be able to build and investigate in both the bad and the good rock with adequate personal safety. Data shall be collected and evaluated in parallel with the tunnelling. Experience from Äspö serves as a basis for SKB's planning of coming detailed characterization at a possible deep repository site.

The work performed at the Äspö Hard Rock Laboratory will demonstrate the deepening of knowledge that is possible to achieve in relation to what was known from 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.

3.2 INVESTIGATIONS IN THE TBM TUNNEL

3.2.1 Results

A cored borehole (KA3191F) was drilled from the TBM assembly hall in the centre line of the planned TBM tunnel down to the lowest position of the excavation at a

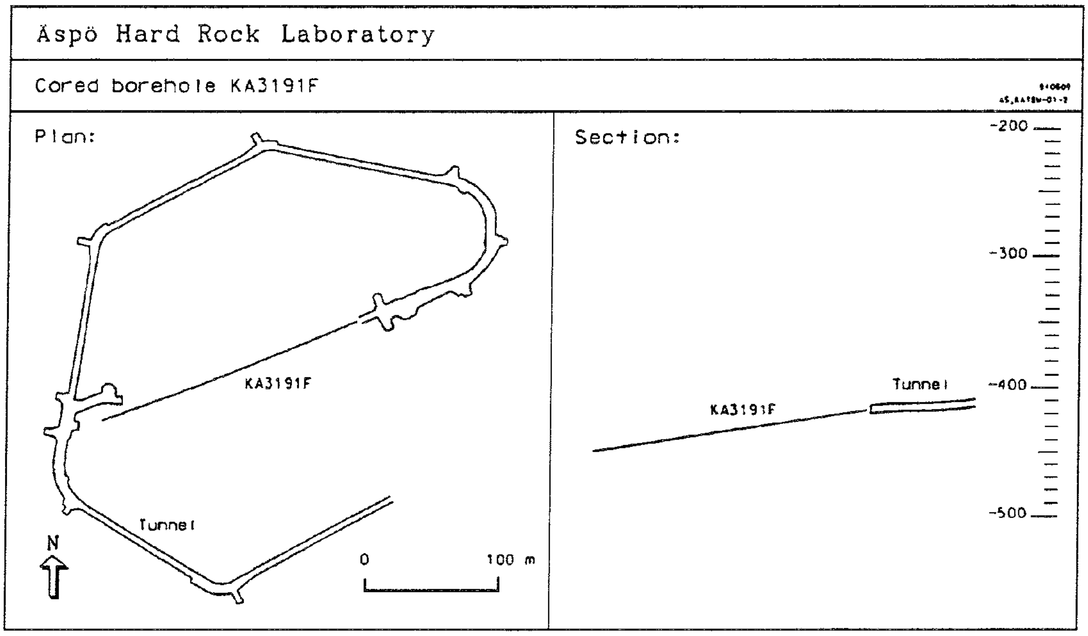


Figure 3-1. Overview of the cored borehole KA3191F.

depth of 450 metres below ground surface in the vicinity of the shafts, see Figure 3-1. The borehole was 210 m long. The objective of this borehole was to:

- provide data in advance of the TBM tunnel for characterization of the rock properties and fracture zones which could give additional information of value in advance of the TBM boring,
- provide additional data for geological, geohydrological and groundwater chemical modelling within the whole spiral loop and give additional data to test and upgrade the structural conceptual model of Äspö,
- provide geological, geohydrological and groundwater chemical data necessary for the siting process of the experimental volumes,
- provide data for comparison of the evaluation of geological and geophysical data collected from a borehole compared to the same data collected from a TBM tunnel. The results are reported in /3-1/.

Some results from the comparison is shown in Figures 3-2 and 3-3. The main geological-geophysical results are summarized in section 3.3.2.

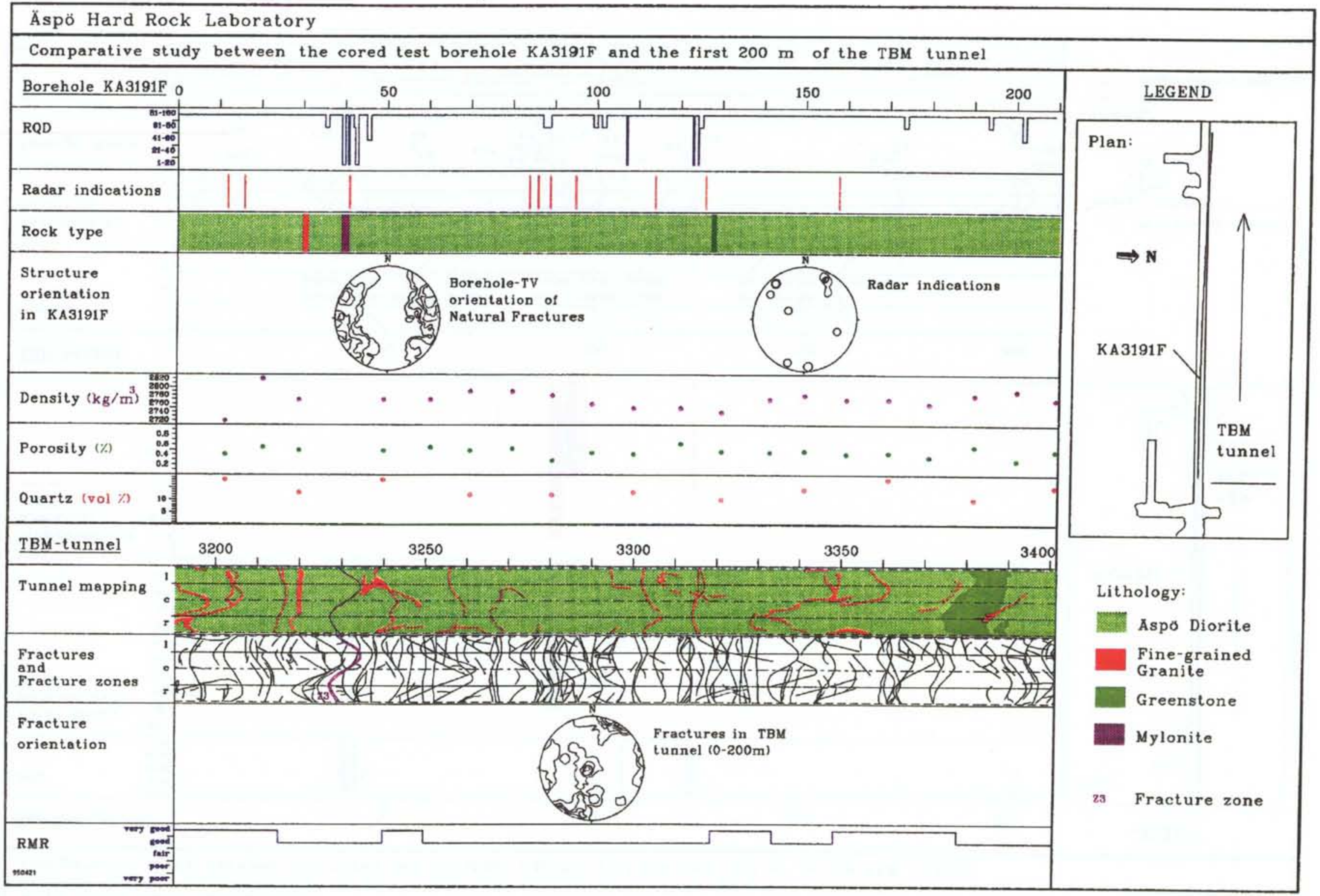


Figure 3-2. Comparison between geological mapping of borehole KA3191F and mapping of the first 200 m of the TBM tunnel

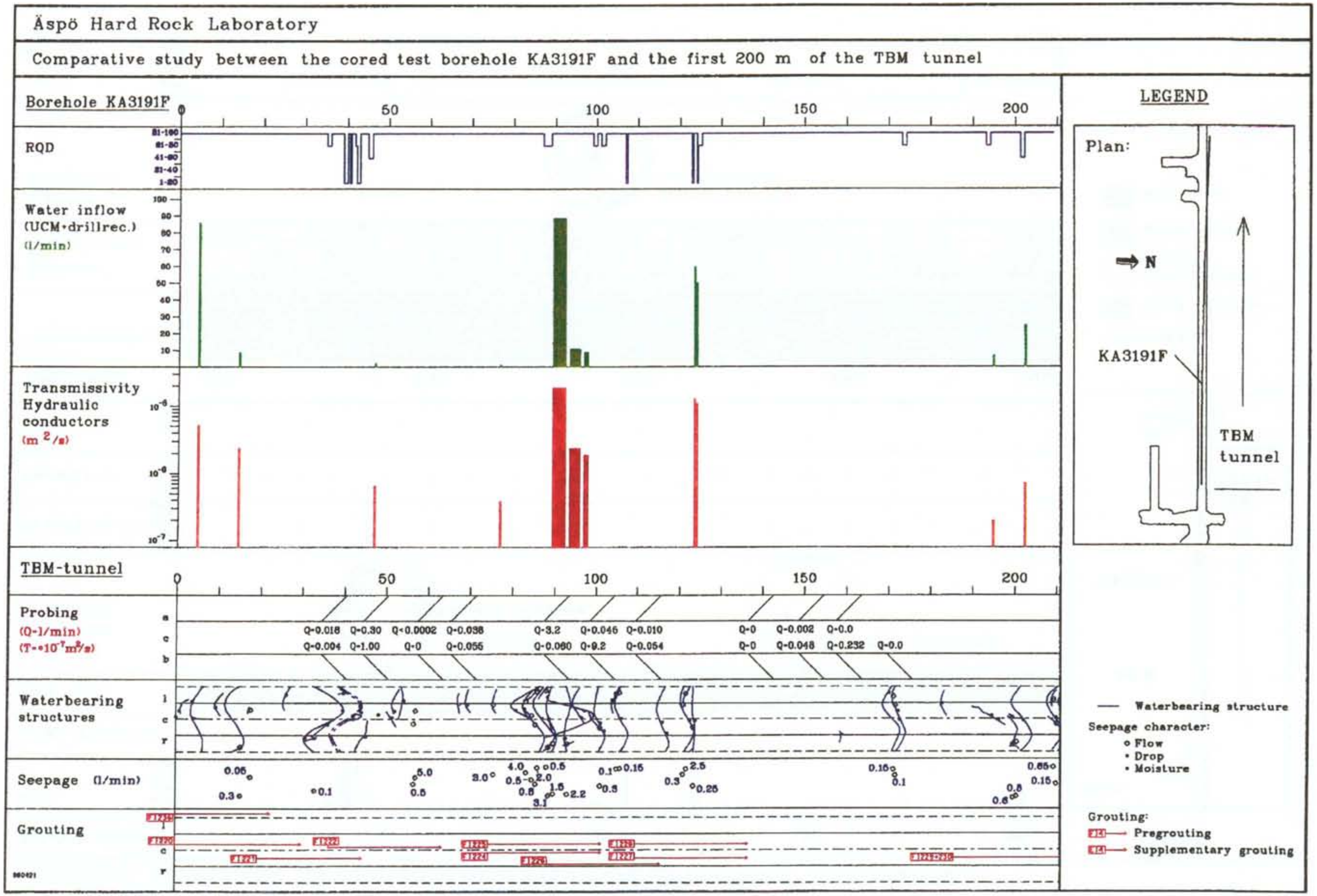


Figure 3-3. Comparison between geohydrological documentation of borehole KA3191F and the mapping of the first 200 m of the TBM tunnel.

3.3 COMPARATIVE STUDY ON THE USE OF TUNNEL AND BOREHOLE DATA

3.3.1 Background

In the Pre-investigation Phase, the characterization of the rock was to a large extent based on data collected from boreholes. In the Construction Phase, a lot of data are collected by observations made directly in the drift. However, observations made in boreholes and in tunnels differ with respect to the quality and density of data collected of a specific parameter and also with respect to what types of data that can be collected. It is essential to understand how the differences in data collected in boreholes and tunnels influence our understanding of the rock. For this purpose, an evaluation of data from Äspö was performed with the objectives:

- To evaluate the differences in information content of the data sets normally collected in cored boreholes and TBM tunnels.
- To assess the differences in data quality for specific parameters (e.g. lithology and RQD) that can be measured in both tunnels and boreholes.
- To compare radar data from boreholes with documentation from the tunnel.

3.3.2 New results

Comparison between data collected in cored boreholes and TBM tunnels

Data collected in the cored test borehole KA3191F along the first 200 m extension of the TBM tunnel have been compared to data from the TBM tunnel. This study is reported in /3-1/.

The main geological-geophysical results may be summarized by the following remarks:

- It's possible to make a good prediction of the major rocks in a tunnel by use of a cored borehole like KA3191F. Minor rocks with an orientation more or less parallel to the borehole may of course be misjudged.
- Fracture data (frequency, fracture fill) is possible to predict while fracture orientation by use of TV-inspection is much dependent on the orientation of the borehole in relation to the orientation of the main fracture sets.
- It's possible to find a correlation between some but not all borehole radar reflectors and structures in the tunnel (increased fracturing/alteration and lithological contacts).
- There is normally a good correlation between geophysical logging data in the borehole and sections with increased fracturing/alteration of rock in the tunnel.

The main geohydrological results may be summarized in the following remarks:

- It is possible to make predictions of major conductive sections in a tunnel by use of a cored borehole like KA3191F. However, minor conductive structures may not be seen as inflows in the cored borehole if they appear as single

fractures which happen to be more or less closed at the intersection of the borehole.
- Inflow mapping during core drilling is important to get a first estimate on position and magnitude of conductive sections. However, hydraulic tests are needed to get more reliable data on how conductive the rock is where inflow is mapped. Mapped inflow during drilling of KA3191F corresponds well to mapped major conductive waterbearing structures in the tunnel.
- The mapped inflow to the borehole and results from the hydraulic tests correspond to the sections grouted. A fairly long part of the TBM tunnel was not grouted and in that section no inflows to the cored borehole were recorded and low transmissivities were evaluated.
- Radar reflectors and low RQD in the core do to some extent correspond to conductive parts of the rock. However, neither radar nor low RQD capture all waterbearing structures mapped in the tunnel or in the borehole.

Comparison between borehole logging data and tunnel mapping data

The techniques used in the investigation included geophysical borehole logging with electrical, radioactive, sonic and electromagnetic methods, core mapping with the computer based system, Petro Core, and tunnel mapping. Data from the core mapping and data from the geophysical logging were compiled, and analyzed with two different computer assisted pattern recognition techniques, discriminant analysis and neural networks, The purpose of using pattern recognition was to create models that enable direct interpretations of lithology, Rock Quality Designation (RQD), Rock Mass Rating (RMR) and alteration in the borehole from geophysical measurements. The information obtained from the geophysical prediction models and the core mapping was then compared with the actual situation in the tunnel.

The results show that geophysical borehole logging together with interpretations based on pattern recognition techniques can be used in order to determine lithology and RQD in a borehole. Prediction models of alteration could not be established, since the core mapping did not provide a good estimate of alteration. In one borehole, RMR was estimated using geophysical measurements and information obtained from the drilling report. The result from this test indicates that a good estimate of RMR in the borehole can be obtained. Results in this thesis also demonstrate that boreholes give very useful information but must not be used as an infallible information source, especially for structures that may change character away from the borehole. Moreover, there is a need to use a borehole radar with directional antenna or an oriented core, unless a unique and recognisable feature is present for which orientations are known. This study is reported in /3-2/.

3.4 *ZEDEX* – COMPARATIVE STUDY OF EXCAVATION INDUCED DISTURBANCE

3.4.1 Background

The excavation of a tunnel will cause a disturbance in the rock surrounding the tunnel. The character and the magnitude of the disturbance is dependent on to the existence of the air-filled void represented by the tunnel and the method of excavation used to construct the tunnel. The properties of the disturbed zone around excavations are of importance to repository performance in that the zone may provide a preferential pathway for radionuclide transport or may affect the efficiency of plugs placed to seal drifts.

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. Contributions to the project have also been provided by BMBF. The project is named ZEDEX (Zone of Excavation Disturbance EXperiment). The Test Plan is published as in /3-3/.

The objectives of ZEDEX are:

- to understand the mechanical behaviour 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 was started in conjunction with the change of excavation method from drill & blast to tunnel boring that took 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.

3.4.2 Experimental configuration and scope

The experiment is performed in two test drifts near the TBM Assembly hall at an approximate depth of 420 m below the ground surface. The experimental drift for the drill and blast operations was located parallel and 23 m from the TBM drift with the intention of locating the two test drifts in relatively homogeneous Äspö diorite so that the geological conditions for both drifts would be similar, facilitating a meaningful comparison. Measurements of rock properties were made before, during, and after excavation. The experimental configuration is outlined in Figure 3-4.

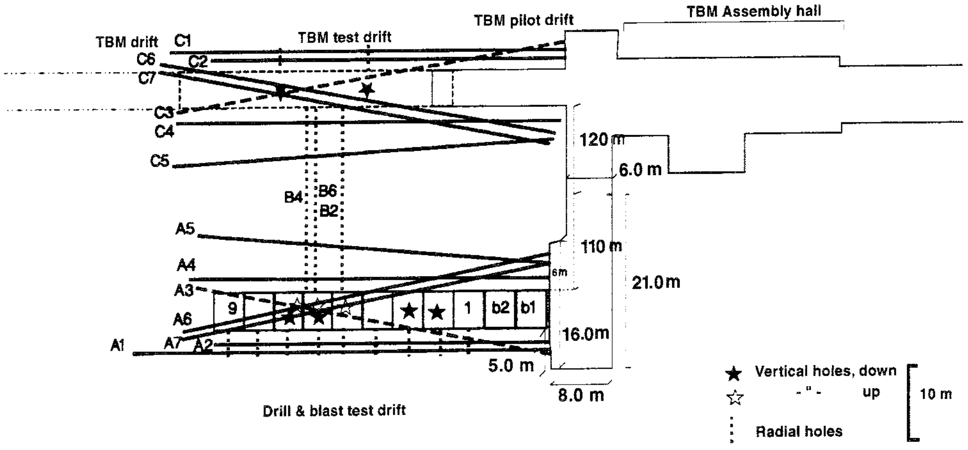


Figure 3-4. Configuration of test drifts and investigation boreholes for the ZEDEX study.

The TBM test drift constitutes part of the main access tunnel of the Äspö HRL, the test section is 35 m long and located directly after the TBM assembly hall. A drift was excavated from the end of the assembly hall to access the D&B test drift with the blast design being optimized during the excavation of this drift. The first two rounds in the D&B test drift were not part of the test and were made to reduce the effects of the anomalous stress field caused by the drilling niches and D&B access drift. The following four rounds were used for testing the "smooth blasting technique" based on low-shock explosives and the remaining five rounds were used for testing the effects of "normal blasting". The shape of the blasted drift was designed to be circular with a flat floor and the diameter (5 m) was designed to be about the same as the TBM drift. A number of boreholes were drilled axially and radially relative to the test drifts to assess the properties and extent of the EDZ. After excavation of the drifts a number of short (3 m) radial boreholes were drilled in each drift to assess the extent of the disturbed zone in the near-field (also termed the "damaged zone"). A set of longer boreholes (about 15 m) was drilled radially from the drift to investigate properties of the disturbed zone, in the far-field, at a larger distance from the drift wall.

The initial conditions in the rock mass have been characterized by several techniques including; tunnel mapping and core logging to determine geotechnical classification factors (Q, RMR), *in situ* seismic (P- and S-wave) velocity measurements and radar measurements. The rock mass response to excavation has been observed by mapping of induced fractures, multi point borehole extensometers (MPBX) and convergence measurements, laboratory testing on core samples, and by acceleration, vibration, seismic velocity, permeability and acoustic emission (AE) measurements.

3.4.3 Results

Initial characterization

The two test drifts were located in grey medium grained Äspö diorite with irregular sheets of red fine grained granite cutting the drifts at various locations, see Figure 3-5. The rock mass is intersected by three dominant sets of fractures, some of which are water bearing with considerable outflow. The D&B drift is only intersected by two water-conducting fractures while the number of water-conducting fractures intersecting the TBM drift is considerably larger. Borehole radar, seismic reflection and geotechnical mapping were all useful in delineating the features. The main fracture sets are all steeply dipping, striking NW and NE. Geotechnical Q and RMR logging used to determine the rock mass quality gave quite uniform results of good quality rock in the TBM drift (Q=20 to 26) but showed more variability in the D&B drift (Q=5 to 37).

Seismic tomographic imaging showed variability in velocity and attenuation interpreted to be associated with fracturing. One or two features in the tomograms were seen to correlate with the mapped fractures in the TBM drift. However, identifying smaller features from tomographic imaging alone is generally more problematic. The average P-wave velocity of about 6 km/s indicated a very good quality rock mass. Seismic anisotropy measurements showed good correlation with fracture orientations.

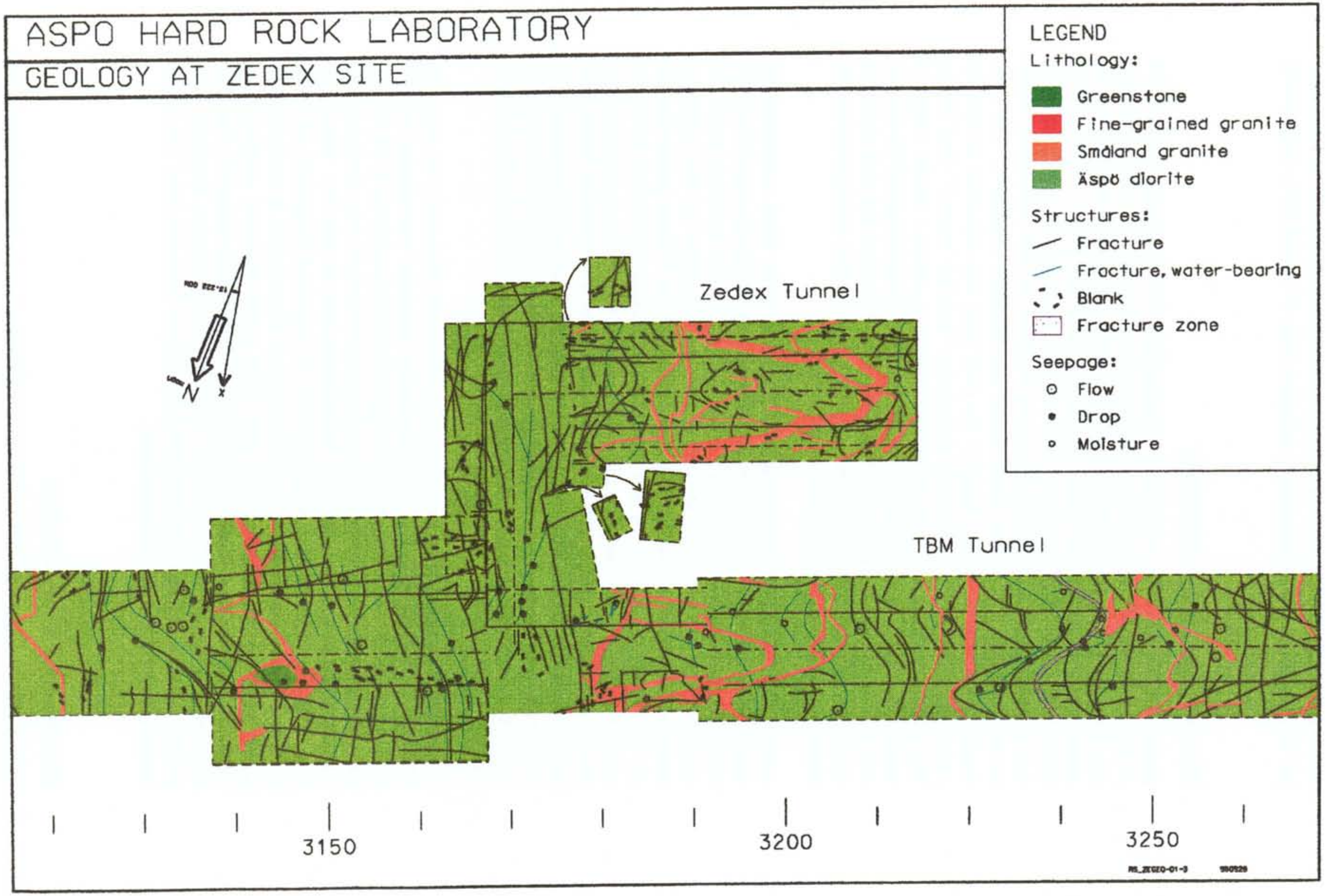


Figure 3-5. *Geological map of the ZEDEX test drifts.*

The magnitude of the main principal stress (σ_1) is estimated to be approximately 32 MPa at the ZEDEX site. The direction of σ_1 is approximately NW and horizontal. The magnitudes of σ_2 and σ_3 are estimated to be 17 and 10 MPa, respectively.

Measurements during excavation

During TBM excavation, vibration measurements showed that only about 0.03% of the energy used to excavate the tunnel and bore through the rock was radiated into the surrounding rock as seismic energy. Maximum particle velocities determined 3 m from the tunnel wall during cutting were only about 1 mm/s. For the D&B drift, 4–7% of the energy applied in the form of explosives was converted into seismic energy. Accelerations measured 3 m from the drift wall reached values in excess of 500 g. However, these values were reached in peaks of very short duration. The seismic energy input to the rock mass was somewhat smaller for rounds excavated using the "smooth blast design" than the "normal" blast design. The TBM requires much more cumulative energy to create a similar length of tunnel compared to a drill and blast round. However, the time required for excavation and the minimal seismic efficiency of the TBM means that drill and blast methods may input somewhere in the range of a million times more power into the rock as seismic waves or ground vibration.

Acoustic Emission (AE) monitoring was performed when TBM excavation was stopped overnight at 9 m, 15 m, 22 m and 25 m measured from the start of the TBM tunnel. In the D&B drift AE monitoring was undertaken after each blast round. The spatial distribution of AE events was similar for both drifts but the number of events recorded for the D&B drift excavation was about 10 times greater than for the TBM drift, see Figure 3-6. For rounds where blasting failed most AE events were located within the blasted yet in place rock, but there was some evidence that the damage also extended further into the walls than for successful blasts. Estimates of crack initiation stress based on the maximum differential stress (σ_1–σ_3) at the AE event locations gave an average value of about 25 MPa. This low stress value suggests that the cracking may have been occurring in rock already damaged directly by the excavation process.

Convergence measurements were made at two sections, 9 m and 24 m, along the TBM-drift. The results indicate predominantly horizontal convergence in both sections (3.6 mm and 1.3 mm, respectively), with little convergence in the vertical direction. This pattern of convergence is consistent with the *in situ* stress measurements which indicate a horizontal to vertical stress ratio of about 3:1. The magnitude of the displacements is consistent with the expected magnitudes of initial stress and when the mass modulus is in the range of 50 to 60 GPa. In the D&B drift, displacements were measured after each blast round. Measured displacements were generally less than 1 mm and most of the displacement occurred when drift excavation advanced one blast round. The small displacements measured were partly due to the fact that the convergence pins had to be placed about 2 m behind the centre of the face due to its curvature.

