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TECHNICAL REPORT 85-46

GRIMSEL TEST SITE

Overview and Test Programs

August 1985

GRIMSEL TEST SITE / SWITZERLAND
A JOINT RESEARCH PROGRAM BY

- NAGRA – National Cooperative for the Storage of Radioactive Waste, Baden, Switzerland
- BGR – Federal Institute for Geoscience and Natural Resources, Hannover, Federal Republic of Germany
- GSF – Research Centre for Environmental Sciences, Munich, Federal Republic of Germany

Parkstrasse 23 5401 Baden / Schweiz Telephon 056 / 20 55 11

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SYNOPSIS

Knowledge of the host rock and surrounding rock strata is of fundamental importance for concepts which provide for final disposal of radioactive waste in geological formations.

Taking the studies in the Stripa Rock Laboratory into account, the objectives of the Grimsel Test Site were defined as follows:

- Checking the applicability of foreign research results to geological conditions in Switzerland
- Carrying out specific experiments which are necessary in the context of the Nagra disposal concepts
- Acquisition of know-how in planning, implementation and interpretation of underground tests in different experimental areas
- Acquisition of practical experience in development, testing and use of experimental apparatus and measurement methods.

At Grimsel, experiments are to be carried out in the following fields:

- Excavation tests
- Rock stress measurements
- Geophysics
- Hydrogeology
- Migration
- Neo-tectonics
- Heat-induced processes
- Laboratory experiments

Various tests are already under way.

The Grimsel Test Site was established between April 1983 and May 1984. It lies at a depth of 450 m under the Juchlistock and is reached by an access tunnel.

The Test Site is operated by Nagra. The experiments are carried out by Nagra and the following two German research establishments: the "Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)" and the "Gesellschaft für Strahlen- und Umweltforschung (GSF)", both under the auspices of the German "Bundesministerium für Forschung und Technologie (BMFT)".

The responsibility for the project Grimsel Test Site lies with the Engineering Division of Nagra, headed by A.L. Nold. The project leader is R.W. Lieb who also compiled the present report. The descriptions of the various investigation programs and the chapter on geology-hydrogeology in this report are based on detailed documentation provided by the principal investigators in each field.

RESUME

La connaissance de la roche d'accueil et des couches rocheuses avoisinantes est d'importance fondamentale pour l'étude de concepts de stockage final de déchets radioactifs dans des formations géologiques.

Tenant compte des travaux réalisés dans le laboratoire souterrain de Stripa (Suède), les objectifs pour le laboratoire souterrain du Grimsel ont été définis comme suit:

- Vérification de la possibilité de transposer des résultats de recherches faites à l'étranger aux conditions géologiques suisses
- Exécution de recherches spécifiques requises par les concepts de stockage de la Cédra
- Constitution d'un savoir faire dans la planification, la réalisation et l'interprétation d'essais souterrains dans divers domaines de techniques expérimentales
- Acquisition d'expérience pratique dans le développement, la mise au point et la mise en oeuvre de dispositifs d'essais et de techniques de mesures.

Des investigations dans les domaines suivant devront être réalisées au Grimsel:

- zones de perturbations
- contraintes dans les roches
- géophysique
- phénomènes induits par la chaleur
- migration
- néotectonique
- hydrogéologie
- essais en laboratoire

Diverses investigations ont déjà été entreprises.

Le laboratoire souterrain du Grimsel a été construit d'avril 1983 à mai 1984. Il se situe à 450 m de profondeur sous le Juchlistock et on y accède par une galerie.

Le laboratoire est exploité par la Cédra. Les investigations sont réalisées par la Cédra et les sociétés allemandes suivantes: "Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)" et "Gesellschaft für Strahlen- und Umweltforschung (GSF)", ces deux dernières pour le compte du "Bundesministerium für Forschung und Technologie (BMFT)".

C'est la divison génie civil de la Cédra, dirigée par A.L. Nold, qui est responsable des investigations au laboratoire souterrain du Grimsel. Le chef de projet est R.W. Lieb qui est aussi le redacteur du présent rapport. La description des domaines d'investigations ainsi que le chapitre géologie-hydrogéologie de ce rapport, sont basés sur des documents détaillés établis par les responsables des divers essais.

UEBERBLICK

Bei Konzepten, die die Endlagerung radioaktiver Abfälle in geologischen Formationen vorsehen, ist die Kenntnis des Wirtgesteins und der angrenzenden Gesteinsschichten von grundlegender Bedeutung.

Unter Berücksichtigung der Arbeiten im Felslabor Stripa (Schweden) wurde die Zielsetzung für das Felslabor Grimsel wie folgt definiert:

- Nachprüfung der Uebertragbarkeit von ausländischen Forschungsergebnissen auf die geologischen Verhältnisse der Schweiz

- Durchführung spezifischer Untersuchungen, die sich aufgrund der Nagra-Lagerkonzepte aufdrängen

- Aufbau von Know-how in der Planung, Ausführung und Interpretation von Untergrundversuchen in verschiedenen Experimentierbereichen

- Erwerb praktischer Erfahrung in der Entwicklung, Erprobung und dem Einsatz von Testapparaturen und Messverfahren.

Auf der Grimsel sollen Untersuchungen auf nachstehenden Gebieten durchgeführt werden:

- Auflockerungszone
- Gebirgsspannungen
- Geophysik
- Hydrogeologie
- Migration
- Neotektonik
- Wärmeinduzierte Vorgänge
- Laborexperimente

Verschiedene Untersuchungen sind bereits angelaufen.

Das Felslabor Grimsel wurde in der Zeit vom April 1983 bis Mai 1984 gebaut. Es liegt in 450 m Tiefe unter dem Juchlistock und wird durch einen Zugangsstollen erschlossen.

Betrieben wird es durch die Nagra. Untersuchungen werden durch die Nagra, die Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) und die Gesellschaft für Strahlen- und Umweltforschung (GSF) durchgeführt, beide gefördert vom Deutschen Bundesministerium für Forschung und Technologie (BMFT).

Das Untersuchungsvorhaben Felslabor Grimsel ist dem Bereich Bautechnik der Nagra, Bereichsleiter A.L. Nold, zugeordnet. Projektleiter ist R.W. Lieb, der auch die Redaktion des vorliegenden Berichtes besorgte. Die Beschreibung der Untersuchungsvorhaben sowie das Kapitel Geologie-Hydrogeologie im vorliegenden Bericht basiert auf ausführlichen Unterlagen der verantwortlichen Versuchsleiter.

Dieser Bericht ist auch auf Deutsch erhältlich (NTB 85-47).

Grimsel area, view to the west

Centre: Juchlistock, Test Site, Lake Räterichs-
boden

Left: Hydropower Station Grimsel II East,
Lake Grimsel

SUMMARY AND CONCLUSIONS

Knowledge of the host rock and surrounding rock strata is of fundamental importance for concepts which provide for final disposal of radioactive waste in geological formations.

Of special importance is the knowledge of the geometry of the host rock, the existing and expected hydrogeological conditions and the reactions which influence the transport of nuclides in the groundwater.

Taking the studies in the Stripa Rock Laboratory into account, the objectives of the Grimsel Test Site were defined as follows:

- Checking the applicability of foreign research results to geological conditions in Switzerland
- Carrying out specific experiments which are necessary in the context of the Nagra disposal concepts
- Acquisition of know-how in planning, execution and interpretation of underground tests in different experimental areas
- Acquisition of practical experience in development, testing and use of experimental apparatus and methods of measurement.

It was decided to carry out investigations at the Grimsel in the following scientific fields (in alphabetical order):

Excavation effects: Testing the rock mass surrounding man-made openings in crystalline rock, in order to assess the influence of these cavities on the hydrogeological conditions.

Geophysics: Testing and further development of non-destructive methods for locating hydrogeologically important rock discontinuities and weaknesses with respect to rock mechanics from exploratory boreholes and underground openings, in close ranges of up to approx. 50m as well as in the far field.

Heat induced reactions: Investigations which lead to an understanding of heat induced reactions in fractured crystalline rocks.

Hydrogeology: The acquisition of additional hydrogeological fundamental knowledge necessary for developing a general hydrogeological model, adaptable to specific field situations, in fractured crystalline rock of low permeability.

Laboratory experiments: Supplementation of the in situ tests by laboratory experiments and the development of mathematical models.

Migration: The acquisition of additional chemical and physical fundamental knowledge necessary for understanding the transport of nuclides in the fractures of crystalline rock.

Neotectonics: Testing and further development of methods for locating neotectonically active disturbance zones.

Rock stress measurements: Testing and further development of methods proven only in shallow boreholes for determining the rock stresses in deep boreholes.

Based on the above, the following investigation programs were defined for the Grimsel Test Site (for layout, see Fig. 1):

EM Electromagnetic high frequency (HF) measurements

US Underground seismic testing

TM Tiltmeters

ND Locating active neotectonic disturbance zones

FF Fracture system flow test

VE Ventilation test

HP Hydraulic potential

MI Migration

EX Excavation effects around underground openings

RS Rock stress measurements

CO Convection

HT Heat test

LT Laboratory tests

The Grimsel Test Site was built between April, 1983 and May, 1984. It lies at a depth of 450 m under the Juchlistock and is reached after a passage of 1,3 km through the slightly rising access tunnel to the hydropower station Grimsel II of the Oberhasli Power Station Company (KWO). The Grimsel Test Site consists of about 900 m' of tunnels, 3.50 m diameter, and some caverns. The entire infrastructure, required for permanent operation all year round, is also below ground.

The in situ work for the excavation test (phase I) and rock stress tests is almost completed. Six further investigation programs have already been planned in detail and the appropriate preparation and installation work is well advanced. Till now, over 3000 m' of borings have been made, mainly with continuous core extraction. The basic geological surveys are completed.

The Test Site is operated by Nagra. The investigation programs are carried out by Nagra and the following two German research establishments: The Federal Institute for Geoscience and Natural Resources (BGR) and the Research Centre for Environmental Sciences (GSF), both under the auspices of the German Federal Ministry for Research and Technology (BMFT).

Experiences and conclusions to date can be summarized as follows:

- The selected test site has proved to be ideal. Within short distances, areas of very low water permeability as well as relatively strong water-conducting disturbance zones have been found.

- With the exception of a few slight modifications, the investigations can be carried out at the locations envisaged in the original project.

- As a result of the safety analyses for the "Project Gewähr" in 1985, the correctness and high importance of the planned investigation programs could be confirmed.

- The constructional and operational concepts chosen, especially the layout of the central facilities, have proved to be practical and appropriate to the prevailing conditions.

- No rock mechanical difficulties were encountered during construction of the Test Site.

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1. INTRODUCTION

1.1 The Grimsel Test Site

The concept developed by Nagra provides for the disposal of radioactive waste in stable rock formation of the highest possible density.

As part of its investigation program for the preparation of the storage of radioactive waste in Switzerland, Nagra is participating in the international research project Stripa, Sweden.

Although many results of the Stripa experiments are not specific to any particular location, but rather furnish fundamental general data which contribute to the understanding of the transportation of nuclides in fractured crystalline rock and of the effectiveness of man-made barriers, Nagra considers it desirable to check the results of the Swedish research with regard to the Swiss geological conditions using its own field tests, and to gather experience.

In attempting to find the best possible solution, Nagra has evaluated potential test sites in granitic formations of the Aar Massif, in an area with existing and accessible power station tunnels and caverns. In autumn 1980, six horizontal exploratory borings were made, each 100 m long, in the Gerstenegg access tunnel to the hydropower station Grimsel II. The results of these investigations which were supplemented by petrographic, rockmechanical, hydrogeological and geophysical measurements, showed that the mountain range to the west of the access tunnel would be suitable as the location for a test site to be constructed approx. 500 m under the Juchligrat (NTB 81-07).

Based on this knowledge, planning of the various investigation programs was started and in December 1981 a draft of a possible test site layout was submitted to the Swiss Authorities together with a request for an appropriate building and operating permit.

This was granted on 29th November, 1982 for a period of ten years, with a proviso forbidding tests with radioactive waste, as well as the intermediate or final storage of radioactive waste.

After completion of substantial preparatory work on the site, tunneling work began on 30th May, 1983. It took six months. The subsequent finishing work lasted till spring 1984.

On 20th June, 1984, the Grimsel Test Site (GTS) was officially opened.

At this time, various investigation programs were already under way or being started.

Fig. 1 shows the layout of the Test Site and the main geological features.

1.2 Aim and Scope of this Report

This report describes the aim and scope of the investigations planned at the GTS, as well as the work carried out till the end of June, 1985. An outlook on activities planned for the coming years is also given.

Chapter 1 introduces the GTS project, outlines the importance of in situ investigations, lists the existing in situ laboratories and describes the connections which Nagra has to the Stripa Rock Laboratory and to the Underground Research Laboratory in Canada. The connections to BGR/GSF and BMFT are also explained.

The Basic Program, chapter 2, outlines the objectives of the GTS and gives a synopsis of the individual investigation concepts which are then described in detail in chapter 5.

Chapter 3 gives the criteria and procedures for selection of the site.

Chapter 4 provides information about the conceptional design and the project organisation during construction and operation of the GTS. Chapter 6 describes the work already carried out and gives an indication of the work planned for 1986/87.

In chapter 7, which concludes this report, the results of the geological and hydrogeological surveys and investigations are summarized.

