SKB

TECHNICAL REPORT

93-08

Äspö Hard Rock Laboratory Annual Report 1992

SKB

April 1993

SVENSK KÄRNBRÄNSLEHANTERING AB
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO

BOX 5864 S-102 48 STOCKHOLM

TEL 08-665 28 00 TELEX 13108 SKB S
TELEFAX 08-661 57 19

ÄSPÖ HARD ROCK LABORATORY ANNUAL REPORT 1992

SKB

April 1993

Information on SKB technical reports from
1977-1978 (TR 121), 1979 (TR 79-28), 1980 (TR 80-26),
1981 (TR 81-17), 1982 (TR 82-28), 1983 (TR 83-77),
1984 (TR 85-01), 1985 (TR 85-20), 1986 (TR 86-31),
1987 (TR 87-33), 1988 (TR 88-32), 1989 (TR 89-40),
1990 (TR 90-46) and 1991 (TR 91-64) is available
through SKB.

ÄSPÖ HARD ROCK LABORATORY

ANNUAL REPORT 1992

STOCKHOLM, APRIL 1993

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

ABSTRACT

The Äspö Hard Rock Laboratory is being constructed in preparation for the deep geological repository of spent fuel in Sweden. This Annual Report 1992 for the Äspö Hard Rock Laboratory contains an overview of the work conducted.

Present work is focused on verification of pre-investigation methods and development of the detailed investigation methodology. Construction of the facility and investigation of the bedrock are being carried out in parallel. December 1992 1925 m of the tunnel had been excavated to a depth of 255 m below surface.

An important and integrated part of the work is further refinement of conceptual and numerical models for groundwater flow and radionuclide migration. This work is carried out in cooperation with seven organizations from six countries that participate in the project.

SAMMANFATTNING

Äspölaboratoriet anläggs som en förberedelse för djupförvaret av det svenska använda kärnbränslet. Denna årsrapport för 1992 ger en översikt av det genomförda arbetet.

Nuvarande arbete är inriktat på att verifiera förundersökningsmetoder och att utveckla detaljundersökningsmetodik. Byggande och undersökningar av berggrunden sker parallellt. December 1992 var 1925 m tunnel utsprängd, motsvarande ett djup av 255 m under marknivån.

En viktig och integrerad del av arbetet är att förbättra metoder för att utveckla konceptuella och numeriska modeller för grundvattenströmning och radionuklidmigration.. Detta arbete sker i samarbete med de sju organisationer från sex länder som deltar i projektet.

CONTENTS

1. GENERAL

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

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

In the autumn of 1986, SKB initiated field work for the siting of an underground laboratory in the Simpevarp area in the municipality of Oskarshamn. At the end of 1988, SKB arrived at a decision in principle to site the facility on southern Äspö, about 2 km north of the Oskarshamn Nuclear Power Station (see Figure 1-1). After regulatory review , SKB ordered the excavation of the Äspö Hard Rock Laboratory facility to commence in the autumn of 1990. A number of investigations have been conducted in conjunction with the excavation of the facility. Up to December 31 1992, 1925 m of the access ramp had been excavated to a depth of 255 m below the surface.

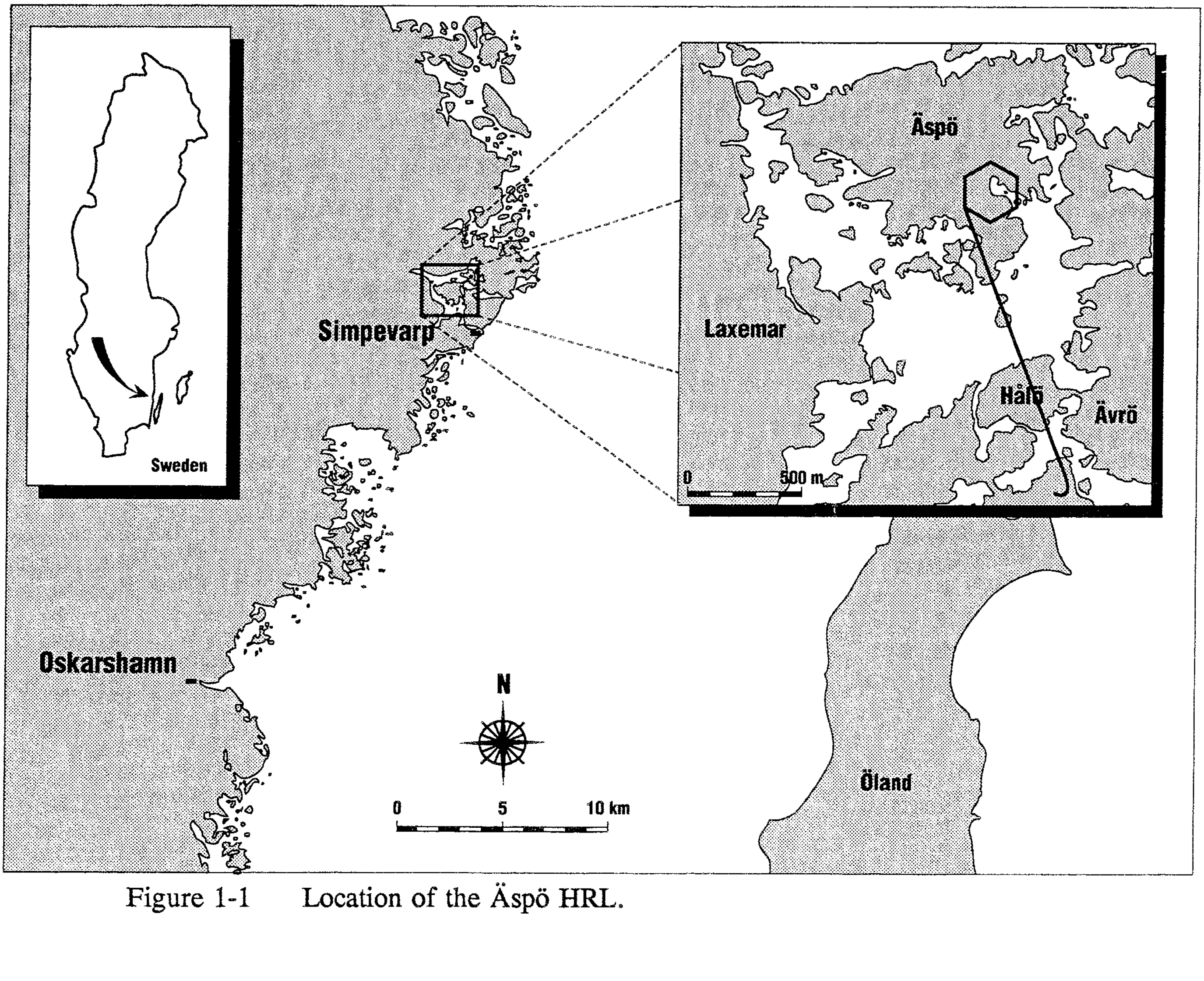


Figure 1-1 Location of the Äspö HRL.

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

The pre-investigation phase was aimed at selecting a site for the laboratory, describing the natural conditions in the bedrock and predicting changes that will occur during construction of the laboratory. The investigations have been summarized in eight Technical Reports /1-2--9/. The construction of the 3900 m long access ramp to a depth of 460 m (see Figure 1-3) will be used to check the prediction models set up from the pre-investigation phase, to develop methodology for detailed characterization underground, including construction/testing integration, and to increase the database on the bedrock properties in order to improve models of groundwater flow and radionuclide migration. A preliminary programme for the operating phase has been set up, /1-10/ as a part of the general SKB RD&D Programme 92 /1-10/. The operating phase will focus on research and the development of models for groundwater flow and radionuclide migration, tests of construction and handling methods and pilottests of important parts of a repository system.

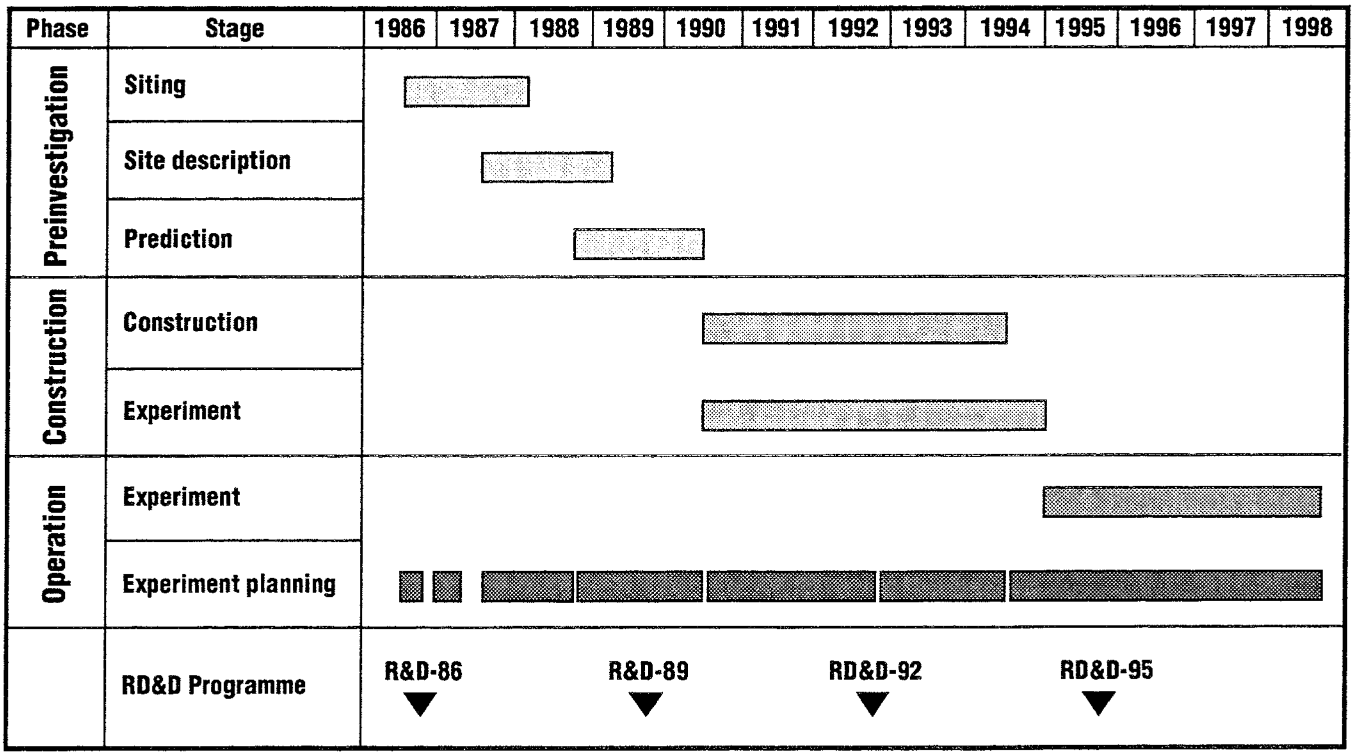


Figure 1-2 Master time schedule for the Äspö HRL.

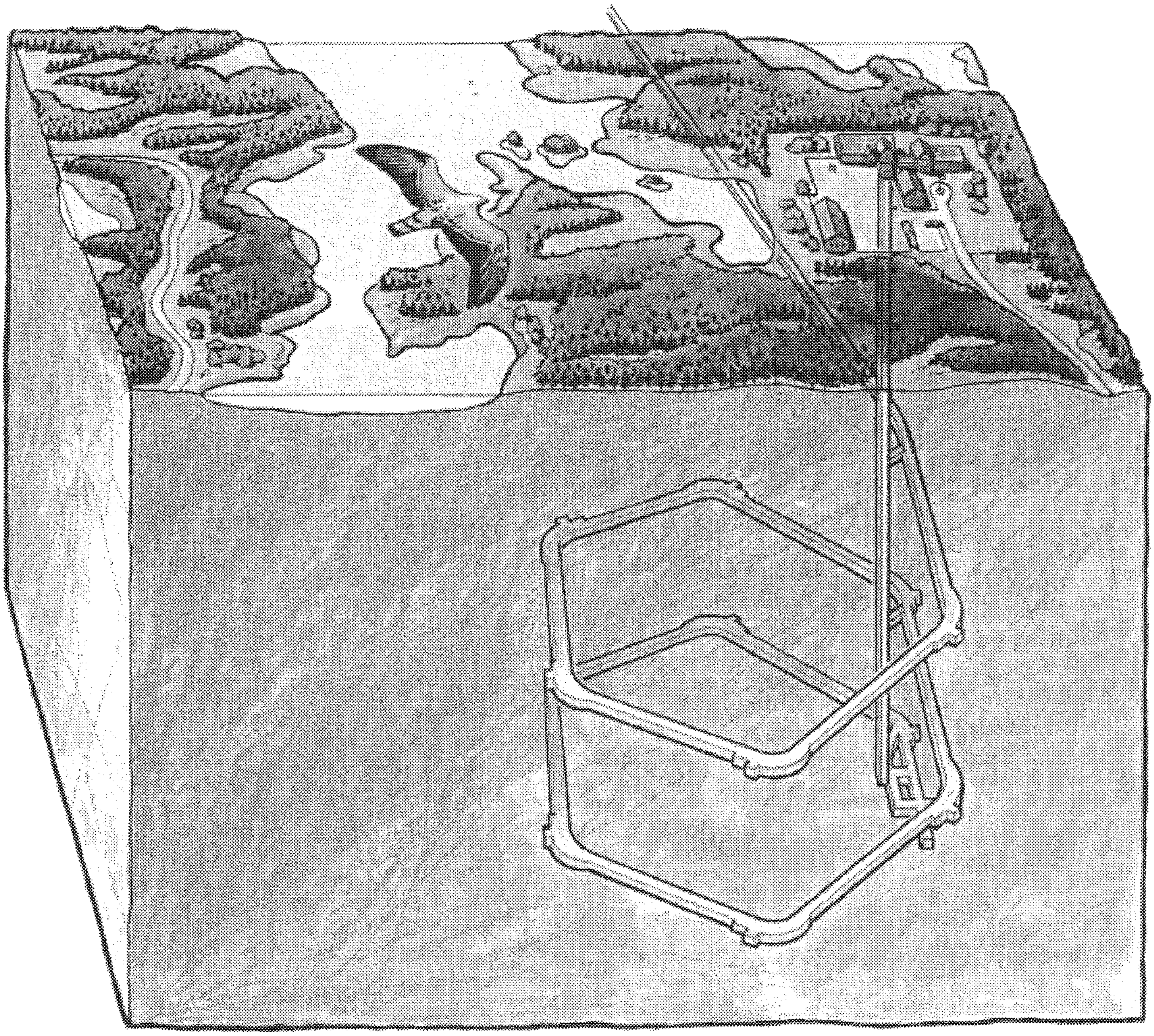


Figure 1-3 Schematic design of the Äspö HRL.

The project has so far attracted considerable international interest. As of December 31, 1992, seven international organizations were participating in the Äspö HRL. They are Atomic Energy of Canada Limited (AECL, Canada), Teollisuuden Voima Oy (TVO, Finland), Agence nationale pour de gestion des déchets radioactifs, (ANDRA, France), Power Reactor and Nuclear Fuel Development (PNC, Japan), the Central Research Institute of the Electric Power Industry, (CRIEPI, Japan), UK NIREX Ltd and the US Department of Energy.

A detailed outline of the project (goals, scope, schedules, organization, previous work) can be found in RD&D Programme 92 /1-11/.

A chart of the 1992 organization is shown in Figures 1-4 and 1-5.

This annual report describes on activities during the year 1992.