Measurements after excavation

The seismic tomography results showed no effects of excavation on the seismic properties of the rock at distances larger than 1.5 m from the drift wall for any of

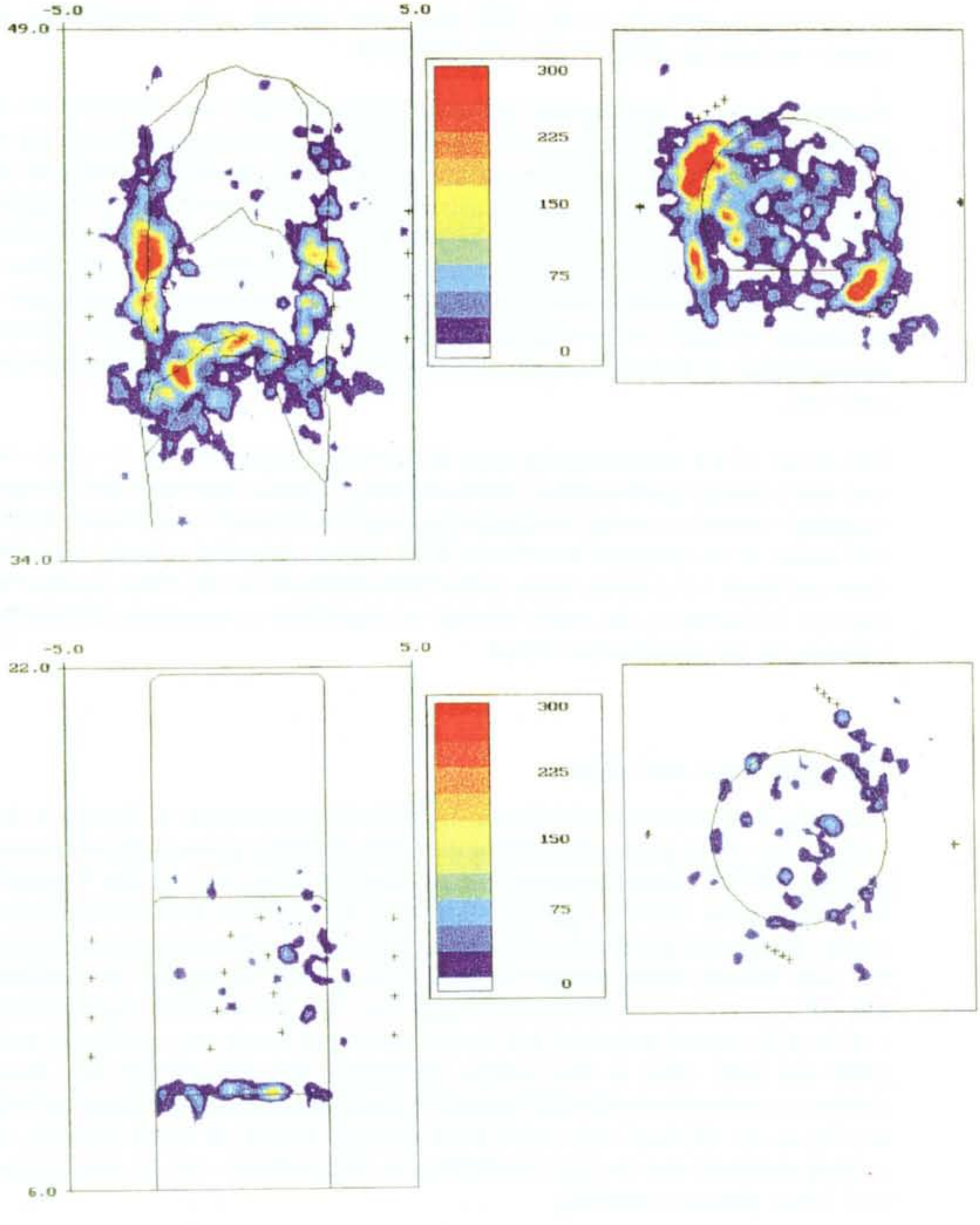


Figure 3-6. *Comparison of acoustic emission source location event density between the blasting and the TBM excavation. The upper figures show event density for monitoring after three successive blast rounds. Events recorded are displayed in both plan view and cross section looking toward the drift face. The lower figures show event density of events recorded over 3 successive nights of monitoring during excavation of the TBM drift.*

the excavation methods. In the D&B drift a low velocity zone extending up to about 1 m from the drift perimeter was observed.

Hydraulic pressure build-up tests performed before and after excavation in two of the boreholes (C4 and C5) parallel to the TBM drift showed a general decrease in permeability after the excavation. Hydraulic tests in the short radial boreholes in the TBM drift did not show any notable induced effect by excavation on matrix permeability. Around the D&B drift hydraulic properties in the boreholes parallel (A4 and A5) and radial (B2 and B4) to the drift generally show increased permeability after excavation even though both large increases and decreases were observed locally. Hydraulic tests in the short radial holes from the D&B drift showed clear evidence of increased matrix permeability in a zone in close proximity to the drift wall.

The results of the measurements made in the short radial boreholes to assess the near-field damage (permeability, seismic velocity, acoustic impedance and fracture mapping) showed a strong correlation between the different measurement types. The extent of the damaged zone in the D&B drift is estimated to be 0.8 m in the floor and about 0.3 m in the walls. In the TBM drift there is very little evidence of damage. Furthermore, the results showed no significant or consistent differences between the two blast designs tested.

EDZ properties and extent

Generally, the measurements in the far-field showed no evidence of damage to the rock for any of the excavation techniques in this generally good quality rock mass at Äspö. MPBX displacement measurements, performed only for the "normal" blast excavation, showed that deformation in the far-field was predominantly elastic, despite this being the excavation technique that put the highest energy into the rock. Seismic measurements showed no measurable change in the far-field. The AE source locations showed that there was very sparse activity beyond about 2 m from the tunnel perimeter, but the distribution of events was similar for both TBM and D&B drifts at that distance. Hydraulic tests showed that there were changes occurring in the far-field around both tunnels. Hydraulic changes and AE activity in the far-field may result from opening, closing or minor shearing of existing fractures due to stress redistribution. These effects will be investigated with future planned modelling.

From the measurements performed it is possible to conclude that the damaged zone formed by the excavation of the D&B drift was greater in degree and extent than that caused by excavating the TBM drift. This damaged zone is characterized by induced fracturing, increased permeability and reduced seismic velocities. It must, however, be borne in mind that relatively few measurements were made around the TBM drift to determine the extent of the damaged zone. The maximum measurable damage zone was approximately 80 cm in the floor of the D&B drift is probably a consequence of the larger charges used in the lifter holes for the rounds and the effect of the larger displacement caused by the flat shape of the floor. The extent of the damaged zone in the walls of the D&B drift was approximately 30 cm. The extent of the damaged zone was corroborated by AE data which showed that the majority of the AE events were located within a "thin skin", less than 1 m thick, around the drifts.

Two different blast designs were used during excavation of the D&B drift. Measurement results show only minor differences in terms of damage between the blast designs used. Differences in initial conditions, coupled with relatively small differences between results from the two drill and blast designs, make it difficult to draw any precise conclusions regarding the differences between the effect of excavation method between "low shock energy smooth blasting" and "normal" smooth blasting. However, failed rounds of both designs have shown more damage than successful rounds.

3.4.4 Planned work

In general, the suite of methods employed in the ZEDEX Project has been effective in characterizing the extent and magnitude of property change in the EDZ. However, a significant problem in evaluating the results which have been obtained in a heterogeneous geologic setting is the relative scarcity of data points. To obtain a better statistical base to substantiate conclusions made above, the ZEDEX Project will be extended by another year. The project extension will include drilling and measurements in additional short radial holes, predictive modelling and extended data evaluations focused on understanding the crack initiation mechanisms and observed changes in hydraulic properties.

3.5 INSTRUMENT DEVELOPMENT

3.5.1 General

In this section instrument developments, refinements of instruments and/or special events related to use of instruments, etc, of general interest for the experimental phase of the Äspö HRL are handled.

During 1995 one major activity in this field has been the manufacturing of the CHEMLAB system for radionuclide experiments. This work is further described in section 4.9. Another major activity has been the development of a new hydraulic testing equipment for underground use, see section 3.5.2.

A few words will be written on experiences from the new borehole-TV system BIP 1500, see section 3.5.3. Work carried out on the groundwater monitoring system HMS, regarding refinement and expansion, etc, are described in section 6.4.

Instruments which are developed for the different experiments are described under the specific experiment. Furthermore, some instrument issues related to the construction phase are also discussed. The summary reporting of investigation methods and instruments used during the construction phase is described in section 3.6.

3.5.2 Hydraulic testing system for underground

3.5.2.1 Background

Hydraulic testing in boreholes drilled from underground is associated with special problems. High water pressures in boreholes, sometimes in combination with large water outflows are examples of problems which have to be handled. Other aspects are the need of easy mobilization in sometimes narrow and/or difficult to access test sites, and reliable function in the tough underground environment of a dirty, high humidity and saline water inflow. Based on experiences gained during the construction phase it was decided to develop an integrated hydraulic test system which fulfils these basic requirements.

3.5.2.2 Work carried out

The first step was to set up a detailed design specification for the system, based on the need of hydraulic testing methods from the different experiment leaders. In order to be used for different kind of tests the system will be composed by modules, easy to integrate and to later on add new modules for new kind of methods. The modules are:

- borehole test probes,
- measurement modules,
- data acquisition system,
- communication equipment (pipes, lines, cables),
- rig.

The test types to be operated with the system are in the first stage flow tests (passive and constant flow), pressure build-up tests, and injection tests. Pulse tests are regarded as an option to be integrated later on if needed.

The design specification gave detailed requirements on operation and measurement ranges on pressures and flow rates and time periods, including resolutions and accuracies.

Based on the design specification a technical specification and quotation for constructing and manufacturing the system was submitted to SKB. After final modification of the specifications, Geosigma was contracted to carry out the construction and manufacturing. The work was started in February 1996.

3.5.2.3 Planned work

The construction and manufacturing will continue during 1996. A final acceptance test are scheduled to be carried out in december 1996.

3.5.3 Borehole TV techniques

As mentioned in the Äspö Annual Report 1994 (and more detailed described in SKB Annual report 1994) a new borehole TV equipment, the BIP-1500 system was delivered to SKB in December 1994. During 1995 the system has been very useful for geological characterization in boreholes, in particular for orientation of fractures. Also some refinements of the BIP-1500 system are going on, based on the experiments gained during use and in order to obtain even better functionality regarding measurement hardware and analysis software. This work is made outside the Äspö HRL and is therefore reported more in detail in SKB Annual Report 1995.

3.6 UNDERGROUND MEASUREMENT METHODS AND METHODOLOGY

3.6.1 Reporting from the construction phase

A summary report describing and evaluating the investigation methods and instruments used from underground during the construction phase of the Äspö HRL will be compiled. For all areas of methods, tunnel documentation, drilling, borehole geology, borehole geophysics, hydrogeology, etc., the individual methods and instruments will be described, the accuracies will be discussed and the methods will be judged with regard to feasibility and usefulness. Moreover, needs of further improvement for the methods will also addressed.

The work has been initiated during 1995 and the report will be released mid 1996.

The conclusions presented in the report will be useful for evaluating the status of know-how in detailed investigation methods. It is foreseen that in some areas more development or refinement of methods and instruments has to be made, and preferably tested in the Äspö facility.

3.6.2 Detailed investigation methods

Programmes for detailed investigation methods for the deep repository involves measurements in several geometrical scales during the course of detailed investigation stage and the repository construction. The detailed layout must then be based on detailed knowledge on the relevant rock characteristics. Hence, methodologies for layout work and investigations must be developed and, not of less importance, integrated with each other.

For this purpose, and in a first step, some investigation methods will be tested at Äspö, some of them based on the results from the above mentioned report. Seismic methods are examples of methods which are foreseen to be useful for guiding the layout work, and therefore must be tested more in the relevant programme.

4 TEST OF MODELS FOR GROUNDWATER FLOW AND RADIONUCLIDE MIGRATION

4.1 GENERAL

The rock surrounding the repository constitutes a natural barrier to release of radionuclides from a deep repository. The most important function of the natural barrier is to provide protection for the engineered barriers through stable chemical and mechanical conditions and to limit transport of corrodants and radionuclides through slow and stable groundwater flux through the repository and reactions of radionuclides with the host rock. In performance assessments of a repository the function of the host rock as a barrier is described by different models.

In this context it is important to be able to understand and describe

- the nature and evolution of the chemical environment for the engineered barriers,
- transport of corrodants to the waste containers, and
- transport of radionuclides through the host rock,

in order to assess the safety of a deep repository for spent fuel. Another important aspect is to ensure that the changes in mechanical and chemical conditions induced by construction and operation of the repository before closure do not have negative effects on long term safety. An understanding of chemical conditions at repository level and transport of radionuclides is also essential for assessing the environmental impact of other long-lived waste planned to be stored in a separate part of the deep Swedish repository.

Performance and safety assessments are based on models describing processes considered to be of relevance for transport of contaminants in fractured rock. These assessment models are being further developed, where necessary, as a part of SKB's program for research and development. In addition, the relationship between model parameters and field data needs to be described more accurately. The issue of conceptual model uncertainty is also a major concern.

This Stage Goal includes projects with the aim to evaluate the usefulness and reliability of different models and to develop and test methods for determination of parameters required as input to the models. An important part of this work is performed in the Äspö Task Force on Groundwater Flow and Transport of solutes. The work in the Task Force is closely tied to ongoing and planned experiments at the Äspö HRL. Well specified tasks are defined where several modelling groups work on the same set of field data. The modelling results are then compared to experimental outcome and evaluated by the Task Force delegates.

Studies are also performed of the geochemical and hydraulic disturbances induced by excavation and operation of a repository on the host rock barrier to ensure it has no negative effect on the long-term safety of a repository.

Major projects planned to meet this Stage Goal include the Tracer Retention Understanding Experiments (TRUE) which focuses on retardation processes im-

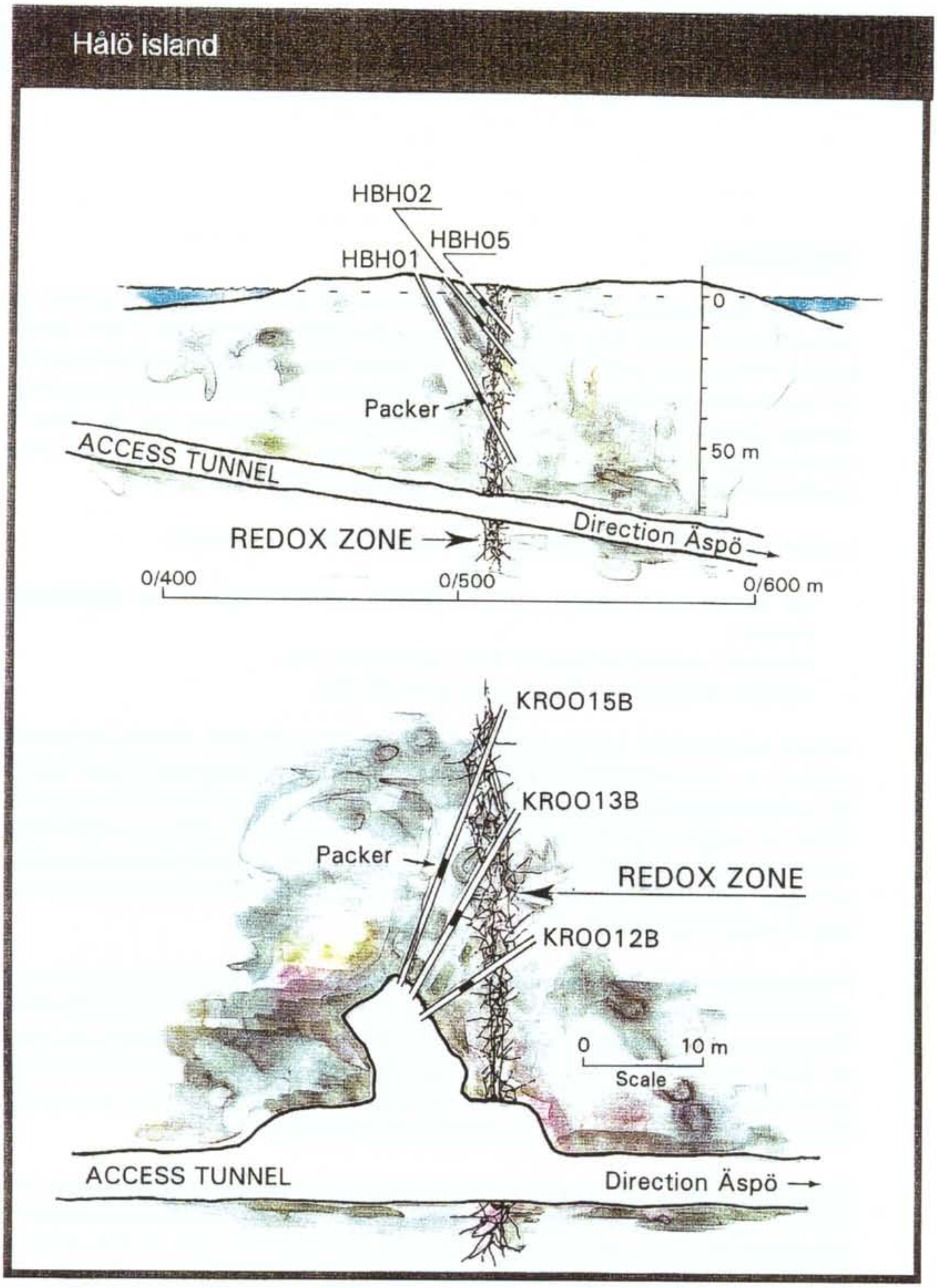


Figure 4-1. *Section and plan views of the access tunnel, fracture zone and intersecting boreholes. The plan view shows the side tunnel used for instrumentation of the three investigation boreholes drilled into the fracture zone.*

portant for radionuclide transport, studies of reaction rates for oxygen with rock minerals (REX), degassing and two-phase flow near drifts, hydrochemical modelling, and verification validation of chemical models and verification of laboratory data through in-situ experiments in a borehole laboratory (CHEMLAB).

4.2 THE BLOCK-SCALE REDOX EXPERIMENT

4.2.1 Background

The purpose of the block scale redox experiment is to investigate the chemical changes when oxidizing water is penetrating previously reducing fracture systems and to evaluate if complete flow paths can be oxidized from the surface to the repository. This is an unwanted scenario for two reasons. It would be easier for oxygenated surface water to penetrate to the repository along such a path, which has already been oxidized. Secondly redox sensitive radionuclides may potentially be more mobile if the flow goes in the other direction from the repository up to the biosphere.

4.2.2 Results

The experiment started in 1991 and lasted until 1994. The scientific results of the experiment have been reported at several stages of the project. Final results were presented in /4-1/. Figure 4-1 illustrates the layout and configuration of the experiment.

A final project report has been published /4-2/.

The inflow of surface derived freshwater was reducing already at the depth of 70 m. The explanation to the rapid consumption of oxygen was the redox reactions mediated by bacteria. The content of organic matter in the infiltrating surface water was higher than the amount of dissolved oxygen. It took about twenty days for the bacteria to adjust to the changes of groundwater flow which took place when the tunnel breached the fracture zone. The bacterial processes continue even when the oxygen has been consumed in case there is organic matter left to be oxidized. In stead of reducing oxygen some bacteria can reduce iron (III) minerals as electron acceptors. Thus the content of dissolved ferrous iron increases.

4.3 FRACTURE CLASSIFICATION AND CHARACTERIZATION

4.3.1 Background

Small-scale geological, hydrological and hydrochemical features are highly variable in nature, while radionuclide transport models rely on simple concepts e.g. water flow through a channel with constant water chemistry, hydraulic gradient, wallrock mineralogy and porosity across the whole flow path.

Groundwater flow and nuclide transport is taking place in water conducting paths which are transmissive due to their genesis and history. Therefore, eventually,

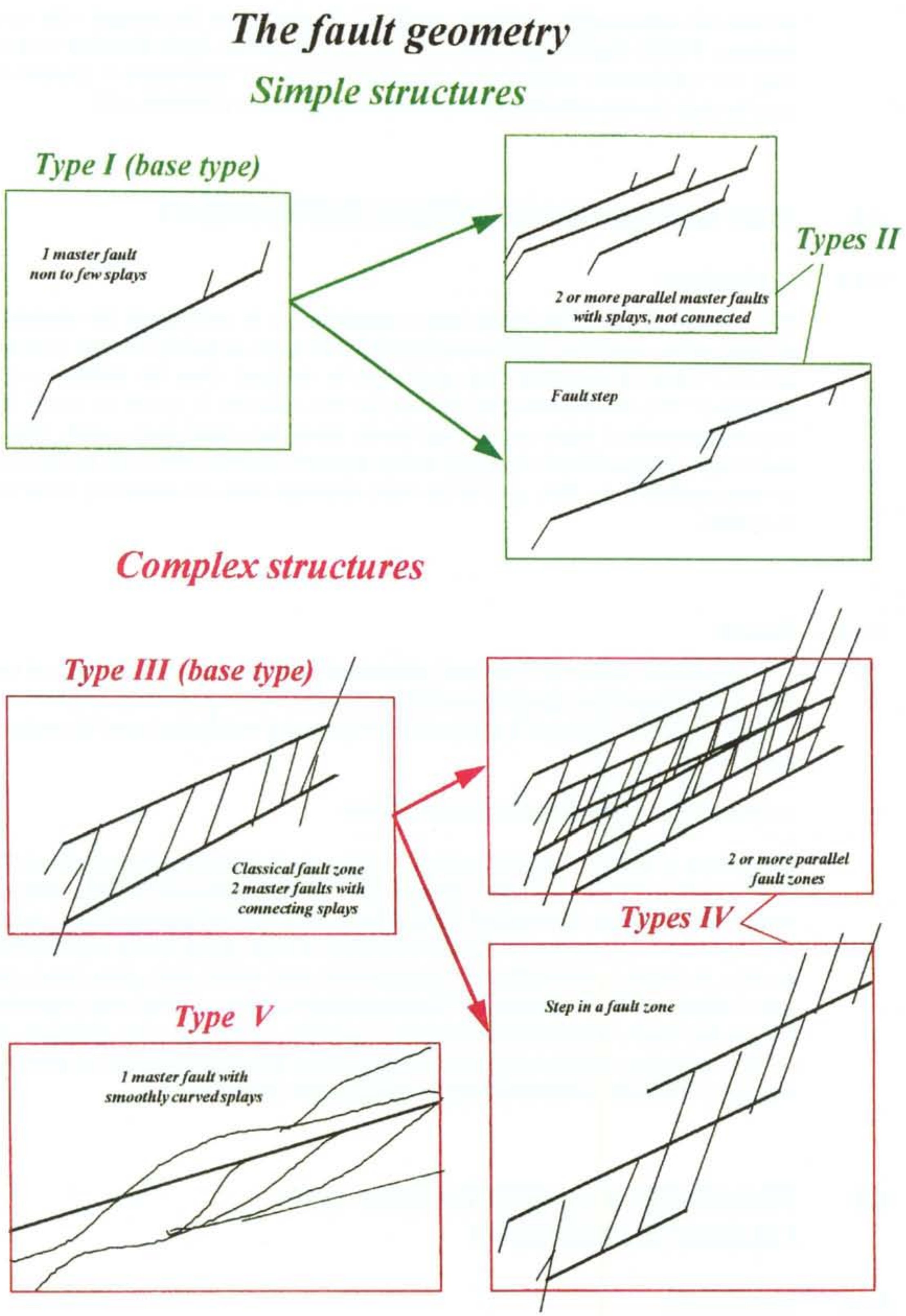


Figure 4-2. *Conceptual model of the five fracture classes.*

parameter values used in the numerical transport calculations should reflect the type of water conducting feature and include those variations which are important for the nuclide migration, e.g. sorption coefficients, diffusivity and volume/surface area ratio.

Fracture characterization and classification aim at suggesting suitable type of fractures for tracer tests and at giving parameter values for modelling of relevant flow paths for nuclide migration.

The objectives of the study are:

- to develop a methodology for characterization of fractures with respect to rock type, tectonic evolution, infillings and wallrock alteration,

and by means of this characterization be able:

- to classify different fractures in terms of their importance for parameter assignment for the radionuclide transport and retardation modelling.

4.3.2 Results

The initial characterization and preliminary classification of the fractures in the Äspö HRL tunnel has given two classes, simple and complex. The results are presented in /4-3/ based on the mapping of some 100 fractures along the tunnel. During the course of more careful examination of the data together with a few samples analyzed for mineralogy, diffusivity and porosity the two main groups could be subdivided into five different groups. Type I and II are subdivisions of the simple type and III, IV and V are subdivisions of the complex type.

Along with the mapping of fractures in the TRUE site it has been possible to classify also the selected TRUE fractures according to the scheme. Fracture A is a type III feature, which consists of two master faults.

In more detail the cores from TRUE 1 give a reasonable mechanistic explanation to the structures and the master/splay arrangement appears plausible. Even though the fracture A does not necessarily persist to the tunnel, there are related features which do and which thus can be carefully investigated in the tunnel wall.

The tunnel mapping on small scale at the TRUE site show self similar features. Comparison between tunnel and borehole observations show:

- identical genetic mylonitic-cataclastic features,
- different orientations,
- high variability in the tunnel observations,

Conceptual models for all five classes have been attempted, see Figure 4-2.

4.3.3 Planned work

The third phase of the project has started. During 1996 the different fracture types will be quantified in relation to the important transport parameters, e.g. porosity and diffusivity. The predictive capability of the FCC concept need to be tested before an entire flow path from a canister position to the biosphere could be described. In detail the phase III will include:

- Integration of tunnel and borehole observations.
- Construction of a fracture network model linked to the conceptual modelling of the TRUE-1 site.
- Integration of hydraulic information with the structural conceptual model.
- Construction of possible large scale flow paths using the existing five fracture types.

4.4 THE SELECT PROJECT

4.4.1 Background

Several experiments are planned for the Operating Phase of the Äspö HRL. These experiments require sites which meet specific requirements with respect to rock conditions and groundwater properties. A separate project was carried out which provided base data and recommendations for locating experiments, /4-4/. Based on this work provisional allocation was made of experimental sites for the Radionuclide Retention Experiment (RNR), the Redox Experiment on a local scale (REX) and the Tracer Retention Understanding Experiment (TRUE) at the experimental level (340-460 m level). It was identified that access to the allocated rock volumes, with one exception, is facilitated by drilling 20-30 m long boreholes from existing niches along the tunnel spiral. A separate project, the SELECT project, was set up to realize the above intention.

The following objectives were defined for the SELECT project;

- to perform geological, hydrogeological and hydrogeochemical characterization of designated experimental volumes,
- to establish whether the studied experimental volumes meet the specific needs of the planned experiments,
- to provide the necessary information by which specific experimental sites can be selected.

4.4.2 Results

Based on defined experimental criteria, experimental volumes tentatively allocated for the REX, RNR (Chemlab) and TRUE experiments have been investigated within the SELECT Project using eight cored boreholes. The rock sampled by the boreholes has been characterized with different geological, geophysical and hydrogeological techniques. As a complement to conventional core logging, the new BIP borehole TV system was successfully utilized. The results of the SELECT programme are presented in /4-5/.

