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ÄSPÖ HRL – Geoscientific evaluation 1997/1

Overwiew of site characterization 1986–1995

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March 1997

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ÄSPÖ HRL - GEOSCIENTIFIC EVALUATION 1997/1

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Information on SKB technical reports from1977-1978 (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), 1991 (TR 91-64), 1992 (TR 92-46), 1993 (TR 93-34), 1994 (TR 94-33) and 1995 (TR 95-37) is available through SKB.

ÄSPÖ HRL

GEOSCIENTIFIC EVALUATION 1997/1

OVERVIEW OF SITE CHARACTERIZATION 1986-1995

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FOREWORD

The booklet Äspö Hard Rock Laboratory – 10 years of research, available from the SKB, provides the reader with a popular review of the achievements. This report is No 1 of six summarizing the pre-investigation and construction phase of the Äspö Hard Rock Laboratory.

The reports are:

1 Stanfors R, Erlström M, Markström I.
Äspö HRL - Geoscientific evaluation 1997/1.
Overview of site characterization 1986-1995
SKB TR 97-02.

2 Rhén I (ed), Bäckblom (ed), Gustafson G, Stanfors R, Wikberg P.
Äspö HRL - Geoscientific evaluation 1997/2.
Results from pre-investigations and detailed site characterization.
Summary report.
SKB TR 97-03.

3 Stanfors R, Olsson P, Stille H .
Äspö HRL - Geoscientific evaluation 1997/3.
Results from pre-investigations and detailed site characterization.
Comparison of predictions and observations.
Geology and Mechanical stability.
SKB TR 97-04.

4 Rhén I, Gustafson G, Wikberg P.
Äspö HRL - Geoscientific evaluation 1997/4.
Results from pre-investigations and detailed site characterization.
Comparison of predictions and observations.
Geohydrology, Groundwater chemistry and Transport of solutes.
SKB TR 97-05.

5 Rhén I (ed), Gustafson G, Stanfors R, Wikberg P.
Äspö HRL - Geoscientific evaluation 1997/5.
Models based on site characterization 1986-1995.
SKB TR 97-06.

6 Almén K-E (ed), Olsson P, Rhén I, Stanfors R, Wikberg P
Äspö Hard Rock Laboratory
Feasibility and usefulness of site investigation methods.
Experiences from pre-investigation phase.
SKB TR 94-24

The background and objectives of the project are presented in a background report to SKB R&D Programme 1989 (Hard Rock Laboratory), which contains a detailed description of the HRL project.

The purpose of this report, No. 1, is to present an overview of all investigations performed during both the pre-investigation and construction phase. The evaluation of the pre-investigation is presented in *Report 2-4*. The 1996 models over Äspö HRL, the concepts behind it and some comments regarding how the model has developed based on data from the pre-investigation and construction phase of Äspö HRL are presented in *Report 5*.

March 1997

Roy Stanfors Mikael Erlström Ingemar Markström

ABSTRACT

Geological investigations for the Äspö Hard Rock Laboratory in the region around Äspö began in 1986. Äspö was selected as the laboratory site in 1988 and construction of the underground facility started in October 1990. Construction of the laboratory was completed in the summer of 1995.

This report gives a comprehensive compilation of the different investigations performed during the pre-investigation phase 1986-1990 and the excavation phase 1990-1995. The information is mainly compiled in CAD-generated maps, tables and illustrations in which the reader can gather information concerning the scope of work as well as references to more detailed reports for further study.

ABSTRACT (Swedish)

Geologiska förundersökningar för Äspölaboratoriet påbörjades 1986. 1988 utsågs Äspö som lämplig plats för laboratoriet och i oktober 1990 påbörjades utsprängningen av undermarksdelarna. Anläggningen var färdigställd 1995.

Denna rapport ger en sammanställning av alla undersökningar som utförts såväl under förundersökningsskedet (1986-1990) som under konstruktionsskedet (1990-1995). Information redovisas huvudsakligen på CAD-ritningar och i tabeller med referens till rapporter.

TABLE OF CONTENTS

1 INTRODUCTION

The aim of this report is to compile all investigations performed for the Äspö Hard Rock Laboratory during 1986-1995. In *Chapter 2* of the report all the different pre-investigations are listed in chronological order (*Tables 2-1* to *2-3*) with figures and references. *Chapter 3* comprises an overview of complementary surface investigations performed after the pre-investigations. *Chapter 4* comprises an overview of all investigations performed in the tunnel during the excavation phase.

Roy Stanfors and Mikael Erlström compiled the report. CAD-generated maps and illustrations were performed by Ingemar Markström and Gitte Isacsson.

An overview of the pre-investigations (*Chapter 2* in this report) was presented in SKB TR 91-20. This report replaces TR 91-20.

1.1 INVESTIGATION DATABASE (SICADA)

Investigation data collected during the pre-investigation phase and the construction phase can be found in the SKB Site Characterisation Database System (SICADA). Three database applications are available:

SICADA/Diary	A graphical application for logging activities performed
SICADA/Finder	A graphical application for data retrieval
SICADA/Retriever	A text-based application for data retrieval (replaces previous database GEOTAB).

The SICADA/Diary application is used to log activities and capture data from the work performed. The activity log table is an activity diary and all selected activities are shown chronologically. All data has a time and user identification code.

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).

The SICADA/Retriever application is a classic text terminal programme 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.

2 OVERVIEW OF THE PRE-INVESTIGATIONS 1986-1990

Pre-investigations for the ÄHRL were made in several stages 1986-1990. The regional investigation area measured about 25 by 25 km, see *Figure 2-1*.

2.1 PRE-INVESTIGATION - SITING STAGE

The pre-investigations started with a regional survey comprising many different methods (magnetic, coaxial EM, Radiometric and two-station VLF). Gravity measurements and some ground geophysical profiles (magnetic and VLF) complemented the aerogeophysical survey on the islands of Ävrö and Äspö and in the Laxemar area.

Lineaments in the Simpevarp area were interpreted from different digital terrain models and solid rock was mapped to a scale of 1:10 000 in an area close to Simpevarp and to a scale of 1:50 000 in a larger, outer area. Fracture mapping and special tectonic studies were carried out with the main goal of describing the geometry of the fractures and characterizing the main sets of tectonic zones identified in the area.

An analysis was made of data from SGU Well Records and a compilation made of geohydrological data from the pre-investigations and construction works for the power plant and the CLAB interim storage facility for spent fuel, all in the Simpevarp area. Chemical data from the SGU Well Records were used to define the composition of the shallow groundwater in the area.

The investigation methods used in the first regional stage and the main issue of the surveys are presented in *Table 2-1* and *Figures 2-1, 2-2* and *2-3*.

2.2 PRE-INVESTIGATION - SITE DESCRIPTION STAGE

During investigation in 1987 drilling was performed in the areas of Ävrö, Äspö and Laxemar. A number of percussion boreholes were drilled to obtain preliminary information of the bedrock composition and hydraulic properties of the shallow portion of the bedrock. The shallow groundwater chemistry was analysed as well. On Äspö 12 percussion boreholes were drilled, at Laxemar seven and on Ävrö four percussion boreholes.

Three core boreholes (KAS[1] 02-04) were drilled based on a preliminary geological and geohydrological model of Äspö. The core borehole KLX 01 in the central part of a major block in the Laxemar area was drilled as a reference hole.

The solid rocks on Äspö were mapped to a scale of 1:2000.

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[1] 'K' stands for cored borehole, 'H' stands for percussion drilled boreholes, 'AS' stands for Äspö, 'AV' stands for Ävrö and 'LX' stands for Laxemar.

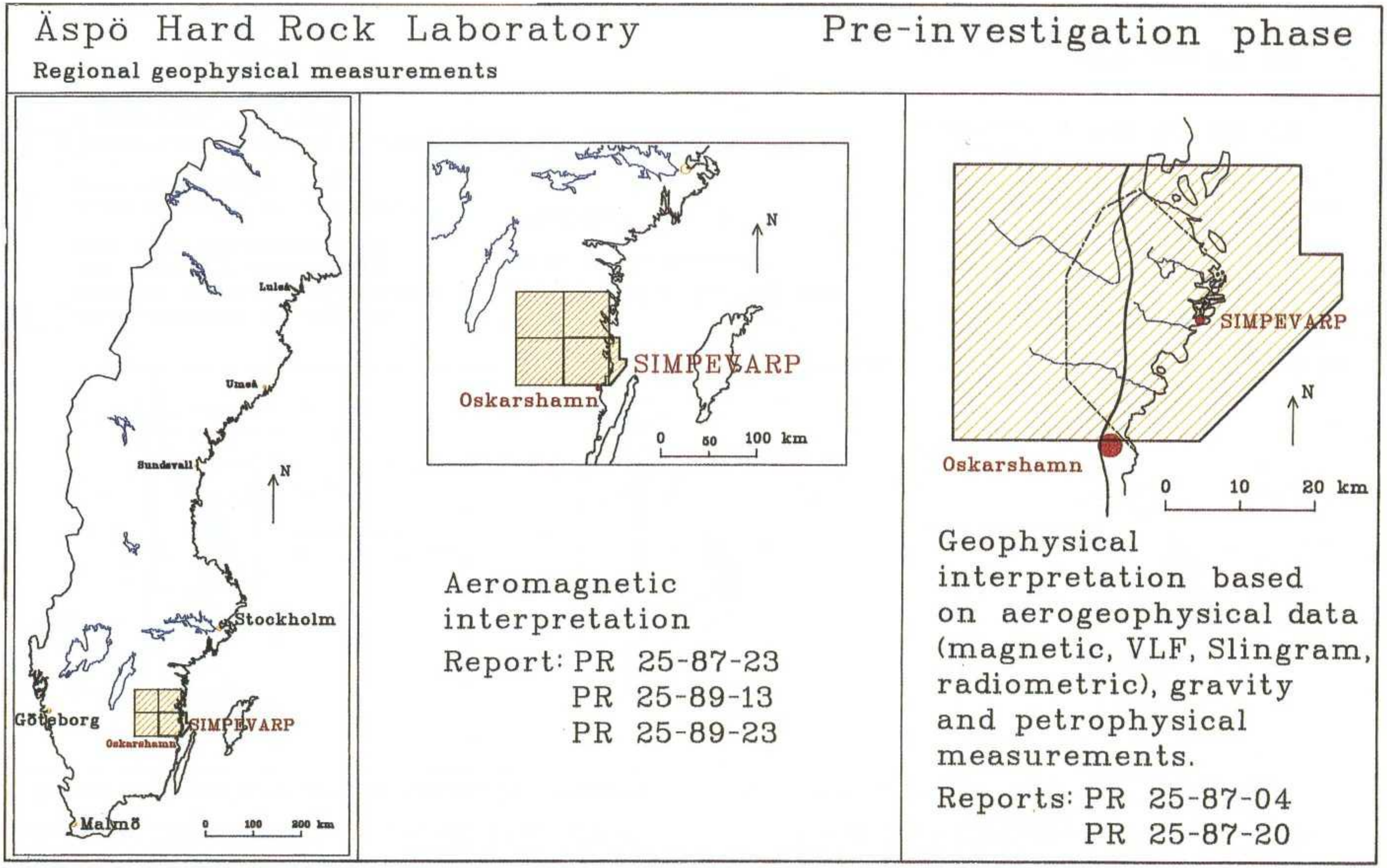

Figure 2-1. Regional geophysical measurement.

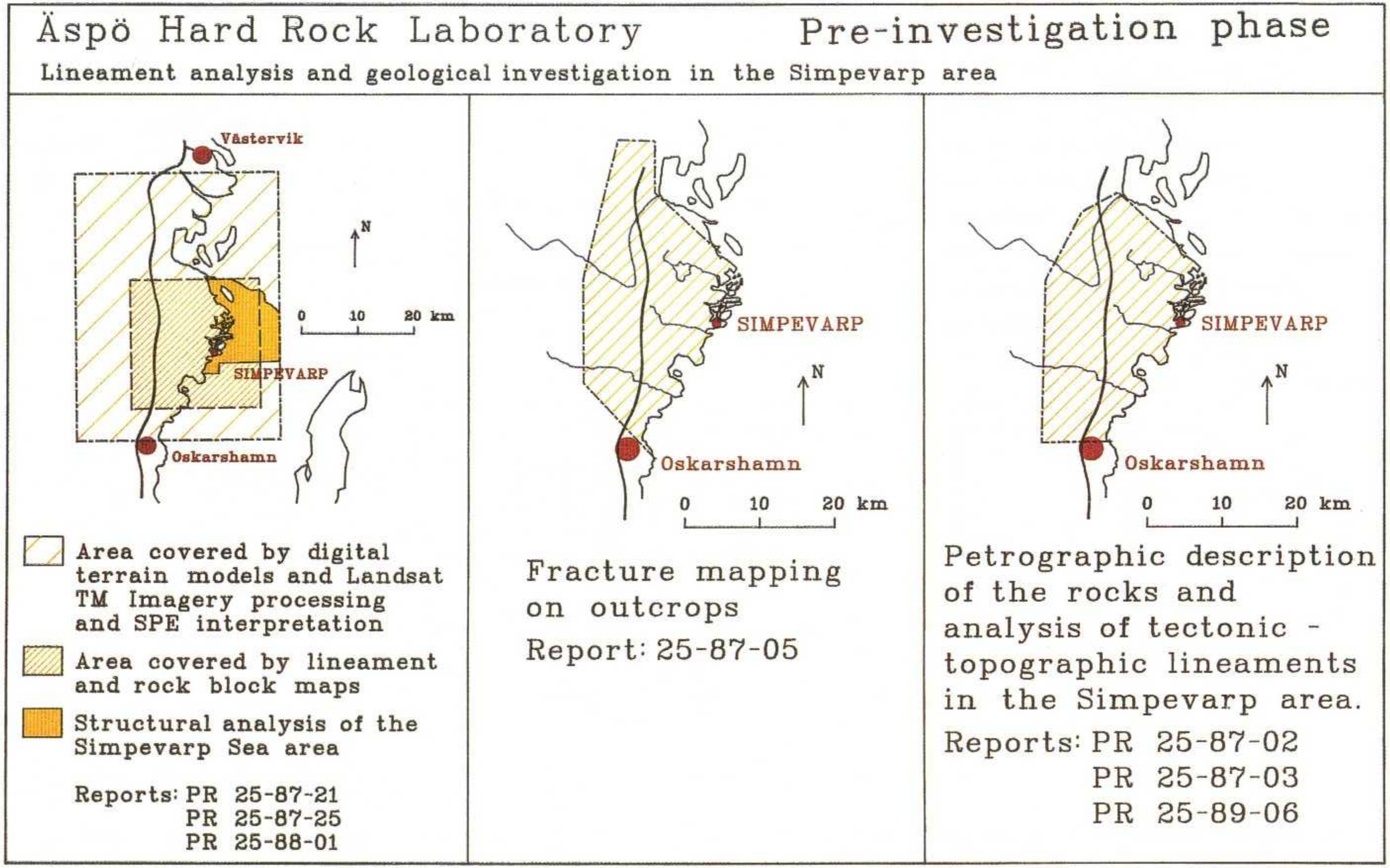

Figure 2-2. Lineament analysis and geophysical investigation in the Simpevarp area.

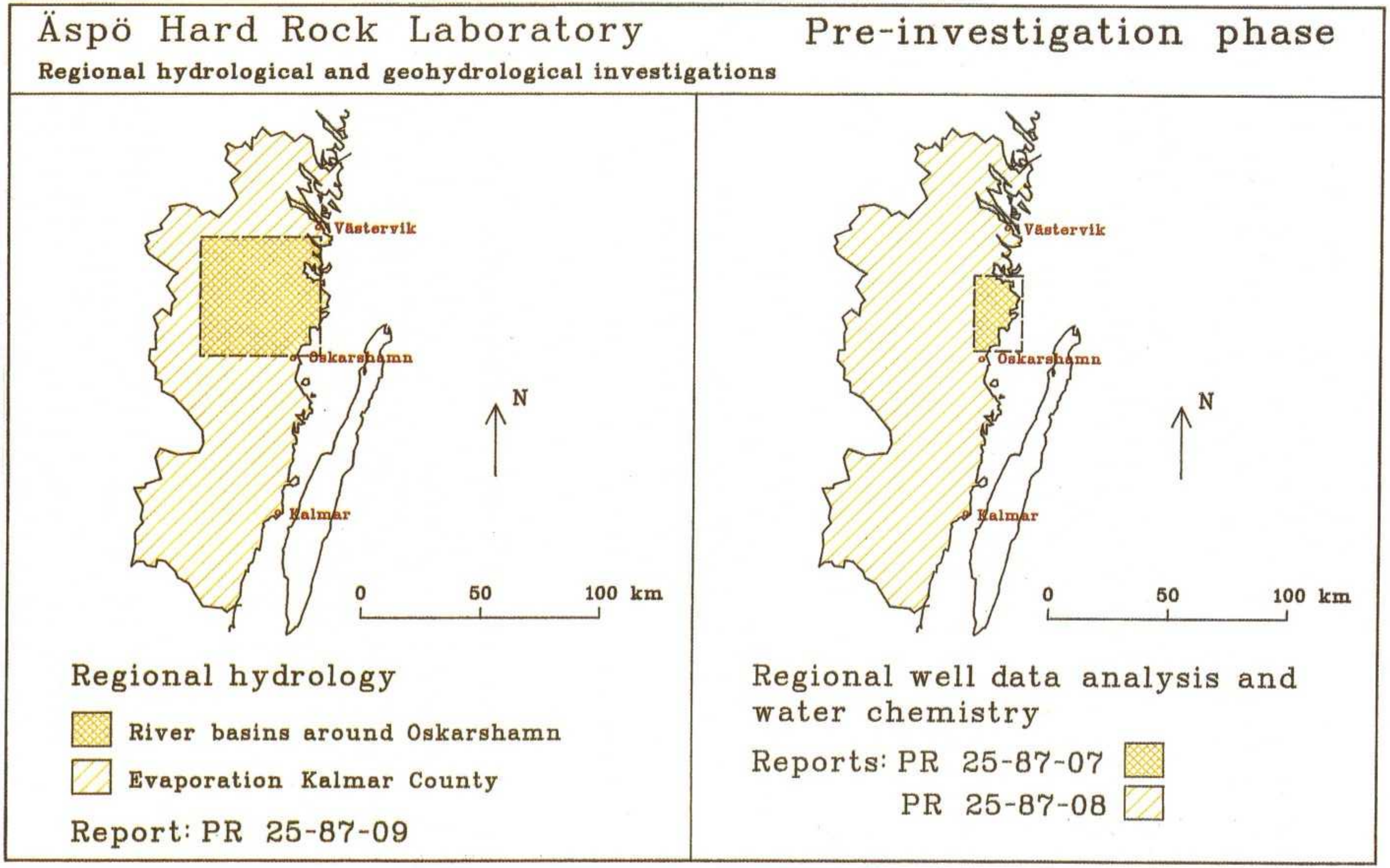

Figure 2-3. Regional hydrological and geohydrological investigations.

A very detailed study of lithology and fracturing was made along cleaned trenches across the island. A detailed structural analysis was made of terrain features on Äspö, based on the study of topographical maps to a scale of 1:4000, and with a contour interval of 1.0 m. Maps showing lineaments and rock blocks of different orders were presented.

A fracture mapping programme was executed on outcrops following the cleaned trenches. It included integrated results regarding strikes, dips and fracture densities, lengths and spacings of the fractures.

In order to investigate and delineate the local tectonic setting of the island of Äspö, detailed magnetic and electric mapping of the entire island was carried out during the autumn of 1988. Ground radar measurements were performed on the southern part of Äspö.

Transient interference pump tests were performed in the cored boreholes KAS 02 and KAS 03, and from these investigations major hydraulic conductors were identified. The surface hydrology of the Simpevarp area was compiled to provide basic input.

Detailed groundwater chemical analyses were made on the water sampled from conductive sections of boreholes KAS 02-04 and KLX 01. Additionally, percussion boreholes on Äspö, Laxemar and Ävrö were sampled in order to provide background information on the composition of shallow groundwater.

The methods used for the local scale investigations are presented in *Figures 2-4 to 2-12* and *Table 2-2*.

2.3 PRE-INVESTIGATION - PREDICTION STAGE

Based on the results from the local investigations the southern part of Äspö was selected as the most suitable location for the HRL. Four additional core boreholes were directed towards indicated zones of geological and hydraulic importance. They were drilled to a vertical depth of approximately 500 m. Short term pumping tests were made to find out the hydraulic connections in the rock mass.

The results of the site scale investigations are presented in *Figures 2-13* to *2-16* and *Table 2-3*.

Due to the change in layout, in which the entrance to the tunnel was moved to the Simpevarp area, a complementary drilling programme was executed. KAS 09-11 and KAS 14 were drilled to give information on the indicated fracture zones to the south of Äspö. An almost horizontal core borehole, KBH 02, was drilled from Hålö-Äspö, approximately parallel to the tunnel (*Figure 2-14*).

The percussion boreholes, HAS 18-20 and two more boreholes, KAS 12-13, were performed in order to improve the knowledge about the main fracture zones on southern Äspö.

Table 2-1. Pre-investigation - siting stage. Regional scale 25 x 25 km.

Investigation method	Main issue of the survey
AERIAL GEOPHYSICAL SURVEY (*Figure 2-1*) PR 25-87-04, PR 25-87-23	
• Magnetic	• Bedrock interpretation.
• Co-axial EM (slingram)	• Fracture zone interpretation.
• VLF (two station, GQD and JXZ)	• Fracture zone (waterbearing) interpretation.
• Radiometric	• Bedrock interpretation.
GROUND GEOPHYSICS (*Figure 2-1*) PR 25-87-20, PR 25-89-13 PR 25-89-23	
• Gravity (one station/km^2)	• Bedrock interpretation.
• Magnetic and VLF profile measurements	• Investigation of aeromagnetically indicated lineaments.
• Seismic refraction	• -"-
PETROPHYSICS (*Figure 2-1*) PR 25-88-06	
• Density, magnetic susceptibility, magnetic remanence, IP, porosity (257 rock samples)	• Bedrock interpretation.
LINEAMENT ANALYSIS (*Figure 2-1*) PR 25-87-21	• Fracture zone interpretation.
MAPPING OF SOLID ROCKS, 1:50000 (*Figure 2-2*) PR 25-87-02	• Distribution and characterization of the main rock units.
TECTONIC ANALYSIS - FRACTURE MAPPING (*Figure 2-2*) PR 25-87-03, PR 25-87-05	• Characterization of the main tectonic zones. • Description of general fracture pattern.
REGIONAL HYDROLOGY (*Figure 2-3*) • Compilation of available data in databases and reports. PR 25-87-09	• Precipitation, evaporation, run-off and groundwater recharge.
GEOHYDROLOGY (*Figure 2-3*)	
• Compilation of available data in SGU well database. PR 25-87-07	• Groundwater chemical composition and the specific capacity of wells in relation to the rocktype and subareas.
• Well water chemical records (*Figure 2-3*). PR 25-87-08	• Define the variation of the well water composition correlated to the bedrock and the hydraulic properties.

Table 2-2. Pre-investigation - siting stage. The Ävrö, Äspö, Laxemar and Glostad areas.

Investigation method	Main issue of the survey
STRUCTURAL ANALYSIS (*Figure 2-4*) PR 25-87-22, PR 25-87-27	• Fracture zone interpretation.
MAPPING OF SOLID ROCKS 1:10 000 (*Figure 2-4*) PR 25-87-02a,	• Bedrock interpretation.
STRUCTURAL GEOLOGICAL ANALYSIS (*Figure 2-4*) PR 25-88-05	• Structural geological characterization.
GROUND GEOPHYSICS (*Figures 2-4* and *2-5*), PR 25-87-01, PR 25-87-16, PRAV 77/1, PR 25-88-16 • Magnetic • VLF • Slingram • Seismic refraction (*Figure 2-6*), PR 25-87-15 • Seismic reflection (*Figure 2-6*), PR 25-89-02, PR 25-87-14	• Fracture zone interpretation. • Fracture zone interpretation (vertical or more or less vertical). • -"- • -"- • -"- • Fracture zone interpretation (sub-horizontal).
DETAILED GEOLOGICAL MAPPING (*Figure 2-7*), PR 25-88-12	• Detailed petrological description of rocks.
DETAILED GEOPHYSICAL INVESTIGATION (*Figure 2-7*) PR 25-88-16, PR 25-89-01, PR 25-89-12	• Delineate the local pattern of fracture zones.
DETAILED STUDY OF GEOLOGICAL STRUCTURES AND TECTONIC HISTORY (*Figure 2-7*), PR 25-88-05, PR 25-89-11, PR 25-89-15	• Understanding the geological history of the rocks and to study the main sets of tectonic zones.
FRACTURE MAPPING STUDY (*Figure 2-3*), PR 25-88-10	• Obtain data for use in geo-hydrological and rock mechanics model studies.
FIRST DRILLING PROGRAMME (*Figures 2-8* and *2-9*), PR 25-88-03, PR 25-88-06, PR 25-88-07, PR 25-88-11, PR 25-88-15, PR 25-88-18, PR 25-89-10, PR 25-88-17 • HAS 01-12 (Percussion boreholes) • HAV01-04, 07 • HLX 01-07 • KAS 01-04 (Core boreholes)	• Obtain preliminary information on the bedrock composition and the hydraulic properties of the shallow portion of the bedrock. • Test the first geological model of Äspö. • Obtain basic information on the bedrock composition, orientation and characteristics of the local fracture zones and the hydraulic properties of the rock mass at increasing depth.

Table 2-2 *(continued).* **Pre-investigation - siting stage. The Ävrö, Äspö, Laxemar and Glostad areas.**

Investigation method	Main issue of the survey
FIRST DRILLING PROGRAMME *(cont.)* • Geophysical logging • Core logging • TV-orientation • Fracture mineral study • Rock stress measurement	
GEOHYDROLOGY *(Figure 2-10)* • Compilation of available data from reports mainly considering CLAB and OIII. PR 25-87-10	• Hydraulic conductivity of the bedrock and common fracture directions.
HYDRAULIC TESTS IN PERCUSSION BOREHOLES *(Figure 2-10)* • Drilling records, air-lift tests and pumping tests. PR 25-87-11, PR 25-88-14	• Find conductive parts and the specific capacity of the boreholes. Determine the transmissivity and preliminary indications of hydraulic structures.

Table 2-2 *(continued).* **Pre-investigation - siting stage. The Äspö - Hålö area.**

Investigation method	Main issue of the survey
HYDRAULIC TESTS IN CORE BOREHOLES *(Figure 2-10)*, PR 25-87-04, PR 25-87-23 KAS 01-04	
• Air-lift tests, PR 25-88-14	• Transmissivity of a part of the whole borehole.
• Pumping tests, PR 25-88-14	• Clean up the boreholes. Pumping for the spinner survey and estimating the transmissivity of the whole borehole. Preliminary indications of hydraulic structures.
• Spinner survey, PR 25-88-14	• Identification of hydraulic conductors intersecting the borehole and flow distribution in the borehole.
• Injection tests with packers (3 m and 30 m test interval), PR 25-88-14	• Hydraulic conductivity of the bedrock in a small scale.
• Interference tests, pumped sections limited by packers. Six tests in KAS 03 and three in KAS 02. PR 25-88-13	• Identification of important hydraulically conductive zones and their transmissivity.

Table 2-2 *(continue).* **Pre-investigation - siting stage. The Äspö - Hålö area.**

Investigation method	Main issue of the survey
COMBINED EVALUATION OF GEOLOGICAL, GEOHYDRO-LOGICAL AND GEOPHYSICAL INFORMATIONS. (*Figure 2-10*) • PR 25-89-03	• Find correlation between geological, geohydrological and geophysical data. • Examine the distribution of some of the parameters along the boreholes and the correlation between the boreholes. Evaluate how to optimize the hydrogeological investigation. Present information for the conceptual model.
PIEZOMETRIC HEAD MEASUREMENTS • PR 25-90-18	
NUMERICAL GEOHYDROLOGICAL SIMULATIONS (*Figure 2-10*) • 3-D model, PR 25-87-12 • 2-D vertical profile model, PR 25-88-17 • 3-D model, PR 25-88-17 • 2-D vertical profile model including density dependent flow, PR 25-88-02 • 2-D vertical profile model including density dependent flow and random distributed hydraulic conductivities, PR 25-88-09 • 3-D FE model, PR 25-89-05	• Evaluate the hydraulic heads and inflow to tunnels for two proposed design alternatives of the rock laboratory. • Examine the influence of the laboratory to decide the size of the 3-D model. • Examine different boundary conditions. • Examine the interface between fresh groundwater and saline water below an island for a few cases with different sets of hydraulic conductivities. • Examine the salinity stratification and flow field due to random distributed hydraulic conductivities with a given statistical distribution. • Sensitivity analysis of boundary conditions and structure properties.
FRACTURE MINERAL STATISTICS PR 25-88-11	• Define the special variation in fracture minerals in correlation to hydraulic properties.
GROUNDWATER SAMPLING FROM SHALLOW PERCUSSION BOREHOLES. (*Figure 2-11*) PR 25-87-02	• Define the character of the groundwater in the uppermost 100 m part of the bedrock. Characterize the chemical composition of the deep groundwater.

Table 2-2 *(continued).* **Pre-investigation - siting stage. The Äspö - Hålö area.**

Investigation method	Main issue of the survey
SAMPLING AND ANALYSIS OF GROUND-WATER FROM DEEP CORE DRILLED BOREHOLES (*Figure 2-11*) PR 25-87-03, PR 25-87-05	• Define the chemistry and radioactivity of the surface water in the area.
SAMPLING AND ANALYSIS OF SURFACE WATER. PR 25-87-09	• Define the chemistry and radioactivity of the surface water in the area.

Table 2-3. Pre-investigation - prediction stage. Äspö-Hålö.

Investigation method	Main issue of the survey
SECOND DRILLING PROGRAMME (*Figure 2-12*) PR 25-89-07, PR 25-89-08, PR 25-89-09, PR 25-89-10, PR 25-89-16, PR 25-89-17 • KAS 05-08 • HAS 13-17 • Geophysical logging • Core logging • Rock stress measurement • VSP • Tele-viewer-orientation • Fracture mineral study	• Test the second geological model of southern Äspö. • Obtain information of the rock distribution at depth. • Obtain more detailed information on orientation and characteristics of the local fracture zones including hydraulic properties.
SEISMIC REFRACTION (*Figure 2-6*). PR 25-89-18	• Detailed identification of supposed narrow fracture zones.
FRACTURE MINERAL STATISTICS. PR 25-88-06	• Define the special variation in fracture minerals in correlation to hydraulic properties
SAMPLING AND ANALYSIS OF GROUND-WATER FROM DEEP COREDRILLED BOREHOLES (*Figure 2-11*). PR 25-89-14	• Characterize the chemical composition of the deep groundwater.

Table 2-3 *(continued)*. **Pre-investigation - prediction stage. Äspö-Hålö.**

Investigation method	Main issue of the survey
CHEMICAL ANALYSIS OF FRACTURE MINERALS IN CONDUCTIVE FRACTURES	• To characterize the chemical conditions in the fracture minerals of conductive fractures in order to be able to model the groundwater-fracture mineral reactions on southern Äspö.
HYDRAULIC TESTS, SECOND DRILLING PROGRAMME (*Figure 2-12*) PR 25-89-20, PR 25-90-09	
• Drilling records, air lift tests HAS 13-17	• see second phase, "Hydraulic tests".
• Air lift tests, KAS 05-08	• -"-
• Pumping tests, KAS 06-07	• -"-
• Spinner survey, KAS 06-07	• -"-
• Injection tests with packers (3 m test interval),KAS 05-08	• -"-
• Longtime pumping test, KAS 07	• Identification of important hydraulically conductive zones, their transmissivity and boundary conditions.
NUMERICAL GEOHYDROLOGICAL SIMULATIONS (*Figure 2-12*)	
• 3D-FE-model PR 25-90-04	• Prediction of the long time pumping test in KAS 07
• 3D-FD-model PR 25-90-03	• -"-
• A1 (see sep.)	• -"-
THIRD DRILLING PROGRAMME (*Figures 2-13* and *2-14*). PR 25-90-05, PR 25-90-06, PR 25-90-07, PR 25-90-08 • KBH 01-02 (*Figure 2-14*) • KAS 09-14 (*Figure 2-13*) • HAS 18-20 (*Figure 2-13*) • Geophysical logging • Core logging	• Localize and characterize fracture zones in the tunnel area. • Get more detailed information concerning the fracture zones EW-1 and NE-2.

Table 2-3 *(continued).* **Pre-investigation - prediction stage. Äspö-Hålö.**

Investigation method	Main issue of the survey
HYDRAULIC TESTS, THIRD DRILLING PROGRAMME (*Figures 2-13 and 2-14*) • Drilling records, air lift tests HAS 18-20, pumping test in HAS 20 • Air lift tests, KAS 09-14, KBH 01-02 • Pumping tests, KAS 09, 11-14, KBH 02 • Spinner survey, KAS 09, 11-14	• see second phase, "Hydraulic tests" • -"- • -"- • -"-
GROUNDWATER SAMPLING AND ANALYSIS	• Define salinity and major constituents of the groundwater in conductive zones.
SEISMIC REFRACTION (Simpevarp-Äspö-Hålö) (*Figure 2-15*). PR 25-89-18	
DETAILED ELECTRIC AND MAGNETIC INVESTIGATION (Hålö-Äspö) (*Figure 2-15*) PR 25-89-19, PR 25-89-22	
DISCRETE FRACTURE MODELLING PR 25-89-21	• Generic modelling of the flow through a 50 m cube. The object was to test discrete fracture flow modelling.
NUMERICAL GEOHYDROLOGICAL SIMULATIONS (*Figure 2-16*) • 3D+FE model PR 25-90-10 • 3D+FD model PR 25-90-11 • 3D+FD model PR 25-91-03	• Preliminary predictions of the long time pumping test in KAS 06 performed as a tracer test. Model based on a preliminary conceptual model. • Preliminary predictions of the drawdown and the inflow to the tunnel during the excavation of the Äspö HRL. Model based on a preliminary conceptual model. • Predictions of the drawdown and the inflow to the tunnel during the excavation of the Äspö HRL. Model based on the conceptual model 1990.
GEOHYDROLOGY • Work up measured data PR 25-91-16a PR 25-91-16b • Input data for numerical modelling PR 25-91-17a PR 25-91-17b	• Evaluate and reevaluate measured data and present theoretical consideration in short text which are successively presented according to a mail list. The reports are worked up texts. • Gather and work up the information that is necessary for the numerical simulations from other reports.

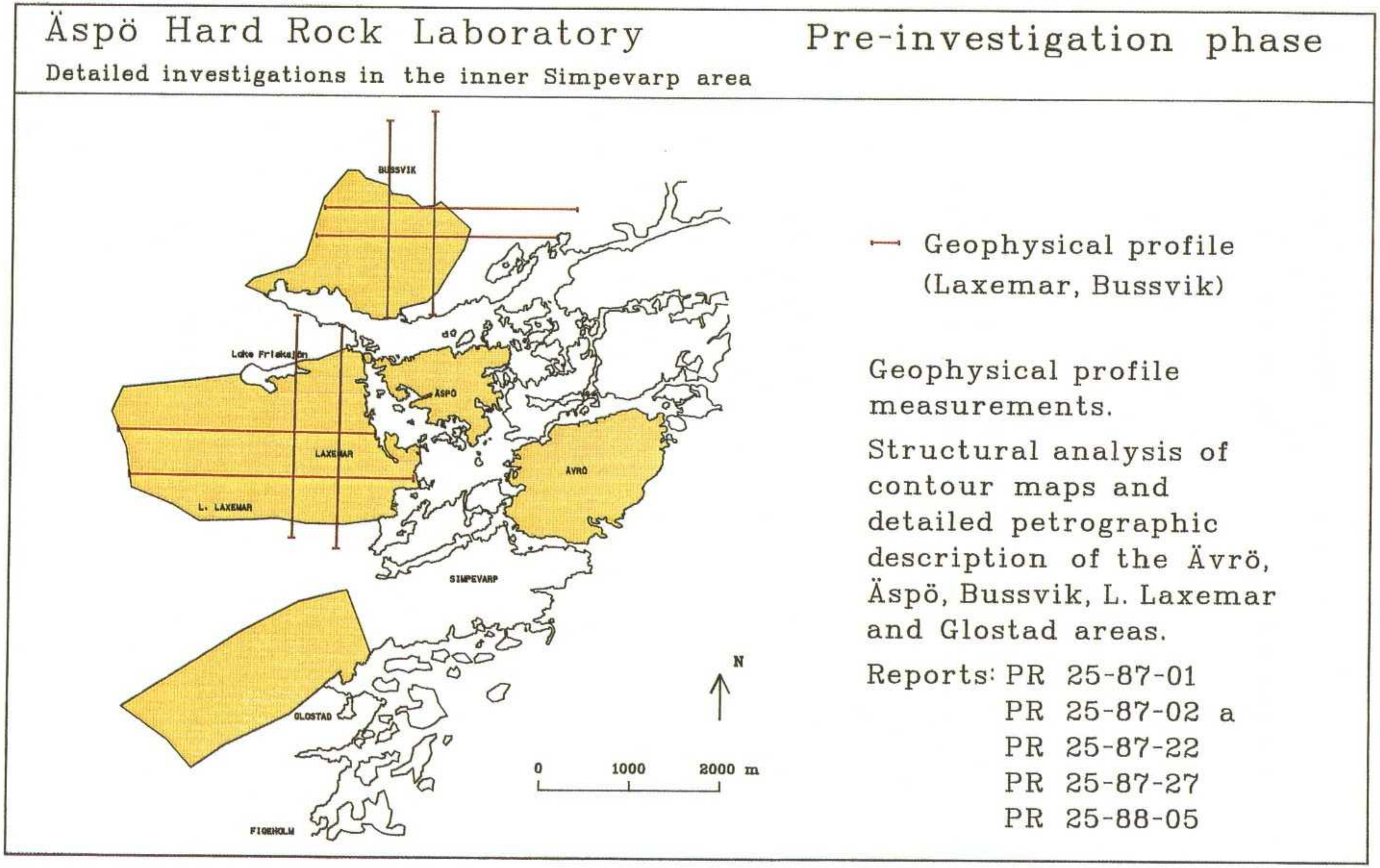

Figure 2-4. Detailed investigations in the inner Simpevarp area

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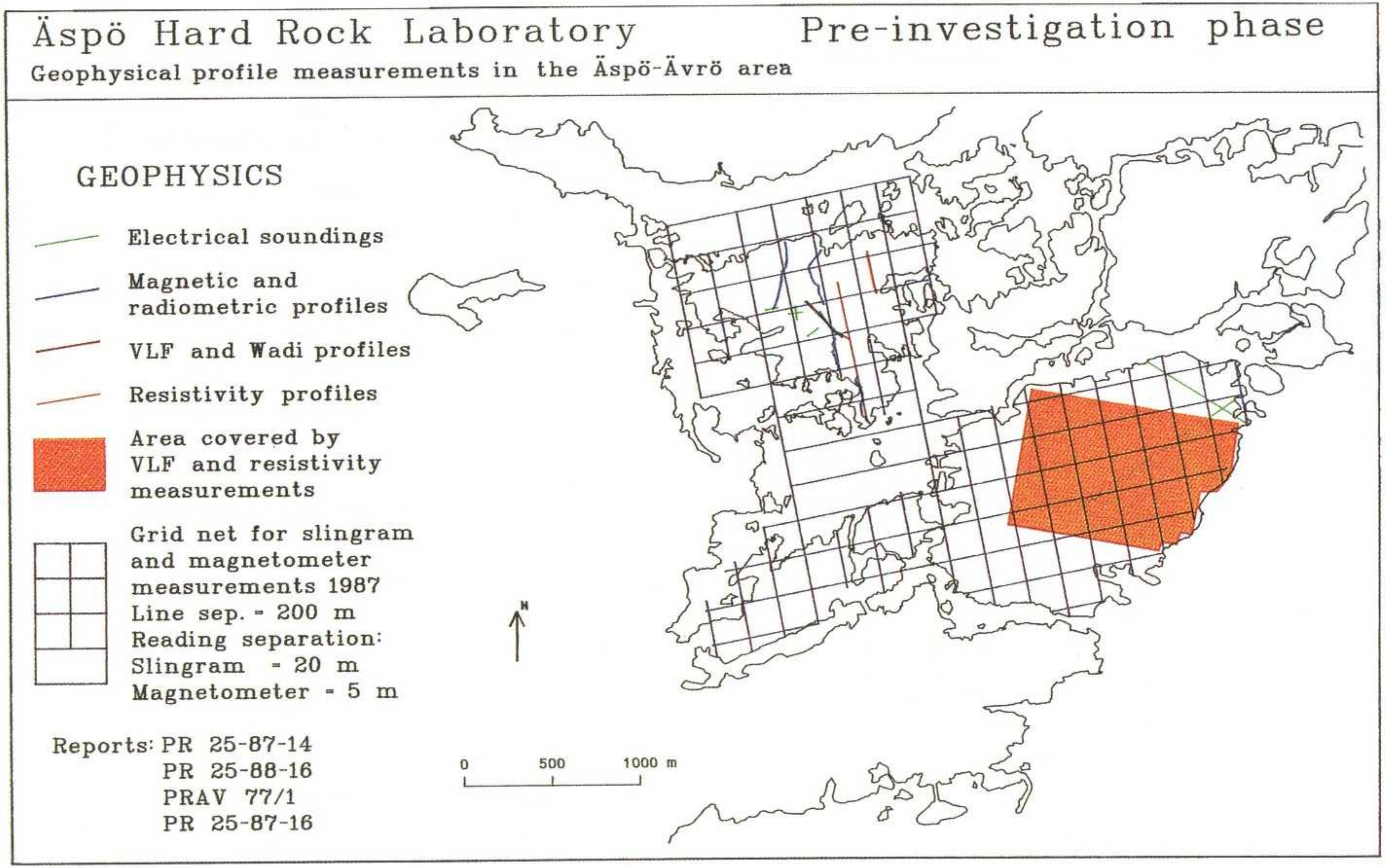


Figure 2-5. Geophysical profile measurements in the Äspö-Ävrö area.

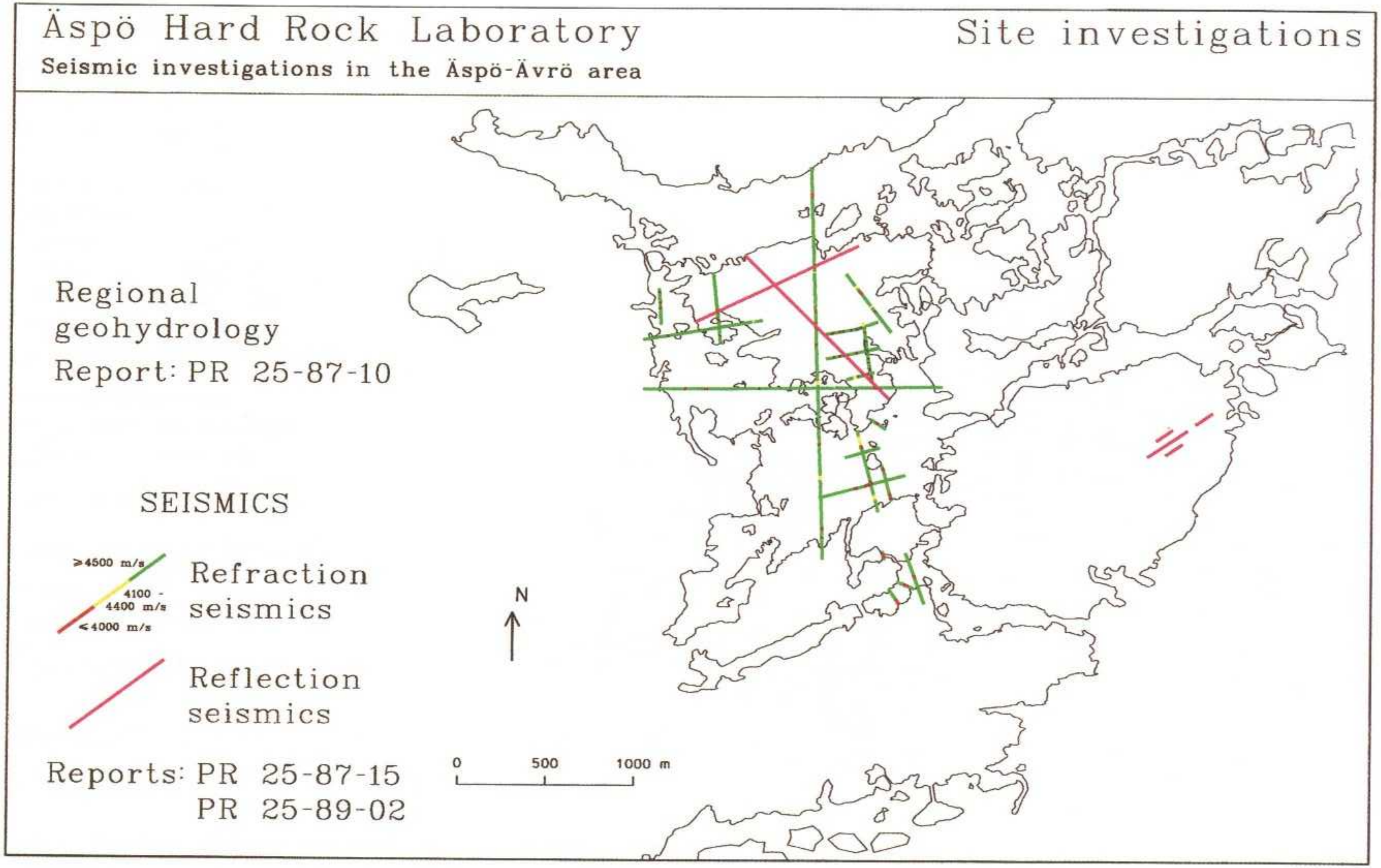
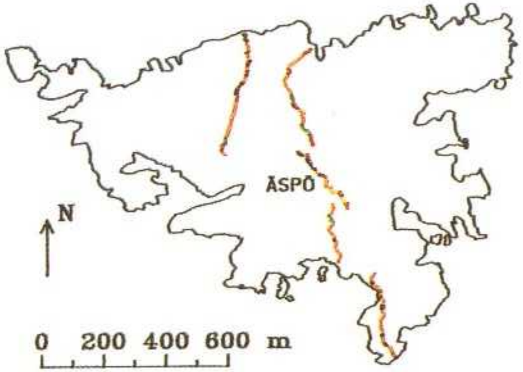


Figure 2-6. *Seismic investigations in the Äspö-Ävrö area.*

Äspö Hard Rock Laboratory — Pre-investigation phase

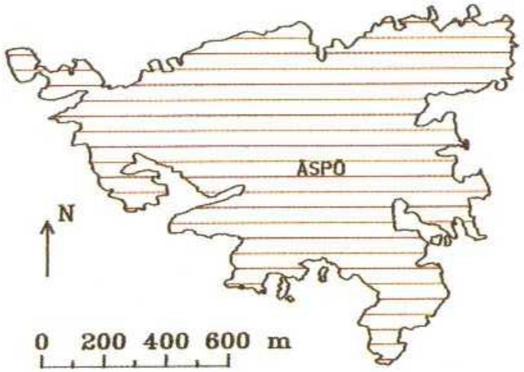
Detailed geological and geophysical investigations on Äspö



Description to detailed maps of solid rocks including 3 cleaned trenches.

- **Greenstone**
- **Äspö diorite**
- **Granite, fine-grained**
- **Småland granite**
- **Mylonite**

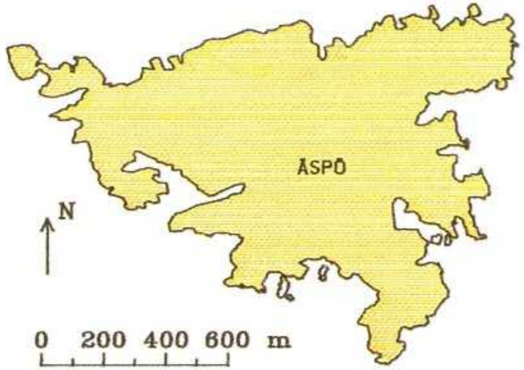
Report: PR 25-88-12



Detailed geomagnetic and geoelectric mapping.

Ground surface radar measurements.

Reports: PR 25-89-01
PR 25-89-12



Detailed study of geological stuctures and tectonic history.

Fracture mapping study.

Reports: PR 25-88-05
PR 25-88-10
PR 25-89-11
PR 25-89-15
PR 25-89-24

Figure 2-7. Detailed geological and geophysical investigations on Äspö.