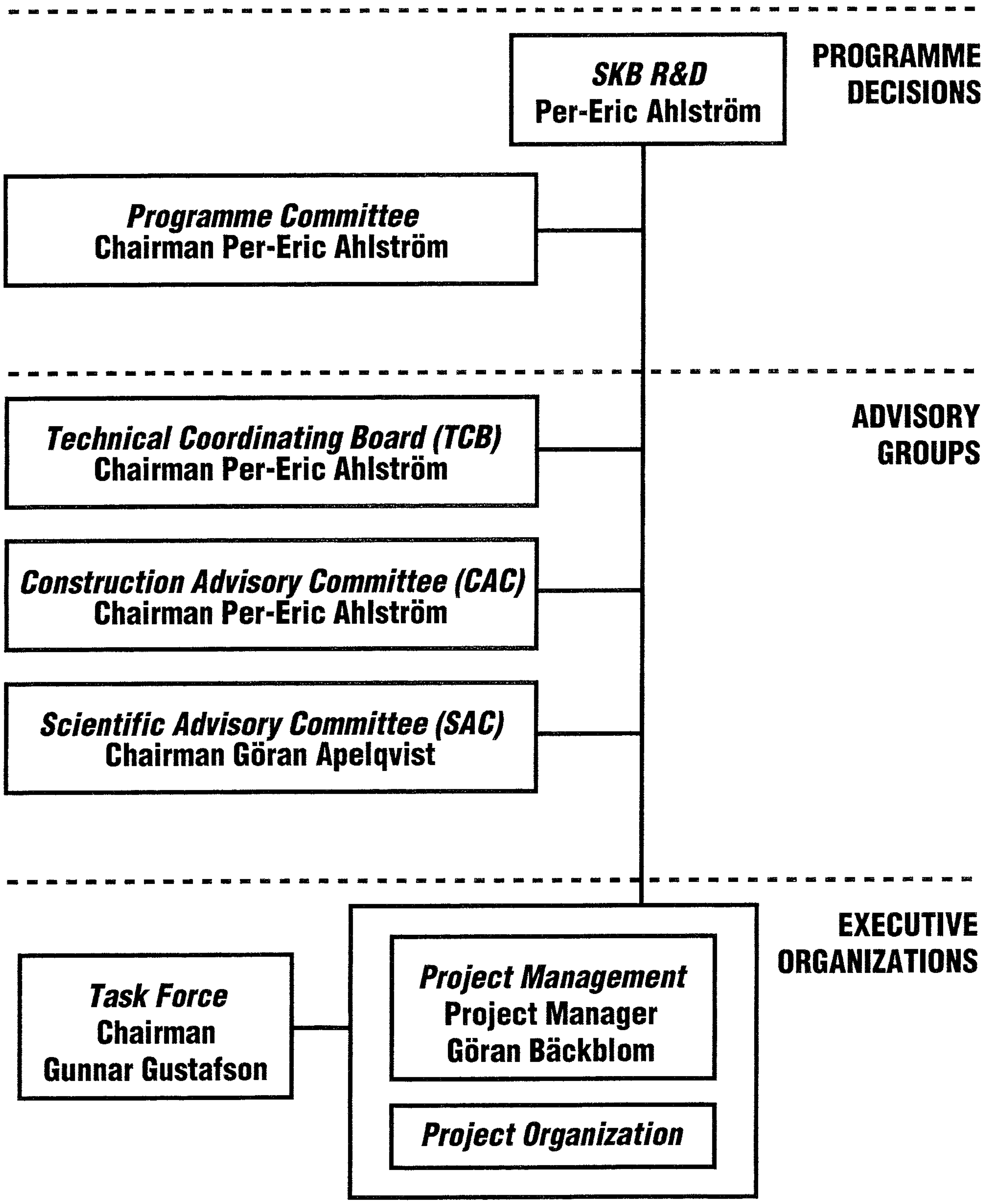


Figure 1-4 Äspö Hard Rock Laboratory - Overview of the organization 1992

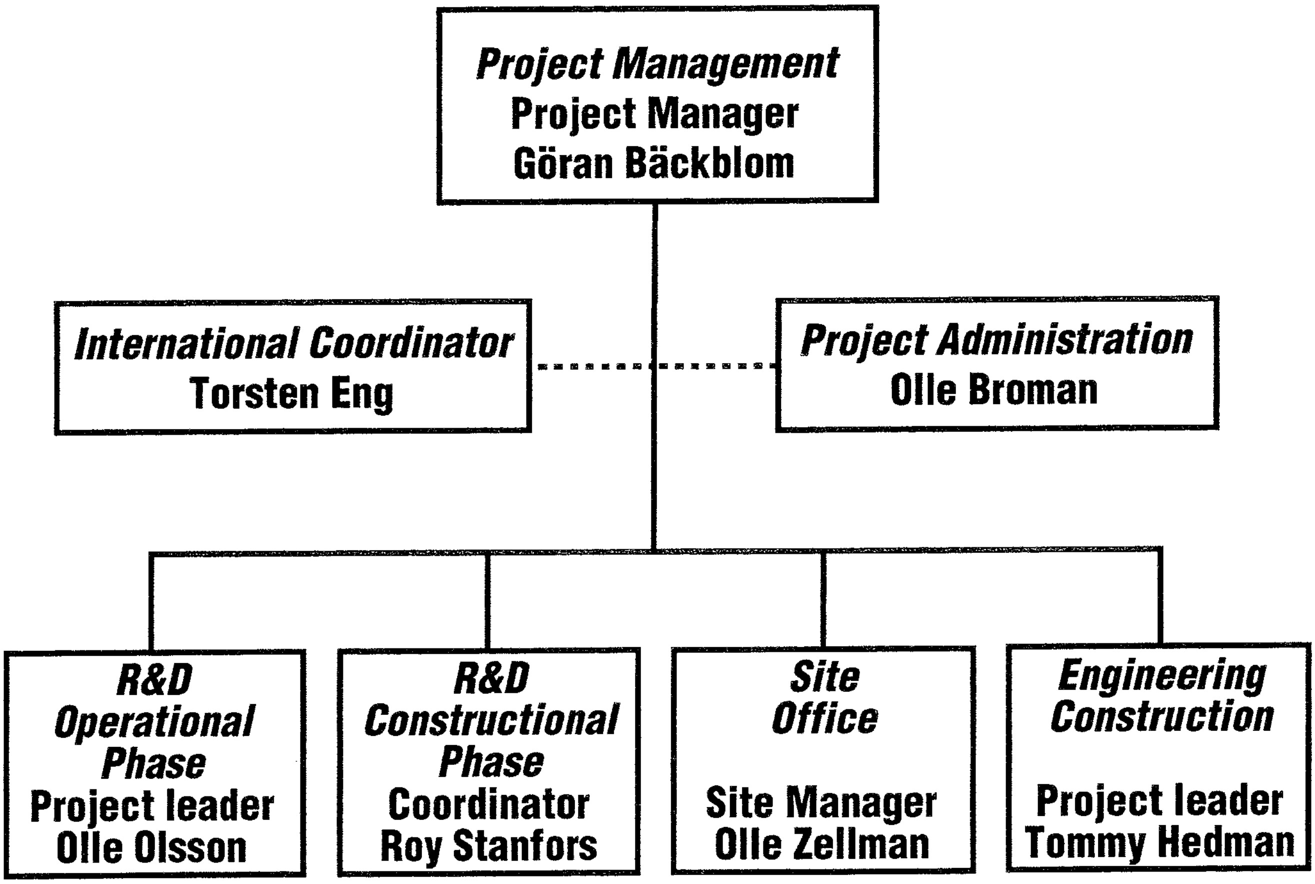


Figure 1-5 Äspö Hard Rock Laboratory - Project organisation 1992

2. R & D ACTIVITIES FOR COMPLETION OF THE PRE-INVESTIGATION PHASE

The results of the pre-investigations were evaluated and modelled jointly for the disciplines geology, geohydrology and groundwater chemistry. Four SKB Technical Reports TR 91-20, -21, -22 and -23 /1-4--7/ were published presenting respectively an overview, the methodology, on evaluation and predictions based on the site investigations conducted during 1986-1990.

The large scale combined pumping and tracer test, LPT-2, was conducted as a verification experiment at the end of the pre-investigation phase. It included three major field activities - a pumping test, a tracer test and dilution measurements - and is reported in SKB Technical Report TR 92-32 /1-8/. The breakthrough times for the tracers were quite close to those predicted before the experiment. In addition, the experiment produced information on the porosity and dispersivity of the fracture zones.

A more complete evaluation of the hydrogeochemical pre-investigations in relation to existing geologic and hydraulic conditions was concluded in 1992, SKB Technical Report TR 92-31 /1-9/ These analyses show that the salinity distribution of salinity under undisturbed conditions is much more complex than it was modelled previously. Conductive sections of the rock mass carrying less saline water surround low conductive rock volumes containing more saline water.

3. CONSTRUCTION AND ENGINEERING WORKS

During the year the tunnelling work advanced from section 1103 m to section 1925 m, a distance of 822 m. The depth at section 1925 m was 255 m below sea level. A major fracture zone (NE-1) was crossed during the spring at section 1300 m, see 6.2. This zone-crossing required extensive grouting and reinforcement of the rock mass. The tunnelling proceeded very smoothly after the passage of zone NE-1 due to the favourable rock conditions.

The passage of fracture zone NE-1 included pre-grouting with various types of grout, e.g. cement/bentonite, cement/silicates, cement/calcium chloride and chemical groutings. Various types of cements have also been tested for the groutings. Finally, a mixture of grouting cement and 15 % of calcium chloride was found to be the best choice under the present conditions, with a high water pressure in the fractures (1,5-1,8MPa).

Extensive support measures have also been necessary in some parts of the tunnel. Pre-bolting was performed during the passage of fracture zone NE-1, and the blasting rounds were shortened to ensure full safety during passage. Further checks were obtained by convergence measurements of the tunnel profile. These measurements showed that the displacement did not exceed calculated values.

Since November 1992 the 3-beam drilling rig has been equipped with a computerized aiming device called Bever Control. It helps the operator to aim the drilling. This control device also records parameters during drilling, such as drilling pressure, drill rotation pressure and penetration rate. The Bever Control has functioned satisfactorily so far.

A drift connecting the tunnel to the shafts was excavated on level -220 m. Raise-boring of two ventilation shafts and one shaft for a hoist began when this drift was finished in October. The pilot holes were grouted to reduce groundwater inflow to the shafts. Reaming of the two ventilation shafts (⌀ 1.5 m) and the shaft for the hoist (⌀ 3.7 m) is planned to be completed at the beginning of March 1993. The specifications for the installation of the hoist are very exact and the deviation of the shaft must be very small, less than 0.15%.

The Äspö Research Village was designed during the year, and the start of construction is scheduled for April 1993. The village will include buildings for ventilation equipment, hoist machinery, offices and service buildings. Bidding documents were prepared and invitations to tender were sent out in November 1992. SKANSKA was selected as contractor April 1993 and construction work is planned to be finished in April 1994.

4. ACTIVITIES AT THE SITE OFFICE

4.1 GENERAL

A major fracture zone (NE-1) was passed during the spring, see 6.2. From a technical point of view it caused us some problems. On the other hand we learned a lot and developed several new techniques for both construction and investigation.

Documentation of the tunnel proceeded satisfactorily and routines for distribution of data have been established.

The organization was supplemented with a resource for co-ordination of international participation on the site. A vacancy on the chemistry side was also filled.

Many public relations activities were held. Nearly three thousand people visited the site, most of whom were also underground.

4.2 UNDERGROUND DOCUMENTATION

Documentation at the tunnel face was carried out according to the established documentation manual for field work in the tunnel by the Characterization Team at the Site Office.

Overviews of the results of geological mapping and data on geohydrology, ground water chemistry, bedrock stability and rock support grouting were presented after every 150 m of excavation in the tunnel on three different sheets, see examples in Figures 4-1--4-3. The data summarized on these sheets were collected during one hour at the tunnel face after each round of excavation.

The geology sheet provides a summary of lithology and fracture data. The Geohydrology sheet presents data on water-bearing fractures, the locations of seepage points, probe-hole locations and summaries of test results, seepage and the location of groundwater sampling points. Groundwater chemistry data (pH, Cl and HCO_3) were presented in separate tables. The third sheet presents data on weekly tunnel advance and grouting and rock support measures. An estimation of rock quality was performed using the Bienawski Rock Mass Rating (RMR).

Overview sheets on conditions up to 1762 metres were compiled and distributed on five different occasions during the year.

A special summary of tunnel history data was distributed together with the data sheets during 1992 . This document describes by date and time all events that have taken place in the tunnel, blasting, grouting, probe hole drilling, coring, packer settings and so on. This document is needed in order to evaluate e.g. the monitoring programme. Tunnel history data covering the period June 18, 1991 - November 10, 1992 were compiled and distributed.

The personnel in the documentation group were also in charge of with quality control of all data compiled. This work included transfer of data to the database GEOTAB.

The documentation group also performed systematic documentation of the drilling of pregrouting boreholes during the pregrouting of fracture zone NE-1.

Tables on groundwater chemistry data (pH, Cl and HCO_3) have been presented in separate tables up to tunnel section 1762 m.

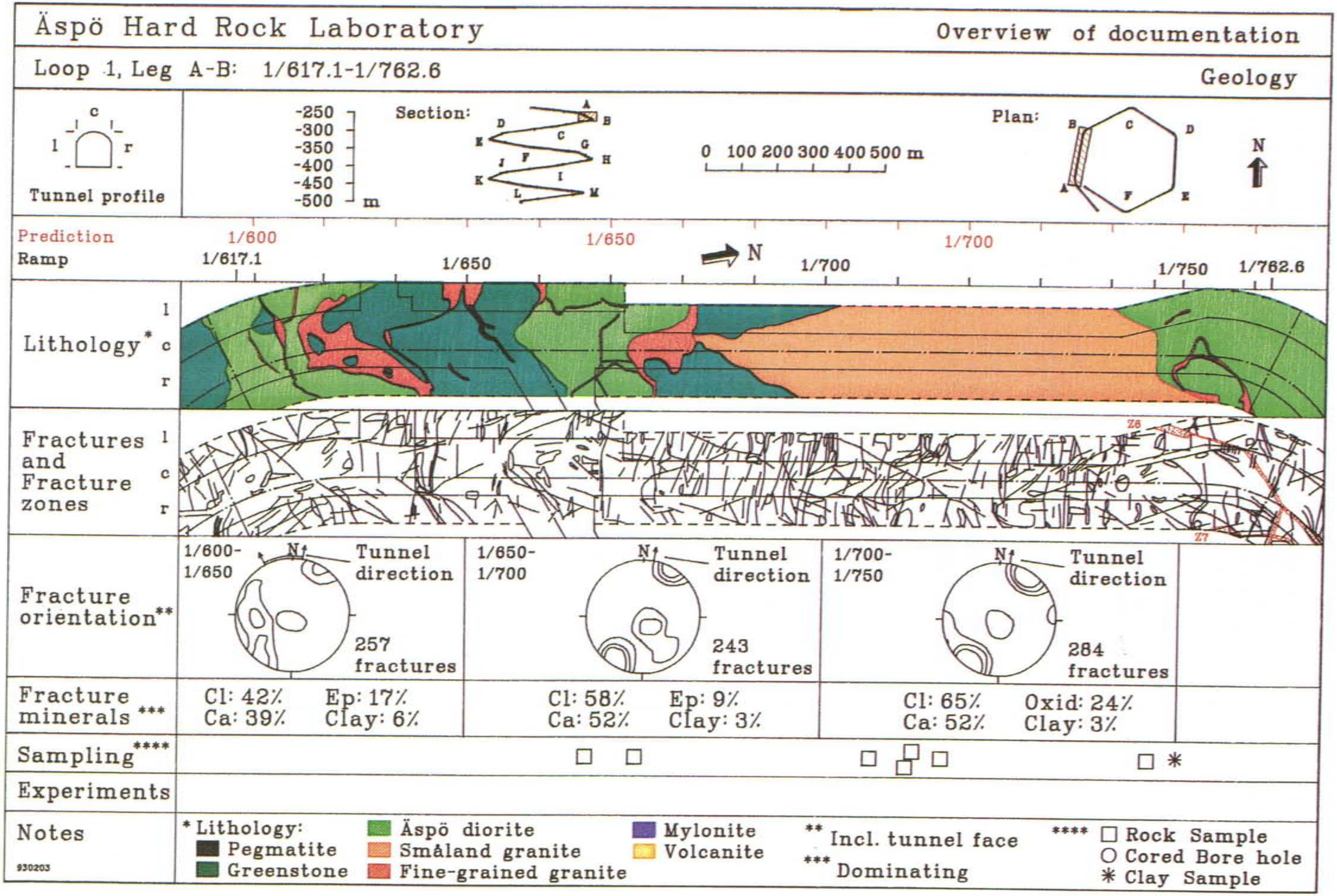


Figure 4-1 Overview of documentation, Geology sheet. Example from section 1617-1763 m.