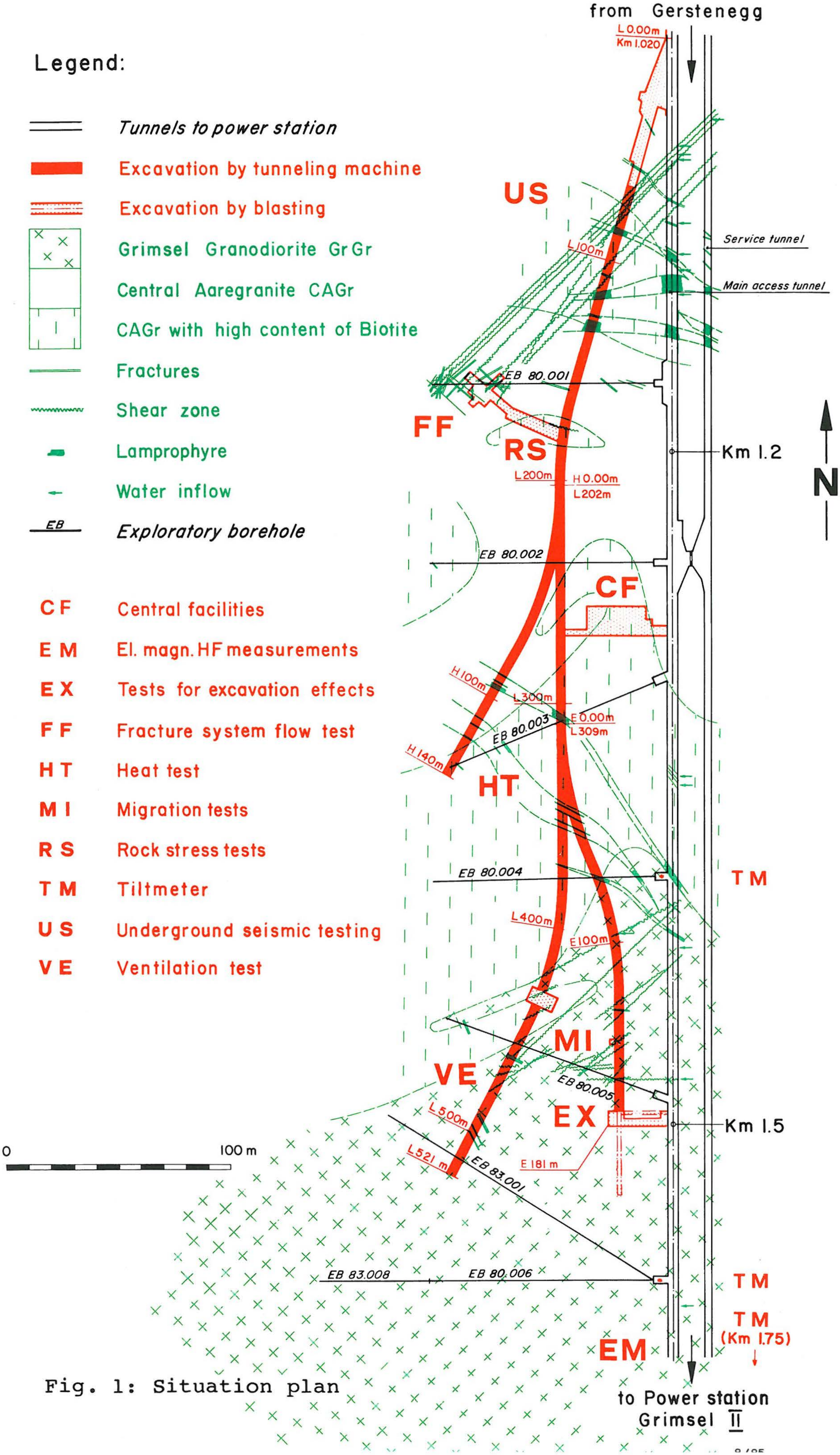

Fig. 1: Situation plan

1.3 The Importance of in situ Investigations

In designing a final repository for radioactive waste it is of greatest importance to have well-founded knowledge of the extent of the host rock and the layout-determining disturbance zones contained therein, i.e. the geometry of the available host rock body. In addition, the rock-mechanical characteristics of the host rock must be established beyond doubt.

Decisive for the safety analyses is not only the behaviour of the man-made barriers, such as steel containers, backfill or buffer material, etc. but also a knowledge of the existing and expected hydrogeological conditions both in the vicinity of the final repository and in the far field.

In addition to investigating the existing condition, influences such as temperature and sorption on the transport of water and nuclides must be clarified on a large scale basis.

Although many investigations have already been made, the results must continue to be checked and some of the necessary measuring instruments and methods suitably modified. Also, the specific experience required for the conception of such investigations must be acquired and extended.

1.4 Foreign Test Sites

1.4.1 Overview

The Stripa Rock Laboratory in Sweden and the Underground Research Laboratory (URL) in Canada are of special interest to Nagra. They are described in the next two sections.

Also worthy of mention are the following in situ laboratories:

- Colorado School of Mines test site (USA), in crystalline
- Nevada Nuclear Waste Storage Investigations in the Climax Plant (USA), in crystalline
- Basalt Waste Isolation Project (USA), in basalt
- Clay Laboratory of CEN/SCK in Mol, Belgium, in the Boom Clay layer
- Clay Laboratory of Pasquasia, Sicily, Italy (planned)
- Experiments in salt in the Asse mine and in the iron ore deposit of the Konrad mine in Germany
- Various Laboratories in the USA, in salt.

1.4.2 Stripa Rock Laboratory

The Stripa iron ore mine, which has been in operation in various phases since 1485, was taken over by the Swedish Nuclear Fuel and Waste Management Company (SKB) when the ore mining was stopped in 1976. The mine is about 150 km west of Stockholm. The test plant lies approx. 340 m below the surface, in fractured granite. Four main fracture directions can be distinguished. The test area lies below water level, and the surrounding rock area is saturated with water.

From 1977 to 1980, the Lawrence Berkeley Laboratory (LBL) and the Swedish Nuclear Fuel Safety Program (KBS) carried out thermo-mechanical and hydrogeological tests. The subsequent research program of the Stripa I Project was carried out on the basis of these tests by a group of five nations (Sweden, USA, Finland, Japan and Switzerland) from 1980 to 1983.

The Stripa I program involved:

- geochemical and geophysical experiments
- two-dimensional migration investigations
- experiments on backfill material with a bentonite base (buffer mass test)

For the Stripa II Project, which was started in 1983 and is planned to continue till 1986, the cooperation was extended to a total of nine member nations through the participation of England, France, Canada and Spain.

The Stripa II project comprises:

- geophysical experiments for locating disturbance zones
- three-dimensional migration investigations
- the sealing of boreholes, tunnels and shafts

Both, Stripa I and Stripa II, have been and are being executed as autonomous projects under the sponsorship of the OECD's (Organisation for Economic Co-operation and Development) Nuclear Energy Agency (NEA). Both projects are managed by SKB.

Planning is now in progress for a continuation of the joint research work (Project Stripa III, 1986 to 1990).

Switzerland is represented in the Stripa projects by Nagra, both in the steering committee and in the technical expert groups.

Nagra's investigation program in general and the work at the Grimsel Test Site in particular, are based on and are complementary to the previous and the current work in Stripa.

1.4.3 Underground Research Laboratory (Canada)

The Underground Research Laboratory (URL) in South-East Manitoba, Canada, is being built by the White-shell Nuclear Research Establishment of the Atomic Energy of Canada Ltd. (AECL), Pinawa, Manitoba as part of the Canadian program for the disposal of radioactive waste. Drilling work began in 1981, the rectangular access shaft (2.8 m by 4.9 m) and a ventilation raise were excavated by smooth blasting in the granite during 1984. The operating phase will start in 1986 and will continue until 1999. A system of tunnels, ultimately some 850 m long, will be constructed in the granitic rock at the testing level 240 m below the surface, i.e. at 50 m AMSL.

The URL is of special importance for Switzerland because the points of emphasis of the investigation program largely coincide with those of the Nagra program. For example, URL also places great importance on the excavation effects around man-made openings in the rock mass and on hydrogeological investigations. Nagra maintains good relationship to the AECL and a close exchange of experience has been introduced between the two test sites URL and Grimsel.

1.5 Cooperation with BGR and GSF

Since 1965, methods and technologies for the safe final disposal of radioactive wastes have been developed and tested at the disused salt mine of ASSE II near Wolfenbüttel. From 1975 to 1982, investigations were carried out to assess the suitability of the disused iron ore mine Konrad near Salzgitter-Lebenstedt as a final repository for non-heatgenerating radioactive waste from operation and shut down of nuclear power plants. Since then, further tests are being carried out at Konrad, such as a ventilation test for example, as a purely experimental program for the disposal of radioactive waste in hard rock formations. On 22nd February, 1977, the Lower Saxony State Government chose the Gorleben salt dome as the provisional site for a Federal final repository for all categories of radioactive waste. Suitability tests have been carried out there since 1979.

In Germany, experience and knowledge have been built up over the last years with respect to specific investigations concerning a final repository for radioactive waste in deep geological formations and mining caverns. Discussions which took place during the planning stage of the Grimsel Test Site, showed that the German Federal Ministry for Research and Technology (BMFT) was interested to validate in crystalline rock the knowledge gained from other types of rock, and to achieve specific experience with granite as a host rock.

Responsible for the investigations at Asse, Konrad and Gorleben are the Federal Institute for Geoscience and Natural Resources, Hannover (BGR) and the Research Centre for Environmental Sciences, in Munich (GSF) through its Institute for "Tieflagerung" in Braunschweig. Thus, a contract was signed between Nagra on the one hand, and BGR and GSF on the other hand, according to which BGR and GSF will carry out three tests each in the Grimsel Test Site. Nagra is responsible for the construction work, all borings, the infrastructure and the operation of the entire Test Site. Furthermore Nagra provides the management of the whole project and executes six tests. The contract also includes an exchange scheme for personnel training.

The three tests to be carried out by BGR are: Electromagnetic high frequency measurements, fracture system flow tests and rock stress measurements. The tiltmeter measurements, ventilation test and heat test will be carried out by GSF.

1.6 Literature

The relevant literature for the Grimsel Test Site is very comprehensive and multi-layered. Therefore, no references to literature have been made in the text. The bibliography annexed to this report makes no claim to completeness. It is intended rather to give the interested reader some selected indications to simplify the entry to an in-depth study of certain fields of expertise.

2. BASIC PROGRAM

2.1 Significance of the Basic Program

The Grimsel Test Site (GTS) is an important element of the Nagra investigation program. Its planning is based for the present on a 5-year program extending till 1988. Since in investigation programs of this type and duration new aspects always arise, and there is a natural tendency to attach the greatest importance to the last known statement of a problem and thus often allot to it an unjustifiably high priority, a binding Basic Program for the Grimsel Test Site was laid down in 1981.

This program, the essentials of which are summarized below, fixes the strategic aim of the Test Site and defines the targets, both generally for the whole project and individually for each specialized field. It also lists the separate investigation programs and describes the basic concept of each test. The Basic Program is the basis for integrating the Grimsel Test Site Project into the overall concept of Nagra, for cooperation with the German partners, and for the financial planning. It permits a clear concept to be maintained when drawing up the detailed programs, and provides oversight and control of the targets and priorities of the individual investigation programs.

The Basic Program will be examined periodically and, if necessary, appropriately adapted through decisions of the Steering Committee (section 4.5.1).

2.2 General Targets

The Grimsel area is not a site which is being considered as a final repository. Also, no tests with radioactive wastes are envisaged on the Grimsel.

The Grimsel Test Site lies in a mountain complex which is relatively easily accessible and which belongs to the same crystalline bedrock formation as the crystalline in Northern Switzerland which lies at a depth (500 m - 1500 m) suitable for a final repository.

With the Test Site on the Grimsel, Nagra aims

- to build up the know-how for a rational, well-defined and informative investigation program at the future final repository site; and
- to validate certain components of a final repository system under conditions which as closely as possible correspond to those of a final repository.

The know-how is defined as the knowledge and experience which are necessary

- to judge which in situ investigations are possible, necessary and sufficient to provide the parameters finally required for proof of safety, and then
- to carry out and evaluate these investigations reliably and efficiently.

The general targets of the FLG are therefore:

- **Checking the applicability of foreign research results to the geological conditions in Switzerland, and**
- **carrying out specific experiments which derive from the Nagra repository concept, and**
- **building up know-how in the planning, execution and interpretation of underground tests in various experimental fields, and**
- **acquiring practical experience in the development, testing and use of test apparatus and measuring methodology.**

2.3 Objectives for Individual Scientific Investigations

The basic goals for the individual scientific investigations formulated about three years ago with the aid of several advisers of Nagra, are still valid in June, 1985.

Excavation effects: Testing the rock mass surrounding man-made openings in crystalline rock, in order to assess the influence of these cavities on the hydrogeological conditions.

Geophysics: Testing and further development of non-destructive methods for locating hydrogeologically important rock discontinuities and weaknesses with respect to rock mechanics from exploratory boreholes and underground openings, in close ranges of up to approx. 50m as well as in the far field.

Heat induced reactions: Investigations which lead to an understanding of heat induced reactions in fractured crystalline rocks.

Hydrogeology: The acquisition of additional hydrogeological fundamental knowledge necessary for developing a general hydrogeological model, adaptable to specific field situations, in fractured crystalline rock of low permeability.

Laboratory experiments: Supplementation of the in situ tests by laboratory experiments and the development of mathematical models.

Migration: The acquisition of additional chemical and physical fundamental knowledge necessary for understanding the transport of nuclides in the fractures of crystalline rock.

Neotectonics: Testing and further development of methods for locating neotectonically active disturbance zones.

Rock stress measurements: Testing and further development of methods proven only in shallow boreholes for determining the rock stresses in deep boreholes.

2.4 Priorities

The chronological and scientific priorities of the tests at the Test Site are based on

- the present status of the know-how,
- the progress made in other investigation programs (e.g. Stripa, URL),
- the safety concept of Nagra,
- the investigation program for the B-repository (from 1985),
- the choice of site for a C-repository (from approx. 1988), and
- the laboratory programme at the final repository site C (in the 90's).

The **safety concept** for the final storage of radioactive waste on the one hand, demands the entry into the computation models of certain data which can only be obtained from field tests; on the other hand, it must also be possible to verify by in situ measurement at least some of the results obtained by modelling. To both ends, information from the Grimsel Test Site is valuable for the first phase, i.e. computation with a model data set. Such information from the GTS will, however, also prove that the corresponding data can be obtained and verified at a final repository site.

For Nagra's three potential **B-repository sites**, the exploratory work is scheduled to commence in 1986. Of special importance will be: obtaining the best possible information about the rock, using the least number of tunnels and borings, reliable comprehension of the hydaulic potential, and a detailed knowledge of the excavation effects in the vicinity of the access tunnel. The application of technology tested in the GTS, especially in the fields of geophysics and hydrogeology, will be very valuable for these investigations. In addition to the findings which influence the choice of site, data necessary for the design of the structures and installations will also be obtained.

The choice of site for a **C-repository** will be based on the results of the deep boring program in Northern Switzerland and a subsequent investigation phase. Here, the geophysical methods, further developed at the Grimsel Test Site, will be applied from boreholes, in order to obtain information about the rock volume between the borings. The methods of measuring rock stress in deep boreholes, tested in the GTS, will provide information about the local stress field in the final repository formation.

A carefully conceived **investigation program** carried out at each potential final repository site will be the basis for the detailed planning of the installation and the final safety analyses. Technology, the strength of the information which can be derived, and the reliability of the individual investigations must first be tested, proven and evaluated at the Grimsel Test Site.

These considerations point to a high chronological and scientific priority for geophysics (non-destructive exploration) and hydrogeology, and for the project program to investigate the excavation effects.

2.5 Short Summary

The Basic Program comprises the following individual investigations:

EM* Electromagnetic high frequency (HF) measurements

US* Underground seismic testing

TM* Tiltmeters

ND Locating active neotectonic disturbance zones

FF* Fracture system flow test

VE* Ventilation test

HP Hydraulic potential

MI Migration

EX* Excavation effects around underground openings

RS* Rock stress measurements

CO Convection

HT Heat test

LT Laboratory tests

The tests marked with an asterisk (*) have already been planned in detail and are in the execution phase. They are described in detail in chapter 5. Figure 2 shows their locations in the perspective diagram.

In the following sections, the basic concepts of the above 13 investigations are briefly described.