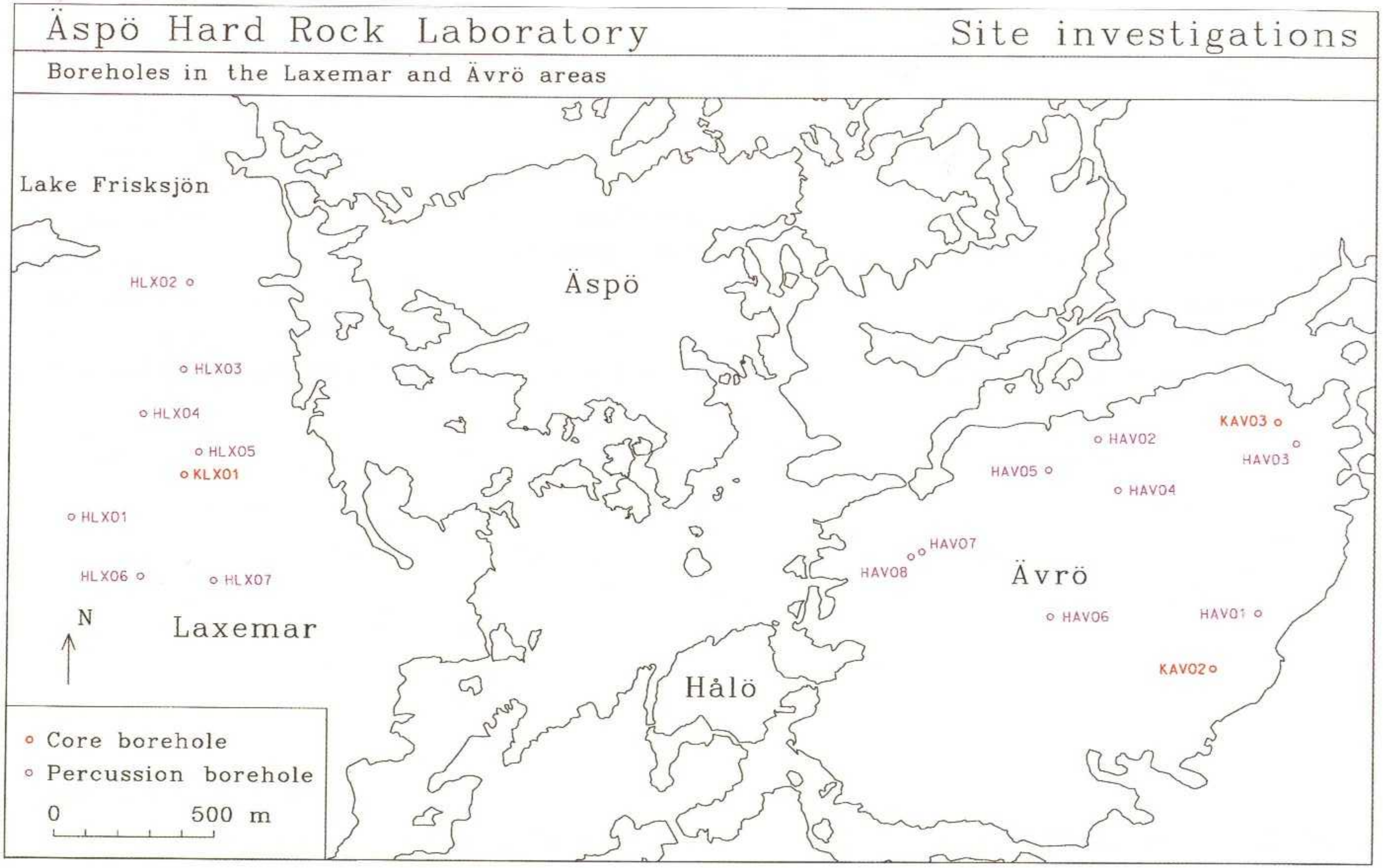


Figure 2-8. Boreholes in the Laxemar and Ävrö areas.

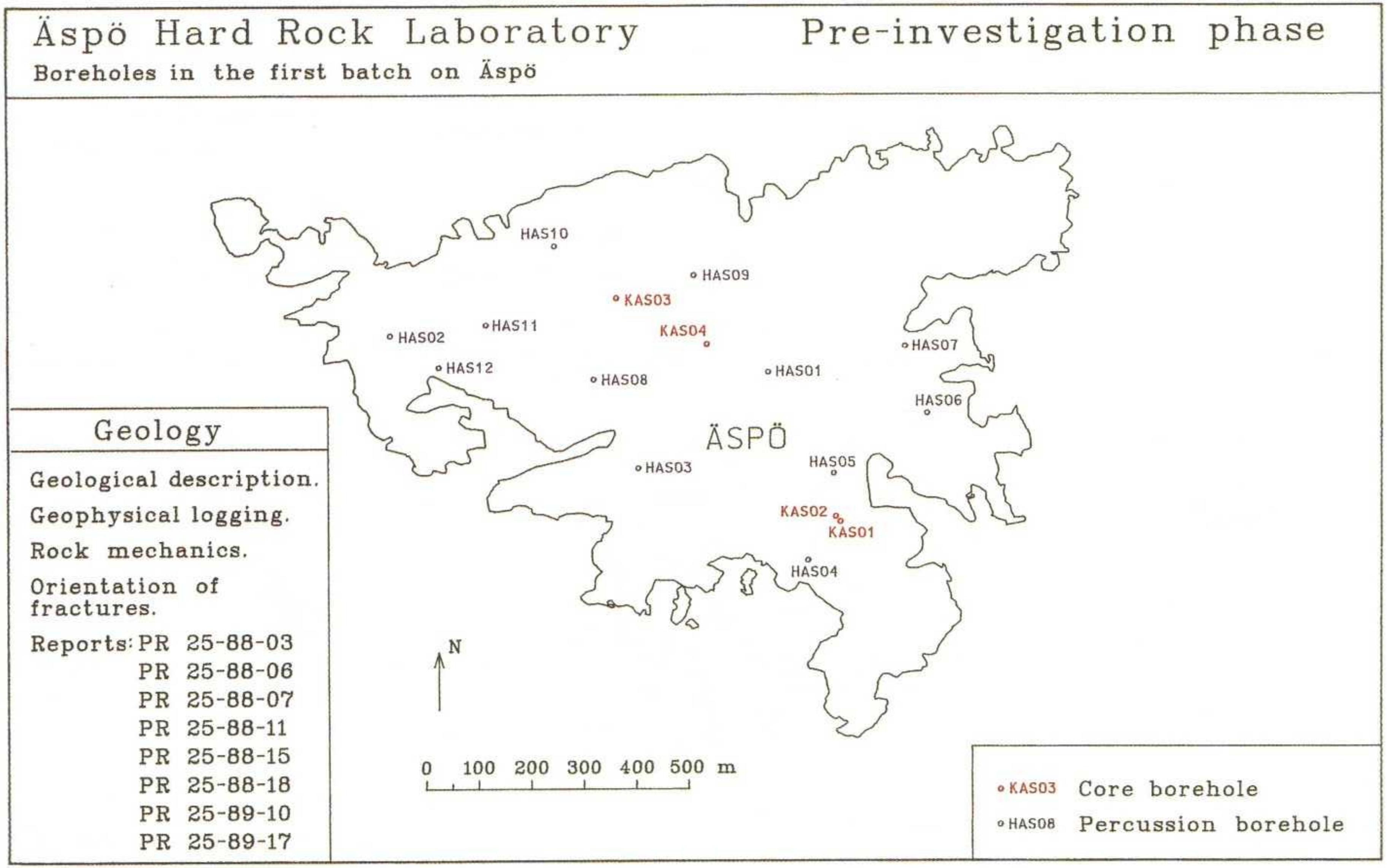


Figure 2-9. Boreholes in the first batch on Äspö.

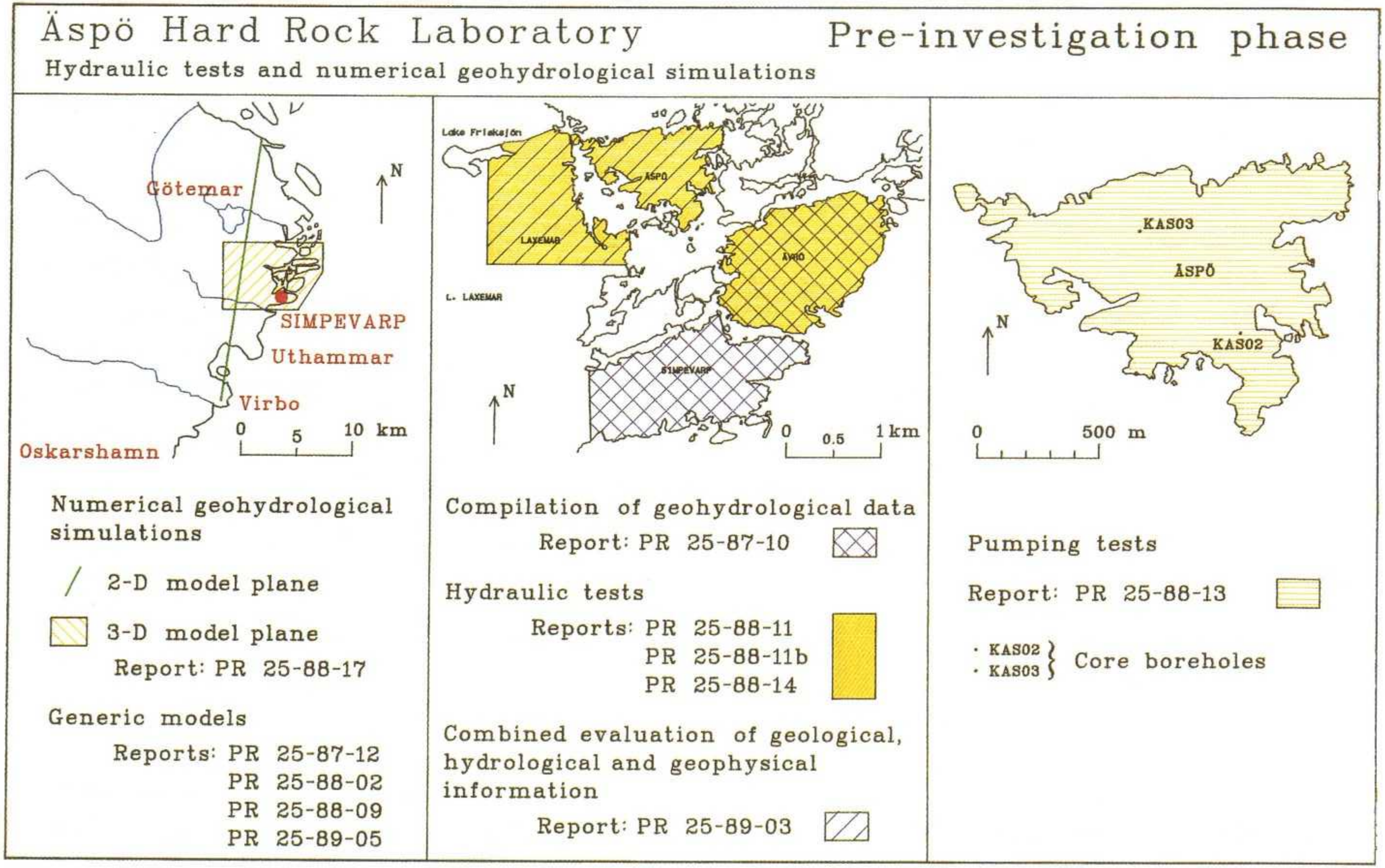


Figure 2-10. Hydraulic tests and numerical geohydrological simulations.

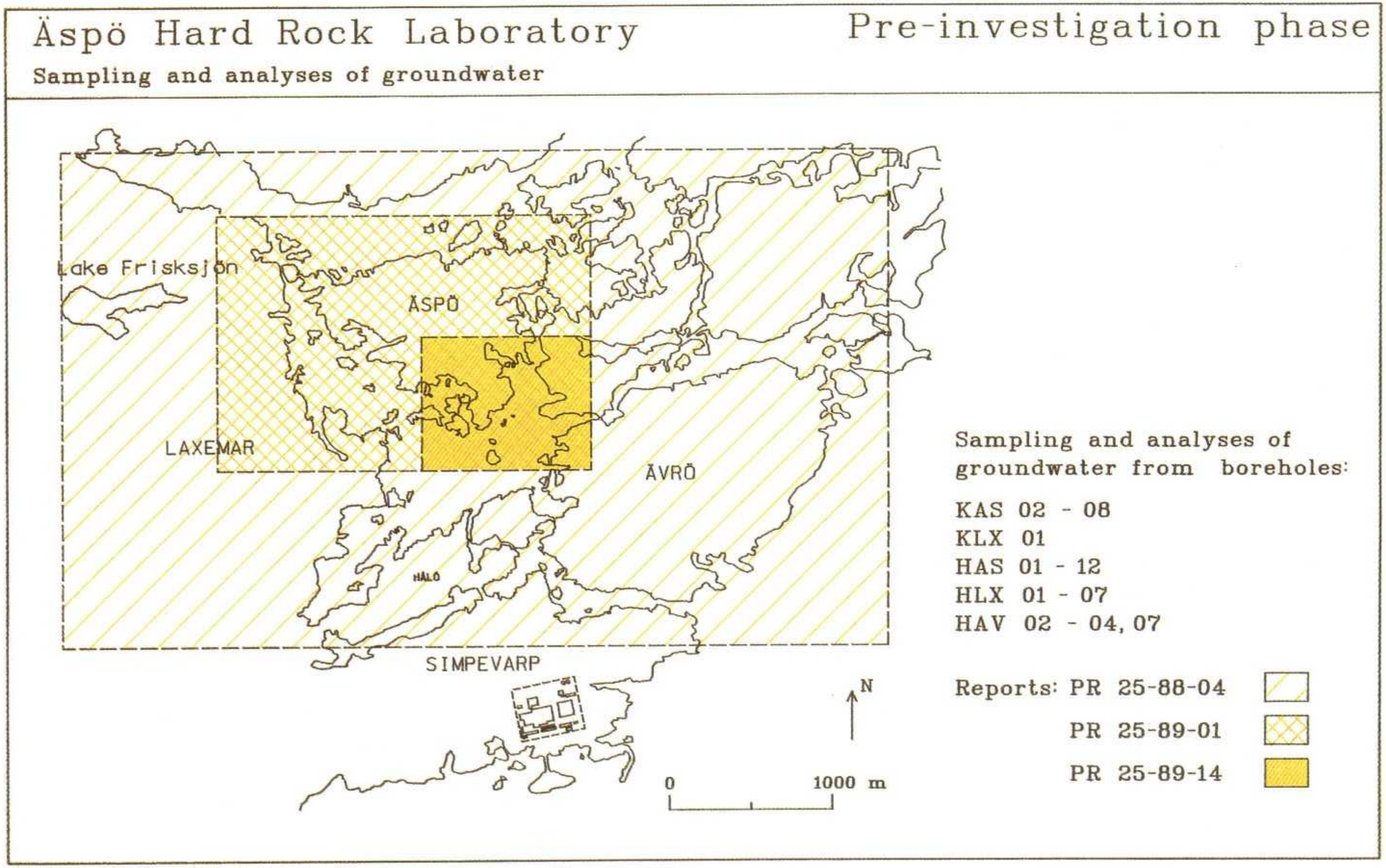


Figure 2-11. Sampling and analyses of groundwater.

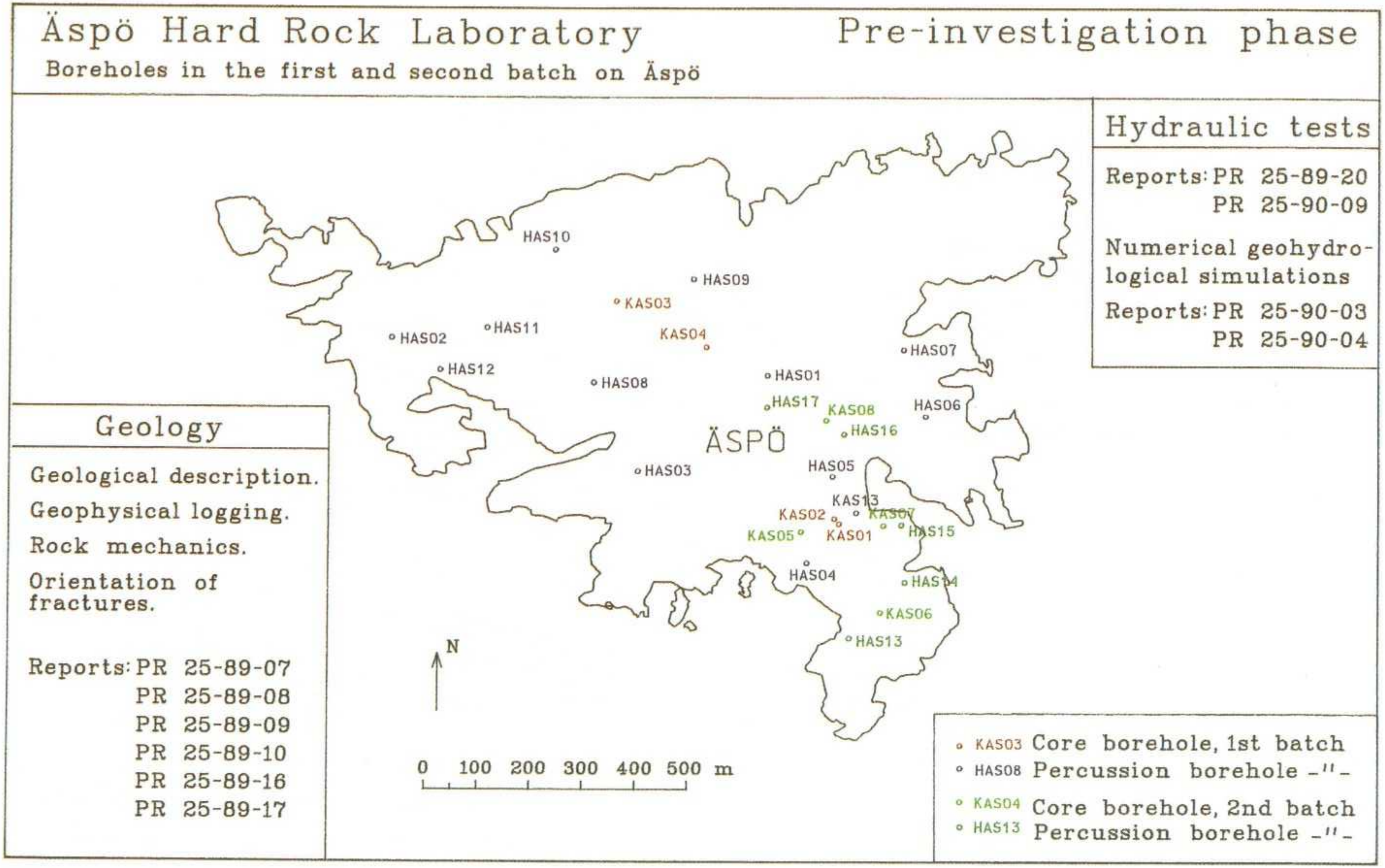


Figure 2-12. Boreholes in the first and second batches on Äspö.

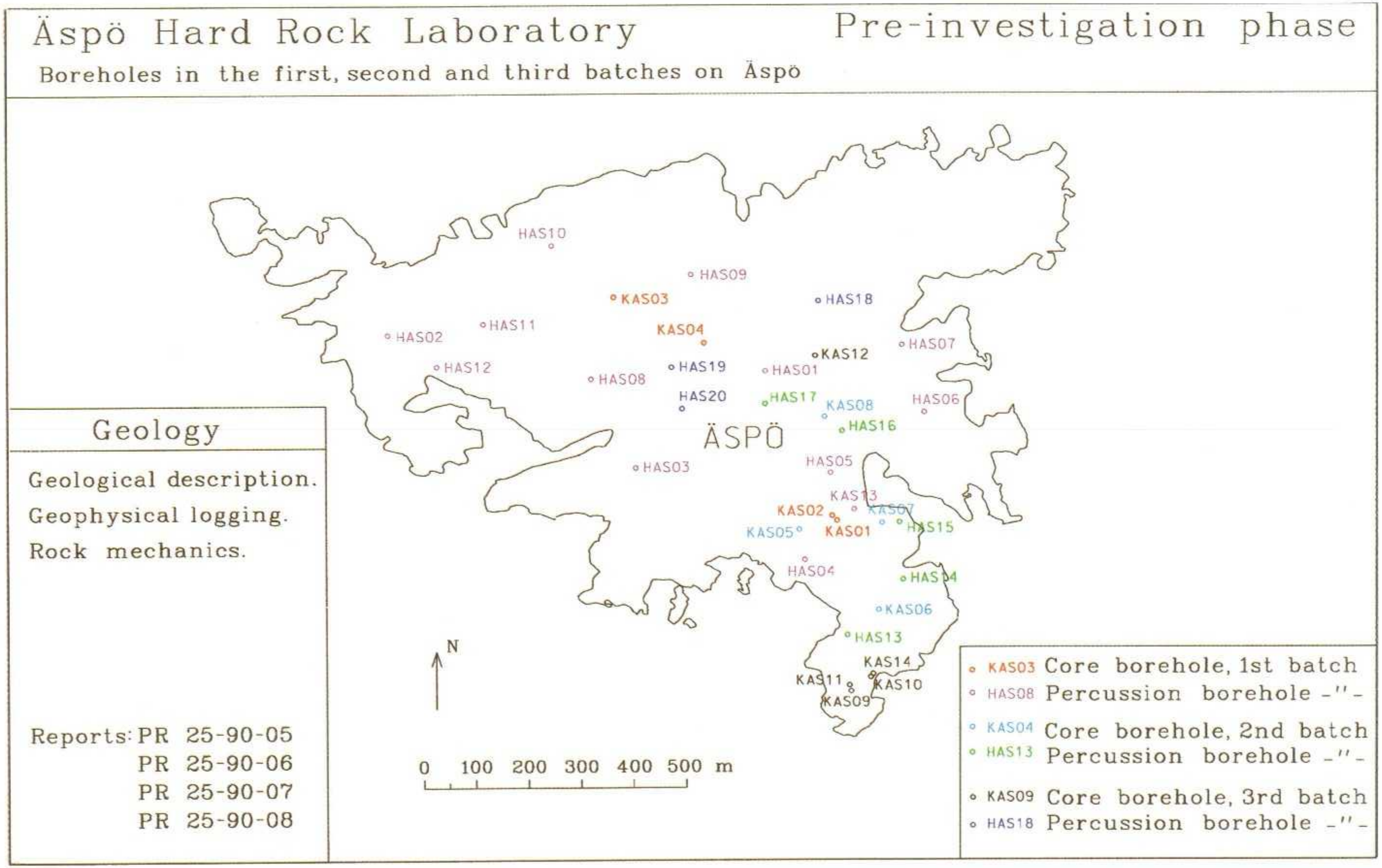


Figure 2-13. Boreholes in the first, second and third batches on Äspö.

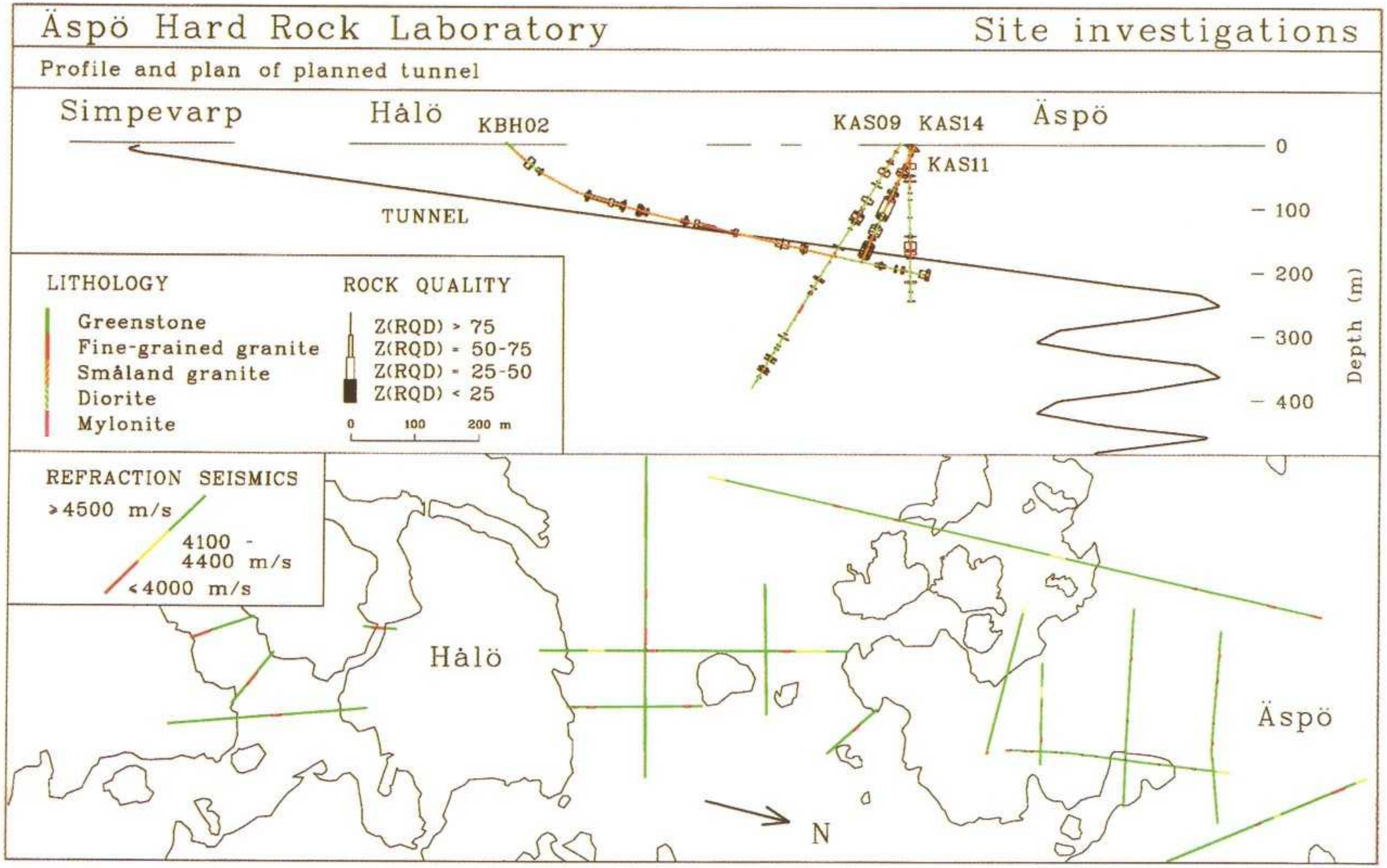


Figure 2-14. Profile and plan of planned tunnel.

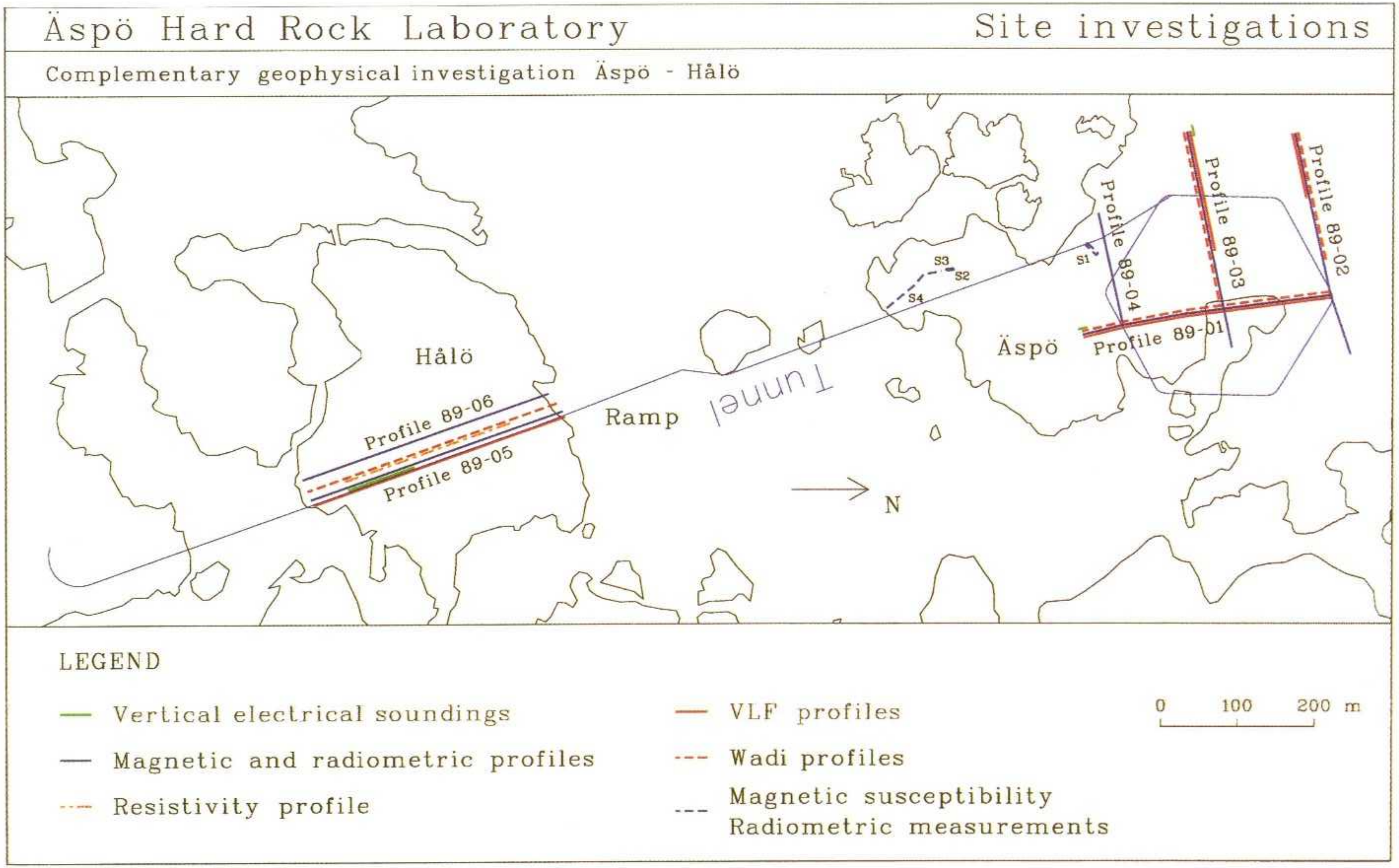


Figure 2-15. Complementary geophysical investigation on Äspö-Hålö.

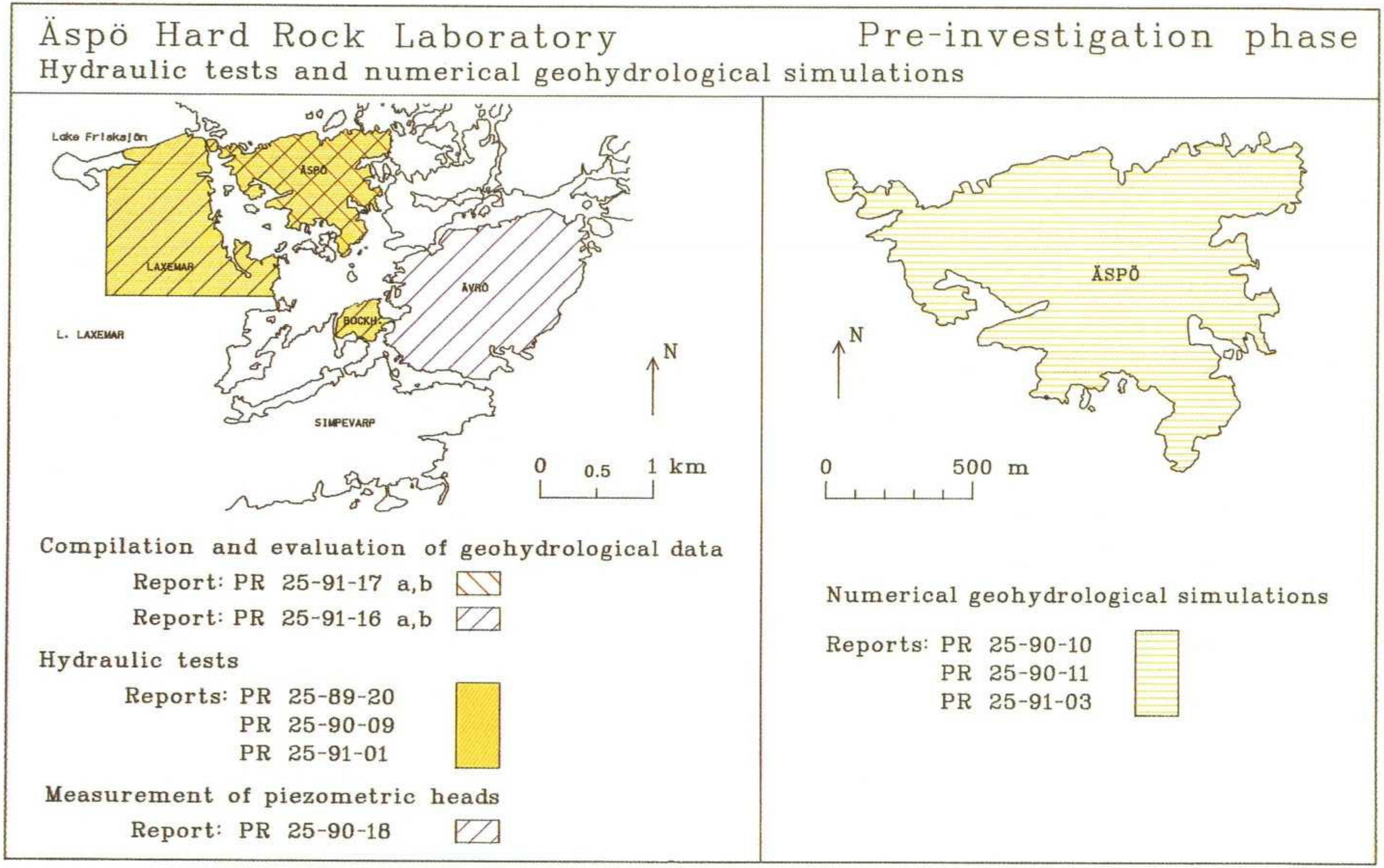


Figure 2-16. Hydraulic tests and numerical geohydrological simulations.

2.4 PRE-INVESTIGATION - BOREHOLES

This part of the report comprises a compilation of borehole data and investigations performed in the boreholes during the pre-investigation phase. The information is given in CAD generated illustrations which can be used as a reference guide for more detailed investigations.

Figures 2-17 to *2-18* give information concerning the location of the percussion and cored boreholes on Äspö -Hålö and Laxemar. An overview of the scope of work performed in the different boreholes are compiled in *Figures 2-19* and *2-20*. The borehole lithologies are illustrated in *Figures 2-21* to *2-23* for the cored boreholes and *Figures 2-52* to *2-58* for the percussion boreholes. More detailed information for the cored boreholes concerning the different methods are compiled in *Figures 2-24* to *2-51*.

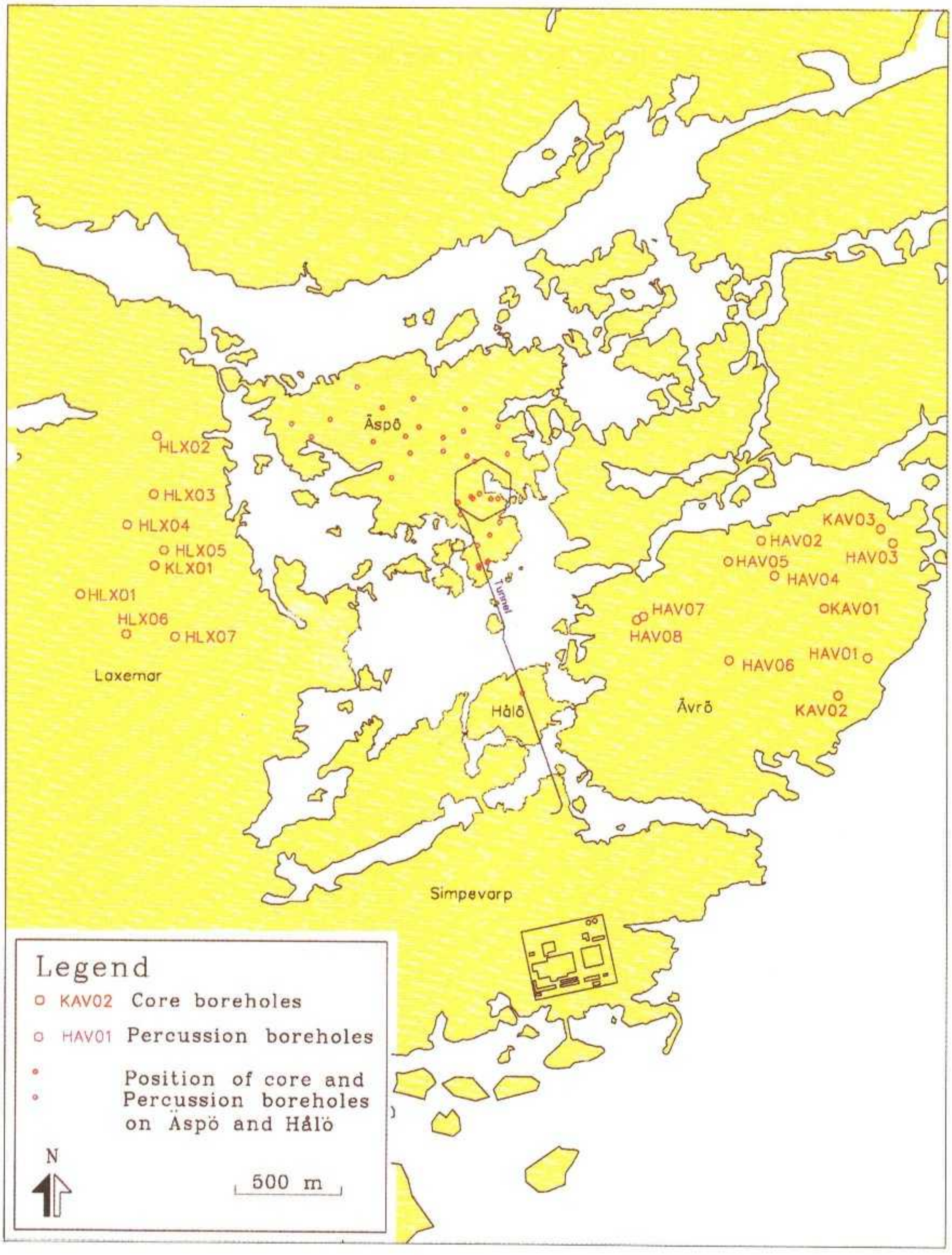


Figure 2-17. *Overview of the borehole locations in the pre-investigation area.*

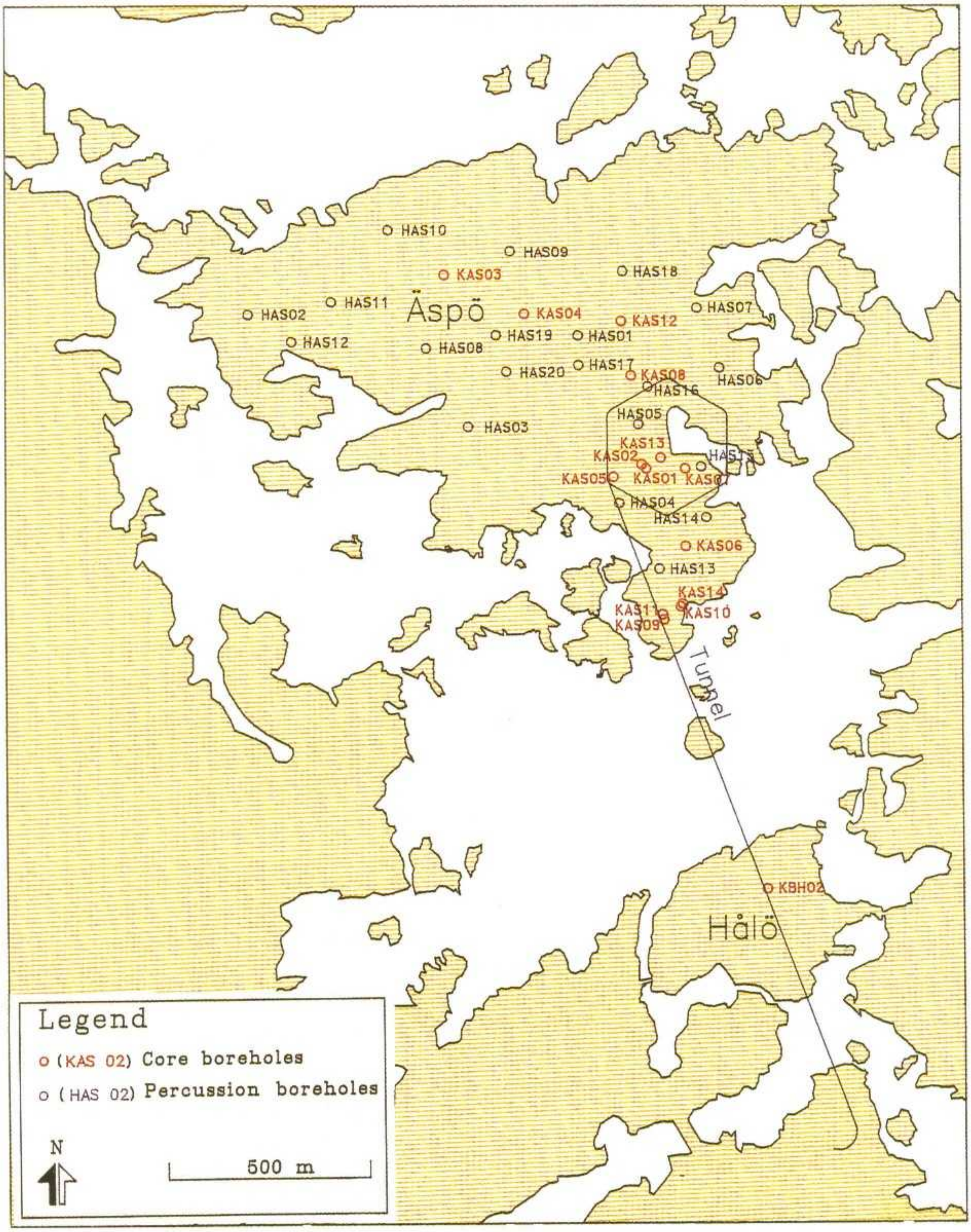


Figure 2-18. Borehole locations in the Äspö-Hålö area.

Pre-investigation phase

Borehole investigations

	CORED BOREHOLES KAS02-KAS14													KBH 02	KLX 01
	02	03	04	05	06	07	08	09	10	11	12	13	14		
LENGTH (M)/DIP	924/85	1002/85	481/60	550/85	602/60	604/59	601/60	450/60	99/60	249/89	380/69	406/62	212/60	706/45	702/85
CORE LOGGING															
Lithology	●	●	●	●	●	●	●	●		●	●	●	●	●	●
Thin section analyses	●	●	●	●	●	●	●	●		●	●	●		●	●
Chemical rock analyses	●	●	●											●	●
Fracture mapping + RQD	●	●	●	●	●	●	●	●		●	●	●	●	●	●
Fracture mineral analyses	●	●	●	●	●	●	●								●
TV-orientation/Televiewer*	●	●	●	●*	●*										
PETROPHYSICS															
Density + Porosity	●														●
Magn. suscep. + Remanence	●														●
Resistivity + I P	●														●
U,Th,K	●														●
GEOPHYSICAL LOGGING															
Borehole deviation	●	●	●	●	●	●	●	●		●	●	●	●		●
Caliper + Magnetic suscept.	●	●	●	●	●	●	●	●		●	●	●	●		●
Sonic	●	●	●	●	●	●	●	●		●	●	●	●		●
Natural gamma	●	●	●	●	●	●	●	●		●	●	●	●		●
Density + Neutron				●	●	●	●	●		●	●	●	●		
Resistivity+Spontaneous potent.*	●*	●*	●*	●	●	●	●	●		●	●	●	●		●
Temperature	●	●	●	●	●	●	●	●		●	●	●	●		●
Borehole fluid resistivity	●	●	●	●	●	●	●	●		●	●	●	●		●
Radar	●	●	●	●	●	●	●	●		●	●	●	●		●
ROCK STRESS MEASUREMENT															
Hydraulic fracturing	●	●													
Overcoring				●											
Lab. tests	●	●													
GEOHYDROLOGY															
Airlift test, intervals	●	●	●	●	●	●	●	●		●	●	●	●	●	●
Injection test, 3m interval	●	●	●	●	●	●	●								●
Injection test, 30m interval	●	●													●
Spinner(flow meter logging)	●	●	●		●	●	●	●		●	●	●	●		
Pumping test	●	●	●	●	●	●	●	●					●		●
Pumping interference test	●	●			●	●		●		●	●	●	●	●	
Dilution test, intervals	●	●	●	●	●	●	●	●		●	●	●	●	●	
Observation, packer settings	●	●	●	●	●	●	●	●		●	●	●	●	●	
Fluid conductivity	●	●	●	●	●	●	●	●		●	●	●	●	●	
Circulation sections	●	●	●	●	●	●	●	●		●	●	●	●	●	
GROUNDWATER CHEMISTRY															
Complete chemical character.	●	●	●												●
Sampling during pumping test	●	●			●										
Sampling during drilling				●	●	●	●	●		●	●	●	●	●	●
Fracture mineral statistics	●	●	●	●	●	●	●								●
Fracture mineral chemistry	●				●										●

Figure 2-19. Compilation of performed borehole investigations in cored boreholes.

Pre-investigation phase Borehole investigations

	PERCUSSION BOREHOLES HAS01-HAS20																			
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
LENGTH (M)/DIP	100/61	93/55	100/56	200/61	100/58	100/88	100/62	125/58	125/59	125/61	125/89	125/60	100/63	100/88	120/60	120/60	120/60	150/62	150/57	150/60
DRILLING DATA																				
Drill cutting analyses	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●
Thin section analyses																				
Drilling rate	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Fracture identification	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
GEOPHYSICAL LOGGING																				
Borehole deviation	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Density				●									●	●				●	●	●
Magnetic suscept.	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●
Sonic				●									●	●				●	●	●
Natural gamma	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●
Resistivity	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●
Temperature	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●
Borehole fluid resistivity	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●	●
Radar		●	●																	
GEOHYDROLOGY																				
Airlift test, intervals	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Injection test, 3m interval																				
Injection test, 30m interval																				
Spinner (flow meter logging)																				
Pumping test	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Pumping interference test													●							●
Dilution, test intervals																				
Observation packer settings																				
Fluid conductivity																				
Circulation sections																				
GROUNDWATER CHEMISTRY																				
Complete chemical character.																				
Sampling during pumping test																				
Sampling during drilling		●	●		●	●	●													
Fracture mineral statistics																				
Fracture mineral chemistry																				

Figure 2-20. *Compilation of performed borehole investigations in percussion boreholes.*

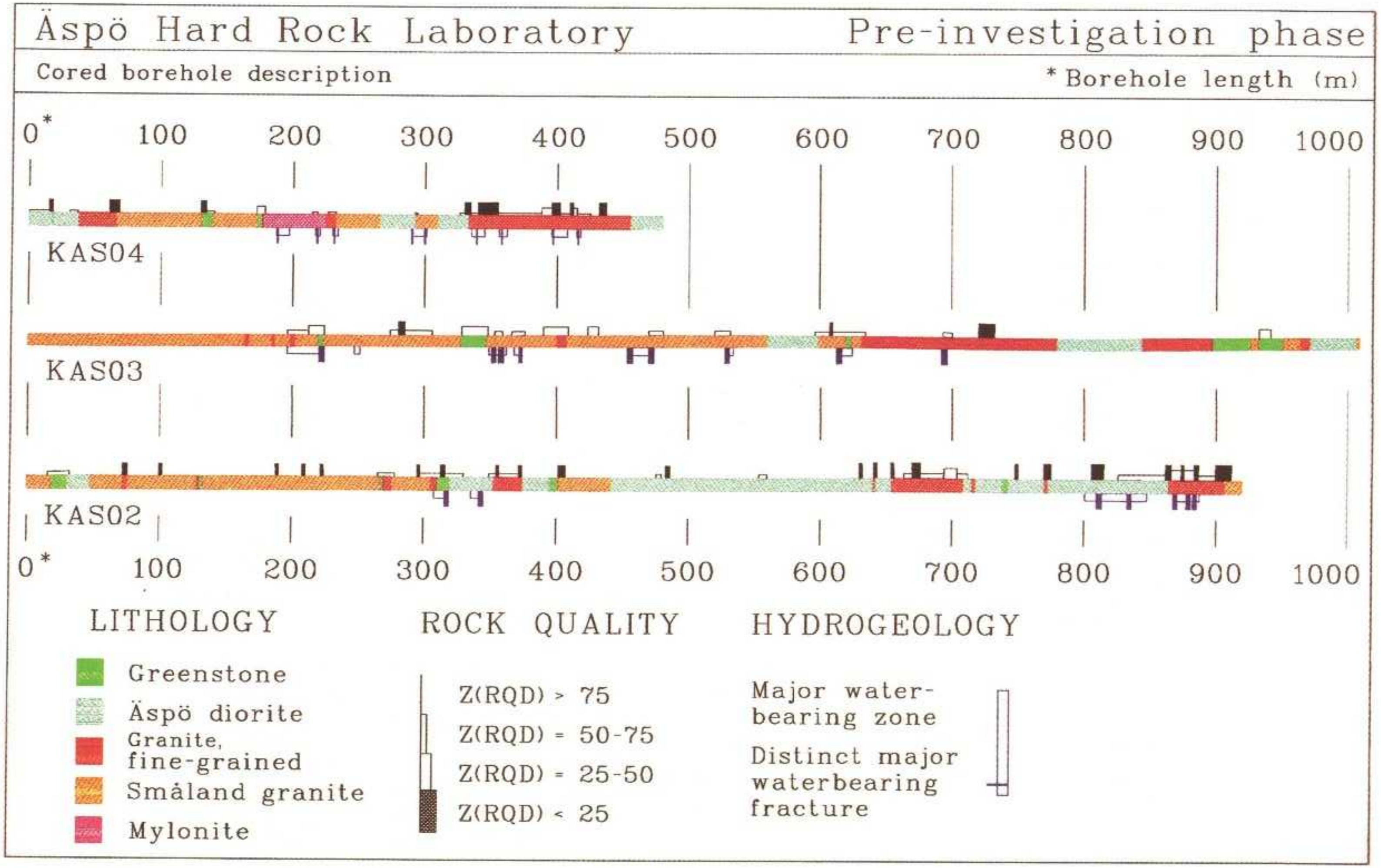


Figure 2-21. Cored boreholes KAS 02-04.