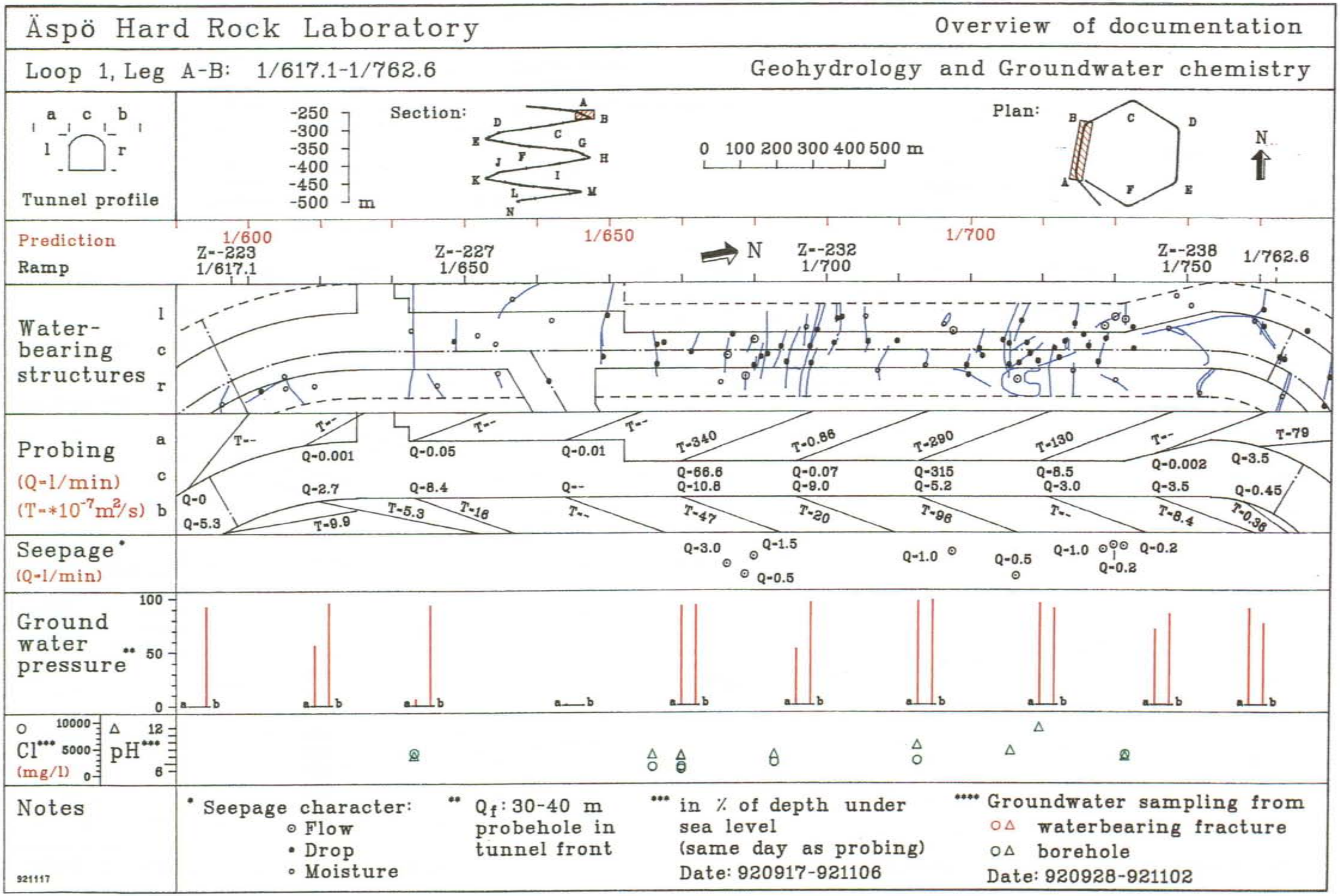
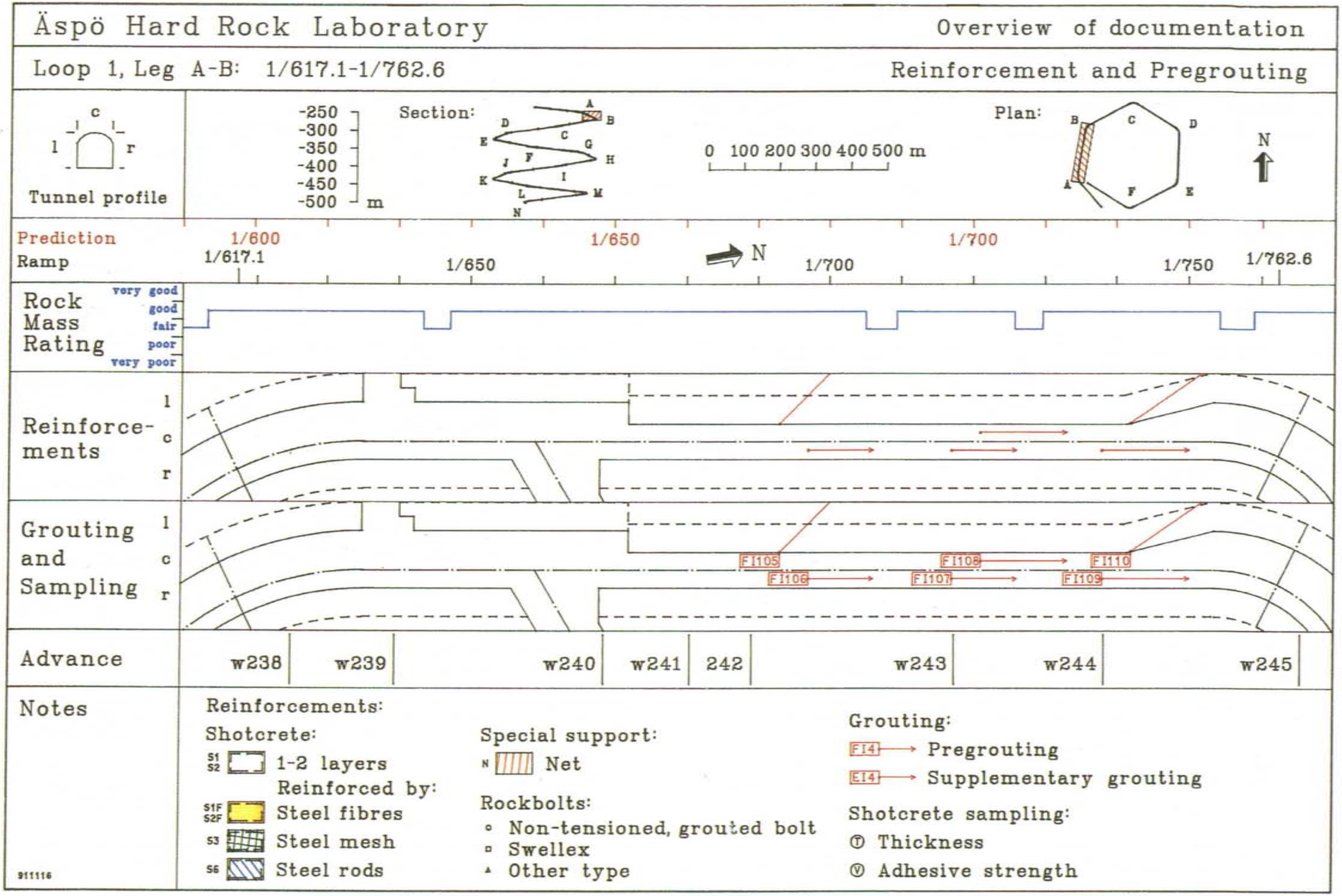


Figure 4-2 Overview of documentation, Geohydrology and groundwater chemistry sheet. Example from section 1617-1763 m.



12

Figure 4-3 Overview of documentation, Rock support and grouting sheet. Example from section 1617-1763 m.

4.3 GROUNDWATER MONITORING

The groundwater monitoring programme consists of recording of long-term changes in hydraulic and chemical parameters in different core-drilled and percussion-drilled boreholes in the tunnel and the vicinity of the tunnel excavation, see Figure 4-5. The observation programme carried out during the pre-investigation period has continued through the start of the construction phase.

Groundwater level data from all core-drilled and most of the percussion-drilled boreholes located on Äspö are now transmitted to the main office via radio. Changes in groundwater level in the measuring points can then be followed on-line at the office. Draw down effects of the groundwater level due to tunnel activities, i.e. percussion-drilling penetrating strongly water bearing fractures, pregrouting activities etc., can then be followed and plotted a few hours after the activity.

Daily and weekly quality check of preliminary data were made by means of different trend plots, see Figure 4-6, calibrated every second month. Annual time series for 1992 reduced to one data point per day will be presented separately as an annual report of groundwater monitoring data in 1993.

A measuring station located in the side tunnel at section 690 m has also been incorporated in the HMS- (Hydro Monitoring System) system. Groundwater level data from the first weir located at 690 m, velocity of ventilation air and tunnel air, humidity, and amount of water pumped into and out of the tunnel have been monitored. Absolute calibration of groundwater levels monitored was performed during the year. The Eh electrode potentials also are monitored at the redox experiment site, see 5.5.1.

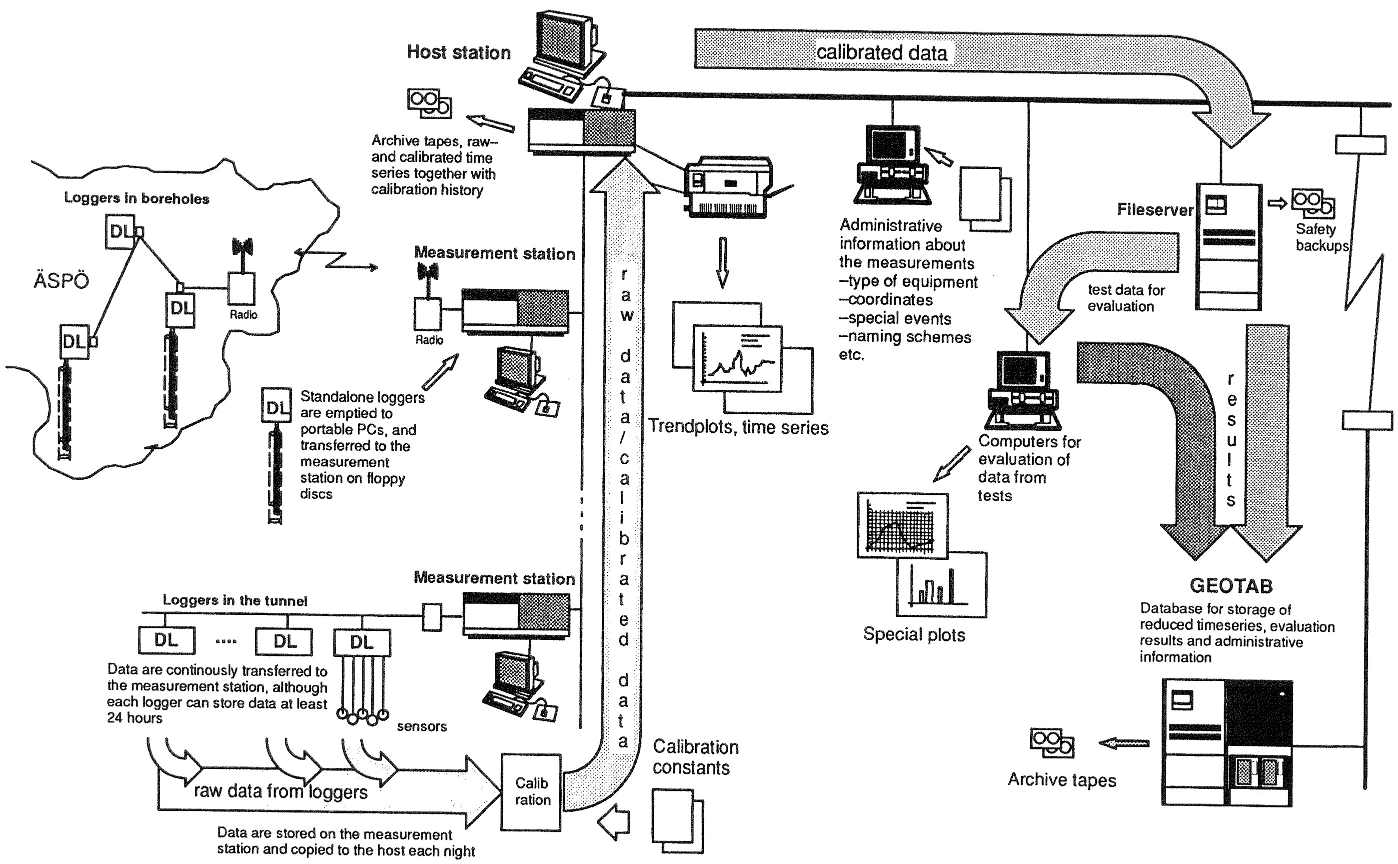


Figure 4-5 Data acquisition system for groundwater monitoring.

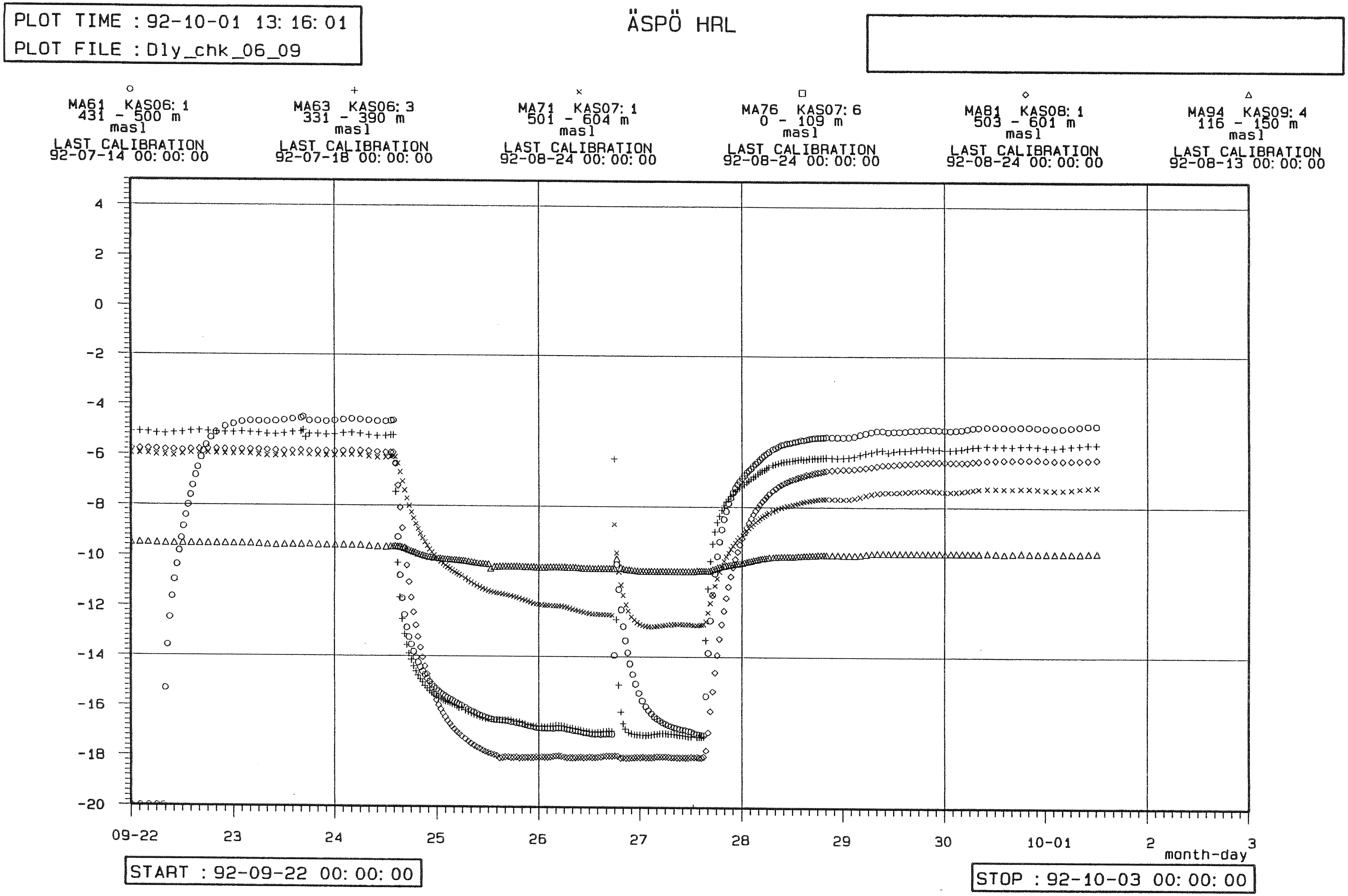


Figure 4-6 Groundwater monitoring, daily check.

4.4 DATA MANAGEMENT

4.4.1 General

Rock conditions have been favourable since the passage of NE-1, so the contractor has had no problem keeping to the schedule. In parallel, the Principal Investigators have been working with data from section 700 m - 1475 m. This means that the Site Office has for the first time been forced to deliver a large amount of collected data concurrently with the ongoing investigation activities in the tunnel.

We have had some problems delivering all data on time. But now we have most of the work behind us. All data have been delivered to the Principal Investigators with good quality. Some of the collected data still require some more quality control. We plan to have all data ready to be transferred to GEOTAB in February 1993. After that, data will be transferred to GEOTAB one week after the date of collection.

4.4.2 Hardware

Several important steps were taken during the year to improve the computer environment at the site office.

A special room was built to house the central computer resources at the site office. The room was equipped with an air conditioning unit. The computer equipment is now operating under good conditions.

The Local Area Network (LAN) was extended to enable PCs, located in the new part of the site office to be linked to the SKB Computer Network.

A new powerful UNIX workstation, Sun SPARC Station 2GX+, was installed in February. The workstation is mainly used as a file server in the LAN, but also as a CAD workstation.

Software

Software was installed to make it possible for external users to run the Hydro Monitoring System. All the user needs is KERMIT 3.11 running on a PC, a modem connected to the public telephone network and a basic knowledge of how to use HMS.