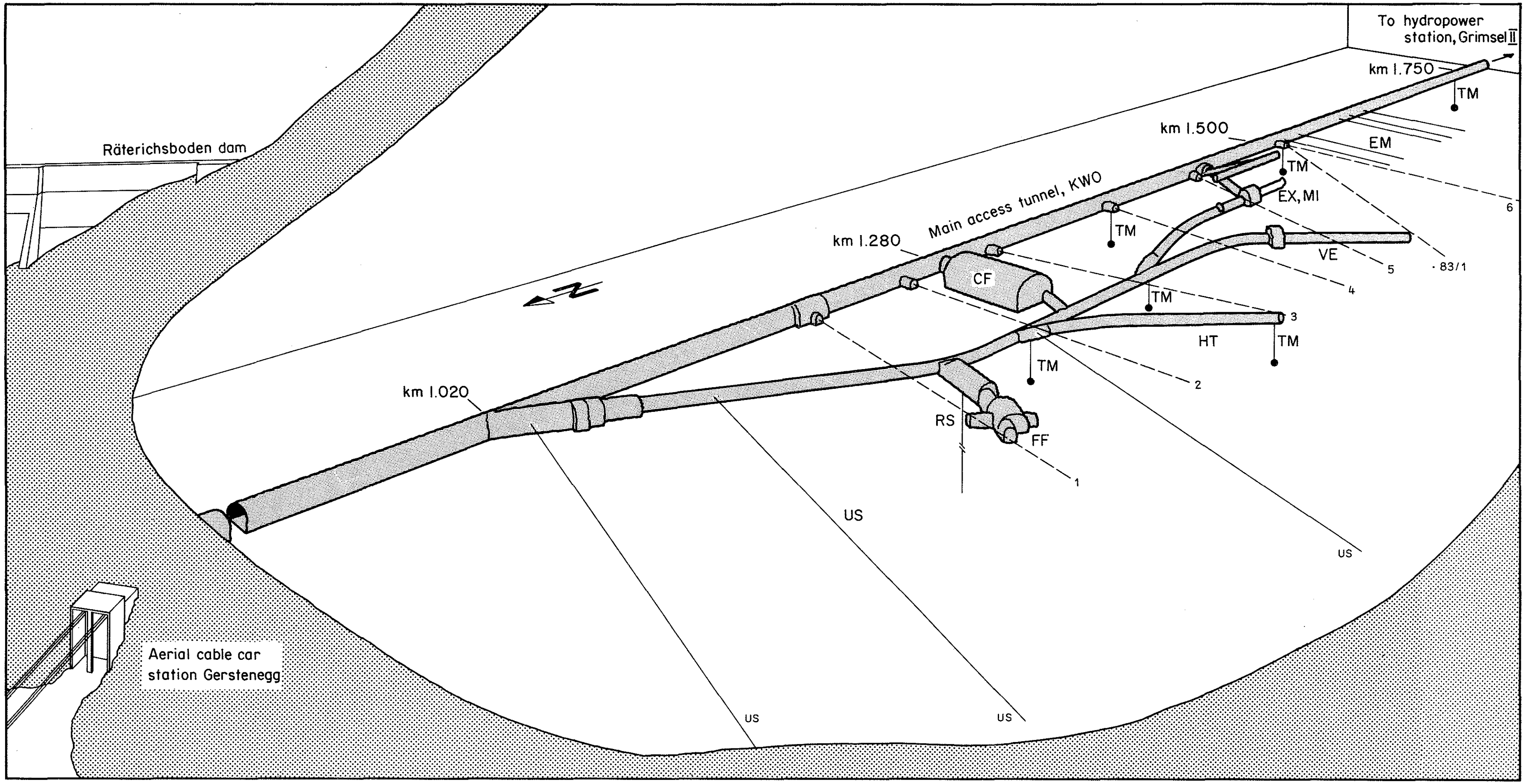

Fig. 2: Perspective diagram of Grimsel Test Site, showing location of tests

LEGEND

CF Central facilities
EM El. magn. HF measurements
EX Tests for excavation effects
FF Fracture system flow test
HT Heat test
MI Migration tests
RS Rock stress tests
TM Tiltmeter
US Underground seismic testing
VE Ventilation test
-- Exploratory boreholes

2.5.1 Electromagnetic High Frequency Measurements (EM)

2.5.1.1 Aims and objectives

These measurements are used for the non-destructive investigation of the rock from individual boreholes and tunnels. The objectives of the tests on the Grimsel are to determine the possibilities and limits of the methods known today, and to develop these methods further. Also, a check will be made as to which parameters are not dependent on the rock, in order to obtain essential indications on the suitability of these methods for investigating other host rocks. Typically, the factors affecting the relationship between resolution and measuring frequency will be investigated.

2.5.1.2 State of the Art

As a result of several foreign research projects, the equipment was developed, built and improved upon till it was ready for carrying out

- absorption measurements in areas, shafts, dry boreholes up to 300 m long in any direction, boreholes up to 300 m long filled with any kind of drilling fluid, and boreholes 3000 m deep (450 bar) filled with drilling oil
- reflection measurements in mining drifts and shafts, dry boreholes up to 100 m long and boreholes up to 3000 m deep filled with drilling oil.

The absorption method has been used till now in salt, sediment and crystalline rock, the reflection method additionally in permafrost areas.

2.5.1.3 Test concept

The emphasis of these tests which were carried out by BGR at the Grimsel Test Site, lies in the development and perfection of the transmitters and the antennae. In an extensive test program with EM measurements at Stripa, the emphasis lies mainly on recording and evaluation of the greatest possible numbers of signals, using modern computer techniques. Nagra is aiming to optimise the development by combining these two lines of development.

For the EM measurements at the GTS, the boreholes of different tests will be used at times when they are not required for the particular test. In addition, four calibration boreholes, each 50 m long, will be reserved for calibrating the further developed transmitters and antennae.

2.5.2 Underground Seismic Testing (US)

2.5.2.1 Aims and objectives

The underground seismic testing and the electromagnetic HF measurements complement each other for the nondestructive investigation of the rock. For the selection of the site for a C-repository, emphasis is placed on the most wide-ranging investigation possible from a single borehole, whereas for the close-range investigation of a definite repository location (type B or type C), the detailed scanning of a rock body between boreholes is of greatest importance.

The basic objectives of the underground seismic tests are thus similar to those of the EM (see above). By knowing the parameters which determine the Seismic Crosshole Tomographic (SCT) measurements and their interdependencies, it should be possible to develop the SCT into a routine method for exploring sites.

2.5.2.2 State of the Art

Underground seismic testing has been used till now on a large scale mainly in coal mines. The so-called "seam wave seismic" is based on the observation of channel waves (Stoneley waves) in the coal seam which, because of its low seismic impedance, represents a seismic "wave carrier". However, this technique cannot be used for final repository investigations. Discontinuities in the host rock can be located and characterized by means of seismic reflection - or transmission - measurements, provided they have a sufficiently large acoustic contrast with respect to their environment. For this, there is no technology available today which has been tested on a large scale and over a long period of time, though in the last two years the development of the STC, described in detail in section 5.3, has made rapid progress. It seems to be very promising for the detailed investigation of a potential final repository site.

2.5.2.3 Test concept

In the northern starting tunnel, three boreholes will be made in the WNW direction, each 150 m long, spaced at distances of 75 m and 150 m apart. Using a "sparker" chain, seismic signals will be produced in each borehole, which will be registered in a second borehole and in the tunnel. The structure of the inhomogeneites in the rock will then be calculated mathematically from the large sets of data obtained, using the so called inversion method.

2.5.3 Tiltmeters (TM)

2.5.3.1 Aims and objectives

For both B and C type repositorities, it is important to prove that the host rock body will not be disturbed by neotectonic movements. Such disturbances would make themselves manifest through displacements of certain rock masses against each other. Such movements despite their extremely slow progress in human terms, can be detected by very high-sensitive instruments.

The investigation program TM on the Grimsel is intended to show that tiltmeters can be used to detect even the slightest displacements, and that disturbance effects such as, for example, changes in the water level of the power station reservoirs and meteorological influences, can be reliably filtered out of the measured data.

2.5.3.2 State of the Art

Since the introduction of the Askania vertical tiltmeter in 1966, these instruments have proved to be of great value as high-precision instruments for measuring tilt. Because of their extremely high resolution of 1/10'000 angular seconds, they can be used to measure regional and local tilts which cannot be measured by other methods. These tiltmeters are especially suitable for measuring even the slightest tilts of the surrounding rock which result, for example, from earthquakes, tectonic displacements, heat influx into rocks, mechanical interference (e.g. the construction of neighbouring tunnels), etc.

2.5.3.3 Test concept

The tiltmeters are installed in vertical boreholes of approx. 22 cm diameter. They measure the tilt in two vertical planes which are perpendicular to each other. The measured values are recorded automatically as functions of time and summed up during the entire test. By suitably filtering the measured data, using model calculations which also take into account the simplified geological conditions and the elastic parameters of the rock, the different progressions of movement are analysed.

2.5.4 Locating Active Neotectonic Disturbance Zones (ND)

2.5.4.1 Aims and objectives

These investigations supplement the measurements with the tiltmeters which indicate the presence and the approximate location of disturbance zones. The purpose of these tests is to locate as closely as possible neotectonically active disturbance zones.

2.5.4.2 State of the Art

To locate disturbance zones, the three-dimensional displacement condition is measured at discrete points in the rock mass. Because of the high accuracy required and the unknown situation of possible disturbance zones, line observations should be made, i.e. the displacements must be measured at close intervals along a path (borehole).

Since neotectonic displacements often progress very slowly, high demands are made on the accuracy and long-term stability of the instruments which must allow checking for correct operation and accuracy at all times. For such measurements there are different instruments available on the market at varying stages of development. Typical examples are the extenso-deflectometer and the sliding micrometer from the ETH-Z (Federal Institute of Technology, Zuerich) which can measure displacements within the range of one meter with an accuracy of a few thousandths of a millimeter.

2.5.4.3 Test concept

Such instruments will be used in the investigations for a final repository site if, on the basis of other information (tiltmeters, geophones, etc.), it appears advisable to locate neotectonically active disturbance zones relatively accurately. The procedure is similar for the tests at the Grimsel Test Site. This investigation program will therefore be conceived in detail if and when indications of such disturbance zones are provided by other tests.

2.5.5 Fracture System Flow Test (FF)

2.5.5.1 Aims and objectives

In order to be able to judge the long-term safety of a final repository, it is important to comprehend correctly the effects of the individual fractures and complete fracture systems on the hydaulic conditions prevailing in the environment of the repository. The objective of the fracture system flow test is to determine the permeability of the rock and the flow mechanism of the water in fractures and fracture systems.

To this end, the following individual objectives will be pursued:

- The exploration of possible water tracks in fractures

- The determination of the directional permeability

- The determination of the propagation speed of contaminated substances in function of hydraulic gradients and of temperature, measured by tracer tests

- The confirmation of the suitability of warm water as a tracer fluid.

2.5.5.2 State of the Art

Similar tests, in different rock formations, have been carried out by BGR during the last five years at various test sites.

2.5.5.3 Test concept

From the FF cavern, the fracture systems and the hydrogeological conditions prevailing in them, will first be investigated in detail from exploratory boreholes. On this basis, a three-dimensional array of boreholes will then be arranged, with one central borehole which will serve primarily as the injection borehole. The main fractures traversed by the individual boreholes will be separated from each other by a system of packers. By injecting liquid (hot or with tracer substances) into the central boreholes and measuring the inflows and water pressures in the individual test sections of the other boreholes, the movements of water in the rock can be detected. The measured results will be supplemented by theoretical considerations and model calculations.

2.5.6 Ventilation Test (VE)

2.5.6.1 Aims and objectives

In many respects, the permeability of the host rock is a very important parameter for the safety analysis of a final repository. Even for crystalline rocks which are very similar to each other, the hitherto published coefficients of permeability vary widely from about 10^{-12} m/s to 10^{-7} m/s. The lowest values derive from the permeability measurements made on compact drilling cores; the higher values relate mostly to a rock matrix with fissures of varying size. The customary laboratory tests made on drilling cores or rock specimen do not allow a reliable assessment of the permeability of the in situ rock.

The ventilation test is used to measure very small quantities of moisture and allocate these to the established water penetrability of the rock mass, in order to determine the overall permeability of large volumes of rock ("macropermeability") and to observe the same over a long period of time.

2.5.6.2 State of the Art

The ventilation test planned in the GTS is a further development of similar tests made in Stripa and in the Konrad mine.

2.5.6.3 Test concept

Two tunnel sections, each approx. 30 m long, will be closed off tightly by two mobile inflatable rubber cushions. Ventilation tubes passing through these sealing walls are used to heat, cool or dry out the two test tunnels. The quantities of air and moisture extracted from the two chambers will be measured during varying climatic conditions and the outflow of water from the rock determined.

A large number of measurements will be made in two boreholes parallel to the tunnel and in two exploratory boreholes running transverse to it, in order to determine the hydraulic pressure gradient in the rock present at the particular test stages and moments in time.

2.5.7 Hydraulic Potential (HP)

2.5.7.1 Aims and objectives

The hydraulic potential in the host rock surrounding the final repository determines the flow conditions in the vicinity of the repository. Of special interest are the changes resulting from mechanical interventions (e.g. borings, tunnel construction) and the long-term behaviour of the HP. Such knowledge is also necessary for the design of the constructional work for the repository. Previous measurements made at the Grimsel have shown that, in crystalline rock, the hydraulic potential can vary considerably over a relatively small area. The objective of the HP investigations is to prepare suitable instruments for the short-term and long-term observation of hydraulic potentials, as well as to gain experience in measuring methodology and in the interpretation of data.

2.5.7.2 State of the Art

Practical experience in measuring hydraulic pressures was and is being gained by Nagra as part of its deep drilling program. During various investigations undertaken abroad, especially in Stripa, systems for measuring hydraulic pressures in boreholes have been developed. The currently known methods and instruments for determining the permeability and the hydraulic potential in boreholes are now being compiled by Nagra.

The sliding piezometer recently developed at the ETH in Zürich permits line measurements to be made of the hydraulic pressure along a borehole of any direction, without any removal of ground water. A similar instrument has been developed in Canada.

2.5.7.3 Test concept

The sliding piezometer from the ETH-Z, and possibly similar foreign instruments, will be tried out in practice. At the same time the most promising of the different packer systems will also be tested and, if necessary, developed further to permit reliable measurement of the hydraulic potential. An appropriate test concept is being prepared.

2.5.8 Migration (MI)

2.5.8.1 Aims and objectives

The spreading and retention of nuclides in water-conducting fractures have a significant influence on the results of the safety analyses.

The aim of the migration test is to determine the governing parameters involved in the migration mechanism such as spreading and dispersion, sorption and matrix difusion, etc. This also includes the verification of laboratory experiments and computer models for comprehending the migration phenomena in crystalline rock under in situ conditions. In addition, methods for obtaining larger rock samples and suitable samples of rock water must be developed and tried out.

2.5.8.2 State of the Art

Since knowledge about the in situ behaviour of radionuclides is still rudimentary, field tests are urgently necessary. The two possibilities are: macroscopic tests in which a complete fracture system is examined, and detailed experiments which investigate the behaviour of the nuclides in individual fractures and provide useful data for setting up the computer models and laboratory tests.

Large-scale tests on individual fractures have already been carried out at the Climax test site in the USA and in Stripa. A large-scale, three-dimensional migration test is currently under way in Stripa.

2.5.8.3 Test concept

The concept for a migration test at the Grimsel depends on the results of the theoretical investigations carried out in Switzerland under the auspices of Nagra, and on the further progress of the 3-D migration test in Stripa. Favourable conditions for undertaking a migration test seem to prevail in the areas of the ventilation test and of the tests for excavation effects. The advantage of using any of these two areas after completion of the corresponding test is that a number of parameters which are essential for the migration test would already be available.

2.5.9 Excavation Effects around Underground Openings (EX)

2.5.9.1 Aims and objectives

The excavation of tunnels, caverns and shafts may cause a loosening up of the rock in the immediate surroundings. A precise knowledge of the excavation effects is important for assessing if and how far along the access tunnel or shaft preferential waterways from the repository to the biosphere are created.