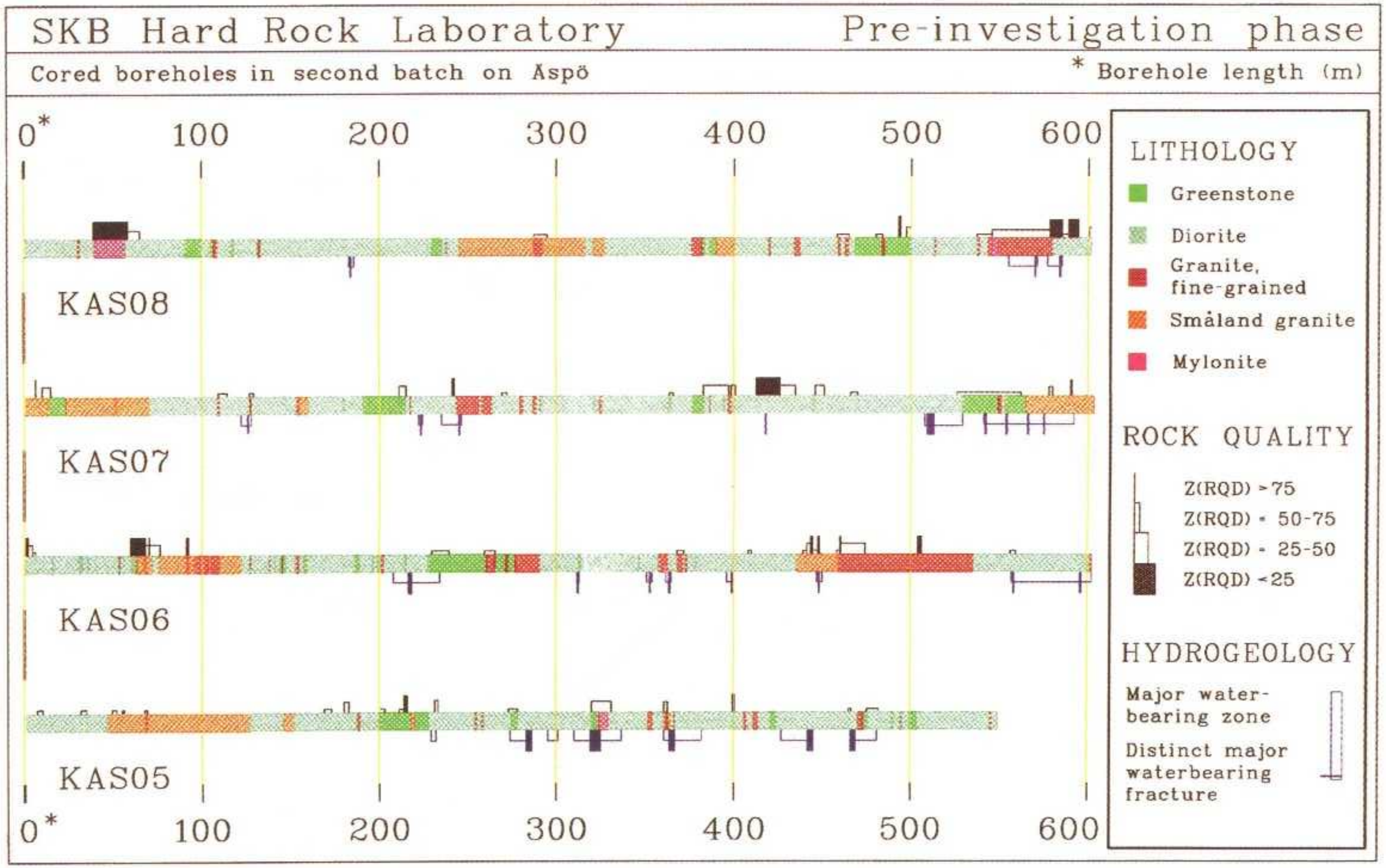


Figure 2-22. Cored boreholes KAS 05-08.

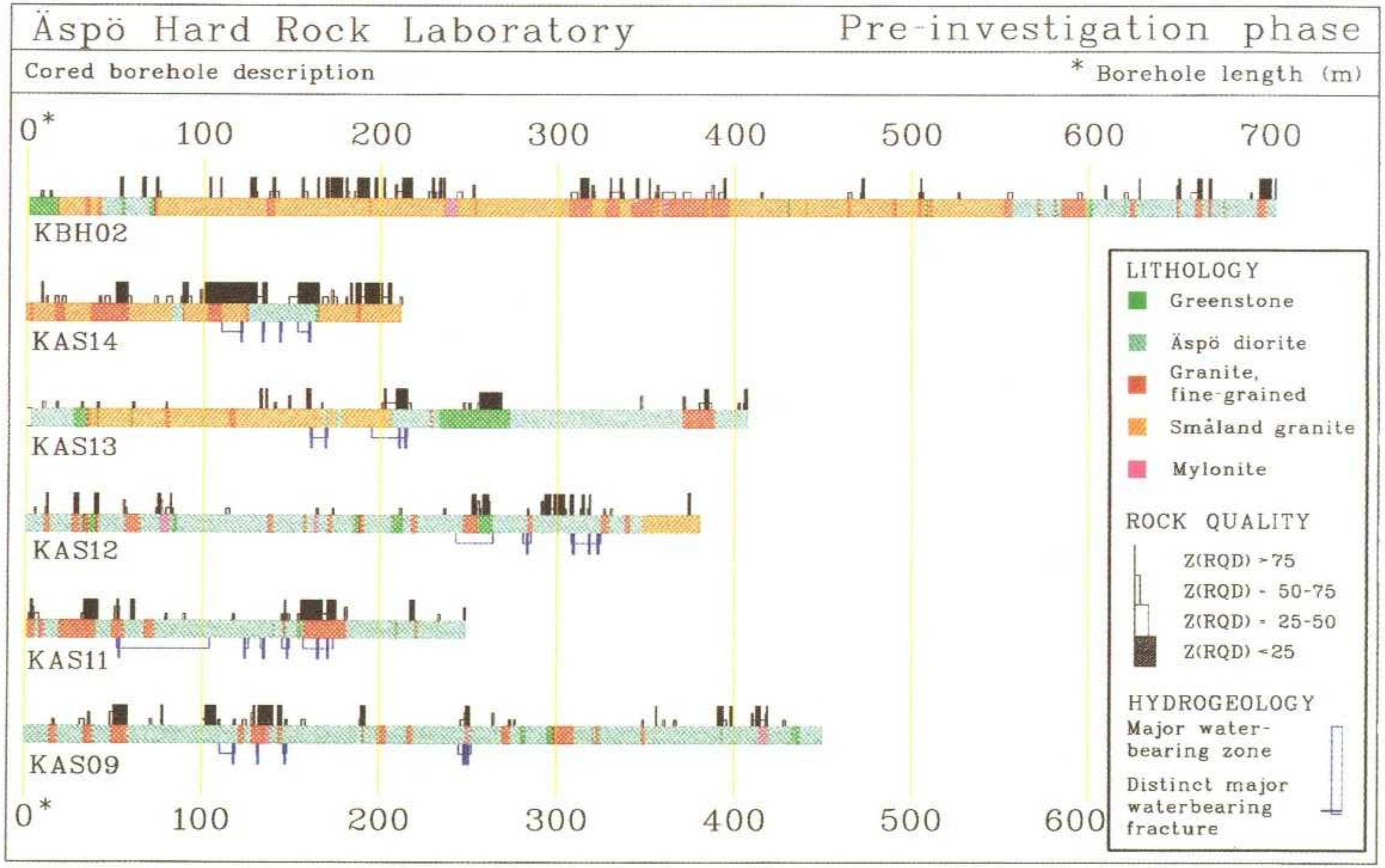


Figure 2-23. Cored boreholes KAS 09, KAS 11-14 and KBH 02.

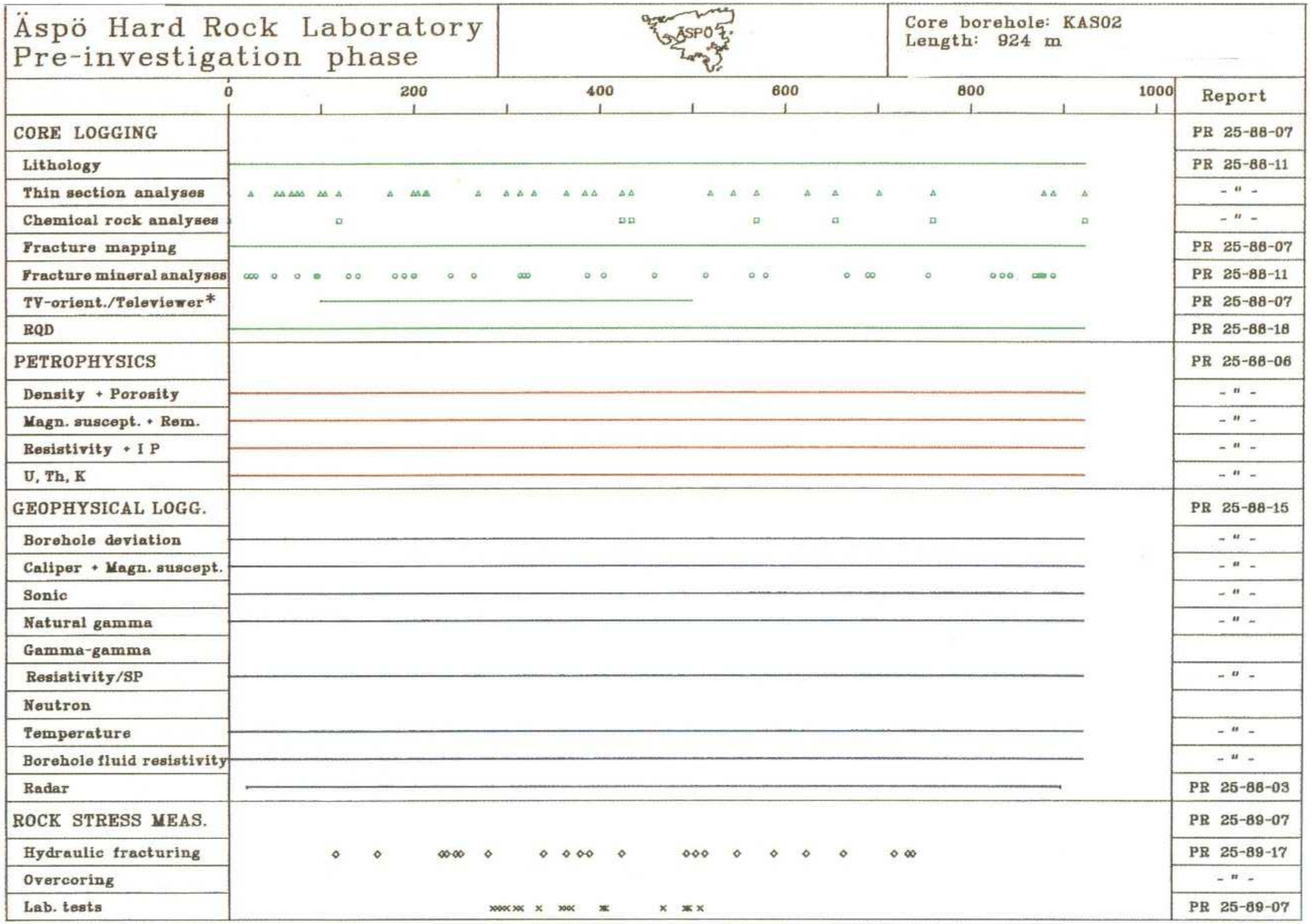


Figure 2-24. KAS 02. Borehole data. Geology.

Figure 2-25. KAS 03. Borehole data. Geology.

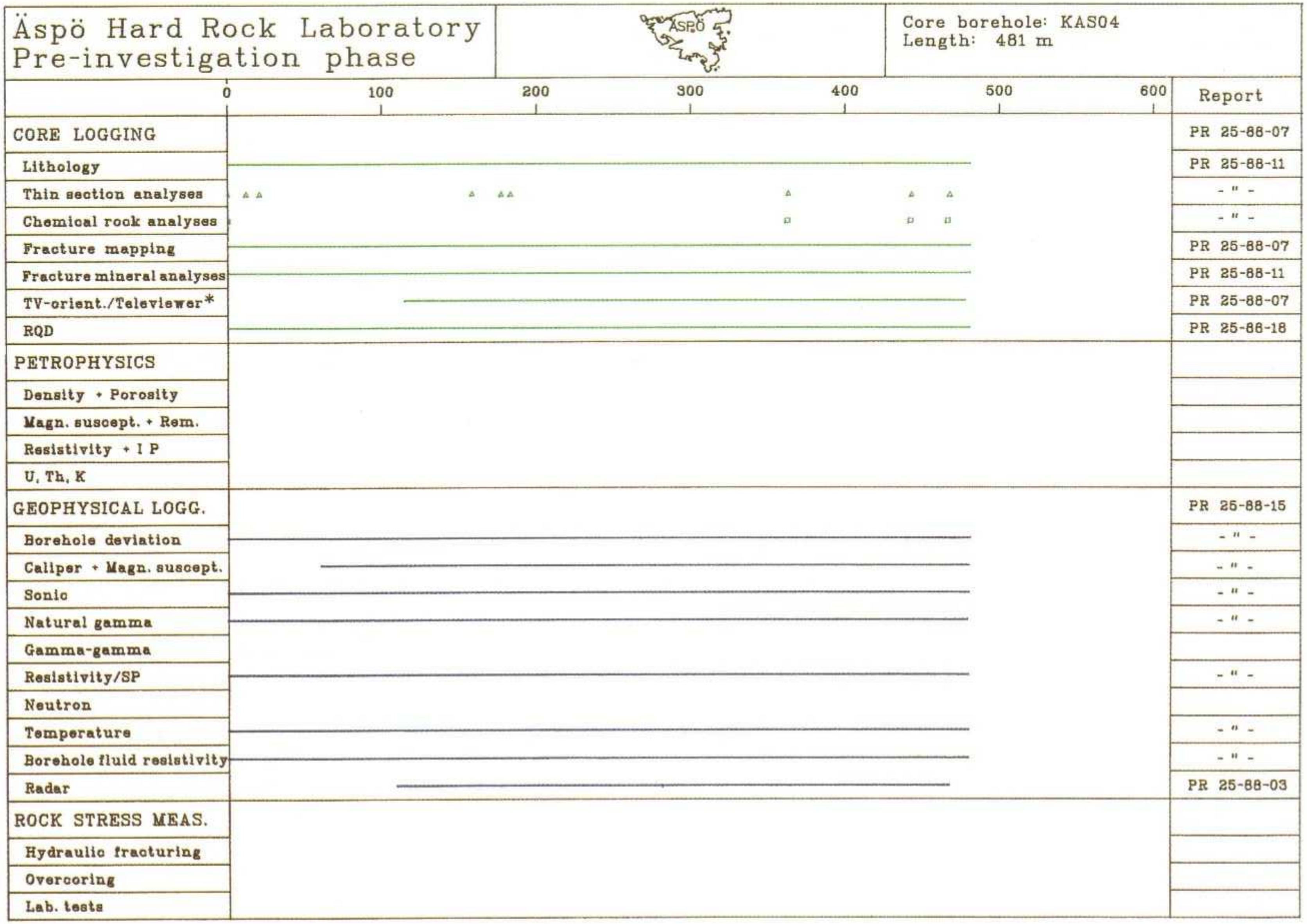


Figure 2-26. KAS 04. Borehole data. Geology.

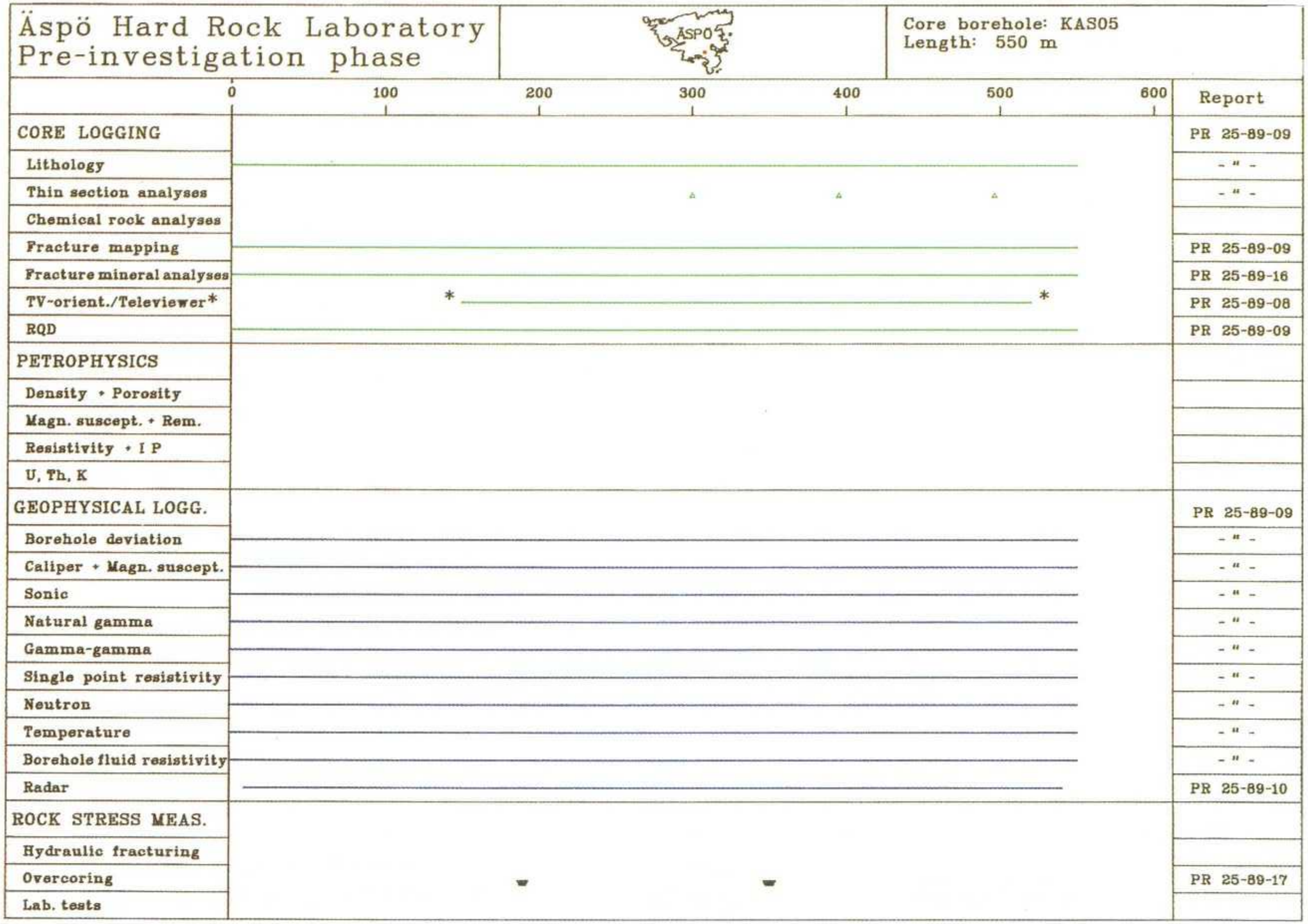


Figure 2-27. KAS 05. Borehole data. Geology.

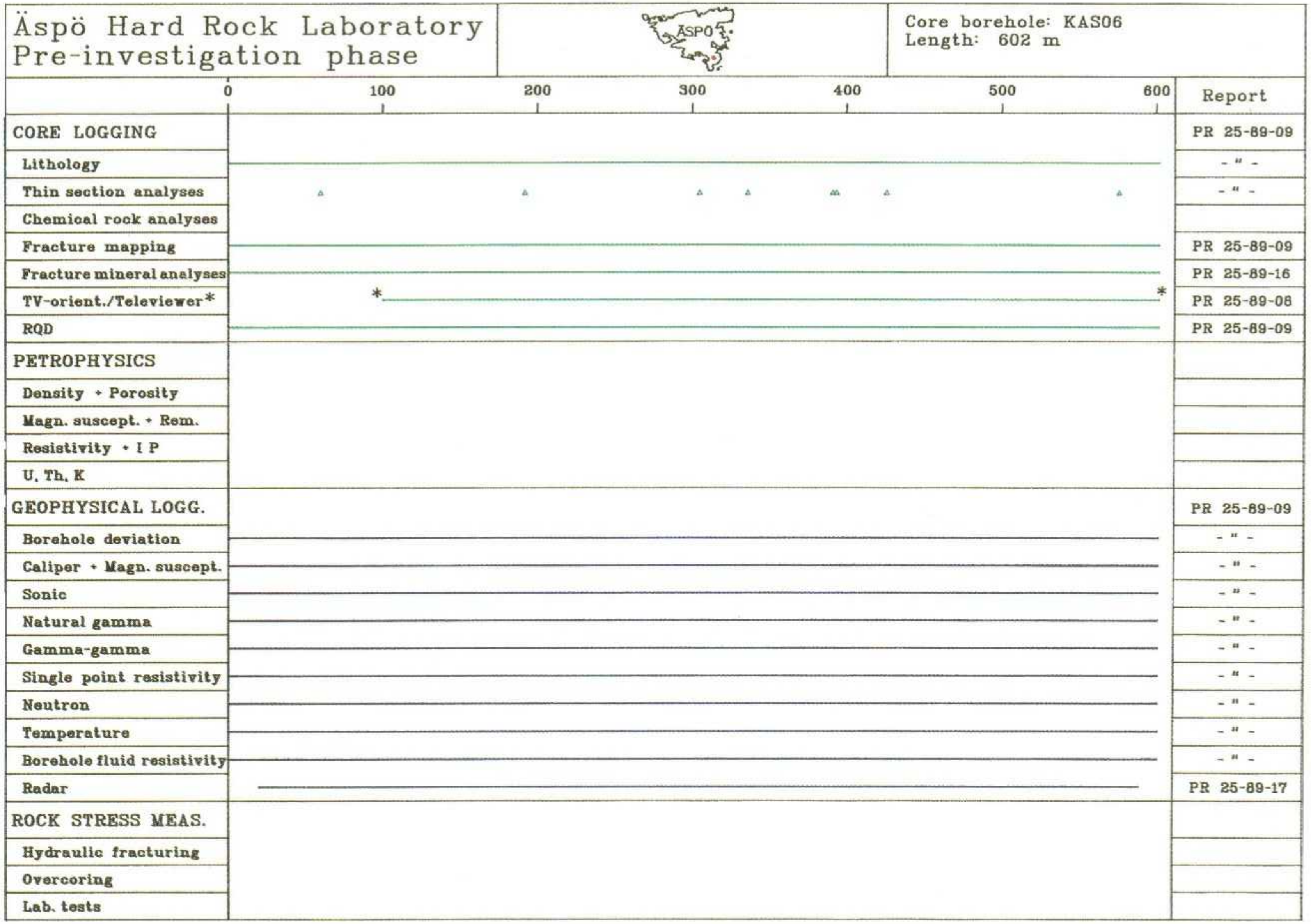


Figure 2-28. KAS 06. Borehole data. Geology.

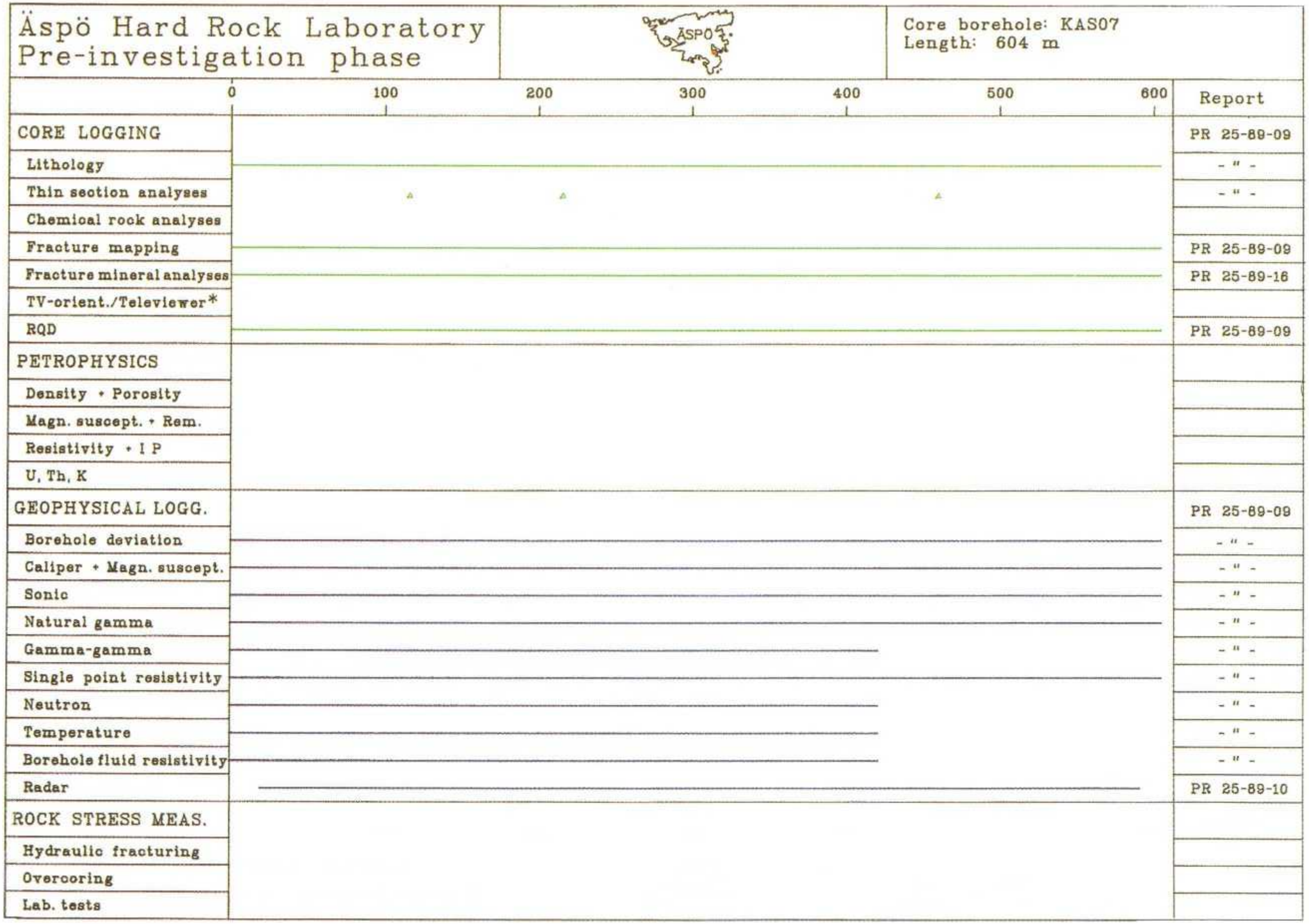


Figure 2-29. KAS 07. Borehole data. Geology.

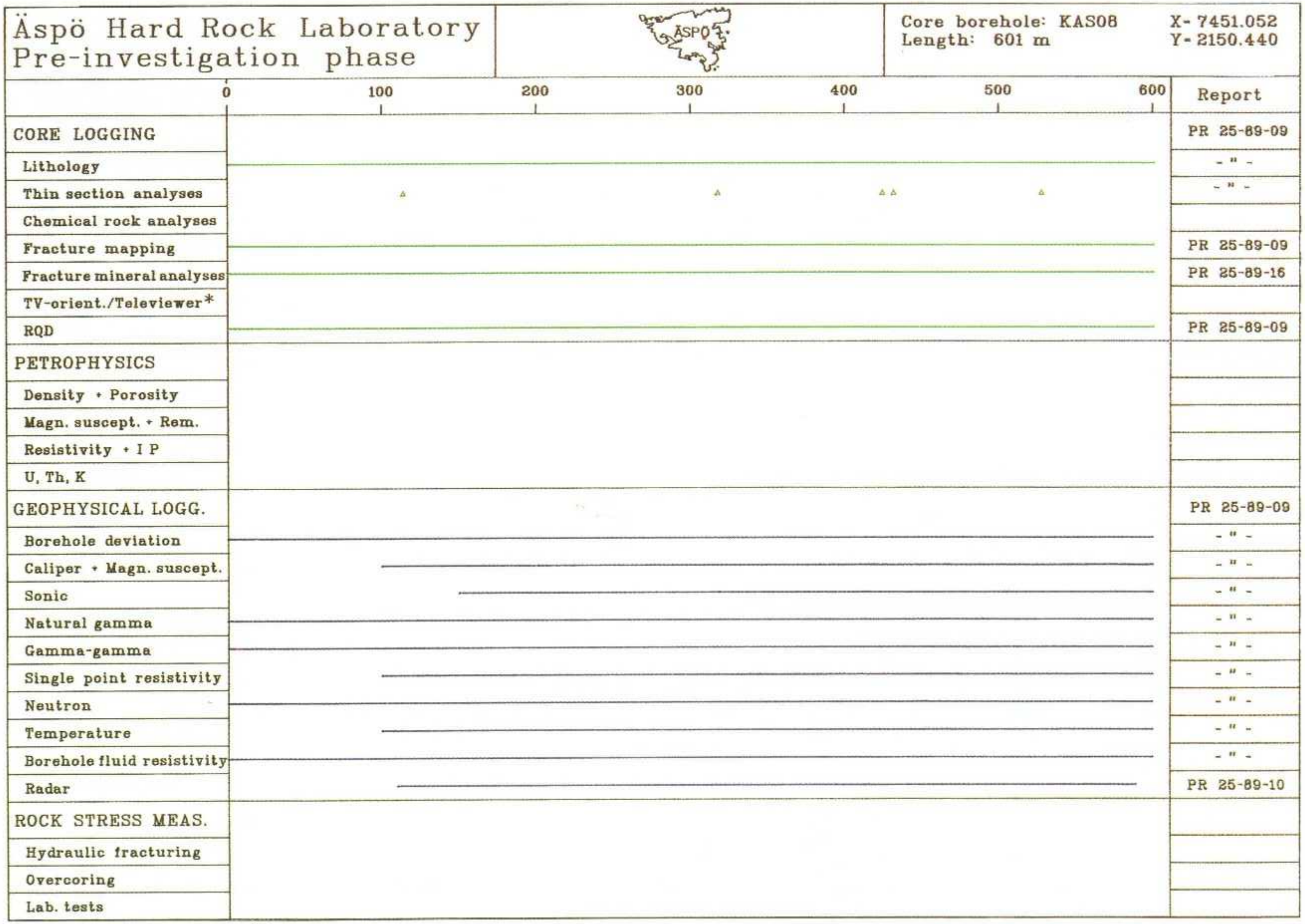


Figure 2-30. KAS 08. Borehole data. Geology.

Äspö Hard Rock Laboratory
Pre-investigation phase

Core borehole: KAS09
Length: 450 m

	0	100	200	300	400	500	600	Report
CORE LOGGING								
Lithology								PR 25-90-06
Thin section analyses								KAS09, Bh-rep.
Chemical rock analyses								
Fracture mapping								PR 25-90-06
Fracture mineral analyses								
TV-orient./Televiewer*								
RQD								PR 25-90-06
PETROPHYSICS								
Density + Porosity								
Magn. suscept. + Rem.								
Resistivity + I P								
U, Th, K								
GEOPHYSICAL LOGG.								
Borehole deviation								KAS09, Bh-rep.
Caliper + Magn. suscept.								PR 25-90-06
Sonic								- " -
Natural gamma								- " -
Gamma-gamma								- " -
Single point resistivity								- " -
Neutron								- " -
Temperature								- " -
Borehole fluid resistivity								- " -
Radar								PR 25-90-05
ROCK STRESS MEAS.								
Hydraulic fracturing								
Overcoring								
Lab. tests								

Figure 2-31. KAS 09. Borehole data. Geology.

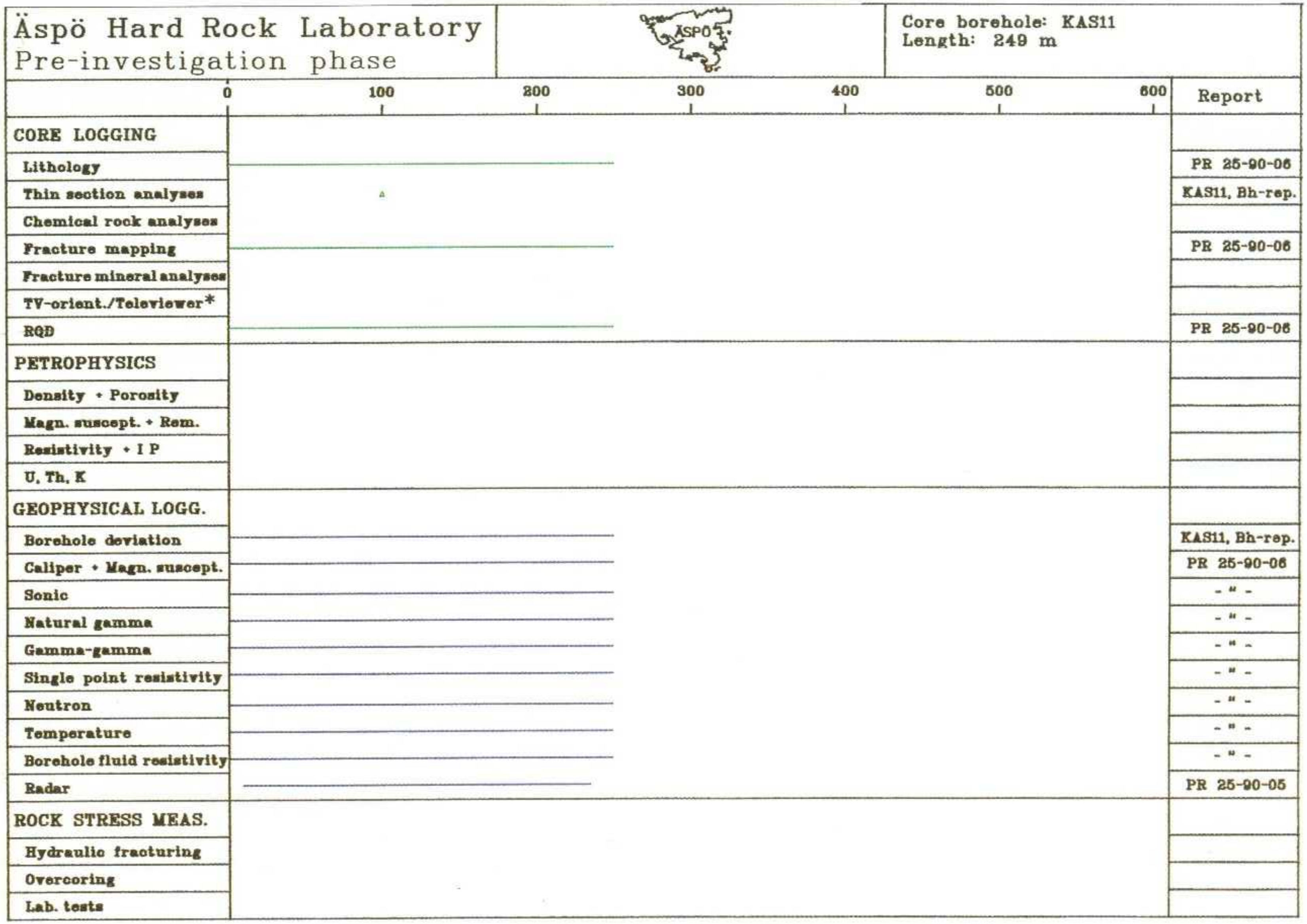


Figure 2-32. KAS 11. Borehole data. Geology.

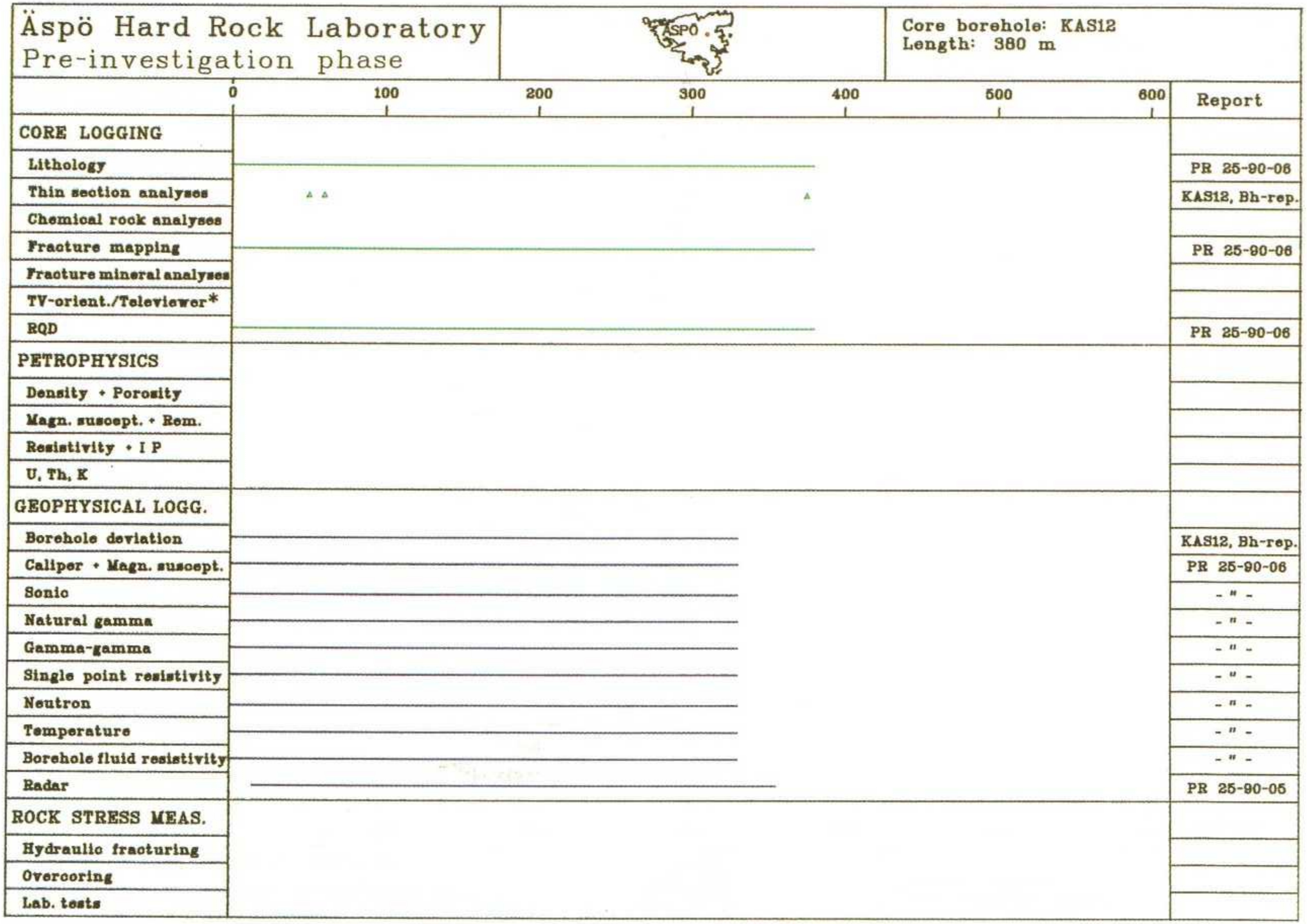


Figure 2-33. KAS 12. Borehole data. Geology.

Äspö Hard Rock Laboratory Pre-investigation phase	Core borehole: KAS13 Length: 406 m

	0 — 100 — 200 — 300 — 400 — 500 — 600	Report
CORE LOGGING		
Lithology		PR 25-90-06
Thin section analyses		KAS13, Bh-rep.
Chemical rock analyses		
Fracture mapping		PR 25-90-06
Fracture mineral analyses		
TV-orient./Televiewer*		
RQD		PR 25-90-06
PETROPHYSICS		
Density + Porosity		
Magn. suscept. + Rem.		
Resistivity + I P		
U, Th, K		
GEOPHYSICAL LOGG.		
Borehole deviation		KAS13, Bh-rep.
Caliper + Magn. suscept.		PR 25-90-06
Sonic		- " -
Natural gamma		- " -
Gamma-gamma		- " -
Single point resistivity		- " -
Neutron		- " -
Temperature		- " -
Borehole fluid resistivity		- " -
Radar		PR 25-90-05
ROCK STRESS MEAS.		
Hydraulic fracturing		
Overcoring		
Lab. tests		

Figure 2-34. KAS 13. Borehole data. Geology.

Äspö Hard Rock Laboratory Pre-investigation phase		Core borehole: KAS14 Length: 212 m
	0 100 200 300 400 500 600	Report
CORE LOGGING		
Lithology		PR 25-90-06
Thin section analyses		
Chemical rock analyses		
Fracture mapping		PR 25-90-06
Fracture mineral analyses		
TV-orient./Televiewer*		
RQD		PR 25-90-06
PETROPHYSICS		
Density + Porosity		
Magn. suscept. + Rem.		
Resistivity + I P		
U, Th, K		
GEOPHYSICAL LOGG.		
Borehole deviation		KAS14, Bh-rep.
Caliper + Magn. suscept.		PR 25-90-06
Sonic		- " -
Natural gamma		- " -
Gamma-gamma		- " -
Single point resistivity		- " -
Neutron		- " -
Temperature		- " -
Borehole fluid resistivity		- " -
Radar		PR 25-90-05
ROCK STRESS MEAS.		
Hydraulic fracturing		
Overcoring		
Lab. tests		

Figure 2-35. KAS 14. Borehole data. Geology.

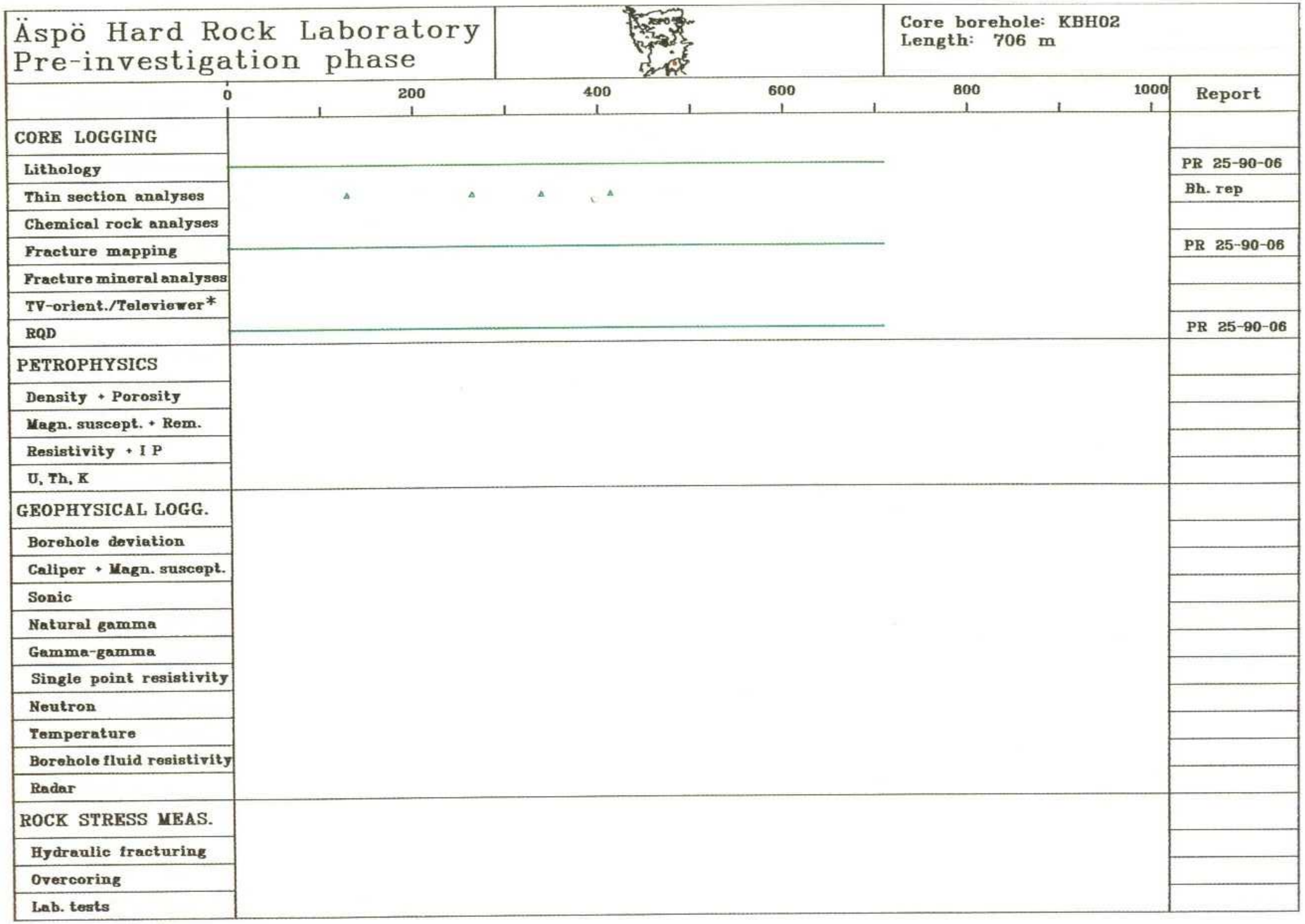


Figure 2-36. KBH 02. Borehole data. Geology.

Äspö Hard Rock Laboratory
Pre-investigation phase

ÄSPÖ
LAXEMAR

Core borehole: KLX01
Length: 702 m

	0 200 400 600 800 1000	Report
CORE LOGGING		PR 25-88-07
Lithology		PR 25-88-11
Thin section analyses		- " -
Chemical rock analyses		- " -
Fracture mapping		- " -
Fracture mineral analyses		
TV-orient./Televiewer*		
RQD		PR 25-88-18
PETROPHYSICS		PR 25-88-06
Density + Porosity		- " -
Magn. suscept. + Rem.		- " -
Resistivity + I P		- " -
U, Th, K		
GEOPHYSICAL LOGG.		PR 25-88-15
Borehole deviation		- " -
Caliper + Magn. suscept.		- " -
Sonic		- " -
Natural gamma		- " -
Gamma-gamma		
Single point resistivity		- " -
Neutron		
Temperature		- " -
Borehole fluid resistivity		- " -
Radar		PR 25-88-03
ROCK STRESS MEAS.		
Hydraulic fracturing		
Overcoring		
Lab. tests		

Figure 2-37. KLX 01. Borehole data. Geology.

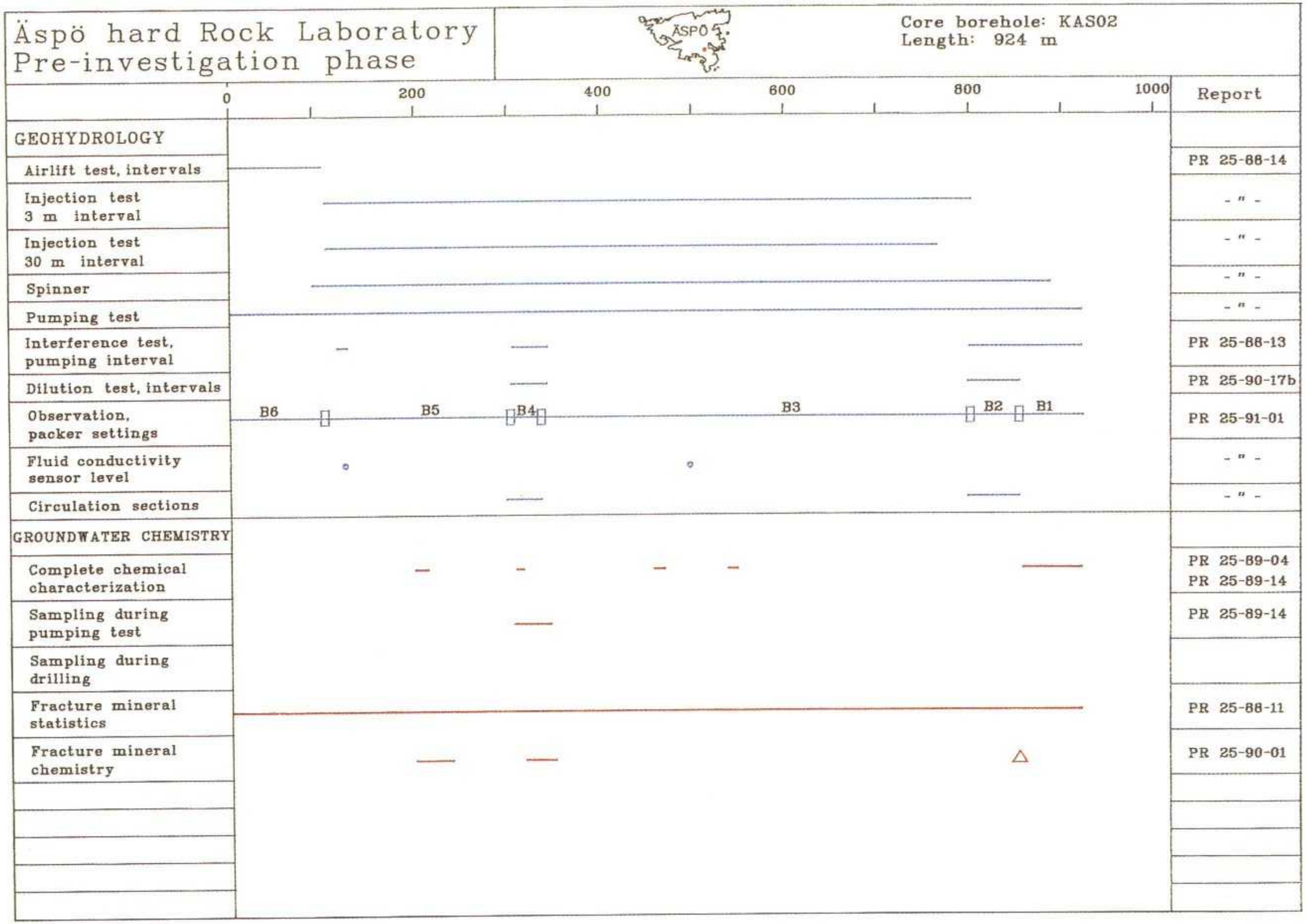


Figure 2-38. KAS 02. Borehole data. Geohydrology and groundwater chemistry.