Investigation database

A new logical network disc, the I-disc(I stands for investigation), has been defined. All investigation data resides on that disc. The I-disc is backed up automatically.

The amount of investigation data is growing larger for every day, and they are now stored continuously in DBASE IV tables by the documentation group. The relational database INGRES was installed at the site office in the beginning of December. The first database to be transferred to INGRES will be TUNNEL HISTORY.

5. R & D ACTIVITIES FOR THE CONSTRUCTION PHASE

5.1 GENERAL

Siting and construction of a deep repository in Sweden is planned to take place in stages during the 1990s and a few years into the 21st century. Considering the time it takes to make decisions, conduct the necessary investigations and obtain the necessary permits, demonstration deposition will not be able to commence for at least 15 years.

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

The detailed characterization will encompass investigations during construction of shafts/tunnels to the repository depth. The objectives of these investigations are to confirm the suitability of the site for a repository and to use the data for the detailed layout of the repository, for performance assessments and for licence application.

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

The Äspö Hard Rock Laboratory is 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.

5.2 GEOLOGY AND MECHANICAL STABILITY

The excavation of the first 1475 m of the access ramp in the Äspö HRL is now complete and the results of the documentation in the ramp have been compared with the geological predictions made before the start of excavation /1-7/.

The results of the first part of the comparison (section 0-700 m) have already been reported /5-1/ and a judgement on the agreement between prediction and outcome has been made /5-2/.

A systematic comparison of prediction and outcome has also been made for the second part of the tunnel (700-1475 m) and the results are planned to be reported in a Progress Report at spring 1993. This Progress Report mainly comprises evaluation on different scales (500 m, 50 m and 5 m) and a discussion of the pre-investigation methods used. An example of evaluation on the 500 m scale is presented in Figure 5-1.

Rock mechanical conditions have been evaluated for the 700-1475 m section of the access ramp. The evaluations cover parameters relating to both the individual rock types and the rock mass.

For the individual rock types both elastic parameters, e.g. compressive strength and Poisson's ratio, and fracture properties have been evaluated.

The evaluation of the rock mass covers rock quality distribution and rock stress situation. All the performed evaluations have been based on predictions made before the start of the excavation work and on observations made in the tunnel and during laboratory testing.

The magnitudes of rock stresses measured in three rock blocks (Figure 5-1) are generally higher than were predicted.

The measured values of the orientation of maximum- and minimum horizontal stresses are within 30 degrees of the predicted values, or 15 degrees from the predicted range.

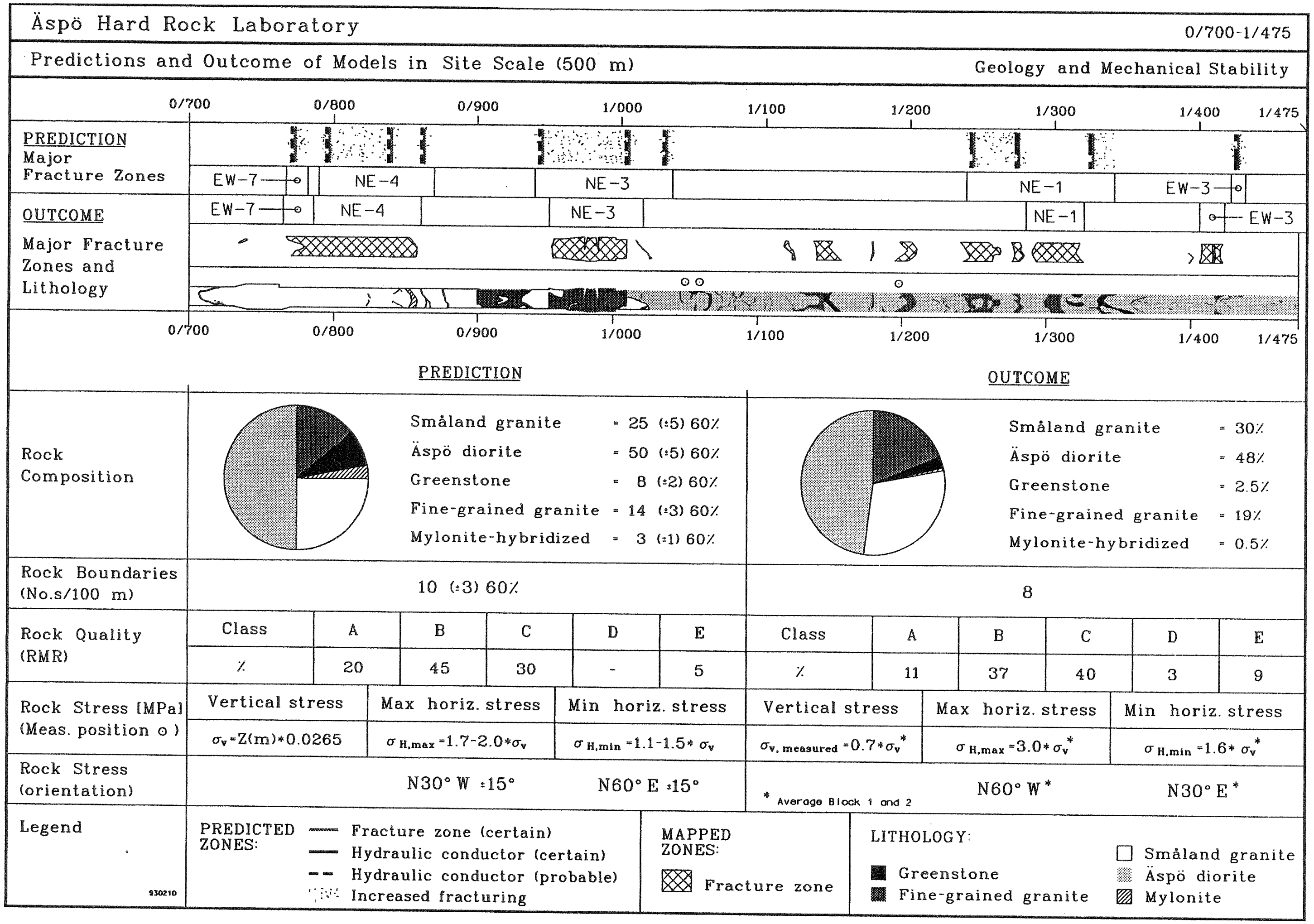


Figure 5-1. Predictions and outcome of models on site scale (500 m). Geological and mechanical stability 700-1475 m. Stanfors (in prep).

5.3 GEOHYDROLOGY

The geohydrological work in 1992 has concentrated on:

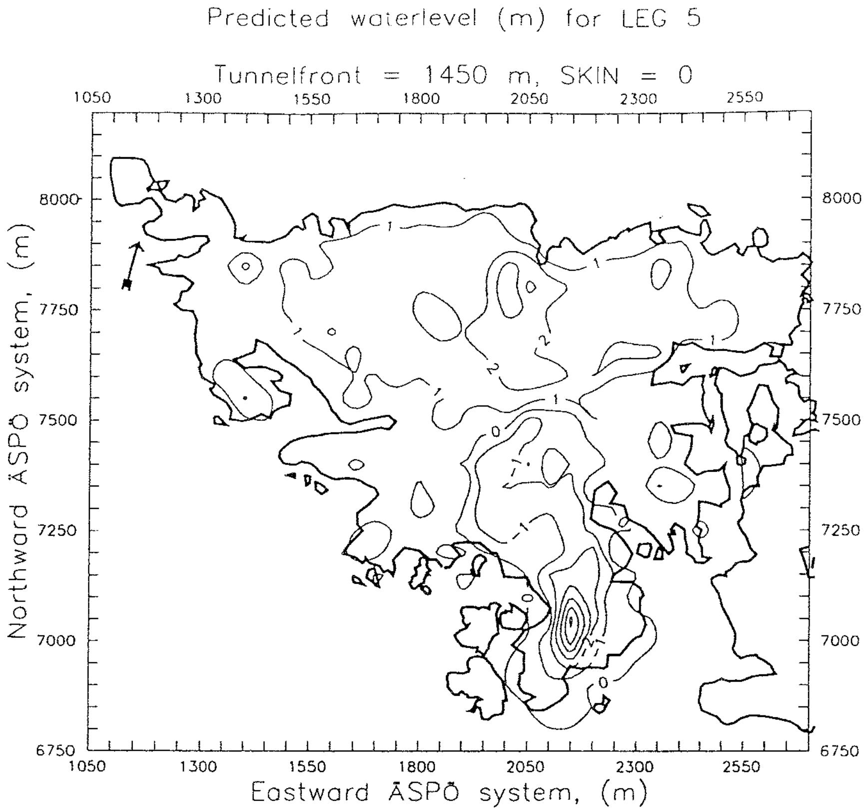
- documentation in conjunction with the excavation of the ramp;
- numerical modelling of the pumping and tracer test LPT2 and code development;
- the project "Passage of water-bearing fracture zones", see 6.2.

To enable the predictions made before the excavation of the Äspö HRL to be checked, a large number of variables are documented /1-7/. The documentation involves pressure build-up tests in probe holes, inflow mapping on the access ramp walls, measurement of water inflow to the tunnel and pressure responses in some 150 borehole sections. The data for tunnel section 700-1475 m is now under evaluation and a Progress Report on predictions and outcome is expected to be printed in the spring of 1993. As an example of the results of the documentation, predicted and measured drawdown of the water table are shown in Figure 5-2. As can be seen in Figure 5-2, drawdown is greater than predicted. However, inflow to the tunnel is also about 50 % greater than predicted.

The results of the large scale pumping and tracer test LPT2 in KAS 06 have now been reported /1-8/ and are included among the calibration cases for numerical simulation /5-3/. The LPT2 case has also been used to test the numerical modelling concept for transport /5-4/, and is also being used as an initial test case by the Task Force, see 9.3.

The program code PHOENICS was also further refined. The relationship between effective hydraulic conductivity and the standard deviation of the hydraulic conductivity was studied. In the PHOENICS code, cell--wall conductivities are calculated as an average of cell conductivities. For stochastically distributed hydraulic conductivities, geometric averaging of each cell-wall conductivity seems to give an effective hydraulic conductivity (for a block of cells) as a function of the standard deviation according to what can be expected from theory. The development work also included high resolution technique around boreholes and refined modelling of infiltration and dispersion in fractured rock /5-5/.

Extensive work was also done in the project "Passage of water bearing fracture zones", that is presented in 6.2.



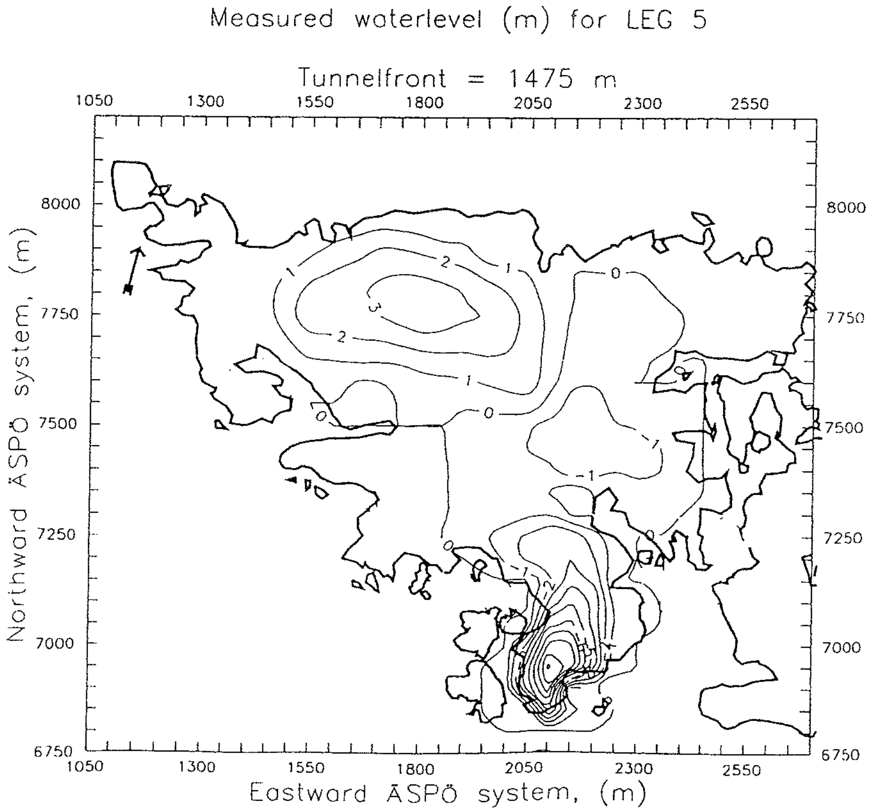


Figure 5-2. Predicted (top) /1-7/ and measured water level on Äspö when the tunnel front has reached 1475 m (depth below sea level 200 m) close to the south part of Äspö. Rhén (in prep).

5.4 GROUNDWATER CHEMISTRY AND TRANSPORT OF SOLUTES

The whole pre-investigation phase ended with a series of predictions for the construction phase /1-7/. The predictions concern the rock mass under Äspö and include geostructural, geohydrological and hydromechanical characteristics of the rock mass. The groundwater samples were collected from seepage points in the tunnel, from probe holes drilled some 20 metres into the rock and from cored boreholes of varying length. In addition groundwater samples were collected from the permanently packed off borehole section on Äspö.

The results of the analyses serve two main purposes:

- to evaluate the geohydrochemical situation and compare results with predictions

- to evaluate the groundwater flow situation and compare results with predictions

In both cases, but especially for the groundwater flow situation, the evaluation extends far beyond a comparison with the predictions.

5.4.1 Groundwater chemistry

Final evaluation of pre-investigations

The pre-investigation phase on Äspö was concluded in 1991 with the completion of the conceptual modelling for geological, geohydrological and geohydrochemical data. Since then a re-evaluation of the geohydrochemical data has been done based on the reported geohydrological and geological conditions /1-9/. This critical evaluation is much more complete than the modelling. However, the results do not contradict each other. The main difference is that the latter (final) evaluation of the data provides a more complex picture of the groundwater flow situation on Äspö. The conceptual groundwater flow model is illustrated in Figure 5-3.

For the evaluation of the geohydrochemical situation the salinity of the water was the most useful parameter. The salinity of the groundwater at Äspö increases linearly with depth, giving the water a chloride concentration of approximately 6000 mg/l at a depth of 500 m. This linear relationship is not strict, however. There are borehole sections where the salinity is either higher or lower than the linear relationship would indicate. These borehole sections are located in water conducting fracture zones, and the higher or lower salinity is thought to be due to discharge or recharge of groundwater.

The isotopic signature (oxygen-18) suggests that the water below a depth of 400 to 600 metres is very stagnant and that it has not been involved in surface water circulation since the latest glaciation. In the upper part of the rock mass meteoric water, glacial melt water and sea water have been mixed. At present there is a wash-out of the saline water by the precipitating rainwater, a process which started when Äspö rose above sea level some 3000 years ago.

Comparison between collected tunnel data and predictions

The results of the investigations carried out in tunnel section 0 - 700 m were reported in 1991 /5-1/. The first predicted tunnel section was investigated during 1992. Comparison between outcome and prediction for tunnel section 700 - 1475 m is currently under way.

Groundwater samples have been collected from 81 different locations in the tunnel between 700 and 1475 m. Most samples are from probe holes 20 m deep at an angle of 20-45 degrees out from the tunnel. The probe holes are drilled ahead of the tunnel face. Thus the samples are quite undisturbed. The other sampling points are grouting holes, coredrilled holes and one conductive spot in the tunnel wall. During grouting of fracture zone NE-1, seven adjacent boreholes were carefully monitored for changes in groundwater composition. The samples, collected during drilling of the probe holes, were analyzed for bicarbonate, chloride and pH.

On the basis of the results from the first sampling campaign, a few boreholes were selected for renewed sampling. This second sampling campaign was more carefully executed than the first one. In addition, many more parameters were analyzed in these samples, and on the sampling occasion the water was filtered through a 0.45 micron filter and preserved for specific analyses. The results of these analyses are the ones that are being used for evaluation of the chemical conditions.

The analyses of the water sampled in the probe holes give the initial groundwater composition before the drainage to the tunnel has caused a major disturbance in the natural conditions. If there is a change in the groundwater flow conditions this can be clearly seen from the results of the subsequent groundwater sampling. So far only minor changes can be seen in most of the boreholes.

The best check of the stability in the observed chemical conditions is found in the results from boreholes SA1195A, SA1195B, SA1210A, SA1210B, SA1229A, SA1229B and SA1247B. During a three-month period, these boreholes were sampled regularly while the major fracture zone NE-1 was being passed by the tunnel. The regular sampling was done in order to check if the grouting of the fracture zone affected the chemistry some distance away from the injection points, see 6.2. During this time approximately 1000 l/minute was drained from the rock into the tunnel. In spite of this there were no changes in the composition of the groundwater in any of the boreholes. Initial and final concentrations of chloride and bicarbonate and pH are presented in Table 5-1 .