Suitable target features for three experiments (REX, RNR (Chemlab) and TRUE) which answer up to preset requirements were identified in four of the drilled boreholes, KA2858A, KA2862A, KA3385A and KA3005A, respectively. Identified features and important boundary conditions were sectioned-off using multipacker systems with up to five test sections. An important issue in the SELECT investigation programme has been to assess the risk for disturbance between

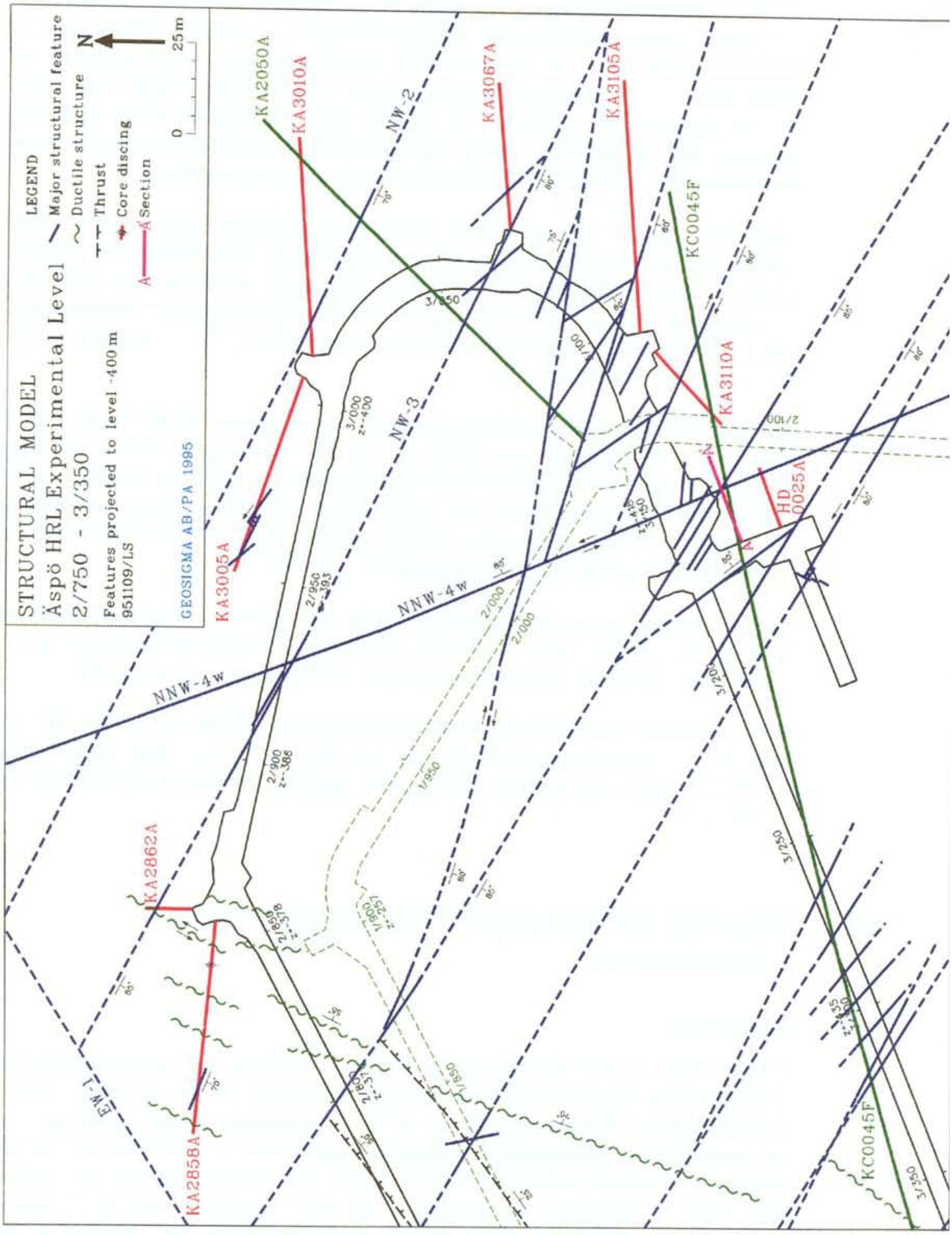


Figure 4-3. SELECT Project – Condensated structural-geologic model of the experimental level. Features projected to level Z=-400 masl.

different experimental sites. The hydraulic connectivity between sections in an individual borehole and between boreholes (blocks) was assessed with the use of a hydraulic interference test programme. It was noted that hydraulic responses are transmitted over hundreds of metres. However, the identified volumes and target features appear to be relatively well isolated from disturbances in the respective boreholes and adjacent rock blocks. The interference test results have been reported in terms of evaluated material properties and a response matrix.

Descriptive models for rock blocks containing the identified target features have been produced on the basis of the collected information. The orientation of hydraulically conductive fractures and zones is predominantly north-west, as opposed to the presumed north-northwesterly orientation. During the course of the investigations and subsequent evaluation two new fracture zones, NW-2 and NW-3, have been identified, see Figure 4-3.

The data from boreholes including potential target features for the REX Project, KA2858A and KA2862A, see Figure 4-3, were presented at the Review Meeting for the REX project on March 27 in Stockholm. The two fractures identified in the two boreholes represent, in the case of KA2858A, possible reducing conditions as indicated by the identified pyrite fracture coating. In the case of KA2862A the fracture is featured by reddening imposed by oxidation.

The proposed site for the RNR Chemlab sonde measurements, which is sampled by borehole KA3385A, show favourable hydraulics but may be impaired by the grouting which had to be preformed between L=2-25.5 m in the borehole.

Three potential target features were identified in KA3005A at L=36.9–37.4 m, L=45.0–45.25 m and between L=48.4–49.4 m, see Figure 4-3. Further study within the TRUE Project has focused on the feature identified between L=45.0–45.25, see Section 4.5.

4.5 TRACER RETENTION UNDERSTANDING EXPERIMENT

4.5.1 Background

A programme has been defined for tracer tests at different experimental scales, the so-called Tracer Retention Understanding Experiments (TRUE), /4-6/. The overall objective of the TRUE experiments is to increase the understanding of the processes which govern retention of radionuclides transported in crystalline rock, and to increase the credibility in the computer models for radionuclide transport which will be used in licensing of a repository. The basic concept is that tracer experiments will be performed in cycles with an approximate duration of 2 years. At the end of each test cycle, results and experience will be evaluated and the programme revised.

The basic idea is to perform a series of tracer tests with progressively increasing complexity. In principle, each tracer experiment will consist of a cycle of activities beginning with geological characterization of the selected site, followed by hydraulic and tracer tests, after which resin will be injected. Subsequently the tested rock volume will be excavated and analyzed with regards to flow path geometry, and tracer concentration.

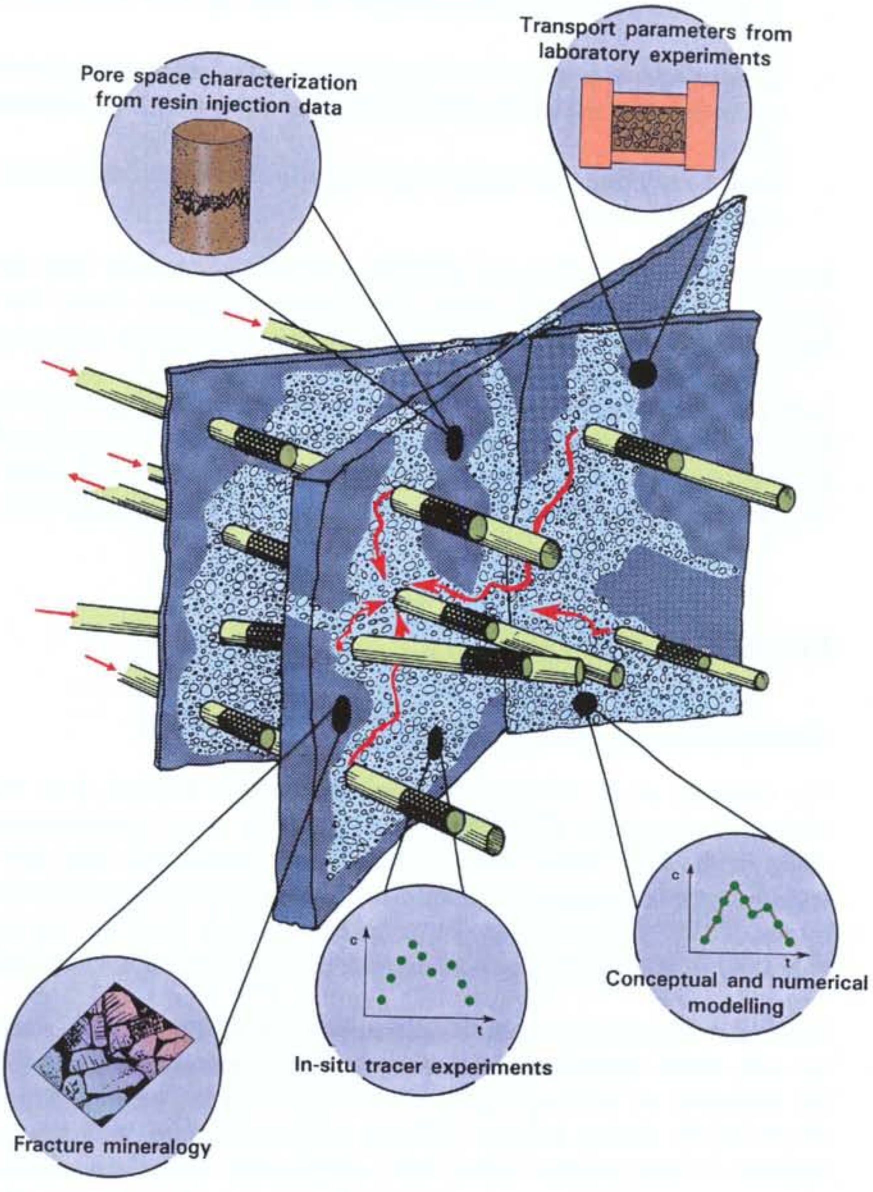


Figure 4-4. Principal outline and components of the TRUE-1 experiment.

The first tracer test cycle (TRUE-1) constitutes a training exercise for tracer testing technology on a detailed scale using non-reactive tracers in a simple test geometry, see Figure 4-4. In addition, supporting technology development is performed for sampling and analysis techniques for matrix diffusion, and for understanding of tracer transport through detailed aperture distributions obtained from resin injection. The TRUE-1 cycle is expected to contribute data and experience which will constitute the necessary platform for subsequent more elaborate experiments within TRUE.

The stated objectives of the first tracer test cycle (TRUE-1) are /4-6/;

- To conceptualize and parametrize an experimental site on a detailed scale (L=5 m) using non-reactive tracers in a simple test geometry.

- To improve tracer test methodologies for non-reactive tracer tests on a detailed scale.
- To develop and test a technology for injection of epoxy resin on a detailed scale and to develop and test techniques for excavation (drilling) of injected volumes, and
- To test sampling and analysis technologies to be employed in the analysis of matrix diffusion.

During 1995 work within the TRUE experiment has mainly been devoted to site characterization of the site where the tracer experiments during the First TRUE Stage will be conducted, and development of resin injection technology.

Late 1995 SKB identified the need for early data on reactive tracer transport and took the strategic decision also to include reactive tracer experiments during the First Tracer test cycle. This has implied a prolongation of the First TRUE stage with another year, with reactive tracer tests to be performed late 1996.

4.5.2 Results

Characterization of TRUE-1 site

The outcome of the SELECT project, see Section 4.4 and /4-5/, was that three features in borehole KA3005A, see Figure 4-3, were recommended for further study in the First TRUE Stage (TRUE-1). The collected data and results were reviewed and it was recommended to continue investigation of the site put forward by the TRUE Project Team. In order to facilitate study of the target features identified in KA3005A, a new niche was developed at tunnel length 2/950 m.

Subsequently four new characterization holes, KXTT1–KXTT4, were drilled from the new niche towards the northeast, inclined approximately 35–45° down, with the objective of intersecting the features at lengths varying between 8–15 m. Observations during drilling (inflows, drilling advance with time and pressure response in instrumented holes) were emphasized. These observations were used to construct a preliminary structural-hydraulic model of the site. Two main features, Feature A at L~15 m and Feature B at L~10 m were tentatively identified.

After drilling the following characterizations have been carried out at the site;

- Geological core logging.
- Single packer flow-logging of each borehole (and KA3005A) using a single packer assembly mainly in 0.5–1 m increments.
- Structural mapping and modelling, with the aim of establishing a structural model of the identified features and bounding fracture zones.
- Mineralogical sampling and analysis with the aim of providing a basic description of the mineralogy of the host rock and the mineralogy of the coatings and infillings of the target features.
- Measurements of borehole deviation using the MAXI-BOR/FOTOBOR system with the aim of providing accurate absolute description of the geometry of the identified features.

- Borehole TV measurements using the RAAX-BIP system with the aim of providing support for the core logging and the structural interpretation.
- Pressure build-up tests in selected intervals in order to provide parameter values of transmissivity for the target features and bounding fracture zones.
- Installation of multi-packer assemblies which isolate identified target features and bounding fractured zones.
- Interference tests with the primary objective of establishing and quantifying hydraulic connectivity of identified features within the TRUE-1 borehole array.
- Preliminary tracer tests in radially converging (two hole) configuration with the aim of providing preliminary transport material properties (e.g. flow porosity and dispersivities) to be employed in predictions of the planned main tracer tests.
- Dilution tests performed in test sections in the TRUE-1 array which allows circulation. This with the purpose of assessing flow under natural gradient conditions.

The integrated analysis of the results of the characterization listed above has been used to construct a descriptive structural-hydraulic model of the TRUE-1 Block on a Block scale (L~50 m) and on a Detailed scale (L~5–10 m). This work has constituted Task 4A of the Äspö Task Force and has been a joint effort of the TRUE Project team, the PNC/Golder team and the USDOE/LBNL. The developed models are the basis for predictions of the radially converging and dipole tracer tests planned for the Spring 1996.

The following sections highlights the main results of the conceptualization work reported by /4-7/.

Block scale conceptualization

The TRUE-1 Block is surrounded by three fracture zones, Zone NNW-4, NW-3 and NW-2, see Table 4-1 and Figure 4-5. None of these zones have been investigated in detail in the characterization work. The inferred geometries are based on observations in the tunnel, core logs and core inspections. The rock between Feature A and Zone NW-2 contains what is interpreted as flanks of Zone NW-2. The exact geometry of these flanking zones has not been substantiated.

Table 4-1. Characteristics of minor fracture zones near the TRUE site.

Zone	Intercept	Orientation	Width at intercept	T (m^2/s)
NNW-4	Tunnel	365/90	5 m	$1 \cdot 10^{-4}$
NW-2	KA3010A	132/70	10 m	$1 \cdot 10^{-6}$
NW-3	Tunnel, bh	300/75–90	10 m	$1 \cdot 10^{-6}$

These three zones and the tunnel are considered as the main hydraulic controls for the hydraulic situation in the TRUE-1 Block. However, Zone NW-4 appears to be less conductive in the vicinity of the TRUE-1 Block than where it is intersected at other parts of the Äspö HRL.

The fractures mapped in the cores of the TRUE-1 boreholes have a dominating northwesterly strike with an apparent absence of north-easterly and sub-horizontal

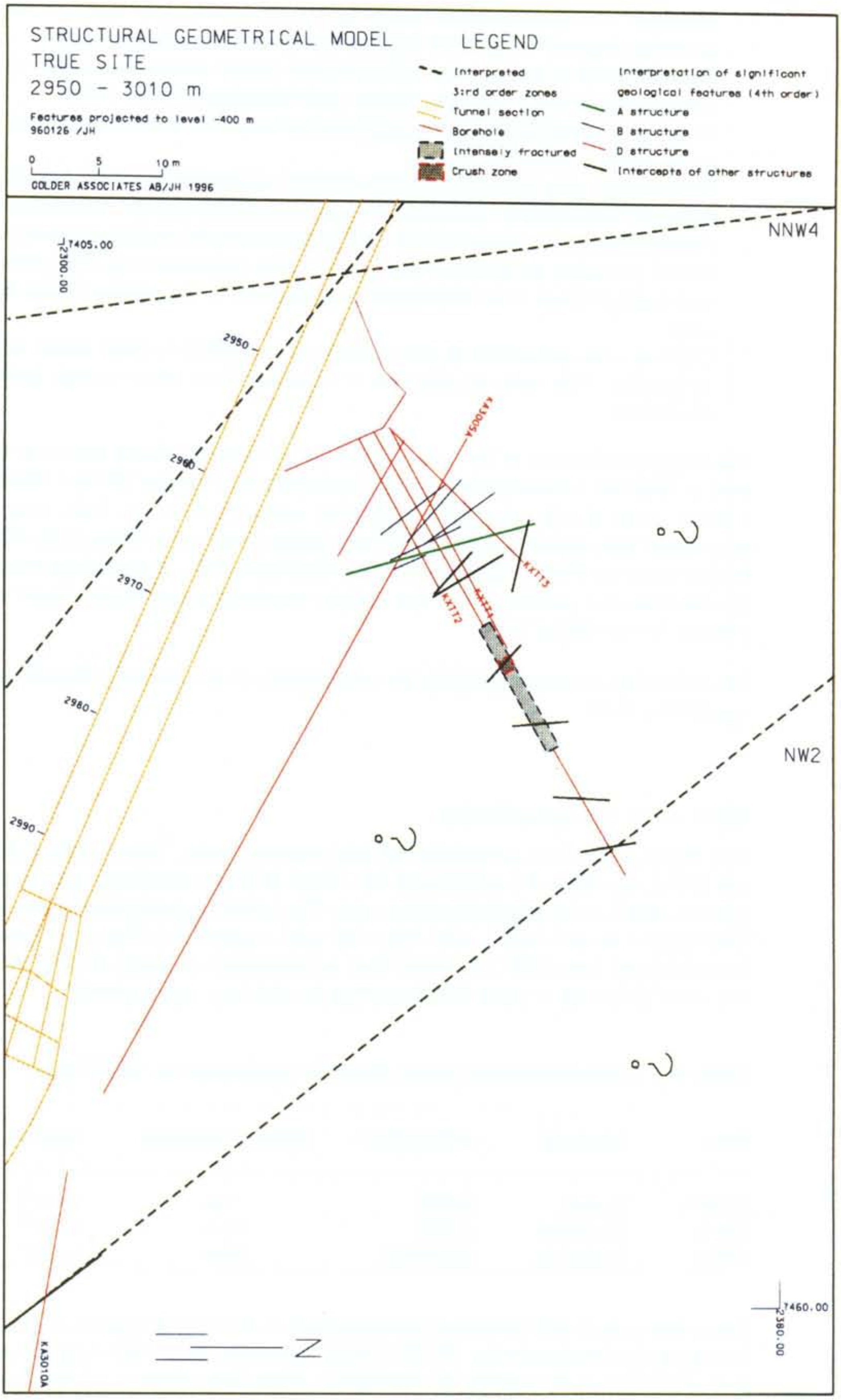


Figure 4-5. *Structural-geologic model of the TRUE-Rock Block in a horizontal section at Z=-400 m.*

fractures. The lack of NE fractures is attributed to the bias introduced by the northeasterly oriented boreholes. The absence of a distinct sub-horizontal fracture set has not been fully explained. The frequency of conductive fractures obtained from discrete fracture network analysis, λ=1.7 fractures/m, is in parity with that obtained independently on the basis of core and borehole TV observations.

The performed interference tests show that induced pressure disturbances in the TRUE-1 Block can be transmitted significant distances.

Detailed scale conceptualization

The analysis showed that Feature A is a gently undulating feature intercepted in all five boreholes which can be represented by a steeply dipping plane oriented NW (N29°W/79°E) made up of one major fault plane.

Feature B on the other hand is more complex and has been interpreted to consist of four fracture planes. The complexity of Feature B and its documented hydraulic interconnection to more superficial parts of the boreholes (Feature D) resulted in focus being shifted to Feature A.

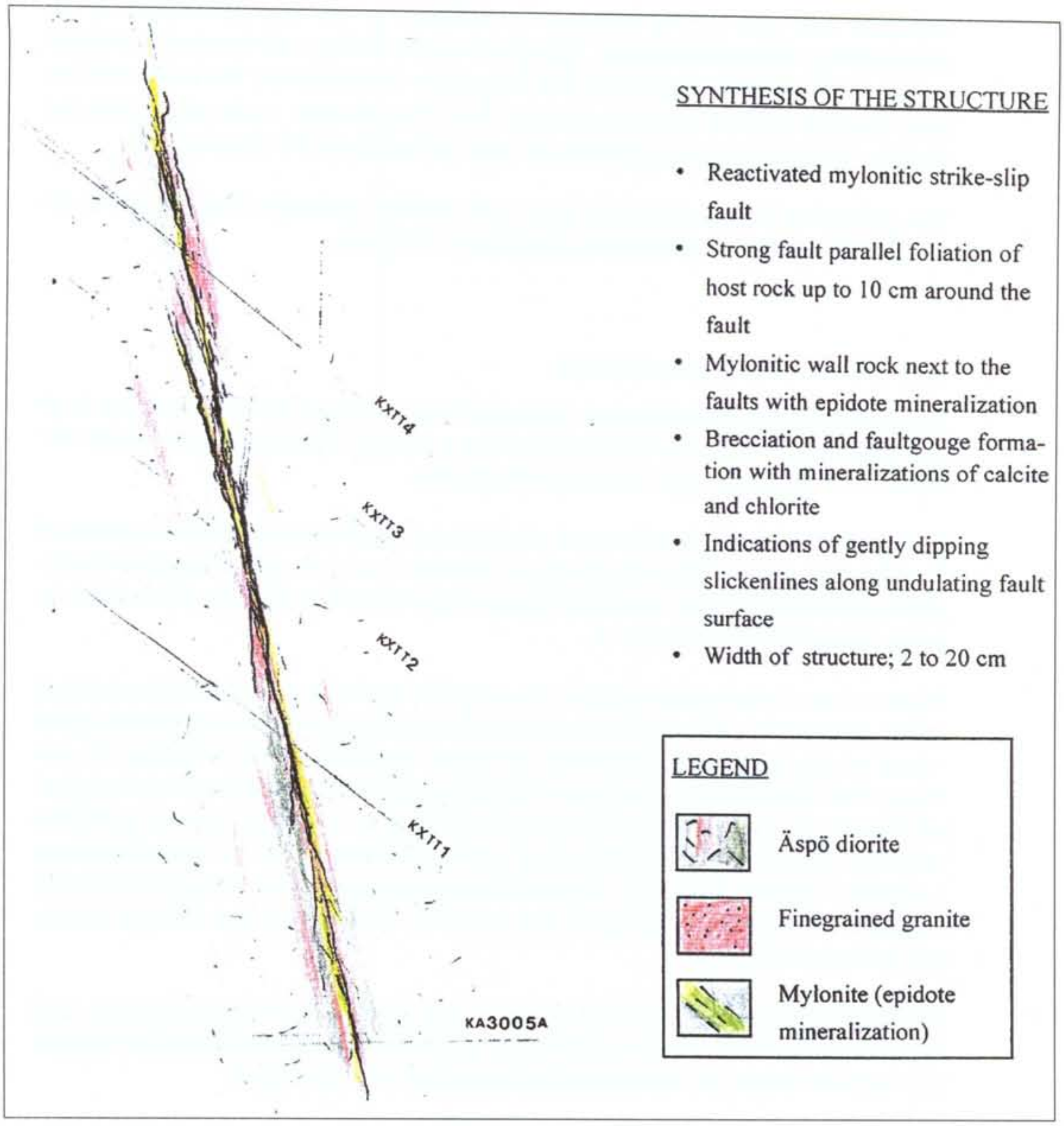
Feature A is a reactivated mylonite, i.e. a ductile mylonite which has later suffered brittle deformation. The brittle reactivation is associated with one major fault plane which is also assumed to represent the water conducting part of Feature A, see Figure 4-6. Mineralogical analyses of the five samples collected from the interpreted Feature A, support that these samples belong to the same type of mylonitic structure. There are also indications of mylonitic structures in the tunnel between L=3/950 – 3/970 m with very much of the same appearance as in the KXTT-cores, although not with the same dip. It has not been substantiated that Feature A does **not** intersect the tunnel.

It cannot be ruled out that one of the mylonitic seams observed in the tunnel may be an extension of Feature A. However, available hydraulic information support the fact that Feature A is not in hydraulic contact with the tunnel.

Mineralogically the mylonites (green in Figure 4-6) are characterised by very fine-grained epidote, quartz, K-feldspar/albite and in some cases chlorite. Calcite, fluorite, quartz and k-feldspar are found as idiomorphic crystals in voids and microfractures. Red staining (red in Figure 4-6) of the wall rock is common.

Selective pressure build-up tests were performed in 3 m sections show that the transmissivity of Feature A is varying between $1 \cdot 10^{-8} - 3.3 \cdot 10^{-7}$ m^2/s. Flow dimension inferred from analysis of the performed tests using the generalized radial flow model indicate pseudo-spherical flow. This indicates that not only the major fault (master fault) of Feature A but also associated splay fractures contribute to the flow during the tests. The TRUE-1 boreholes have been instrumented with packer systems with 4-5 test sections. Of these sections, 1-2 sections in each borehole facilitate circulation of water, and can thus be used for tracer injection/abstraction and water sampling. Registration of hydraulic pressure in the instrumented array show that Feature A has about 10 m higher head than Feature B. The hydraulic head in feature A is similar to that in the flanks of Zone NW-2.

Interference tests were performed by flowing 14 sections in 6 boreholes and registration of responses in about 50 observation sections. Interpretation of con-



SYNTHESIS OF THE STRUCTURE

- Reactivated mylonitic strike-slip fault
- Strong fault parallel foliation of host rock up to 10 cm around the fault
- Mylonitic wall rock next to the faults with epidote mineralization
- Brecciation and faultgouge formation with mineralizations of calcite and chlorite
- Indications of gently dipping slickenlines along undulating fault surface
- Width of structure; 2 to 20 cm

Figure 4-6. *Schematic integrated structural-geological description of Feature A.*

nectivity was performed using indexed response variables tabulated in matrix format, and by graphical techniques. The test interpretation has showed that Feature A is internally well connected with second order connections to the flanks of Zone NW-2.

Two preliminary tracer tests have been performed, one test in Feature B between KXTT4:P4 (pump) and KXTT3:P3 (injection) and one in Feature A between KXTT3:P2 and KXTT1:P2, see Figure 4-7. In both cases uranine was introduced as a decaying pulse. First arrivals where obtained after 30 and 58 minutes, respectively. The evaluation of the tracer tests indicated dispersivities in the order of 10% of the travel distance. The evaluated porosity for the studied flow path in Feature A is in the order of $1.8 \cdot 10^{-4}$.

The results of the dilution tests show natural flows in sections containing Feature A ranging between 0.08 and 1.4 ml/min.

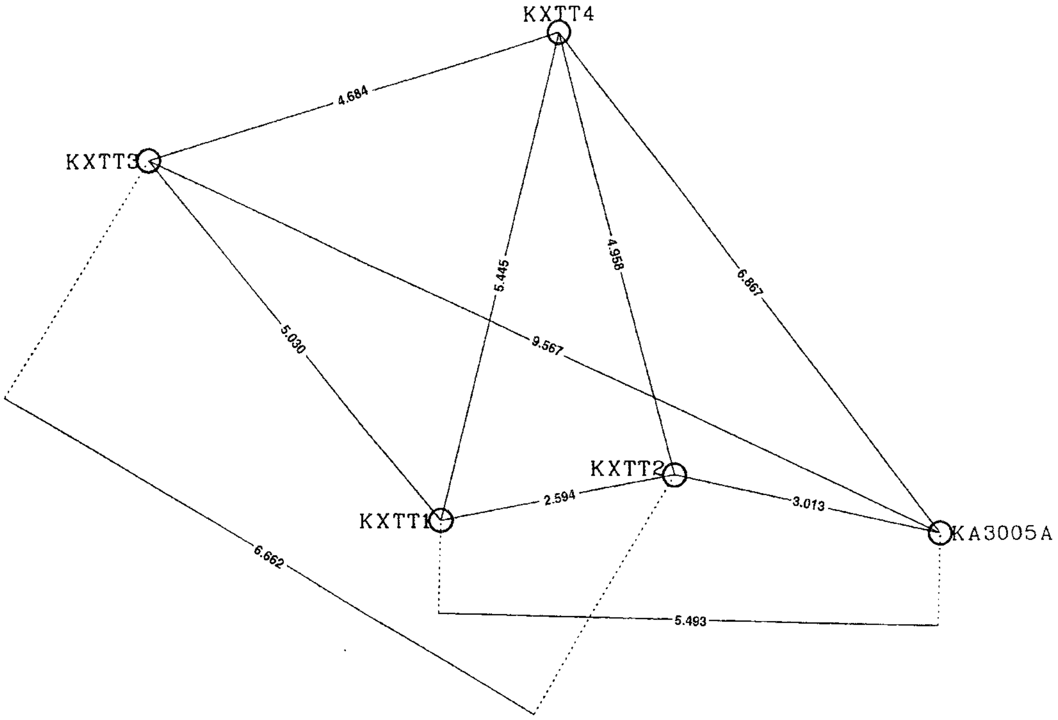


Figure 4-7. Configuration of borehole intersections with the plane of Feature A.