In the EX test, methods for assessing and comprehending such loosening up processes will be developed further. At the same time however, quantitative information about the significance of the suspected excavation effects in the crystalline rock must be obtained.

Of special interest are the deformations and the hydraulic conductivity of the excavation zone. It is planned to establish a computer model to simulate the special features of the excavation zone around an underground opening.

2.5.9.2 State of the Art

Different investigations of the looseningup of the rock resulting from the excavation of underground openings have been undertaken with varying results. However, even an approximate prognosis or quantification of the influencing factors is still not possible today. Till now, only excavation effects resulting from blasting have been investigated. The measurements to be carried out as part of the Grimsel Project in the area of a tunnel excavated by a tunnelling machine represents new ground.

2.5.9.3 Test concept

In a first phase, a 30 m length of tunnel, 3,5 m in diameter, will be excavated full face with a tunnel boring machine. Previous to this, a number of boreholes will be made through and in the immediate vicinity of the testing tunnel. By carrying out a large number of measurements before, during and after the boring of the tunnel the changes occuring during excavation can be recorded.

A possible second phase involves similar investigations for a 30 m long tunnel excavated by blasting.

2.5.10 Rock Stress Measurements (RS)

2.5.10.1 Aims and objectives

Depending on the height of the overlaying strata and the previous geological history, the rock stresses at the final repository site can be considerable. Under certain conditions they can vary substantially from those calculated on the basis of the lithostatical pressure. A knowledge of the magnitude and direction of the three principal stresses is particularly important for the constructional planning and design of the repository. In addition, the rock stresses in the vicinity of the repository are used as parameters in various other safety considerations.

In the rock stress tests, known methods of determining the stress and deformation behaviour of the rock will be checked and developed further for the use in deep boreholes. The advantages and disadvantages of the different instruments will be examined in more detail by comparative applications of different methods.

2.5.10.2 State of the Art

Overcoring methods for measuring stress, used till now in deep boreholes (more than 100 m depth), are all based on measurements with wire strain gauges which are glued to the rock surface in the borehole by different methods. Readings from these so-called triaxial cells are usually obtained only before and after (but not during) overcoring. It is then unclear whether and to what degree the true deformation (stress) values are falsified during overcoring. Investigations were carried out in Stripa to compare different methods, and the results were published. However, for deep boreholes only the overcoring method of the Swedish State Power Board with triaxial cells, and the Hydrofrac method were used.

2.5.10.3 Test concept

A drilling machine will be positioned stationary over the test borehole of ultimately 200 m depth. While the hole is being sunk, measurements will be made with different instruments at progressively deeper levels. More than 50 individual tests are planned. In particular, the inductive deformation gauge developed by BGR will be tested, and its results will be compared with those of other stress measuring methods.

2.5.11 Heat Test (HT)

2.5.11.1 Aims and objectives

The heat test is intended to provide information on the reaction of the crystalline bedrock formation to an influx of heat. Special attention is paid to the behaviour of a proximate disturbance zone.

2.5.11.2 State of the Art

Several different heat tests have already been carried out in the past; The host rock was either salt (Avery Island, ONWI, USA and Asse salt mine in Germany) or granite (Stripa, Sweden).

Because of the different objectives and thus also the different equipment, the various experiments are only conditionally comparable with each other and some of the results are not applicable to other locations. Variations are due in particular to a basically different mechanical behaviour and to different hydrogeological conditions: Water plays a much greater role in granite than in salt. Contrary to the fissured structure of the largely elastic crystalline rock, salt, with its exceptionally high viscosity, can close even fairly large openings again.

The experiments in Stripa have shown that the water conductivity and chemistry and their heat-induced changes in the crystalline rock must be given special attention with due consideration of the local geological conditions (e.g. disturbance zones).

2.5.11.3 Test concept

From the base of the totally 140 m long heat testing tunnel, two boreholes 18 m deep and 2.20 m apart are sunk. An electrical borehole heater 6 m high, with a heating output of 4 kW/m', is placed in each borehole. One of the heaters lies directly in a lamprophyre vein (disturbance zone) and the other directly near it. Surrounding these two heaters which can be operated individually, about 500 m' measurement boreholes will be made.

The measuring systems record the stresses, deformations and the changes of the thermal and hydraulic conditions resulting from an influx of heat adapted to the final repository concept, and generated by the computer-controlled heaters.

2.5.12 Convection (CO)

2.5.12.1 Aims and objectives

The storage of highly radioactive wastes will constitute a considerable source of heat in the rock formation, which will heat up any water present in the vicinity of the repository. This could result in large-scale circulation currents.

The objective of this investigation program is to examine more closely the possibilities of such circulation currents arising, and their significance.

2.5.12.2 State of the Art

This problem has hitherto been approached by mathematical models only. They have not yet been verified by in situ investigations.

2.5.12.3 Test concept

In a first phase, studies of literature and supplementary theoretical experiments will be used to clarify the importance of these convection currents. Should they prove to be significant, a second phase will involve the planning and execution of in situ tests at the Grimsel Test Site. The program has been given a low priority for the present.

2.5.13 Laboratory Tests (LT)

Accompanying laboratory tests (in customary laboratories for examining rock samples) will naturally be a part of the test concept for most experiments. They are therefore not listed here.

Special experiments will be carried out to prepare basic data on the Central Aaregranite and the Grimsel Granodiorite. These basic data concern deformation, permeability and the heat-conditioned characteristics of the rock samples.

2.6 Basic Time Schedule

The Basic Time Schedule (Fig. 3) shows the current status of the planning for the individual investigation programs which make up the Basic Program. The detailed planning of the tests had to be based on the financial planning and approval periods of the three partners. It had to be ensured that meaningful results can be obtained in any case with the definitely granted resources.

The current permit granted by the Federal Government for the construction and operation of the GTS is valid until 28th November, 1992. Both Nagra and the BFMT are interested in making use of the facilities set up at the GTS for further investigations. At the appropriate time the Basic Program might therefore be extended beyond the planning period shown in Fig. 3.

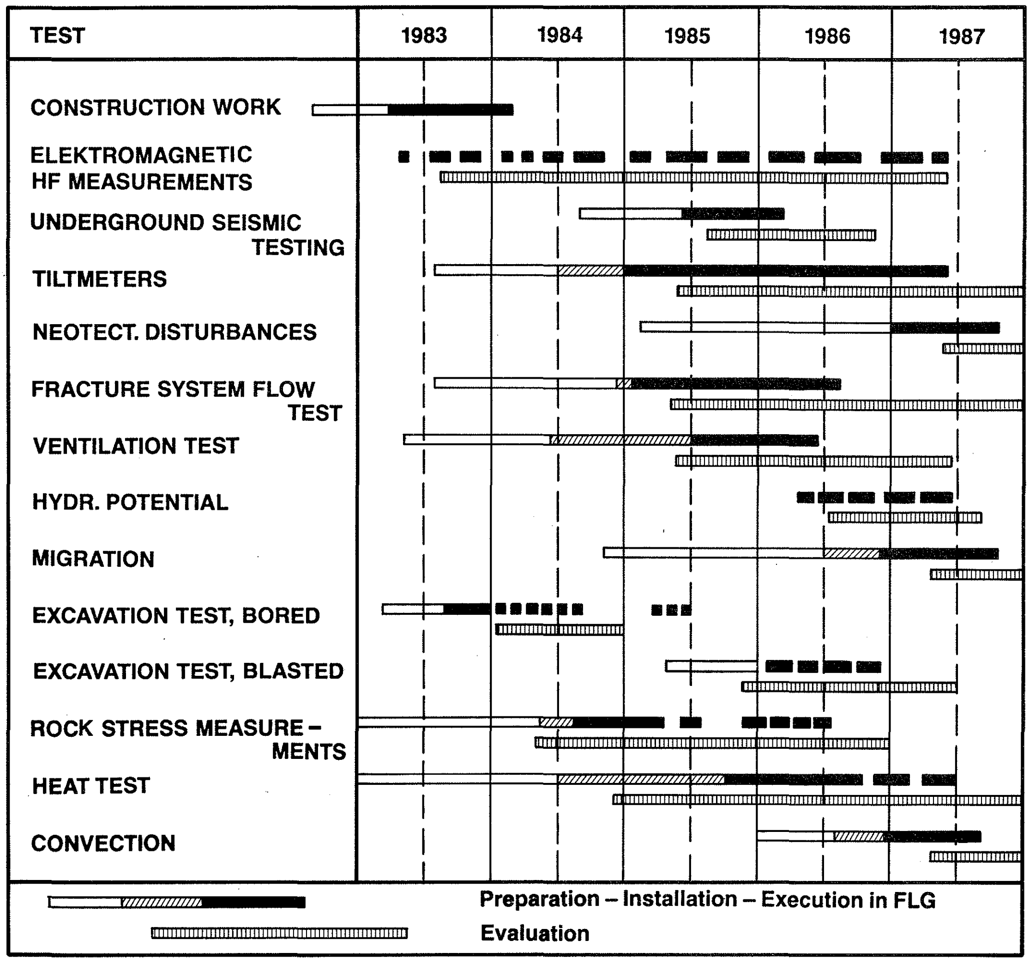

Fig. 3: Basic Time Schedule

3. SITE SELECTION

3.1 Basic Considerations

The in situ investigations relating to the final disposal of radioactive waste can be subdivided into three categories:

a) Examinations of rock bodies which are as typical as possible of the formation existing at the planned site of the final repository.

b) Investigations at the site of the planned repository, without the use of radioactive waste.

c) Pilot tests with radioactive waste at the site of the final repository.

The b) and c) type investigations require that the site of the final repository is known. However, in order to determine this site, detailed geological examinations and safety calculations must be made, which, in the case of a repository for high level radioactive waste, will take many years to complete. Furthermore, a costly and protracted licencing procedure must be reckoned with, especially in the case of pilot tests.

The general objectives for the type a) investigations are outlined in section 2.2. Reduced to the simplest denominator, the basic questions are:

- What can/should be measured, and how exactly?

- What are the most suitable measuring methods for it?

The answers to these questions are the prerequisites for the planning of investigations which will determine and confirm the site of the final repository.

As such, Nagra decided in 1979 to construct a **Test Site for the type a)** investigations:

Nagra's primary objective in its investigations into the disposal of high level radioactive waste is the clarification of the suitability of the crystalline bedrock formation as host rock for such a final repository. It was logical, therefore, to construct the Test Site in autochthonous crystalline rock, though with the additional target of checking the applicability of the knowledge gained and of the results obtained, to other host rock formations, especially with respect to Nagra's B-repository (ILW/LLW).

For the C-repository (HLW), examinations will be made of the crystalline bedrock formation in northern Switzerland. As shown in Appendix 2, this dips southwards from the surface in the Black Forest to depths of some thousands of meters and then rises steeply in central Switzerland to reach the surface again in the Aar/Gotthard Massif. Since, contrary to Germany and Sweden, there are no disused deep mines in central Switzerland, a Test Site in the crystalline rock formation in northern Switzerland, with the minimum required rock overlay of at least some hundreds of meters, would have to be prepared by sinking a new vertical access shaft with lift and hoisting plant, ventilation, etc.

It was therefore manifest to check if a suitable location for a Test Site could be found in the Aar/Gotthard Massive.

3.2 Requirements

In view of the planned investigations and in order to be as flexible as possible with regard to future tests, the following requirement was made:

- Crystalline rock formation of good quality; mainly of low permeability, but with some discrete water zones; different, but in general rather weak fractures. The varying characteristics of the rock formation should be present as far as possible in distinct zones, to facilitated the identification of individual test areas.

In order to allow an early and economic construction and to minimize operating costs, the following criteria were laid down:

- Good development possibilities, using an existing infrastructure

- Access through an existing tunnel, but neither an active rail nor road tunnel

- The best possible, already carried out, geological survey of the area.

3.3 The Selection of the Grimsel Site

Investigations carried out in 1979 and 1980 soon showed that of all the areas considered in the Aar/Gotthard Massif, none came even close to fulfilling the requirements so well as the area under the Juchlistock made accessible by the access tunnel to the Grimsel II Hydropower Station of the Oberhasli Power Station Company (KWO) (Fig. 4,5 and 6).

The particular specific advantages of the present location of the GTS under the Juchlistock are:

- The area of the Juchlistock is a topographically and geologically clearly structured rock body
- The mineralogy and petrography of the existing rock formations have been examined in many earlier projects (mainly by the University of Bern)
- The considerable number of KWO underground structures afforded a good insight of the rock formation even before excavation of the testing tunnel
- The preliminary examinations made by Nagra (section 7.2.1) have confirmed that the desired diversity of geological and tectonic conditions are present within the close confines of the Test Site, e.g. varying petrographical conditions, fracture zones and permeabilities
- The accessibility is good (section 4.2.1)
- The well-planned, extensive infrastructure for the Grimsel I and the (recently completed) Grimsel II Hydropower Station can also be used for the Test Site

The following disadvantages must however be taken into account:

- The disturbance to the hydrogeology of the rock formation caused by the KWO structures
- Interferences caused by the power station operation (pump storage scheme) affecting, for example, the seismic measurements and possibly the electronic instruments.

3.4 The Oberhasli Power Station Company (KWO)

The Oberhasli Power Station Company (KWO) uses the hydraulic potential of the Upper Aare, the Gadmen and the Gen Valleys. Nine power stations have been erected, with a total generator capacity of about 1000 MW. The control centre is in Innertkirchen. It is connected to all the KWO plants by means of two independent communication networks. The access tunnel which skirts the Test Site, connects the Gerstenegg tunnel entrance with the Grimsel II East Hydropower Station, which lies 2,2 km inside the mountain. This pump storage scheme (300 MW) utilizes the hydraulic potential between lake Oberaar and lake Grimsel.

The KWO infrastructure which has also been placed at the disposal of Nagra for the Test Site, comprises, among other things: The tunnel-railway and aerial cableway between Guttannen and Gerstenegg, snow clearing and avalanche warning services, round-the-clock emergency organisation including a station fire-brigade, escapeways out of the access tunnel, meteorological measurements, recording of the levels of the various storage lakes and local knowledge gained from experience over decades.