Table 5-1 Initial and final concentrations of chloride and bicarbonate and pH in the groundwaters from boreholes.

Borehole	Cl/mg/l		HCO_3/mg/l		pH	
	Initial	Final	Initial	Final	Initial	Final
SA1195A	5100	4600	510	590	7,6	7,4
SA1195B	5800	5200	320	430	7,6	7,3
SA1210A	4900	4400	480	530	7,3	7,4
SA1210B	5300	5400	430	410	7,3	7,3
SA1229A	5500	5500	530	490	7,3	7,2
SA1229B	5300	5000	400	450	7,3	7,4
SA1247B	5500	5300	290	350	7,4	7,4

The changes are small and mostly in the direction towards a lower salinity. This indicates that the drainage into the tunnel causes a withdrawal of water with a lower chloride concentration, perhaps from the overlaying Baltic sea, which has a concentration of about 4000 mg/l or less. However, the decrease in chloride concentration is not accompanied by an expected decrease in the bicarbonate concentration.

From the small changes in pH during the excavation and grouting of NE-1 it one can be concluded that the groundwater in fracture systems connected with the NE-1 zone was not affected. This result should be compared with similar monitoring in boreholes in the zones that were grouted, where changes in the pH values were observed /6-1/.

5.4.2 Transport of solutes

Changes in groundwater chemistry, and especially in chloride concentration, are used as indicators of solute transport. The natural tracers tritium and oxygen-18 are also used. In addition to these parameters, groundwater flow and the measured electrical conductivity of selected borehole sections at Äspö were used to evaluate the changes in the salinity of the water caused by drainage into the tunnel.

In tunnel section 700 - 1475 m groundwater samples were collected for analyses of deuterium, tritium and oxygen-18. Some results are presented in Table 5-2 .

Table 5-2 Deuterium, tritium and oxygen-18 values for groundwater samples from tunnel section 700-1475 m

Borehole	oxygen-18 ‰ SMOW	deuterium ‰ SMOW	tritium Bq/l
SA1062B	-7.7	-58.0	1
SA1077A	-7.5	-58.7	2
SA1094	-7.3	-60.3	2
SA1111B	-7.7	-60.3	3
SA1163B	-7.9	-61.9	3
SA1210A	-7.4	-61.5	2
SA1229A	-8.1	-63.6	2

The tritium data in Table 5-2 indicate that there is a measurable proportion of modern water in the analyzed samples. The deuterium data are also close to the values in the Baltic Sea. It is impossible to tell whether this is an effect of drainage into the tunnel or not, since no pre-investigation data are available from this area.

It is nevertheless quite obvious that drainage into the tunnel has caused water from the overlying Baltic sea to enter the rock mass at these locations.

Dilution measurements

The deep boreholes on Äspö are equipped with permanent packer arrangements in which two of the packed-off intervals can be used for circulation of water to the surface. A colour tracer that can be easily analyzed is added to the circulating volume. Within this loop, any dilution of the colour is due to groundwater flow through the packed off section. Thus, by analysing the tracer concentration at regular time intervals the groundwater flow can be calculated down to the limit of molecular diffusion, which is less than 0.1 ml/min.

Dilution measurements were performed in all the core drilled boreholes on southern Äspö, i.e. KAS 02, KAS 04, KAS 05, KAS 06, KAS 07, KAS 08, KAS 09, KAS 11, KAS 12 and KAS 13. On the northern part of Äspö Kas 03 was tested. These tests were performed during the long term pumping tests LPT-1 and LPT-2, under undisturbed conditions before tunnel construction started, and during tunnel construction /5-6--8/. The results are presented in Table 5-3.

Table 5-3 Groundwater flow in packed-off borehole sections under natural and disturbed conditions.

Borehole	Code	Section (m)	Flow (ml/min) LPT-1[A]	NG1[B]	NG2[C]	LPT-2[D]	TP1[E]	TP2
KAS02-4	B4	309-345	1.1	-	fm	2	1.0	0.5
KAS02-2	B2	800-854	fm	-	fm	4	3.0	2.5
KAS04-2	D2	332-392	28	-	12	-	4.7	4.3
KAS06-5	F5	191-249	197	25	27	ph	3.0	2.5
KAS06-1	F1	431-500	79	52	25	ph	96	119

- = No measurement, ph = Pump hole, fm = Failed measurement
A = (LPT-1) August 1989, B = (NG1) September 1989, C = (NG2) June-August 1990,
D = (LPT-2) October 1990, E = (TP1) February 1992

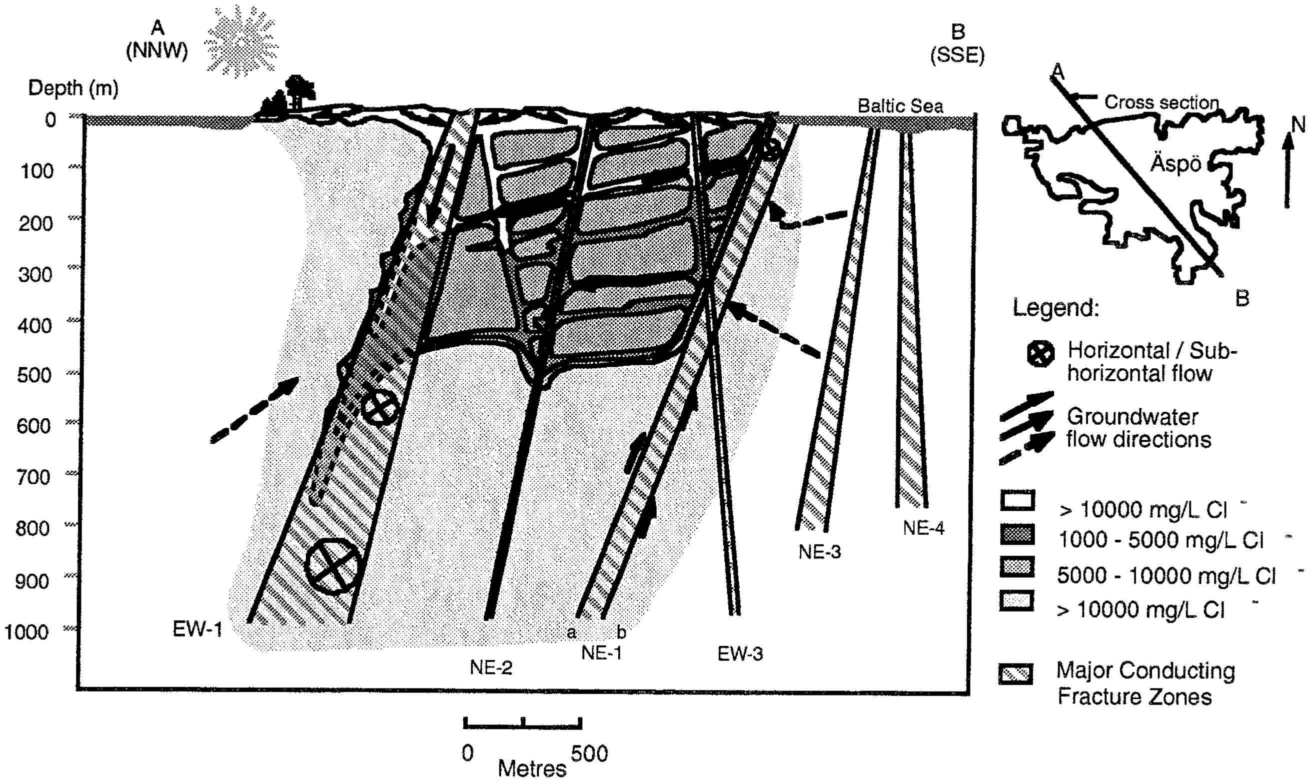


Figure 5-3 Conceptual groundwater flow model /1-9/.

5.5 METHOD AND INSTRUMENT DEVELOPMENT

5.5.1 The Hydro Monitoring System

Monitoring of groundwater pressures and chemistry is an essential part of the ongoing work. The establishment of the Hydro Monitoring System (HMS) for on-line recording of groundwater pressure levels in most of the boreholes at Äspö, equipped with multipackers, and a great number of measuring points in the tunnel, measuring air and water flow and pressures in boreholes, was made in 1991.

The system was enlarged in 1992 by connection of new measuring points in the tunnel, see Figure 5-4. This includes the incorporation of a Chemmac flow cell, for recording Eh, pH and electrical conductivity at the Redox Zone. Moreover, a new borehole from the surface was drilled, equipped with multipackers and recording devices and connected to the HMS. A condensed description of the Hydro Monitoring System was published during the year /5-9/. Improvements of the HMS have focused on the software for data management and quality control, data presentation and routines for export of data. An instrument database was developed for the set-up of all components in the HMS, present and past. The writing of detailed technical documentation and a users manual for the HMS is now almost completed.

The drawdown of the groundwater levels has been greater than expected in some boreholes, which has caused some measurement problems. The search for a solution to these problems is underway.

5.5.2 Groundwater sampler for "stagnant water"

Sampling of groundwater from very low-conductivity rock is very important for gaining an understanding of the interaction between rock and water. However, this sampling is very difficult to perform, due to the small amount of water. The first criterion in designing a sampling system is to minimize the "dead" water volume involved. Very slim boreholes, 36 mm or 46 mm, will therefore be used. The choice of materials for all components that come in contact with the water is critical for the development work in order to avoid contamination.

The prototype of a packer system has been built and is undergoing testing in a borehole. The next step in the development of the sampling system will be to desing a miniature flow cell for measurements of Eh and pH at these very low water flows. The planning for this work has just been initiated.

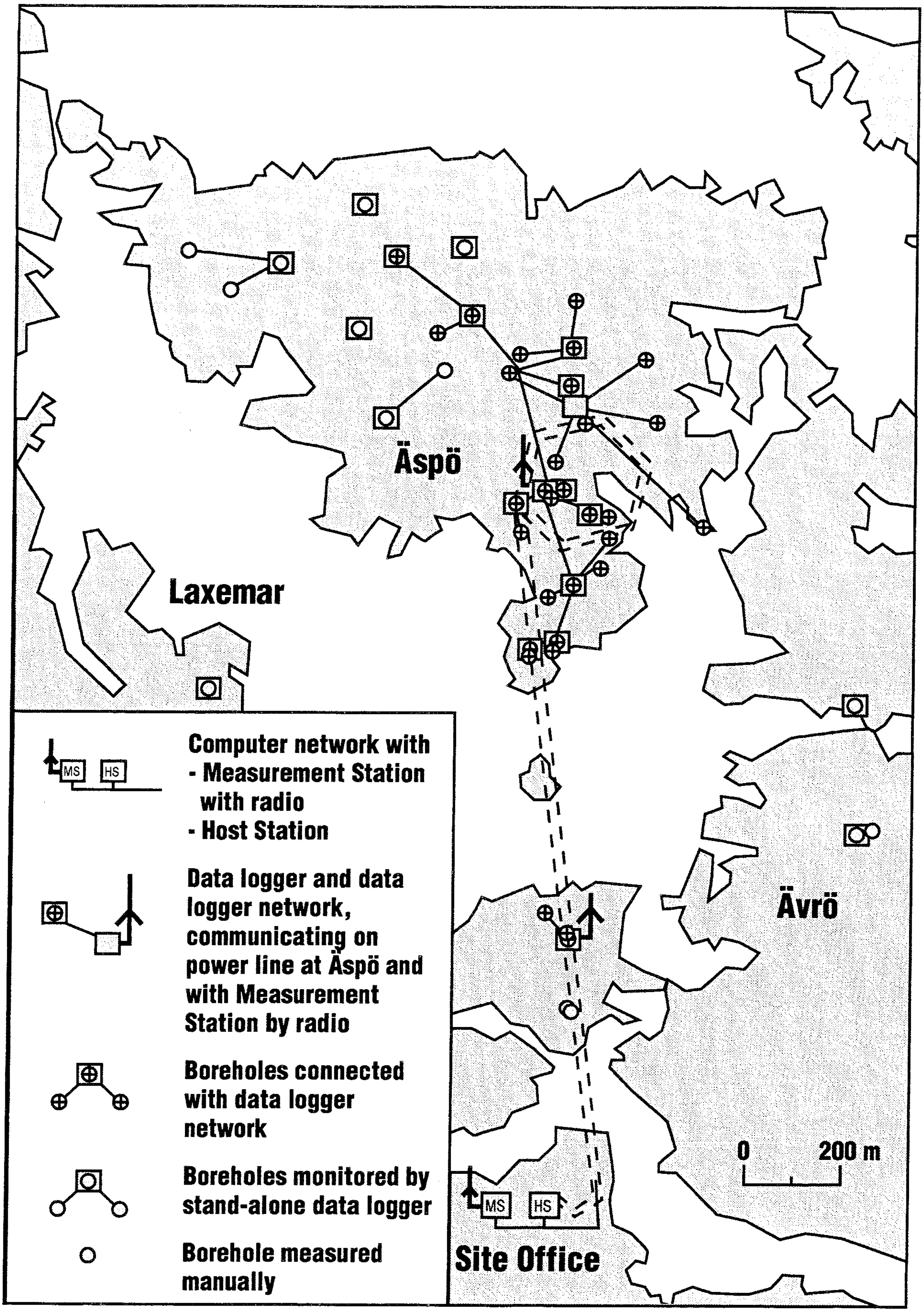


Figure 5-4 Measurement points and monitoring network for the Hydro Monitoring System

5.5.3 Recording of drilling parameters

The recording of drilling parameters during percussion drilling can provide supplementary and detailed information on rock boundaries, fracturing and water capacity of fractures or fracture zones. A system for recording drilling parameters during the construction phase, is now being installed on the drill rig. One planned use of the drilling parameters is for the drilling of the probe holes. A strategy for management of these data and for use of this information in the documentation work has not yet been developed.

5.5.4 The CHEMLAB probe

The migration of radionuclides is a very slow process, due to the sorption of the nuclides on the rock minerals. These kinds of experiments are therefore usually performed on rock samples in laboratories. However, it is very difficult to create the right conditions for these experiments artificially in a laboratory. Within the Äspö HRL programme, radionuclide migration experiments are planned to be carried out in a borehole laboratory, the CHEMLAB probe. Migration experiments will be conducted on rock samples inside the probe. The CHEMLAB will be placed in a borehole, and the water for the experiments will be taken from the formation groundwater. All radionuclides will be kept inside the probe.

IPSN/CEA in Chadarache, France has been contracted for the development work. The design work of the CHEMLAB has been almost finished. Components of the system, such as chromatography pumps, valves, couplings etc, have been constructed and tested. The planning of supporting laboratories - test site laboratory in the tunnel and test preparation laboratory located at the SKB CLAB facility - has been initiated.

6. SUPPLEMENTARY INVESTIGATIONS

6.1 GENERAL

In order to meet the stage goal "Finalize detailed investigation methodology" separate subprojects are carried out from time to time. During 1991 blasting damage and the methodology for passing water-bearing fracture zones were investigated. A large scale redox experiment was started. Furthermore, "design-as-you-go" activities have been initiated.

6.2 PASSAGE OF WATER-BEARING FRACTURE ZONES

A number of tests and experiments have been conducted on various methods for passing the major water-bearing fracture zones EW-7, NE-3 and NE-1 during excavation of the Hard Rock Laboratory Access tunnel (Figure 6-1) / 6-1/.

As a first phase of the experiment a pilot study was conducted in the tunnel during the passage of fracture zone EW-7 in order to enable the planned main test in fracture zone NE-1 to be conducted in as efficient a manner as possible. It was estimated that EW-7, which was predicted to trend ENE and dip approximately 60° to the south, would intersect the ramp at 600-700 m, and its transmissivity would be $1.4 \cdot 10^{-4}$ m^2/s.

6.2.1 Pilot Study EW-7

The main aim of the pilot study was to locate and characterize EW-7 more exactly before passage, and then during passage to carry out controlled pre-grouting - primarily as regards the spread of grout. In order to locate EW-7 more exactly, two cored boreholes - KA0575A and KA0644B - were drilled from niches in the tunnel. Single hole directional antenna reflection measurement was performed with a 45-50 MHz antenna in borehole KA0575A. Observations of water inflow from three different sections in the cored boreholes, combined with radar measurement data and indications from the earlier surface boreholes, supported the prediction that EW-7 was a fracture zone comprising three different branches with increased fracturing or open water-bearing fractures.

The pressure build-up tests showed that the highest transmissivities in the cored holes were approximately as predicted for EW-7 and located approximately where larger water inflows and higher fracture frequencies were mapped. However, no interference tests were performed.