A Tracer Test Programme has been conceived on the basis of the developed descriptive model. The first test, the radially converging tracer test/-s (RC), will be performed with pumping in KXTT3:R2 with injection in the remaining four sections containing Feature A, i.e. KXTT1:R2, KXTT4:R3, KXTT2:R2 and KA3005A:R3. The travel distances vary between roughly 5 and 10 m, see Figure 4-7. The injections will be performed as pulse injections in an established constant flow field. The injections will be done in two batches involving KXTT1/KXTT4 and KXTT2/KA3005A, respectively.

Resin technology development

The literature review and established conceptual platform for use of pore space data from resin injection is presented by Birgersson and Lindbom (1995). It is shown that resin injection *in-situ*, in a feature similar to Feature A has not been performed in the field. It is however identified that existing laboratory techniques can form the basis for field application under conditions expected in the TRUE experiments. The information which will emerge from a resin injection and subsequent excavation and analysis will be both quantitative and qualitative. Resin may reveal the overall geometry of the flow pattern but may also be used for actual determination of physical aperture. The qualitative information is important in improving our conceptual understanding of pore space distribution, and the quantitative information may be used as input in models used to evaluate the TRUE experiments.

Prior to application in the TRUE-1 Block, a Pilot Resin injection Experiment will be conducted in a fracture identified in the F-tunnel (near the sump at the lower

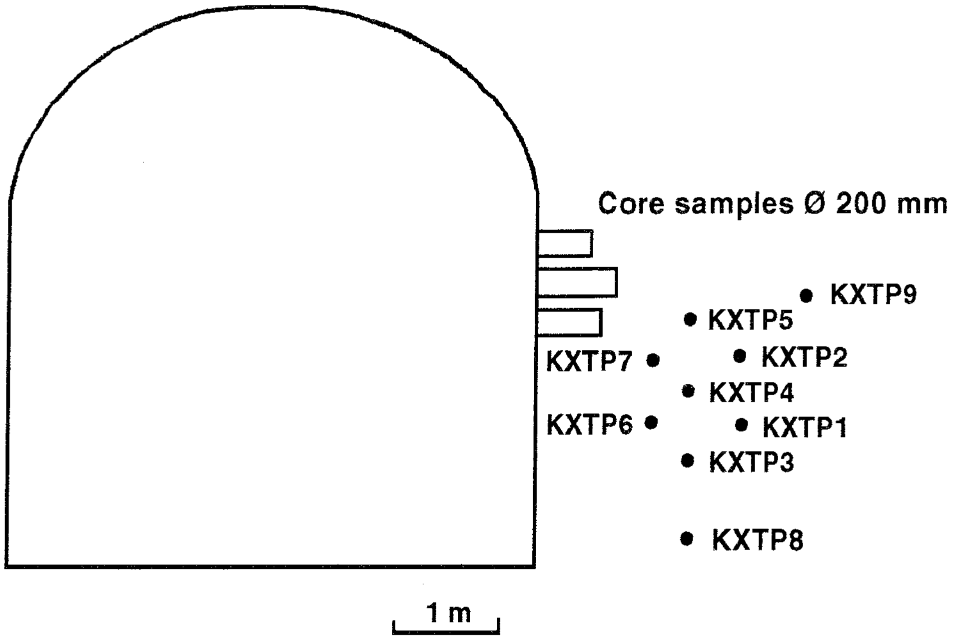


Figure 4-8. *Schematic illustration of borehole intersections (56 mm) with pilot resin fracture.*

shaft station). The experiment will be conducted in a near-drift environment in a fracture with characteristics similar to those observed in the TRUE-1 Block. An engineering test plan has been prepared for the experiment /4-8/. A drilling programme has been conducted which a) has produced large diameter cores (200 mm) for supporting laboratory experiments, and b) has provided 9 sampling points in the selected fracture, see Figure 4-8. The intercepts are located about 1-3 m away from the drift. Recorded inflows range from 0.1 to 2.6 l/hr. The recorded pressures range from 1–30 bars.

The continued characterization include i.a. logging of the drill cores, borehole TV logging, borehole deviation, flow logging and a tracer test. The collected data is integrated in a CAD model of the studied rock volume. Results so far indicate a more complex fracture system than expected, i.a fractures parallel to the tunnel wall.

International cooperation (TRUE Block Scale)

In conjunction with the 7th Task force meeting a planning meeting was held where the interest in, and level of participation in future TRUE stages was identified and discussed. A brainstorming session to define the objectives, issues, scope and division of work for the planned Block scale experiment will be organized April 16–17, 1996 at Äspö.

4.5.3 Planned work

Model predictions will be made of the tracer tests planned for 1996. Radially converging and dipole tracer tests with conservative tracers will be performed before summer 1996. These will be followed by additional diverging/converging tracer tests with conservative tracers. Towards the end of the year test with reactive tracers will be initiated.

The Pilot Resin experiment will continue with characterization of the experimental site. Injection of resin is planned for the summer of 1996 and will be followed by excavation of the fracture and analysis of pore space characteristics of the excavated fracture.

Planning for the TRUE Block Scale experiment will be initiated. Site selection and initial characterization will begin late 1996.

4.6 DEVELOPMENT OF TRACERS

4.6.1 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 applied in the in-situ performance,
- to provide laboratory data on transport parameters (distribution coefficients and diffusivities) for comparison with in-situ derived parameters and/or for evaluation of in-sit results, and
- to show that the tracers do not sorb on equipment used in the in-situ experiments.

4.6.2 Results

Batch experiments

Investigations of the sorption behaviour of ^{137}Cs to Äspö diorite have been finalized during the year. The results show that the K_d for Cs varies between 0.001 – 0.07 m^3/kg depending on particle size. A new method of desorbing Cs from the available surface has been tested for the different size fractions by replacing the synthetic groundwater several times after completion of the experiment. It was found that the different size fractions used showed a larger variation in sorption behaviour than could be explained by the change in surface area alone. It was identified that detailed mineralogical analyses are necessary for the different size fractions to explain the findings.

The Cs-experiments have shown that the sorption experiments take relatively long time to reach equilibrium. In order to obtain information on the kinetics of the sorption behaviour, long experiment times have to be considered.

Batch sorption experiments with $^{22}Na^{+}$, $^{85}Sr^{2+}$ have been performed. The evaluation is in progress. However, some samples are still in contact with tracer-spiked water in order to study long term sorption effects. Some preliminary results are shown in Table 4-2.

Table 4-2. Some preliminary K_d for Na, Ca, Rb, Sr, Cs and Ba.

All results in the table are preliminary and may be changed.

K_d is evaluated from measurements of the aqueous phase.

K_d(solid) is evaluated from measurements of the aqueous and solid phases.

K_d(des) is evaluated from measurements of the aqueous phase and desorption solution.

K_d-values given as intervals represents the different size fractions of the geological material used.

Element	**Geological material**[1]	**Contact time (days)**	**K_d (m^3/kg)**	**K_d(solid) (m^3/kg)**	**K_d(des) (m^3/kg)**	**Desorption time (days)**
Na	ÄD	14	-	5-10 · 10^{-6}	4-7 · 10^{-6}	7
Na	FGG	14	-	4-27 · 10^{-6}	3-20 · 10^{-6}	7
Ca	ÄD	14	20-50 · 10^{-6}	-	40-60 · 10^{-6}	
Ca	FGG	14	-	-	10-30 · 10^{-6}	
Rb	ÄD	14	2-8 · 10^{-3}	-	0.4-1 · 10^{-3}	9
Rb	FGG	14	0.8-3 · 10^{-3}	-	0.4-8 · 10^{-3}	9
Sr	ÄD	14	30-130 · 10^{-6}	-	20-90 · 10^{-6}	7
Sr	FGG	14	20-130 · 10^{-6}	-	10-70 · 10^{-6}	7
Cs	ÄD	14	30-300 · 10^{-3}	-	4-6 · 10^{-3}	9
Cs	FGG	14	6-60 · 10^{-3}	-	-	9
Ba	ÄD	14	0.9-4 · 10^{-3}	-	0.5-2 · 10^{-3}	9
Ba	FGG	14	0.6-3 · 10^{-3}	-	0.4-1 · 10^{-3}	9

[1] ÄD = Äspö diorite
FGG = Fine grained granite

The following preliminary conclusions can be drawn;

- The K_d for the different tracers are increasing in the order

$$Na << Ca \approx Sr << Rb \approx Ba << Cs.$$

This result is in parity with results on geological material from the Finnsjön test site.

- Generally, the sorption is higher on Äspö diorite compared to the Fine-grained granite. This can be explained by the higher content of biotite in the Äspö diorite. Among the common naturally occurring minerals, biotite is the mineral which has the highest cation exchange capacity.
- It is shown that for Na, Ca and Sr, the sorbed part can be easily desorbed. For Rb, Ba and especially for Cs, it is observed that a significant part cannot be desorbed by simply replacing the old water phase with a non-spiked synthetic groundwater.

- The K_d- values vary with the particle size; decreasing particle size results in increasing K_d. The variation in K_d is approximately one order of magnitude from the largest particle size (2 – 4 mm) to the smallest particle size (0.045 – 0.090 mm). It is also shown that the non-desorbed part increases with decreasing particle size.

Diffusion experiments

Diffusion experiments with tritiated water (H^3TO), sodium ($^{22}Na^+$) and strontium ($^{85}Sr^+$) are in progress. Injection of the remaining tracers ($^{45}Ca^{2+}$, $^{86}Rb^+$ and $^{133}Ba^{2+}$) have been performed. Three different thicknesses of granite samples are considered; 10, 20 and 40 mm.

For the tracers ($^{45}Ca^{2+}$, $^{86}Rb^+$ and $^{133}Ba^{2+}$), no breakthrough has been observed. The initial sorption of the tracers on the surface of the geological material, on the injection side of the diffusion cell, has also been studied. In the cells with Äspö diorite which have Cs as tracer, a slight sorption has been observed. For the other cells, no significant sorption has been observed.

The evaluated diffusivities and K_d-values are presented in Table 4-3. The observed breakthrough of **HTO, Na and Sr** are shown in Figure 4-9. The K_d-values obtained from the diffusion experiments have been calculated by comparing the breakthrough of the sorbing tracers with that of HTO. A comparison of the calculated K_d-values for Na and Sr with those obtained from the batch sorption experiments, indicates a good agreement for the largest particle size (2 – 4 mm). This may indicate that this particular particle size is the most representative, i.e. that matrix diffusion in the rock occurs in a network of grains having a size in the order of 2 – 4 mm. It may also indicate that some phenomena, e.g. strong and non-reversible sorption, occurring in the batch sorption experiment, and most strongly in the smallest particle sizes, may be an effect of crushing of the mineral grains whereby surfaces are created which are not representative of the intact rock.

Geological characterization

In order to assess the sorption characteristics of different size fractions of Äspö diorite, a representative sample collected in the Äspö tunnel was crushed and sieved and six different size fractions were prepared for the laboratory experiments. One sample from each size fraction was analyzed for chemical composition using ICP and INA analysis.

Thin sections from the original rock sample have been prepared and studied in transmissive light. Plagioclase, quartz, K-feldspars, biotite and epidote dominate in the samples. Accessoric minerals are muscovite, titanite, apatite, fluorite, zircon and opaque phases (mostly magnetite). The biotite is greenish in colour indicative of slight alteration. Chlorite is not observed. Some microcracks filled with calcite are observed.

The chemical composition of the different size fractions show significant differences between the coarse and fine fractions. This is due, in part, to different original mineral grain sizes and is also due to a variable degree of brittleness found for different types of minerals. The chemical analyses have been used to estimate

Table 4-3. Preliminary results of the diffusion experiments (951231).

All results in the table are preliminary and may be changed.
Results within ( ) will be changed.
Results marked "-" indicates not sufficient experimental data to be evaluated.
ÄD = Äspö Diorite
FGG = Fine Grained Granite

Rock density and porosity:

Material	Density (kg/m^3)	Porosity[1] (volume)
ÄD	2750	(0.005)
FGG	2630	(0.0025)

[1] Determined by the dry and wet method.

H^3TO diffusion:

Material	Exp. no.	Cell length (mm)	Diffusivity D_e (m^2/s)	Retardation factor, α, (unit less) [= Porosity]
ÄD	3	10	$1.5 \cdot 10^{-13}$	$4.5 \cdot 10^{-3}$
ÄD	4	20	$1.3 \cdot 10^{-13}$	$7.0 \cdot 10^{-3}$
ÄD	5	40	$(3.7 \cdot 10^{-14})$	$(1.4 \cdot 10^{-3})$
FGG	1	10	$1.1 \cdot 10^{-13}$	$6.6 \cdot 10^{-3}$
FGG	2	20	$8.7 \cdot 10^{-14}$	$8 \cdot 10^{-3}$

$^{22}Na^+$ diffusion:

Material	Exp. no.	Cell length (mm)	Diffusivity D_e (m^2/s)	Retardation factor, α, (unit less)	Calc. K_d (m^3/kg)
ÄD	3	10	$7.9 \cdot 10^{-14}$	$8.5 \cdot 10^{-3}$	$1.5 \cdot 10^{-6}$
ÄD	4	20	$7.3 \cdot 10^{-14}$	$11 \cdot 10^{-3}$	$1.3 \cdot 10^{-6}$
ÄD	5	40	$(5.5 \cdot 10^{-15})$	$(4.5 \cdot 10^{-4})$	-
ÄD	7	40	-	-	-
			Breakthrough observed after ~ 160 d		
FGG	1	10	$6.3 \cdot 10^{-14}$	$11 \cdot 10^{-3}$	$1.6 \cdot 10^{-6}$
FGG	2	20	$5.5 \cdot 10^{-14}$	$10 \cdot 10^{-3}$	$8.0 \cdot 10^{-7}$
FGG	6	40	-	-	-
			Breakthrough observed after ~ 80 d		

$^{85}Sr^{2+}$ diffusion:

Material	Exp. no.	Cell length (mm)	Diffusivity D_e (m^2/s)	Retardation factor, α, (unit less)	Calc. K_d (m^3/kg)
ÄD	10	10	$6.4 \cdot 10^{-14}$	$29 \cdot 10^{-3}$	$9.2 \cdot 10^{-6}$
ÄD	11	20	$(1.4 \cdot 10^{-15})$	$(32 \cdot 10^{-3})$	$(9.2 \cdot 10^{-6})$
FGG	8	10	$3.4 \cdot 10^{-14}$	$22 \cdot 10^{-3}$	$5.7 \cdot 10^{-6}$
FGG	9	20	-	-	-

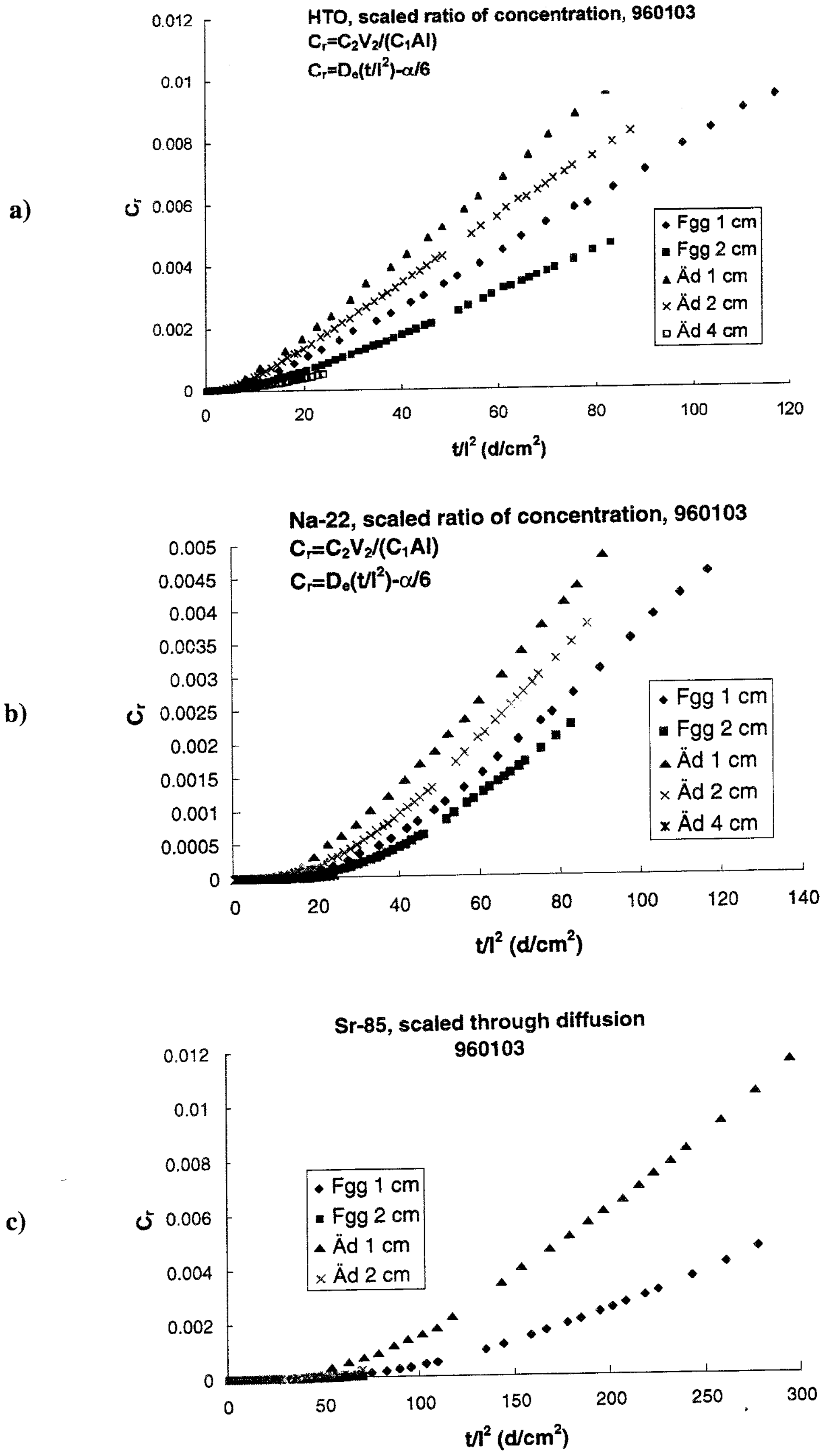


Figure 4-9. *Experimental diffusion results. Cumulative fraction of tracer on the target side of the diffusion cell as a function of time,* **a) HTO, b) ^{22}Na, c) ^{85}Sr.**

(calculate) the mineralogical composition of the different size fractions under a set of specified assumptions.

The calculated mineralogical composition is presented in Table 4-4. The results show a significantly higher proportion of biotite in the finest fractions, whereas the feldspars show an opposite trend. The calculated results are in accord with the established trace element chemistry, and with performed point counting for mineralogical composition (Tullborg, pers. comm.). The observed difference in biotite content is relevant to the batch experiments and planned in-situ experiments, and to overall performance assessment, in that the biotite accounts for orders of magnitude higher sorption capacity than other minerals.

Table 4-4. Calculated mineralogical composition of different fractions of Äspö diorite and an average mineral composition (*) from /4-9/.

Element	ÄD1 0.045–0.09	ÄD2 0.09–0.25	ÄD3 0.25–0.5	ÄD4 0.5–1	ÄD5 1–2	ÄD6 2–4 mm	*
Biotite	25	18	19	18	18	17	15
Plagioclase	35	44	51	53	52	51	45
K-feldspar	6	8	9	10	8.5	10	15
Quartz	22	19	12	10	13.5	15	14
Epidote	7	5.5	6	6	5.5	5	6
Apatite	2	1	0.5	1	1	1	0.5
Titanite	2	2	2	1	1	1	2
Opaque	2	2.5	1	1	1	1	1

Complementary mineralogical characterization of remaining size fractions of Äspö diorite and Fine-grained granite. Enrichment in biotite using magnetic separation on eight fractions of crushed Äspö granite and fine-grained granite. ICP and NAA analyses.

4.6.3 Planned work

Batch sorption experiments will be finalized and reporting will begin.

Measurement of diffusion in the HTO, Na, Ca, Sr, Rb, Cs and Ba cells will continue.

Complementary mineralogical characterization is continuing according to plan, i.e. geological analyses of different size fractions of fine-grained granite and site-specific material from the TRUE-1 site will be performed.

Batch sorption experiments on site-specific material from Feature A in the TRUE-1 Block. Diffusion measurements on site specific material with slightly sorbing tracers and conservative tracers.

4.7 DEGASSING AND TWO-PHASE FLOW

4.7.1 Background

Two-phase flow conditions, i.e. a mixed flow of gas and water, may develop in the vicinity of a repository situated in a regionally saturated rock mass. The main sources of two-phase flow conditions are 1) gas generation in the repository due to corrosion or biological processes, 2) exsolution of gas (bubble generation) due to pressure decrease, and 3) entry of gas (air) into the rock mass from ventilated tunnels. The presence of a gas phase in the repository before and after closure must be understood in relation to its effect on repository performance. Waste-generated gas may affect repository integrity and hazardous material may be transported in the gas phase.

Understanding evolution and characteristics of two-phase flow conditions near drifts is essential for understanding observations of hydraulic conditions made in drifts, interpretation of experiments performed close to drifts, and performance of buffer mass and backfill, particularly during emplacement and repository closure.

The objectives for the project on degassing and two-phase flow are:

- To show if degassing of groundwater at low pressures has significant effects on measurements of hydraulic properties in boreholes and drifts.
- To study and quantify other processes causing two-phase flow near excavations such as air invasion due to buoyancy and evaporation.
- To show under what conditions two-phase flow will occur and be significant. Conditions expected to be of importance are gas content, chemical composition of groundwater, fracture characteristics (aperture distribution and transmissivities), and flow conditions.
- To get an idea of the time scales required for resaturation of a repository.
- To develop technology for measurement of saturation.

This project is performed as one of the bilateral cooperation projects between USDOE and SKB for studies at the Äspö Hard Rock Laboratory in the Areas of Site Characterization and Repository Performance. Contributions to the project are also provided by NAGRA and PNC.

4.7.2 Results

Pilot Hole Test

A Pilot Hole Test was performed in December 1994 to support the design of the Degassing and two-phase flow experiments to be performed at Äspö. The test consisted of a sequence of constant pressure borehole inflow tests (CPTs) and pressure recovery tests (PRTs) in borehole KA2512A. The test sequence was designed to detect degassing effects from the change in transmissivity/hydraulic conductivity, and storativity/specific storage when the borehole pressure is lowered below the groundwater bubble pressure. A bubble pressure estimate of 300 kPa was calculated from earlier gas contents measurements in KA2511A and KA2598A. Borehole KA2512A was drilled while maintaining the borehole pressure greater than 1500 kPa to prevent the possible formation of a gas phase and ensure that single phase flow behaviour could be well characterized. The entire

37.3 m of the borehole section was tested without packers. Flow response to pressure changes in CPTs occurred rapidly. Flowrates fluctuated before attaining a steady trend, probably due to effective stress changes when borehole pressure was reduced for the first time. These factors, along with the rapid response of the borehole to pressure changes, decreased the sensitivity of the single-well analysis for specific storage. The analysis of the pressure response in the monitoring well, KA2512A, provided more reliable estimates of the specific storage.

The relationship between borehole pressure and steady-state flowrates was linear over borehole pressures of 1500 kPa (abs) down to 120 kPa (abs) during testing in December 1994, indicating that processes that may change hydraulic conductivity at low borehole pressures, such as degassing, calcite precipitation or turbulence, did not occur to a measurable degree. The gas contents of water from KA2512A, KA2598A, KA3010A and KA3067A were measured by two methods which indicated the volume of evolved gas per known volume of liquid at atmospheric pressure. These methods indicated a gas contents in KA2512A on the order of 0.5% v/v, in which case it is possible that pressures below the groundwater bubble pressure were not attained in the formation. Samples from other boreholes had higher gas contents (ranging from 1 to 3% v/v). Test results during January and February of 1995 suggest that degassing may have occurred. One CPT at a borehole pressure equal to 120 kPa (abs) indicated a 20% decrease compared to the hydraulic conductivity measured at a borehole pressure of 1500 kPa (abs); the latter value was 10% lower than the hydraulic conductivity measured in December, 1994. The volumetric gas content measured during this time was 1% v/v. However, the hydraulic conductivity in a subsequent CPT test at 120 kpa, returned to within the standard deviation of previous measurements.

The results from the Pilot Hole test are reported by Geller and Jarsjö in /4-10/.

Laboratory experiments at LBNL

Degassing and two phase flow was a likely cause for the significant inflow reductions that was observed in a drift in the Stripa mine, where the local water gas contents were about 5%. However, the contribution of degassing and two phase flow in relation to other possible causes of the observed flow reduction is not known. The pilot hole field test described above did not detect any significant reductions in flowrates due to degassing. Laboratory experiments have been carried out at Lawrence Berkeley National Laboratory (LBNL) during 1995 to investigate the effect of gas contents of similar low range as observed in the pilot hole field test on flow reductions due to degassing.

The transparent epoxy fracture replicas used in the laboratory experiments had a diameter of 115 mm and were oriented horizontally. The degassing experiments were conducted with one fracture replica from Stripa and one fracture replica from Äspö. The fracture aperture widths were mapped through light intensity measurements of the fracture saturated with dyed water. The fracture transmissivity was also measured, and for the Äspö fracture replica, it decreased with time due to plastic deformation of the epoxy under the confining pressure of 345 kPa. The transmissivity and aperture width measurements were compared by calculating the mean aperture width from the measured transmissivities using the parallel plate assumption. The aperture widths estimated from the transmissivities showed good agreement with the mean aperture width obtained from the light intensity measurements.

In each degassing experiment, CO_2 saturated water was first introduced into the fracture while the effluent pressure was maintained above the bubble pressure of the gas in the water. The effluent pressure was then reduced to below the bubble pressure. Data on the inlet tank pressure, the outlet pressure, the differential pressure over the fracture, the temperature in the inlet tank and the flowrate was sampled regularly. The experiments continued until the fracture gas saturation, the flowrates and the differential pressures over the fracture were constant.

In the Stripa fracture replica, experiments were conducted at water gas contents of 1% and 3%. In the Äspö fracture replica, two experiments were conducted at gas contents of 3%, two experiments were conducted at gas contents of 7% and one experiment was conducted at a gas content of 15%. In the Stripa fracture at a water gas content of 1%, the steady-state gas saturation of the fracture was 1 – 2% and no reduction in flowrates due to degassing was observed. For the Äspö fracture at a water gas content of 3%, only small reductions in flowrates due to degassing (i.e. less than 20%) were observed. Greater flowrate reductions were observed for greater gas contents, however, for relatively high gas contents, no further decrease in steady state flowrates and increase in gas saturations were observed for increasing gas contents.

In addition to water gas contents, a number of parameters are of importance for the magnitude of flowrate reduction. Orders of magnitude differences in flowrate reduction were observed for fractures with different aperture distribution, aperture widths and inlet conditions.

Enhanced bubble nucleation in the vicinity of a flow regulating valve is a plausible reason for the appearance of gas in the Äspö fracture for one of the two experiments conducted at water gas contents of 3%. In the other experiment at a gas content of 3%, without the flow regulating valve, no gas appeared in the fracture. Local conditions in regions with estimated average pressures well above the bubble pressure may thus be of importance for the evolution of a gas phase in the fracture.

A comparison of two experiments conducted with the same boundary conditions and fracture aperture distribution, but with different water gas contents (7% and 15%, respectively) showed that the reduction in flowrates were linearly correlated with the gas saturations of the fracture and that the same gas saturation gave approximately the same flowrate reduction in both experiments.

Laboratory experiments by Fracflow Consultants

The two-phase flow studies consist of single and two phase flow experiments using (1) a suite of five small scale samples, approximately 200 mm wide by 300 mm in length and 200 mm high, that contain either fabricated, induced or natural fracture planes, (2) a large scale (approximately 2 m by 2 m by 2 m) physical model that contains a single horizontal fabricated fracture surface with a uniform surface roughness, and (3) a plastic replica of part of this fabricated fracture surface. The experimental studies are supported by numerical model simulations of the experimental data in collaboration with the other research groups that are involved in the two-phase flow study.