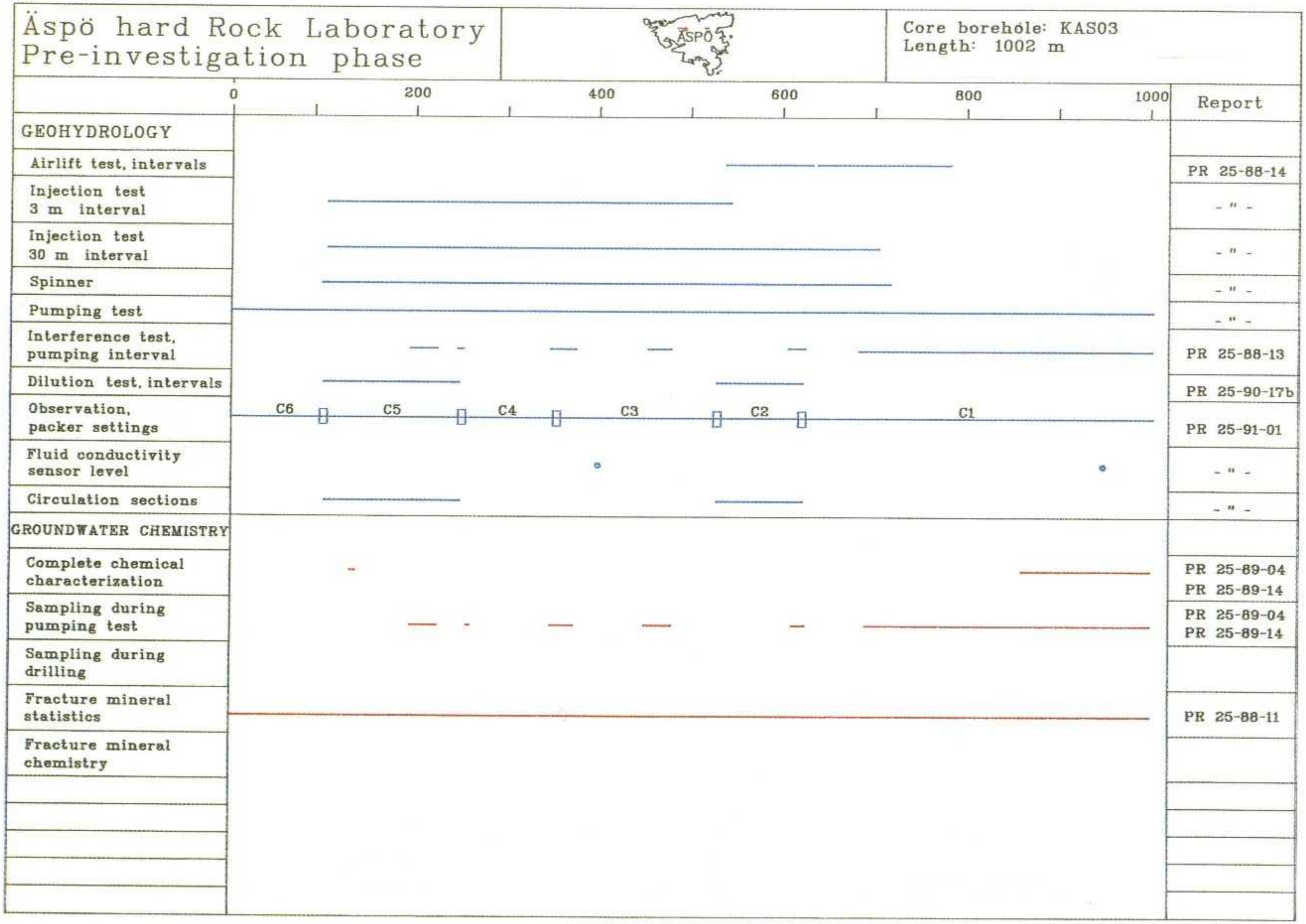


Figure 2-39. KAS 03. Borehole data. Geohydrology and groundwater chemistry.

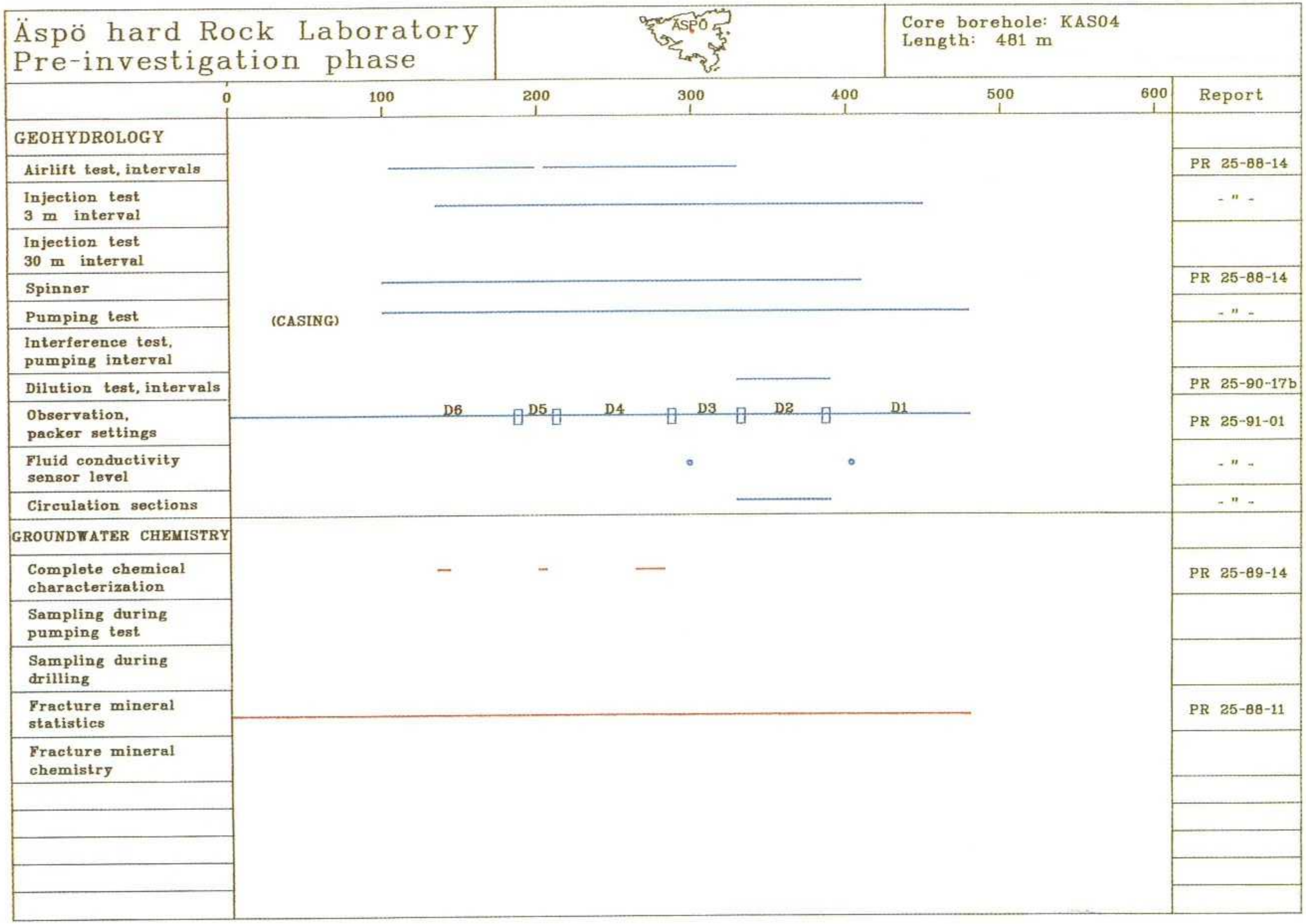


Figure 2-40. KAS 04. Borehole data. Geohydrology and groundwater chemistry.

Figure 2-41. KAS 05. Borehole data. Geohydrology and groundwater chemistry.

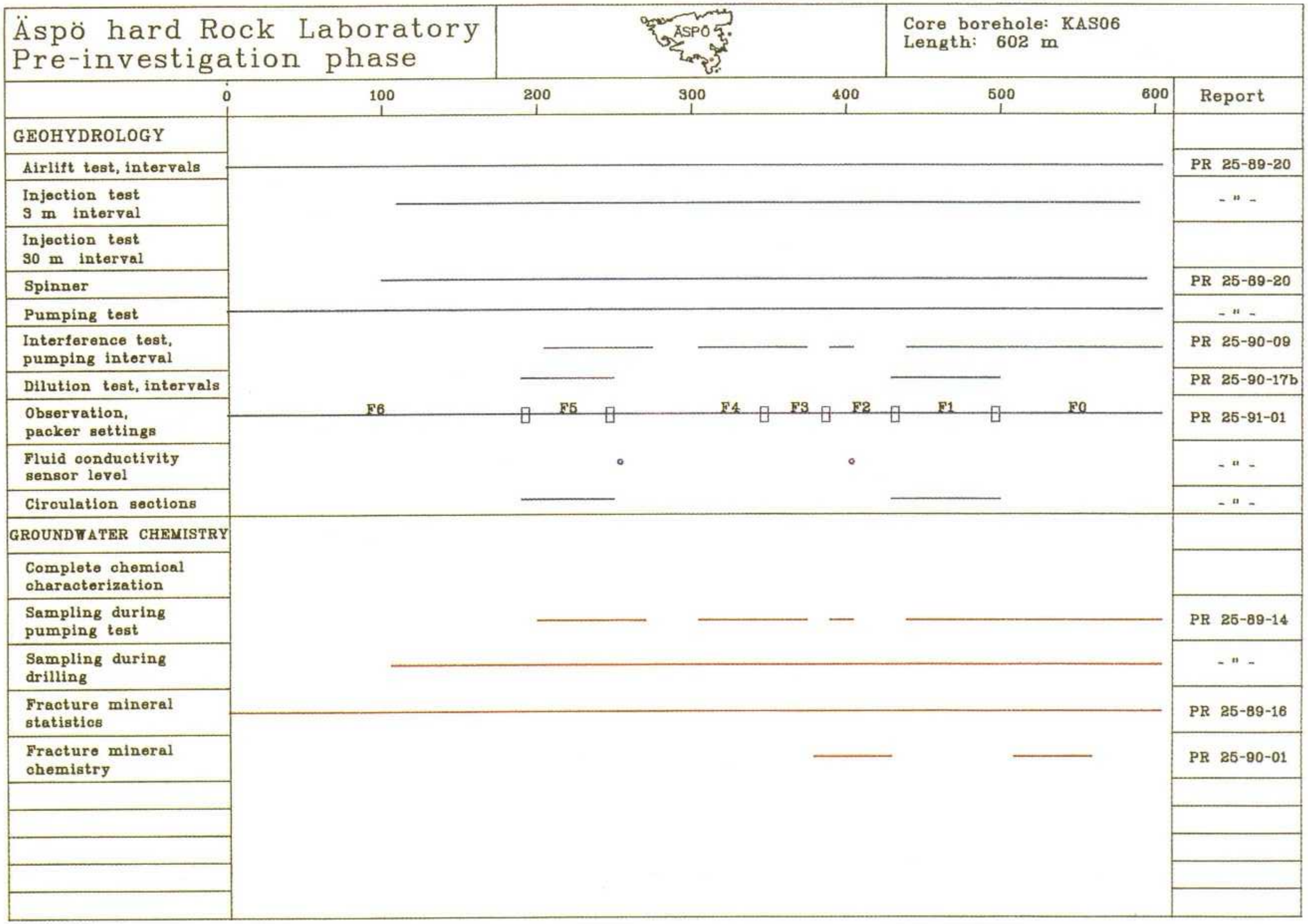


Figure 2-42. *KAS 06. Borehole data. Geohydrology and groundwater chemistry.*

Figure 2-43. KAS 07. Borehole data. Geohydrology and groundwater chemistry.

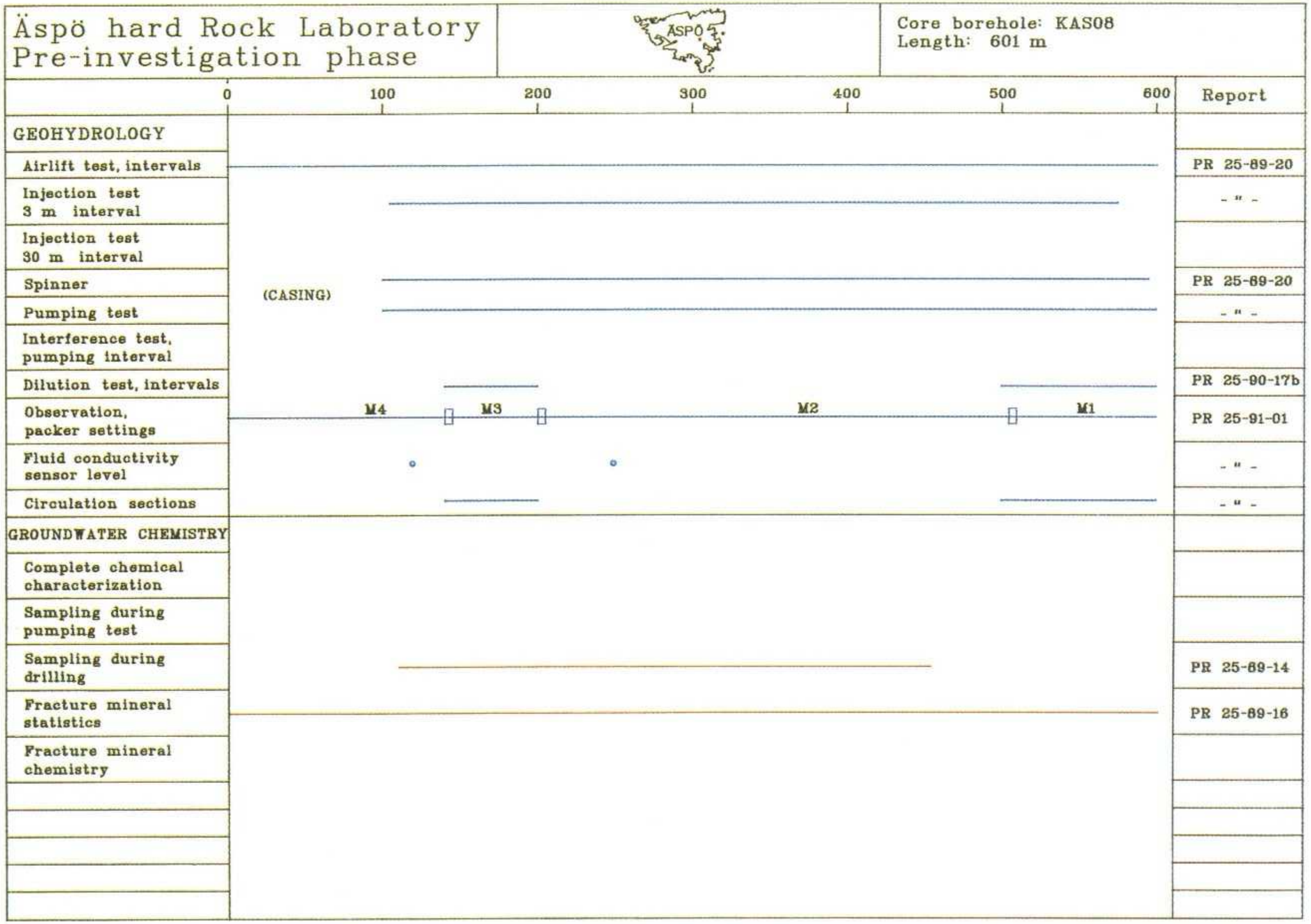


Figure 2-44. *KAS 08. Borehole data. Geohydrology and groundwater chemistry.*

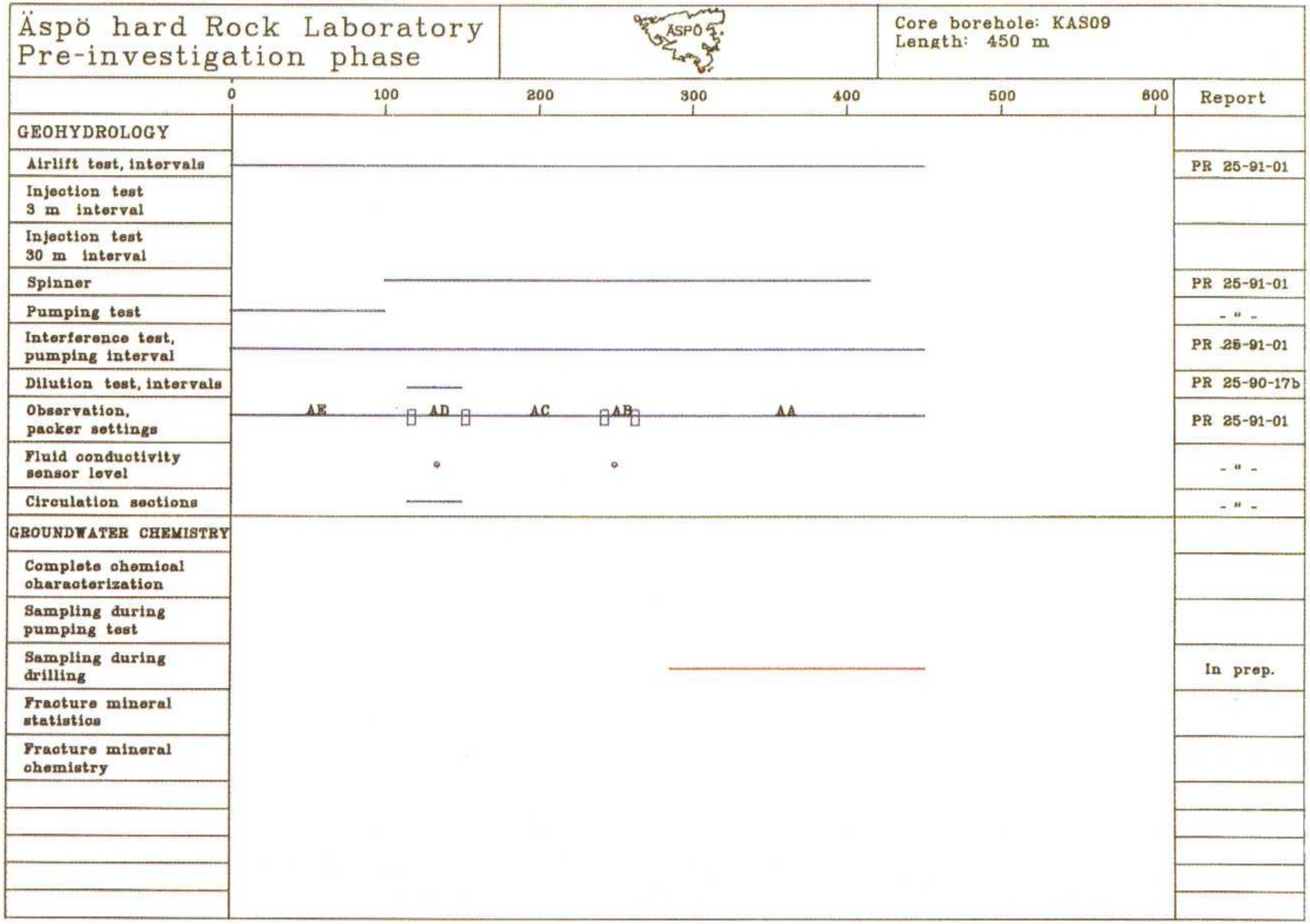


Figure 2-45. KAS 09. Borehole data. Geohydrology and groundwater chemistry.

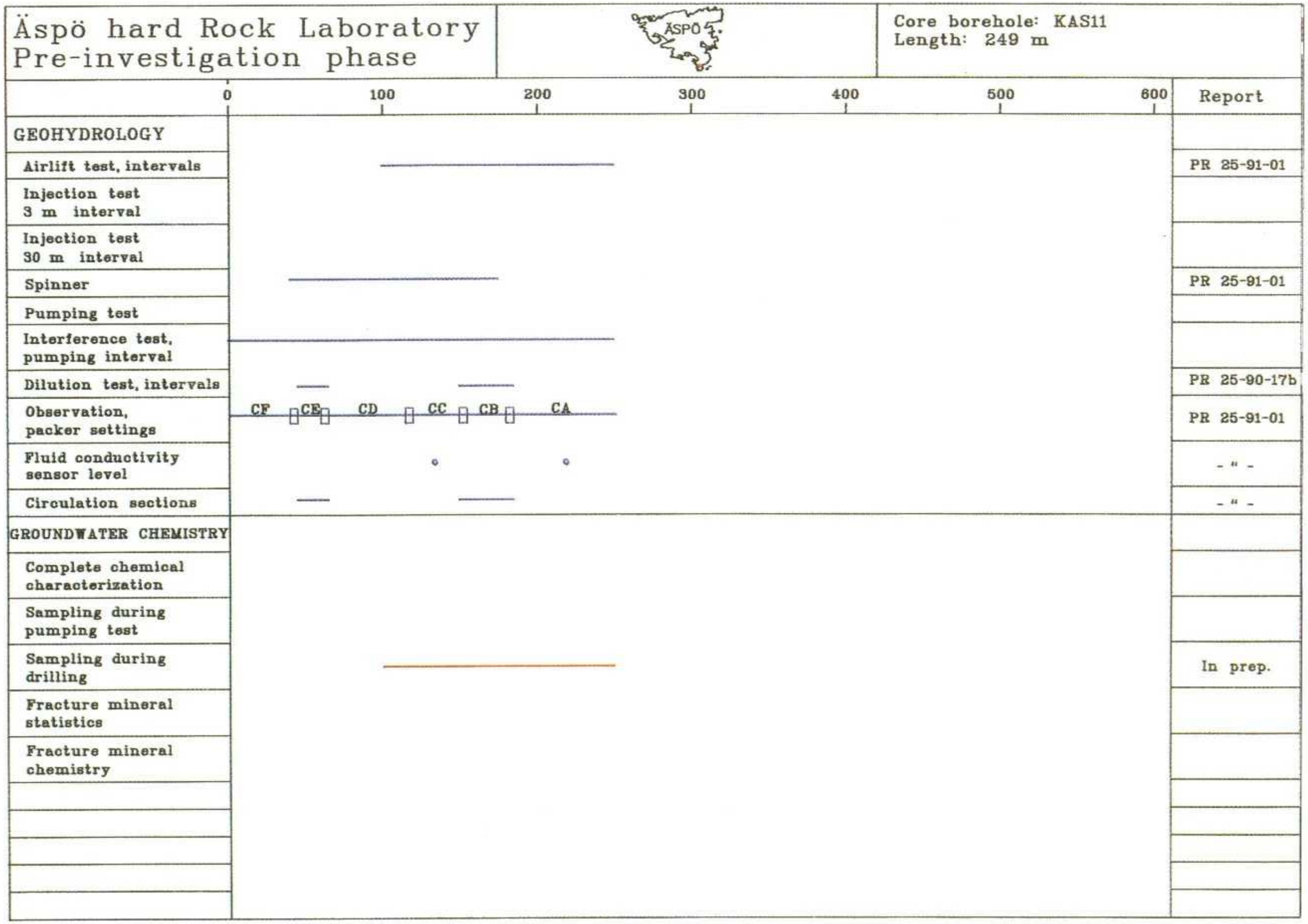


Figure 2-46. KAS 11. Borehole data. Geohydrology and groundwater chemistry.

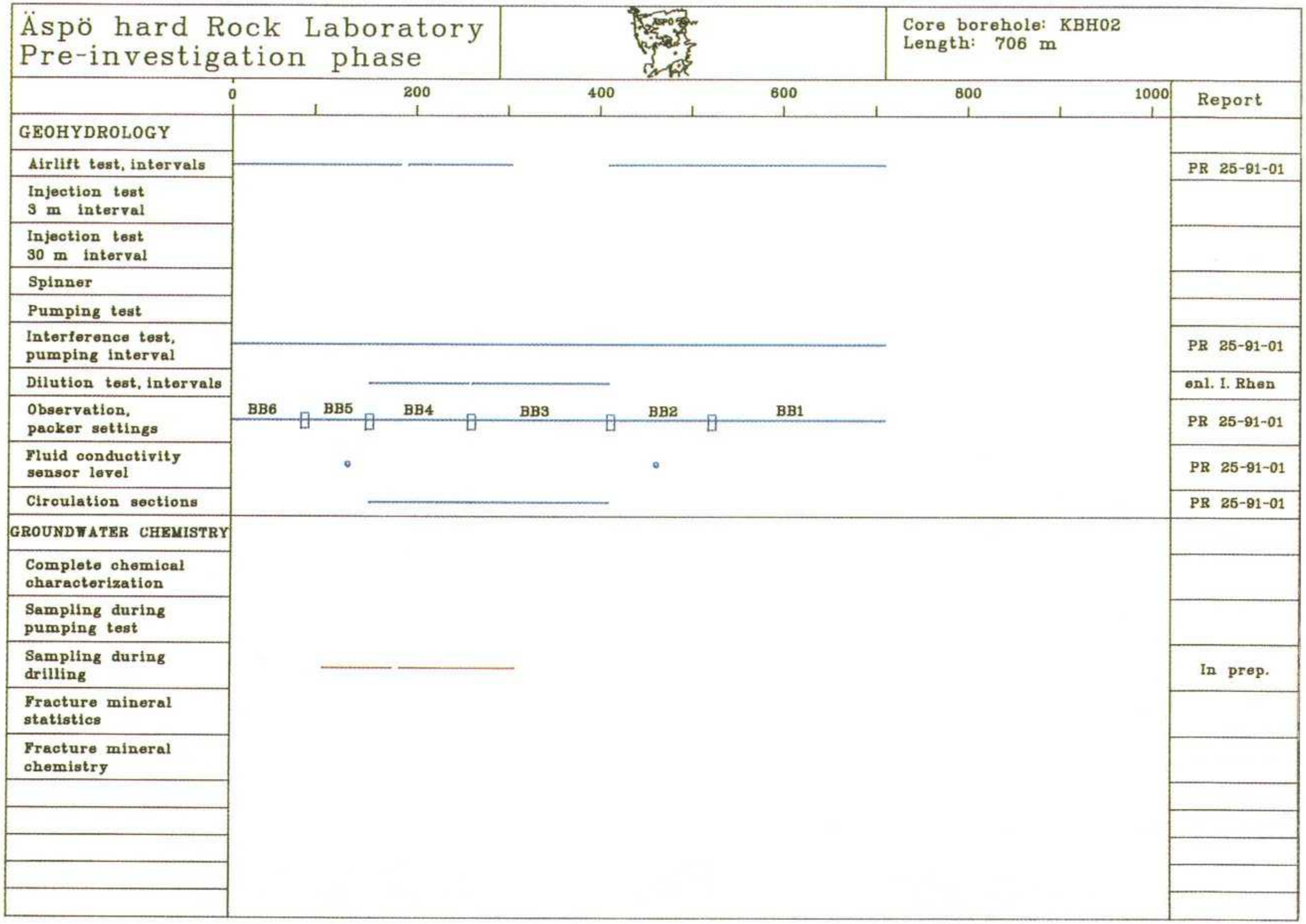


Figure 2-47. *KAS 12. Borehole data. Geohydrology and groundwater chemistry.*

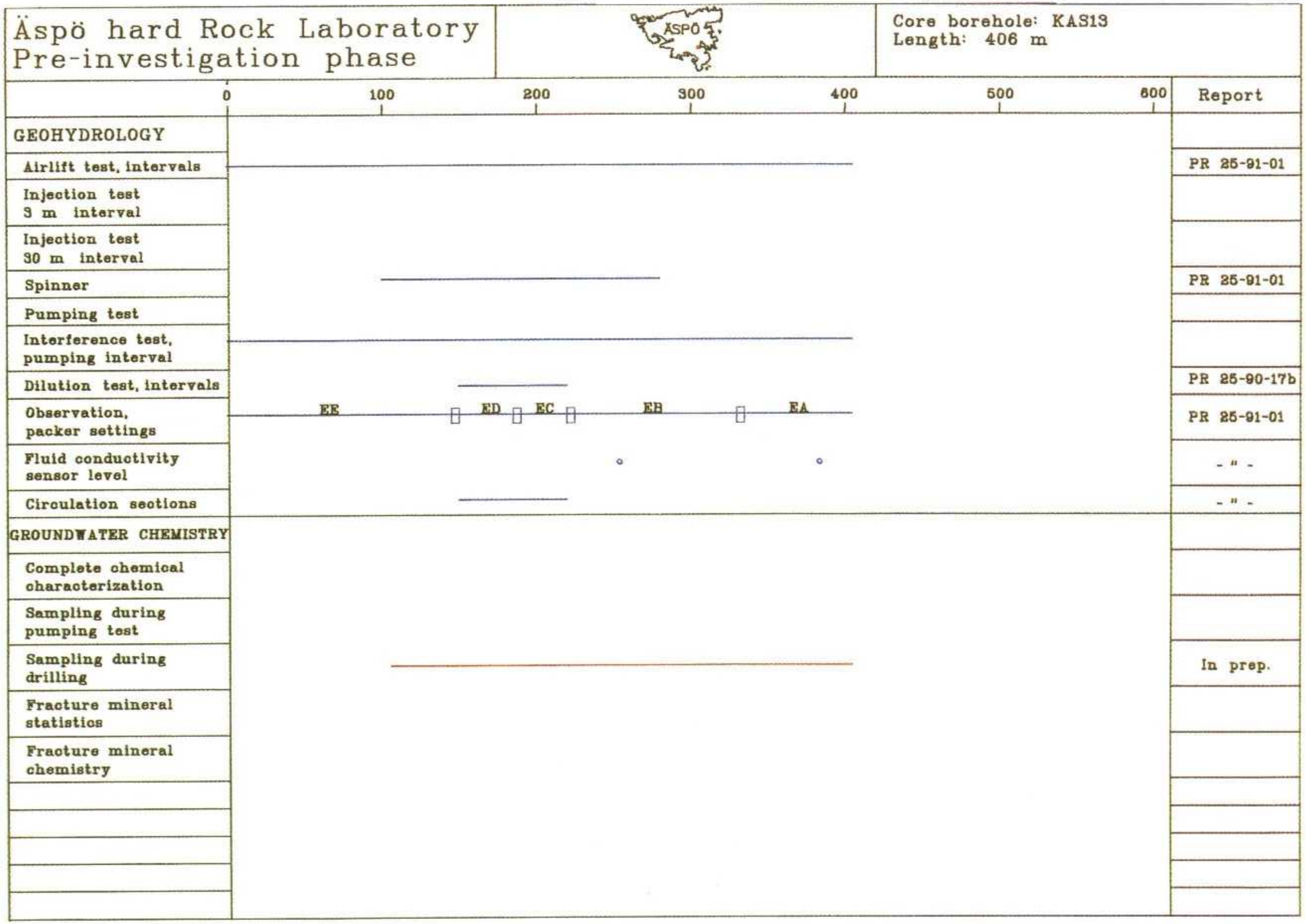


Figure 2-48. KAS 13. Borehole data. Geohydrology and groundwater chemistry.

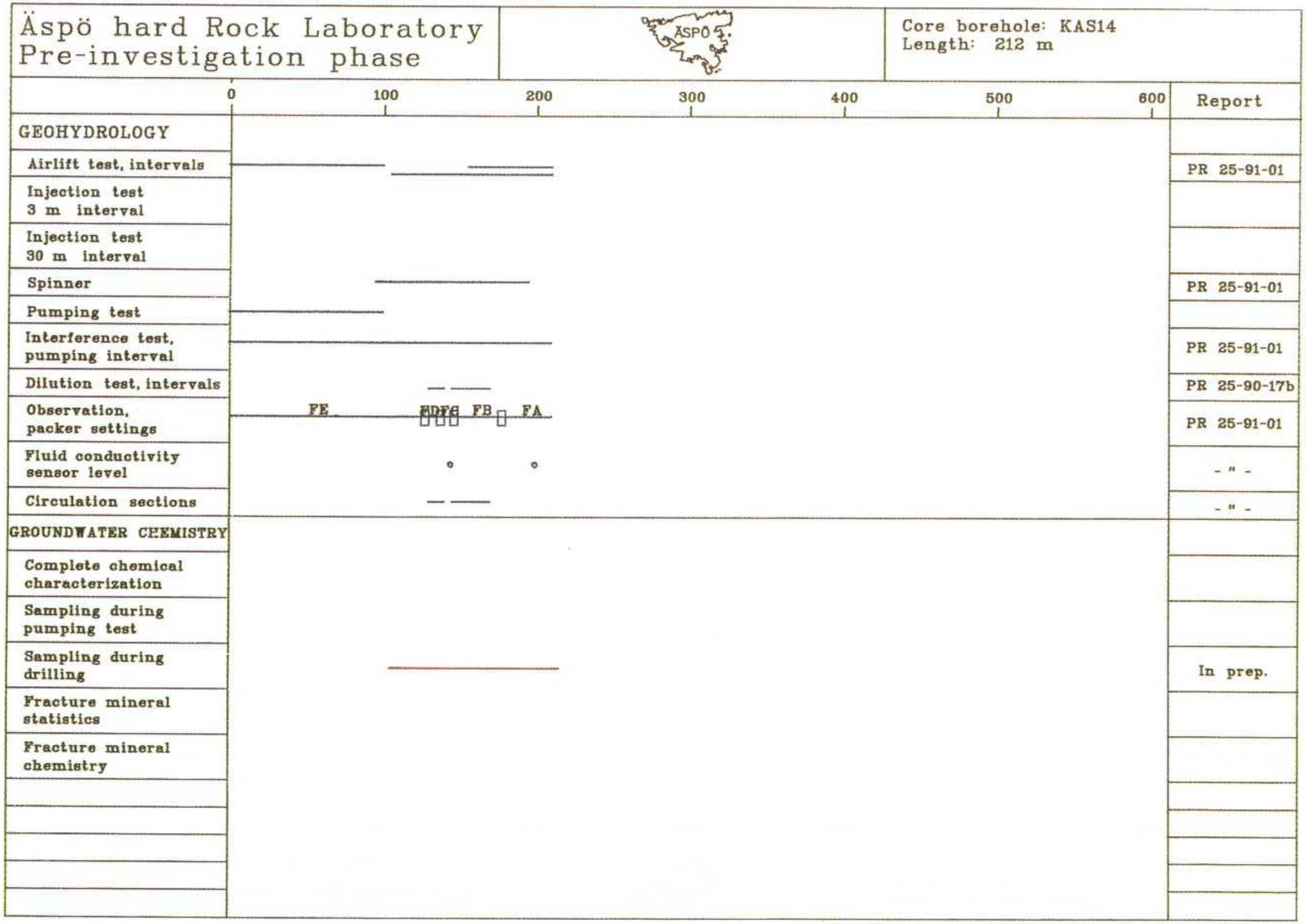


Figure 2-49. KAS 14. Borehole data. Geohydrology and groundwater chemistry.

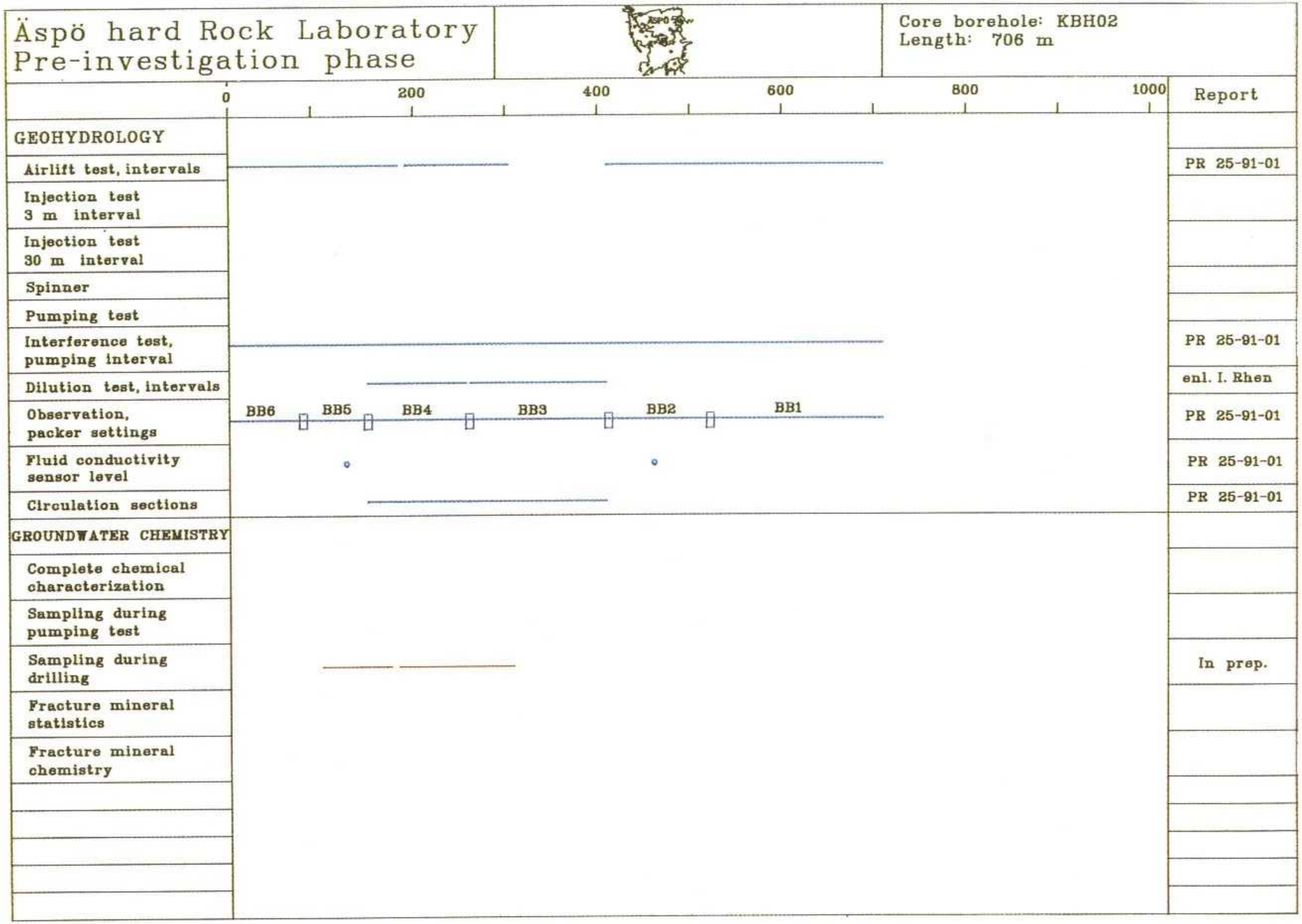


Figure 2-50. KBH 02. Borehole data. Geohydrology and groundwater chemistry.

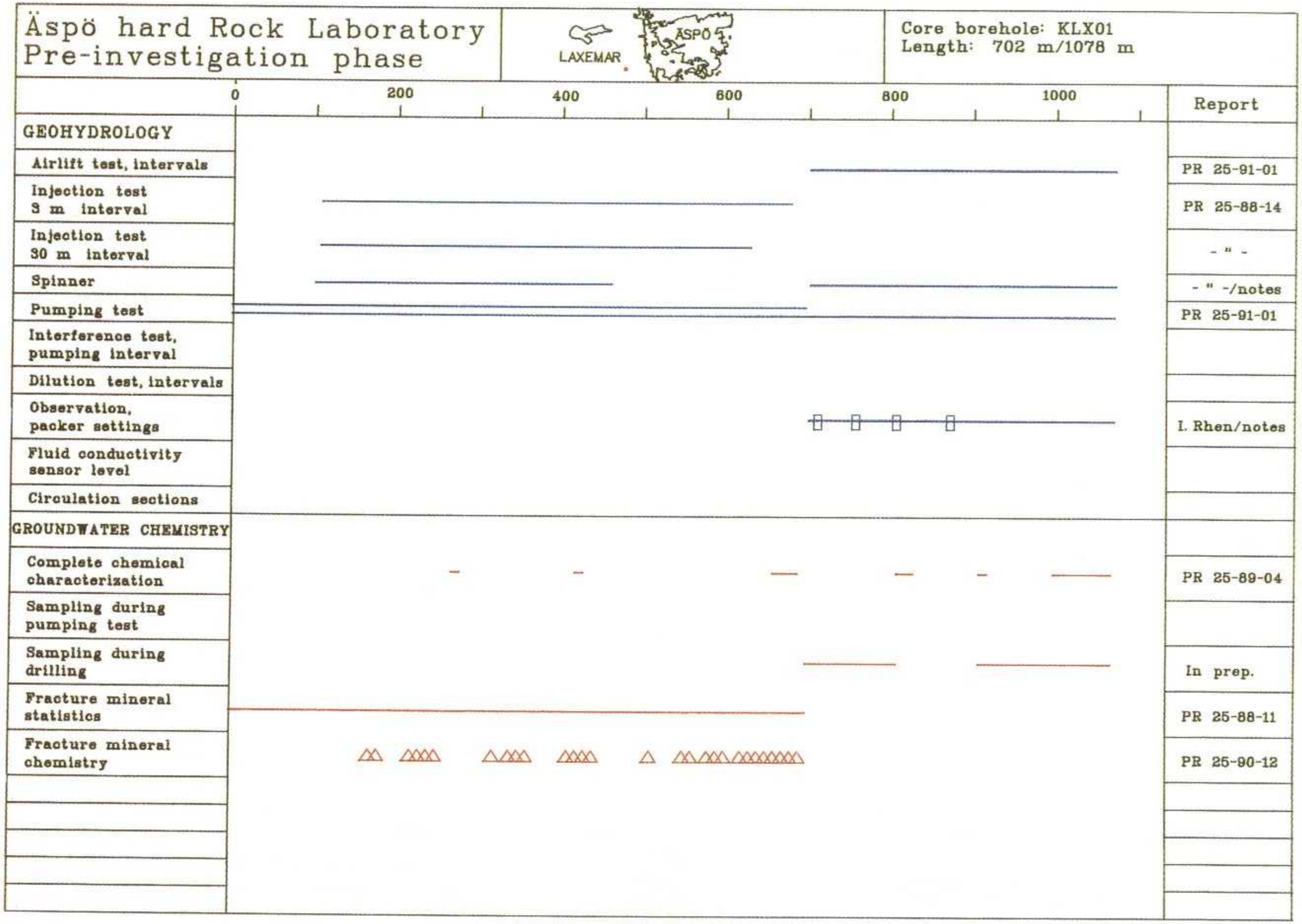


Figure 2-51. KLX 01. Borehole data. Geohydrology and groundwater chemistry.

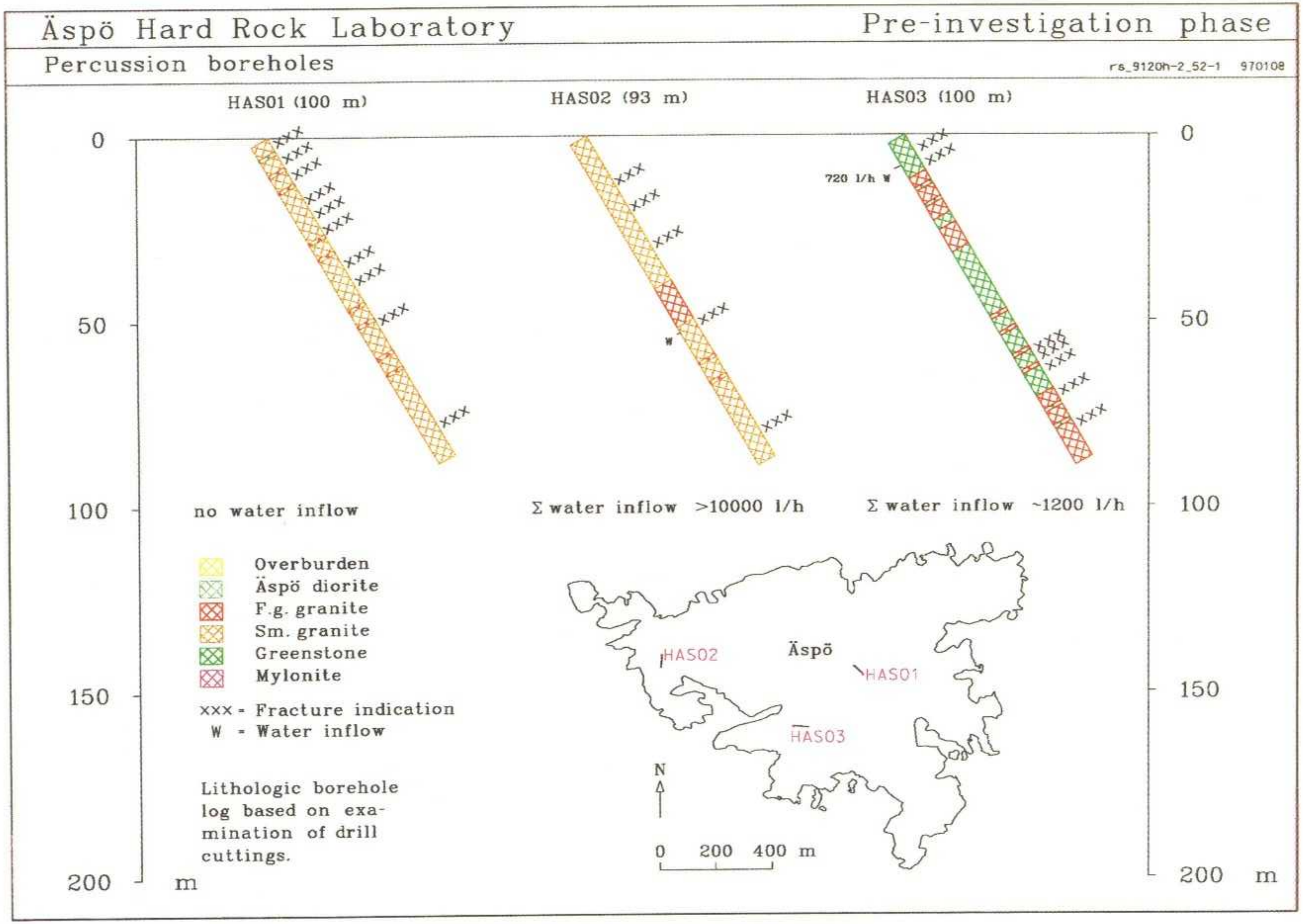


Figure 2-52. Percussion boreholes HAS 01-03.

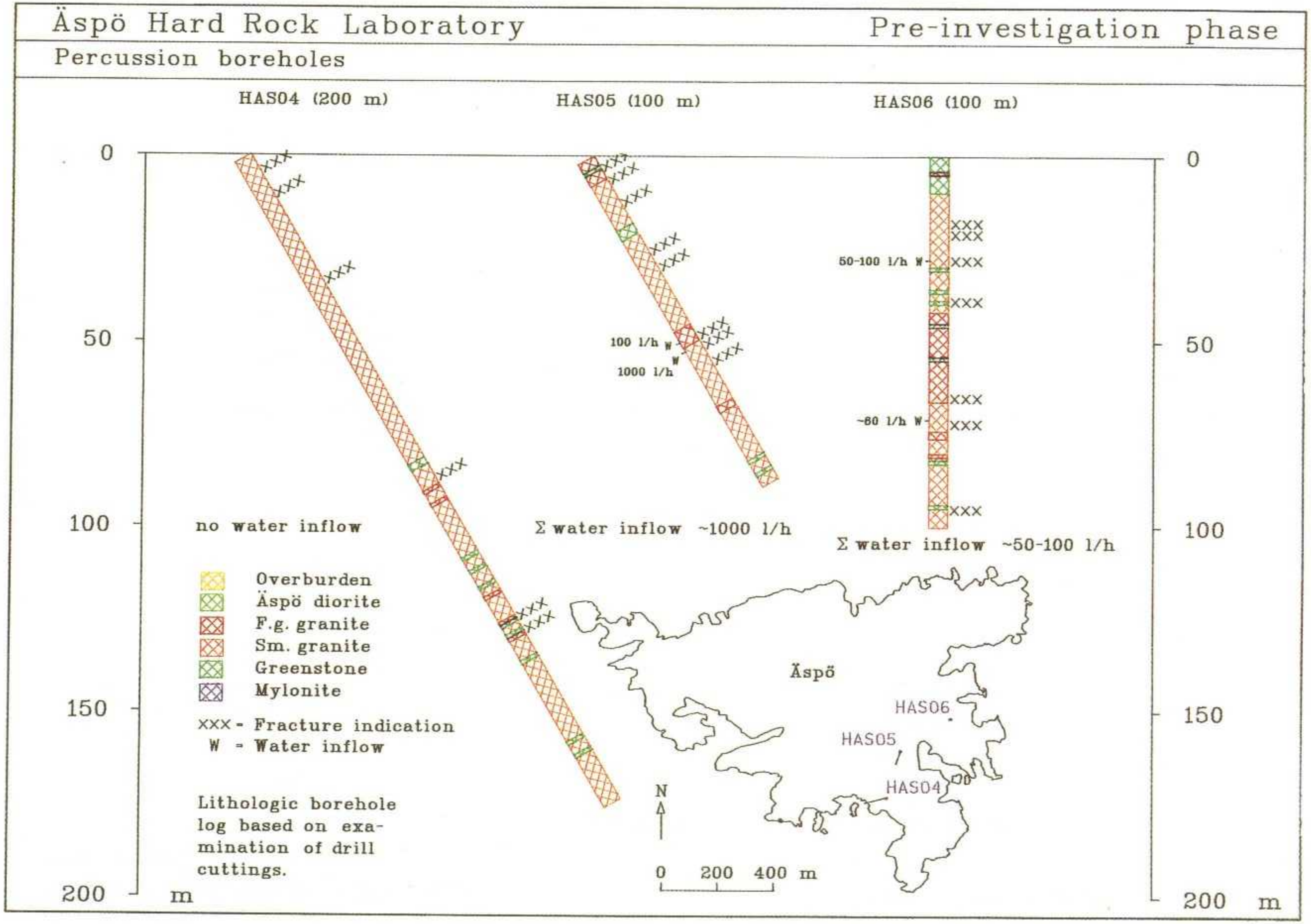


Figure 2-53. Percussion boreholes HAS 04-06.