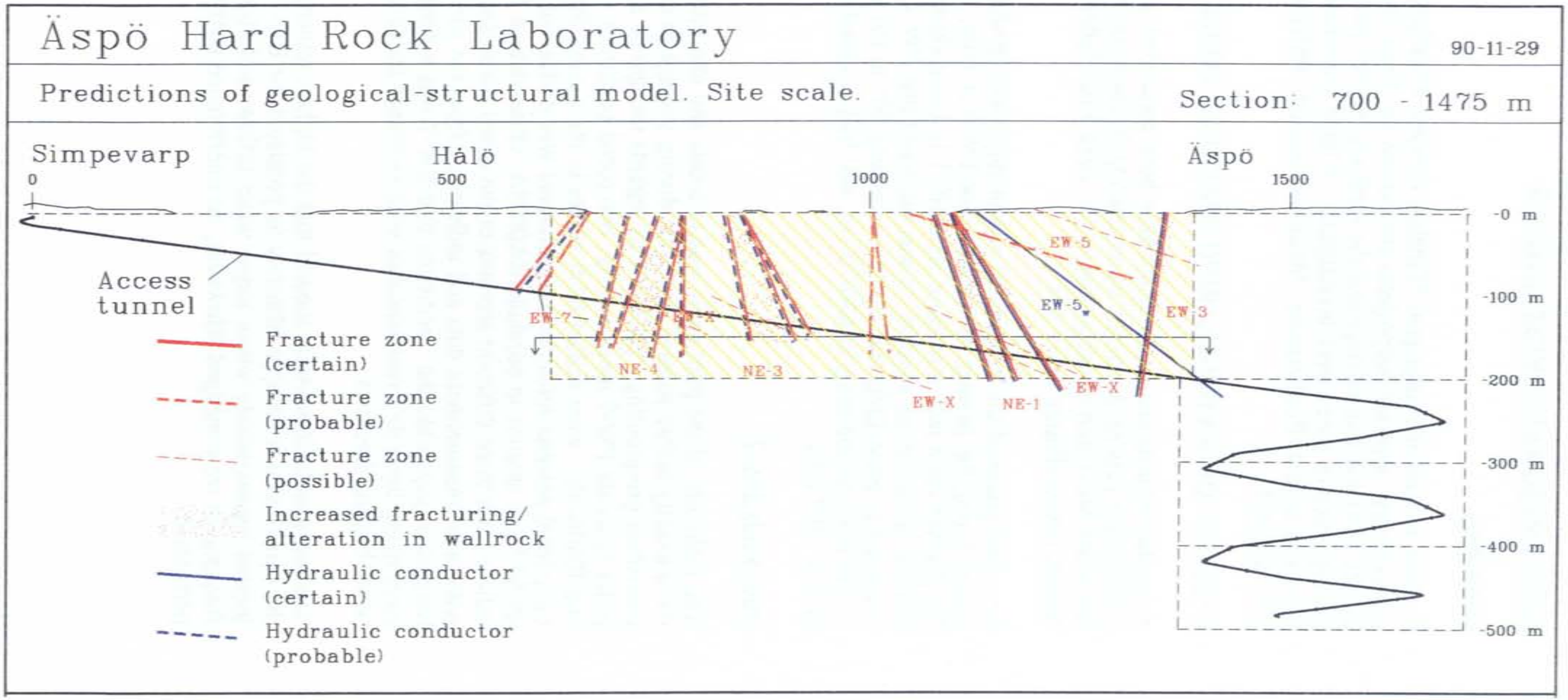


Figure 6-1 Predictions of the location of fracture zones EW-7, NE-3 and NE-1.

During excavation, however, only one branch of EW-7, trending ENE, was found in the tunnel. The most conductive structures are vertical and strike more or less N-S.

6.2.2 Supplementary Pilot Study EW-7

Experience from the test in EW-7 showed a need for supplementary investigations to be conducted before the NE-1 experiment, the main objectives being:

- to identify and locate water-bearing structures parallel to the access tunnel (NNW) in connection with zone EW-7;

- to perform controlled grouting - especially as regards the spread of the grout.

The geological mapping of fractures in tunnel section 650-750 m was analyzed with respect to orientation, length, mineralogy and relative ages. It was found that epidotecoated and oxidized fractures have similar fracture orientations. Fractures with a steep dip striking N are most common.

Chlorite and calcite-coated fractures have about the same orientation and spatial frequencies. The directional maxima are 305/80, 192/80 and 000/00. The epidote-coated and oxidized fractures are generally longer than the calcite and chlorite-coated ones (mean length 3.4 and 4.3 m compared with 3.1 and 3.0 m). This may lead to higher hydraulic conductivity in the N-S direction because of the possibility of a higher degree of connection between fractures striking N-S. The longest fractures are steep and strike NNE.

Radar and seismic measurements were performed in the interval 680 to 950 m in the access tunnel to test the ability of these methods to detect fracture zones and other rock inhomogeneities ahead of the tunnel front. There is good agreement between a couple of class 1 radar reflectors and the hydraulically significant feature, NS-1. The hydraulic data indicate several parallel N-S fractures. No feature corresponding to the hydraulically significant feature NS-1 was found in the seismic data.

Four 50 m long cored holes and six 30 m long percussion holes were drilled from the tunnel in order to identify water-bearing structures. Pressure monitoring in drilled boreholes during drilling, pressure build-up tests and interference tests were used to identify possible hydraulic structures. A system of conductive fractures striking more or less N-S and with an approximately vertical dip were judged to be probable from these tests. Videoscope investigations in boreholes drilled through grouted fractures also confirmed the existence of vertical N-S fractures. The fractures may possibly form an echelon pattern constituting a conductive structure with a NNW strike.

The spread of grout in the fracture system around EW-7 was estimated to be within a radius of 20-40 m (sphere) or 25-80 m (single fracture). The estimate was considered uncertain.

6.2.3 Subproject NE-3

As the grouting experiment in fracture zone EW-7 had not followed the primary programme it was decided to carry out another test in fracture zone NE-3 in order to improve the grouting method before passing through fracture zone NE-1.

NE-3 was indicated geophysically during the pre-investigations and in inclined cored borehole KBH02 ($T = 3 \cdot 10^{-4}$ m^2/s) and was predicted to cross the tunnel at approximately 920- 960 m.

Both radar and seismic reflectors intersect the tunnel at 920 to 960 m with an intersection angle of approximately 20°. Several fractures with this orientation have been mapped in the tunnel and are probably related to the fracture zone encountered at 963 m. The radar data also indicate a significant feature with a strike of 15-20°.

It was predicted that NE-3 was probably composed of a number of one-to-a-few-metres wide subzones alternating with slabs of less fractured and altered rock and was associated with several dykes of fine-grained granite and some mylonites in the Småland granite. Some open fractures (narrow fracture zones) in NE-3 were assumed to be highly conductive. Narrow fracture zones trending N-S, probably hydraulically connecting the NE-1/EW-5 system to NE-3, were also predicted.

The transmissivities evaluated from the tests in probe boreholes penetrating NE-3 were as predicted or higher.

The zone was very difficult to grout because of:

- temporary leakage through the tunnel face

- a complex zone structure with parts containing gouge.

The grout penetration out of the tunnel was estimated to be 3-11 m from the theoretical calculations and observations of grout (in boreholes drilled through the zone) with a videoscope.

6.2.4 Subproject NE-1

Fracture zone NE-1, which pre-investigations (geophysics and drilling) located at the southern end of Äspö, had during different tests exhibited high transmissivity (possible range $0.8 \cdot 10^{-4}$ to $8 \cdot 10^{-4}$ m^2/s). This zone was considered suitable for an extensive characterization and grouting experiment.

Before being entered, NE-1 was carefully characterized, both from ground level and from the tunnel. To complement boreholes drilled during the pre-investigations in the area around Äspö, four new percussion holes were drilled from ground level.

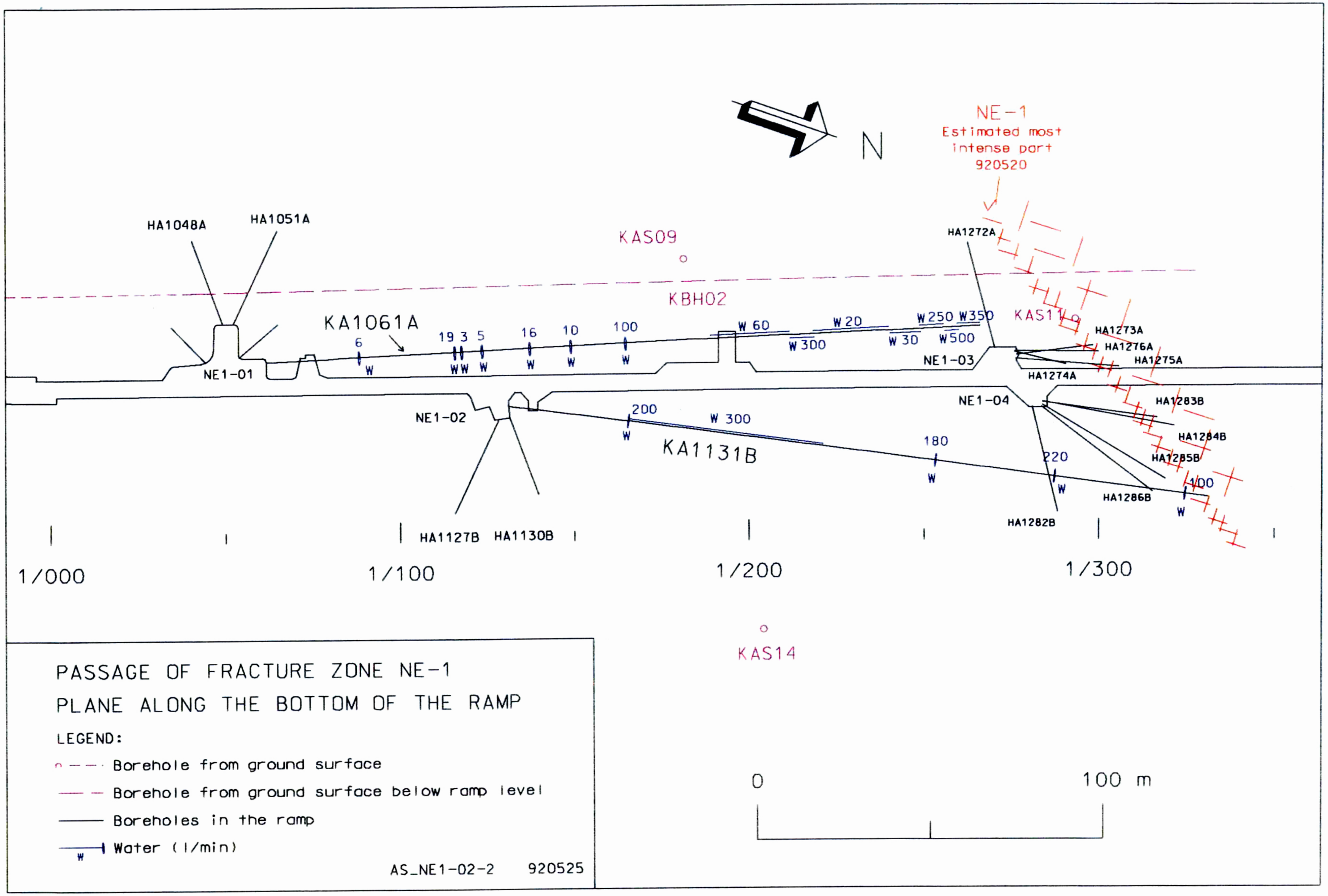
The first phase of the NE-1 experiment involved drilling two cored boreholes from niches approximately 200 m in front of the predicted position of NE-1, in order to locate the fracture zone more exactly. From each niche two percussion holes were also drilled to detect possible water-bearing fractures trending N-S. The boreholes were investigated to some extent by use of a spinner and borehole radar. In a second phase, 8 percussion boreholes (26-40 m) were drilled from two niches just in front of NE-1 to locate exactly the southern part of fracture zone NE-1. Two percussion boreholes were also drilled from each niche to detect possible water-bearing fractures trending N-S, Figure 6-2.

Fracture data from the mapping of tunnel section 1035 - 1265 m were analyzed with respect to orientations, lengths and mineralogy. Data from the core mapping of one of the cored holes were also used to augment the data base with information on mineralogy and fracture spacing.

The most common mineral fillings are in decreasing order of appearance, calcite, chlorite, epidote and iron oxides. Fractures with Fe oxides, red discolouration rim, epidote or quartz generally coincide with mapped fracture zones or faults. Calcite and chlorite are more homogeneously distributed.

The mean length of the fractures is 3.15 m (2.84 m for tunnel section 0-700 m). The longest fractures seem to be the oldest and are filled with pegmatite and quartz. Fractures filled with chlorite and calcite are significantly shorter.

Fractures with quartz and epidote generally strike NNE with a steep dip towards ESE. Pegmatite veins dip moderately towards SE. Fractures with oxidized walls are generally subhorizontal but minor portions strike steeply NW and NE. Chlorite and calcitic fractures have almost identical arrays: subhorizontal steep WNW and steep



c:/dgn/as_nel.dgn Dec. 4, 1992 16:47:35

Figure 6-2 Passage through fracture zone NE-1.

NNE. Fractures with Fe oxides generally strike EW with a dip between 45° and 90° N or S. Faults with fault gouge or fractures with filling of clay strike NS and WNW with a steep dip.

The mapped water-bearing fractures are steep with the same strike as the fractures with Fe oxides.

The flow-meter survey in the cored holes and the interference tests in the cored holes and the percussion holes drilled through the southern part of NE-1 all indicated a very conductive structure with a transmissivity around $4 \cdot 10^{-4}$ m^2/s. The responses indicated that the major conductive structure should be NE-1 but it could also be seen that conductive structures running N-S were probably in contact with NE-1.

After passage through the zone, NE-1 proved to be highly water-bearing and is assumed to trend N60°E and dip 70° to the north.

The most intensive part of the zone, which intersects the tunnel at 1300 m, is approximately 5 m wide and highly fractured or crushed in an approximately 1 m wide partly clay-altered section. The gouge material includes fragments of all sizes from centimetre size down to <0.125 mm.

The fragments are sharp angled, more or less tectonized granite and mylonite. Older fracture formations are also found as fragments, indicating that the gouge formation is a reactivation of an existing zone which developed under ductile-semiductile conditions. Some fragments are penetratively oxidized, probably before the fragmentation took place, and post-fragmentation precipitation of pyrite on the grain surfaces is visible, indicating that reducing conditions prevail. The clay minerals present in the gouge are mainly mixed-layer illite/smectite.

The intensive part of the zone with open, centimetre-wide fractures and cavities is surrounded by 10-15 m wide sections of more or less fractured rock. The tunnel intersects the zone along a length of approximately 30 m. The main rock type in the zone is Småland granite with minor inclusions of greenstone and mylonite, while the most intensive part of the zone is located in a 10 m wide section of fine-grained granite. A set of highly water-bearing structures - gently dipping towards the north - contributes to the complex character of zone NE-1.

The grouting work was very difficult in NE-1 due to high water pressure and highly fractured rock. A lot of regrouting was done. Grout penetration in NE-1 was estimated to be up to 15 m according to theoretical calculations and estimated to be more than 3-13 m according to the videoscope investigations of grout in boreholes drilled into NE-1. The porosity of NE-1 close to the tunnel was estimated at 0.3-1.0%.

After a period of very extensive grouting the most intensive part of NE-1 could finally be passed.

6.3 REDOX EXPERIMENT IN BLOCK SCALE

The objectives of the experiment are to evaluate the oxygen reduction rate in a water- conducting fracture zone and to evaluate the effects of having an oxidising front penetrate a previously reducing fracture system. Both effects on groundwater chemistry and effects on fracture minerals will be investigated.

6.3.1 Background and purpose

During the operating phase, when the repository is kept open for the emplacement of the spent fuel canisters, the drainage of groundwater into the tunnels will cause an enhanced water circulation in the surrounding rock mass. This water circulation causes oxygenated surface water to be transported to great depth. An increase of the flow of infiltrating surface water by one order of magnitude might cause oxygenated water, which is normally reduced at a depth of a few tens of metres, to be drawn to several hundred metres depth. Such a situation might cause an oxidation of the fracture minerals in the water-conducting fractures all the way from the surface down to the repository. The consequences of this would be that, in the post closure phase, radionuclides oxidised by the radiolysis might be transported in an oxidised form through the geosphere from a leaking canister up to the surface.

A comparison between oxidising and reducing conditions was made in the KBS-3 safety analyses. The calculations, with all other parameters equal, showed that the dose to man was two orders of magnitude higher in the oxidising than in the reducing conditions.

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

The effect of drainage into the tunnel system has not been specifically investigated in previous work. The experiment is located in a fracture zone at a depth of 70 metres below the surface. Breakthrough of oxidising surface water is expected to occur at this location.

6.3.2 Operation

Before the tunnel reached the fracture zone, a borehole was drilled through it. The borehole was sampled immediately, indicating that the water was stagnant with a salinity approximately twice that of the surrounding Baltic Sea. Two weeks after the tunnel had reached the fracture zone, the salinity and iron content of the inflowing water had decreased to zero. Afterwards the salinity and the iron content increased again.