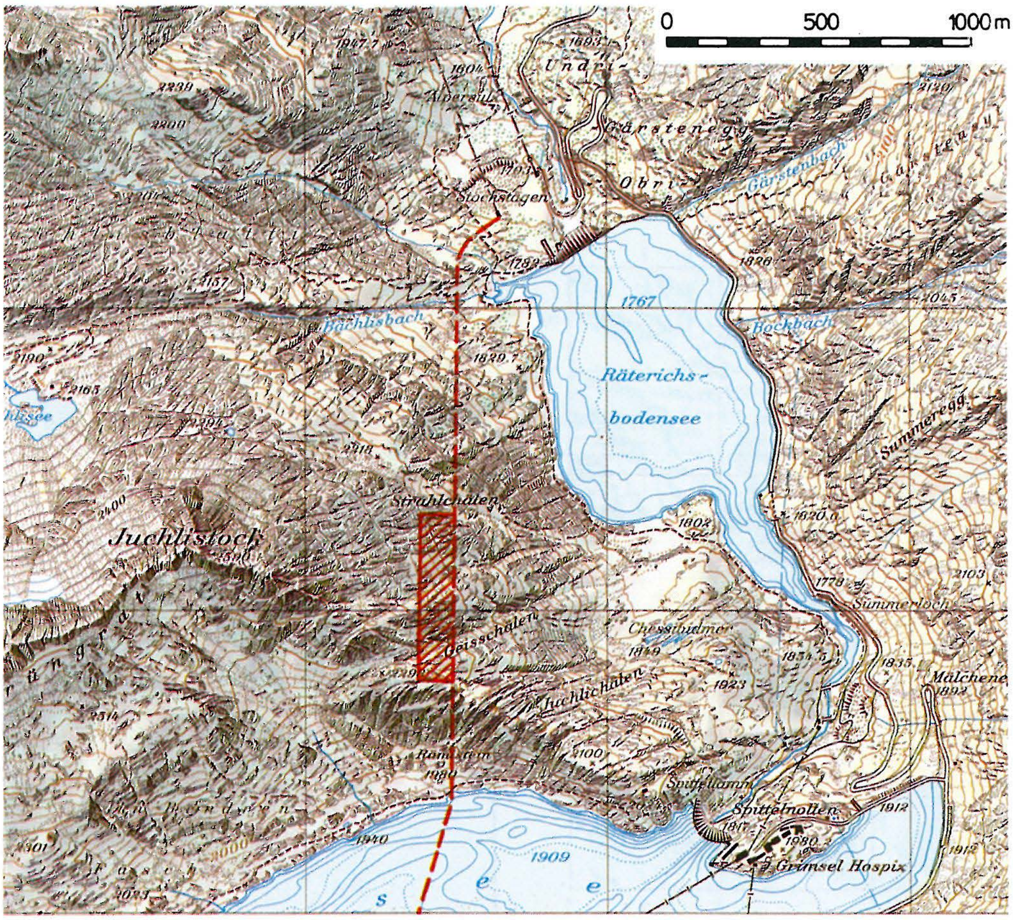

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Fig. 4: Juchlistock, scale 1:25 000

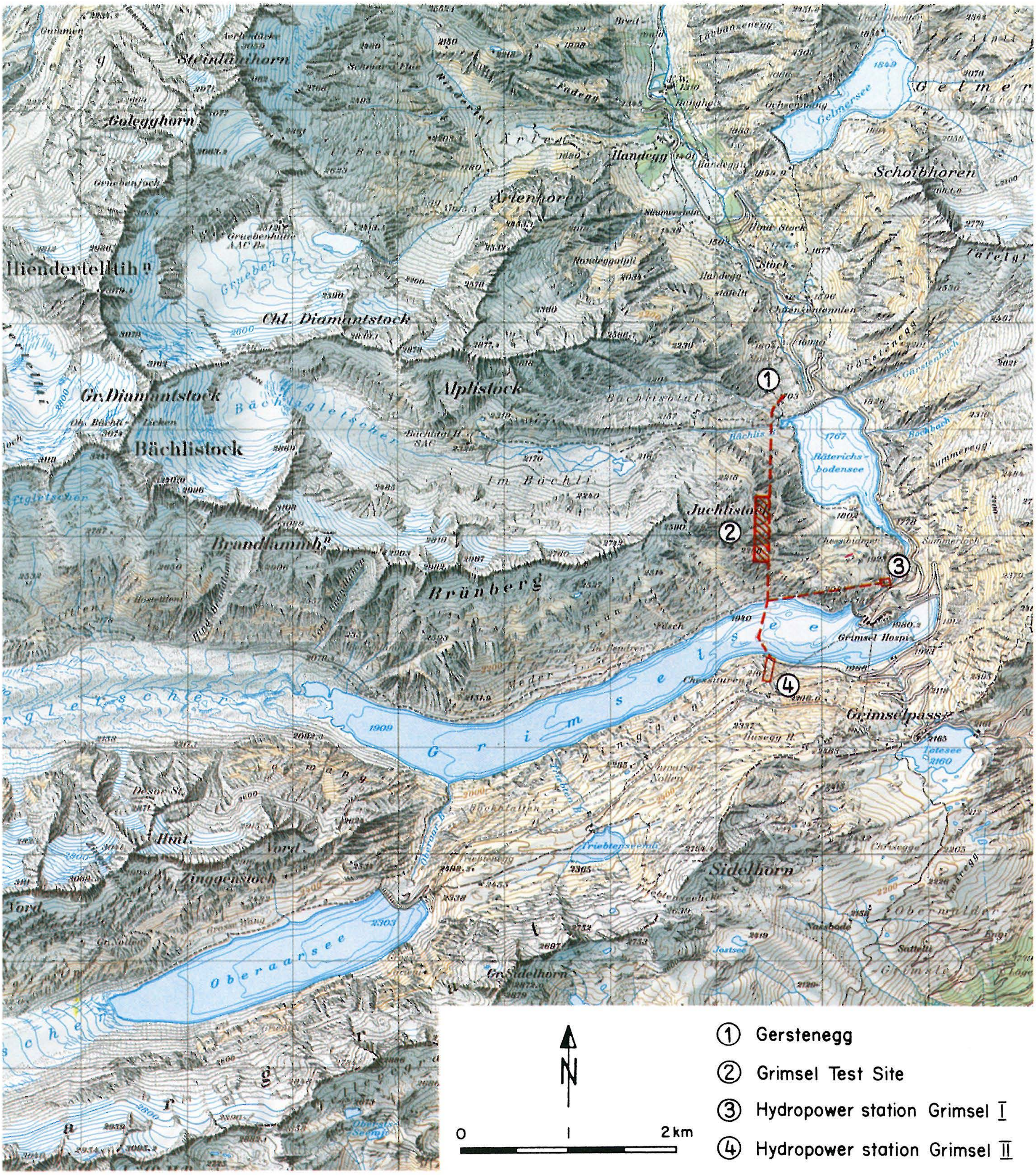

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Fig. 5: Grimsel area, scale 1:50 000

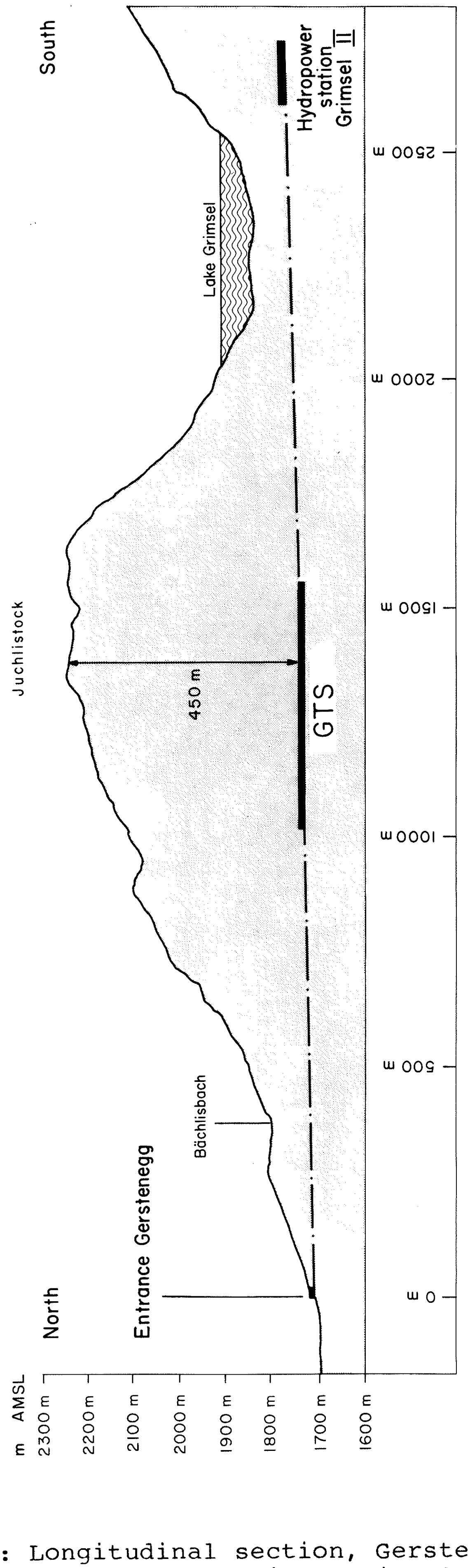


Fig. 6: Longitudinal section, Gerstenegg-hydropower station, Grimsel II

4. CONSTRUCTION AND OPERATION

4.1 Requirements

In addition to the criteria for site selection mentioned in the previous chapter, a number of requirements had to be met in order to ensure a safe and efficient continuous operation of the Test Site. The most important of these are:

- The boundary conditions for the test arrangements must be as simple as possible.

- Year-round continuous operation of the Test Site must be possible. Since the whole Gerstenegg area is strongly endangered by avalanches in winter, the whole infrastructure of the Test Site must be underground. The working conditions must be such as to avoid fatigue symptoms among the members of the operating team who work continuously underground. Since access to the Test Site is time-consuming in winter (cableway or tunnel railway), all the necessary facilities must be provided for an autonomous operation of the Test Site (workshop, catering, etc.).

- It must be possible to carry out the various types of tests independently of each other, without reciprocal interference. The infrastructure must be able to cope with the overlapping of load peaks deriving from the individual test programs (e.g. power supply, personnel). It must also be able to cope with the greatly varying demand required by the separate test phases and the execution of tests still to be conceived, without costly adaptation work.

- For certain tests, highly sensitive electronic instruments will be used either at the control centre (data acquisition, control) or at the test locations (measuring instruments). The ventilating system, including temperature and humidity control, in the whole Test Site area must take this situation into consideration. Appropriate protective devices must be used to prevent as far as possible any electrical influencing of these instruments, despite the high electric resistivity of the rock and the neighbouring power station operation.

- The safety of the personnel working at the Test Site must be fully ensured, also in the case of untoward incidents such as, e.g. accidents occurring after regular working hours, fire or failure of the main power supply. A continuous, failure-free power supply must be guaranteed for some instruments and the EDP installation. All test locations, including outside measuring stations, must be provided with a carefully conceived earthing network.

- A good communication system within the testing area and with the outside world, as well as a well considered alarm system are required primarily for safety reasons. However, they must also ensure that if there is a failure in a critical test installation, such as the heater in the heat test for example, the appropriate corrective measures can be taken in good time by a round-the-clock on-call organisation.

- The Test Site must be receptive to visitors and offer the possibility of suitably receiving and acquainting visiting groups of up to 60 persons.

- Furthermore, a number of government regulations must be observed, e.g. concerning the protection of waters, nature conservation and preservation of the countryside, the use of radioactive substances (e.g. as tracers) and SUVA (Institute for Accident Prevention).

- The Site must be designed for an operating period of ten years, at the most favourable cost/benefit ratio possible. It must also be taken into consideration that this period could be extended.

These partly overlapping, but also sometimes contradictory requirements had to be taken into account and suitably matched by well-considered engineering and an adequate operational concept. The respective main features of the Grimsel Test Site are briefly described in the next few chapters.

4.2 The Concept for Construction and Infrastructure

During the summer months, the entrance to the Gerstenegg tunnel is reached by road. In winter, access to the Gerstenegg is by cableway. At times of serious danger of avalanches, a small tunnel train conveys people from Guttannen directly to the valley station of the cableway (Fig. 7).

The building for the Central Facilities (CF), accommodated in a rock cavern between the main access tunnel and the testing tunnels contains the entire infrastructure for the Test Site. This ensures continuity of the Test Site operation, even if all connections with the outer world are interrupted by avalanches.

From the Central Facilities the testing tunnels of 3.50 m diameter are reached through a short connecting tunnel. The testing tunnel has a 1% downward slope in the northerly direction. Appendix 1 shows the cross-section of the tunnel and of the most important caverns, the locations of which are shown in Figure 1. Every testing area is provided with connections for telephones, water and the central earthing system.

The elaborate ventilation system takes into account the alpine situation of the Test Site. The air temperature in the tunnel is about 12° C and fairly constant in winter, in summer it may rise by some degrees. The radon gas content is not critical.

The power supply (380 V and 220 V) is fed from two independent points of the KWO grid to provide the greatest possible reliability. In addition, the most important installations are connected to an interruption-free emergency battery supply.

Non-potable water is taken from the KWO system and additionally filtered for drinking purposes. From a septic tank in the CF, the sewage is discharged by gravity flow through the tunnel to the biological sewage-treatment plant at the Gerstenegg. Drainage of the tunnel system is also by gravity flow.

The individual testing areas are connected to the telephone exchange in the CF via an internal telephone network. An efficient telecopier permits fast transmission of documents. An alarm system detects incidents or malfunctions which could endanger the personnel at the GTS or cause serious damage to equipment or jeopardize the results of a test.

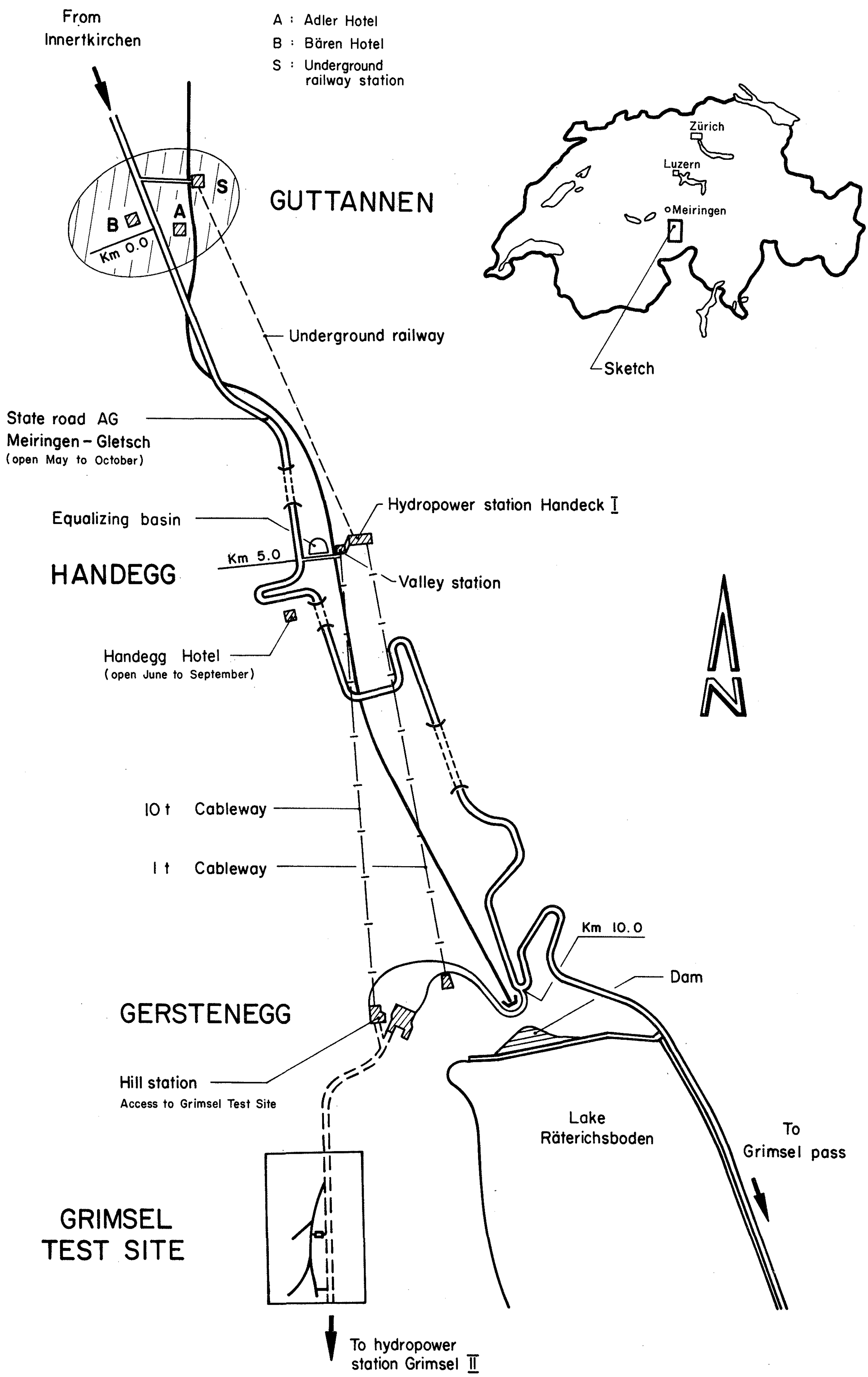


Fig. 7: Access to the Grimsel Test Site

4.3 Construction

The caverns and the branches of the trunk tunnel were excavated by blasting. The ceilings in the areas occupied by personnel were secured with shotcrete, without nets or anchors. The tunnel system (3.50 m dia.) was excavated full face with a Wirth tunnel boring machine, type TB II-H (TBM) in two-shift operation. It remained unlined, with the exception of the base and a short section in the heat test area where some spalling made it necessary to use nets for safety purposes.