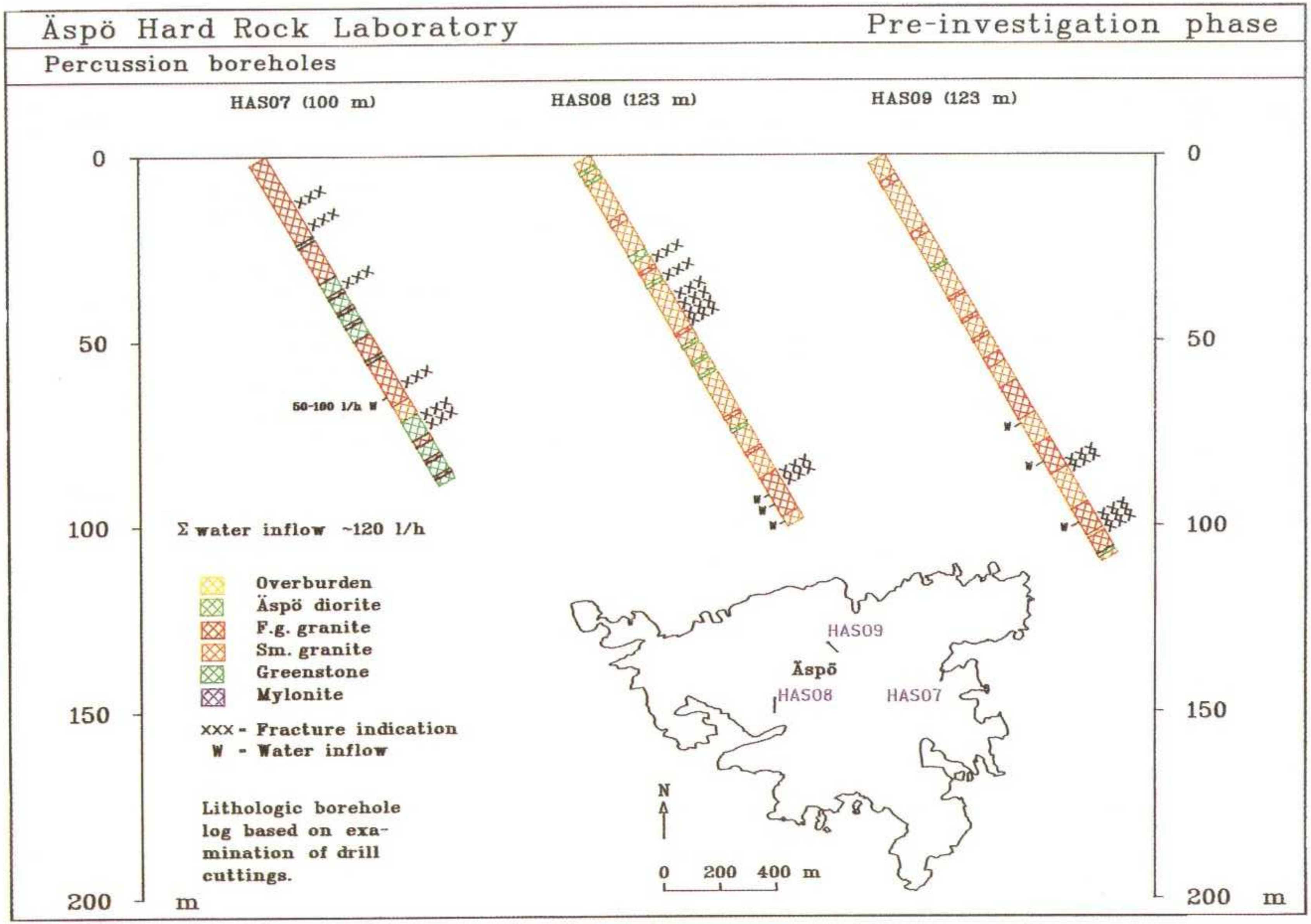


Figure 2-54. Percussion boreholes HAS 07-09.

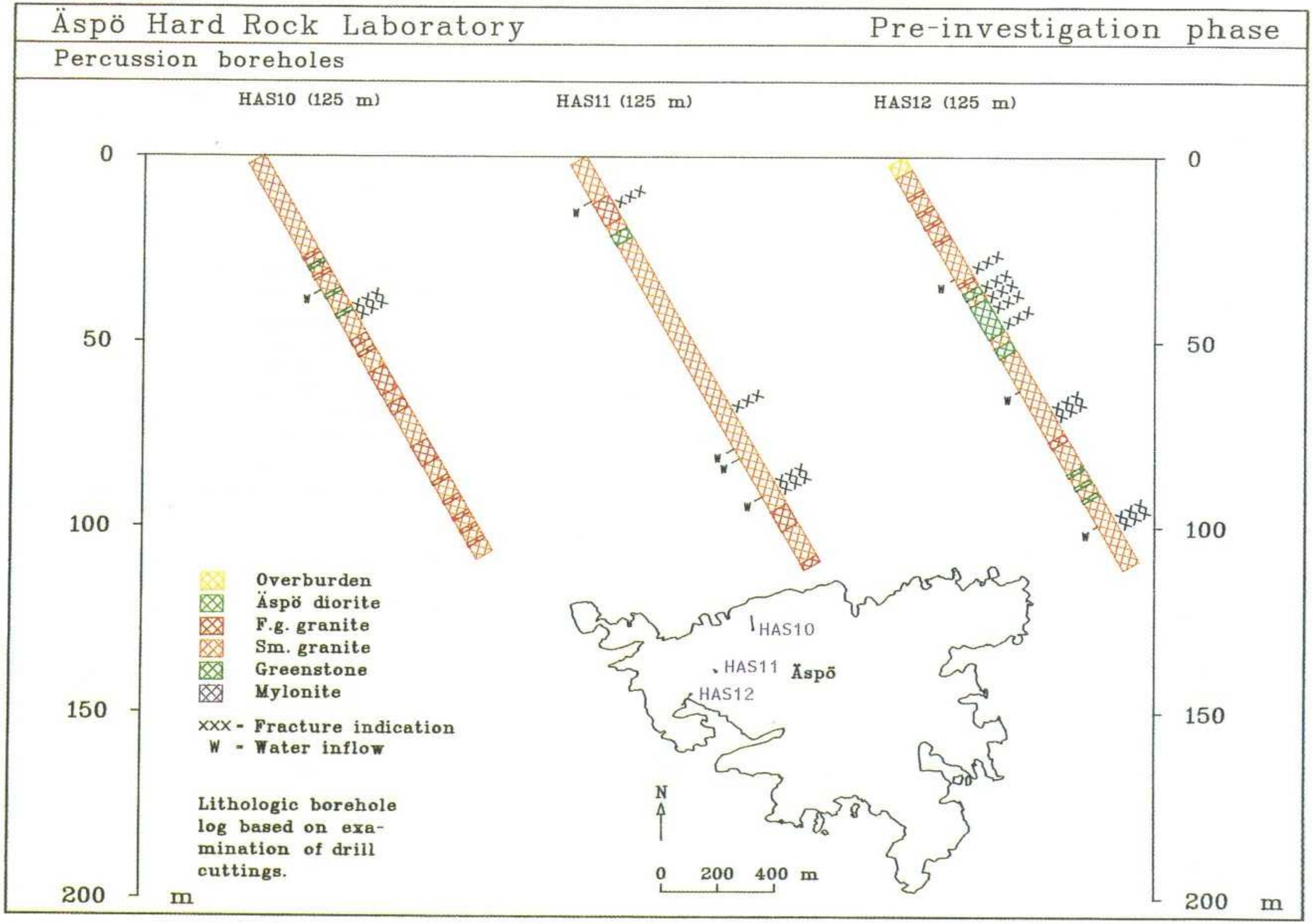


Figure 2-55. Percussion boreholes HAS 10-12.

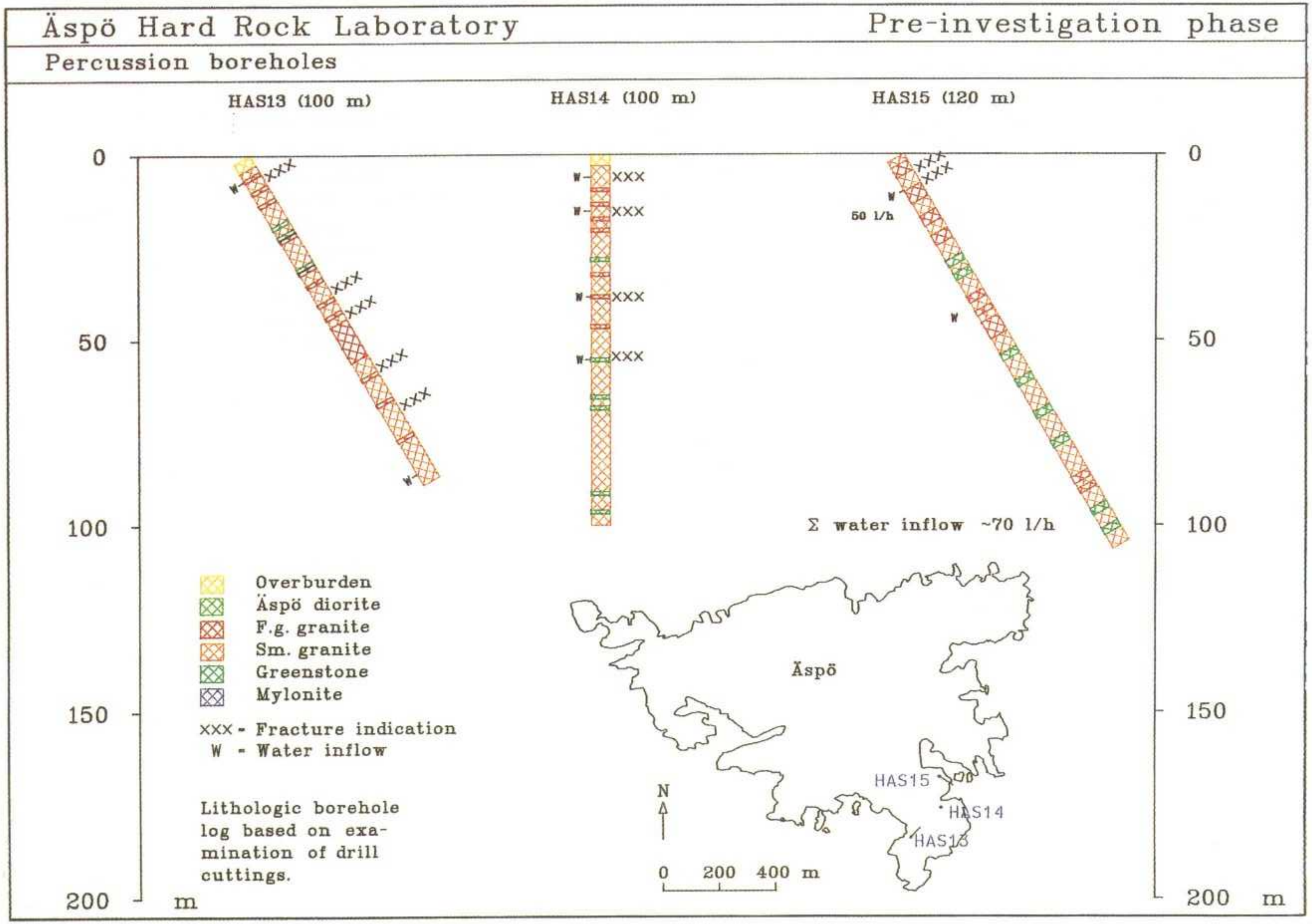


Figure 2-56. Percussion boreholes HAS 13-15.

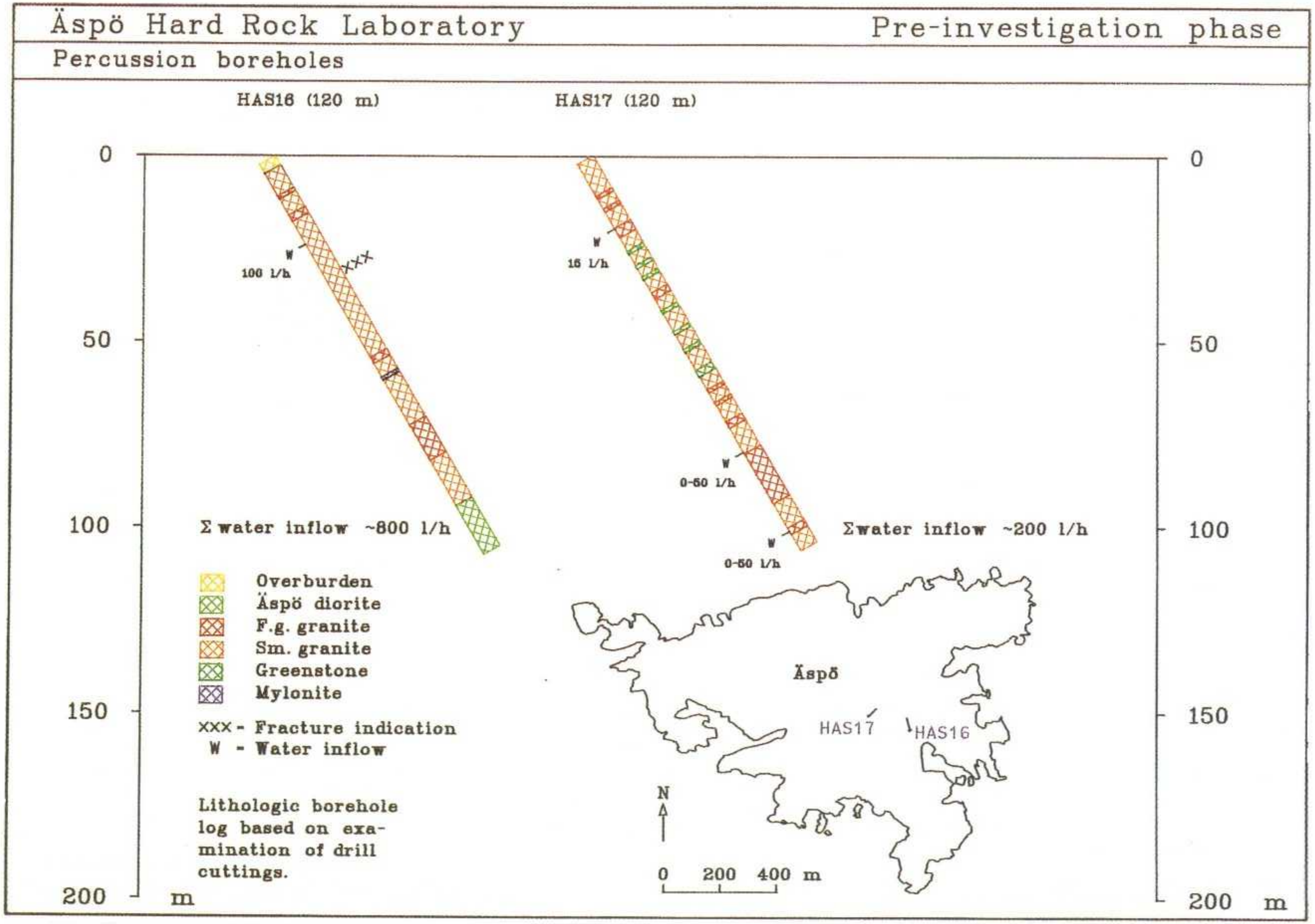


Figure 2-57. Percussion boreholes HAS 16-17.

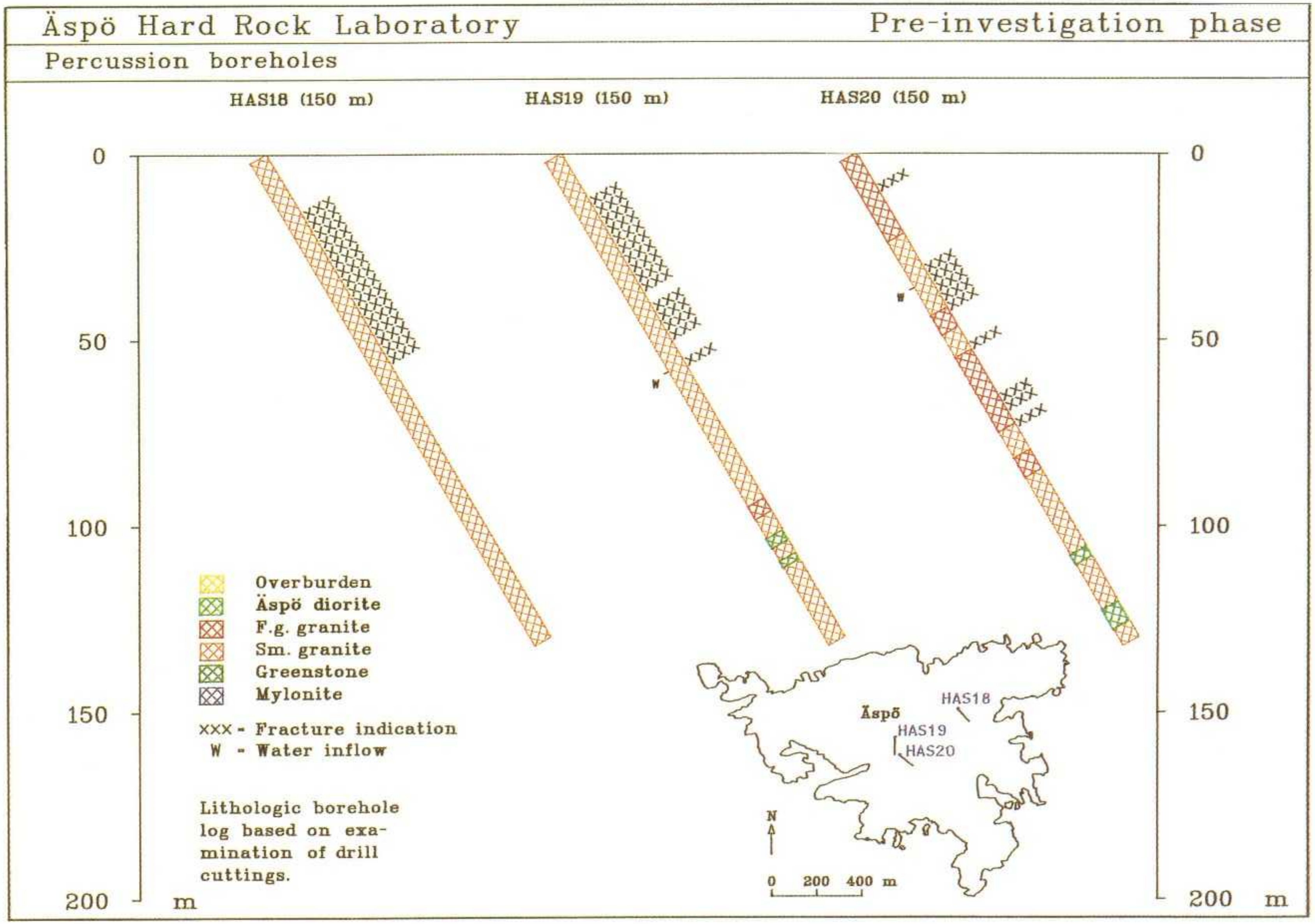


Figure 2-58. Percussion boreholes HAS 18-20.

3 COMPLEMENTARY SURFACE INVESTIGATIONS

After excavation of the tunnel had started drilling from the surface was performed in three cored boreholes and twelve percussion holes in the Äspö-Laxemar area. *Figures 3-1* and *3-2* present location of the boreholes.

3.1 CORED BOREHOLES

KLX 01
The first 702 m of core borehole KLX 01 was drilled during the pre-investigation phase (*Figures 3-2* and *2-21*). In 1990 the hole was extended to a length of 1078 m. Core logging data is presented in *Figure 3-3*.

KLX 02
The main objective of deep core borehole KLX 02 (*Figure 3-2*) was to demonstrate a feasible drilling technique for investigations and sampling at depth down to at least 1500 m. The hole was drilled in 1992 using a wireline method, NQ dimension (76 mm), to a final depth of 1700.5 m. Investigations in KLX 02 are still going on. Core logging data is presented in *Figure 3-4*.

Reference: TR 94-19

KAS 16
When the tunnel had passed through fracture zone NE-1 core borehole KAS 16 (*Figure 3-1*) was drilled to check the orientation and character of the zone (*Figure 3-1*). Core mapping data is presented in *Figure 3-5*.

Reference: PR 25-93-01

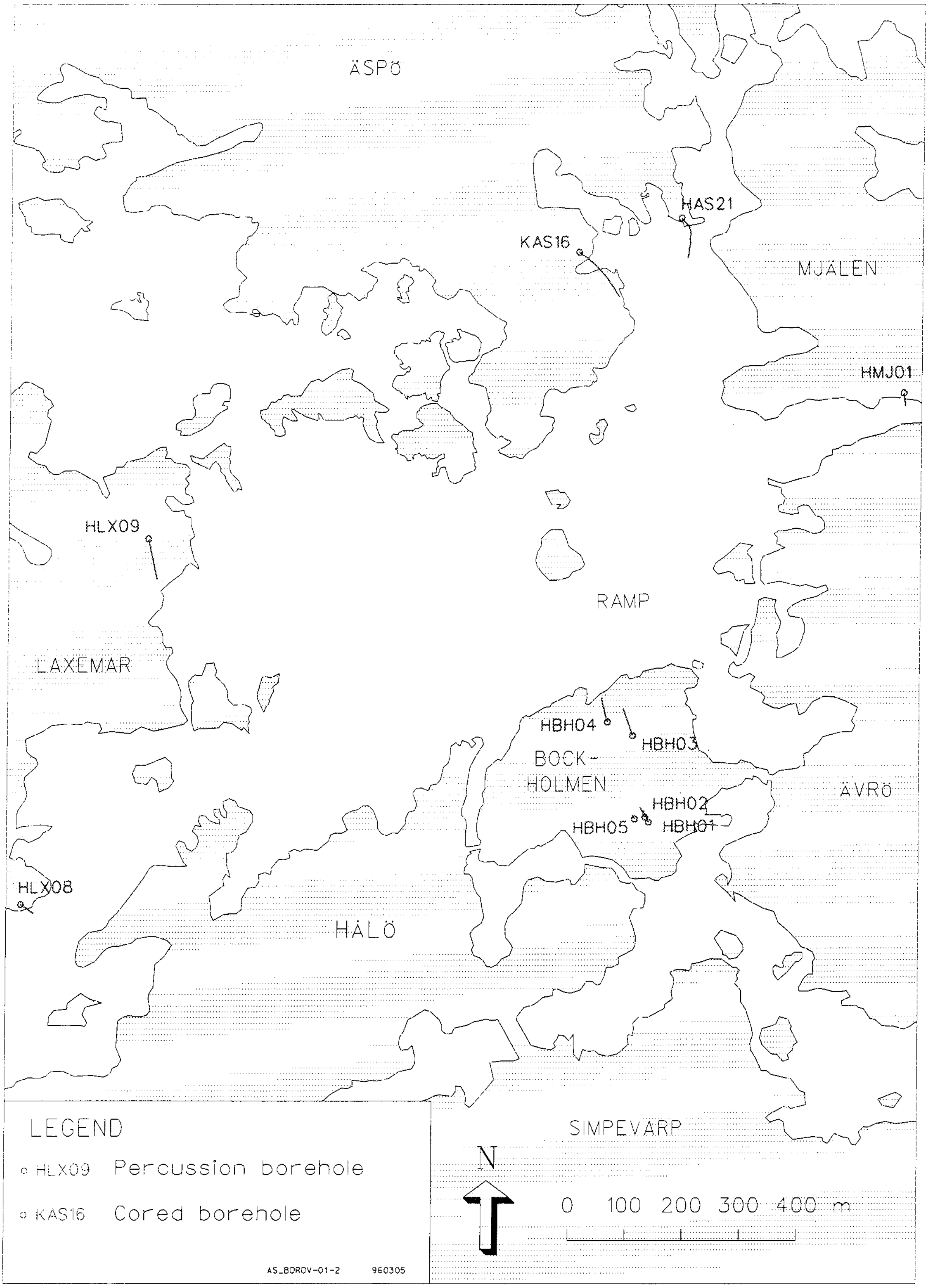


Figure 3-1. Location of complementary boreholes.

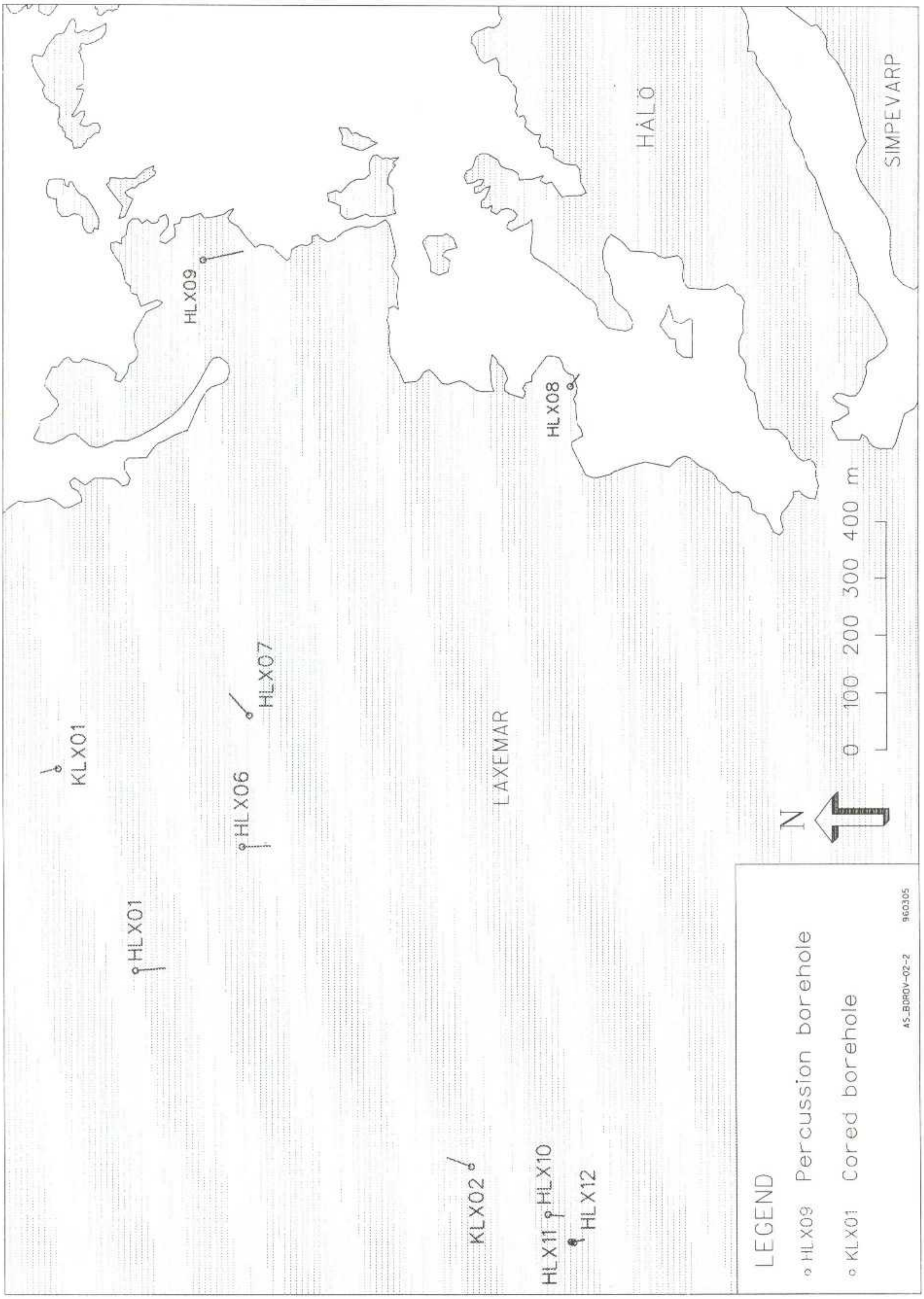


Figure 3-2. *Location of complementary boreholes.*

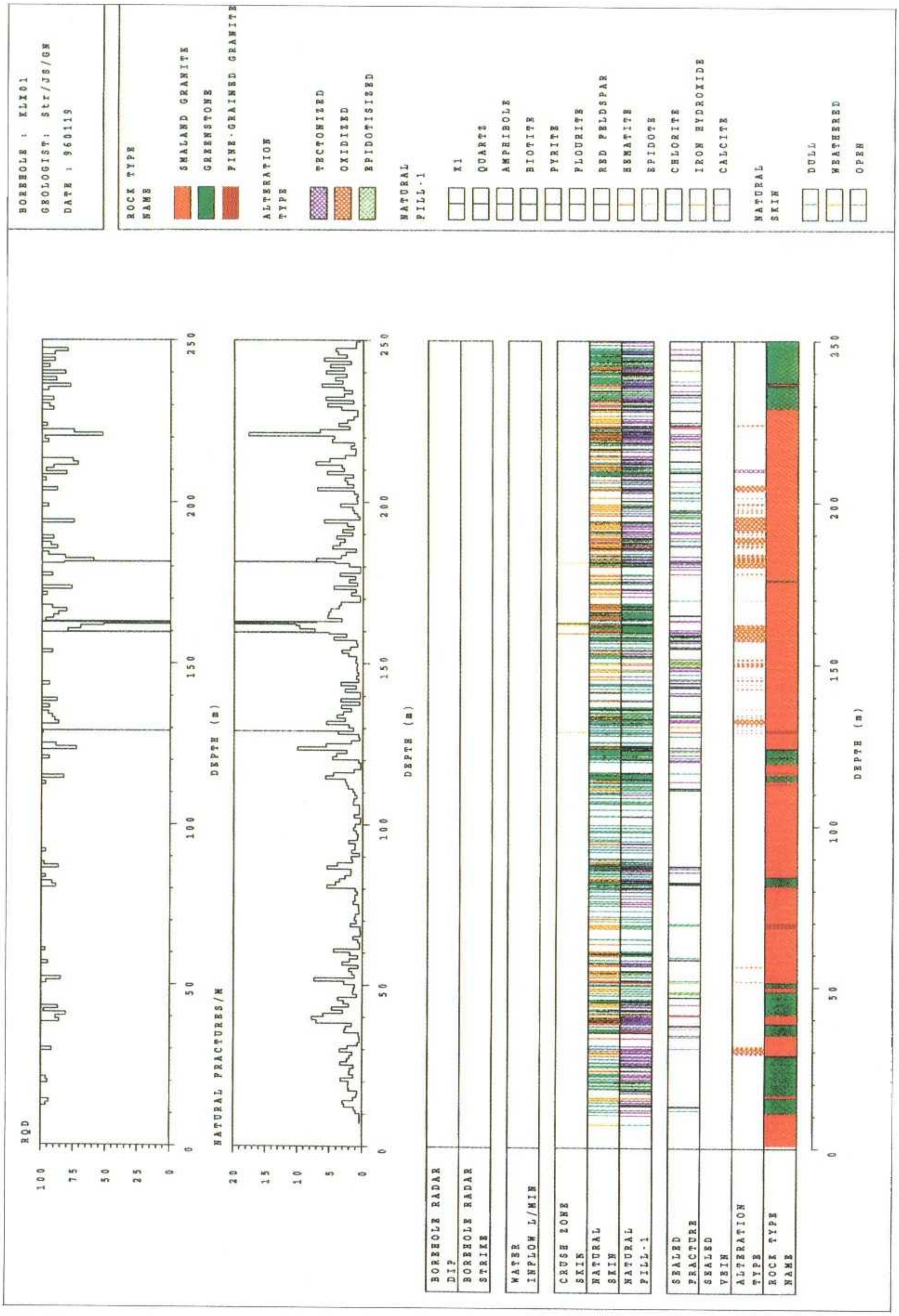


Figure 3-3. Core logging data KLX 01.

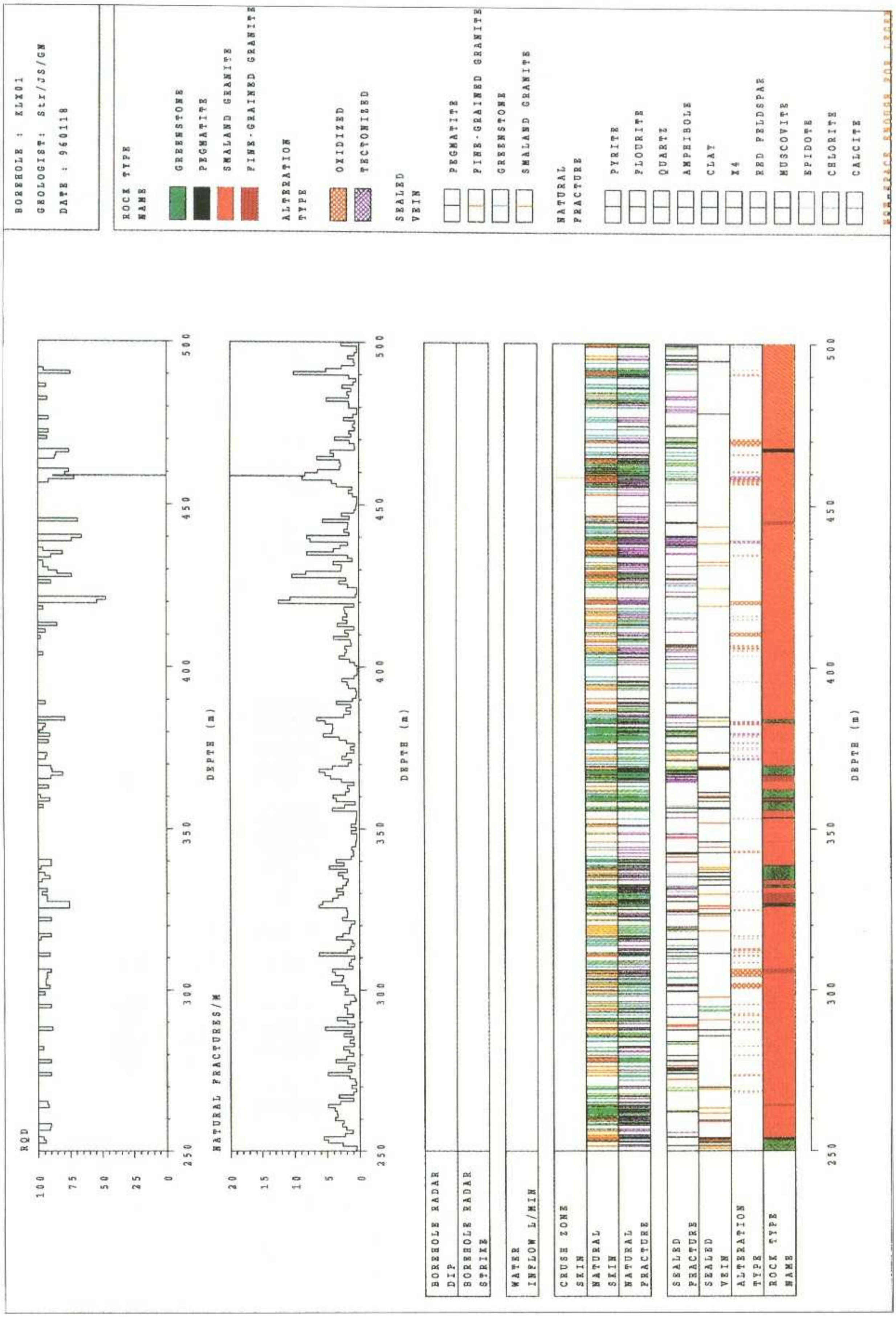


Figure 3-3 (continued). *Core logging data KLX 01.*

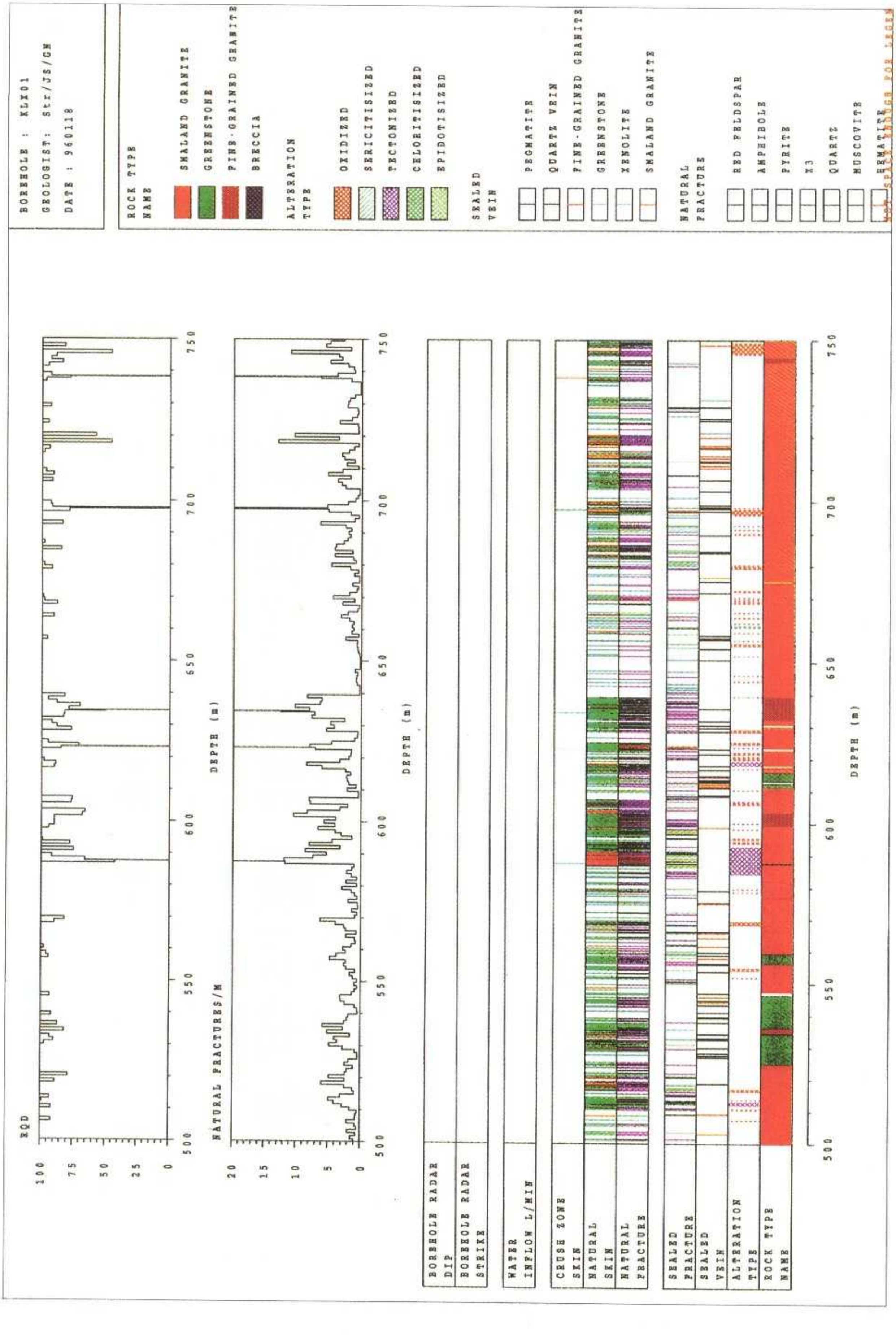


Figure 3-3 (continued). *Core logging data KLX 01.*

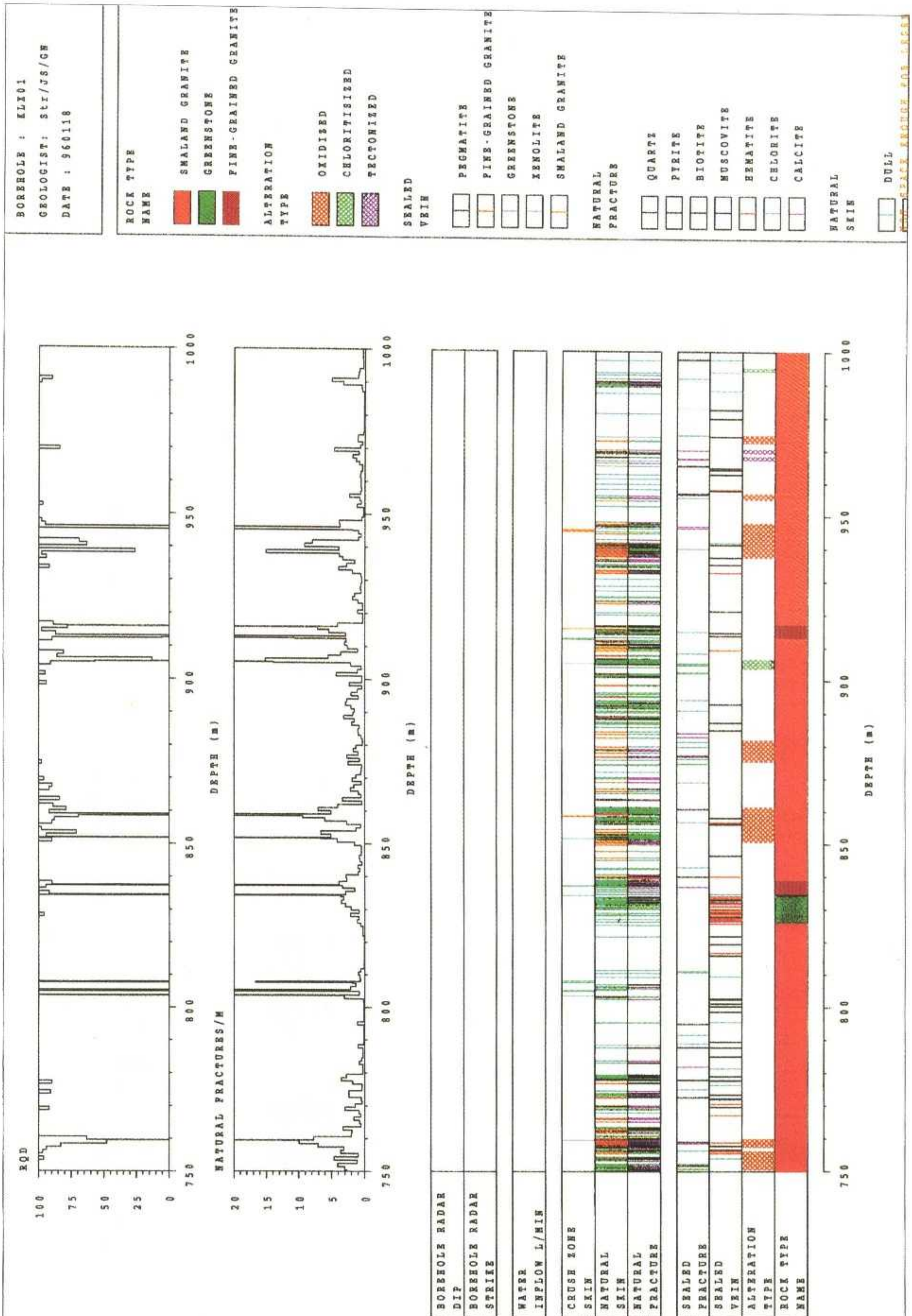


Figure 3-3 (continued). Core logging data KLX 01.

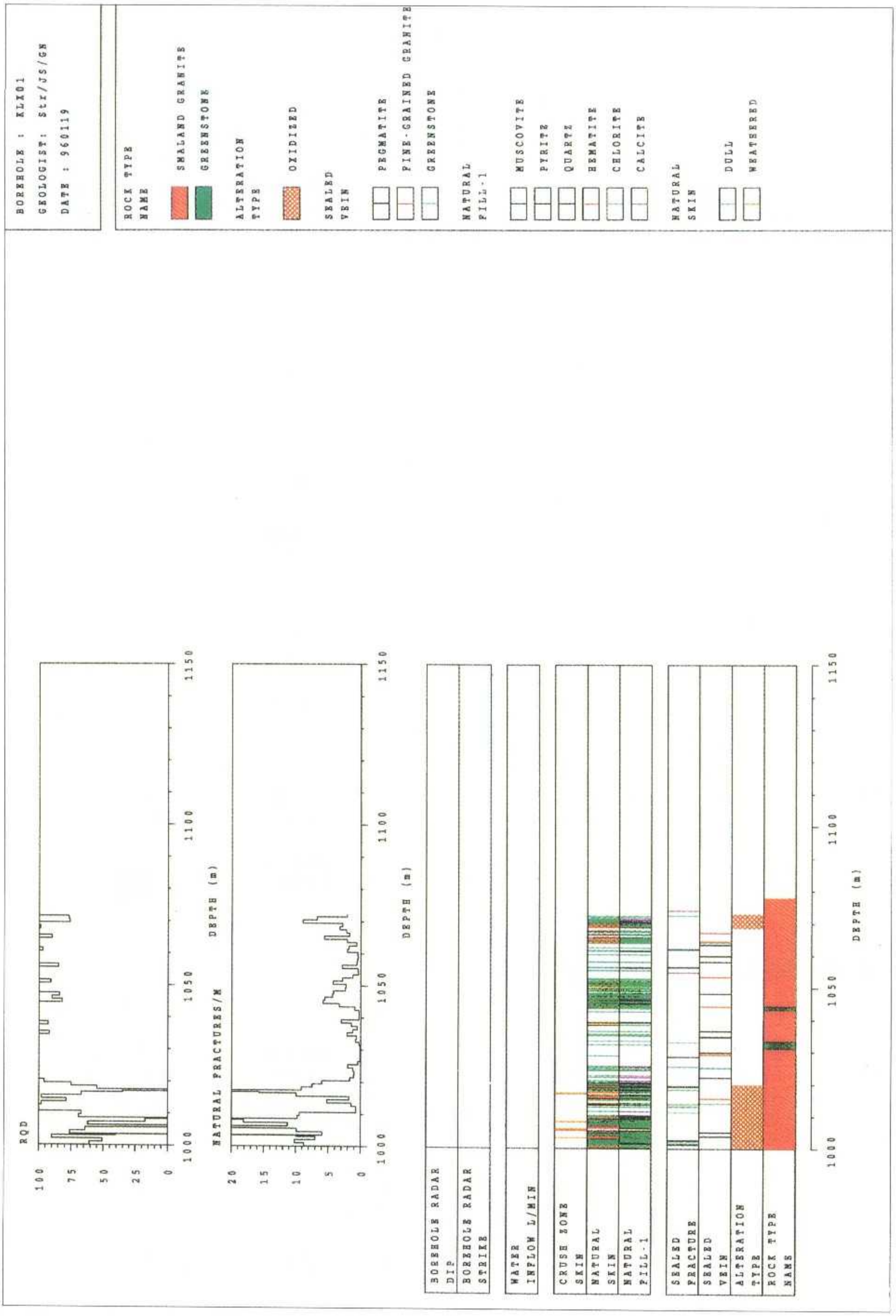


__Figure 3-3 (continued).__ Core logging data KLX 01.

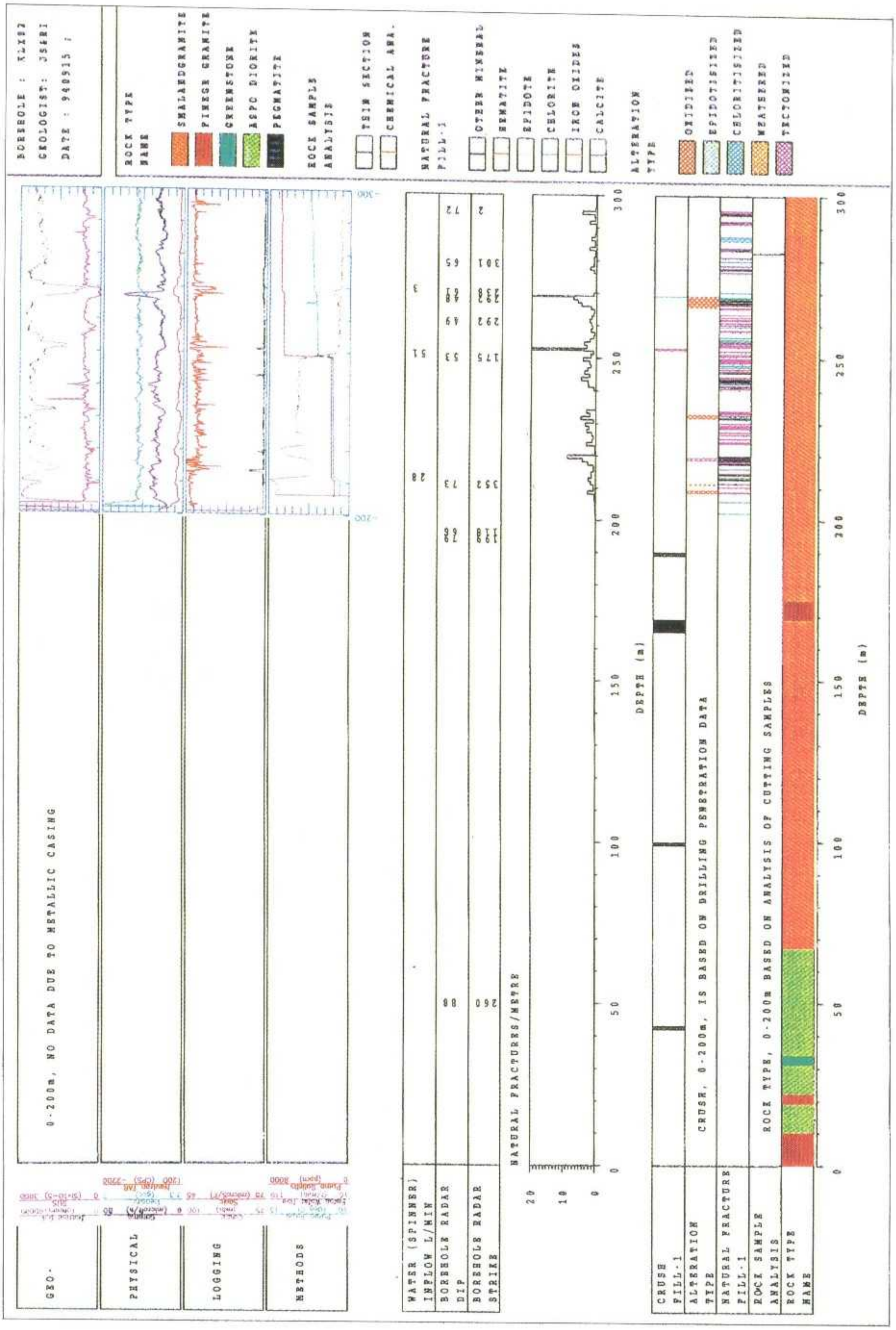


Figure 3-4. Core logging data KLX 02.