The breakthrough of surface water and oxygen was calculated based on the estimated water inflow to the tunnel, but before the fresh water reached the tunnel /6-2/.

The drill cores have been carefully mapped with respect to fracture and bulk rock minerals. The same boreholes will be overcored after oxygen breakthrough and the mapping repeated. Appropriate analyses will be made in order to find out how much of the minerals have reacted.

Water samples are regularly collected and analyzed for principal constituents and redox-sensitive elements. Isotopic analyses are also made in order to facilitate interpretation of the complex flow situation. The results are compiled and will be presented in a common report. Such reports will be published once a year until the project in finished. A scientific coordinator has been appointed to the project.

Conditions in the fracture zone were monitored during 1992 and the data evaluated. TVO joined the Äspö project with a specific request to participate in the redox experiment.

6.3.3 Reporting

The results of the initial investigations were published in a Progress Report /6-3/ and the results from 1992 are currently being compiled. The ongoing reporting is done three times a year within the project group. Detailed planning is done by the scientific coordinator supported by a few persons from the project group. Evaluation of the observed geohydrochemical processes taking place in the fracture zone was carried out in 1992.

6.4 INVESTIGATIONS FOR THE LAYOUT

The layout of the underground excavations for the Äspö HRL was based on the geological data obtained from surface and borehole investigations /1-6/. The objective of the layout was to avoid major water-conducting fracture zones.

During the excavation of the tunnel, supplementary investigations will be performed in order to check and up-date the geological model. If necessary the layout will be changed so that the facility is constructed in good rock. This approach is termed "design-as-you-go".

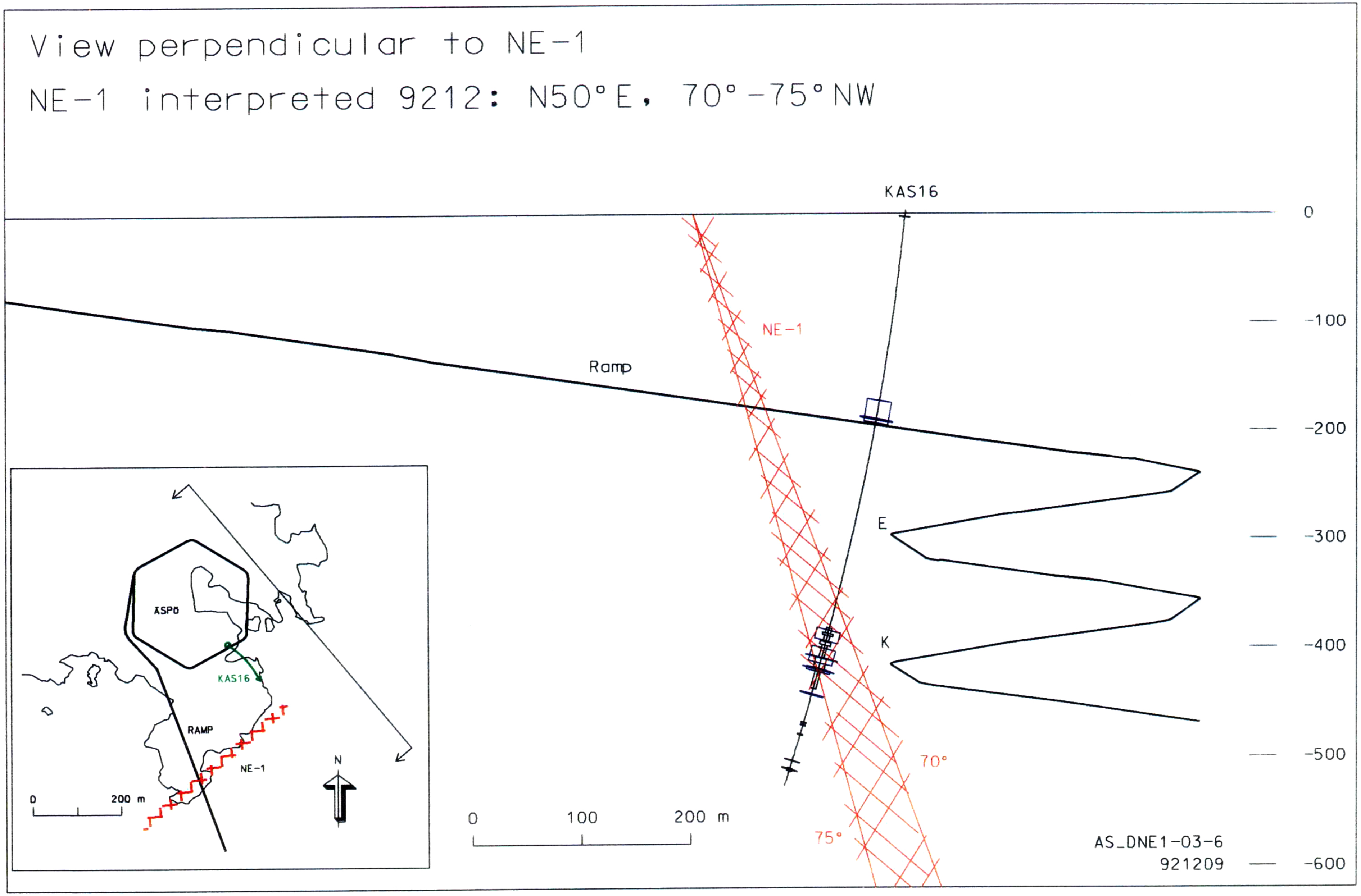
In order to avoid the fracture zone NE-1 in the spiral, it was decided to conduct supplementary investigations comprising core drilling (KAS16), hydrotests and radar measurements in the borehole, seismic investigations in the tunnel and a study of fracture minerals in borehole KAS16 in order to compare minerals in the tunnel.

The data collected in these investigations, aimed at determining the location and orientation of NE-1 relative to the tunnel spiral, clearly show that the intensely fractured part of KAS16 intersected at a depth of 390-450 m corresponds to NE-1. In KAS16, NE-1 consists of three major branches which intersect the borehole at about 400, 420 and 450 m (Figure 6-3).

Geochemical studies of NE-1 in the Access Ramp and the crushed sections in KAS16 (400-450 m) reveal many similarities especially with regard to the composition and character of the gouge material /6-4/.

The previous hydraulic tests in NE-1 have shown transmissivities of the same order of magnitude as the tests performed in KAS16: The pressure responses in other boreholes drilled through NE-1 also seem to confirm that KAS16 is drilled through NE-1 /6-5/.

The estimated width of NE-1 - at a depth of approximately 200 m in the Access Ramp - is 26 m. The corresponding width of the zone, at a depth of approximately 400 m in KAS16, is 32 m. Based on the observations of NE-1 in the Access Ramp and the crushed section (400-450 m) in KAS16, an orientation of N50°E/75°NW seems to be the most likely for NE-1.



c:/dgn/as_dne1.dgn

Figure 6-3 Investigation in borehole KAS 16.

The radar and seismic investigations give approximately the same orientation for NE-1. It should be noted that orientation is actually determined for two different parts of the fracture zone. The seismic orientation is based on data relatively close to the access ramp, while the radar orientation is based on data close to borehole KAS16. The difference in estimated orientation between the two methods is approximately 5° which implies that NE-1 is essentially planar. The average orientation of NE-1 is estimated to strike N45°E and dip 75° NW.

With this orientation, the upper surface of NE-1, taken to be 390 m in KAS16, would intersect a vertical line through the eastern corner of the spiral at a vertical depth of 600 m. If the dip is taken to be 70°, which is still within the error margin, NE-1 would intersect this line at a depth of 540 m. Hence, it seems to be very probable that NE-1 will not intersect the tunnel spiral with its currently planned layout. It should be understood that this conclusion is made based on the assumption that NE-1 is a planar feature.

In order to locate NE-1 more exactly, supplementary investigations are planned to be performed when the tunnel excavation approaches the zone.

6.5 ROCK VOLUME DESCRIPTIONS

As in ordinary underground construction, it is advantageous if site characterization, design and performance assessment can be integrated and treated as an iterative process, "design-as-you-go". The safety of the repository is very dependent on the properties of the near field around the canisters. It is thus important to describe the properties of this near field, both as averages and in terms of their variability. Based on pre-investigation data it is possible to determine parameters such as hydraulic conductivity (average, variance) on a characterized site. In connection with performance assessment it is of interest to describe the variation in the near field over the repository volume e g based on pre-investigation data. These assessments can then be checked against the data obtained during construction of the laboratory.

With regard to repository siting and excavation, it is of interest to develop a prediction methodology to

- Assess the possibilities of making robust rock volume descriptions (average, variance) based on pre-investigation data.

- Compare the predictions with descriptions based on data gathered during construction.

- Establish robust methodologies to determine where and if boundaries exist between rock volume domains.

A project for these purposes was initiated during 1992. The goals of the "Rock Volume Description" programme for 1992 have been to:

- prepare a Progress Report that compares the conceptual models obtained at different stages in the pre-investigation phase for the target volume Äspö - Hålö

- study the key aspects of the rock volume descriptions mentioned above

- prepare some examples of pilot study predictions using Äspö HRL data.

In regard to the first goal a Technical Document has been prepared which conforms to the iterative process of prediction, data collection and validation. The TD supports the ongoing work of preparing a Progress Report on development of the conceptual models in the siting, site description and prediction stages for the Äspö HRL. This Progress Report is scheduled to be published in May, 1993.

During the autumn of 1992 a separate project was initiated for the other studies mentioned above. Statistical methods during the Prediction Phase were reviewed. Furthermore, special interest was devoted to procedures for observation, characterization and prediction.

A proposed strategy for making predictions was tested along the access tunnel between roughly section 700 and 1300 m. The properties studied were "rock type distribution", "fracture frequency" and "transmissivity". The objective of this study was to characterize and predict the variable properties. Two prediction targets were set up. The first one was a site-specific prediction at tunnel section 1500 m. The second was the rock volume circumscribed by the first tunnel loop.

"Predictability" is now being assessed and a Progress Report is scheduled to be published in spring, 1993.

7. PREPARATION OF THE RD&D IN THE OPERATING PHASE

The main experiments to be performed in the Operating Phase of the Äspö HRL are defined in the SKB RD&D Programme 1992 /1-10/ which was published in September 1992. The Operating Phase will start in 1995 and is foreseen to continue for 10-15 years or possibly a longer period of time. The activities of the Operating Phase will focus on meeting stage goals 3, 4, and 5 defined for the Äspö HRL:

3 **Test models for groundwater flow and radionuclide migration**

4 **Demonstrate construction and handling methods**

5 **Test important parts of the repository system**

The preparations for the RD&D work in the Operating Phase have during 1992 been aimed at identifying suitable experiments to meet the stage goals defined above. Following the publication of the SKB RD&D Programme the continued work has focused on formulating a strategy for detailing test plans, review, and initiation of work. The RD&D work will be defined in a series of Test Plans, one for each major experiment. Draft test plans will be prepared approximately one year before the described experiment is planned to start. The draft test plan will then be sent to the Task Force on Modelling of Groundwater Flow and Transport of Solutes for review (the SAC will at this stage receive a copy for information). The intention is to engage the Task Force in scoping calculations to assess wether the experiments can meet the set goals. Test plans will then be revised according to comments received and submitted to SAC and TCB for review. After a final revision the Test Plan will be published as a Progress Report and the formal decision to execute the work will be taken.

To assure that the important issues for each experiment are addressed, a common format has been defined for the Test Plans. Each Test Plan should present the objectives for the work to be done, the rationale for doing the work, the concepts on which the experiment is based, and a detailed description of the experimental tasks.

The first set of test plans has been prepared for the following experiments (for a brief description of the experiments see /1-10/:

- Flow and Transport on a Detailed Scale
- Flow and Transport on a Block Scale
- Disturbed Zone Effects - Two-Phase Flow

These test plans were distributed in early January 1993. The intention is to initiate some of these experiments already during 1993. The exact time schedule will depend on the progress of the construction of the laboratory.

8 QUALITY ASSURANCE PROGRAMME

SKB is required, and recognizes the need, to implement formal Quality Assurance (QA) programmes for a number of its areas of management, such as repository site investigations. The Quality Assurance Manual for the HRL is a document that will be developed and refined as the activities of the HRL develop. A more complete and proven manual should be available before the repository site investigations are made.

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

A structure for the HRL General Quality Assurance Handbook was prepared in 1992. The general handbook describes the purpose and scope of the QA programme.

- organizational and administrative procedures
- quality management
- overall and master project plans
- documents and records
- procurement procedures.

Parallell to this general QA handbook, twenty detailed quality assurance manuals for the different disciplines and tasks for investigations and rock works were started in 1992 and will be completed in 1993, Figure 8-1.

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

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

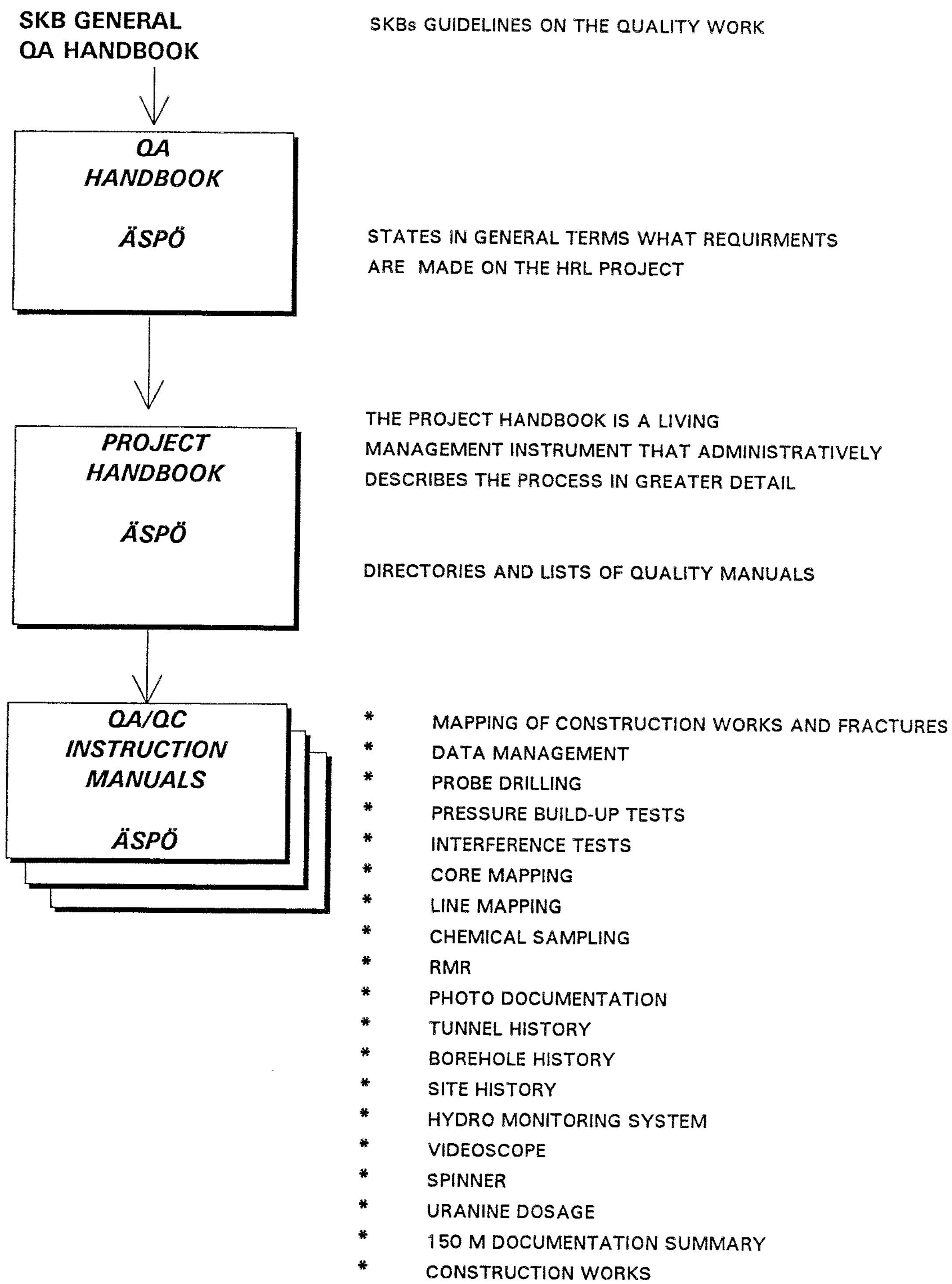


Figure 8-1 Overview of the Äspö HRL QA-structure.