The TBM was assembled in front of the Gerstenegg entrance, after which it progressed into the pre-blasted starting tunnel. The excavated material at the rear end of the boring machine was picked up by a tunnel train, unloaded on to a dumper in the starting tunnel and deposited near the Gerstenegg entrance. Concrete was produced on the Gerstenegg by a stationary mixer, using aggregates prepared from blast excavated material or, in winter, mixed by a small machine directly in the cavern for the Central Facilites (CF, Fig. 2).

After preparatory work on the construction site since February, 1983, excavation by the tunneling machine was commenced on 30th May and concluded on 21st November, 1983. The structural work for the building housing the Central Facilities and the whole finishing work lasted from December, 1983 to May, 1984. Figure 8 shows the time schedule of the construction program. The very tight schedule could be successfully completed without difficulties worth mentioning. There were no serious accidents.

4.4 Boreholes

By the end of June, 1985 about 3'700 m' of boreholes had been completed, of which 3'200 m' were cored boreholes of 56 mm, 86 mm, 101 mm and 146 mm diameter, with complete core recovery and orientation of all cores as well as approx. 500 m' of percussion-drilled boreholes of 76 mm to 305 mm diameter. The large-caliber percussion boreholes were used to accommodate the tiltmeters and the heaters for the heat test.

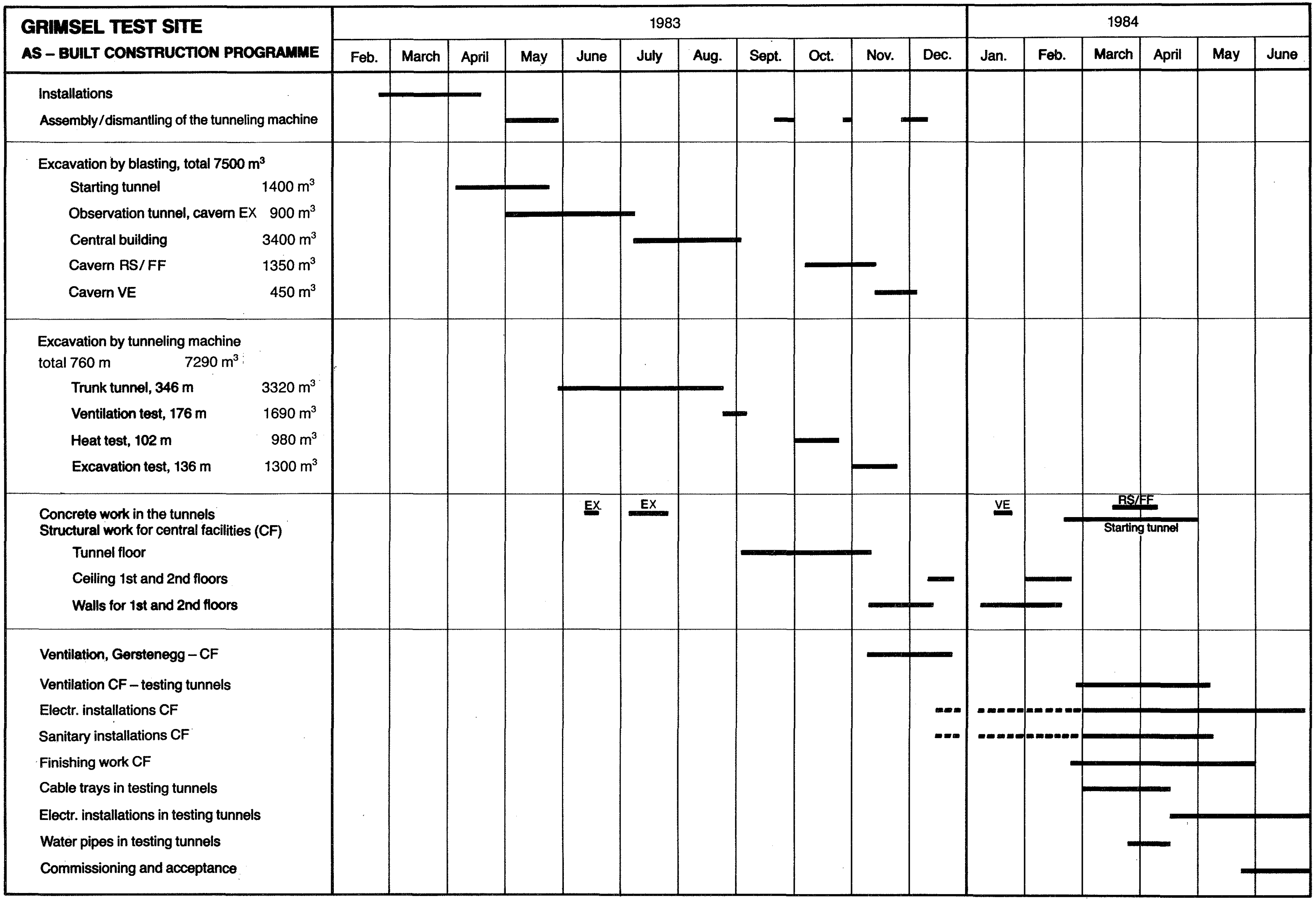


Fig. 8: As-built construction program

4.5 Organisation

4.5.1 Project organisation

The following responsible bodies and persons were created/nominated to execute the Grimsel Test Site project within the framework of the cooperation contract with BGR/GSF:

- Steering Committee
- Technical Specialist Groups
- Project Management
- Principal Investigators

Nagra provides three of the six members of the steering committee, including the chairman, as well as the project management. Figure 9 shows the organisation chart.

The steering committee is responsible for the management and control of the overall Grimsel Test Site project. In particular, it approves the scientific annual programs and the main aspects of execution of the individual test programs for the GTS, and decides on the formation and dissolution of technical specialist groups.

The technical specialist groups are responsible for the scientific oversight of one or more investigation programs falling in any one scientific field. They are the scientific advisers to the steering committee and to the principal investigators.

The project management lies in Nagra's hands. Nagra appoints a responsible project manager and scientific technical specialists in the fields of geophysics, rock mechanics, rock hydraulics, geology, construction and operation. The project manager coordinates and directs the execution of the project.

There is one principal investigator heading each investigation program. He is appointed by the organisation which conceives and executes the particular program. The duties of the principal investigator consist essentially in working out the details of the test program, in directing the corresponding tests during the execution phase in consultation with the project manager and in reporting about progress and results of his test program.

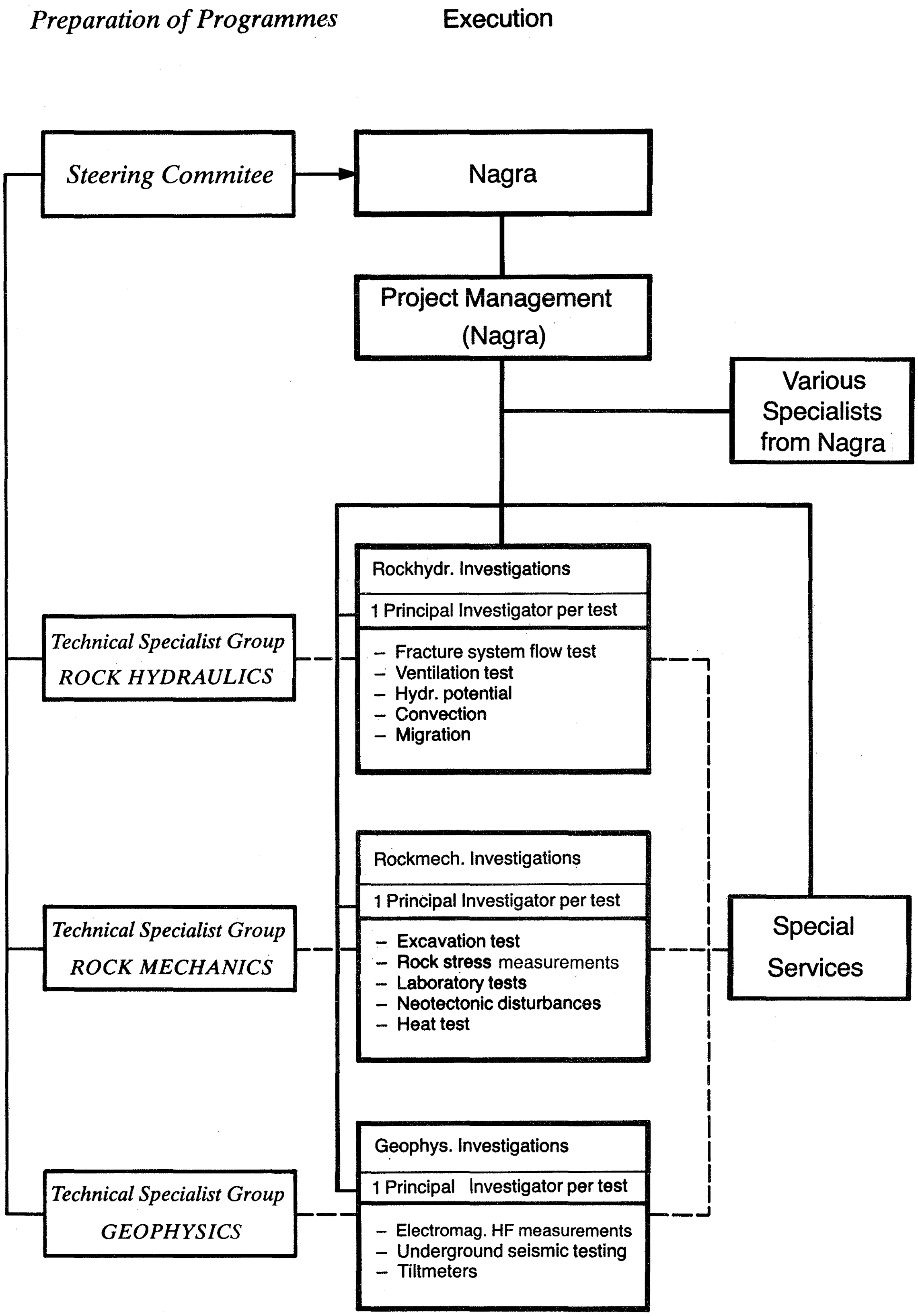


Fig. 9: Organisation of the Grimsel Project

4.5.2 Organisation during Construction

The organisation described below has proved to be successful:

Design and supervision of the engineering works was contracted to IUB (Engineering Consultants, Bern), who knew the local conditions from previous work in the area and for KWO. The overall control and direction remained with the full-time project manager appointed by Nagra. The lead time for the design work was nine months (from June, 1982). During this time, an average of one engineer and two draughtsmen worked on the Grimsel Test Site Project.

During the execution phase, IUB employed an additional engineer as the local construction manager (partly supported by local personnel) and one more draughtsman in the office in Bern. Shortly before the internal finishing work began, Nagra augmented the personnel at the construction site with their local manager, who also directed the preparations for operation. The number of personnel at the Test Site on any typical day of the different phases is shown in Table 1 below. At peak times during the internal finishing work which was executed according to a very tight program, there were up to 60 persons working simultaneously at the GTS.

The main contract for all excavation and structural work was awarded to a joint venture which consisted of the three companies: Frutiger Söhne AG, Thun (leading), H.R. Schmalz AG, Bern and Maurer AG, Innertkirchen. Subcontractor to the joint venture for the excavation with the tunneling machine was the firm Kopp AG, Luzern.

For the drilling work, the company selected from several competitive offers for the total scope of the then envisaged drilling work was SIF, Sondages, Injections, Forages SA, Renens. It has been retained till today, which allowed to accumulate valuable experience in the drilling of Grimsel rocks.

In awarding contracts for work at the GTS, local firms were considered as far as could be justified technically and economically.

4.5.3 Organisation for Operation

The responsible principal investigator for each of the investigation programs, is an experienced scientist who, in addition to the investigations at the GTS, also carries out other duties. His Grimsel team of investigators normally consists of one or two scientists/engineers who work full-time on the particular investigation program. They are supported by the part-time assistance of the necessary specialists (e.g. for EDP).

An experienced engineer from Nagra, resident in the local area (Haslital), is responsible for the local management. He is supported by one mechanic and one electrician (local personnel), as well as an administrative assistant. This team coordinates and supports the installation work for the individual tests, makes adaptations to the infrastructure where necessary and is responsible for upkeep and maintenance of all GTS facilities.

For the acquisition of know-how and its application at Nagra, the project manager is supported by the aforementioned scientific/technical specialists and an additional specialist for measuring methodology.

The number of investigators and measuring personnel working at the Test Site (Table 1) depends on the number of tests progressing simultaneously.

	1983			1984			
Quarters	2	3	4	1	2	3	4
Installations							
Excavation and structural work							
Finishing work							
Installation of the test							
Excavation and structural work	24	22	26	18	18-3	3	-
Tunnneling	2	2	2	4	4	4	3
Finishing	-	-	3	5	20-40	5	2
Geologists	1	1	2		1	1	1
Personnel for testing and measuring	-	3	7	3	8	10	10
Construction management	1.5	1.5	2	2	2	0.5	0.5
Operating personnel	-	-		2	2	2.5	2.5
TOTAL	28.5	29.5	42	34	40-60	26	19

Table 1: Typical number of personnel at the Test Site

5. DETAILED DESCRIPTION OF THE INVESTIGATION PROGRAMS

In 1984, the principal investigators presented detailed descriptions, ranging in scope from 20 to 60 pages, for eight of the twelve investigations forming the Basic Program. Based on the recommendations of the individual specialists from Nagra, and its advisers, the technical specialist groups and the steering committee then gave the go-ahead for carrying out the respective investigation programs.

The most important features of these eight descriptions are summarized in the following sections.