The suite of small scale samples includes one fabricated fracture surface, two induced fracture plane surfaces and two cores contained sections of the natural fracture from the pilot resin experiment site at Äspö. Two samples from this group of five samples have been tested. The first sample tested was a block of limestone that contained a sandblasted sawcut surface. The second sample was made of high strength concrete and a woven geotextile was used to imprint a uniform roughness on the fracture surface. In the third sample, a block of Berea sandstone, with a porous and permeable matrix, was split to create an extensional fracture. This sample has been prepared for testing. The initial preparation work on the two natural fracture plane samples from Äspö has been completed.

A full suite of single phase flow tests, using both linear and convergent flow geometries, have been conducted on the large scale fabricated fracture plane in the physical model. These initial tests have been conducted in order to separate any non-linearities in the flowrate versus hydraulic head relationship, that are a function of flowrate, fracture transmissivity and flow geometry, from those that are created by two-phase flow. In order to visualize the effects of increasing flowrate under both linear and convergent flow geometry, a 300 mm by 300 mm fracture, with uniform surface roughness, was fabricated from high strength concrete to duplicate a section of the fracture surface in the large physical model. These fabricated fracture surfaces will be used as the molds for casting plastic replicas of the fracture surfaces which will be used to conduct a series of two-phase flow experiments at Sandia National Laboratory.

Most two-phase flow laboratory experiments on rough fractures have been conducted on small samples or plastic fracture replicas, under low effective stress. Conducting two-phase flow experiments on fracture planes that are similar in scale to those that are of importance in drift inflows, requires a re-evaluation of the experimental procedures. Hence, the main focus of the two-phase flow experiments, on the first two small scale samples, has been to establish the test procedures for the rest of the two-phase flow laboratory experiments and provide a preliminary set of data for discussion prior to the testing of the natural fractures from Äspö and the fracture plane in the large physical model.

Both the induced fracture in the limestone sample and the fabricated fracture in the concrete sample were cycled through several loading and unloading steps. Each sample was first tested under normal stress (up to 8 to 10 MPa) conditions only, then under one or more cycles of shear loading at a selected normal load, allowing one to determine the effects of a range of relative roughnesses on both single phase and two-phase flow. The two-phase flow experiments consisted of three individual tests at each stress level, using one or more of either air, nitrogen or carbon dioxide as the gas phase.

The first test consisted of a gas "invasion" experiment. After the desired stress level was reached on a particular loading cycle, each test was started by injecting water until a steady state flowrate was reached. The gas invasion tests were designed to remove a fixed percentage of the water filling the fracture pore space. This was accomplished by first closing the inflow water line to the sample and then injecting gas across the outflow end of the sample using gas pressures that were equal to about 10 to 20 cm of water pressure head. This gas pressure was maintained until most of the free water in the fracture pore space had drained from the fracture plane. This was assumed to represent about 100% of the water that could be removed from the fracture pore space for that particular gas and gas pressure. As soon as the water stopped draining from the fracture plane, the inflow water line was opened and water was again injected and the flowrate monitored to determine if and over what time period the flowrates would return to those that existed prior to the air invasion.

Water flow was maintained for a considerable period of time (tens of hours in some cases) after each gas invasion. If air or nitrogen had been used as the gas, flowrates usually took too long to recover and the fracture plane had to be flushed with carbon dioxide to remove the air or nitrogen. This flushing of the fracture plane with carbon dioxide was followed by additional water injection until a stable water flowrate was achieved. For the second sample (the concrete sample), the first gas invasion test was followed by three additional gas invasion tests in which the amount of water removed from the fracture plane at the start of each test was systematically reduced to 75%, 50% and 25%, respectively, of the original water volume extracted from the fracture plane in the first gas invasion step.

After the gas invasion experiments were completed, a gas "injection" experiment was conducted. In this case, gas was injected under low pressure (equal to 60 cm of water head) at the upstream or inflow end of the sample and the volume of water that was expelled from the downstream or outflow end of the sample was measured as a function of time. The gas injection pressure was maintained until the water outflow ceased and only gas was discharging from the downstream end of the sample. At this point, gas injection was stopped and water injection was resumed and the change in flowrate versus time was recorded to determine both the length of time required to recover the original water flowrates and the shape of the flowrate versus time curve. At the end of this gas injection test, carbon dioxide was flushed through the sample, to ensure that all of the air or nitrogen gas had been removed from the fracture plane, followed by water injection.

The third step consisted of a "degassing" experiment. A bubbler system was used to saturate the injection water with the selected gas at a pressure greater than the water pressure on the upstream end of the sample. While the inflow tube was still filled with partly degassed water, the outflow tube was gradually closed off until the pressure gradient across the sample was very small and the flowrate through the sample was very small. Once these conditions had been established, water was slowly removed from the upstream reservoir until the reservoir was filled with gas saturated water. The reduced outflow condition was maintained until several pore volumes had passed through the fracture plane suggesting that the fracture plane was filled with gas saturated water. At this point, the outflow tube was opened in increments, resulting in a drop in the water pressure in the downstream end of the fracture plane which in turn migrated back through the fracture plane towards the upstream end of the sample, allowing degassing to occur in the fracture plane.

The final steps in testing each sample were to conduct a tracer test and impregnate the sample with a resin to enable one to describe the pore structure. The fracture pore space in the limestone sample is quite tabular, producing a high aspect ratio, while the pore space in the fabricated fracture plane, which has a well defined uniform roughness, has a smaller aspect ratio.

There appears to be a distinct difference between the flowrate versus time curves from the gas invasion experiments for different stress conditions. Similarly, the slope of the curve differs significantly if carbon dioxide is used instead of air or nitrogen. The transmissivity versus time curves, following a gas injection test, usually show a slow and erratic increase in the transmissivity, as a percent of the original transmissivity. This is partly due to the formation of bubbles in and at the entrance to the manometer tubes in the fracture plane. The capillary pressures produced by these gas bubbles in a direct function of the size of the local fracture apertures and significant changes in the measured pressure heads within the local fracture pore space are produced.

The time required to recover the original transmissivities is a function of the fracture transmissivity and the pore structure. Under high normal stresses in the concrete sample, in which the sample is characterized by a uniform roughness, it required hours to tens of hours to recover the original flowrates.

When the data from the gas invasion experiments are plotted as a typical relative permeability versus gas saturation curve, the data suggest that the water permeability increases with increasing gas saturation, the reverse of the typical drainage/rewetting curves. These results suggest that the measured transmissivities are pathway dependent. That is, we are seeing a continued build-up of gas in the fracture plane from each air invasion experiment and this gas is not being removed by the injected water over the time frames that these experiments are being conducted and nor is the gas being completely removed by the subsequent carbon dioxide flushing. This build-up of gas during the tests is amplified in the gas invasion experiments by removing 100% of the water in the first step.

The combination of the three individual gas experiments, together with the tracer tests and the resin impregnation of the pore space, appear to provide the most realistic approach to measuring the impact of two-phase flow in large fracture samples. The same series of tests will be completed on the fracture plane in the large physical model. However, the data obtained from the first two samples suggest that longer test times will be required if the time to recover the original transmissivities in the tight fractures is to be determined. Given the long time frames needed to reestablish the original fracture transmissivities, the data collection part of the water injection and head monitoring system for the small scale experiments has been redesigned and automated.

4.7.3 Planned work

A field test of degassing effects will be performed in the fracture selected for the Pilot Resin Injection Experiment to investigate if degassing effects are significant in fractures tighter than the one tested in December 1994.

The laboratory tests on fracture samples from Äspö and artificial fractures will continue.

4.8 THE REX EXPERIMENT

4.8.1 Background

The detailed scale experiment (REX) is planned to focus the question of oxygen that is trapped in the tunnels when the repository is closed. Questions are:

- Will oxygen penetrate into the rock matrix during construction and operation?
- If yes, how much of the rock will be oxidized and how long time will it take before oxygen is consumed?

The objectives of the REX experiment are:

- How does oxygen trapped in the closed repository react with the rock minerals in the tunnel and deposition holes and in the water conducting fractures?
- How long time will it take for the oxygen to be consumed and how far into the rock matrix and water conducting fractures will the oxygen penetrate?

4.8.2 Results

The laboratory part of the experiment started in september 1995. The work conducted at University of Bradford will concentrate on the inorganic reactions between the oxygen and the minerals, while the field experiments will be affected by the existence of microbes in the groundwater. Planning for the field experiment is on-going. PNC and ANDRA have joined the laboratory part of the experiment.

Scoping calculations of the rates for oxygen reduction indicate that the reactions could be faster than previously expected. The results up to now have mainly been definition of the laboratory reactor configuration and the prediction of the laboratory and field conditions. The reaction curve, based on the scoping calculations, would imply that there is a first rapid reaction followed by a slow long-term reaction.

A report on the use of uranium(VI) in a tracer test conducted by AECL in URL has been compiled as a background and planning document for the REX experiment.

4.8.3 Planned work

Detailed planning of the laboratory work by PNC (BGS) and by ANDRA will be made up to middle of April 1996 when the selection of the field site will be made. PNC will focus their efforts on the microbial aspects of the deep groundwater fracture system, whereas ANDRA plan to concentrate on the behaviour of uranium.

4.9 RADIONUCLIDE RETENTION

4.9.1 Background

The retention of radionuclides in the rock is the most effective protection mechanism if the engineering barriers have failed. The retention is mainly caused by the chemical character of the radionuclides themselves, the chemical composition of the groundwater, and to some extent also by the conditions of the water conducting fractures and the groundwater flow.

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 some of these retardation processes the sorption could well be considered to be irreversible and thus the propagation of the front will stop as soon as the source term is ending.

Laboratory studies under natural conditions are extremely difficult to conduct. Even though the experiences from different scientists are uniform it is of great

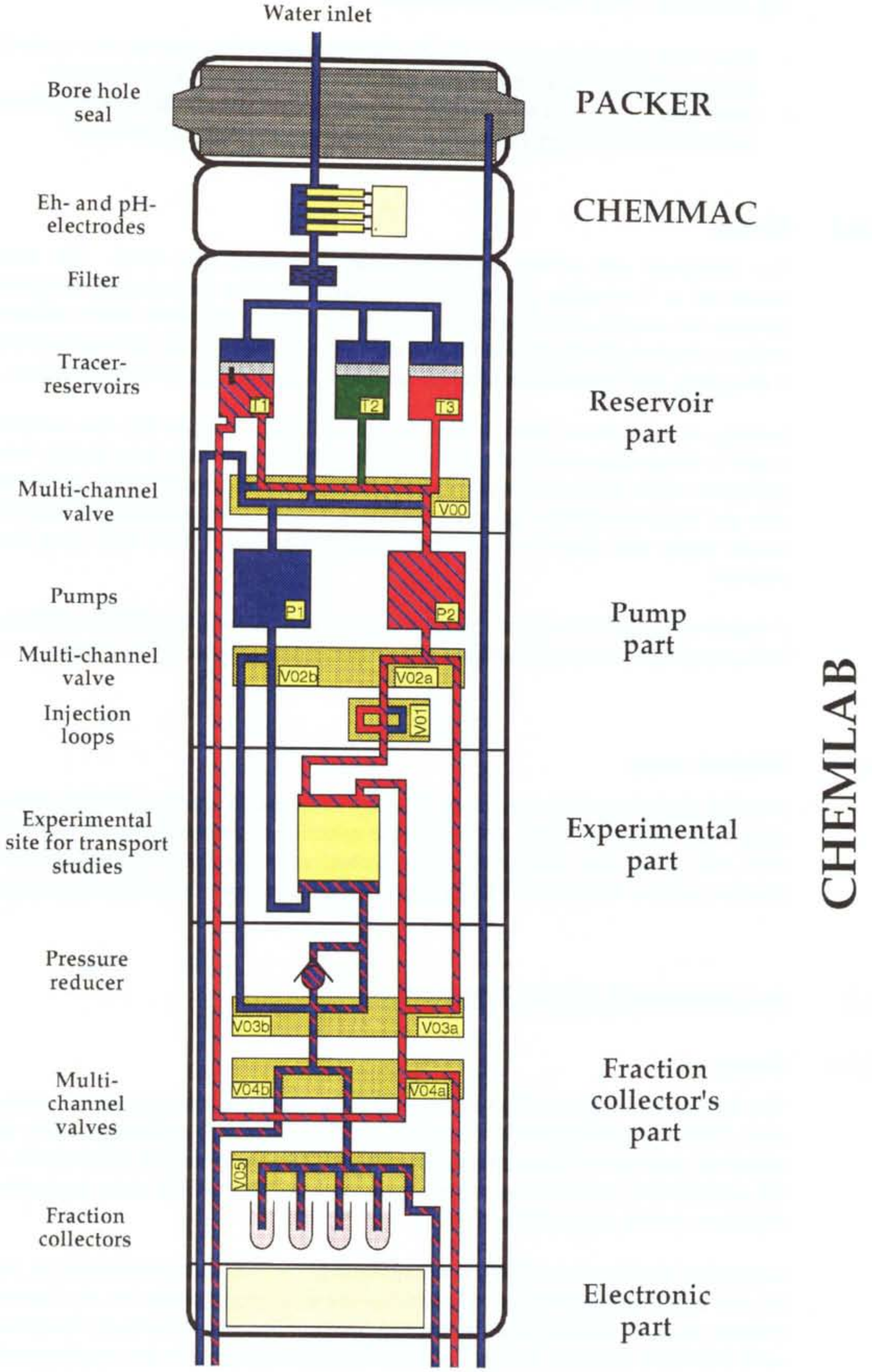


Figure 4-10. *Schematic illustration of the CHEMLAB probe.*

value to be able to demonstrate the results of the laboratory studies in situ. The natural contents of colloids, of organic matter, of bacteria etc are difficult to simulate in laboratory investigations. The CHEMLAB probe, see Figure 4-10, is therefore aimed to be used to conduct validation experiments in situ at undisturbed natural conditions.

4.9.2 Results

The manufacturing of the CHEMLAB probe is completed. Presently performance tests are conducted before the probe is delivered to Äspö.

The location of the experiment has been switched from the deepest level in the tunnel up to borehole KA2512A at the 335 m level below the surface.

The manufacturing of the CHEMLAB is almost completed, however, delayed compared to the time plan. During the course of the manufacturing minor changes of the design have been made in order to fulfil the functional specification given. Finally a test of the whole system will be made at the suppliers workshop in France, scheduled for January 1996. Delivery, training and acceptance tests will be made at the Äspö HRL in April 1996.

The length of the CHEMLAB will be approx 16 m, and the diameter 89 mm. While running experiments in a hole a CHEMMAC (down-hole probe for measuring Eh and pH) and packer will be connected to the CHEMLAB, increasing the length to approx 18,5 m. The weight of the CHEMLAB will be around 360 kg.

For installation of the CHEMLAB system in a borehole a feeding rig has been manufactured. Also a dummy probe for checking the accessibility in a borehole before installation has been made. Both rig and dummy probe were tested and used for checking borehole KA2512A as being a potential experimental hole in the Äspö HRL.

The experimental programme for CHEMLAB and the test plan for the performance and acceptance tests have been completed. The radiological laboratory for preparation of the CHEMLAB probe is established in the CLAB interim storage facility. The laboratory is called BASLAB and will be used also for the handling of short-lived nuclides to be used in TRUE tracer tests.

4.9.3 Planned work

Acceptance tests are scheduled to begin in April. Diffusion experiments using strontium and cesium are scheduled to begin later during 1996.

Experiments with spent fuel are planned to be conducted in a separate experimental probe. The planning for these experiments will start by the middle of 1996. The goal of the planning is to start spent fuel experiments in 1999.

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

4.10.1 Background

The Äspö Task Force on modelling of groundwater flow and transport of solutes was initiated in 1992. The 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. The group consists of Task Force delegates as well as modelling expertise from nine organizations and meets regularly twice a year. The work within the Task Force is being performed on well defined and focused Modelling Tasks and the following have been defined so far:

Task No 1:	The LPT-2 pumping and tracer experiments.
Task No 2:	Scoping calculations for a number of planned experiments at the Äspö site.
Task No 3:	The hydraulic impact of the Äspö tunnel excavation.
Task No 4:	TRUE – The Tracer Retention and Understanding Experiment, 1st stage.

Much emphasis is put on building of confidence in the approaches and methods in use for modelling of groundwater flow and nuclide migration in order to demonstrate their use for performance and safety assessment.

4.10.2 Results

During 1995 the sixth and the seventh meetings of the Äspö Task Force (TF) were held. The sixth meeting was arranged by SKB close to the Äspö site and the seventh meeting took place in Hergiswil, Switzerland, with NAGRA as host organization.

The long term strategy of the Äspö TF has been discussed within the Äspö International Joint Committee (IJC). It was concluded that the work in the TF should be tied to the experimental work performed at the Äspö HRL. Furthermore, the work should be performed within the framework of well defined and focused Modelling Tasks. The TF group should attempt to evaluate different concepts and modelling approaches. Finally, the TF should provide advice on experimental design to the Project Teams, responsible for different experiments.

An Issue Evaluation Table has been compiled by the delegates of the Äspö TF, /4-11/. The table aims at reflecting our current understanding of the key issues related to performance of the geological barrier, availability of reliable data, how they can be or are being addressed by different organizations or at different underground laboratories. The Table will also provide valuable help in relating performance assessment as well as characterisation key issues to the actual, forthcoming experiments at Äspö.

Task No 1 concerned modelling of the LPT2 experiments and has now been finalized. An evaluation report on Task No 1 has been written, /4-12/. Eleven different groups have modelled Task No 1 using different conceptual and numerical methodologies for simulating flow and transport in fractured rocks. The task was above all a learning exercise for the modelling groups entering the Task Force and for the Task Force organization as such.

With respect to groundwater flow, all models represented the measured LPT2 data well. Therefore, the capacity exists to perform three-dimensional groundwater flow modelling on a site scale. In general, the data supplied for Äspö, including the geologic structural model, provided a good representation of the real system. However, a few consistent errors in the modelling work indicate minor errors in the geologic structural model of the Äspö site.

If calibration of transport parameters is made reasonable modelling results are obtained for the tracer tests of LPT2. However, the low recovery obtained in the tests was not completely understood. Hence, there is a need to consider if any important processes have been disregarded in the modelling of conservative tracer transport.

The hydraulic impact of the tunnel excavation at Äspö HRL was defined as the 3rd Modelling Task. The objective will be to evaluate how the monitoring and the study of the hydraulic impact of the tunnel excavation may help for site characterisation. Task No 3 will be an exercise in forward as well as inverse modelling. The first part may be regarded as a direct continuation using the existing groundwater flow models from Task No 1. The modelling work is in the reporting phase, see Table 4-5.

Table 4-5. Modelling groups involved in Task No 3 and status of reporting.

Modelling Team	Task 3A	Task 3B	Reporting of Task No 3
PNC/ Golder Associates	X	X	Jan-96
PNC/Hazama	X		Jan-96
UK Nirex/ AEA Technology	X	X	Jan-96
TVO/VTT	X	X	Jan-96
CRIEPI	X	X	ROUGH DRAFT Nov -95
SKB/CFE	X	X	SKB HRL PR 25-94-27
ANDRA/Itasca	X		Jan -96

Task No 4 concerns the tracer retention and understanding experiment (TRUE-1) at Äspö HRL and has been divided into three sub-tasks:

- Task 4A involved modelling in support of the development of a descriptive structural model of the test site. This exercise will be summarized in one report, "Descriptive Structural-hydraulic Models on Block and Detailed Scales".

- Task 4B meant design modelling, i e modelling in support of the experimental design, and has been performed by three groups.
- The following Task 4C definition has been agreed upon: "To perform predictive modelling of the radially converging tracer tests as well as the dipole tests in Feature A of the TRUE-1 site. Comparison of model output with experimental results."

Task 4C objectives:

- Develop understanding of radionuclide migration and retention in fractured rock.
- Evaluate what can be achieved with the existing data set of TRUE-1 in terms of transport predictions.
- Evaluate the usefulness and feasibility of different approaches to model radionuclide migration.

Concerning Task No 4, special TRUE-1 modelling group meetings were arranged at two occasions during 1995. This facilitates interaction between the Project Team of the TRUE experiments and the Modelling Teams of the Äspö TF.

4.10.3 Planned work

All modelling work on Task No 3 is expected to be reported in the ICR-series during the first half of 1996. The reports and a Modelling Questionnaire will be the basis for the Task No 3 evaluation work.

Task No 4A will be reported early 1996 and also constitutes the basis for predictive modelling in Task No 4C. The predictive modelling will be presented at the next TF meeting. The predictive modelling involves both the radially converging tracer tests and the dipole tests. A number of modelling reports are expected during 1996.

The modelling efforts on Task No 4B will be compiled to an Äspö ICR report.

The next TF meeting will take place in Sweden on June 5-7, 1996.

4.11 HYDROCHEMISTRY MODELLING

4.11.1 Background

The outcome of a geochemistry workshop held in June 1994 was the definition of two modelling exercises to be carried out and reported at a second workshop in June 1995. The main objective of these exercises is to develop a site model for integrated geochemical and hydrogeological processes at Äspö.

The integrated modelling will aim at:

- Improving the models or more strictly the basis for the models describing the performance of a repository and the migration of radionuclides from a leaky repository to the biosphere.

Palaeohydrochemistry; process identification aim at:

- Refinement and improvement of the models or the basis for the models predicting future evolution in groundwater flow and hydrogeochemistry.
- Application of these models to predict, under realistic timescales, the future performance of a repository system assuming that the migration of radionuclides from a leaky repository to the biosphere will ultimately occur.

4.11.2 Results

The presentations made at the workshop in June 1995 are compiled to an ICR report on "Integration of hydrology and hydrochemistry models of Äspö". The contents of the report, based on the discussions and presentations, is put together by the coordinators of the two modelling tasks. A final draft for review has been sent to the authors.

4.11.3 Planned work

A final model exercise to be executed is the description of the Äspö site hydrochemistry for the next 100.000 years, i.e. a full glacial cycle. The work is intended to be conducted in 1996-1997. During 1996 the task description will be prepared and reviewed.

5 DEMONSTRATION OF TECHNOLOGY FOR AND FUNCTION OF IMPORTANT PARTS OF THE REPOSITORY SYSTEM

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) 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 to be transported to the canisters and any escaping radionuclides to be transported away from them.

The Äspö Hard Rock Laboratory makes it possible to demonstrate and perform full scale tests of the function of different components of the repository system which are of importance for long-term safety. It is also important to show that high quality can be achieved in design, construction, and operation of a repository. A major project within this Stage Goal is the design and construction of a prototype repository which is built to simulate the steps of a deposition sequence. Tests will be made of different backfill materials and technology will be developed for backfilling and plugging of tunnels. In addition, experiments are planned to study the interaction between the engineered barriers and the host rock, in some cases for long periods of time.

5.2 EVALUATION OF UNDERGROUND DESIGN AND CONSTRUCTION WORK

In the end of the construction work a meeting was held with participants from the civil designer and the construction inspection. Experiences from the design and construction work were discussed over the documents which have been used for the work. Notes from this meeting will be used as a base for a report on evaluation on underground design and construction work to be issued 1996.

5.3 MECHANICAL MODELLING OF THE CRACKS IN GRANITE CAUSED BY MECHANICAL EXCAVATION

Theoretical analysis and numerical modelling

Introduction of a modified cavity model and simulation of side cracks

Analysis of rock indentation failure is made based on the laboratory rock indentation test data. Improvement was made to Yoffe´s cavity model to represent rock non-linearity behaviour caused by the expansion of crushed rock in a small zone underneath an indenter. The modified cavity model is implemented numerically into the BEM program for simulation of indentation side cracks which contribute both to the formation of chips and subsurface cracks inside the rock.

Crack propagation below an indenter is assumed to occur in an elastic field outside the cavity. A modified fracture G-criterion is applied to simulate the propagation of side and chipping cracks. Simulation of the side cracks is made using a boundary element code for the indentation in granite, marble and sandstone, Figure 5-1.

Some interesting results are as follows:

- The paths of side crack development are affected by the characters of the cavity zone, its size and shape, which in turn are determined by the loading force, indenter shape and rock mechanical properties.
- Side cracks initiate at a preferred location and take preferred paths or directions which have a minimum resistance. The cracks may be either tensile or shear, and the former appear unstable. Moreover, the cracks may either stop in the middle or intersect finally with the free surface, depending on level of load and the crack positions.
- The cavity zone becomes wider and deeper with increase in load. Its shape is dependent on both rock type and indenter shape.

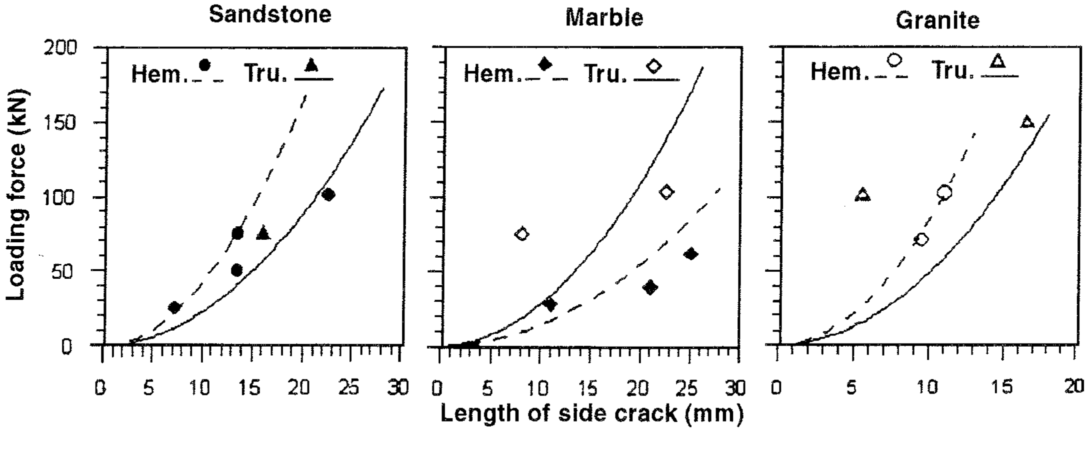


Figure 5-1. Simulation of side crack developments.

Modelling of median cracks

The median crack propagation was simulated using the same approaches as above. Due to the tensile feature a steady and reasonably finite propagation was not obtained. A different loading approach - displacement control was used in order to obtain a stable crack length for the median crack. Some preliminary results indicated that some inconsistency arose in the quantities of some fracture parameters due to the different loading and boundary specifications.

Formulation of models for indentation depth and crack length

Models for formulating indentation depth and crack length have been established through similarity analysis. Comparisons between the experimental data and the semi-theoretical models are shown in Figures 5-2 and 5-3 for indentation depth and length of radial/median cracks induced by a hemispherical indenter, respectively.

Figure 5-4 shows a relationship between the length of radial/median crack and loading force for different rocks induced by a hemispherical indenter predicted by our model. The experimentally obtained data are also shown in Figure 5-4 together with the model prediction. Formulas based on these models have wide application and adaptability since they take the indenter geometry and the rock properties into consideration.