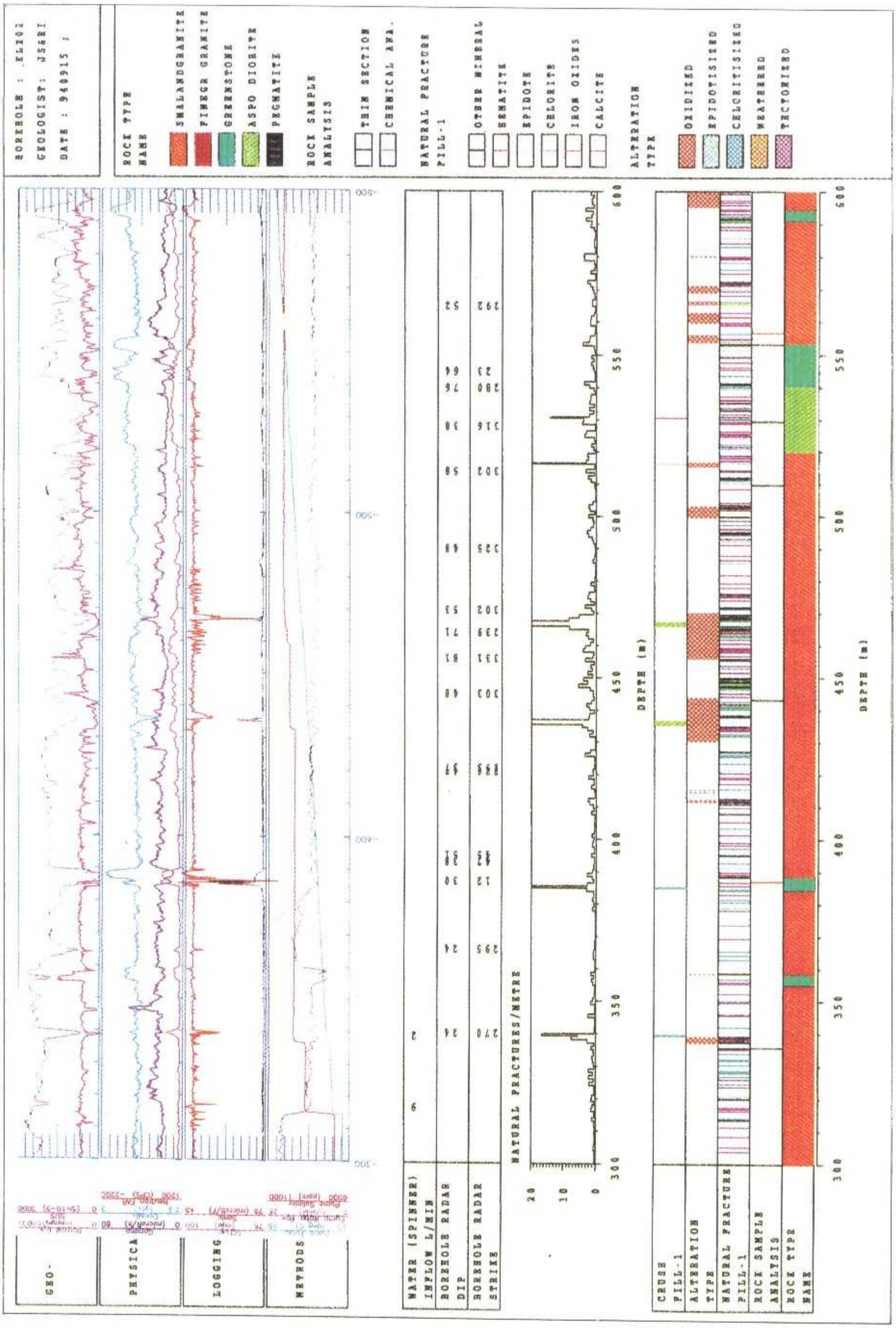


Figure 3-4 (continued). *Core logging data KLX 02.*

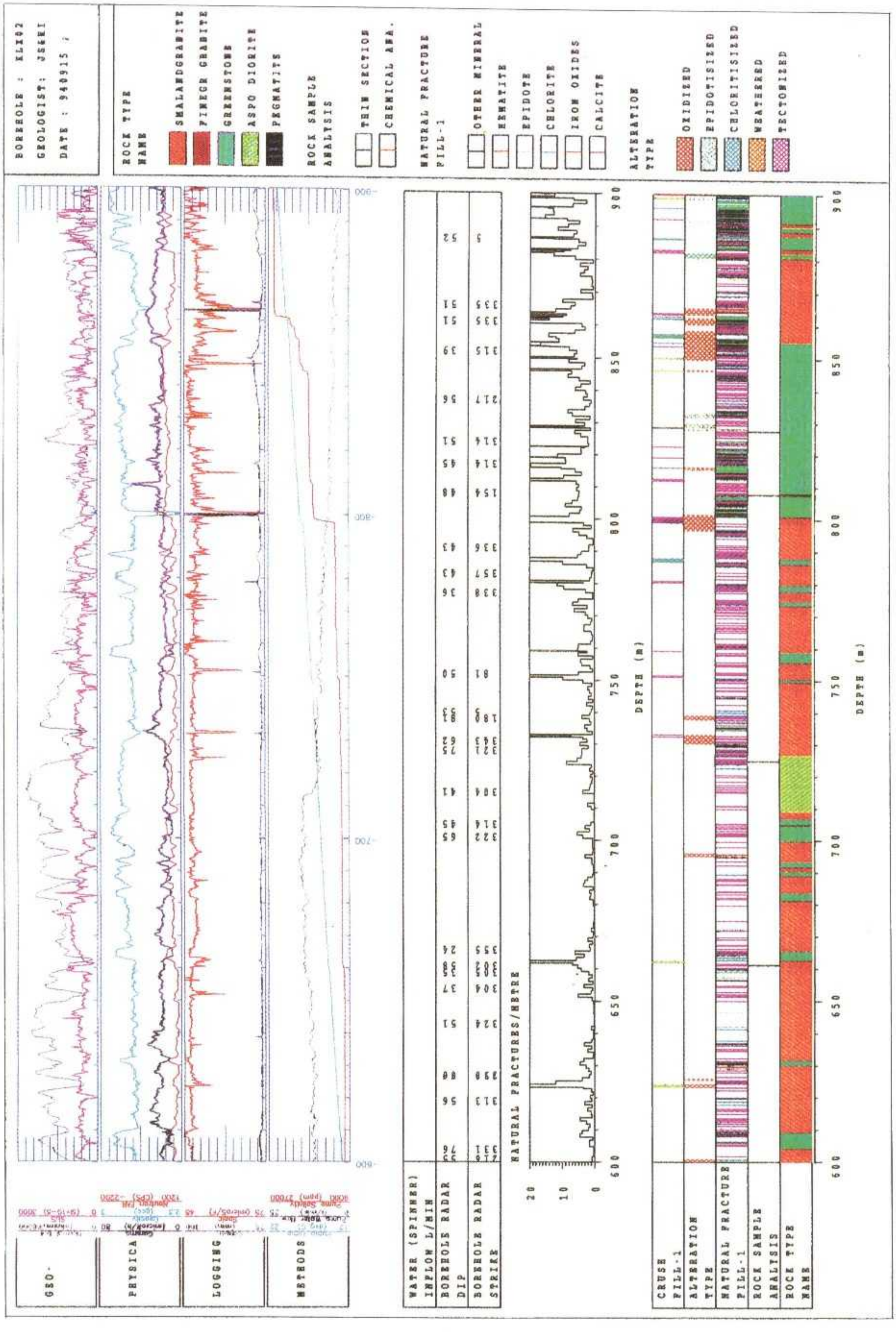


Figure 3-4 (continued). *Core logging data KLX 02.*

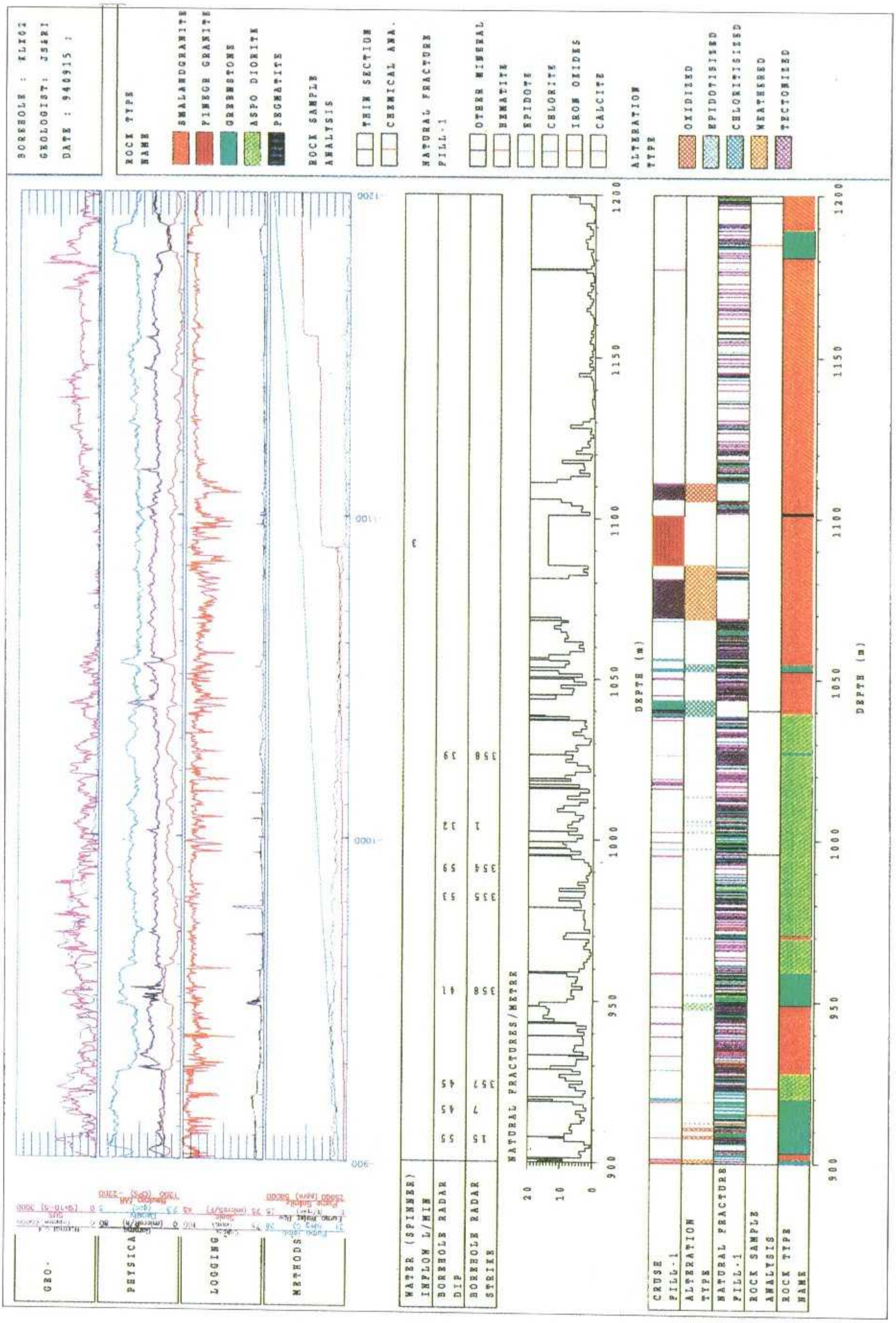


Figure 3-4 (continued). Core logging data KLX 02.

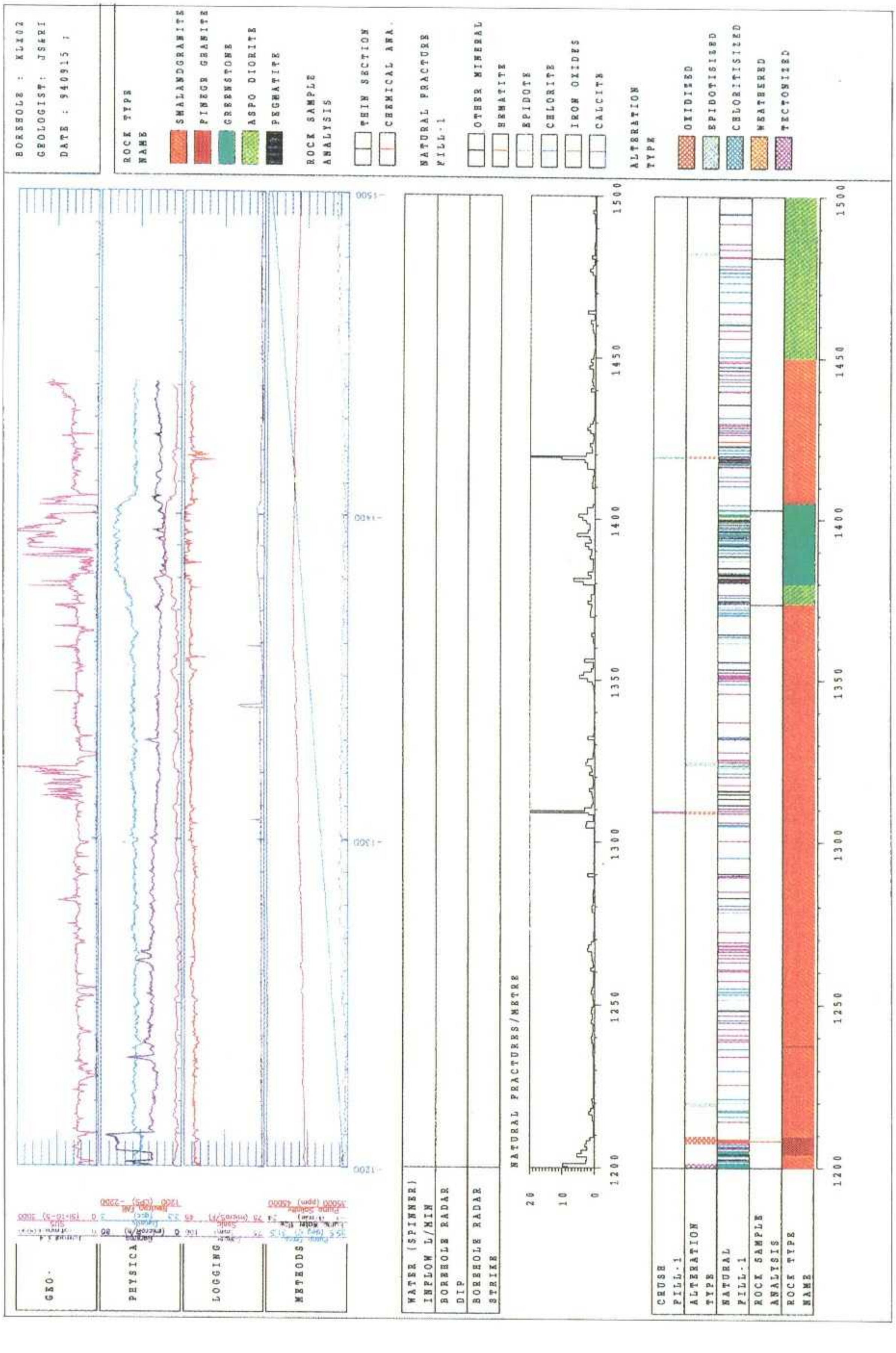


Figure 3-4 (continued). Core logging data KLX 02.

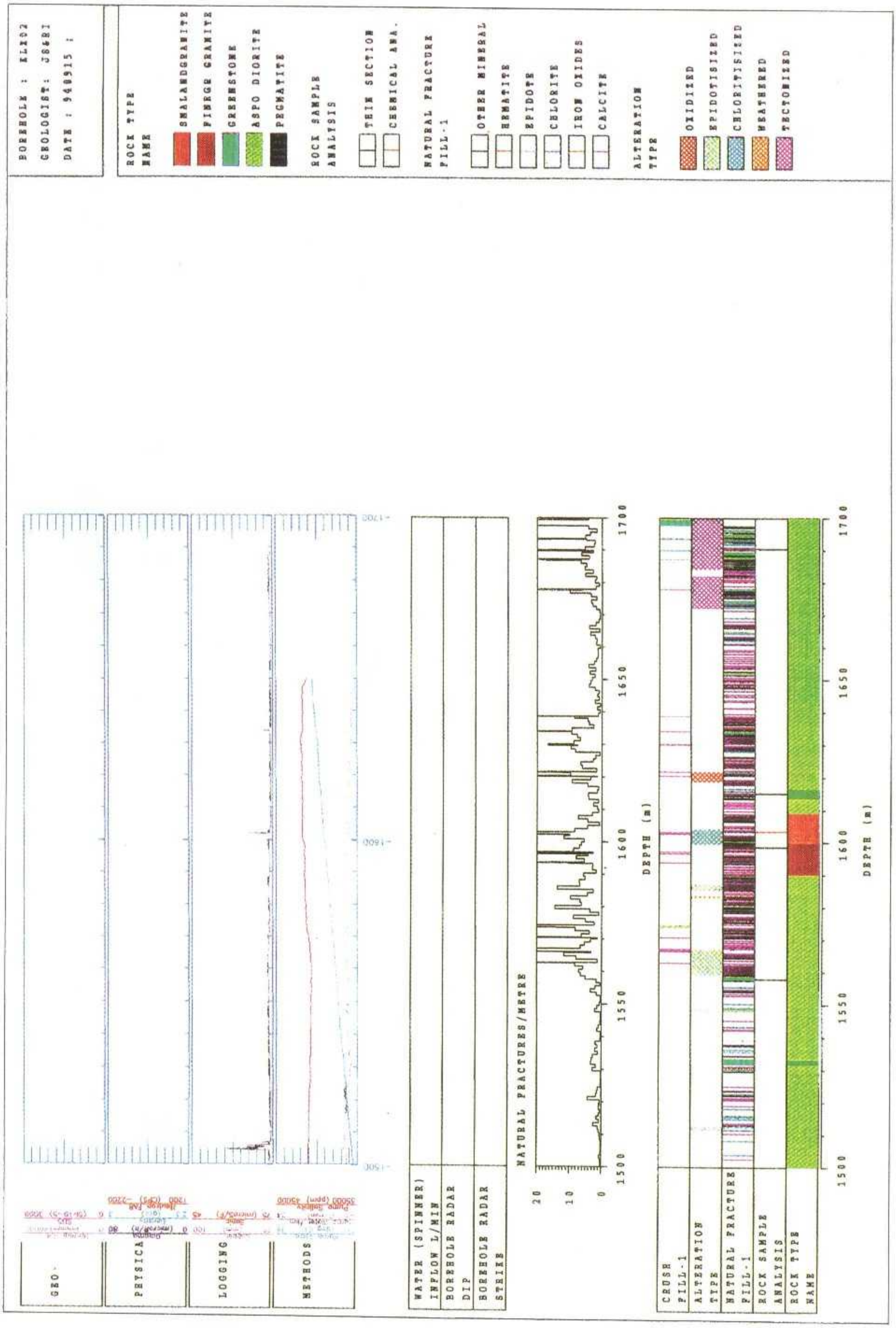


Figure 3-4 (continued). Core logging data KLX 02.

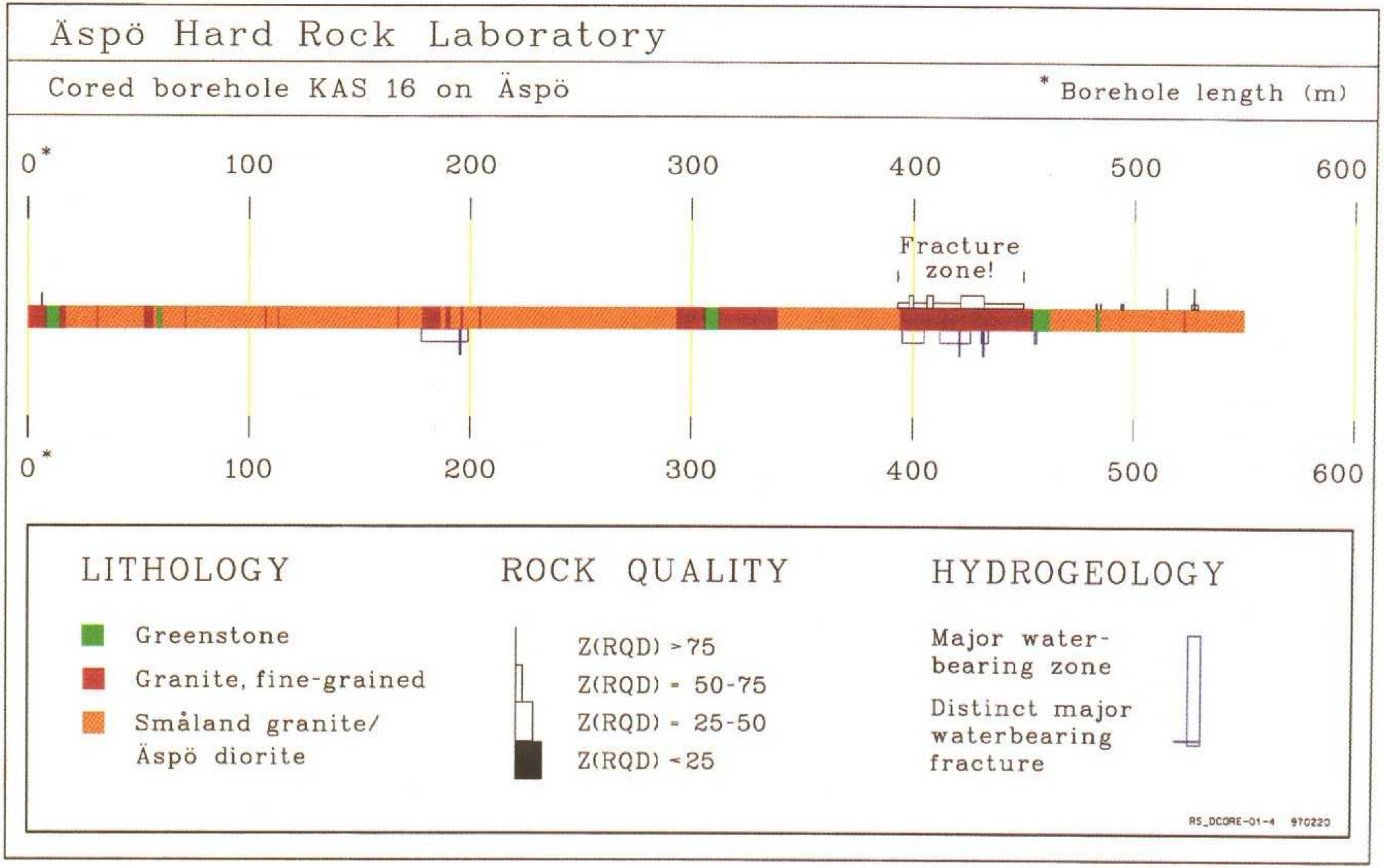


Figure 3-5. Core logging data KAS 16.

3.2 PERCUSSION BOREHOLES

Percussion boreholes *HLX 10-11 and 12* were drilled as water supply wells for core borehole KLX 02 in Laxemar (*Figures 3-2* and *3-6*).

Reference: TR 94-19

HBH 03 and 04 were drilled to get more information of fracture zone EW-7 (*Figures 3-1, 3-7 and 3-8*).

Reference: PR 25-92-18

Percussion holes *HMJ 01, HAS 21, HLX 08 and HLX 09* were all to get more information of fracture zone NE-1 (*Figures 3-1, 3-2, 3-8* and *3-9*).

Reference: PR 25-92-18

Percussion holes *HBH 01-02 and 05* were drilled in order to localize and characterize a suitable fracture zone for the "Redox experiment" (*Figures 3-1* and *3-8*).

Reference: PR 25-95-06

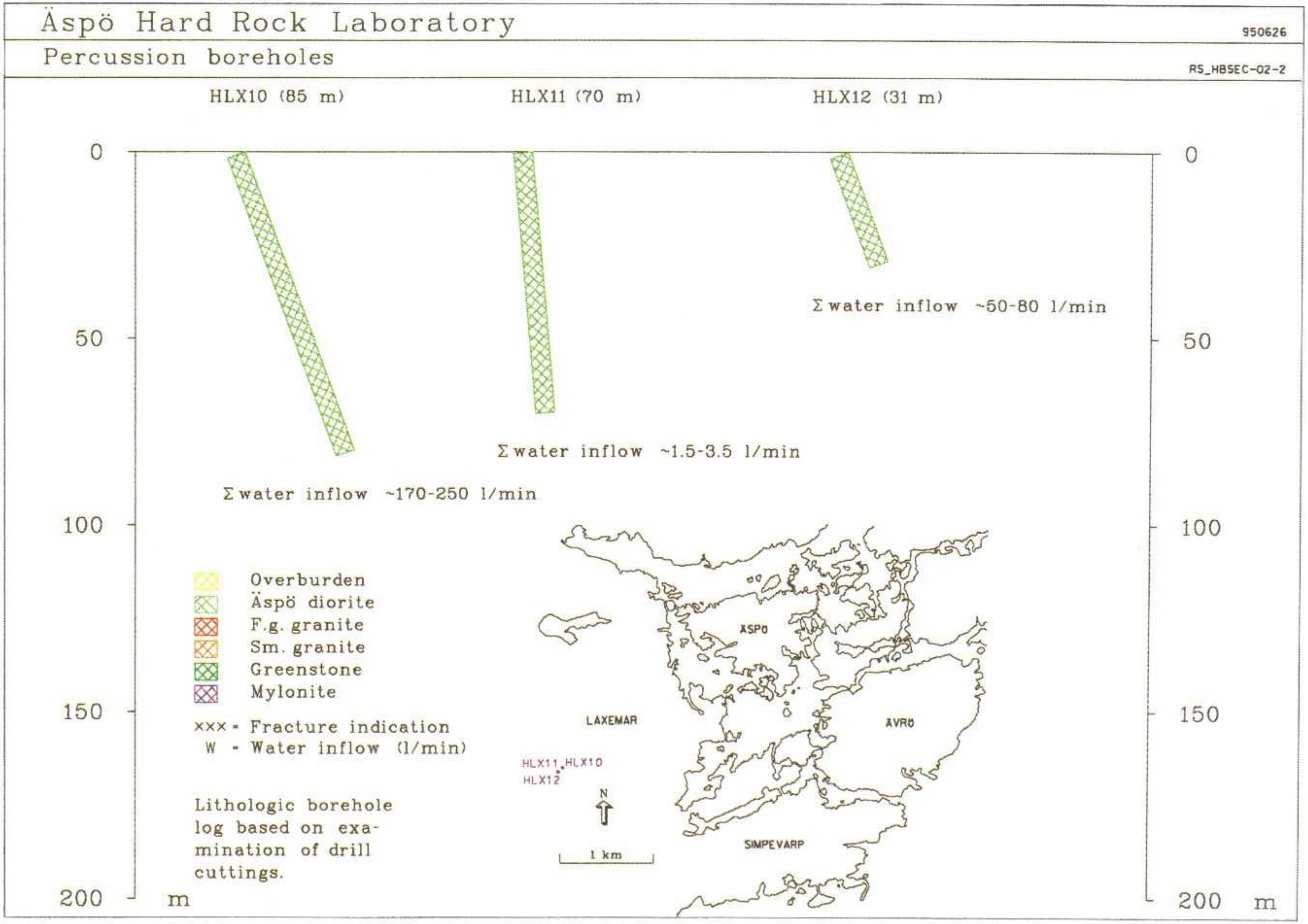


Figure 3-6. Percussion boreholes HLX 10-12.

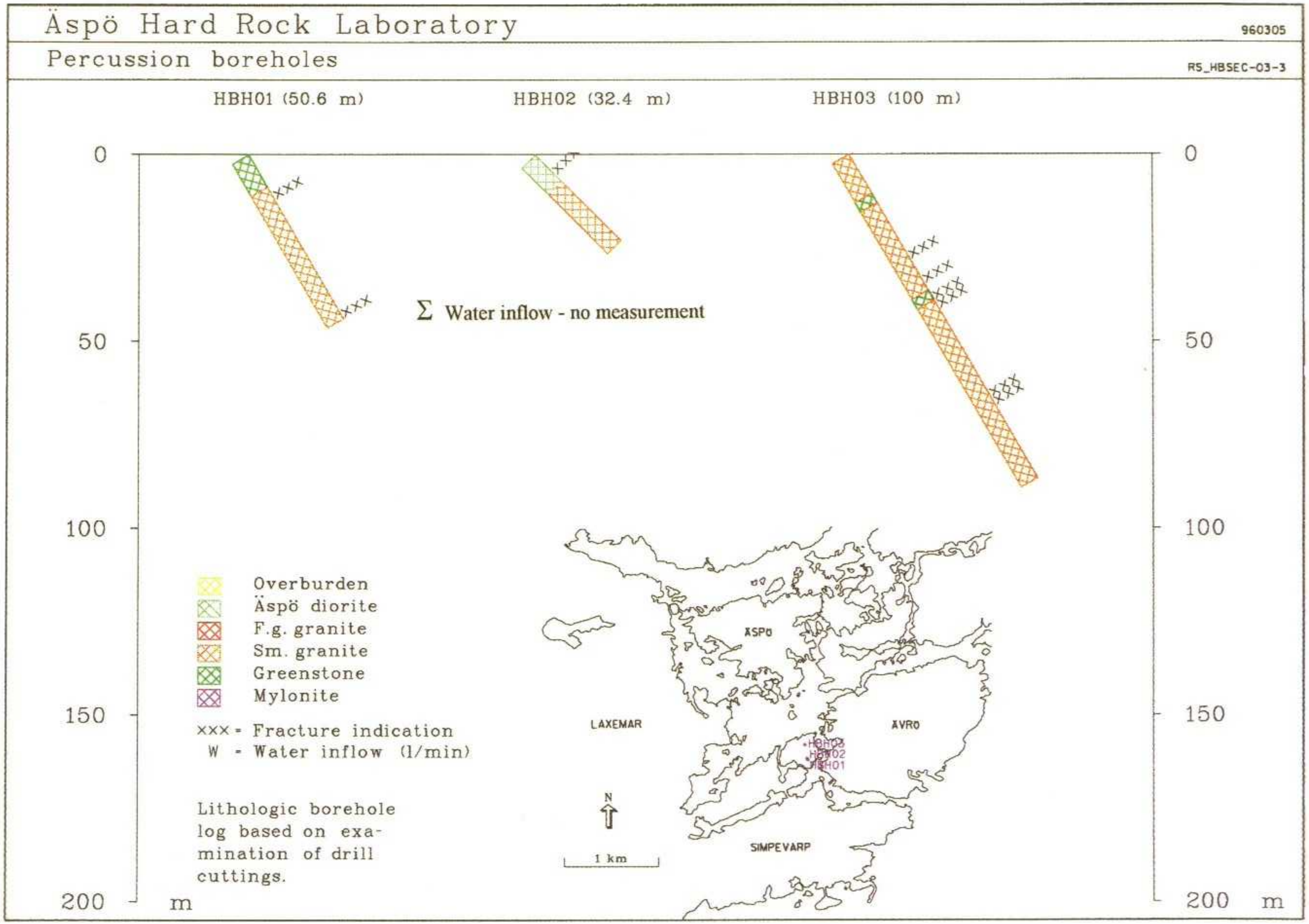


Figure 3-7. Percussion boreholes HBH 01-03.

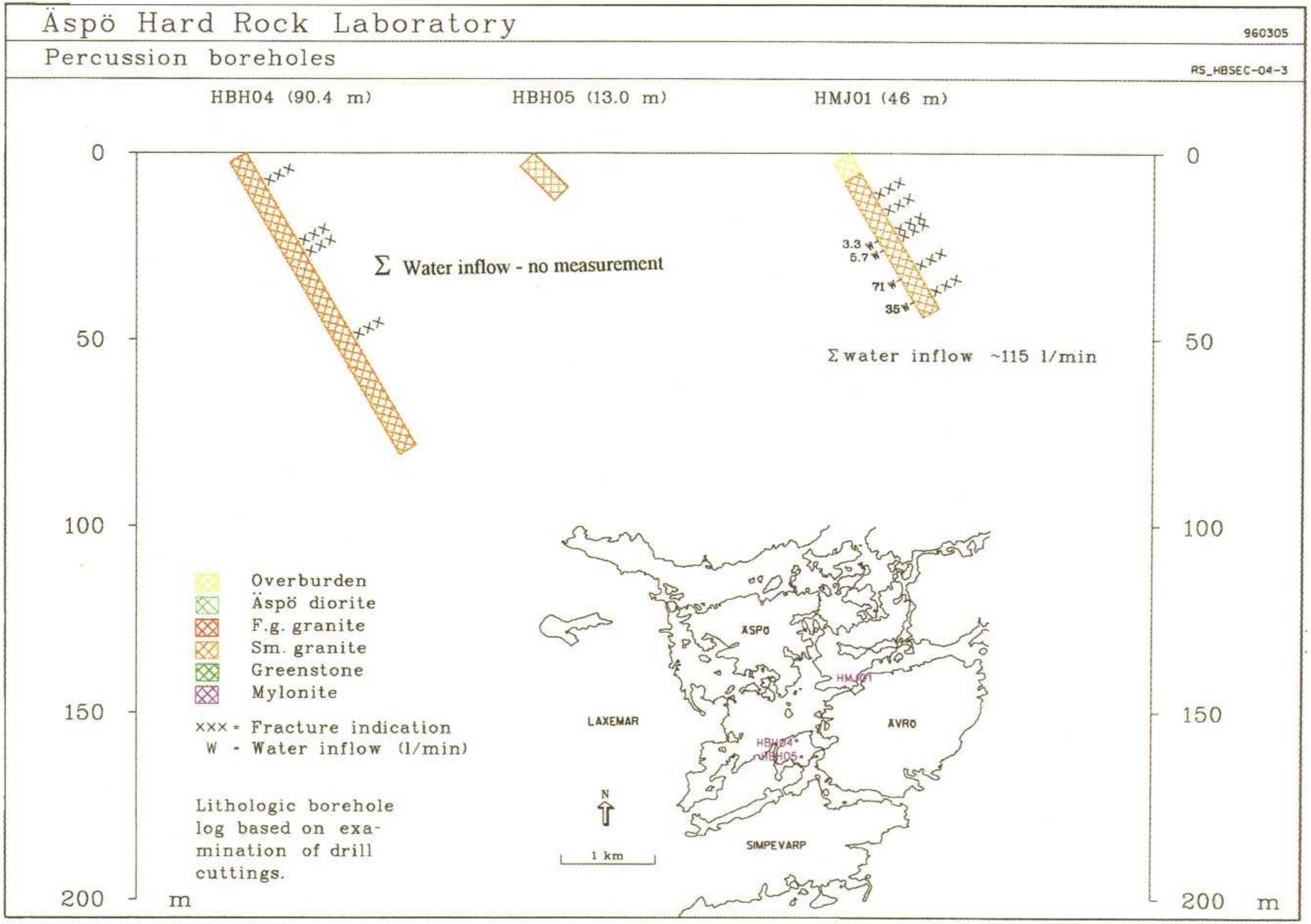


Figure 3-8. Percussion boreholes HBH 04-05, HMJ01.

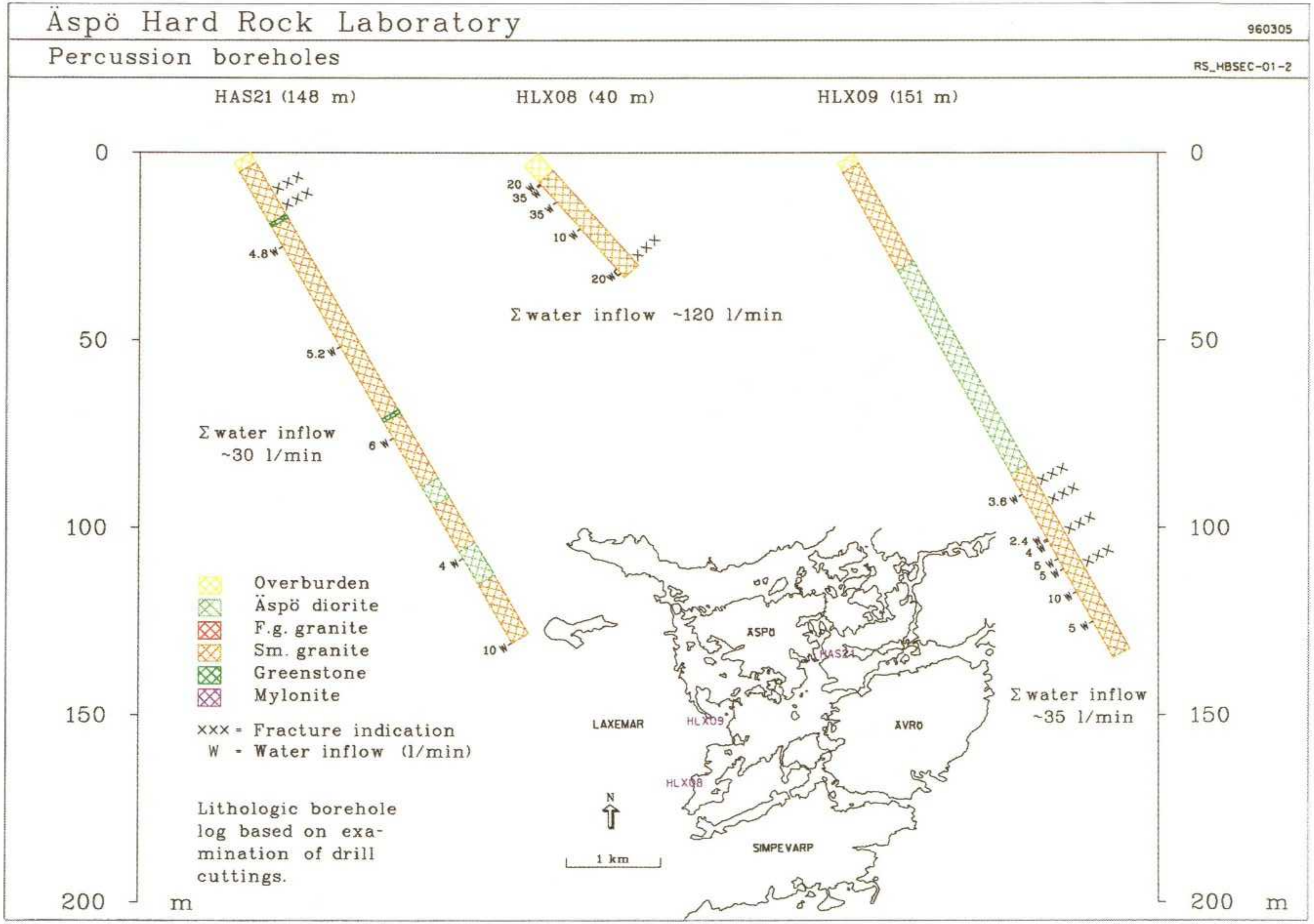


Figure 3-9. Percussion boreholes HAS 21, HLX08-09.

4 TUNNEL INVESTIGATIONS

During the excavation work a great number of boreholes were drilled and special studies made in the tunnel.

4.1 OVERVIEW OF BOREHOLES SAMPLING AND SPECIAL STUDY AREAS

Figures 4-1 to *4-8* present an overview of the location of boreholes, sampling and special study areas in the tunnel. All the framed study areas are described in more detail in *Section 4.2*.

LEGEND:

— Cored Borehole (K)
— Percussion Borehole (H)
— Probe Hole (S)

☆ Rock Stress Measurement
△ HMS
P Pressure Build-up Test
W Water Sampling
R Borehole Radar
TV TV-logging
G Geophysics
I Interference Test
S Spinner Measurement
L Probe Drill Logging
U UCM
J Water Injection Test
O Pressure Observation

50m-Block (P50)

□ Rock Sampling
✱ Clay Sampling
W Water Sampling
— Line Mapping
— Dam (M)
E Electrical Conductivity
— Measuring point for:
VA Air Flow, out and/or in
RA Relative Air Humidity, out and/or in
TA Temperature air, out and/or in
QA Water Flow, out and/or in

Tunnel length on plots:
Length in the horizontal
projection of the tunnel.

Figure 4-1. *Legend to figures 4-2 to 4-8.*

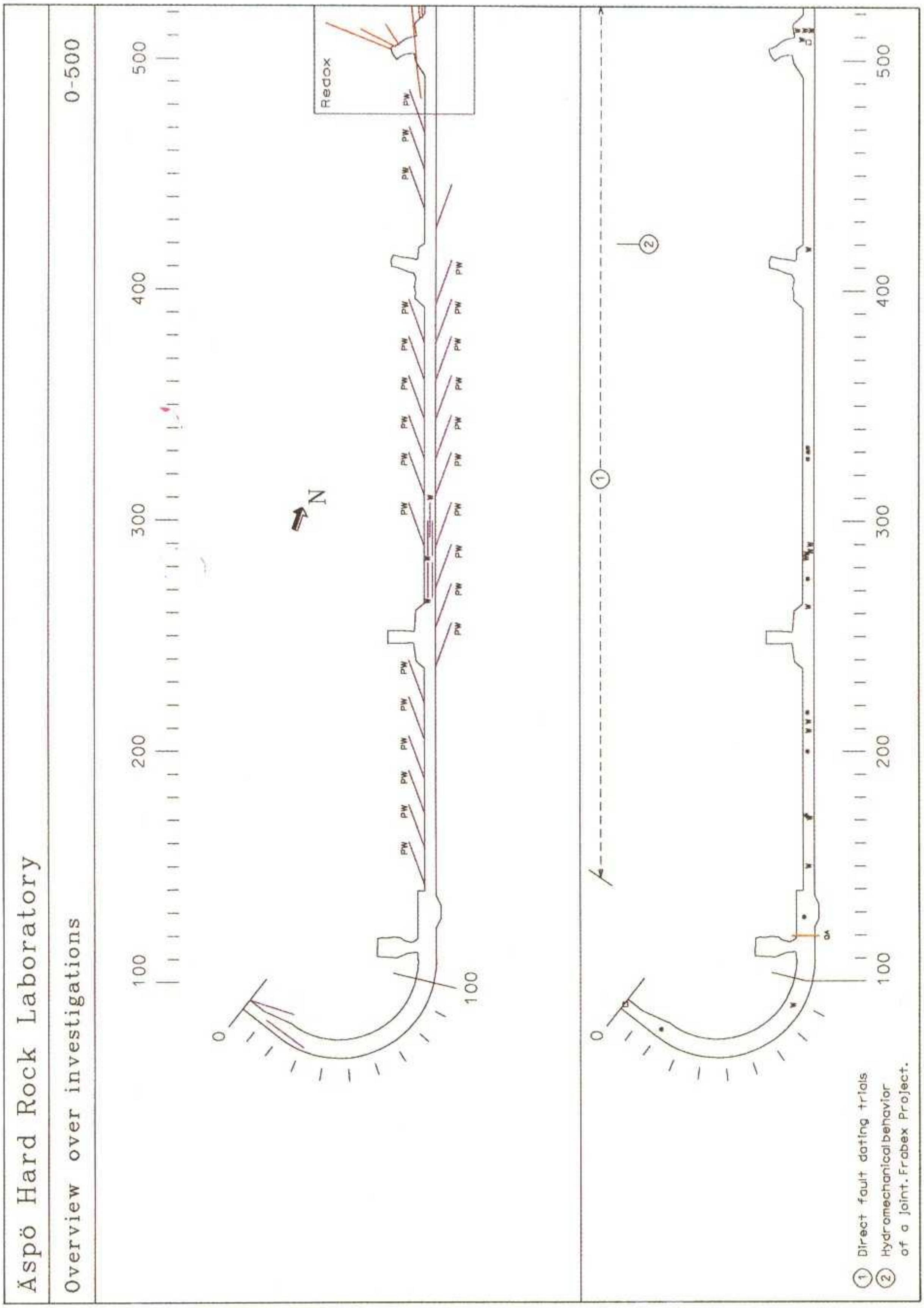


Figure 4-2. *Overview of tunnel section 0-500 m, showing location of boreholes, sampling and special study areas.*

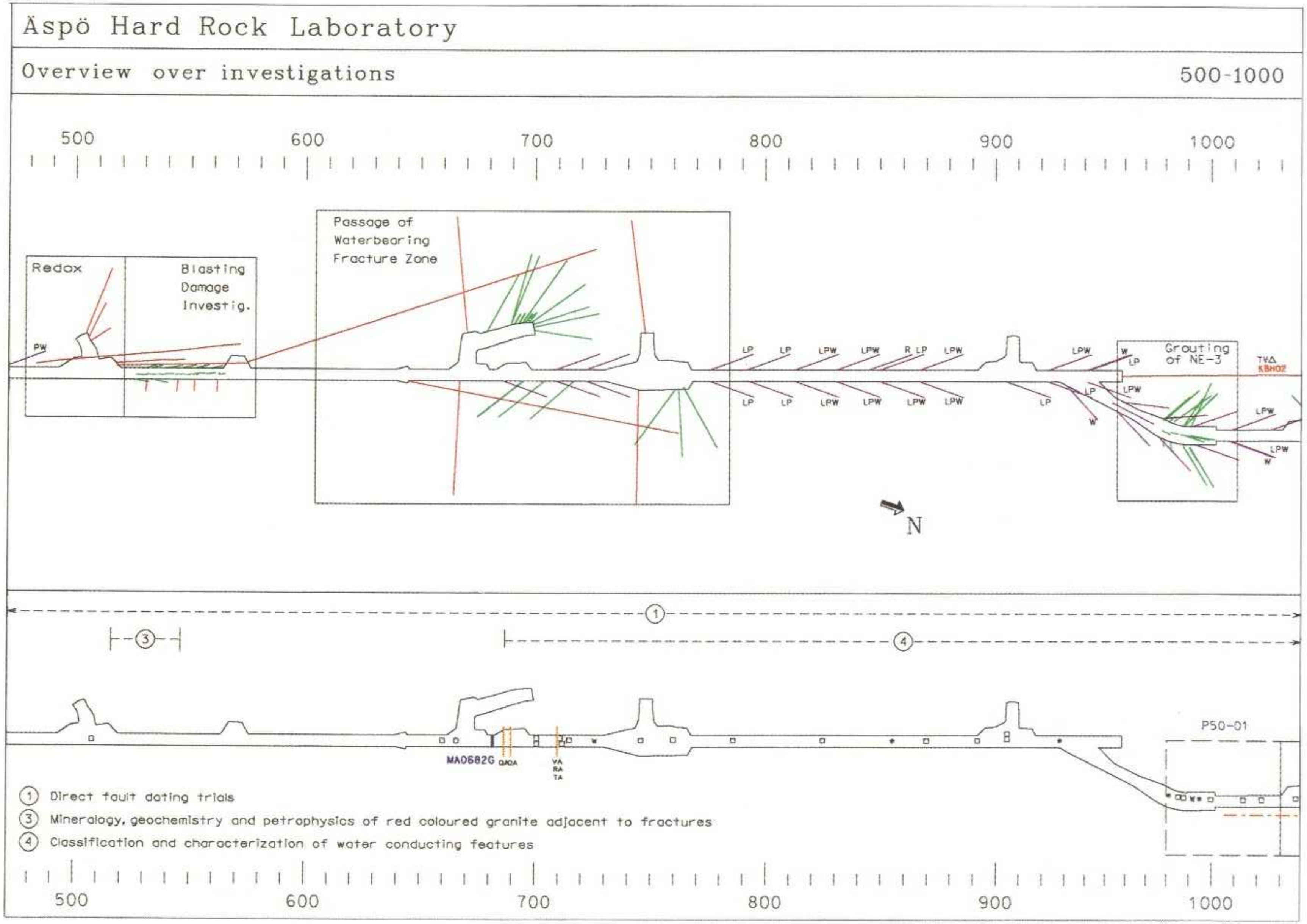


Figure 4-3. *Overview of tunnel section 500-1000 m, showing location of boreholes, sampling and special study areas.*

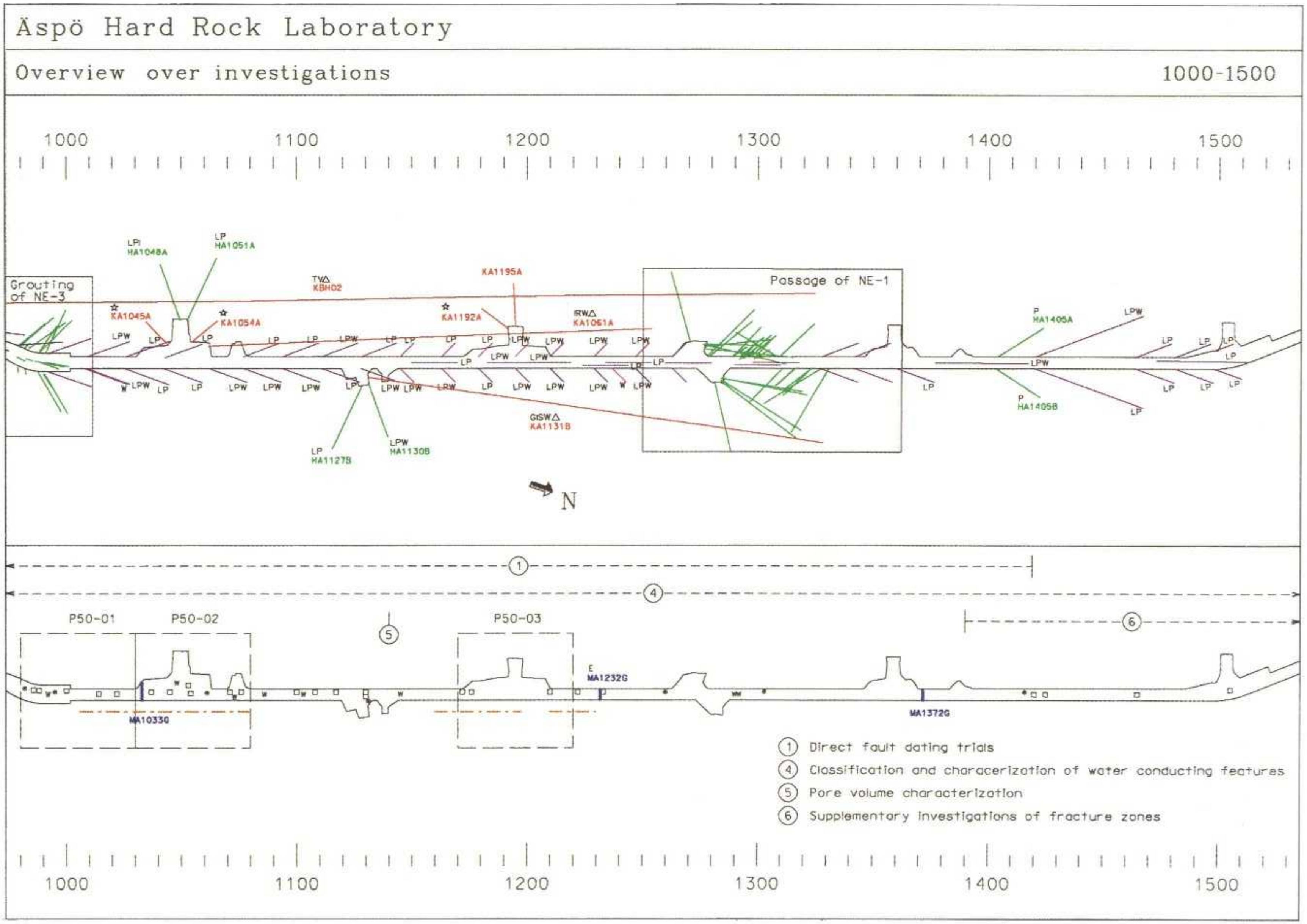


Figure 4-4. Overview of tunnel section 1000-1500 m, showing location of boreholes, sampling and special study areas.