5.1 Electromagnetic HF Measurements, Absorption (EMA)

5.1.1 Basis

It has been known for several decades that it is possible to set up underground radio communication in dry rock formations, with ranges of up to some hundreds of metres, whereas in highly humid rock formations the range reduces to some tens of metres.

The reason for this phenomena is the fact that the attenuation of radio waves (electromagnetic waves) is directly proportional to the electrical conductivity of the rock formation and inversely proportional to the dielectric constant.

Water-conducting excavation zones, for example, always have a very much higher electrical conductivity in crystalline rock formation than the surrounding rock, that is, they produce an increased attenuation when irradiated with electromagnetic waves. This effect can be used with the EM absorption method (EMA) for the specific purpose of searching for weak zones in massive rock formations. The principle of the EMA method is explained briefly below:

As illustrated in Fig. 10, one transmits a radiowave with strictly defined energy into the rock formation, taking into account the characteristics of the antenna in the borehole 1 (Bo 1), and receives the signal in the borehole 2 (Bo 2) with another antenna, leads it via cable to a high performance receiver and records the attenuation which the electromagnetic wave has undergone on its way between transmitter (T) and receiver (E).

By skillful arrangement of the transmitter and receiver antennae in the two boreholes, the intermediate section can be irradiated with several fans. The data derived from the absorption profiles then supply information about the type and structure of any inhomogenities which may be present.

Since with the EMA method only the total energy of the receiver signal is measured and not its form, a certain problem arises with the interpretation of data, because the amount of energy loss always occuring at the disturbance zones, and caused by diffraction and reflection, is unknown. Furthermore, energy components of multiple reflections can inversely influence the recordings.

These undesired "measuring effects" can be controlled to a certain extent by using variable measuring frequencies and inverting the direction of irradiation.

In spite of this however, the interpretation of the data requires much experience and flair.

From 1966 to 1980 BGR carried out six research programs with radiowaves in a salt mine. Parallel to these investigations in salt rock, test measurements were made in crystalline, dolomite, belemnite chalk and sandstone formations. In these tests, the possibilities and limits of the EMA methods for determining inhomogenities in the rock formation were investigated step by step.

In 1982, EMA measurements were made on the Grimsel in five 100 m long exploratory boreholes. They produced the following results with respect to the application of electromagnetic methods:

- Ranges of over 150 m were achieved in the rock formation with 1 watt transmitter output in the frequency range between 10 and 30 MHz.

- The received field strength is reduced significantly by Lamprophyre and shear/fracture zones. The reduction is considerably greater than the scattering of the measured values.

- The measured data are reproducible.

5.1.2 Investigation Targets (EMA)

The most important targets of the EMA investigations in the FLG are:

- Modifying the knowledge gained from measurements in salt for measurements in crystalline rock

- Optimisation of the broad band antennae for application in crystalline rock, including the adaptation of the antennae for use in dry and water-filled boreholes of different diameters

- Determination of the possibilities and limits, when localizing inhomogenities in the crystalline rock, as a function of the measuring frequency and the range.

As an extension to the existing EMA investigation program, efforts are now being made to transform the absorption profile mathematically into tomographs. This will permit similar sectional views of the investigated section to be obtained, as those described in section 5.3.1 for the underground seismic testing.

5.1.3 Test Arrangements (EMA)

Experience and measuring results obtained from the first EMA tests in individual exploratory boreholes of the FLG in 1983, already showed up the necessity to make certain changes in the measuring system and to recalibrate the method with the respective modified instruments. Four calibration boreholes, 50 m long and 50 m diameter, inclined by 5°, in the southern part of the Test Site, were therefore made permanently available to the EMA. Another, equally long, cored borehole was drilled in May 1985.

Two three-month measuring periods were carried out in autumn 1984 and in spring 1985. A first evaluation confirmed the basic suitability of using the method for a nondestructive exploration of crystalline rock formation. The more precise analysis of the measured results will help determine the next phase of the investigation program in detail. It is intended also to include the boreholes of the seismic crosshole tomography (Fig. 13) in the EMA program.

5.1.4 Data Acquisition and Evaluation (EMA)

The rock complex to be investigated is scanned with five radio-frequencies (10-30 MHz). Transmitter and receiver antennae (32 mm dia.) are moved in the borehole by means of nylon rods. For each measuring position, the emitted transmitter energy and the corresponding field strength at the receiver are recorded. Since the transmitter antenna can also be used as receiver antenna, the direction of scanning can be reversed within the same measuring cycle.

The data are evaluated by plotting the absorption profiles obtained in the receiver borehole as function of the depth. As an extension to the present investigation program, efforts are now being made to transform the absorption profiles mathematically into tomographs. This will permit to obtain sectional views of the scanned section, similar to those described in section 5.3.1 for the underground seismic testing.

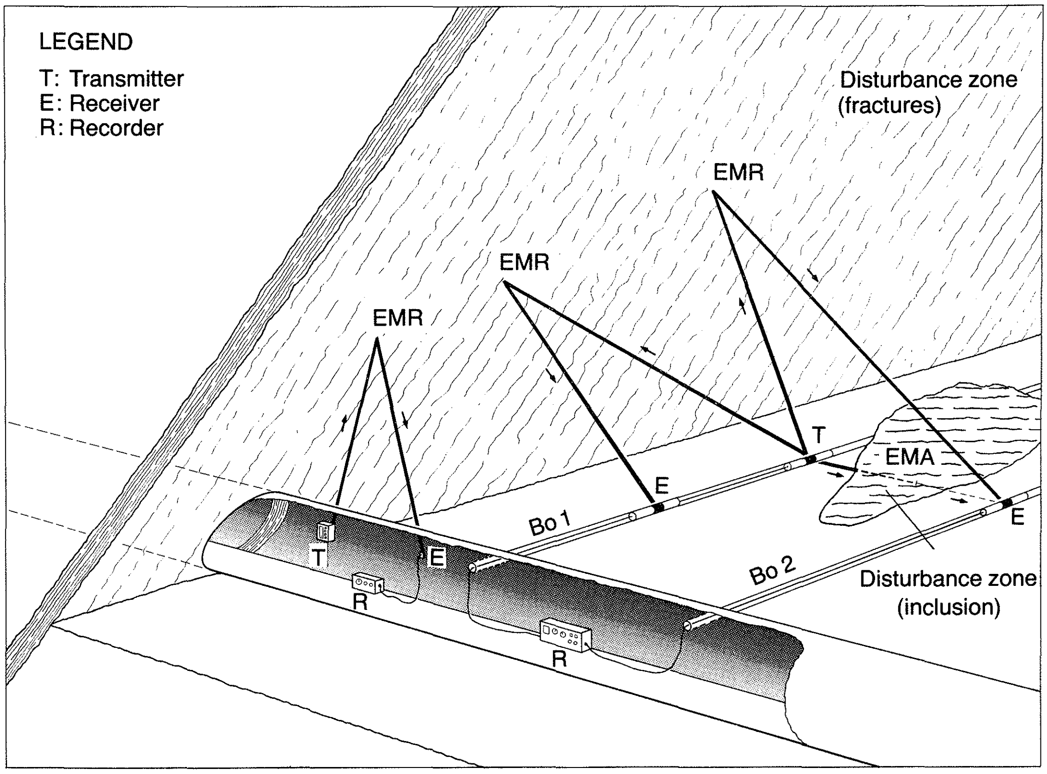


Fig. 10: Principle of electromagnetic high frequency measurements

5.2 High Frequency Electromagnetic Reflection Measurements (EMR)

5.2.1 Basis

As explained in section 5.1.1, the propagation of electromagnetic waves is very strongly influenced by the electrical properties of the rock formation. If the electrical characteristics of the rock change, e.g. at the transition to a water-conducting weakness zone, the corresponding discontinuity represents a reflector for electromagnetic waves.

If an electromagnetic pulse is transmitted into the rock, this pulse will be reflected at the discontinuity and can be recorded after a certain travel time (Fig. 10). By knowledge of the wave propagation speed (approx. 120 m/µs) the travel time can be used to calculate the distance to the discontinuity. Since this principle is comparable to that of Radar, the EMR method is also called Underground Radar.

The EMR method can be used in tunnels as well as in boreholes. In both cases the layout (i.e. the arrangement of the transmitter and receiver antennae) is shifted along the tunnel wall or in the borehole, and the pulse travel times recorded in function of the respective layout positions. From this, the position of the reflecting elements (e.g. lamprophyre or waterconducting disturbance zones) can be derived.

Whereas the EMR measurement in tunnels can rely on a directional effect produced by the dipole antennae placed against the tunnel wall, with measurements made in boreholes, it must be accepted that for any position of a reflecting element, only an ellipsoid as the geometrical location around the borehole, can be determined. In this case a three-dimensional localization of the disturbance zone can be obtained by additional measurements made with other layout geometries, e.g. wide-angle reflections from another borehole. Even direction-finding antennae, which are currently in development, show promise of success here.

In several research programmes carried out since 1971, in cooperation with the German potash and rock salt industries, BGR has developed measuring instruments and optimised them for routine use. They permit EMR measurements to be carried out in a very short time and at little cost. Since 1981 an EMR measuring instrument has been in continuous use in the Permafrost area of North Canada for locating sulphide ore bodies in dolomite. Further examinations, also in granite, have been made in Sweden (Stripa). The results and knowledge gained have been, or will be, published.

5.2.2 Investigation Targets (EMR)

The investigation targets of the EMR are comparable with those of the EMA (section 5.1.2). They are mainly directed at the confirmation and identification of discontinuities in crystalline rock. Attempts will also be made to improve measuring and recording techniques.

5.2.3 Test Arrangements (EMR)

The procedure of the EMR testing is to carry out measurements in intermittent periods and, between these periods to make evaluations of the results and modifications to the instruments.

The following measurements have been carried out to date:

a) With borehole antennae in all exploratory boreholes and in the ventilation test, heat test and tiltmeter boreholes. The measurements were made in a single-borehole arrangement of transmitter and receiver as well as in two-borehole (crosshole) arrangements. When using the single-borehole arrangement, the distance between the antennae was 5 to 10 m.

b) With dipole antennae in the main access tunnel opposite the Test Site area, in the GTS trunk tunnel and in the various test tunnel sections.

The layout length (distances between transmitter and receiver dipoles) was, like the measuring point distance, 10 - 30 m (depending on the pulse centre frequency).

The velocity of electromagnetic waves is an important parameter for converting reflection travel times into the corresponding distances. To determine this parameter, travel time measurements were carried out in various exploratory boreholes and measurements of the permittivity were made on core samples.

The second important parameter influencing the propagation of electromagnetic waves is the specific wave attenuation. To determine the attenuation factor of different sections of the granite within the Test Site area, measurements of the electrical conductivity were made by applying Schlumberger soundings.

5.2.4 Data Acquisition and Evaluation (EMR)

The pulse-shaped wave trains (centre frequency selectable between 10 and 100 MHz, depending on the desired range) sent by the transmitter antenna are received by the receiver antenna as direct and reflected waves, amplified and then displayed in function of the propagation time on the oscilloscope along a trace. Here, the travel time of the direct wave serves as the zero time, also called the trigger. Since the direct wave (air and rock guided) has an amplitude of more than 10 times than of the first reflected wave, this trigger has proved to be reliable.

The oscillogrammes are photographed with a polaroid camera for later evaluation.

The actual interpretation, in general a correlation of certain phase trains, is made after mounting the individual traces appropriate to the layout geometry.

5.3 Underground Seismic Testing (US)

5.3.1 Basis

From the physical point of view, methods for determining the geometrical boundaries of the host rock are subdivided into three groups: Potential-methods (gravimetry, magnetics, geoelectrics), diffusion-methods (magnetotellurics, VLF magnetics, long-period seismics) and wave propagation-methods (reflection and refraction seismics, radar).

Wave propagation methods, by their very nature, provide the best structural resolution. Therefore reflection seismic is of special importance for a preliminary host rock investigation.

The quality testing of a volume of host rock itself (this is understood to be the clear discrimination between layout determining weak zones and compact rock formation) can only be carried out within certain limits, given by the resolution of reflection-seismic measurements or radar. In such a case, ray-scanning methods for a more detailed examination of the host rock can be used to advantage.

The principle of this method is to scan ("X-ray") the rock formation between several boreholes or tunnels in all possible directions with seismic or electromagnetic waves and to register (Fig. 12) the changes in the wave propagation caused by the inhomogeneity of the rock formation. The measured data are then transformed with a certain mathematical formalism into a parameter display, e.g. the absorption of seismic waves as a function of coordinates. This parameter display is called a Seismic Crosshole Tomography (SCT) of the scanned section.

The quality of the tomography depends on the ray coverage of the section concerned. In practice, a resolution of 2.5 x 2.5 m can be achieved by seismic tomography, for a quadratic section between two boreholes approx. 150 m apart and each 150 m deep. Smaller water-conducting zones (0.5 - 1 m) accompanied by an impregnation area, will still appear in the tomography.

First investigations in this direction have been carried out as a part of the STRIPA program. The results were encouraging. However, it was also realised that a considerable amount of development work would still be necessary to make the SCT an efficient routine technique in the future. The GTS will provide a good experimental field for such further work.

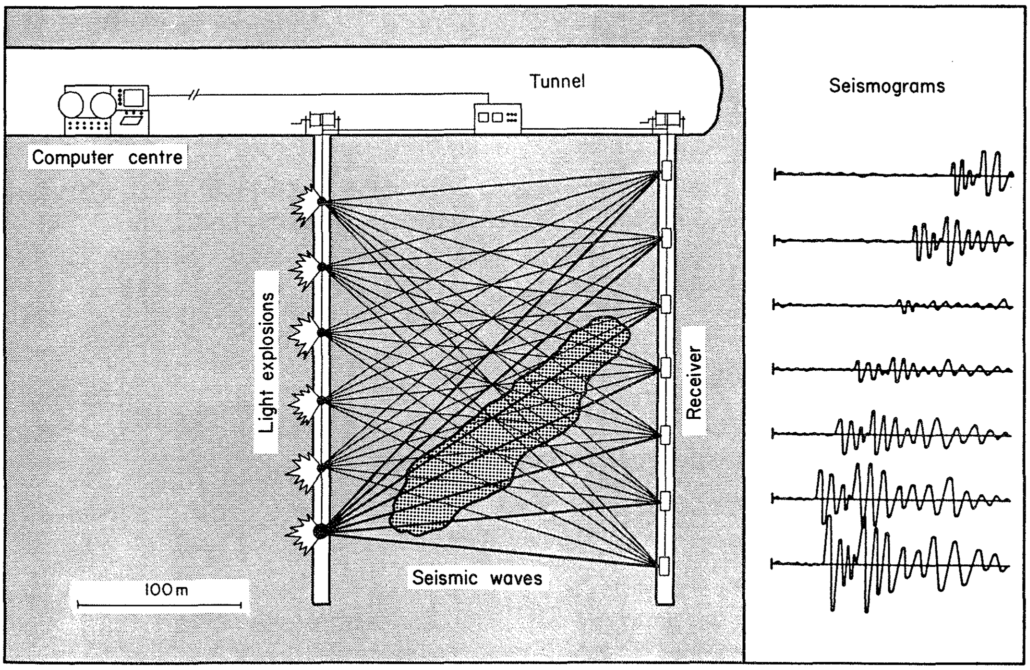


Fig. 11: Principle of the seismic crosshole tomography

5.3.2 Investigation Targets (US)

The seismic Crosshole Tomography (SCT) method shall be optimised to such an extent that it can be used as a routine method, in order to be able to carry out a detailed and comprehensive investigation of the host rock volume with the minimum mechanical disturbance. Individual targets are as follows:

- **Testing** the SCT for investigating zones of weakness in the host rock.