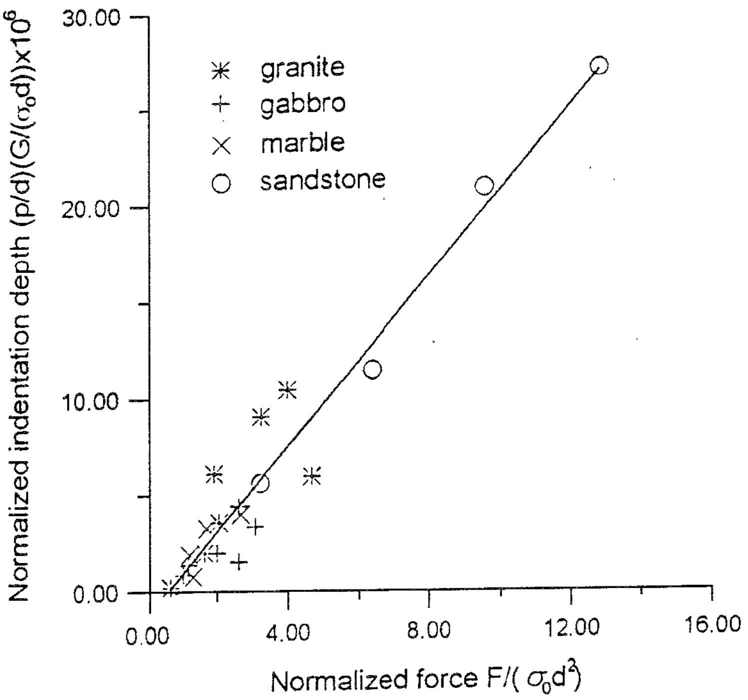


Figure 5-2. *Indentation depth vs. force for hemispherical indenter.*

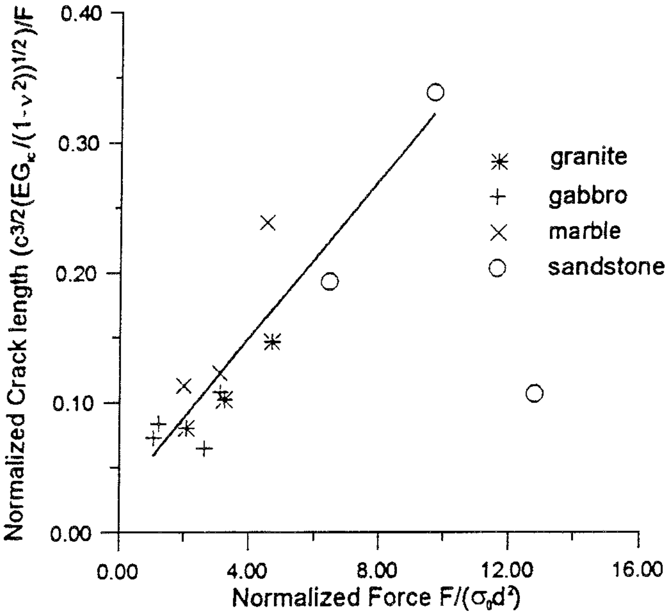


Figure 5-3. *Radial/median crack length vs. indentation force for hemispherical indenter.*

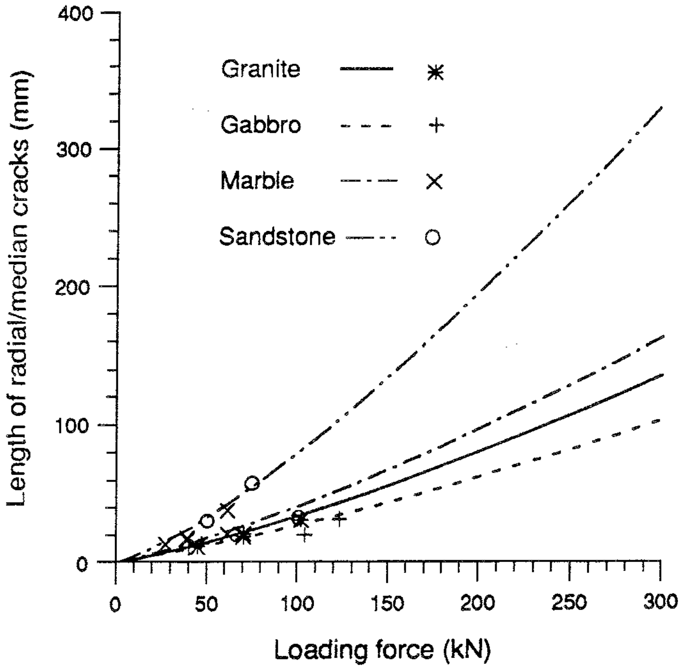


Figure 5-4. *Radial/median crack length vs. loading force.*

5.4 SITING FOR SUITABLE NEAR FIELDS

5.4.1 Background

The maximum number of canisters on a specific length of a nuclear waste repository tunnel is given with respect to practical conditions, such as tunnel-dimensions and drilling equipment. An important issue is how well this maximum capacity can be used, with respect to hydrogeology, stability and geology. A measure of the capacity relative to the maximum capacity may be referred to as a **Positioning Index** (PI). The PI is defined for a given rock volume and a given purpose as the probability that the maximum number of positions can be used, given the approved repository design.

A Bayesian Markov Geostatistical Model (BayMar) was developed and applied for PI-calculations with respect to lithology, hydraulic conductivity, and rock designation index (RQD) along a stretch of a full face boring (TBM) tunnel in the Äspö Hard Rock Laboratory (HRL). Traditionally, the term "geostatistics" is associated with the kriging methods on regionalized variable theory by /5-1/. In the BayMar methodology it is used in the more general sense described by /5-2/. The methodology differs from conventional geostatistical methods in (1) being non-parametric to be able to handle information with complex statistical distributions, which is often the case for classified data, e.g. lithology, and (2) using Bayesian statistics for updating of prior estimates with respect to new information. Data are generally very sparse at early stages, becoming more and more abundant as the investigations get more detailed. Professional judgements thus play an important role for prior estimations at early stages and Bayesian statistics provides a formal way for integrating these with hard data. The BayMar model was described by /5-3/.

5.4.2 Results

PI-calculations using BayMar were made with respect to lithology, Rock Designation Quality (RQD) index, and hydraulic conductivity along a 420 meter stretch of the tunnel. The tunnel was drilled with a full face tunnel boring machine (TBM) at repository depth at approximately 450 meters depth below sea level at the Äspö Hard Rock Laboratory (HRL). The lithology affects a number of factors, such as the fracturing and heat properties of the rock. The RQD value is of importance to the stability of the construction, and the hydraulic conductivity is connected to the inflow of ground water to the repository.

The tunnel was run with a cell size of 20 x 20 x 20 meters, resulting in 21 target cells along the tunnel. Compliance levels were set so that (1) fine-grained granite is not allowed, (2) the RQD value must exceed 75%, and (3) the hydraulic conductivity must be lower than 10^{-9} m/s in order to make a canister position acceptable. The existing information consisted of the geological map in 1:10 000 scale, 13 boreholes from the ground surface on the Äspö island, and 11 boreholes from the access tunnel leading down to the TBM-tunnel. Data was obtained from SKB's GEOTAB database. The prior estimates for the 21 target cells along the tunnel used for the BayMar predictions based on this information are shown in Table 5-1.

The predicted and observed PI-values with respect to each key parameter are given in Figure 5-5 for each cell along the tunnel, together with the Bayesian convince-

Table 5-1. States and prior probabilities (P) for lithology, hydraulic conductivity, and RQD. (ND = no data).

State	Lithology		Hydraulic Conductivity		Rock Quality Designation (RQD)	
	Material	**P**	**Value**	**P**	**RQD**	**P**
1	Soils	0.0	$>10^{-7}$ m/s	0.36	0–25	0.06
2	Greenstone	0.08	$10^{-7} - 10^{-8}$ m/s	0.08	25–50	0.04
3	Fine-grained Granite	0.06	$10^{-8} - 10^{-9}$ m/s	0.12	50–75	0.09
4	Äspö Diorite	0.85	$10^{-9} - 10^{-10}$ m/s	0.07	75–100	0.81
5	Mylonite	0.0	$<10^{-10}$ m/s	0.37	ND	ND

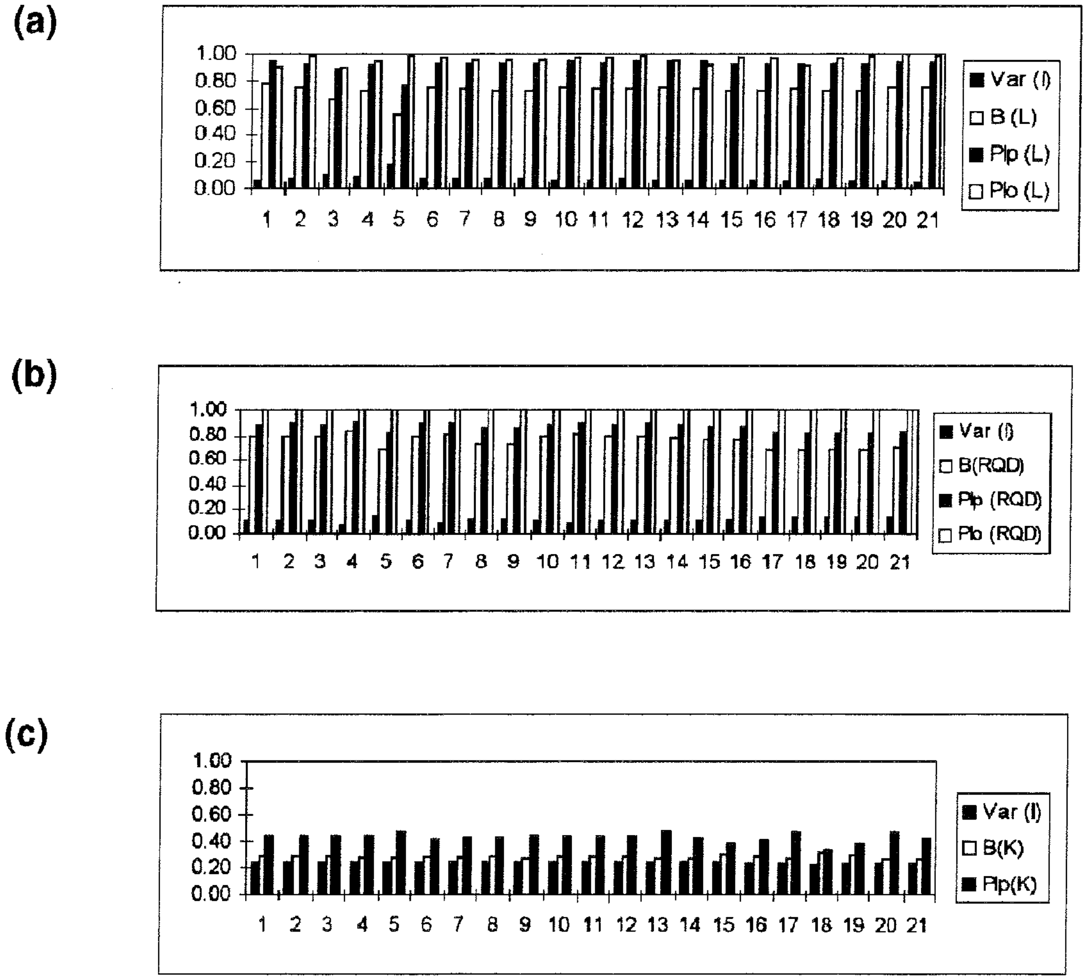


Figure 5-5. *PI-values for cells 1-21 along the TBM-tunnel at the Äspö Hard Rock Laboratory (HL). (a) and (b): Predicted (p) and observed (o) PI-values, Bayesian convincement (B) and variance for the PI-indicator (Var(I)), for lithology (L) and RQD (c). Predicted PI-values, Bayesian convincement and variance for the PI-indicator for Hydraulic Conductivity (K). Piles in the diagrams appear in the same order from to left as from top to bottom in the legend boxes.*

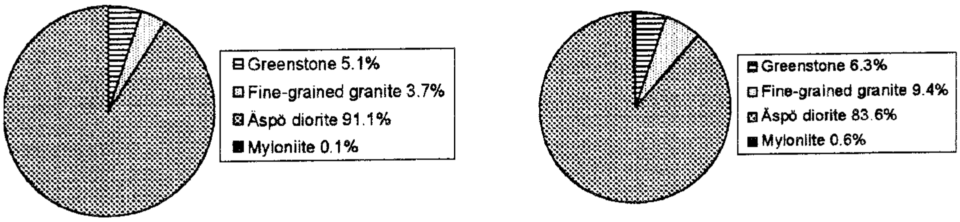


Figure 5-6. Comparison between observed (left) and predicted (right) percentages of lithologies along the first 200 meters of the TBM-tunnel.

ment and variance. The Bayesian convincement parameter, B, reflects the variability of the entire probability vector including all states, e.g lithological states, in all cells, whereas the variance, V(I), reflects the uncertainty of the PI indicator value.

The TBM-tunnel is situated in an environment of high variability with respect to lithology, structures, and hydraulic properties, as described by /5-4/, /5-5/ and /5-6/, among others. This is also reflected in the boreholes used for the PI-calculations. However, locally along the TBM-tunnel the lithological and RQD conditions exhibit relatively little variability.

The BayMar model gave predictions which are in agreement with observations for lithology and RQD along the tunnel. The results show high PI-values for all cells, i.e. good conditions for placing canisters, with respect to lithology and RQD. For hydraulic conductivity, no measurements have been made in the tunnel, but the predictions indicate low PI-values, i.e. poor conditions for canister positioning along most of the tunnel. This is in agreement with the results from hydraulic tests in a borehole (KA3191F) parallel to the TBM-tunnel.

The percentages of the four lithological states based on a continuous mapping of the first 200 meters of the tunnel were given by /5-7/. A comparison between these results and the predictions by the BayMar model is shown in Figure 5-6.

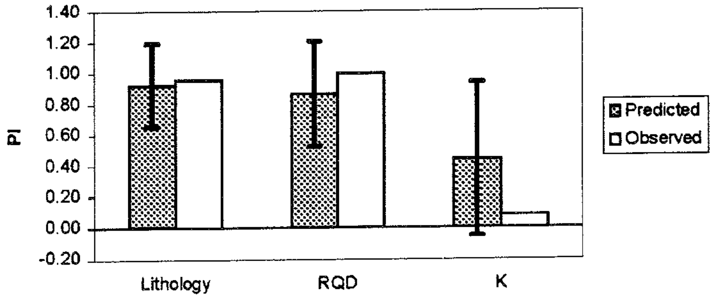


Figure 5-7. *Summary statistics of predicted and observed PI-values for lithology, RQD and hydraulic conductivity (K) along the TBM-tunnel. Uncertainties of each predicted PI indicator are represented by piles showing ± one standard deviation.*

Figure 5-7 shows a compilation of the PI predictions compared to observed conditions, treating the entire TBM-tunnel as one unit. This is from a practical point of view the most interesting figure, since the key issue in design of a repository will be to decide if a drilling of a tunnel in a specific direction should be initiated or not /5-8/.

The results given in Figure 5-7 show that 92% of the positions could be used with respect to lithology, i.e. 19 of 21 possible positions. For RQD the predicted PI was 87%, which is equal to 18 acceptable positions. For hydraulic conductivity the predicted PI was 44%, which equals 9 acceptable positions.

The predicted PI-values for lithology and RQD are high with relatively low standard deviations, indicating a low uncertainty about positioning conditions given assigned compliance levels. For hydraulic conductivity predicted PI-values are low with a high standard deviation, indicating a high uncertainty about the possibilities for placing canisters in the tunnel given assigned compliance levels. The general pattern was thus predicted correctly with good conditions with respect to lithology and RQD, and poor conditions with respect to hydraulic conductivity. The results indicate that a reasonable decision basis would have been obtained by using the BayMar model in the design of the Äspö HRL.

5.4.3 Planned work

Continuous work on the development of the Bayesian Markov Geostatistical Model (BayMar) and the PI-index is planned for the next two years. The work on the PI-index deals with the identification of the key PI-parameters, i.e. the decision parameters for designing a repository. The development of the BayMar methodology is directed towards the following issues:

1. Improvement of the description of the spatial correlation structure of available data.
2. The use of secondary data, e.g. geophysical data, for estimating probabilities on PI-parameters, e.g. stability.
3. Simulation capabilities for using the estimated probability distributions for simulating geological and hydrogeological environments.

5.5 DEVELOPMENT OF A PROTOTYPE REPOSITORY AT ÄSPÖ

5.5.1 Background

Particular aspects of the repository concept have been tested in a number of in-situ and laboratory tests. There is a need to test and demonstrate the execution and function of the deposition sequence with state-of-the-art-technology. It is envisaged that this technology can be developed, tested, and demonstrated in the Prototype Repository /5-9/.

5.5.2 Objectives

The overall ambition of the Äspö HRL is to test, develop and demonstrate the technology that will be used for the siting, construction, and analysis of the deep geological repository for spent fuel in Sweden.

It is of particular importance to test and demonstrate the interaction between the engineered barriers and the rock in as realistic an environment as possible. This will primarily involve long-term tests and demonstration tests on a full or representative scale.

The design, construction and testing of the prototype repository is aimed at a simulated deposition sequence starting from detailed characterization of the host rock to resaturation of the backfilled deposition holes and tunnel in order to fulfil the following specific objectives:

- To translate scientific knowledge and state-of-the-art-technology into engineering practice that can be applied in a real repository.
- To test and demonstrate the practicability of integrating the different steps of a deposition sequence in a realistic environment.
- To show that the deposition sequence can be performed with sufficient quality in relation to relevant standards.
- To develop and test the appropriateness of the engineering standards and the uality assurance plan.
- To test and demonstrate the integrated performance of the prototype repository.
- To demonstrate methods for design, construction, excavation, near-field characterization, backfilling, sealing, plugging, monitoring and retrievability.

The purpose of these tests is to provide the background material necessary for Government approval of the start of construction of the deep geological repository.

The prototype will be limited in the following respects:

- No handling of spent fuel.
- The handling will not simulate radioactive canister dummies, i.e. no remote operation.
- The prototype repository cannot demonstrate the long-term safety of a repository.
- Heating will have to be scaled in time.

5.5.3 Results

The overall idea is to design, construct and test a prototype repository at Äspö. The execution is a dress rehearsal of necessary actions to construct a deep repository. It includes characterization, layout, design, backfilling, resaturation and retrieval. It shall make full use of performance analysis and safety analysis at appropriate stages of the test. The test will be used to construct and test the "normal" behaviour of a repository in full scale in the inner part of the TBM tunnel in Äspö HRL.

Four deposition holes are planned to be simulated on a full scale with a spacing of 6 m, which is the same as planned for KBS-3. The proposed layout of the test is shown in Figure 5-8.

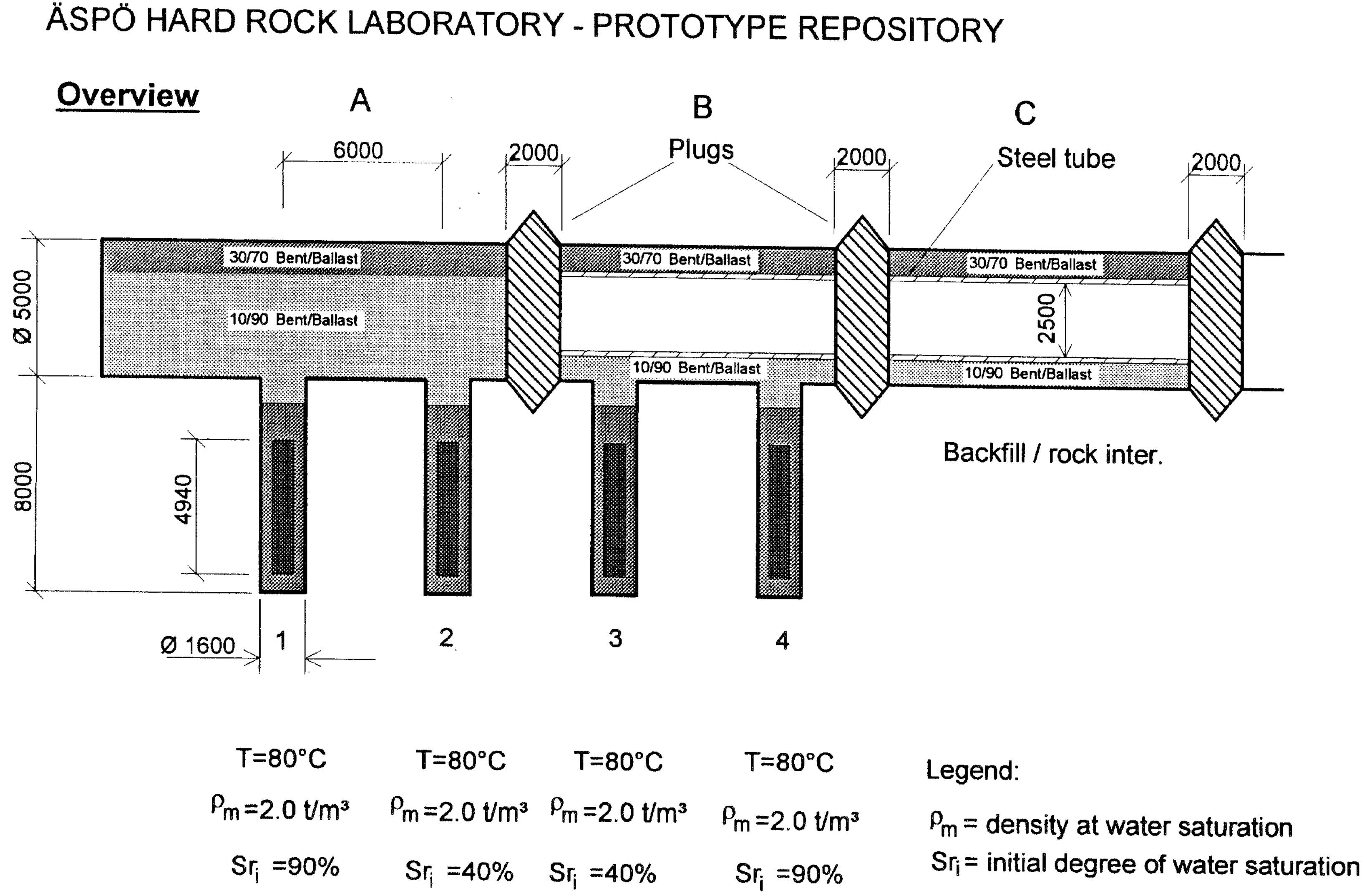


Figure 5-8. *Tentative layout of the Äspö Prototype Repository.*

The general outline of the Prototype Repository project was drafted in 1994 /5-9/. During 1995 efforts have focused on the development and testing of different backfill materials and compaction methods as descried in Section 5.5. Testing of instrumentation to be used for monitoring has been initiated.

5.5.4 Planned work

1996 will be devoted to planning, analyzing, calculations and investigations of the rock in the TBM tunnel. Testing and development of instruments will continue during the entire period. Supporting investigations of buffer material properties will take place as well as improvements of existing models for prediction of the integrated behaviour of the rock and the buffer material during the wetting phase.

5.6 BACK FILL AND PLUG TEST

5.6.1 Background

The *Back Fill and Plug Test* includes a series of tests of alternative backfill materials and emplacement methods and a test of a full scale plug. It is a test of different backfill materials and emplacement techniques. It *will* also be a test of the hydraulic and mechanic functions of a plug and be the basis for the plug design for the plugs in the prototype test. A test plan was made during 1995 /5-10/.

The Backfill and Plug Test is preceded by preparatory testing of backfill properties and technology. In 1995 laboratory tests and full scale field tests of different backfill types have been made. For these tests crushed rock have been used as ballast material in the backfill.

5.6.2 Results

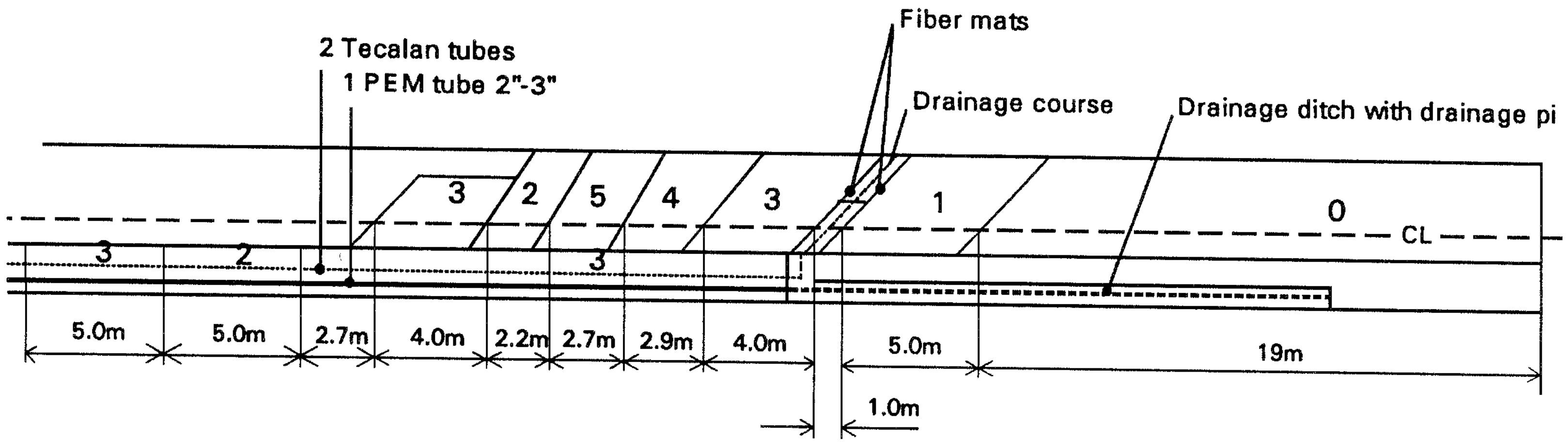
The field tests were made in order to test and further develop available technique for backfilling deposition tunnels. The field tests comprised the three main engineering activities required for backfilling tunnels in a repository. These activities are:

- crushing of rock for ballast material,
- mixing of ballast material, bentonite, and water
- transportation, emplacement, and compaction of the backfill in the deposition tunnels,

Furthermore, the tests comprised the following activities:

- development and testing of compaction tools and techniques,
- continuous measurements of results from the mixing and compaction,
- excavation of the backfill.

The purpose of the **crushing** procedure was to achieve a ballast material with a grain size distribution suitable for backfilling tunnels. The crushing plant was placed close to the TBM-muck deposit at Bockstrupen. About 1600 tons of muck



0	Natural uncompacted TBM muck
1	Natural compacted TBM muck
2	Crushed TBM muck
3	Bentonite/Crushed TBM muck 10/90
4	Bentonite/Crushed TBM muck 20/80
5	Bentonite/Crushed TBM muck 30/70

Figure 5-9. *Final layout of the compaction test.*

was crushed and transported to a tent close to the tunnel opening for intermediate storage.

The purpose of the **mixing** procedure was to develop and test a suitable technique for mixing ballast material, bentonite, and water to the desired proportions in full scale. The mixtures must be homogeneous with respect to water ratio, bentonite content, and grain size distribution. 1025 tons of backfill with different proportions of bentonite, crushed rock, and water were produced in order to use the backfill for the compaction tests in the TBM tunnel. The mixing plant was placed on the ground surface close to the entrance of the tunnel near the tent with the crushed TBM-muck.

Emplacement and compaction of 5 different backfill types were made. Several different machines were used for the compaction. The horizontal layers in the bottom bed were compacted using a vibrating tamp roller with 4 tons weight. The inclined layers were compacted with a vibrating plate with the weight 700 kg, which was rebuilt for electrical power drive and for allowing compaction of inclined layers close to the roof of the tunnel.

About 1050 tons of uncompacted or compacted TBM muck and about 1000 ton of compacted mixtures of bentonite and crushed TBM muck were placed and compacted in the tunnel. The final layout of the test is shown in Figure 5-9. The layout was changed due to water problems in the inner part of the tunnel. The large inflow of water made it impossible to compact horizontal layers, since water was accumulated on the surface of the top layer and destroyed the layer due to the resulting increased water content and the subsequent loosening.

Extensive **sampling and density measurements** were made both during compaction and excavation. Figures 5-10 and 5-11 show examples of measured dry density distribution in some inclined layers with 10/90 bentonite/ballast backfill. Figure 5-10 shows the variations with depth perpendicular to the inclined surfaces. The density is very high in all layers except layer 14, were the measurement was made close to the rock wall. Figure 5-11 shows the variation with horizontal distance from the centre line. The drop in density close to the walls is clearly seen.

The purpose of the **excavation** was, except for emptying the TBM drift of the backfill, to investigate how the backfill can be excavated in an efficient way and to check the density of the backfill. The same telescopic truck, that was used for the emplacement, was also used for the excavation. The backfill could not be excavated directly with the ladle. Instead the truck was equipped with a fork. By working the backfill with the fork to a depth of about 1 m from the surface, it was made loose enough and could be excavated with the ladle.