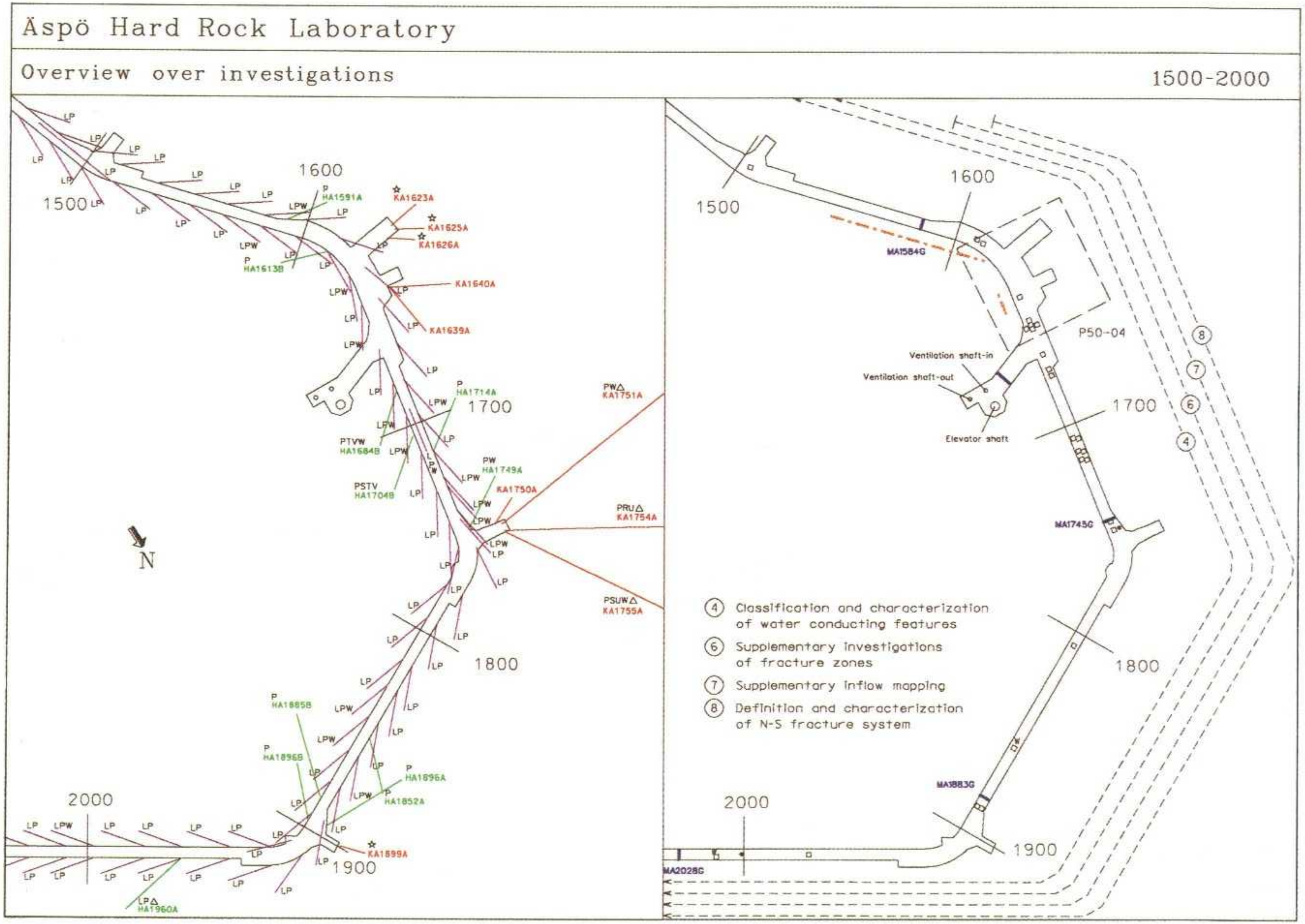


Figure 4-5. *Overview of tunnel section 1500-2000 m, showing location of boreholes, sampling and special study areas.*

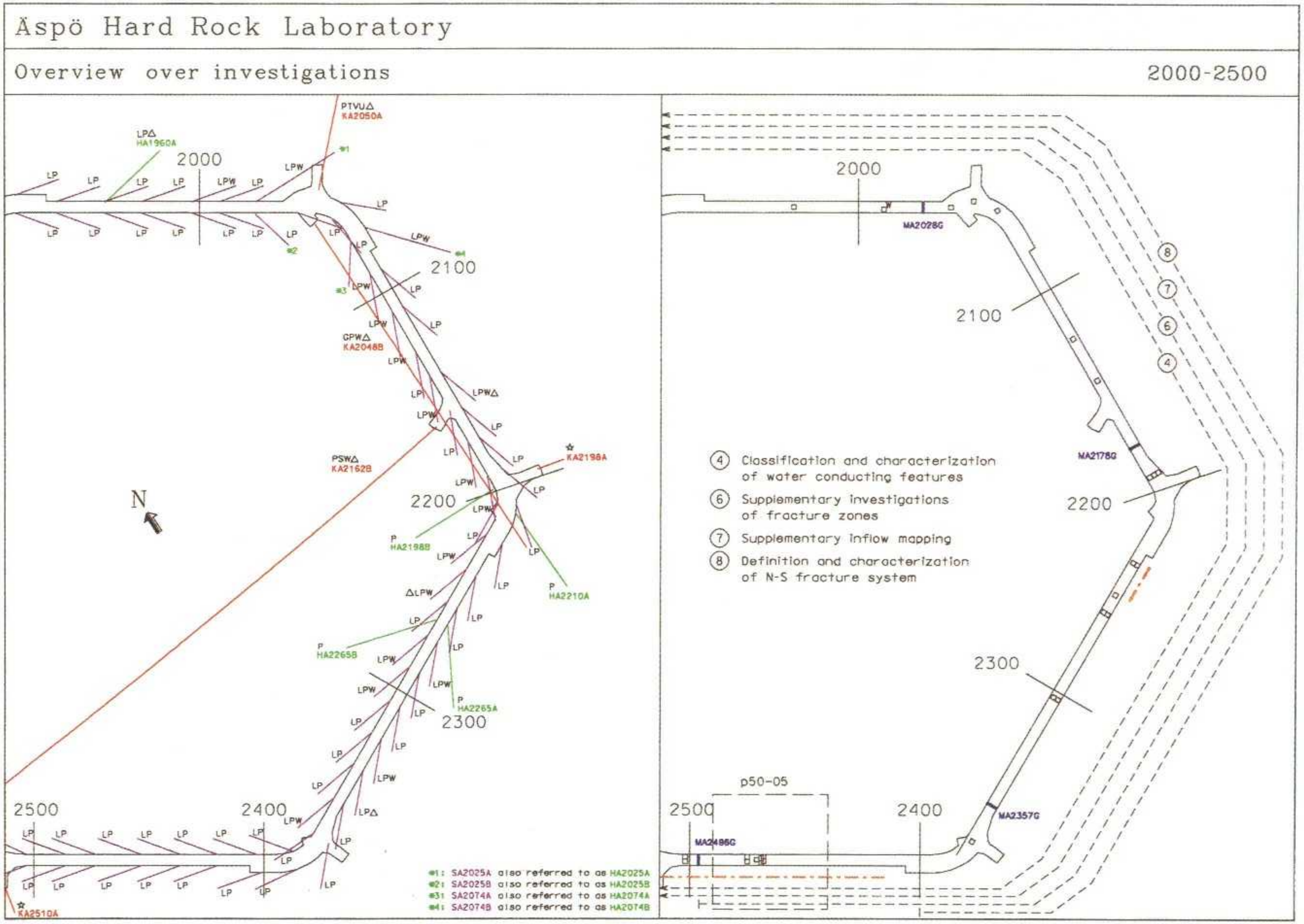


Figure 4-6. *Overview of tunnel section 2000-2500 m, showing location of boreholes, sampling and special study areas.*

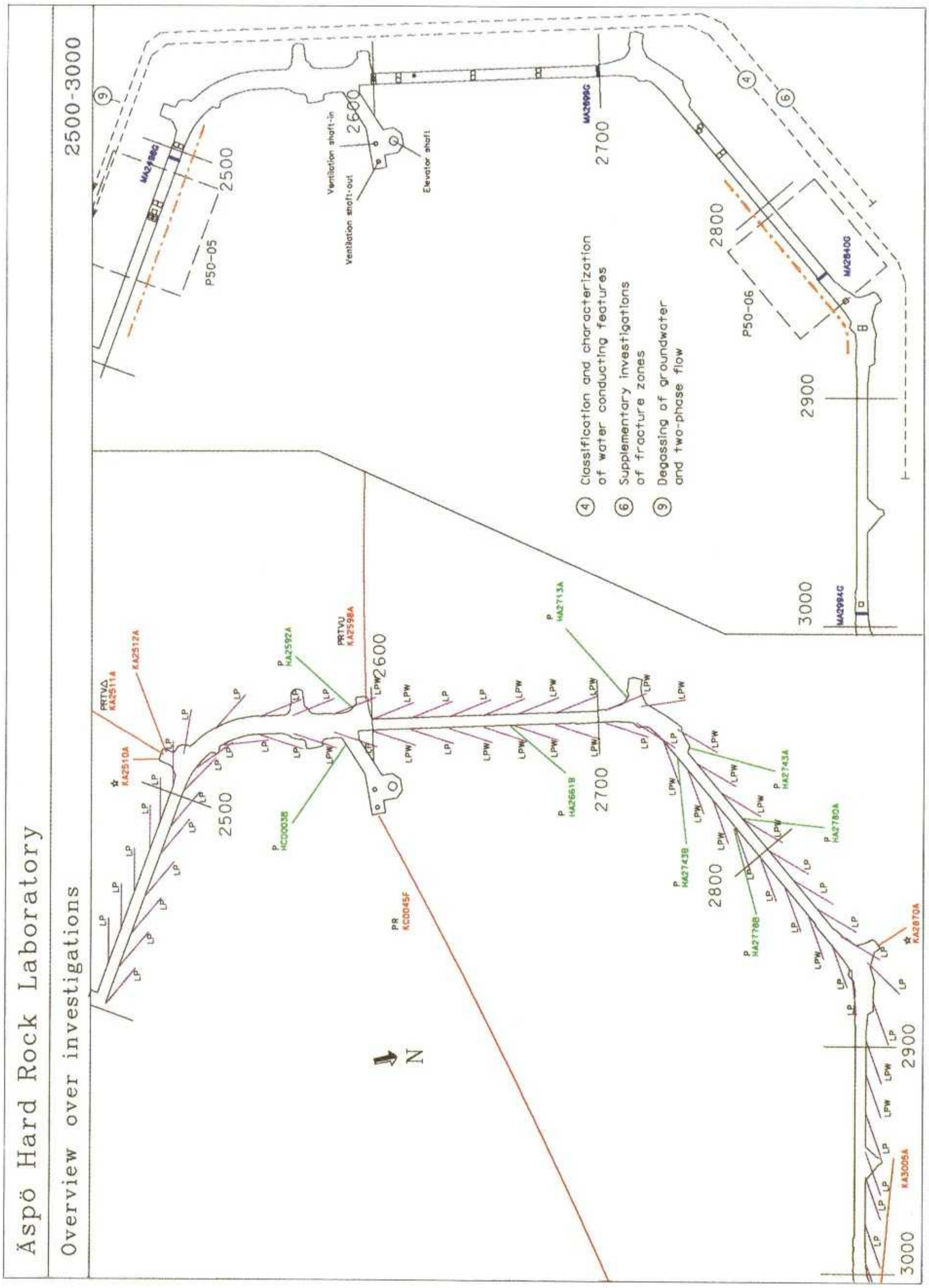


Figure 4-7. Overview of tunnel section 2500-3000 m, showing location of boreholes, sampling and special study areas.

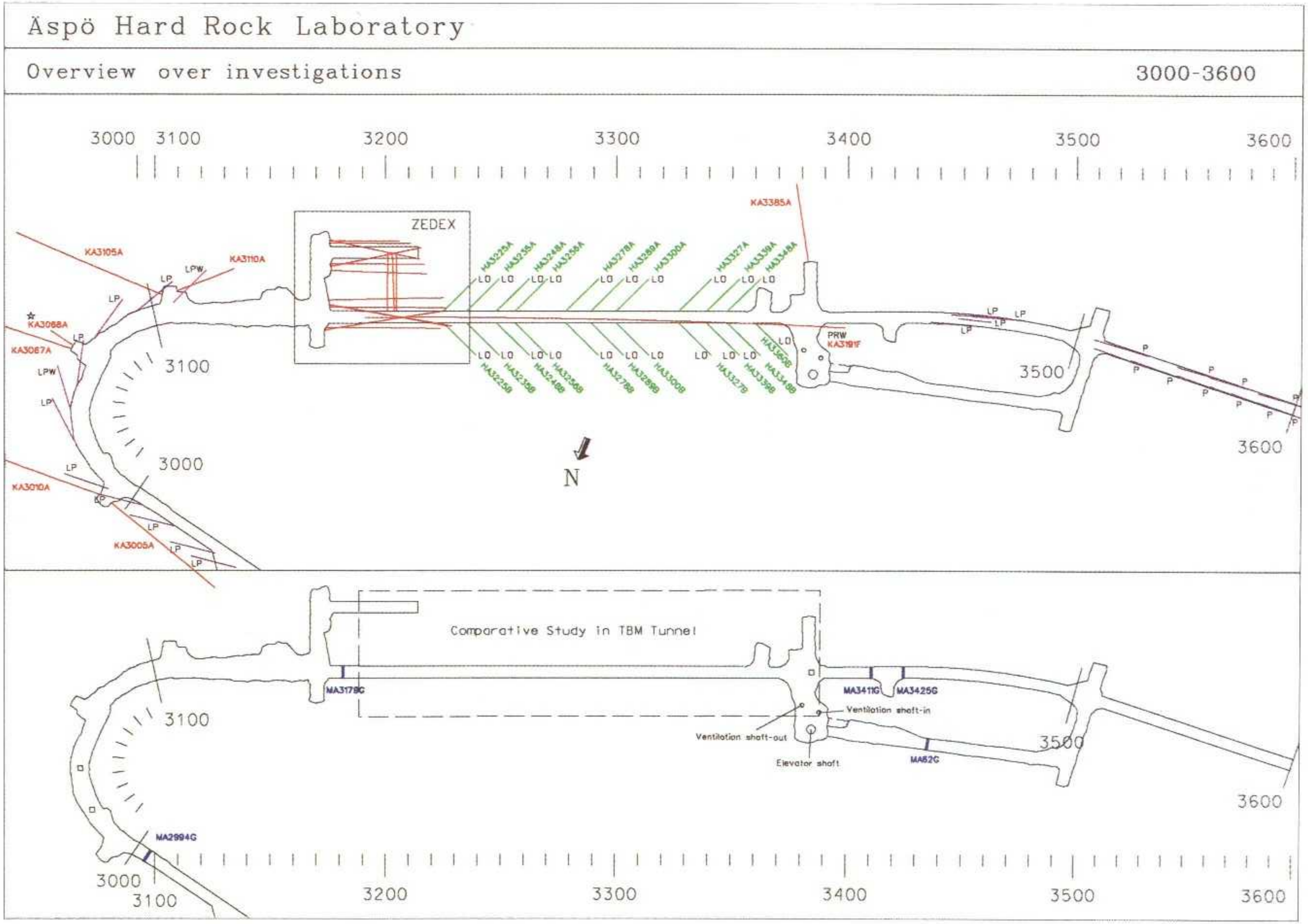


Figure 4-8. Overview of tunnel section 3000-3600 m, showing location of boreholes, sampling and special study areas.

4.2 DETAILED DESCRIPTION OF SPECIAL STUDY AREAS

The special studies listed below are presented on the following pages by an abstract and, in some cases, a detailed illustration (*Figures 4-9* to *4-13*).

- Blasting damage investigation in access ramp section 0526-0565 m.
- Passage through water-bearing fracture zones.
- Supplementary investigations of fracture zones in the Äspö Tunnel.
- Mineralogy, geochemistry and petrophysics of red coloured granite adjacent to fractures.
- Definition and characterization of N-S fracture system tunnel sections 1600 to 2400 m.
- Pore volume characterization. Aperture distribution of a highly conductive single fracture.
- Classification and characterization of water-conducting features at Äspö: Results of Phase I investigations.
- Direct fault dating trials at the Äspö Hard Rock Laboratory.
- Comparative study in the TBM tunnel.
- Supplementary inflow mapping of tunnel section 1584 - 2496 m.
- Groundwater degassing and two-phase flow: Pilot hole test.
- Block scale Redox-experiment.
- Trace elements in low-conductivity rock.
- Sulphate reduction.
- Experiences from the grouting of the tunnel.
- Select.
- Zedex.

Blasting damage investigation in access ramp section 0526-0565 m

In 1991 the blasting damage around the tunnel contour was studied using several different methods both in boreholes (geophysical logging, TV logging and hydraulic testing) and directly on the tunnel walls and floor. Vibration measurements were made during blasting using accelerometers placed in a borehole along the gauge section. Eight short holes were cored in the floor and in one of the walls after the test rounds had been blasted. Samples of the cores were taken from each hole for measurement of the Kaiser effect and examination of microcracks.

The results of the investigation comprising this project are presented in five reports and a few articles:

Christiansson R, Hamberg U, 1991. Tunnel Excavation and Documentation. SKB, PR 25-91-12.

Olsson O, 1991. Geophysical Investigations in boreholes. SKB, PR 25-91-13.

Ouchterlony F, et al., 1991. Damage zone assessment by Vibration measurements. SKB, PR 25-91-14.

Kornfält K-A et al., 1991. Optical examination of Microcracks in thin Sections and Acoustic Emission of core samples. SKB, PR 23-91-15.

Nilsson L, 1991. Hydraulic Tests. SKB PR 25-91-16.

Ouchterlony F, Nakagama K, 1992. Blasting damage in the ramp of the SKB underground Laboratories at Äspö Sweden - Verification of predictions based on vibration measurements. In Proc of the 24th Japan Symposium on Rock mechanics. Japan Soc of Civil Engineers, Tokyo, Japan 6-7 February 1992.

Stanfors R, 1992. Undersökning av sprängskador i Äspölaboratoriet (Blasting damage investigation in the Äspö Hard Rock Laboratory). In papers presented at the Rock Mechanics Meeting in Stockholm, March 1992.

Pusch R, Stanfors R, 1992. The zone of Disturbance Around Blasted Tunnels at Depth. International Journal of Rock Mechanics, Mineralogy Science and Geomechanics. Abstract Vol 29, No 5.

Pusch R, Stanfors R, 1993. Disturbance of rocks around blasted tunnels. Proceedings of the Fourth International Symposium on Rock fragmentation by Blasting, Fragblast-4, Vienna, Austria, 5-8 July 1993. Balkema, Rotterdam.

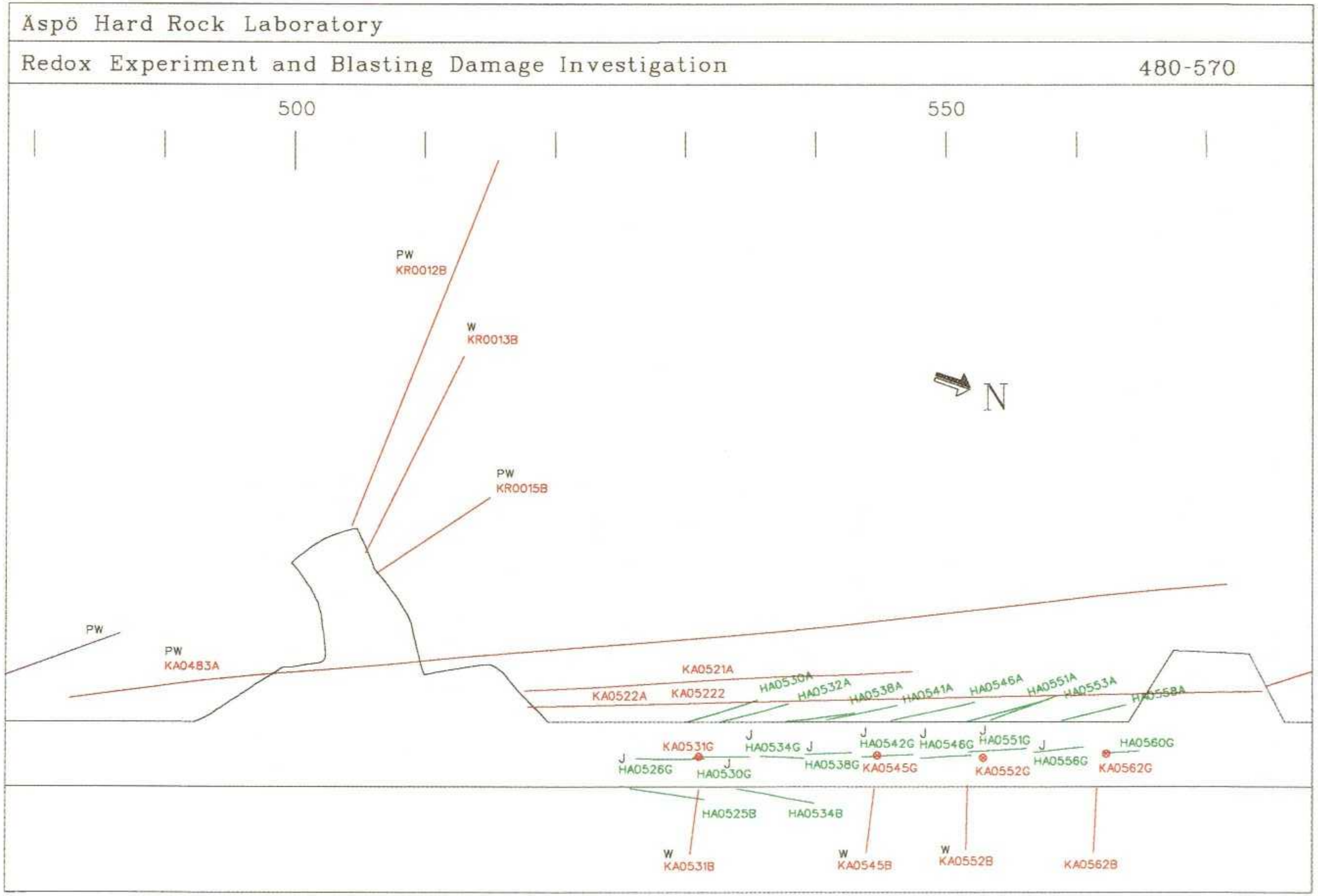


Figure 4-9. Overview of the blasting damage investigation.

Passage through water-bearing fracture zones

In conjunction with pre-investigations for the ÄHRL a number of indications were obtained of major water-bearing fracture zones, specially the Hålö- Äspö stretch of the access tunnel. A "major" water-bearing fracture zone is here taken to mean a zone at least 5 m wide, considered to be of complex composition and permitting water flows that require extensive sealing work.

A number of hydraulic tests performed in fracture zone NE-1 - which was located by means of geophysical methods of measurements and a number of core boreholes - indicated a large transmissivity (1 x 10^{-4} m^2/s). This zone was considered to be suitable for an extensive experiment principally concerning characterization and sealing.

To be able to perform the planned tests in fracture zone NE-1 in as efficient a manner as possible, during the excavation of the tunnel, a number of tests were performed on various methods when passing through fracture zones EW-7 and NE-3. Experience from these tests was used in the experiment in NE-1, thereby considerably increasing the chances of performing this according to plan.

The results of the investigations are presented in:

Bäckblom G (ed), Svemar C (ed)., 1993. First workshop on design and construction of deep repositories - Theme: Excavation through water-conducting major fracture zones. Såstaholm Sweden, March 30-31 1993. SKB TR 94-06.

Rhén I, Stanfors R, 1993. Passage through water-bearing fracture zones. Evaluation of investigations in fracture zones NE-1, EW-7 and NE-3. SKB PR 25-92-18.

Stille H, et al., 1992. Passage of water-bearing fracture zones. Experiences from the grouting of the section 1-1400 m of the tunnel. SKB, PR 25-92-19.

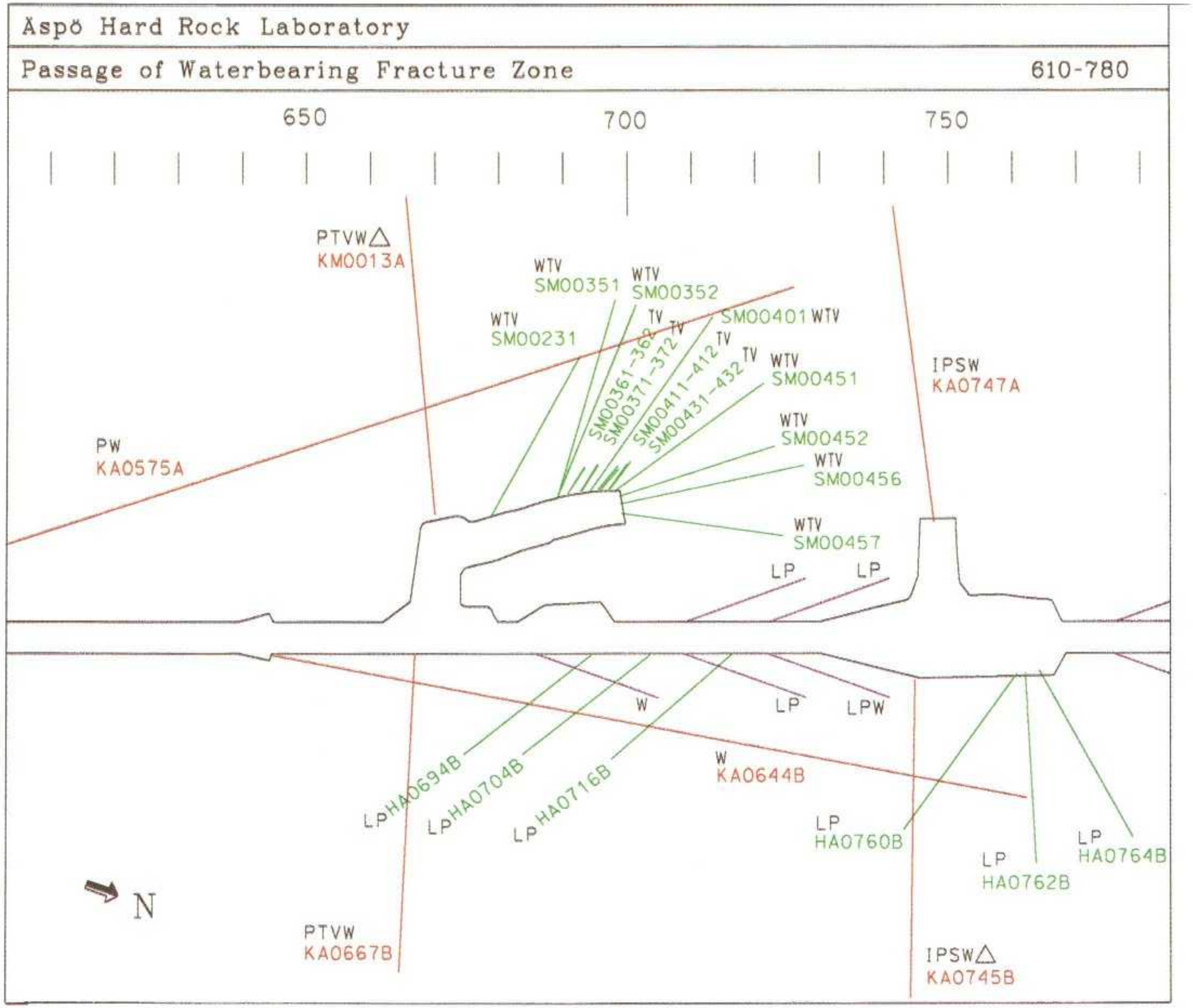


Figure 4-10. Overview of the special study concerning passage through water bearing fracture zones.

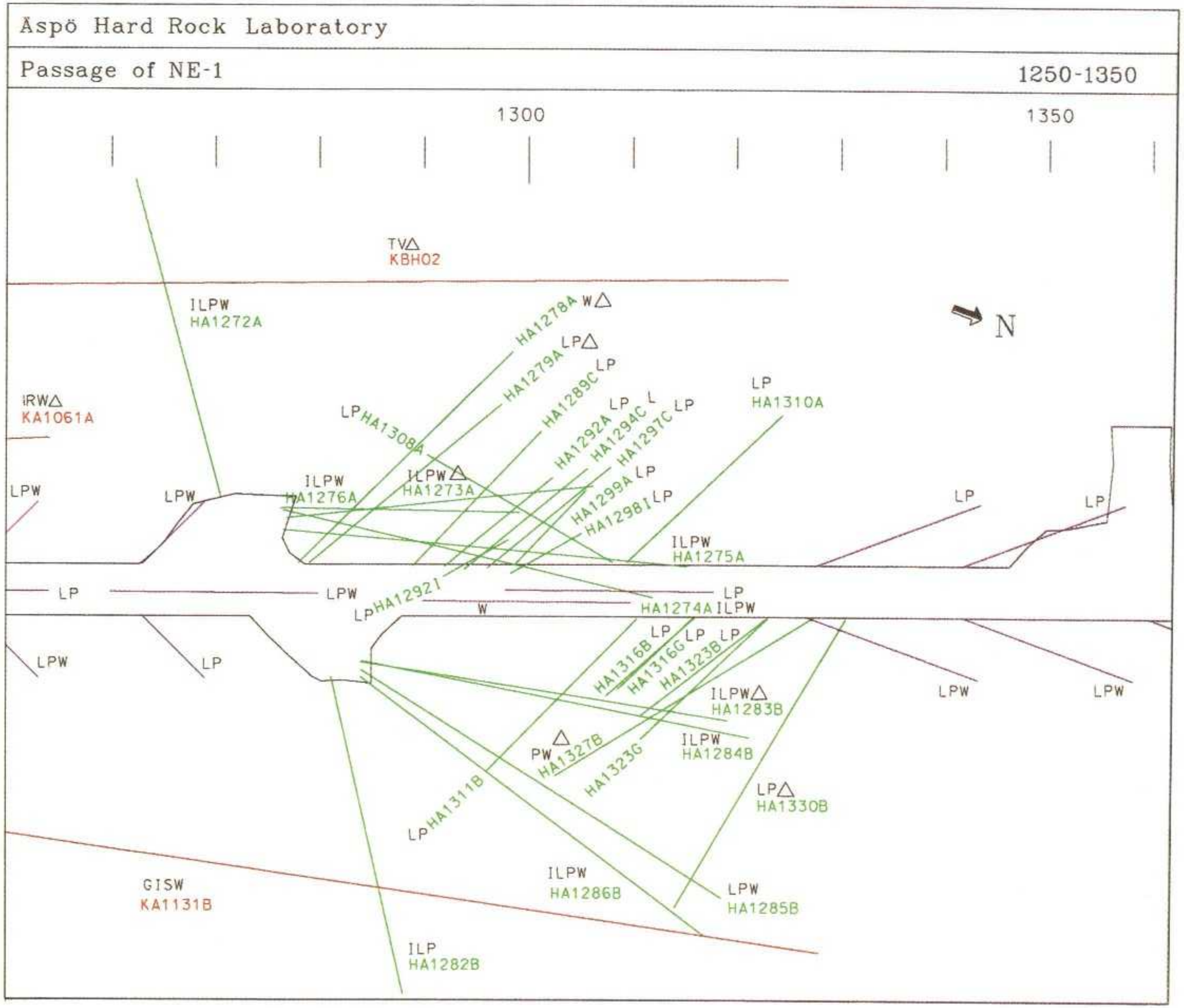


Figure 4-11. Passage of NE-1.

Supplementary investigations of fracture zones in the Äspö Tunnel

In order to obtain more detailed information of different kinds of fracture zones supplementary investigations were performed in the Äspö tunnel after excavation during 1994-95.

The predicted subvertical "NNW-structures" can be identified in some cases 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 WNW to NS.

A special study of gently dipping structures revealed 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).

Rhén I, Stanfors R, 1995. Supplementary investigations of fracture zones in the Äspö Tunnel. SKB PR 25-95-20.

Mineralogy, geochemistry and petrophysics of red-coloured granite adjacent to fractures

Mineralogical, geochemical and petrophysical investigations were made of coloured alteration rims and of neighbouring unaltered equivalents along fractures within granite from Äspö. An investigation was also made of a weak to rather strong, red-coloured granite from the Stripa mine, as well as a weak brownish-red colouration, definitely not hydrothermal in origin, of weathered rinds at a glacially polished rock surface in the Bohus granite.

When approaching the fracture planes in the Äspö granite, the most diagnostic alteration features are 1) the saussuritization and Fe-oxyhydroxide staining of plagioclase, 2) the crystallization of chlorite pseudomorphs after biotite and 3) the hematisation of magnetite. The porosity within the alteration zones increases generally 2 to 3 times that of protolithic rock, whereas the densities decrease by some 5 to 10%. The oxidation of magnetite gives a much as a tenafold reduction of the magnetic susceptibility.

Eliasson T, 1993. Mineralogy, geochemistry and petrophysics of red-coloured granite adjacent to fractures. SKB TR 93-06.

Definition and characterization of N-S fracture system between tunnel sections 1600 to 2400 m

According to the fracture zone classification scheme used in the predictions, some of the "NNW" fractures built up "minor fracture zones". These fracture zones (or single fractures) are thought to intersect the tunnel spiral at various locations. Surface investigations suggest, that this fracture system is probably one of the "main" hydraulic conductors within the group of minor fracture zones. However, it is difficult to predict the location of the elements striking"NNW" and their characteristics at depth.

A detailed characterization of the fracture zones striking NNW and/or a first interpretation of the data set (tunnel section 1600-2400 m), with respect to the hydraulic importance, were not available. Thus one of the tasks of this work was to increase the knowledge of the fracture system striking "NNW" using tunnel mapping data and to define this system in terms of a strike direction intervals.

The investigations were concentrated the first tunnel spiral (tunnel chainage from about 1600 to 2400 m) as an example of a minor fracture system.

Kickmaier W, 1993. Definition and characterization of N-S fracture system tunnel sections 1600 to 2400. Relationships to grouted sections - some remarks. SKB ICR 95-02

Pore volume characterization. Aperture distribution of a highly conductive single fracture

An experimental method of characterizing fracture apertures was applied to a highly conductive, minor fault at the Äspö Hard Rock Laboratory. The method comprises grouting the fracture with coloured grout and measuring the grout layer thickness. Measurements were made on slices of drill cores and on photographs of the borehole walls. The average aperture of the fracture is shown to be about 2 mm and the coefficient of variation about 130%. The contact area, defined as apertures less than 0.1 mm, covers about 40% of the total area of the fracture surface. In areas with apertures greater than 0.1 mm the aperture can be approximated by a log-normal distribution. The spatial variation of the aperture has been analysed using geostatistical methods. A conceptual model is proposed that correlates the spatial distribution of the aperture with the shear displacement of the fracture. The results are discussed in the context of existing experimental and theoretical work, and the difference between measurement methods is analysed. In future studies, the borehole photograph method is recommended for characterization of highly conductive fractures, and the core sectioning method for tighter fractures.

Hakami E, 1994. Pore volume characterization. Aperture distribution of a highly conductive single fracture. SKB PR 25-94-30.

Classification and characterization of water-conducting features at Äspö: Results of Phase I investigations

Water flow in the basement rocks of Äspö takes place along water conducting features that are related to structural discontinuities (faults) created or reactivated during events of brittle deformation. The majority of these features dip steeply and strike NW-SE, parallel to the present maximum horizontal compression direction.

Based on fracture mapping and mechanical structural interpretation in the tunnel as well as on the surface of Äspö, different types of water-conducting features were identified. Most, if not all, water-conducting features on Äspö are faults. Major differences occur in the internal structure of these faults and, thus, they are classified as simple fractures or complex fractures = faults. The degree of complexity of faults depends to some degree on the lithology as well as on the presence of older structures focussing brittle faulting. The resulting classification scheme is presented with respect to radionuclide migration in an imposed experimental dipole flow field as well as in the far field of a hypothetical waste repository.

Both simple and complex fractures were generated during the same geological events, and their character may change from simple to complex (and vice versa) along the strike. Prognostic capabilities defining the structure of faults some decametres away from the tunnel are limited but could possibly be improved by future studies. The simple and complex groups will be divided into more groups.

Mazurek M, Bossart P, Eliasson T, 1995. Classification and characterization of water-conducting features at Äspö: Results of Phase I investigations. SKB PR 25-95-03.

Direct fault dating trials at the Äspö Hard Rock Laboratory

Over seventy rock samples were collected from fault and fracture zones in the Äspö Hard Rock Laboratory tunnel for a study of direct fault-dating techniques. Following microstructural and mineralogical analyses, isotopic, palaeomagnetic and electron spin resonance (ESR) methods were employed in an attempt to determine the age of the most recent movements of the sampled faults.

The larger fracture zones contain fault-rock assemblages and microstructures which are consistent with a prolonged and polyophase movement history, although cumulative displacement is difficult to quantify. For the important fracture zones NE-4 and NE-3, the most recent shear displacements involved formation of fault gouge cemented by authigenic "illite".

ESR dating of quartz grains, separated from gouge from fracture zones NE-4 and NE-3, strongly indicates that the ESR signals have not been reset by fault movements for a minimum time period of several hundred thousand to one million years.

Palaeomagnetic dating of gouge from fracture zone NE-4 shows that a stable component of magnetization overlaps both Precambrian (approx. 1350 Ma) and Permo-Triassic (c. 270-190Ma) parts of the apparent polar wander curve. The younger age of magnetization is preferred on geological grounds and by comparison with the isotopic dating results.

K-Ar dating of clay fractions (<2 to <0.05 μm) separated from gouge from four faults, including fracture zones NE-4 and NE-3, gave model ages in the range 706-301 Ma. Accounting for the effects of contamination by potassium-bearing porphyroclasts, it is likely that authigenic "illite" was formed at least 250 million years ago, after the most recent significant fault movements. Oxygen and hydrogen isotope analyses of the dated clay fractions show that they are not in equilibrium with the present-day groundwaters at Äspö.

Maddock R H, Hailwood E A, Rhodes E J, Muir Wood R, 1993. Direct fault dating trials at the Äspö Hard Rock Laboratory. SKB TR 93-24.

Comparative study between cored test borehole KA3191F and the first 200 m extension of the TBM tunnel

SKB decided in 1993 to use a TBM full-face boring technique for the final part of the Äspö HRL tunnel, in order to get experience of this technique for the future deep repository excavation.

In order to make a good characterization of the TBM rock volume a cored borehole (KA3191F) was drilled in advance of the TBM boring. One aim was to compare data from the cored borehole KA3191F with the documentation data from the TBM-tunnel.

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 depth of 450 metres below ground level in the vicinity of the shafts. The borehole is 210 m long.

It can be concluded that it was possible to make good predictions concerning the major rocks and major conductive sections in the tunnel. It was also possible to find a correlation between some but not all radar reflectors and structures (geological and hydraulic). There is normally a good correlation between geophysical logging data and increased fracturing/alteration of rock in the tunnel. Results from flow mapping during drilling and hydraulic tests correspond well to parts of the tunnel that have been grouted or not.

Rhén I, Stanfors R, Wikberg P, Forsmark T, 1995. Comparative study between cored test borehole KA3191F and the first 200 m extension of the TBM tunnel. SKB PR 25-95-09.

Supplementary inflow mapping of tunnel section 1584-2496 m

The flow into tunnel section 1584-2496 was re-mapped during the period June 30 to July 12 1994. The purpose was to compare with the inflow mapping made at the tunnel face during construction. The purpose was also to get a better estimate of the flow distribution around the tunnel, as weirs at that time the total flow into the tunnel could be measured by dams and weirs along the tunnel.

Rhén I, Danielsson P, Forsmark T, Gustafson G, Liedholm M, 1994.
Geohydrological evaluation of the data from section 2265-2874 m.
SKB PR 25-94-20. (Appendix 5)

Groundwater degassing and two-phase flow: Pilot hole test

A pilot hole test was conducted to support the design of the Degassing of Groundwater and Two-Phase Flow experiments planned for the Hard Rock Laboratory, Äspö, Sweden. 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.

Geller J T, 1995. Groundwater degassing and two-phase flow: Pilot hole test. SKB International Cooperation Report, ICR 95-03.

Block scale Redox-experiment

This project involved studying the performance of the geological barrier to protect a repository from dissolved oxygen entering vertical fracture zones from the surface, especially during construction and operation of the repository.

On March 13, 1991 tunnel construction at the Äspö Hard Rock Laboratory intersected a vertical, hydraulically-conductive fracture zone 513 metres along the tunnel from its mouth and at a depth of 70 metres. For a period of three years the inflow to the tunnel, and discharge from boreholes drilled into the fracture zone from the tunnel, were monitored to observe if dissolved oxygen was transported from the surface into the groundwater under the intense hydraulic disturbance created by tunnel construction. As predicted by model calculations prior to the start of the experiment, dilute recharge water from the surface displaced the native saline water of the fracture zone. A breakthrough of fresh water was observed three weeks after the fracture zone had been intersected by the tunnel.

The model calculations also predicted a breakthrough of dissolved oxygen into the tunnel, transported vertically with the recharge water from the surface. Although a slight oxygen breakthrough was observed a few weeks after the surface water breakthrough, the fracture zone rapidly returned to reducing conditions with intensive anaerobic respiration of organic carbon.

1) The main result of this experiment is the accelerated input of organic carbon which adds net reducing capacity to the groundwater under the disturbed hydraulic conditions created by tunnel construction.
2) No significant vertical transport of dissolved oxygen was observed during this experiment.
3) Microbial respiration provides an important catalytic pathway for organic carbon to scavenge oxidants.

Banwart S, et al., 1992. The large scale redox experiment. Initial characterization of the fracture zone. SKB, PR 25-92-04.
Banwart S, et al., 1992. The Äspö redox investigations in block scale. SKB, TR 95-26.
Banwart S (ed), 1995. The Redox experiment in block scale. Final reporting of results from the Three Year Project. SKB, PR 25-95-06.
Banwart S, et al., 1993. Redox processes in a granitic coastal aquifer: Characterization of the large scale experimental site and some initial results. SKB, PR 25-93-03.
Banwart S, Gustafsson E, Laaksoharju M, Nilsson A.-C, Tullborg E-L and Wallin B, 1994. Large-scale intrusion of shallow water into a vertical fracture zone in crystalline bedrock: Initial hydrochemical perturbation during tunnel construction at the Äspö Hard Rock Laboratory, southeastern Sweden. Water Resour. Res. 30:6, 1747-1763.
Banwart S, Wikberg P, 1994. Redox processes in disturbed groundwater systems: Conclusions from an Äspö-HRL study. Geoval 1994, Paris, France.

Trace elements in low-conductivity rock

This work was aimed at the study of the following concerning sampling of deep saline groundwater in low-conductivity rocks in the HRL: a) to find suitable methods for chemical analysis of trace elements in very saline water (Cl^- content between 4000 and 7000 mg/l), b) to find out how the sampling should be carried out in practice without contamination, c) to study the geochemical differences between waters in low- and high-conductivity zones and d) to study the geochemical interaction between water and rock.

Two boreholes were drilled in different lithologies for sampling of water in low-conductivity zones. The water sampling was done four times during three months. Protection gas was used to avoid contamination from tunnel air. Water in 15 high-conductivity zones was sampled. Petrological and chemical analysis of the drill cores were also made.

The water samples were analysed in three commercial laboratories. Non-parametric statistics analysis (scattergrams and box plots) were used for evaluation of the chemical analysis. Analysis with flame and flameless AAS gave high precision for major elements normally analysed in saline waters but for only two trace elements. Analysis with ICP-MS after pre-concentration and with INAA was unsuccessful for most elements, while ICP-MS analysis presumably with a special nebulizer gave acceptable results for 9 trace elements. The following elements were accepted for use in the interpretation of the geochemistry of saline water: Na, K, Mg, Ca, Sr, Li, Mn, Fe, Y, Pr, La, Br, Rb, U, Mo, Cs and Ba.

In general, the lowest concentrations of Na, K, Ca, Sr, Li, La, Br, Rb and Mo were found in the water of the section with the lowest water flow. Barium was the only element with the highest content in this section. A clear difference in element concentrations was found over a short distance in the greenstone of a low-conductivity zone. A trend of changing (increasing) element concentrations with time was seen in samples taken from low-conductivity zones. A clear trend of higher concentrations of Li, Ca, Br, Sr and Mo was found in the low-conductivity rocks as compared to high-conductivity rocks. The opposite is true for the concentrations of K, Mg, Mn, U, Rb, Y, Cs, whereas no differences were found for the concentrations of Pr, Ba, La, Fe and Na. A trend of decreasing concentrations of Fe and to a less extent of Ba and Cs down the tunnel is obvious, whereas the opposite is true for Mo, Li, Ca, Na, Co and Sr.

Nilsson A-C, 1994. Compilation of groundwater chemistry data from Äspö 1990-1994. SKB, PR 25-95-02,

Wikström L, Björklund A, 1994. Trace elements in waters of low-conductivity rocks in the Äspö Hard Rock Laboratory. SKB, PR 25-94-28.

Sulphate reduction

Sulphate reduction is a well studied process in sea bed sediments, but is less known in deep groundwaters. Sulphate-reducing bacteria can bring about the reduction of sulphate to sulphide using, for example, organic substances present in natural groundwater as reducing agents. Sulphide production is of particular interest for disposal of spent fuel in copper canisters because sulphide is in fact the only substance present in deep groundwaters that will cause the corrosion of copper. Oxygen, another copper-corrodant is not present in deep groundwater and sulphate will not react with copper unless microbes reduce it to sulphide.

Evidence and indications of sulphate reduction based on geological, hydrogeological, groundwater, isotope and microbial data gathered in and around the Äspö Hard Rock Laboratory (HRL) tunnel have been evaluated.

This integrated investigation showed that sulphate reduction had taken place in the past but is most likely also an ongoing process. Anaerobic sulphate-reducing bacteria can live in marine sediments, in the tunnel sections under the sea and in deep groundwaters, since there is no access to oxygen. The sulphate-reducing bacteria seem to thrive when the Cl- concentration of the groundwater is 4000-6000 mg/l. Sulphate reduction is an in-situ process but the resulting hydrogen-sulphide-rich water can be transported to other locations. More vigorous sulphate reduction takes place when the organic content in the groundwater is high (>10 mg/l, DOC) which is the case in the sediments and ground-waters under the sea. Some bacteria use hydrogen (geogas) as an electron donor instead of organic carbon and can therefore live in deep environments where access to organic material is limited. The sulphate-reducing bacteria seem to adapt relatively quickly to changing flow situations caused by the tunnel construction.

Laaksoharju M (ed), 1995. Sulphate reduction in the Äspö HRL tunnel. SKB, TR 95-25

Experiences from the grouting of the tunnel

The tunnel has been pre-grouted where the water leakage was expected to be high. A great number of pre-grouting fans have been made. Besides ordinary demands it was desired to achieve a limited spread of the grout. Two accelerated grout mixes with calcium chloride have been used. The grout properties and time for hardening have been tested. Comparisons with theoretical grout take and penetration and measured values have been made, to find a better method to predict grout take and penetration.

Gustafson G, Stille H, 1996. Prediction of Groutability from Grout Properties and Hydrogeological Data. Tunnel and Underground Space Technology, Vol. 11, No. 3.

Stille H, Gustafson G, Håkansson U, Olsson P, 1993. Passage of water bearing fracture zones. Experiences from grouting the section 1-1400 m of the tunnel. SKB, PR 25-92-19.

Stille H, Jansson T, Olsson P, 1994. Experiences from the grouting of the section 1340-2565 m of the tunnel. SKB, PR 25-94-13.

Stille H, Olsson P, Gustafsson G, 1993. Experience from the grouting of the first part of the tunnel of the Äspö Hard Rock Laboratory. Papers presented at the Rock Mechanics Meeting, Stockholm, March 1993, SveBefo.