9 INTERNATIONAL PARTICIPATION

9.1 GENERAL

The construction of the Äspö Hard Rock Laboratory (HRL) has attracted significant international attention. The experience being gained at Äspö concerning, for instance, site investigation methodologies, rock excavation and characterization techniques and collection of data of importance to safety assessments, will be of interest to most countries that have their own plans for deep geological disposal of nuclear waste. SKB is open to and welcomes international participation in the project. During 1992 cooperation agreements were signed with the following foreign organizations:

- Commissariat à l'Energie Atomique - Agence Nationale pour la Gestion des Dechets Radioactifs (ANDRA), France, March 30, 1992

- Teollisuuden Voima Oy (TVO), Finland, May 15, 1992

- United Kingdom Nirex Limited (NIREX), Great Britain, September 17, 1992.

- United States Department of Energy (USDOE), USA, December 16, 1992

Since the following organisations signed their agreements in 1991, there are now 7 organisations participating in international cooperation at the Äspö Hard Rock Laboratory:

- Atomic Energy of Canada Limited (AECL), Canada, January 21, 1991

- The Power Reactor and Nuclear Fuel Development Co (PNC), Japan, May 14, 1991

- The Central Research Institute of the Electric Power Industry (CRIEPI), Japan, October 22, 1991.

PNC and CRIEPI each has a scientist attached to the project working at the Äspö site office.

9.2 JOINT PROJECTS

The different organisations that have signed agreements on cooperation in the work at Äspö, have expressed somewhat different main areas of interest. All organisations except for AECL have modelling groups for geohydraulic flow that participate in the special Task Force that has been set up, see 9.3 below.

Main interest areas for the different organisations are: **AECL**: General information exchange on site characterization and in-situ experiments at underground research facilities. **PNC**: Improved understanding of specific key processes relevant to repository performance. Validation of specific models on data collection procedures. Optimization of site characterization methods. Numerical modelling of groundwater flow and tracer transport. **CRIEPI**: Improved understanding of specific key processes relevant to repository performance. Validation of specific models on data collection procedures. Optimization of site characterization methods. Numerical modelling of groundwater flow and tracer transport. **ANDRA**: Groundwater flow modelling. Characterization of fracture zones. Instrumentation development. **TVO**: Groundwater modelling. Measurement of flow in-situ Hydrogeochemistry. **NIREX**: Development and validation of flow and transport models. Design of experiments. Development of geotechnical logging procedures. **US DOE**: Flow and transport characterization in fractured rock.. Disturbed zone effects. Geochemical investigations using radiogenic isotope methods. Geochemical modelling. Integration of construction and testing activities.

9.3 TASK FORCE ON MODELLING OF GROUNDWATER FLOW AND TRANSPORT OF SOLUTES

The Task Force was established in 1992. Gunnar Gustafson, Chalmers University, will act as the Task Force Chairman and Anders Ström, SKB, as the Task Force Secretary.

This first meeting of the group was held at Simpevarp, Sweden, near the island of Äspö on the 26-27th of August. 17 participants from 8 different organisations took part in this initial meeting. UK Nirex and US DOE were represented by observers.

A charter for the Äspö Task Force was drawn up. The LPT-2 pumping and tracer field experiment was defined as Task No 1.

The work in 1993 was mainly focused on preparing and delivering documentation and data for the modelling groups within the Task Force. A first set of data was distributed in October. It contained experimental data from the LPT-2 test and some additional information useful for numerical modelling exercises. Performance measures were also specified.

Furthermore, a set of data containing fracture data of interest for the LPT-2 experiment was delivered. The data were extracted from the

SKB database GEOTAB and can be divided into three different categories:

- fracture mapping from outcrops;
- corelogs from 12 boreholes on Äspö;
- tunnel mapping data.

Finally, data from water injection tests in single boreholes were distributed.

Some parts of the experimental programme for the operational phase of the laboratory have been sent out for review to the Task Force. Some of these experiments will eventually become tasks within the Task Force group.

Groundwater flow results, from the LPT-2 experiment are expected in time for the next Task Force meeting on March 9-11, 1993.

10 PUBLIC RELATIONS AND INFORMATION ACTIVITIES

The Visitor's Cavern was visited by more than two thousand people, about twenty percent of whom come from other countries, Figure 10-1.

"Äspö Day" is now a tradition and is held every year on the last Sunday in April. New this year was an open-air service. Several of the principal investigators were involved in the guided tours given. More than 500 people turned up.

More than ten lectures were held within the local community.

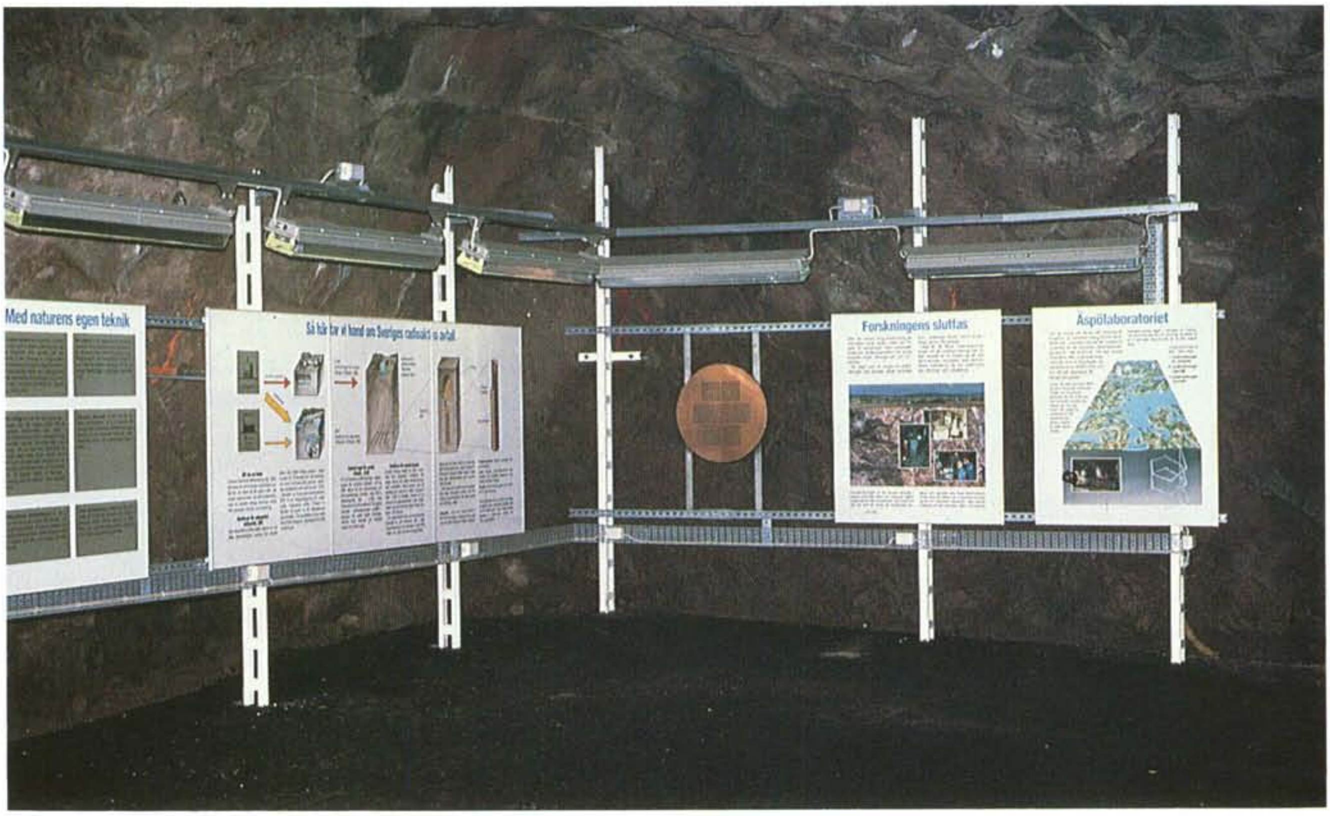


Figure 10-1 The Visitor's Cavern.

REFERENCES

/1-1/ **SKB (1986)**. "Handling and final disposal of nuclear waste. Programme for Research, Development and other Measures, R&D Programme 1986". SKB, Stockholm.

/1-2/ **Gustafson G, Stanfors R, Wikberg P (1988)**. Swedish Hard Rock Laboratory. First evaluation of pre-investigations 1986-87 and target area characterization. SKB Technical Report, TR 88-16.

/1-3/ **Gustafson G, Stanfors R, Wikberg P (1989)**. Swedish Hard Rock Laboratory: Evaluation of 1988 year pre-investigations and description of the target area, the island of Äspö. SKB Technical Report, TR 89-16.

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

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

/1-6/ **Wikberg P, Gustafson G, Rhén I, Stanfors R (1991)**. Äspö Hard Rock Laboratory. Evaluation and conceptual modelling based on the pre-investigations 1986-1990. SKB Technical Report, TR 91-22.

/1-7/ **Gustafson G, Liedholm M, Rhén I, Stanfors R, Wikberg P (1991)**. Äspö Hard Rock Laboratory. Predictions prior to excavation and the process of their validation. SKB Technical Report, TR 91-23.

/1-8/ **Rhén I, Svensson U (eds), Andersson J-E, Andersson P, Eriksson C-O, Gustafsson E, Ittner and Nordqvist R. (1992)**. Äspö Hard Rock Laboratory. Evaluation of the combined longterm pumping and tracer test (LPT2) in borehole KAS06, SKB, SKB Technical Report, TR 92-32

/1-9/ **Smellie J, Laaksoharju M (1992)**. Äspö Hard Rock Laboratory. Final evaluation of thehydrogeochemical pre-investigations in relation to existing geologic and hydraulic conditions. SKB Technical Report, TR 92-31.

/1-10/ **SKB (1992).** Treatment and final disposal of nuclear waste. RD&D Programme 92.

/1-11/ **SKB (1992).** Treatment and final disposal of nuclear waste. RD&D Programme 92, Äspö Hard Rock Laboratory Background Report.

/5-1/ **Stanfors R, Gustafson G, Munier R, Olsson P, Rhén I, Stille H, Wikberg P (1992).** Evaluation of geological predictions in the tunnel 0-0/700 metres. SKB, Progress Report PR 25-92-02.

/5-2/ **Olsson O (1992).** Characterization ahead of the tunnel front by radar and seismic methods - a case history from the Äspö Hard Rock Laboratory.
SKB, Progress Report PR 25-92-01.

/5-3/ **Forsmark T (1992).** Information for numerical modelling 1992. General information and calibration cases for LPT2 and tests in KA 1061 A and KA 1131 B. SKB, Progress Report PR 25-92-14.

/5-4/ **Svensson, 1992 a.** Modelling tracer transport in fractured porous media. An evaluation of concepts and methods using the LPT2 field experiment. SKB, Progress Report PR 25-92-12.

/5-5/ **Svensson U, 1992 b.** Refinements of the numerical model of the Äspö Hard Rock Laboratory. SKB Progress Report PR 25-92-13.

/5-6/ **Ittner T, Gustafsson E, Andersson P, Eriksson C O (1991).** Äspö Hard Rock laboratory. Groundwater flow measurements at Äspö with the dilution method. SKB Progress Report PR 25-91-18.

/5-7/ **Andersson P, Ittner T, Gustafsson E (1992).** Groundwater flow measurements in selected sections at Äspö before tunnel passage of fracture zone NE-1. SKB Progress Report PR 25-92-05.

/5-8/ **Ittner T (1992).** Groundwater flow measurements (TP2) in selected sections at Äspö after tunnel passsage of fracture zone NE-1. SKB Progress Report PR 25-92-17.

/5-9/ **Almén K-E, Johansson B. 1992.** The Hydro Monitoring System (HMS) of the Äspö Hard Rock Laboratory. SKB, Progress Report PR 25-92-09.

/6-1/ **Rhén I, Stanfors R, 1992.** Passage through fracture zones. Evaluation of passage through fracture zones NE-1, EW-7 and NE-3. SKB, Progress Report PR 25-92-18.

/6-2/ **Banwart S, Gustafsson E (1991).** Scoping calculations of surface water and redox front break through. SKB Progress Report, PR 25-91-06.

/6-3/ **Andersson P, Ittner T, Gustafsson E, 1992.** Groundwater flow measurements in selected sections at Äspö before tunnel passage of fracture zone NE-1. SKB Progress Report PR 25-92-05.

/6-4/ **Landström O, Tullborg E-L (1993).** Results from a geochemical study of zone NE-1, based on samples from the Äspö tunnel and drillcore KAS16 (395 m to 451 m). SKB Progress Report PR 25-93-01.

/6-5/ **Forsmark T (1992).** Hydraulic tests at Äspö in KAS16. SKB Progress Report PR 25-92-15.

APPENDIX A

ÄSPÖ HARD ROCK LABORATORY

LIST OF PAPERS AND ARTICLES PUBLISHED IN 1992

Blasting Damage in the Ramp of the SKB Underground Laboratories at Äspö in Sweden - Verification of Predictions based on Vibration Measurements
Ouchterlony F, Nakagawa, K
JSCE Rock Mechanics Meeting, Tokyo, February 1992

The Äspö Hard Rock Laboratory - some notes on the current status.
Bäckblom G.
Lecture at the Bergmekanikdagen 1992.

Blasting Damage Investigations in the Äspö Hard Rock Laboratory.
Stanfors R.
Lecture at the Bergmekanikdagen 1992

Borrprecision av störst vikt vid undvikande av sprängskador?
Hamberger U, Jönsson L.
Väg- och Vattenbyggaren 3/92.

Cementbaserade injekteringsmedels egenskaper
Håkansson U.
Nordiskt symposium i berginjektering, Göteborg, 1992-09-24.

Erfarenheter från Äspö, från teori till praktik
Stille H, Gustafson, G, Olsson P.
Nordiskt symposium i berginjektering, Göteborg, 1992-09-24.

The zone of disturbance around blasted tunnels at depth
Pusch R, Stanfors R.
In. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol 29, No 5. pp 447-456, 1992.
Pergamon Press Ltd.

Mixing calculations of fresh/saline groundwater
Laaksoharju, M.
Saltvattenseminariet. 1992.

Långsiktig överföring mellan geosfär och biosfär beskriven genom sedimentstudier vid Äspö HRL.
Sundblad B.
Presentation vid Nordisk Hydrologisk Konferens, Alta, augusti 1992.

Experiences from geohydrochemical investigations at the Äspö HRL site in Sweden.
Wikberg P, Smellie J, Wallin B, Tullborg, E-L.
Presentation at the OECD/NEA Workshop on paleo-hydrogeological methods and their application for radioactive waste disposal, 9-10 November 1992.

List of SKB reports

Annual Reports

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

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

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

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

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

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

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

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

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

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

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

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

1990
TR 90-46
SKB Annual Report 1990
Including Summaries of Technical Reports Issued during 1990
Stockholm, May 1991

1991
TR 91-64
SKB Annual Report 1991
Including Summaries of Technical Reports Issued during 1991
Stockholm, April 1992

1992
TR 92-46
SKB Annual Report 1992
Including Summaries of Technical Reports Issued during 1992
Stockholm, May 1993

Technical Reports
List of SKB Technical Reports 1993

TR 93-01
Stress redistribution and void growth in butt-welded canisters for spent nuclear fuel
B L Josefson[1], L Karlsson[2], H-Å Häggblad[2]
[1] Division of Solid Mechanics, Chalmers University of Technology, Göteborg, Sweden
[2] Division of Computer Aided Design, Luleå University of Technology, Luleå, Sweden
February 1993

TR 93-02
Hydrothermal field test with French candidate clay embedding steel heater in the Stripa mine
R Pusch[1], O Karnland[1], A Lajudie[2], J Lechelle[2], A Bouchet[3]
[1] Clay Technology AB, Sweden
[2] CEA, France
[3] Etude Recherche Materiaux (ERM), France
December 1992

TR 93-03
MX 80 clay exposed to high temperatures and gamma radiation
R Pusch[1], O Karnland[1], A Lajudie[2], A Decarreau[3],
[1] Clay Technology AB, Sweden
[2] CEA, France
[3] Univ. de Poitiers, France
December 1992

TR 93-04
Project on Alternative Systems Study (PASS).
Final report
October 1992

TR 93-05
Studies of natural analogues and geological systems.
Their importance to performance assessment.
Fredrik Brandberg[1], Bertil Grundfelt[1], Lars Olof Höglund[1], Fred Karlsson[2], Kristina Skagius[1], John Smellie[3]
[1] KEMAKTA Konsult AB
[2] SKB
[3] Conterra AB
April 1993

TR 93-06
Mineralogy, geochemistry and petrophysics of red coloured granite adjacent to fractures
Thomas Eliasson
Chalmers University of Technology and University of Göteborg, Department of Geology, Göteborg, Sweden
March 1993

TR 93-07
Modelling the redox front movement in a KBS-3 nuclear waste repository
L Romero, L Moreno, I Neretnieks
Department of Chemical Engineering,
Royal Institute of Technology, Stockholm, Sweden
May 1993