At the location where the most severe **water problems** appeared, a second compaction test was made with the 10/90 backfill. The existing TBM muck was levelled to 45 degrees inclination and 5 new layers were compacted with the inclined compaction technique and then immediately excavated (after testing). This extra test, which was made in order to study the effect of large water inflow on the possibility to compact inclined layers, showed that although the density was lower in some spots, the filling and compaction procedures could be fulfilled.

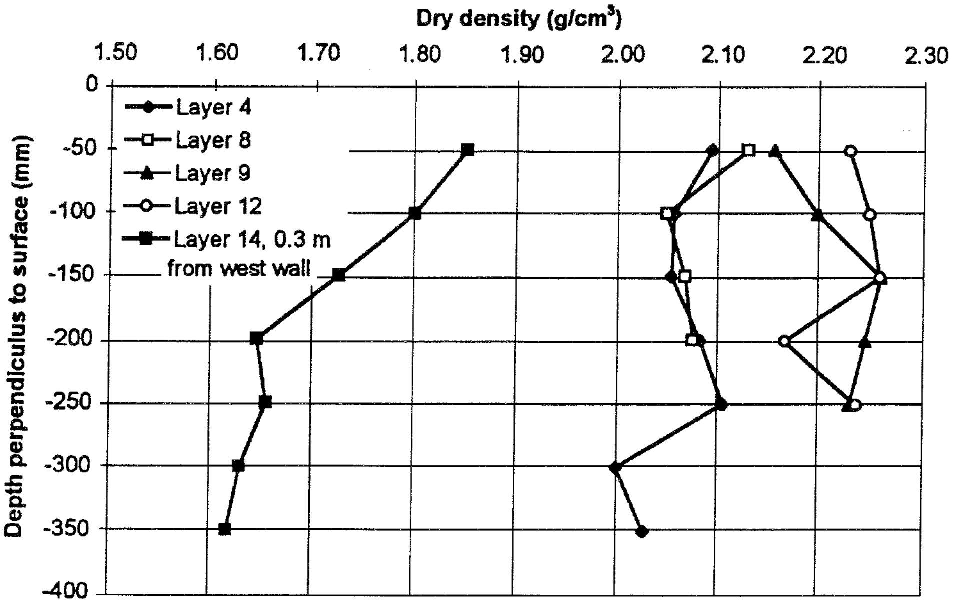


Figure 5-10. Variation in dry density of the inclined layer with depth (10/90 backfill).

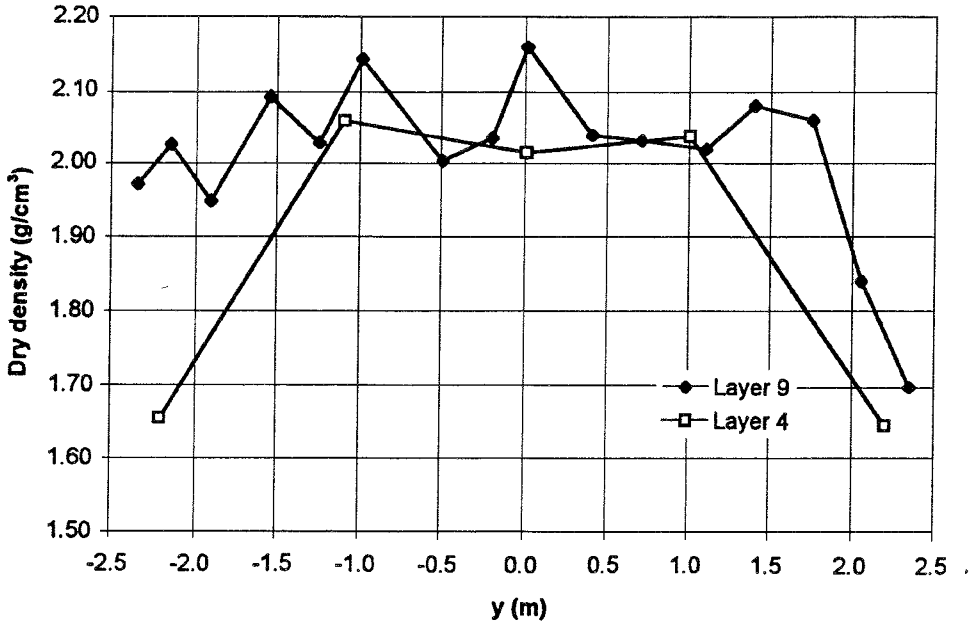


Figure 5-11. Variation in dry density of the inclined layers with distance from the centre line (10/90 backfill).

The following preliminary conclusions could be drawn from the field tests:

- The procedures to crush TBM muck to a desired grain size distribution and to mix bentonite, crushed rock, and water were successful.
- The technique to compact horizontal layers yielded unsolvable problems in wet areas.
- The technique to compact inclined layers was successful except for at the zone close to the rock.
- Very wet areas may require special treatments.
- The excavation was successful.

5.7 LONG TERM PERFORMANCE TESTS

5.7.1 Background

Most work concerning smectite clay stability has been made on natural systems in deep shale's or in the vicinity of hydrothermal events. The conducted buffer field tests have in different ways deviated from expected Swedish repository conditions, e.g. low ground water salinity (BMT, Stripa), low water pressure (URL), and deviating buffer clay composition and high temperature (French clay, Stripa). Relatively large buffer alteration was noticed in the French tests, both with respect to clay mineralogy, redistribution of easily dissolved species and to the physical properties of the material.

5.7.2 Objectives

The proposed test series aims at validating present models of clay buffer performance at standard KBS-3 conditions and at adverse conditions, and at quantifying clay buffer alteration processes at adverse conditions. In this context adverse conditions have reference to e.g. super saline ground water, high temperatures, high temperature gradients over the buffer, high pH and high potassium concentration in clay pore water.

The expected outcome from the tests may be summarized as follows:

- Quantitative information of the long-time performance of the buffer material at standard KBS-3 and at adverse conditions concerning e.g. hydraulic conductivity, swelling pressure and rheological behaviour.
- Information of the applicability of existing mineral alteration models and, if necessary, data for adjustment of model constants for repository conditions.
- Identification of possible cementation reactions, e.g. anhydrite- and quartz-precipitation.

5.7.3 Results

The efforts during 1995 have concentrated on design and planning of the experiment. The tentative design is described below.

The testing philosophy is to place prefabricated units of clay blocks surrounding copper tubes in vertical boreholes and to maintain the tube surfaces at defined

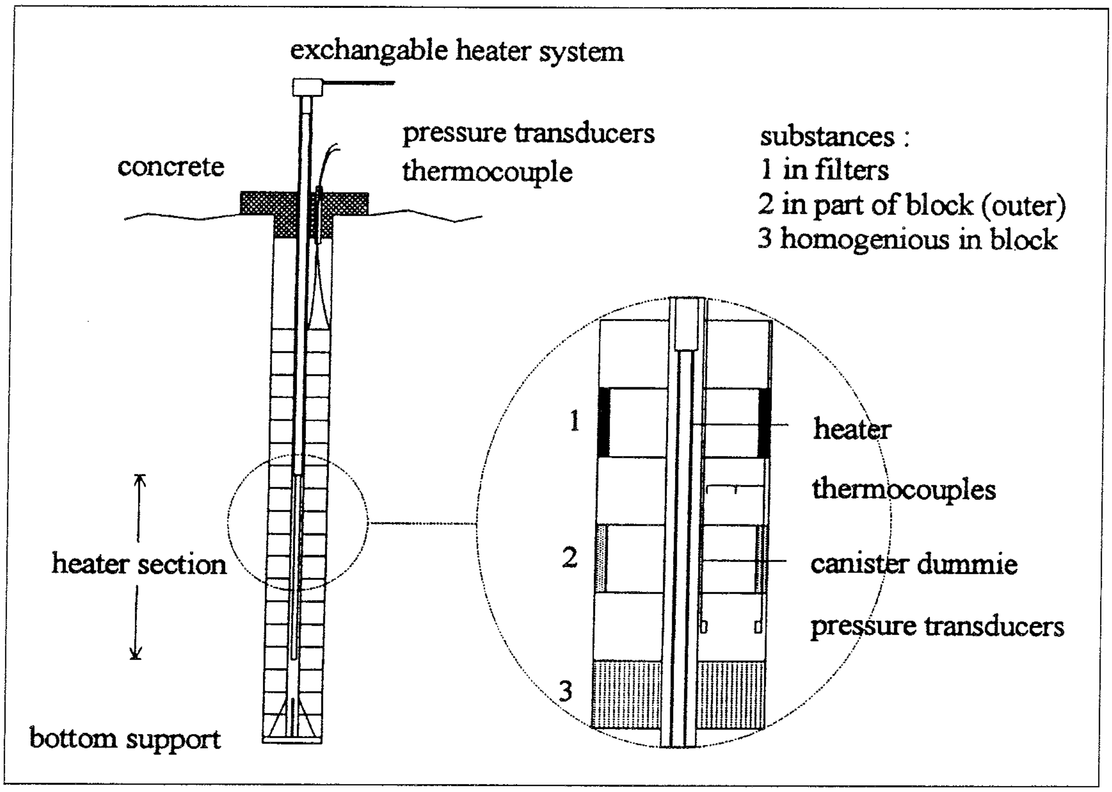


Figure 5-12. Tentative experimental configuration for the Long Term Performance tests.

Table 5-2. Preliminary specification of the Long Term Performance test series.

No	Type	Purpose	T,°C	Pc	time,y
1A	ref	Pilot	90	T	1
1B	ref	LTP	90	T	~ 5
1C	ref	LTP	90	T	~ 20
2	high T	LTP-T	150	T	~ 5
3A	chem	Ma,C,Se	150	T, ([K$^+$], Am, pH)	1
3B	chem	Ma,C,Se	150	T, ([K$^+$], Am, pH)	~ 5

Pc = controlled parameter
LTP = long term performance test
Ma = mineralogical alteration
Se = “salt enrichment”
C = cementation
T = temperature
Am = accessory minerals

temperatures, see Figure 5-12. The test series includes 6 test buffer-parcels (Table 5-2) of which 3 will be exposed to standard KBS-3 conditions in order to validate present models of clay buffer performance, and 3 test parcels which will be exposed to adverse conditions in order to validate models for buffer alteration. The buffer-parcels are placed in boreholes with a diameter of around 26 cm and a length of around 4 to 7 m. The boreholes will be separated from each other by

3–5 m in a representative granitic rock structure containing water-bearing fractures in which the groundwater pressure and salinity are found suitable.

Temperature, swelling pressure and if possible water content will be measured during the heating period. At termination of the tests, the clay will be extracted fast enough not to allow redistribution of water before sampling by overcoring the original borehole. The water distribution in the clay will be determined and subsequent well defined chemical, mineralogical and physical testing will be performed.

5.7.4 Planned work

The experimental design will be finalized and documented in a Test Plan. The two pilot test holes will be drilled and characterized and the test parcels installed in the boreholes.

6 ÄSPÖ FACILITY OPERATION

6.1 GENERAL

1995 was the year when SKB took over the responsibility for the operation of the underground facility from the contractor. We also spent the first year at the new research village which now runs smoothly.

To secure the electric power to the facility a second high voltage cable from the mainland has been connected. The first one comes from the local power company, OKG. Most of the facility, under ground as well as on the surface, can now be supplied independent from any of the two high voltage cables.

A contract concerning service and maintenance has been written between SKB and OKG. This means that OKG takes care of the daily operation. A solution that so far has worked very well.

The drainage system is maybe the most crucial system underground. To prevent future risks for flooding, a risk analysis has been performed and specific activities have been suggested.

Special effort has been put on the working environment. A second safety representative has been chosen and several safety inspections have taken place. A new safety instruction for work at the Äspö HRL has also been prepared. The only major safety related installation which is not in operation yet is a system for radio communication underground.

The hoist was not ready as planned during 1995. An inspection carried out by the National Labour Inspectorate pointed out some safety related actions that have to be done before it can be taken into regular operation.

6.2 DATA MANAGEMENT

6.2.1 Background

One of the main objectives with the Äspö Hard Rock Laboratory is to test, develop and improve techniques before they are applied at the candidate sites. In this context efficient techniques are required to handle, interpret and archive the huge amount of data collected during a site characterization process.

The first investigation database, GEOTAB, was already set up by SKB during the eighties.The aim by setting up this database was to preserve all data from the KBS-3 investigations and the pre-investigations at Äspö.

During the construction phase of the Äspö Hard Rock Laboratory new needs led to the development of the SADB (Site Activity Database). The main data table in SADB was a complete event list describing all performed measurements and engineering activities at the site in sequence, like the contents in an ordinary diary.

The first version of SADB was ready in October 1993. From that time GEOTAB and SADB were used concurrently.

Directly after the introduction of SADB a discussion started concerning the possibilities to combine the concepts of GEOTAB and SADB. This discussion resulted in a decision to develop a new database by combining the concepts of GEOTAB and SADB. A project was defined and the work started in June 1994. It was planned to have the new database in operation one year later (June 1995). SICADA is the name of the project and the system as well. The name has been composed by in sequence put together the bold characters in the descriptive text "The SKB **Si**te **C**haracterization **Da**tabase System".

A three dimensional rock model is built by successive collection, processing and interpretation of site data. All site data will be stored in SICADA. Furthermore all geological and geophysical maps will be available in SKB's GIS database. Some of these maps need to be transferred to the visualization system. The experiences obtained from the investigations at Äspö Hard Rock Laboratory have shown that it is very important to have the possibility to test interactively in 3D different possible connections between observations in boreholes and on the ground surface. By effectively visualizing the rock model, based on available site data, it is possible to optimize new investigation efforts. During the design of the Deep Repository the rock model will be the basis for optimization of the tunnel layout. As several research groups will work with data from one site it is important to have only one "certified" visualization system.

To fulfil above strategy and requirements SKB decided to develop a visualization system in November 1994. Rock Visualization System (RVS) is the name of the project and the system as well.

6.2.2 Results

SICADA (Site Characterization Database System)

All data in the databases GEOTAB and SADB have been successfully transferred to the SICADA system.This part of the project has been much more complex than expected during the planning phase. However, some consolation can be derived from the fact that the quality and completeness of data has been improved.

SICADA is and will be one of SKB's most strategic database systems. The database should efficiently serve planned investigation activities at the future candidate sites as well as the experiments at Äspö HRL. The database should be user friendly and always guarantee a high degree of safety, quality and traceability.

Three database applications have been developed as planned, which are the named below:

SICADA/**Diary**	A new graphical application (Replaces SADB)
SICADA/**Finder**	A new graphical application (Advanced retrieve of data by using SQL)
SICADA/**Retriever**	A new text-based application (Replaces GEOTAB)

The **SICADA/Diary** application is used to log activities and capture data from the work at a typical investigation site. This application is mainly working on the activity log table in the SICADA system. Activities in the log can be added, modified or deleted. By focusing an activity in the log it is possible to show additional information connected or fetch the investigation data associated with the activity.

The activity log table is an activity diary and all selected activities are always shown in time order. The contents shown in the activity log window is dependent on the search criteria specified by the user in the window called "SICADA/Diary Control Panel".

All data rows have an unique activity identifier. This identifier uniquely connects measured data with only ***one*** activity in the activity log table. All data rows also have a time stamp and an user identification code to show and control when data was inserted into the table and who did the input.

Figure 6-1 shows the contents on the screen when SICADA/Diary just has been started and a simple search criteria have been specified and then executed.

The **SICADA/Finder** data retrieval application is used to view data. It is possible to get printed table reports, reports to file and view data on the screen. When working with SICADA/Finder it is possible to retrieve data from one table or join two tables and then retrieve the result. Search conditions can be set on any column in selected table(s) without knowing anything about the tricky SQL-language that is used by the application in the background.

Figure 6-2 shows the contents on the screen when SICADA/Finder just has been started and a simple search criteria have been specified.

The **SICADA/Retriever** application is a classic text terminal program that is useful for the long distance user who is connected to the network by using a serial modem line. The user has only the possibility to retrieve data marked with a quality signature.

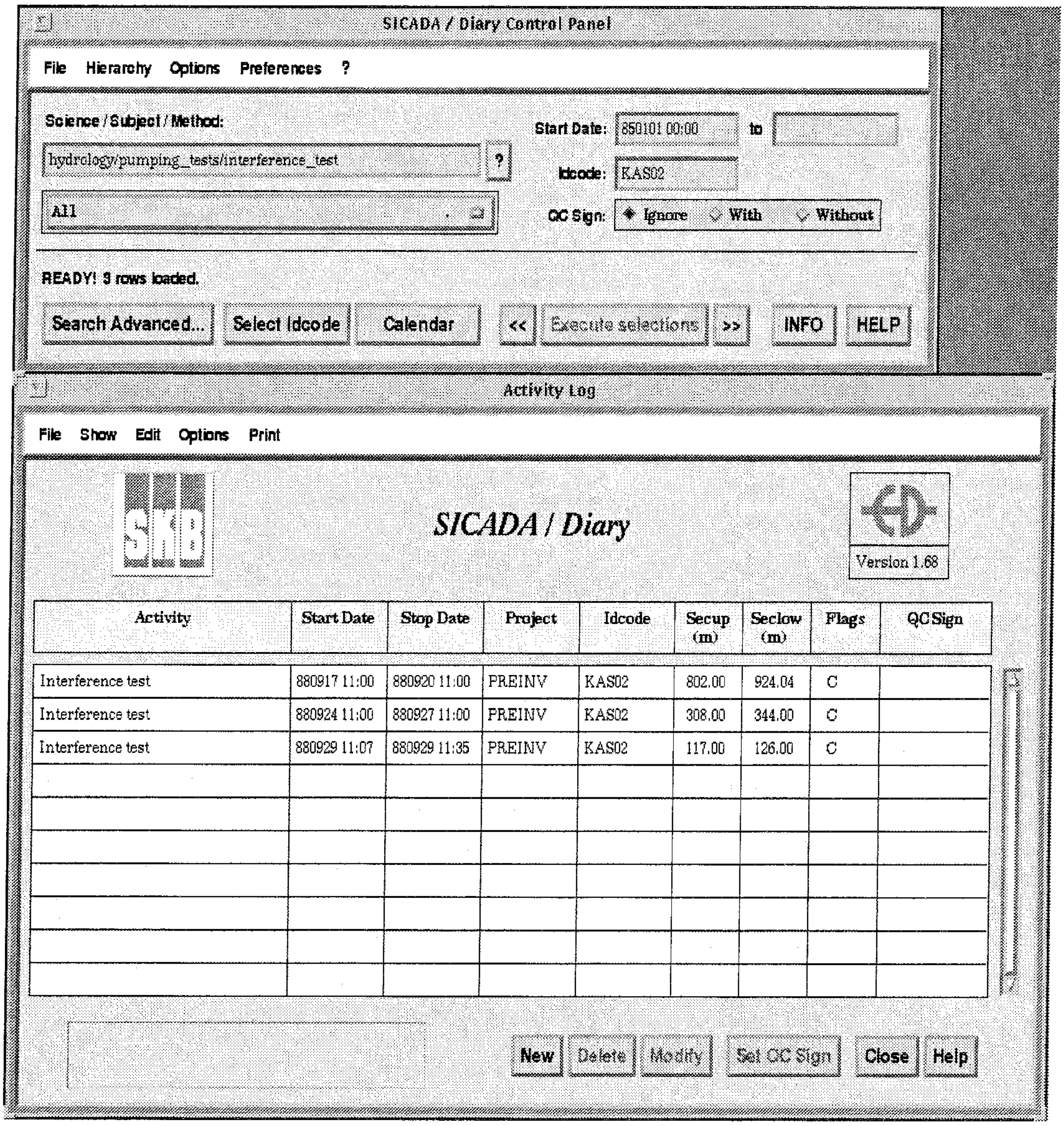
Data are fetched by using the hierarchy model. As an example the investigation data from an interference test is fetched by specifying the following main search criteria:

Science:	Hydrology
Subject:	Pumping tests
Method:	Interference test

Figure 6-3 shows the contents on the screen after executing the above specified search criteria.

RVS (Rock Visualization System)

The SKB Rock Visualization System will be based on the CAD-system MicroStation, developed by Bently Systems, Inc in USA. MicroStation is a modern and powerful 3D-modelling system, running on computers with the most common operating systems as DOS, Windows, Windows 95, Windows NT and UNIX.



Science / Subject / Method: hydrology/pumping_tests/interference_test

All

Start Date: 850101 00:00 to

Idcode: KAS02

QC Sign: ● Ignore ○ With ○ Without

READY! 3 rows loaded.

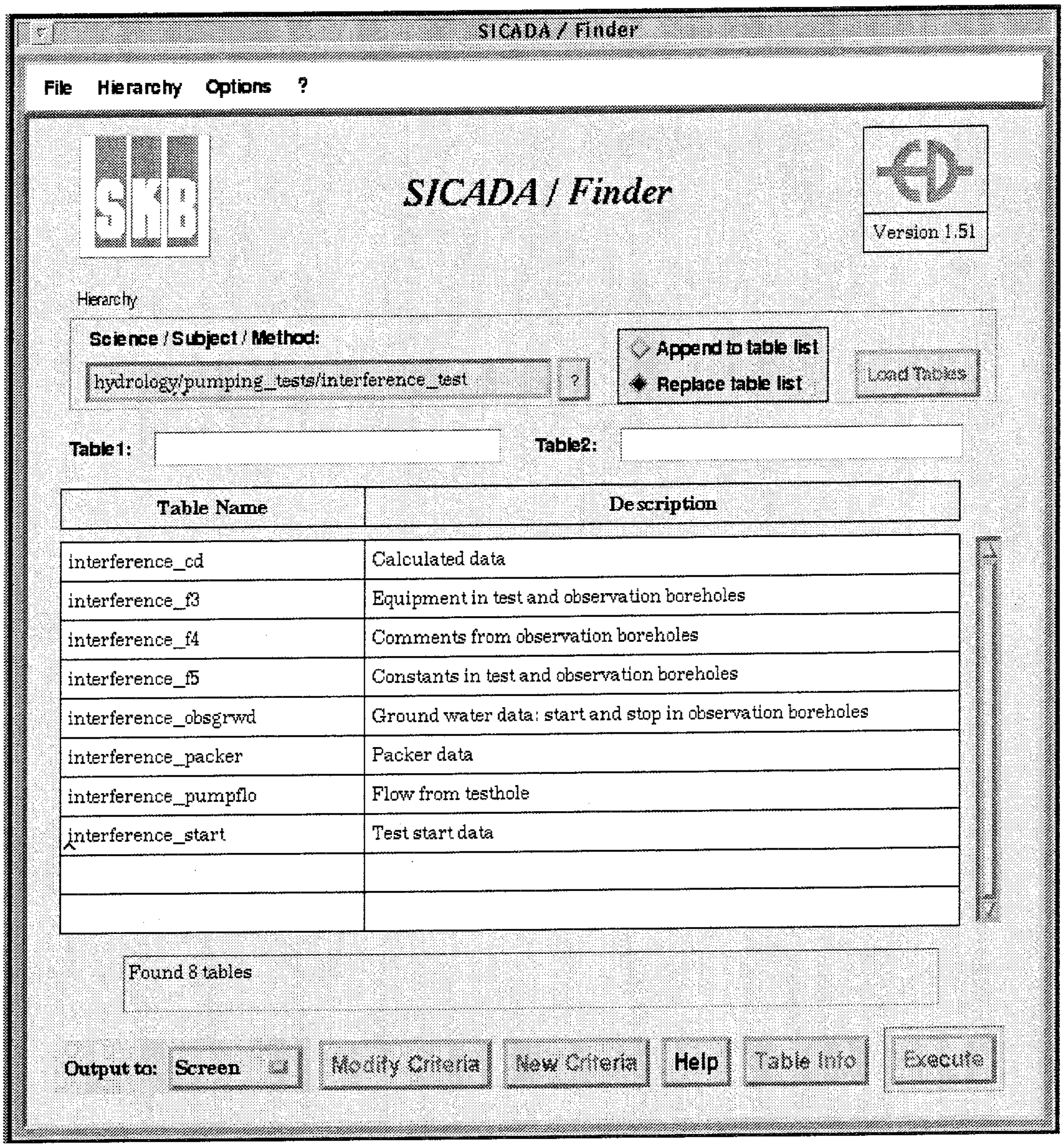
SICADA / Diary

Activity	Start Date	Stop Date	Project	Idcode	Secup (m)	Seclow (m)	Flags	QC Sign
Interference test	880917 11:00	880920 11:00	PREINV	KAS02	802.00	924.04	C	
Interference test	880924 11:00	880927 11:00	PREINV	KAS02	308.00	344.00	C	
Interference test	880929 11:07	880929 11:35	PREINV	KAS02	117.00	126.00	C	

Figure 6-1. *Appearance of SICADA/Diary on the screen.*

Specifications were compiled by the members of the project group (Mats Ohlsson, Ingemar Markström and Ebbe Eriksson) during the spring 1994. The Principal Investigators in the Äspö Project and other geoscientific experts in SKB's organization have greatly been involved in defining many of the functions needed in the system.

The systematization part of the project was ordered from Arctic Software AB in November 1994. The systematization work has been based on the concept of the Yourdon-method. The result of the systematization work, a detailed system specification, was delivered by Arctic Software AB in December 1995. This implicate that the project have been delayed 4 months according to the original time schedule. Up on this at least 2 months are needed to perform the procurement procedure.



Science / Subject / Method: hydrology/pumping_tests/interference_test

○ Append to table list
● Replace table list

Table1:

Table2:

Table Name	Description
interference_cd	Calculated data
interference_f3	Equipment in test and observation boreholes
interference_f4	Comments from observation boreholes
interference_f5	Constants in test and observation boreholes
interference_obsgrwd	Ground water data: start and stop in observation boreholes
interference_packer	Packer data
interference_pumpflo	Flow from testhole
interference_start	Test start data

Found 8 tables

Output to: Screen

Figure 6-2. Appearance of SICADA/Finder on the screen.

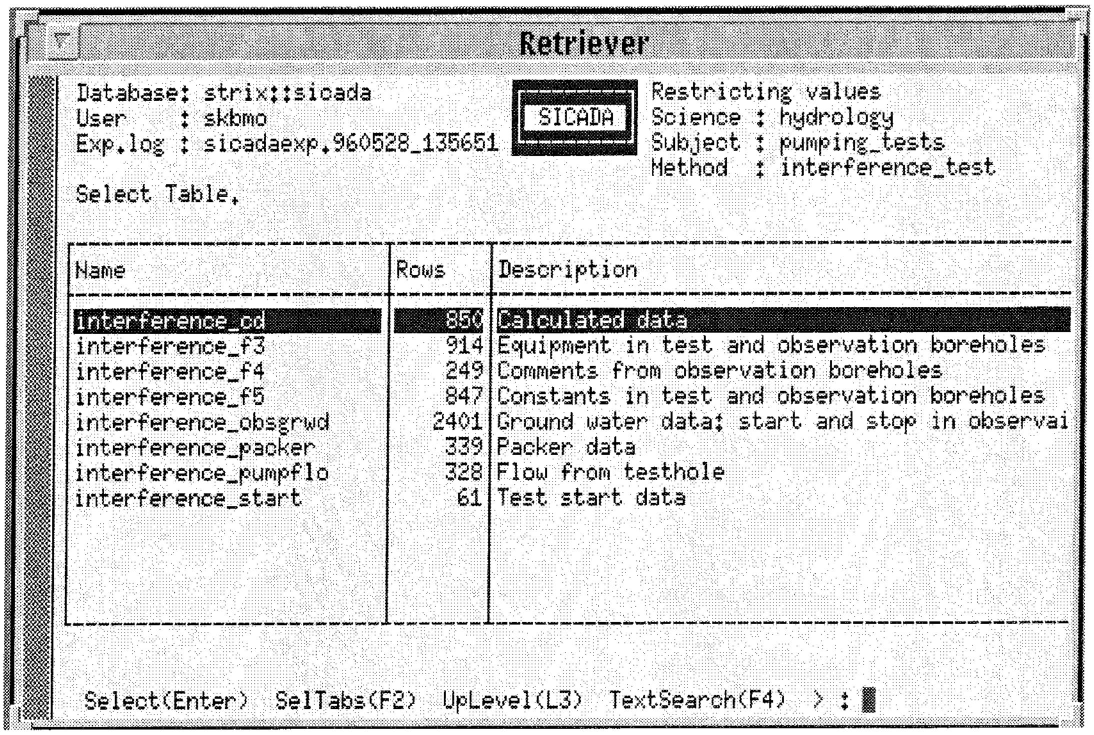
Miscellaneous

The tunnel mapping data have also been converted from 2D to 3D during 1995.