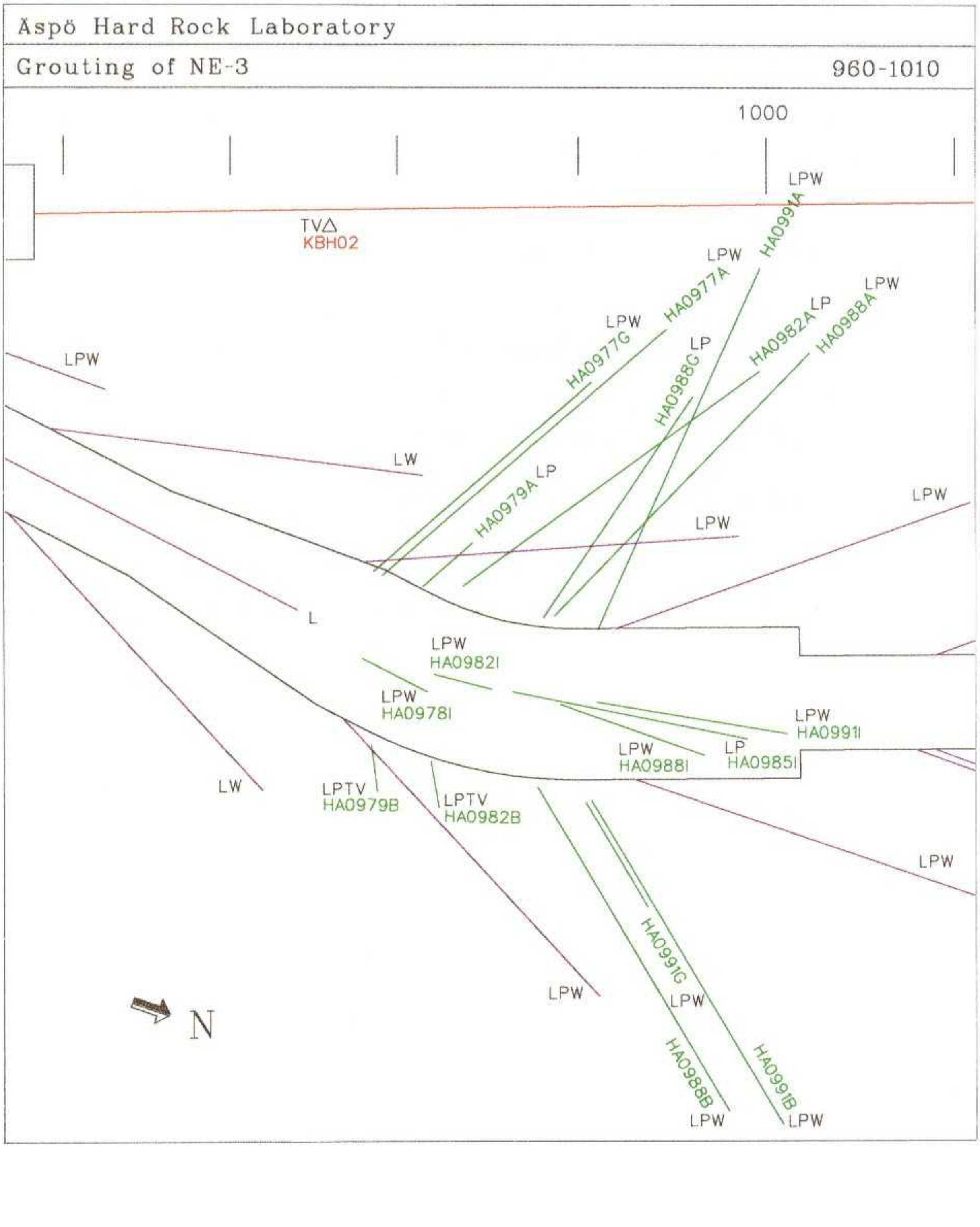


Figure 4-12. *Grouting of NE-3.*

Select

Based on defined experimental criteria, experimental volumes were tentatively allocated for the REX, RNR (Chemlab) and TRUE experiments. The three rock volumes were investigated within the SELECT Project using eight cored boreholes. The rock sampled by the boreholes were characterized with different geological, geophysical and hydrogeological techniques. As a complement to conventional core logging, the new BIP borehole TV system was successfully utilized. Suitable target features for three experiments (REX, RNR and TRUE) which answer up to preset requirements were identified in four of the drilled boreholes. Identified features and important boundary conditions were sectioned-off using multi-packer systems with up to five test sections. An important issue in the SELECT investigation programme was to assess the risk for disturbance between different experimental sites. The intra- and cross-borehole hydraulic connectivity was characterized with a hydraulic interference test programme. It was noted that hydraulic responses are transmitted over hundred 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. Descriptive models for rock blocks containing the identified target features were 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.

Winberg A, Andersson P, Hermansson J, Stenberg L, 1996. Results of the Select Project. Investigation programme for selection of experimental sites for the operational phase. SKB, PR HRL-96-01.

ZEDEX- A study of the zone of excavation disturbance for blasted and bored tunnels

To obtain a better understanding of the properties of the excavation disturbed zone (EDZ) around an excavated tunnel and its dependence on the method of excavation, ANDRA (France), Nirex (UK) and SKB (Sweden) initiated the Zone of Excavation Disturbance Experiment (ZEDEX) Project. The objectives of the ZEDEX project were to understand the mechanical behaviour of the EDZ with respect to its origin, character, magnitude of property change, extent, and its 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. A distinction was made between measuring the excavation-induced damaged zone and the excavation-induced disturbed zone.

The rock mass initial conditions were characterized by several techniques; tunnel mapping and core logging, laboratory testing on core samples, in-situ P- and S-wave velocity measurements, borehole radar and geotechnical classification factors (Q, RMR). The rock mass response to excavation has been recorded by multiple point borehole extensometers (MPBXs), convergence, seismic velocity, permeability and acoustic emission (AE) measurements.

The far-field measurements showed little evidence of damage for any of the excavation techniques. AE source locations showed that there was sparse activity beyond about 2 m from the tunnel perimeter. Hydraulic changes and AE activity in the far-field may result from opening, closing or minor shearing of existing fractures due to stress redistribution. In the near-field, there was little evidence of damage around the drift excavated by tunnel boring machine (TBM) except within a few centimetres of the drift perimeter. AE results showed microcracking occurring predominantly tightly clustered at the tunnel face and walls, with only scattered cracking further from the tunnel.

In the drill and blast (D&B) drift, the damaged zone developed to a maximum depth of about 80 cm in the floor of the tunnel, where higher energy explosives were used and was less well developed in the walls. AE results show that there was up to 10 times the activity occurring around the D&B drift compared with that around the TBM drift but little difference in AE rate between the two methods. No difference was observed in the EDZ extent and magnitude between the low shock energy smooth (LSES) blasting and the normal smooth (NS) blasting. In terms of success criteria in comparison with the expected outcome of the experiment, the ZEDEX project was successful in research and development of suitable methods for characterizing EDZ. It also provides a solid basis for selecting and optimizing methods of excavation.

Bauer C, Falls S, Stenberg L, Emsley S, Olsson O, 1995. ZEDEX- A study of the zone of excavation disturbance for blasted and bored tunnels. SKB International Cooperation Report, ICR 96-03.

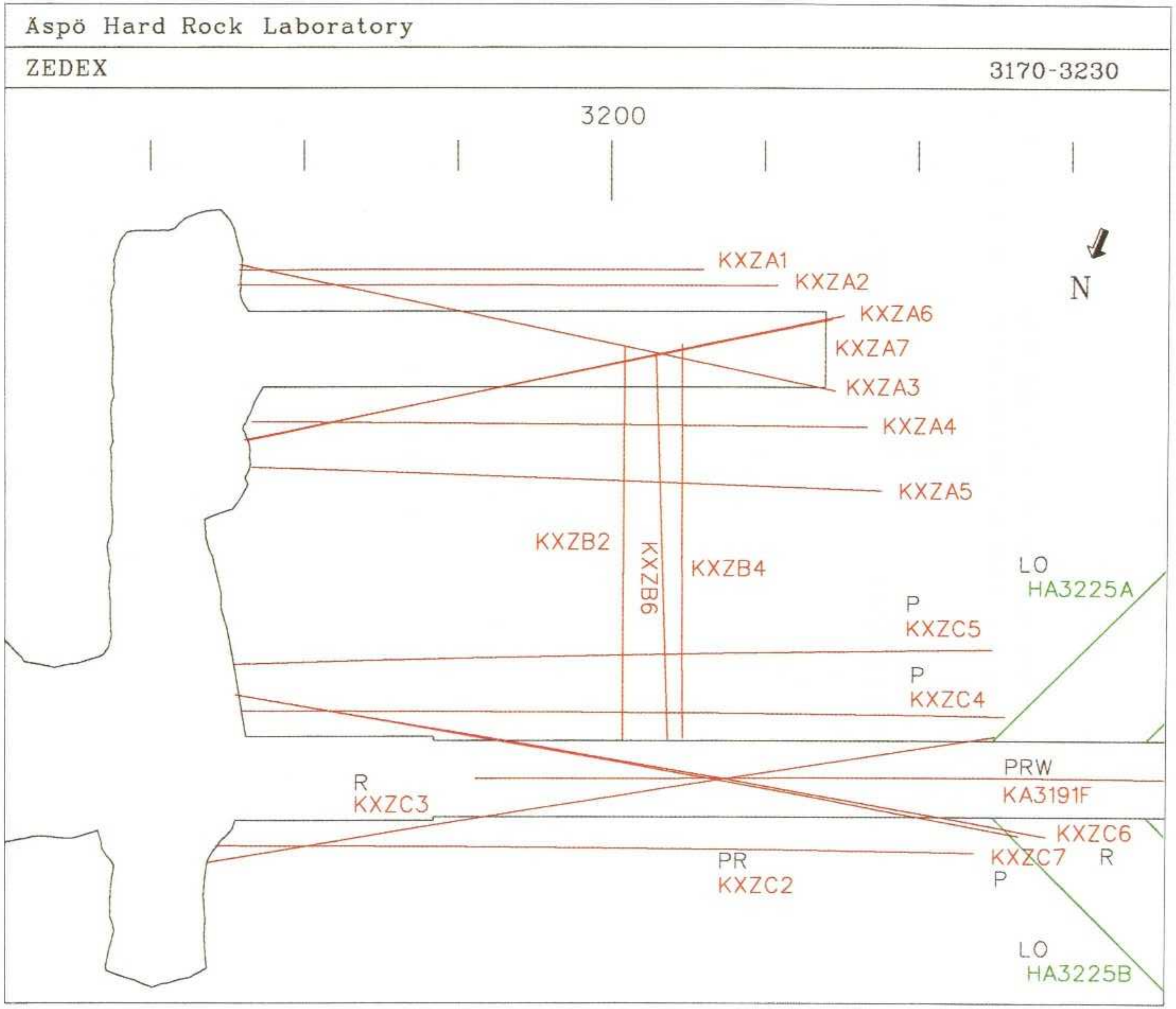


Figure 4-13. Boreholes in the ZEDEX programme.

4.3 COMPILATION OF DIFFERENT INVESTIGATION ACTIVITIES

The different investigation activities with references are described in *Tables 4-1* to *4-3*.

Table 4-1. Investigations of rocks and minerals in the tunnel with references to reports where to find more details concerning results and scope of study.

INVESTIGATION	REPORT
Modal analysis of rocks	PR 25-95-04
Chemical analysis of rocks	PR 25-95-04, PR 25-93-01
Density analysis of rocks	PR 25-93-05, PR 25-93-10, PR 25-94-19
Porosity analysis of rocks	PR 25-93-05, PR 25-93-10, PR 25-94-19, PR 25-95-09
Fracture filling analysis	TR 93-24, PR 25-93-01 PR 25-93-05
Paleomagnetic analysis	TR 93-24
XRD analysis	TR 93-24, TR 93-06
ESR analysis	TR 93-24
Isotopic dating	TR 93-24, PR 25-95-04
Rock mechanics	PR 25-94-02
Magnetic susceptibility	TR 93-06

Table 4-2. Geochemical investigations in the tunnel with references to reports where to find more details concerning results and scope of study.

INVESTIGATION	REPORT
Microbiological investigations	TR 95-10
Fracture mineralogy	TR 95-13, PR 25-93-01, PR 25-93-03
Trace element analyses	PR 25-94-28, PR 25-95-02
Redox front investigations	PR 25-95-06, TR 95-26
Fracture characterization and classification	PR 25-95-03
Isotopic investigations	ICR 94-06, ICR 94-13
Groundwater analyses	PR 25-95-02, TR 92-31
Colloidal investigations	PR 25-95-06, TR 95-24
Hydrochemical modelling	ICR 94-13
Sulphate reduction	TR 95-25

Table 4-3. Geohydrological investigations in the tunnel with references to reports where to find more details concerning results and scope of study.

INVESTIGATION	REPORT
Pressure build-up tests in probeholes.	PR 25-93-06, PR 25-93-11 PR 25-94-20, PR 25-95-28
Flow into the tunnel	PR 25-95-28
Salinity of water measured at weirs	PR 25-95-28
Mapping of water bearing fractures	PR 25-95-28*, PR 25-95-23
Water pressure around the tunnel	PR 25-95-28
Piezometric levels	PR 25-95-08, PR 25-93-13, PR 25-94-22

* *Summary of some data previously presented in PR 25-93-06, PR 25-93-11 and PR 25-94-20.*

4.4 BOREHOLE INVESTIGATIONS

A compilation of investigations performed in boreholes in the Äspö tunnel is presented in *Tables 4-4* to *4-8* with reference to report or database (grey field).

At Äspö four different coordinate systems are used. The systems are rotated relative to each other and have different north directions. Within the Äspö Project all geological information on the orientation of structures is given relative to magnetic north. This reference direction is generally used in this report. Occasionally geographic north is also used as a reference direction, but for practical purposes this is equal to magnetic north considering the accuracy in orientation that can be obtained for geological features. Local drifts and borehole orientations are always given in the local Äspö coordinate system. All coordinates are related to top of casing. Dip and direction are related to casing orientation. The dip is defined as positive when directed upwards and negative when directed downwards. Direction is defined positive clockwise from Äspö local north. The relative orientation between the three coordinate systems are defined below.

Äspö north is 11.1° west of geographic north and 12° west of magnetic north. Geographic north is 1.0 degrees west of magnetic north. Geographic north is 0.7° west of RAK north (Swedish national grid)

The boreholes in the tunnel are named according to an object identification code which is TDLLLLP. Were T stands for the type of object (K=core drilled borehole, S: percussion probing hole, H: Percussion borehole or Y= surface sampling). The D defines the tunnel (A= main tunnel, M: method tunnel, R= redox tunnel). LLLL defines the position along the tunnel in metres. P defines the position in the tunnel wall as described below.

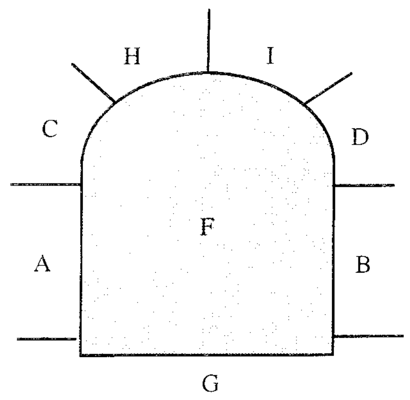


Table 4-4. Compilation of performed investigations in cored boreholes in the Äspö tunnel.

Borehole	Core logging	Geophysical Logging	TV-logging	Borehole Radar	Rock Stress Meas	Water Sample	Pressure Build-up Tests*	Interference Tests	Spinner Meas.	UCM
KH0222G										
KA0483A		PR 25-91-12	PR 25-91-13			PR 25-95-02				
KA0521A										
KA0522A		PR 25-91-12	PR 25-91-13				PR 25-91-16**			
KA05222										
KA0531B		PR 25-91-12	PR 25-91-13			PR 25-95-02				
KA0531G		PR 25-91-12	PR 25-91-13			PR 25-95-02				
KA0545B		PR 25-91-12	PR 25-91-13			PR 25-95-02				
KA0545G		PR 25-91-12	PR 25-91-13							
KA0552B		PR 25-91-12	PR 25-91-13			PR 25-95-02				
KA0552G		PR 25-91-12	PR 25-91-13							
KA0562B		PR 25-91-12	PR 25-91-13							
KA0562G		PR 25-91-12								
KA0575A				PR 25-92-18A		PR 25-95-02	PR 25-92-18			
KA0644B						PR 25-95-02	PR 25-92-18			
KA0667B						PR 25-95-02	PR 25-92-18A	PR 25-92-18A		PR 25-92-18A
KA0747A							PR 25-92-18A	PR 25-92-18A		PR 25-92-18A
KA0745B						PR 25-95-02	PR 25-92-18A	PR 25-92-18A		PR 25-92-18A
KA1045A					PR 25-93-02					
KA1054A					PR 25-93-02					
KA1061A				PR 25-92-18B		PR 25-95-02		PR 25-92-18C	PR 25-92-18B	
KA1131B		PR 25-95-07		PR 25-92-18B		PR 25-95-02		PR 25-92-18C		
KA1192A					PR 25-93-02					
KA1195A										
KA1623A					PR 25-93-02					
KA1625A					PR 25-93-02					
KA1626A					PR 25-93-02					
KA1639A						PR 25-95-02				
KA1750A						PR 25-95-02				
KA1751A						PR 25-93-12	PR 25-94-06		PR 25-94-06	
KA1754A				PR 25-94-01		PR 25-95-02	PR 25-94-06			PR 25-94-06
KA1755A						PR 25-93-12	PR 25-94-39		PR 25-94-39	PR 25-94-39
KA1899A					PR 25-94-02					
KA2048B		PR 25-95-07		PR 25-94-01		PR 25-93-12	PR 25-94-06			

Table 4-4 *(continued)*. **Compilation of performed investigations in cored boreholes in the Äspö tunnel.**

Borehole	Core logging	Geophysical Logging	TV-logging	Borehole Radar	Rock Stress Meas	Water Sample	Pressure Build-up Tests*	Interference Tests	Spinner Meas.	UCM
KA2050A			PR 25-94-14	PR 25-94-04		PR 25-95-02	PR 25-94-14			PR 25-94-15
KA2162B				PR 25-94-01		PR 25-95-02	PR 25-94-06		PR 25-94-06	
KA2198A					PR 25-94-02					
KA2510A					PR 25-94-02					
KA2511A		PR 25-94-14	PR 25-94-14	PR 25-94-04		PR 25-95-02	PR 25-94-14			
KA2512A						PR 25-94-21				
KA2598A		PR 25-94-14	PR 25-94-14	PR 25-94-04		PR 25-95-02	PR 25-94-14			PR 25-94-15
KA2858A										
KA2862A										
KA2870A					PR 25-94-32					
KA3005A				PR 25-95-26						
KA3010A				PR 25-95-26						
KA3067A				PR 25-95-26						
KA3068A					PR 25-94-32					
KA3105A				PR 25-95-26						
KA3110A										
KA3191F		PR 25-95-09	PR 25-95-09	PR 25-95-09		PR 25-95-02	PR 25-95-09			PR 25-95-09
KA3385A				PR 25-95-26						
KBH02T						PR 25-95-02				
KC0045F		PR 25-94-14		PR 25-94-04		PR 25-95-02	PR 25-94-14	PR 25-94-15		
KM0015A										
KM0013A						PR 25-95-02	PR 25-94-14	PR 25-92-18A		
KR0012B						PR 25-95-02				
KR0013B						PR 25-95-02				
KR0015B						PR 25-95-02				
KXZA1										
KXZA2										
KXZA3										
KXZA4										
KXZA5										
KXZA6										
KXZA7										
KXZB1										
KXZB2										

Table 4-4 *(continued)*. **Compilation of performed investigations in cored boreholes in the Äspö tunnel.**

Borehole	Core logging	Geophysical Logging	TV-logging	Borehole Radar	Rock Stress Meas	Water Sample	Pressure Build-up Tests*	Interference Tests	Spinner Meas.	UCM
KXZB3										
KXZB4										
KXZB6										
KXZB7										
KXZB8										
KXZC1										
KXZC2										
KXZC3										
KXZC4										
KXZC5										
KXZC6										
KXZC7										
KXZRT1H										
KXZRT1I										
KXZRTIV										
KXZRT2I										
KXZRT2H										
KXZRT2V										
KXZRD9H										
KXZRD7H										
KXZRD7I										
KXZRD6H										
KXZRD2H										
KXZRD2I										
KXZRD3I										
KXZRD3H										
KXZRD4H										
KXZRD5H										
KXZRD1H										
KXZRD8H										
KXZRD7V										
KXZRD6V										
KXZRD6I										
KXZRD3V										
KXZRD2V										

* If no pressure-build up test has been performed estimate of flowrate after drilling is available in most cases.

** Injection test.

Table 4-5. Compilation of performed investigations in percussion boreholes in the Äspö tunnel.

Borehole	Geo-physical Logging	TV-logging	Water Sampling	Pressure Build-up Tests*	Pressure observation*	Inter-ference Tests	Flow logging spinner	Water Inject. Tests
HA0525B	PR 25-91-12	PR 25-91-13						
HA0526G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0530A	PR 25-91-12	PR 25-91-13						
HA0530G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0532A	PR 25-91-12							
HA0534B								
HA0534G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0538A	PR 25-91-12	PR 25-91-13						
HA0538G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0541A	PR 25-91-12	PR 25-91-13						
HA0542G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0546A	PR 25-91-12	PR 25-91-13						
HA0546G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0551A	PR 25-91-12	PR 25-91-13						
HA0551G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0553A	PR 25-91-12	PR 25-91-13						
HA0556G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0559A	PR 25-91-12	PR 25-91-13						
HA0560G	PR 25-91-12	PR 25-91-13						PR 25-91-16
HA0694B				PR 25-92-18A		PR 25-92-18A		
HA0704B				PR 25-92-18A		PR 25-92-18A		
HA0716B				PR 25-92-18A		PR 25-92-18A		

Table 4-5 *(continued)*. **Compilation of performed investigations in percussion boreholes in the Äspö tunnel.**

Borehole	Geo-physical Logging	TV-logging	Water Sampling	Pressure Build-up Tests*	Pressure Observation*	Inter-ference Tests	Flow logging spinner	Water Inject. Tests
HA0760B				PR 25-92-18A		PR 25-92-18A		
HA0762B				PR 25-92-18A		PR 25-92-18A		
HA0764B				PR 25-92-18A		PR 25-92-18A		
HA0977A		PR 25-92-18a						
HA0977G		PR 25-92-18a						
HA0978I		PR 25-92-18a						
HA0979A		PR 25-92-18a						
HA0979B		PR 25-92-18a						
HA0982A		PR 25-92-18a						
HA0982B		PR 25-92-18a						
HA0982I		PR 25-92-18a	PR 25-93-07					
HA0985I		PR 25-92-18a						
HA0988A		PR 25-92-18a	PR 25-93-07					
HA0988B		PR 25-92-18a	PR 25-93-07					
HA0988G		PR 25-92-18a						
HA0988I		PR 25-92-18a	PR 25-93-07					
HA0991A		PR 25-92-18a	PR 25-93-07					
HA0991B		PR 25-92-18a	PR 25-93-07					
HA0991G		PR 25-92-18a	PR 25-93-07					
HA0991I		PR 25-92-18A	PR 25-93-07					
HA1048A			PR 25-93-07	PR 25-92-18C				
HA1051A				PR 25-92-18C				
HA1127B				PR 25-92-18C				
HA1130B			PR 25-93-07	PR 25-92-18C				

Table 4-5 *(continued)*. **Compilation of performed investigations in percussion boreholes in the Äspö tunnel.**

Borehole	Geo-physical Logging	TV-logging	Water Sampling	Pressure Build-up Tests*	Pressure Observation*	Inter-ference Tests	Flow logging spinner	Water Inject. Tests
HA1272A			PR 25-95-02			PR 25-92-18C		
HA1273A			PR 25-95-02			PR 25-92-18C		
HA1274A			PR 25-95-02			PR 25-92-18C		
HA1275A			PR 25-95-02			PR 25-92-18C		
HA1276A			PR 25-95-02			PR 25-92-18C		
HA1278A		PR 25-92-18D	PR 25-95-02					
HA1279A		PR 25-92-18D						
HA1282B						PR 25-92-18C		
HA1283B			PR 25-95-02			PR 25-92-18C		
HA1284B			PR 25-95-02			PR 25-92-18C		
HA1285B			PR 25-95-02					
HA1286B			PR 25-95-02			PR 25-92-18C		
HA1289C								
HA1292A		PR 25-92-18D						
HA1292I		PR 25-92-18D						
HA1294C								
HA1297C								
HA1298I		PR 25-92-18D						
HA1299A		PR 25-92-18D						
HA1308A								
HA1310A								
HA1311B								
HA1316B		PR 25-92-18D						
HA1316G		PR 25-92-18D						

Table 4-5 *(continued)*. **Compilation of performed investigations in percussion boreholes in the Äspö tunnel.**

Borehole	Geo-physical Logging	TV-logging	Water Sampling	Pressure Build-up Tests*	Pressure Observation*	Inter-ference Tests	Flow logging spinner	Water Inject. Tests
HA1323B		PR 25-92-18D						
HA1323G		PR 25-92-18D						
HA1327B		PR 25-92-18D	PR 25-95-02					
HA1330B		PR 25-92-18D						
HA1405A				PR 25-94-20				
HA1405B			PR 25-93-07	PR 25-94-20				
HA1591A		PR 25-95-20						
HA1613B		PR 25-95-20		PR 25-94-20				
HA1684B		PR 25-95-20	PR 25-95-02	PR 25-94-06				
HA1704B		PR 25-95-20		PR 25-94-06			PR 25-94-06	
HA1714A				PR 25-94-06				
HA1726F								
HA1749A			PR 25-95-02	PR 25-94-06				
HA1852A				PR 25-94-06				
HA1885B		PR 25-95-20		PR 25-94-20				
HA1896A		PR 25-95-20		PR 25-94-20				
HA1896B				PR 25-94-06				
HA1960A				PR 25-94-06				
HA2198B		PR 25-95-20	PR 25-93-12	PR 25-95-20				
HA2210A		PR 25-95-20		PR 25-95-20				
HA2265A		PR 25-95-20	PR 25-93-12	PR 25-95-20				
HA2265B		PR 25-95-20		PR 25-95-20				
HA2592A		PR 25-95-20		PR 25-95-20				
HA2661B		PR 25-95-20		PR 25-95-20				

Table 4-5 *(continued)*. **Compilation of performed investigations in percussion boreholes in the Äspö tunnel.**

Borehole	Geo-physical Logging	TV-logging	Water Sampling	Pressure Build-up Tests*	Pressure Observation*	Inter-ference Tests	Flow logging spinner	Water Inject. Tests
HA2713A		PR 25-95-20	PR 25-94-21	PR 25-95-20				
HA2743A		PR 25-95-20		PR 25-95-20				
HA2743B		PR 25-95-20	PR 25-94-21	PR 25-95-20				
HA2778B		PR 25-95-20	PR 25-94-21	PR 25-95-20				
HA2780A		PR 25-95-20		PR 25-95-20				
HA3225A								
HA3225B								
HA3235A								
HA3235B								
HA3248A								
HA3248B								
HA3256A								
HA3256B								
HA3278A								
HA3278B								
HA3289A								
HA3289B								
HA3300A								
HA3300B								
HA3327A								
HA3327B								
HA3339A								
HA3339B								
HA3348A								

Table 4-5 *(continued)*. **Compilation of performed investigations in percussion boreholes in the Äspö tunnel.**

Borehole	Geo-physical Logging	TV-logging	Water Sampling	Pressure Build-up Tests*	Pressure Observation*	Inter-ference Tests	Flow logging spinner	Water Inject. Tests
HA3348B								
HA3360B								
HC0003B		PR 25-95-20		PR 25-95-20				
SM00231		PR 25-92-18A	PR 25-95-02					
SM0024B			PR 25-95-02					
SM0032A			PR 25-95-02					
SM00351		PR 25-92-18A	PR 25-95-02					
SM00352		PR 25-92-18A	PR 25-95-02					
SM00401		PR 25-92-18A	PR 25-95-02					
SM00451		PR 25-92-18A	PR 25-95-02					
SM00452		PR 25-92-18A	PR 25-95-02					
SM00456		PR 25-92-18A	PR 25-95-02					
SM00457		PR 25-92-18A	PR 25-95-02					
SM00361		PR 25-92-18A						
SM00362		PR 25-92-18A						
SM00371		PR 25-92-18A						
SM00372		PR 25-92-18A						
SM00411		PR 25-92-18A						
SM00412		PR 25-92-18A						
SM00431		PR 25-92-18A						
SM00432		PR 25-92-18A						

* If no pressure-build up test has been performed estimate of flowrate after drilling is available in most cases

Table 4-6. Compilation of performed investigations in probeholes in the Äspö tunnel.

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation	Water Sampling
SA0000A				
SA0011F				
SA0142A				
SA0158A				PR 25-95-02
SA0173A				
SA0188A				
SA0205A				PR 25-95-02
SA0221A				PR 25-95-02
SA0237B				PR 25-95-02
SA0254B				
SA0267G				
SA0267F				PR 25-95-02
SA0271B				PR 25-95-02
SA0285G				
SA0285F				PR 25-95-02
SA0289A				PR 25-95-02
SA0289B				PR 25-95-02
SA0293F				PR 25-95-02
SA0311A				PR 25-95-02
SA0311B				PR 25-95-02
SA0327A				PR 25-95-02
SA0327B				PR 25-95-02
SA0344A				PR 25-95-02
SA0344B				
SA0361A				
SA0361B				PR 25-95-02
SA0377A				PR 25-95-02
SA0377B				
SA0394B				
SA0427B				
SA0435A				PR 25-95-02
SA0452A				PR 25-95-02
SA0468A				PR 25-95-02
SA0627B				
SA0640B				
SA0686I				
SA0709A				
SA0709B				

Table 4-6 *(continued)*. **Compilation of performed investigations in probeholes in the Äspö tunnel.**

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation	Water Sampling
SA0722A				PR 25-95-02
SA0722B				PR 25-95-02
SA0776A				
SA0776B				
SA0792A				
SA0793B				
SA0813A				PR 25-95-02
SA0813B				PR 25-95-02
SA0831A				PR 25-95-02
SA0831B				PR 25-95-02
SA0850A				
SA0850B				PR 25-95-02
SA0867A				PR 25-95-02
SA0867B				PR 25-95-02
SA0905B				
SA0923A				PR 25-95-02
SA0923B				
SA0940B				PR 25-95-02
SA0941A				
SA0954F				
SA0958A				
SA0958B				PR 25-95-02
SA0976A				PR 25-95-02
SA0976B				PR 25-95-02
SA0982B				PR 25-95-02
SA0991I				PR 25-95-02
SA0992A				PR 25-95-02
SA0993B				PR 25-93-07
SA1008D				PR 25-95-02
SA1009A				
SA1009B				PR 25-95-02
SA1026A				
SA1026B				
SA1043A				
SA1043B				
SA1062B				PR 25-95-02

Table 4-6 *(continued).* **Compilation of performed investigations in probeholes in the Äspö tunnel.**

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation	Water Sampling
SA1077A				**PR 25-95-02**
SA1077B				**PR 25-93-07**
SA1086F				**PR 25-93-07**
SA1094A				**PR 25-95-02**
SA1094B				**PR 25-93-07**
SA1111A				**PR 25-93-07**
SA1111B				**PR 25-95-02**
SA1128A				
SA1128B				**PR 25-93-07**
SA1145A				
SA1145B				**PR 25-95-02**
SA1150F				
SA1163A				
SA1163B				**PR 25-95-02**
SA1179A				
SA1179B				
SA1183F				**PR 25-95-02**
SA1195A				**PR 25-93-07**
SA1195B				**PR 25-95-02**
SA1199F				**PR 25-95-02**
SA1210A				**PR 25-95-02**
SA1210B				**PR 25-93-07**
SA1229A				**PR 25-95-02**
SA1229B				**PR 25-93-07**
SA1233F				
SA1247A				**PR 25-93-07**
SA1247B				**PR 25-93-07**
SA1260F				
SA1263A				
SA1263B				
SA1298F				**PR 25-95-02**
SA1327B				**PR 25-95-02**
SA1328A				
SA1342A				
SA1342B				**PR 25-95-02**
SA1360B				
SA1377F				**PR 25-93-07**
SA1420A				**PR 25-95-02**
SA1420B				
SA1464A				
SA1464B				
SA1477F				

Table 4-6 *(continued)*. **Compilation of performed investigations in probeholes in the Äspö tunnel.**

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation	Water Sampling
SA1481A				
SA1481B				
SA1498A				
SA1498B				
SA1514A				
SA1514B				
SA1532A				
SA1532B				
SA1549A				
SA1549B				
SA1564A				
SA1564B				**PR 25-93-12**
SA1581A				**PR 25-93-12**
SA1581B				
SA1597A				
SA1597B				
SA1614A				
SA1614B				**PR 25-95-02**
SA1629A				
SA1629B				
SA1643A				
SA1643B				**PR 25-93-12**
SA1664A				
SA1664B				
SA1680A				
SA1680B		**PR 25-94-06**		**PR 25-95-02**
SA1693F				**PR 25-95-02**
SA1696A				
SA1696B				**PR 25-95-02**
SA1713A				**PR 25-95-02**
SA1713B		**PR 25-94-06**		
SA1726A				**PR 25-95-02**
SA1730A				**PR 25-95-02**
SA1731B		**PR 25-94-06**		
SA1742A				**PR 25-95-02**
SA1746A				
SA1746B				
SA1759A				
SA1759B				
SA1777A				

Table 4-6 *(continued).* **Compilation of performed investigations in probeholes in the Äspö tunnel.**

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation	Water Sampling
SA1777B				
SA1794A				
SA1794B				
SA1815A				
SA1815B				
SA1828A				
SA1828B				**PR 25-95-02**
SA1844A				
SA1844B				**PR 25-95-02**
SA1861A				**PR 25-95-02**
SA1861B		**PR 25-94-06**		
SA1877A				
SA1877B				
SA1893A				
SA1893B				
SA1909A				
SA1909B				
SA1920A				
SA1920B				
SA1938A				
SA1938B				
SA1959A				
SA1959B				
SA1975A				
SA1975B				
SA1997A				**PR 25-95-02**
SA1997B		**PR 25-94-06**		
SA2009A				
SA2009B				
SA2025A		**PR 25-94-06**		**PR 25-95-02**
SA2025B		**PR 25-94-06**		
SA2043B				
SA2058A				
SA2058B				
SA2074A		**PR 25-94-06**		**PR 25-95-02**
SA2074B		**PR 25-94-06**		**PR 25-95-02**
SA2090A				
SA2090B				
SA2109A				
SA2109B				**PR 25-95-02**
SA2130B				

Table 4-6 *(continued).* **Compilation of performed investigations in probeholes in the Äspö tunnel.**

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation	Water Sampling
SA2142A				**PR 25-95-02**
SA2142B				**PR 25-95-02**
SA2159B				
SA2160A				
SA2175A				
SA2175B				**PR 25-95-02**
SA2192A				
SA2192B				**PR 25-95-02**
SA2207A				
SA2207B				
SA2222A				
SA2222B				**PR 25-93-12**
SA2240A				
SA2240B				**PR 25-95-02**
SA2256A				
SA2256B				
SA2273A				**PR 25-95-02**
SA2273B				**PR 25-95-02**
SA2289A				
SA2289B				**PR 25-95-02**
SA2306A				
SA2306B				
SA2322A				**PR 25-95-02**
SA2322B				
SA2338A				
SA2338B				
SA2355B				**PR 25-95-02**
SA2356A				
SA2373A				
SA2373B				
SA2386A				
SA2386B				
SA2401A				
SA2403B				
SA2420A				
SA2420B				
SA2436A				
SA2436B				
SA2453A				
SA2453B				
SA2473A				

Table 4-6 *(continued*. **Compilation of performed investigations in probeholes in the Äspö tunnel.**

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation	Water Sampling
SA2473B				
SA2486A				
SA2486B				
SA2503A				
SA2503B				
SA2517B				
SA2518A				
SA2532A				
SA2532B				
SA2550A				
SA2550B				
SA2565A				
SA2565B				**PR 25-94-21**
SA2583A				**PR 25-95-02**
SA2583B				
SA2600A				**PR 25-95-02**
SA2600B				**PR 25-95-02**
SA2617A				
SA2617B				
SA2634A				
SA2634B				**PR 25-95-02**
SA2649A				**PR 25-95-02**
SA2649B				**PR 25-94-21**
SA2663B				**PR 25-95-02**
SA2664A				**PR 25-95-02**
SA2681A				**PR 25-95-02**
SA2681B				**PR 25-95-02**
SA2703A				**PR 25-95-02**
SA2703B				
SA2718A				**PR 25-95-02**
SA2718B				
SA2734A				**PR 25-94-21**
SA2734B				**PR 25-95-02**
SA2751A				**PR 25-94-21**
SA2751B				
SA2768A				**PR 25-95-02**
SA2768B				**PR 25-95-02**
SA2783A				**PR 25-95-02**
SA2783B				
SA2801A				
SA2801B				
SA2818A				

Table 4-6 *(continued).* **Compilation of performed investigations in probeholes in the Äspö tunnel.**

Borehole	Probe Drill Logging	Pressure Build-up Tests*	Pressure observation*	Water Sampling
SA2818B				
SA2834A				
SA2834B				PR 25-95-02
SA2850A				
SA2850B				
SA2865A				
SA2865B				
SA2880A				
SA2897A				PR 25-95-28
SA2912A				PR 25-95-28
SA2929A				
SA2946A				
SA2957A				
SA2978A				
SA2995A				
SA3011A				
SA3027A				
SA3045A				PR 25-95-28
SA3057A				
SA3075A				
SA3094A				
SA3108A				PR 25-95-28
SA3436B				
SA3445A				
SA3448F				
SA3454A				
SA3508F				
SA3509F				
SA3526F				
SA3546F				
SA3547F				
SA3561F				
SA3562F				
SA3572F				
SA3583F				
SA3584F				

* If no pressure-build up test has been performed estimate of flowrate after drilling is available in most cases.

Table 4-7. Compilation of performed investigations in boreholes in the Äspö tunnel for the SELECT programme.

Borehole	Core logging	Micro-biology	TV-logg.	Borehole Radar	Water Sample	Pressure Build-up Tests*	Inter-ference Tests	Spinner Meas.	UCM
KA2858A									
KA2862A									
KA3005A				PR 25-94-24					
KA3010A				PR 25-94-24					
KA3067A				PR 25-94-24					
KA3105A				PR 25-94-24					
KA3110A									
KA3385A				PR 25-94-24					
KA3068A									

Table 4-8. Compilation of performed investigations in cored boreholes in the Äspö tunnel included in the Zedex experiment.

Borehole	Core logging	Acoustic Emission	Accelera-tion	Seismics	TV-logg.	Borehole Radar	Multiple Point Bore-hole Exten-siomenter	Water Sam-ple	Permea-bility
KXZA1									
KXZA2									
KXZA3									
KXZA4									
KXZA5									
KXZA6									
KXZA7									
KA3068A							Stress mesur		
KXZB1									
KXZB2									
KXZB3									
KXZB4									
KXZB5									
KXZB6									
KXZB7									
KXZB8									
KXZC1									
KXZC2									
KXZC3									
KXZC4									
KXZC5									
KXZC6									
KXZC7									

4.5 DOCUMENTATION OF TUNNEL DATA

Documentation of tunnel and shafts was performed according to "Manual for field work in the tunnel", PR 25-91-10, by the Characterization Team at the Site Office.

The continuous mapping of the tunnel was carried out in direct connection with each new round excavated.

Overview of geological mapping, data on geohydrology, groundwater chemistry and bedrock stability and reinforcement/grouting is presented on data sheets of 150 m long sections of the tunnel. Examples are given in *Figures 4-14* to *4-16*.

A complete collection of all data sheets including tunnel and shaft documentation is presented in the following progress reports.

PR 25-92-02	(0-700 m)
PR 25-93-05, -06, -07 and -08	(700-1475 m)
PR 25-93-10, -11, -12 and -13	(1475-2265 m)
PR 25-94-19, -20, -21 and-22	(2265-2874 m)
PR 25-95-28	(2874-3600 m and shafts)

An overview of the documentation of the tunnel, niches and coreholes was also made in *PR HRL 96-19*. Parts of the documentation which is presented in *PR HRL 96-19* was presented in the previous reports but some minor corrections have been made.

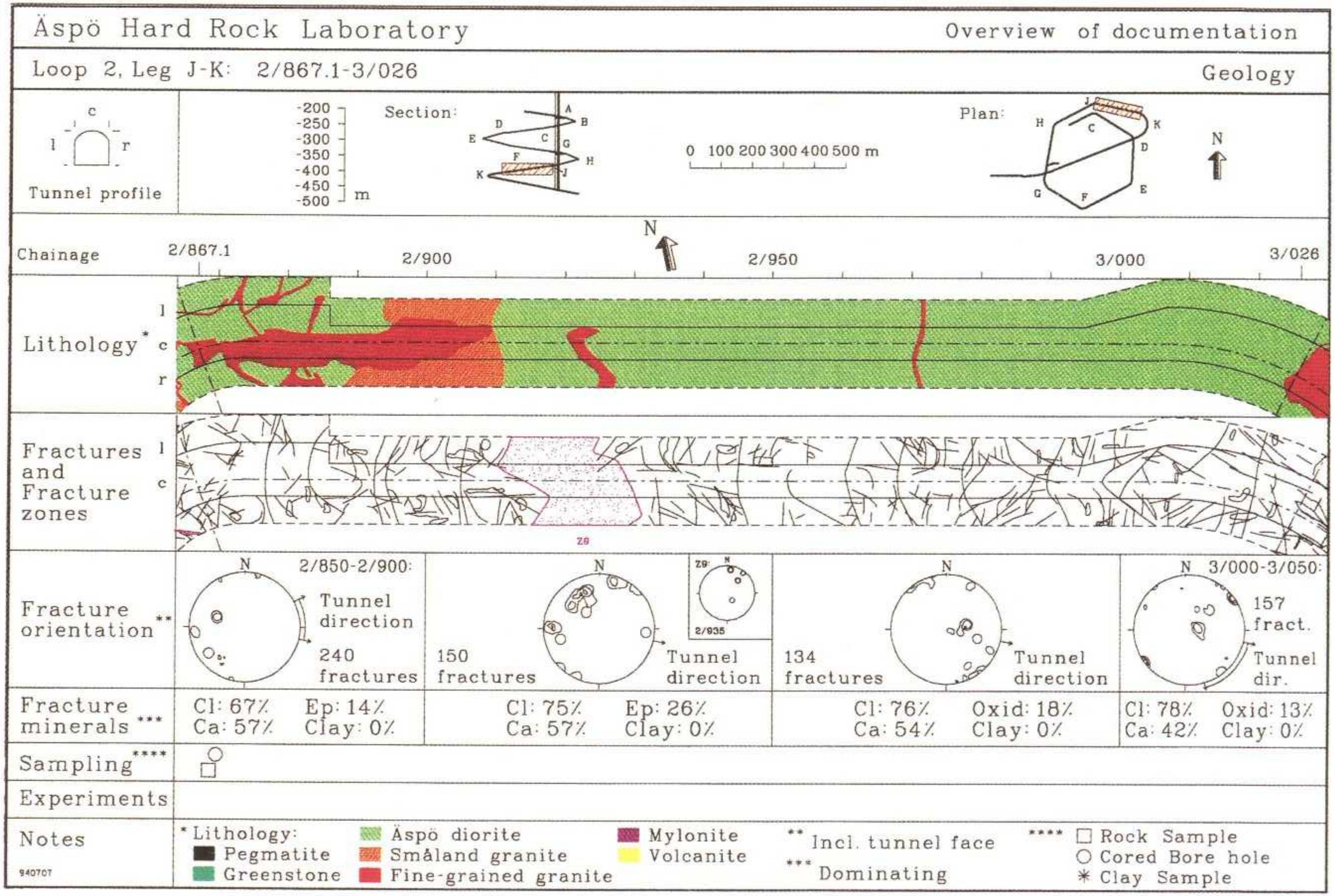


Figure 4-14. Example of documentation sheets. Geology 2867.1-3026 m.

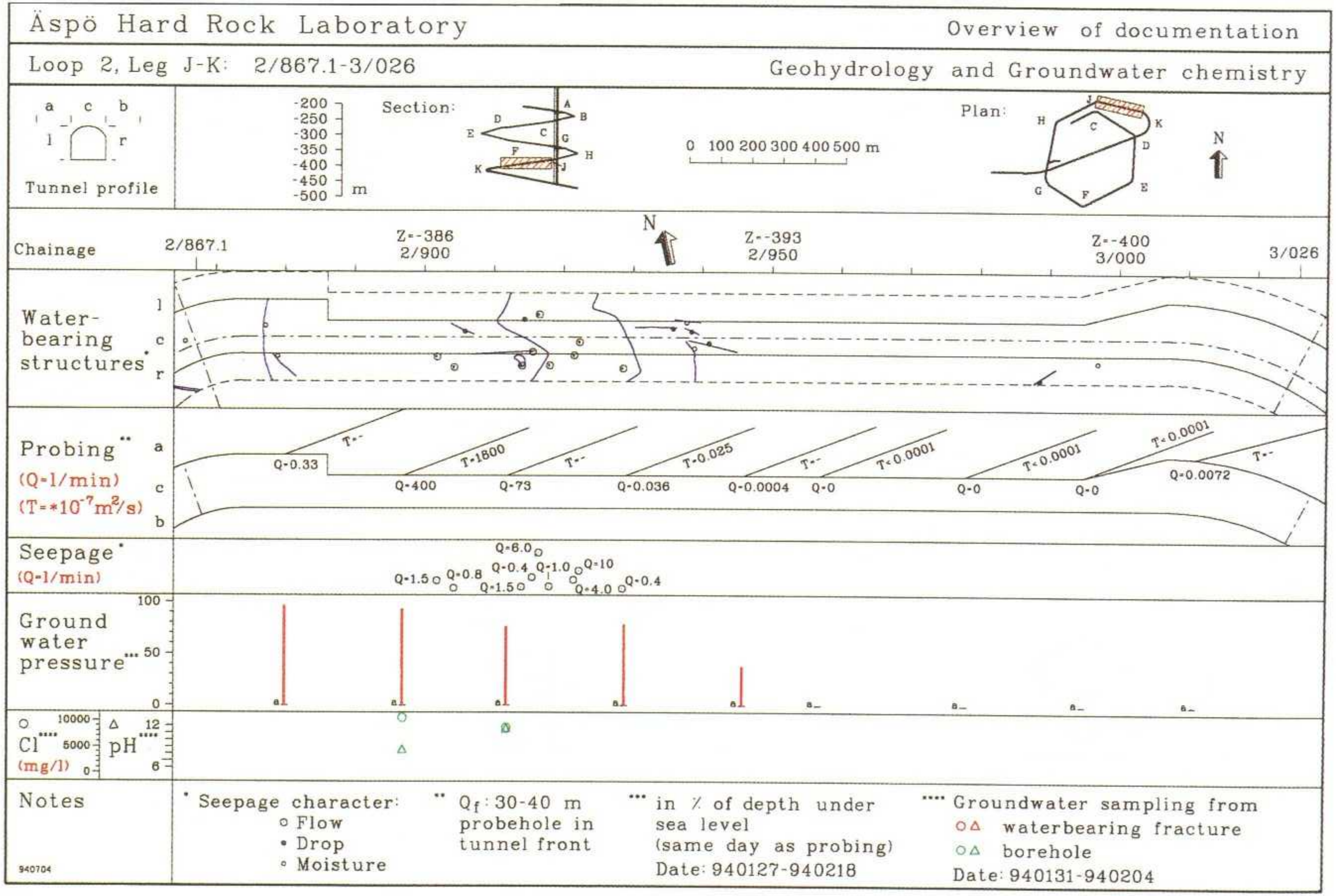


Figure 4-15. *Example of documentation sheets. Geohydrology and chemistry 2867.1-3026 m.*

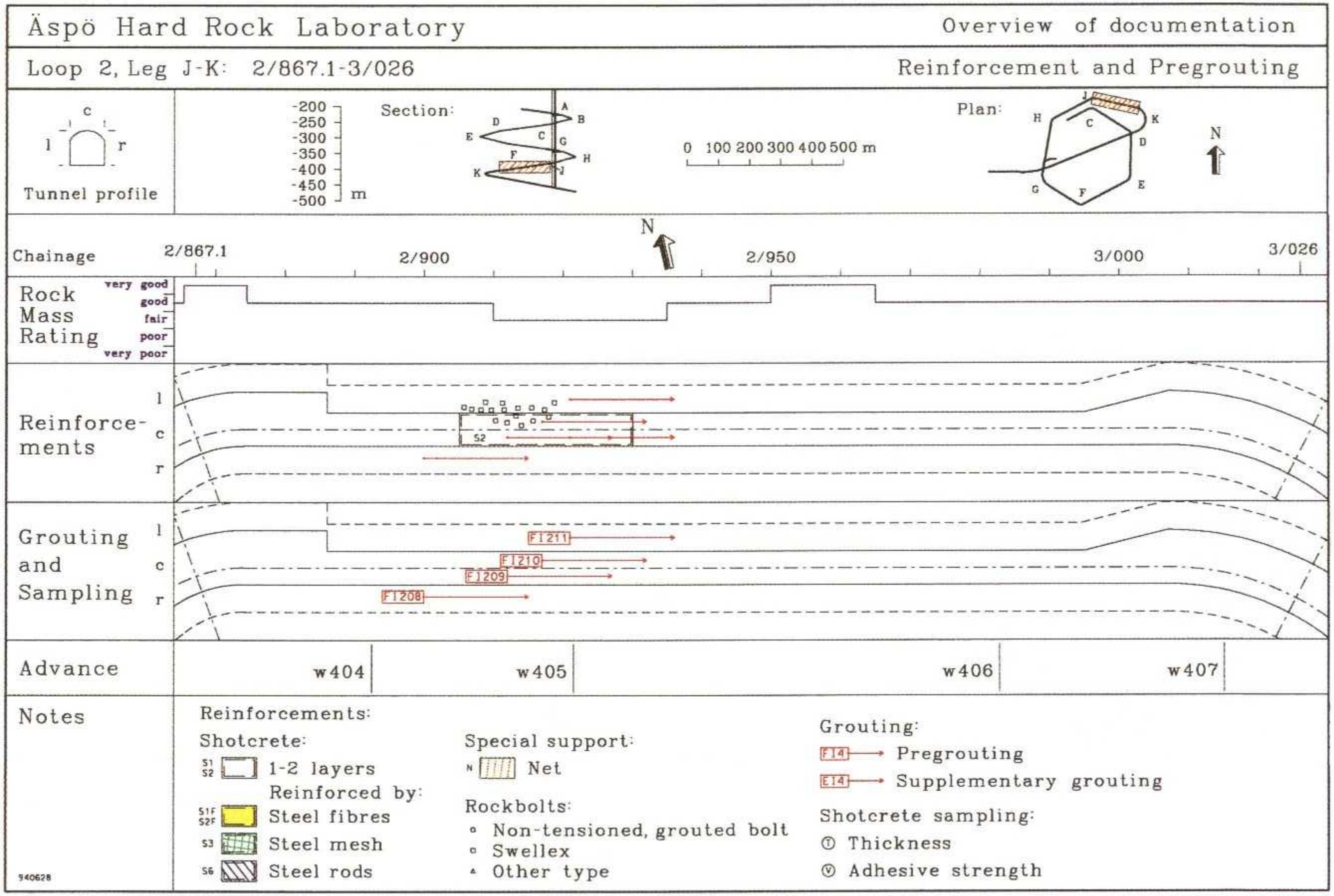


Figure 4-16. *Example of documentation sheets. Reinforcements and grouting, 2867.1-3026 m.*

5 ACKNOWLEDGEMENTS

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APPENDIX 1

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