6.2.3 Planned work

SICADA (Site Characterization Database System)

A first version of SICADA has been developed, and the system is now used by the personnel at Äspö. Hence, the SICADA project is finished. During 1996 SICADA will be improved in parallel with the ongoing activities at Äspö and activities planned by the Deep Repository department.



```
Database: strix::sicada                      Restricting values
User    : skbmo                   SICADA     Science : hydrology
Exp.log : sicadaexp.960528_135651            Subject : pumping_tests
                                             Method  : interference_test
Select Table.

Name                      Rows  Description
interference_cd            850  Calculated data
interference_f3            914  Equipment in test and observation boreholes
interference_f4            249  Comments from observation boreholes
interference_f5            847  Constants in test and observation boreholes
interference_obsgrwd      2401  Ground water data: start and stop in observai
interference_packer        339  Packer data
interference_pumpflo       328  Flow from testhole
interference_start          61  Test start data

 Select(Enter)  SelTabs(F2)  UpLevel(L3)  TextSearch(F4)  > :
```

Figure 6-3. *Appearance of SICADA/Retriever on the screen.*

At the moment the most work are focused on the system documentation. The different User's Guides need to be corrected dependent on new improvements introduced since August 1995.

An introduction course will be held att Äspö Hard Rock Laboratory in February 1996. The personnel at Äspö (those who did not participate in the course held in November) and the Äspö project managers are invited to this introduction course.

Rock Visualization System (RVS)

Concerning the planned realization phase of the project, programming of the visualization system, a procurement document have been compiled in parallel with the ongoing examination process. The procurement basis is planned to be distributed during the first week in January 1996 to at least four software development companies. Two of them will be Arctic Software AB and CADPERFECT Development Lab.

An exact time schedule for the realization phase of the project is not possible to determine just now, but the goals are to start up the programming work in March 1996 and to have a productive system in use at the end of 1996. An updated time schedule will be presented in the next status report (January-March 1996).

6.3 TECHNICAL SYSTEMS

6.3.1 Background

The monitoring of groundwater changes (hydraulic and chemical) during the construction of the laboratory is an essential part of the documentation work aiming at verifying pre-investigation methods. The great amount of data calls for efficient data collection system and data management procedures. Hence, the Hydro Monitoring System (HMS) for on-line recording of these data have been developed and will continuously be expanded along with the tunnelling work and the increased number of monitoring points.

6.3.2 New results

A new measuring station, station C, as well as stand alone Borre Loggers has been connected to the Hydro Monitoring system in the tunnel interval between 2360 m to 3200 m. Most of the new packed-off sections are located in boreholes drilled for the first phase of the TRUE experiment.

Calibration or function control of the transducers measuring the air ventilation velocity and humidity, temperature, water flow pumped in and out as well as function control of the pressure transducers monitoring the flow in the weirs has been done.

New dams have been permanently installed in the lowermost part of the TBM tunnel and parallel tunnel.

Manual control of the flow in the weirs has been done.

The equipment in KAS03, KAS11 and KAS14 has been removed according to the hydro-monitoring program for 1995. The equipment in KAS05 has not been possible to remove yet because of that packers has got stuck in the borehole.

Planned work

A new expansion step of the HMS system is planned. A new measuring station, station D, will be positioned at the level -450 m and connected to the Hydro Monitoring system.

This central will take care of data from boreholes in ZEDEX tunnel, as well as from weirs and loggers that will operate in back-fill test, plug test etc.

Additional boreholes on the surface will be taken out of operation according to the hydro-monitoring program for 1996.

The remaining weirs will be connected and calibrated. Manual control of the flow in the weirs will be performed regularly.

Absolute calibration of ground water levels of sections in boreholes will be performed in January 1996 as a basis for the annual report for groundwater monitoring.

7 CONSTRUCTION AND ENGINEERING WORK

7.1 OVERVIEW OF GOALS AND MAIN TASKS

The construction of the Äspö HRL comprises several parts and stages. A tunnel ramp has been excavated from the Simpevarp peninsula 1.5 km out under the Äspö. The descent to the tunnel is situated in the vicinity of the Oskarshamn nuclear power plant. The research tunnel reaches the Äspö island at a depth of 200 m. The area of the tunnel section is 25 m^2. The tunnel then continues in a hexagonal spiral under Äspö. The first turn of the spiral was completed in the summer of 1993. The depth at that point is 340 m below sea level and the total length of the tunnel is 2600 m from the tunnel entrance. The tunnelling of this first construction part was done by means of conventional drill and blast.

For the second part of the spiral (from 340 to 460 m level), fullface boring with a Tunnel Boring Machine, TBM, has been tested. The first part of the second spiral follows a hexagonal shape and was done by drill and blast. A rock cavern was excavated at 420 m level for assembly of the TBM. The tunnel then goes down to the 450 m level close to the shafts and continue horizontally westward to an experimental volume. The diameter of the TBM drilled tunnel is 5 m. Figure 7-1 shows an overview of the facility.

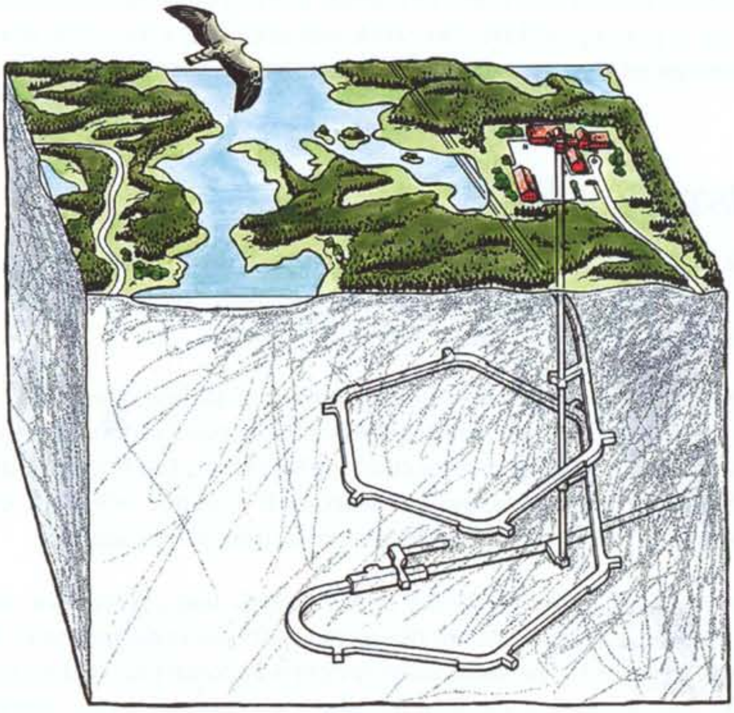


Figure 7-1. *Overview of the facility.*

Three shafts have been built for communication and supplies to the experimental levels. Two shafts (diam 1.5 m) are built for ventilation, and one shaft (diam 3.8 m) is built for the lift. The shafts are excavated by raise-boring technique.

Office and storage buildings have been built on the Äspö island as well as buildings for ventilation equipment and machinery for the lift. Together, these buildings comprise the "Äspö Research Village", which is designed to look like other small villages in the surrounding archipelago.

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

7.2 EXCAVATION AND CONSTRUCTION BELOW GROUND

The rock excavation work on level -450/-460 m was completed by the contractor, Skanska Stockholm AB, in the beginning of the year. During the spring the construction of pumping sumps and fire protection walls by the shafts was finished on levels -220 m, -340 m and -450/-460 m.

The pumping sumps have been casted with concrete in a traditional way. The walls separating the tunnel from the shafts on each level have been built with concrete blocks. This was a way of minimize the need for scaffolding in order not to disturb the ongoing installation work in the shafts. The experience was that to some extent in situ concrete was needed anyway and the advantage was not so big as expected.

The final inspection of the contractual work in construction phase 2 was carried out in the beginning of July. The work was accepted with a list items to be corrected. All items on this list were taken care of by the contractor in September.

7.3 INSTALLATIONS

The machinery with a provisional platform was used for the installation work in the shaft for the elevator. Installation of pipes and cable trays in this shaft was carried out with the same provisional elevator.

The installation work and commissioning of the elevator have continued through the autumn 1995. The contractor ABB Industrial System AB reported the contractual work ready for final inspection in December. The inspector did not approve the installations and the inspection work will continue when the contractor has improved the functions and corrosion protection of installations.

The equipment for ventilation of the tunnels and caverns was earlier installed in the surface building. During the spring 1995 the installations in shafts and tunnels were carried out. The ventilation system was commissioned by the contractor ABB Fläkt Öst AB during the summer and final inspection was carried out in August. The contractual work was approved with a list of items to be corrected.

One item on this list was that humidity in the exhaust air condensates on the way through the ventilation building on ground level. A drip separation device will therefore be added to the system during spring 1996.

At level -220 m, -340 m and -450 m the permanent drainage system has been installed and functional test has been carried out. The total system was commissioned in June and handed over to site organisation in July. In the beginning there were problems with the pumps and the tunnel was flooded. The control system for the pumps has been modified in order to prevent the same type of failure to happen again.

8 INTERNATIONAL COOPERATION

8.1 CURRENT INTERNATIONAL PARTICIPATION IN THE ÄSPÖ HARD ROCK LABORATORY

Nine organizations from eight countries are currently participating in the Äspö Hard Rock Laboratory in addition to SKB. They are:

- Atomic Energy of Canada Limited, **AECL**, Canada
- Teollisuuden Voima Oy, **TVO**, Finland
- Agence Nationale pour la Gestion des Dechets Radioactifs, **ANDRA**, France
- The Power Reactor and Nuclear Fuel Development Co, **PNC**, Japan
- The Central Research Institute of the Electric Power Industry, **CRIEPI**, Japan
- United Kingdom Nirex Limited, **NIREX**, Great Britain
- United States Department of Energy, **USDOE**, USA
- Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle, **NAGRA**, Switzerland
- Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie **BMBF**, Germany

In each case the cooperation is based on a separate agreement between SKB and the organization in question. The work performed within the agreements and the contributions from the participants are described under 8.2.

Most of the organizations are interested in groundwater flow, radionuclide transport and rock 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.

8.2 SUMMARY OF WORK BY PARTICIPATING ORGANIZATIONS

8.2.1 AECL

Dr Derek Martin has followed the ZEDEX experiment as a peer reviewer during the course of the experiment.

8.2.2 TVO

TVO has participated in the Task Force on Groundwater Flow and Transport of Solutes. During the year TVO has actively participated in Tasks 3 and 4, see Section 4.10.

Special modelling studies have also been undertaken based on Äspö data by /8-1/ and /8-2/.

A test of the difference flow meter developed by TVO has been performed in three of the boreholes at the ZEDEX site /8-3/.

TVO has also participated in the Hydrogeochemistry Modelling work described in Section 4.11.

8.2.3 ANDRA

ANDRA has participated in the Task Force on Groundwater Flow and Transport of Solutes. During the year ANDRA has actively participated in Task 3, see Section 4.10.

ANDRA has together with UK Nirex and SKB been one of the three partners in the ZEDEX Project, see Section 3.4.

ANDRA has participated in the planning and review of the REX experiment.

A test intended to characterize the hydro-mechanical coupling within a single fracture has been started during 1993/1994. The work has continue during 1995. The major steps in the in-situ test of the hydro-mechanical behaviour of a single fracture comprise:

- hydraulic cross-hole tests between boreholes intersecting the fracture,
- removing one side of the fracture and measuring roughness,
- hydro-mechanical solicitation of part of the fracture.

8.2.4 PNC

PNC has participated in the Task Force on Groundwater Flow and Transport of Solutes. During the year PNC has actively participated in Tasks 3 and 4, see Section 4.10.

Hiroya Matsui has followed the ZEDEX experiment as a peer reviewer during the course of the experiment.

Regarding fracture classification PNC has applied Äspö data to the DON-CHAN model developed by Prof. Watanabe.

Prof. Watanabe is performing some experiments to determine certain parameters for unsaturated flow.

PNC intends to continue participating in the tasks of the Äspö Task Force. During 1995 PNC plans to test the Discrete Fracture Model on data from the construction phase.

PNC has participated in the planning of the REX experiment.

8.2.5 CRIEPI

CRIEPI has participated in the Task Force on Groundwater Flow and Transport of Solutes. During the year CRIEPI has actively participated in Task 3, see Section 4.10.

CRIEPI has participated in the work at the Äspö HRL by application of methods developed by CRIEPI for geohydrological investigations and performance assessments on engineered and natural barriers. This includes

- Fault activity investigation (ESR, TL, FTD, etc).
- Dating of groundwater (H-3 + He-3, etc).

CRIEPI has dispatched a scientist to Äspö HRL in order to efficiently perform the cooperative research work at the Äspö HRL.

8.2.6 UK Nirex Ltd

Background

The most significant contributions made by UK Nirex Ltd ("Nirex") as an international participant in the Äspö Hard Rock Laboratory have been to the Task Force on modelling of groundwater flow and transport of solutes and through the tripartite ZEDEX Project which is carried out in partnership with SKB and ANDRA.

The work undertaken by Nirex and its contractor AEA Technology for the Task Force has focused on Tasks 1 and 3, the LPT2 Pump Test and Tunnel Drawdown Experiments, and latterly on preliminary modelling of the TRUE experiment (Task 4). In addition, the Issue Evaluation Table was further developed and refined.

Nirex has continued to support the ZEDEX project through: key data acquisition activities performed in the Drill and Blast Drift; the processing and interpretation of data acquired within the Drill and Blast Drift; and formulation of a test plan for the extension to the current ZEDEX project.

New results

Issue Evaluation Table

The Issue Evaluation Table was developed by Masahiro Uchida (PNC), Anna Littleboy (UK Nirex Ltd), Olle Olsson (SKB) and Anders Ström (SKB), reviewed by SKB and the Task Force, and distributed during the first half of 1995.

The objectives of the Table are to: provide a summary of key issues which are of concern in performance assessment; provide a basis for prioritisation of experimental work to be performed at Äspö; list key factors as a basis for identifying issues which could be of interest to resolve in joint projects at the Äspö HRL or elsewhere; and provide information on projects in progress at Äspö or elsewhere to the various issues.

The Table is structured according to the basic components of model descriptions in general, and descriptions of radionuclide transport in particular. It addresses: radionuclide retention processes; influence of heterogeneity on radionuclide transport predictions; long-term stability of geologic environment; modelling aspects and geosphere changes due to the presence of a repository.

Modelling Task Force

The Nirex contribution to the Task Force work on Tasks 1 and 3 was reported by AEA Technology and will be incorporated into an International Co-operation Report in due course.

Task 1 was designed to aid the understanding of the LPT2 combined pump and tracer test. Simulations of LPT2 pump test conducted by Nirex suggested the basic structural model as proposed by SKB is a reasonable one, and proved to be robust. Nirex made some suggestions for changes that could be made to improve the basic model. The most significant change was the introduction of a transmissive zone that intersects the upper parts of borehole KAS07 and connects to the pumped borehole. This suggestion is consistent with findings presented by other groups.

Task 3 was designed to understand the hydraulic impact of the construction of the access tunnel to the HRL on groundwater flow and how it can be used to increase understanding of the Äspö site. Results from the Nirex studies showed that fracture zones with homogeneous properties can give a good simulation of the measured drawdowns. However, to "fine-tune" the models requires some level of heterogeneity to be introduced on individual planes. This was introduced by modifying the local properties of fractures in the neighbourhood of the observation borehole. This process proved successful for providing a better fit to the measured data. However, it is recognised that ideally the process should always start from conditioning the observation boreholes on the field measured data.

The effect of shaft sinking on the drawdown in the tunnel was greater than expected in that the modelled drawdown showed good agreement with observations except near the shaft. This may have been due to a feature that was missed during site investigation, but intersected during construction. However, Nirex studies showed that the use of measured flow rates as the tunnel and shaft boundary conditions gave reasonable results.

Preliminary calculations have been undertaken for Task 4A, the radially convergent tracer test in TRUE. These were presented at the Task Force meeting held in November 1995, and will be incorporated into an International Co-operation Report in due course. Breakthrough times and tracer concentrations were calculated for a range of parameter combinations, representing variations in fracture aperture dispersion, and wellbore volume. The current large uncertainties in flowing/fracture porosity are such that the results were bounded by breakthrough times described by SKB.

ZEDEX

Nirex has supported key data acquisition activities performed in the Drill and Blast drift. The following were performed on behalf of Nirex:

(a) the Norwegian Geotechnical Institute (NGI) undertook Q and RMR geotechnical core logging and drift mapping after drift excavation, rock displacement measurements using convergence and multi-point borehole extensometers during excavation, and tunnel radar measurements after drift excavation;

(b) Vibrometric OY from Finland undertook 4 sections of high resolution seismic tomography both before and after drift excavation;

(c) the Seismology and Rock Physics Laboratory of Keele University undertook Acoustic Emission measurements from 4 sondes surrounding the drift during excavation.

These techniques formed an integrated programme of activities undertaken to measure the development of rock mass disturbance induced by drift excavation. Nirex view this as an important precursor to similar experiments planned for its own proposed Rock Characterisation Facility.

The Nirex consultants to the ZEDEX project (NGI, Keele University and Vibrometric OY) have produced relevant Technical Notes describing processing and interpretation of data acquired within the Drill and Blast drift, have formed the basis of the ZEDEX Final Report, Draft 1 of which was produced in 1995.

Responsibility for the production of the Final Report was allocated to a "writing team". This included Dr S Falls from Keele University, representing Nirex. The report was edited by a committee of two, a member of which is Dr S Emsley of Golder Associates, seconded to Nirex. The Final Report is due to be issued as an International Co-operation Report in March 1996.

Nirex has participated fully in the formulation of a test plan for the extension to the current ZEDEX project which is designed to provide more data to further delineate the damage zones, and provide the means by which predicted P and S wave and stress distributions can be validated.

Planned work

UK Nirex is committed to supporting the ZEDEX extension studies, with particular emphasis on numerical modelling to predict stress change and P and S wave velocity distribution in the damaged zone, 3-D high resolution velocity anisotropy studies to measure P and S waves to determine damage-fabric orientations and further analysis of AE source mechanisms. Nirex will also continue to contribute to the work of the Task Force, in particular predictions and analysis related to Task 4 (TRUE). Further involvement is subject to a renewal of the Nirex/SKB Agreement which expires in September 1996.

8.2.7 US DOE

USDOE has participated in the Task Force on Groundwater Flow and Transport of Solutes. During the year USDOE has actively participated in Tasks 3 and 4, see Section 4.10.

USDOE has undertaken laboratory studies and modelling of two-phase flow phenomena, see Section 4.7.

The studies on geochemical investigations using radiogenic isotopic methods have continued with analyses of collected water samples. Results were presented by Wallin and Peterman at the High Level Radioactive Waste Management Conference in May 1995.

8.2.8 NAGRA

Fracture Classification and Characterization Project

Results of Phase 1 investigations of this joint SKB/Nagra project were reported in /8-4/. The main emphasis was on field mapping and structural/mechanistic interpretation of water-conducting features on a scale of meters to tenth of meters. Phase II investigations were started in spring 1995 and will be reported in 1996. They comprise the quantification of geometric and mineralogic fracture parameters as well as the development of conceptual models of water-conducting features. These models shall be used for flow and transport modelling.

TRUE experiment

Experience from the Migration Tests in the Grimsel Test Site was brought into the design of the TRUE experiment through participation in the Steering Committee and the Review panels. Both Nagra and Nagra's consultants have been involved in the discussions. The focus of the input has been on the geometry chosen for the tracer tests, the time planning and tracers that could be used, and the geological characterisation of the TRUE experiment fractures (see also above). Of specific interest to the project was Nagra's work on resin impregnation techniques which have been developed at GTS and further, close, cooperation is planned.

Task Force on groundwater flow and mass transport

Nagra joined the Task Force in December of 1994. Since then it has actively participated in the Task Force meetings and hosted the 7th meeting in Hergiswil in Switzerland. Nagra's contribution has focused on review work of various documents, for example, the Issue Evaluation table /8-5/, Structural/Hydrogeological Models for Block and detailed Tests, and the Two-Phase Flow/Degassing results and experimental proposals.

Redox experiment

Nagra and Nagra's contractors/consultants provided written and oral contributions for the review seminar held in spring 1995 (review of test plans for redox experiment in detailed scale).

ZEDEX

During 1995 reviewed the Phase I final report. Discussions have been initiated for a participation of Nagra in the ZEDEX Extension with particular emphasis of the potential contributions on: i) tomographic inversions; ii) hydrogeologic synthesis of the results of Phase I and Phase 2; iii) stress modelling.

8.2.9 BMBF

BMBF joined the Äspö HRL Project in July 1995.

BMBF has contributed to the ZEDEX Project by conducting high resolution seismic measurements in the short radial holes drilled from the test drifts and participating in the integrated analysis and reporting of the project results.

BMBF started their participation in the Task Force on Groundwater Flow and Transport of Solutes during the year. BMBF will actively participate in Task 4, see Section 4.10.

Planning of BMBF activities to be undertaken during the coming years has been initiated.

9 OTHER MATTERS

9.1 QUALITY ASSURANCE

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

The purpose and scope of the Quality Assurance Program 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, non-conformances, and corrective actions.
- Document control.
- Quality audits.

The Äspö Handbook, which is the instrument of management and describes in greater detail, routines, formats, and responsibilities. The activity process is described in Manuals for the different disciplines and tasks for investigations and rock work, Figure 9-1.

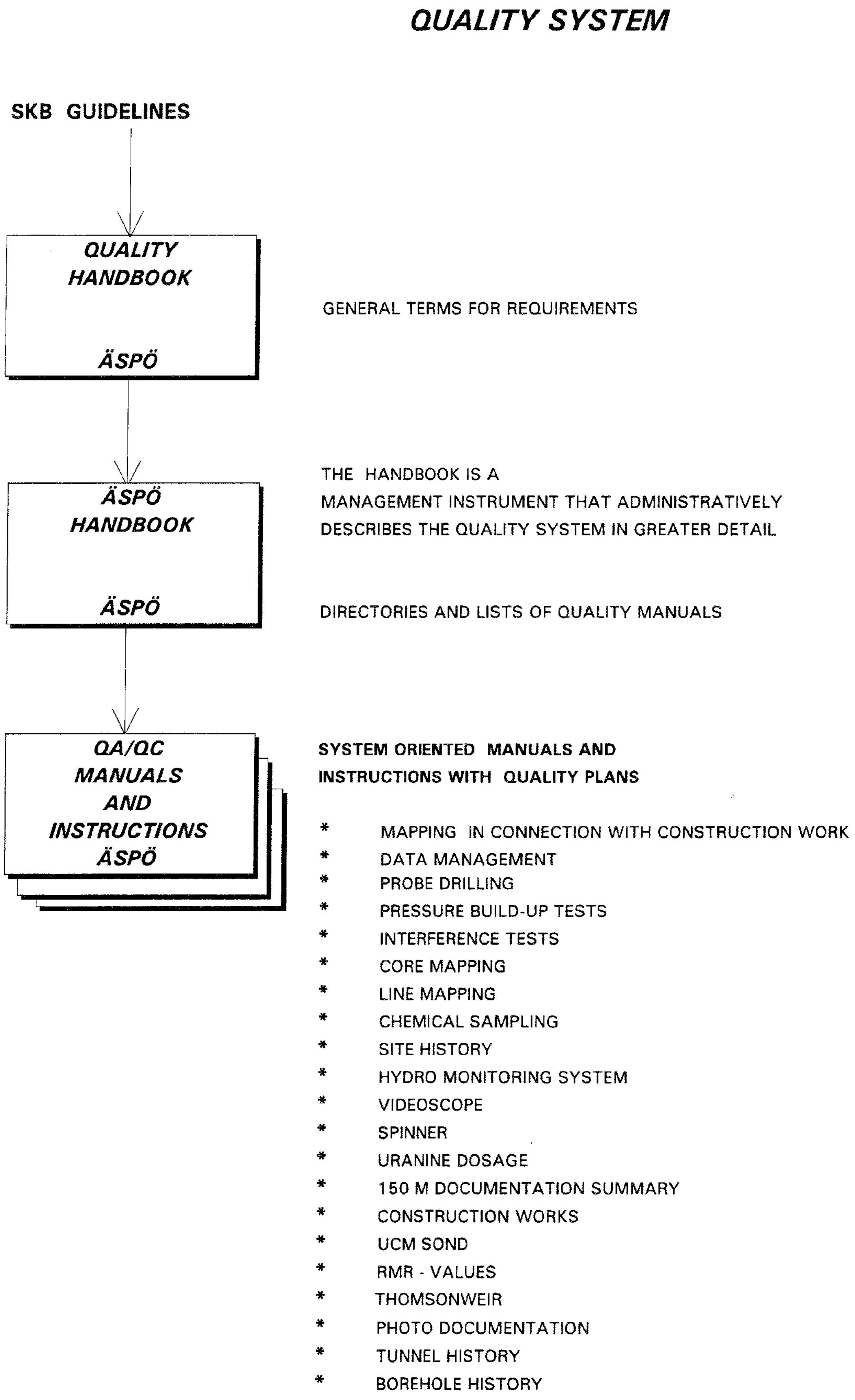
The QA-program is described by the program formats, each of which is described as a procedure in a Manual. The program formats provide a framework for managing all activities and projects for the Äspö HRL that fall under the QA-program.

The final products of the activities at the Äspö HRL will be various kinds of instruments and techniques as well as documents, including descriptions of techniques, methods and computer codes. The ultimate goal for the QA-program is to minimize the risk of mistakes, achieve proven correctness and traceability of data, and increase confidence in the final products.

From 1996 Äspö Quality Handbook will be replaced by SKB-HLK (Handbok för Ledning och Kvalitet).

9.2 PUBLIC RELATIONS AND INFORMATION ACTIVITIES

The Äspö Day, an open house in the beginning of May, was held traditionally and some 500 visitors took the opportunity to visit the facility.



GENERAL TERMS FOR REQUIREMENTS

THE HANDBOOK IS A
MANAGEMENT INSTRUMENT THAT ADMINISTRATIVELY
DESCRIBES THE QUALITY SYSTEM IN GREATER DETAIL

DIRECTORIES AND LISTS OF QUALITY MANUALS

SYSTEM ORIENTED MANUALS AND
INSTRUCTIONS WITH QUALITY PLANS

* MAPPING IN CONNECTION WITH CONSTRUCTION WORK
* DATA MANAGEMENT
* PROBE DRILLING
* PRESSURE BUILD-UP TESTS
* INTERFERENCE TESTS
* CORE MAPPING
* LINE MAPPING
* CHEMICAL SAMPLING
* SITE HISTORY
* HYDRO MONITORING SYSTEM
* VIDEOSCOPE
* SPINNER
* URANINE DOSAGE
* 150 M DOCUMENTATION SUMMARY
* CONSTRUCTION WORKS
* UCM SOND
* RMR - VALUES
* THOMSONWEIR
* PHOTO DOCUMENTATION
* TUNNEL HISTORY
* BOREHOLE HISTORY

Figure 9-1. *Quality system for Äspö HRL.*

254 visits including some 3 100 visitors was brought underground. Many of the visits came from abroad, mainly with technical staff and/or politicians.

In addition, OKG has brought about 4 000 visitors to the Visitor's Niche located 115 m from the tunnel entrance.

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[1] AECL, Whiteshell Laboratories, Pinawa, Manitoba, Canada
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