  Using on the experience gained from tomography experiments in Sweden and Canada, and by carrying out the SCT under strictly defined experimental conditions, the northern area of the GTS, as shown by the model case, will be scanned to obtain a high-resolution tomographic image of the existing zones of weakness. Here, the important objective is to gain knowledge of the new measuring and evaluation techniques.

- **Efficiency Analysis and Optimisation** of the SCT.

  The analysis of the various tomographic experiments to be carried out at the GTS will show, in combination with model calculations, which experimental arrangement guarantees maximum resolution under favourable time and cost terms. At the same time, the efficiency analysis can be used to derive the different conditions for optimising the method:

  - Cost-effective arrangement of the source- and reception boreholes
  - Efficient ray coverage of the crosshole section for maximum resolution
  - Further development of source-, receiver- and recording units to achieve time and cost saving routine application
  - Optimisation of the data inversion techniques.

- **Preparation of Basic Planning Principles** for the **Application** of the SCT at final repository sites.

  The analysis of the tomography experiments in the GTS should permit basic planning principles to be established, which guarantee a successful application of the SCT, independent of the type of rock mass under investigation. These planning principles form the basis of the location-specific conditions of application of the SCT.

5.3.3 Test Arrangements (US)

A compact volume of rock, with a few but striking traces of disturbances, having a surface area of 250 m x 225 m and a height (coverage) of a few hundred metres, is required as the test area. It should be framed by a tunnel borehole-system, arranged if possible in a similar manner to a final repository. The northern area of the GTS fulfils this requirement.

For the SCT programme, three boreholes, each of 101 mm diameter and 150 m length, must be drilled at distances of 75 m and 150 m apart, dipping downwards at 15° from the testing tunnel in the WNW direction (Fig. 13). They must be fully cored and logged by geophysical methods.

The steps of the SCT program are:

- **Model calculations and test measurements:** For the optimisation of the planned measuring program, field parameters are better defined

- **Drilling and logging of the three SCT boreholes:** Careful core mapping and geophysical logging must result in a maximum of geological and petrophysical information

- **Scanning B1-B3:** The measurement will be made by two companies, with SCT experience, independent of each other. They will serve primarily as a comparison of working methods and measuring equipment

- **Scanning B2-B3:** This space-confined scanning is used to test the efficiency of the SCT with respect to the structural examination of fractured and sheared zones

- **Scanning B1-B2:** This scanning produces very narrow ray coverage up to relatively steep angles. A fine-structured tomography of the fractured zone S1b and the surrounding rock is expected

- **Scanning earth's surface-testing tunnel:** This scanning should lead a 3-D extrapolation position of the zones of weakness reconstructed tomographically at the borehole levels. It should also show that with an additional measurement, the information can be transferred from the two-dimensional cross-section to the third dimension.

5.3.4 Data Acquisition and Evaluation (US)

For each of the above mentioned scans, an average of 10'000 - 15'000 already stacked seismograms will be recorded. At the site there will be a continuous quality control of the measured data made by special computer programs (e.g. propagation time displays) as well as an immediate field tomography with BP inversion techniques (Back Projection).

The controlled sets of data will then be analysed in computer centres and inverted into parameter sectional views (velocity and absorption tomography) of the crosshole sections between the individual boreholes. In this phase, which is at least as important as the data recording, different inversion methods will be tested and a simultaneous efficiency analysis of these methods will be made.

Using the experience gained, additional inversions, with numerically reduced ray coverage, will be calculated. The results will represent the bases for optimising field work and inversion techniques for the later application of tomography in final repository areas.

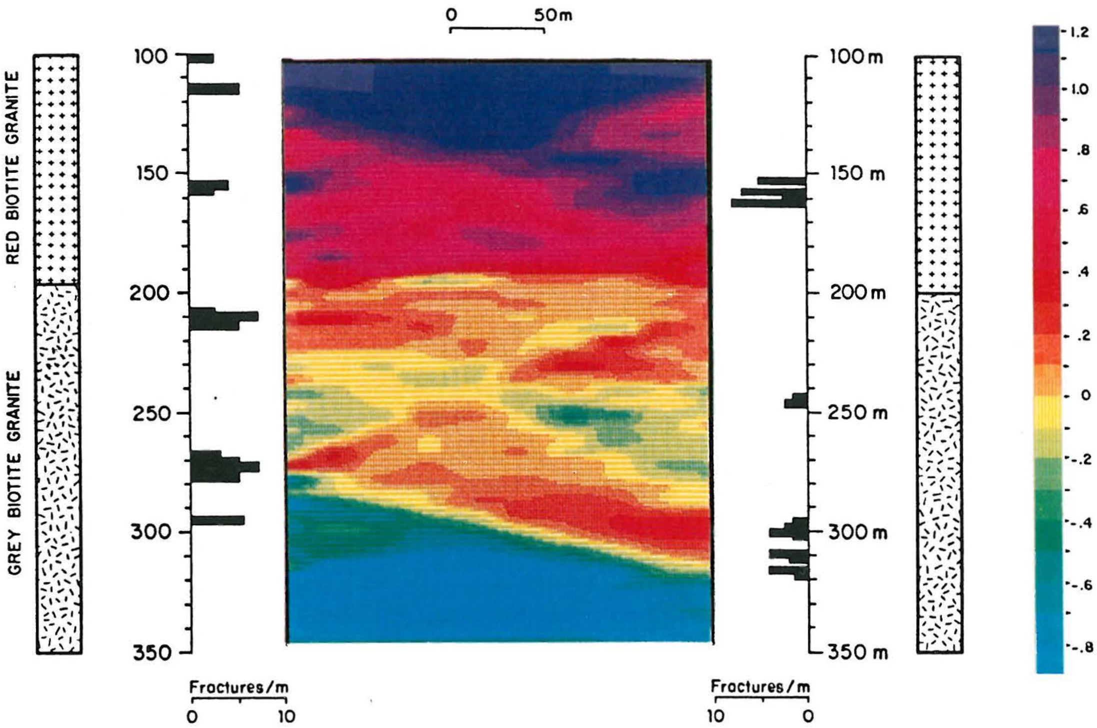


Fig. 12: Example of a seismic crosshole tomography (Wong, URL)

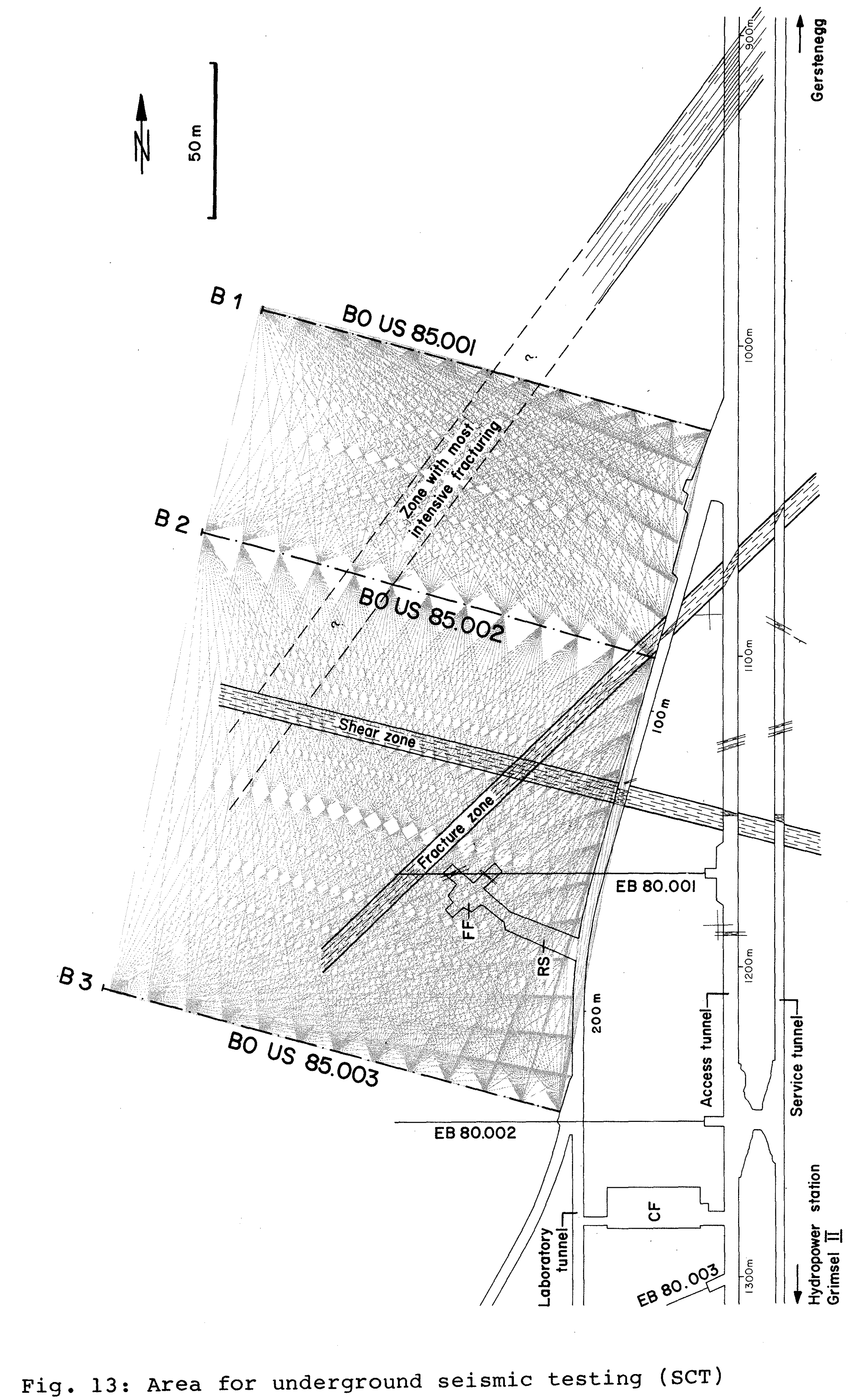


Fig. 13: Area for underground seismic testing (SCT)

5.4 Tiltmeters (TM)

5.4.1 Basis

Three Askania tiltmeters are already being used in the Konrad mine with the same objectives as those of the Basic Program (section 2.5.3). Measurements with the first tiltmeter began in May, 1981, those with the other two tiltmeters at the beginning of 1983. The question of a recent activity of the observed faults can not yet be answered conclusively, but the tiltmeters have indeed fulfilled the expections placed in them. From the experience gained at the Konrad mine, the following problems are associated with tiltmeter measurements:

- **Long-duration measurement:** For an evaluation of the measurements with respect to recent aperiodic tectonic movements, a recording time of well over one year is required, without long lapses (some days)
- **Instrument drift:** The instruments exhibit a long-term drift, the magnitude, direction and cause of which are not known in all their details. The methods used till now to determine this drift must be improved on the bases of the measurements and further developed
- **Evaluation and modelling:** Tilting caused by air pressure changes, temperature waves, etc. can only be separated by accompanying measurement of these parameters. Tilts can be caused by changes in the water levels in fractures, but these are difficult to measure. To prepare model calculations for this problem the fracturing and the water conductivity of the formation must be known very exactly, whereby in the case of a fracture with a complicated structure, even a model calculation is extremely complex.

5.4.2 Investigation Targets (TM)

The basic suitability of these tiltmeters for measuring neotectonic movements in the investigation of final repository sites is to be clarified by answers to the following questions:

a) Which tilts in the rock formation result from the differences in the water levels of the reservoirs (lake Grimsel etc.)? Can tilts be ascertained from local or regional air pressure changes and other meteorological effects (e.g. rain, wind pressure)?

b) Have there been recent tectonic movements in the region under investigation? Are these movements continuous or do they occur in spasms or as episodic phenomena?

c) Are movements of the rock formation induced by earthquakes and/or are existing fault areas reactivated by earthquakes?

d) Which movements are caused by thermoelastic effects? Can changes in the elastic parameter of the rock, caused by heating, be ascertained with the aid of tiltmeters?

The methodic targets are:

e) Improved determination of the instrument drift and its separation out of the measured data.

f) The specification of required conditions and prerequisites for measuring local and regional, recent, aperiodical, episodic or spasmodic movements with vertical tiltmeters.

g) Testing the long-term stability of the instruments with respect to their possible use for the longterm monitoring of final repositories for radioactive waste.

5.4.3 Test Arrangements (TM)

Three Askania tiltmeters will be arranged each in a vertical borehole 30 m deep in the access tunnel of the KWO, between km 1.30 and km 1.75. These three tiltmeters serve primarily to measure rock formation movements resulting from level deviations in the reservoirs. Three additional such tiltmeters will be installed each in a 20 m deep borehole in a triangular installation surrounding the heaters for the heat test. Their main purpose will be to measure movements induced by heat. Figure 2 shows the location of these six tiltmeters.

The rock formation of the Juchlistock is characterised by the presence of several steep-standing compact discs or prisms of rock flanked by disturbance zones (chapter 7). Appendix 3 shows the relationship of the three tiltmeters in the access tunnel to the geology of the Juchlistock. An effort was made to place the measuring points in compact rock bodies which are separated from each other by pronounced disturbance zones which can be followed up to the surface.

The tiltmeters 1 and 2 encompass the disturbance zones in s_1 in the access tunnel between tunnel meters (Tm) 1420 and 1450, which also appear at the surface as prominent discontinuities in the terrain. Between the tiltmeters 2 and 3 are disturbance zones in s_1/s_2 (Tm 1575 - 1585) and k_2 (Tm 1692 - 1698). Both disturbance zones could also be observed at the surface of the terrain, whereby the former must probably be associated with the "Geisschälen". The tiltmeters can provide information as to whether or not deformations still arise today along these disturbances, on which strong shifting is presumed to have occurred during the orogeny.

The three tiltmeters surrounding the heat test lie outside of the actual heat field, but still near enough to be able to measure the tilts in the rock bodies produced by the heat-induced shifting and rearrangements of stress. Of interest here also, are mainly any signs of deformation in the region of the lamprophyre zone near the heater.

After the running-in phase (approx. 4 - 8 weeks), the tiltmeters will record continuously. The signals will be analog filtered and the recordings will be made in two frequency ranges. In addition to the tiltmeters, six microbarographs (one outside each of the boreholes) and three temperature gauges will be installed. The barographs have a measuring accuracy of $\pm$ 0,3 mbar. Figures 14 and 15 show a section through the borehole and the tiltmeter.

5.4.4 Data Acquisition and Evaluation (TM)

The physical parameters such as temperature, pressure, air humidity, etc. will be converted by suitable sensors into electrical signals. These will be amplified in the measuring area and then transmitted by cable in digital or analog form to the EDP installation in the computer room in the Central Facilities Building.

The central EDP installation of the GSF in the CF is used for the tests with tiltmeters, the ventilation test and the heat test. It can serve 1'100 measuring points. At the present time approx. 600 measuring points, including the process control of the heat test, are foreseen for these tests. The entire sequence of the measuring program is supervised by process computers which control all three tests and evaluate and store the measured data. Error and alarm indications are given in critical situations which are detected by monitoring the measured values.

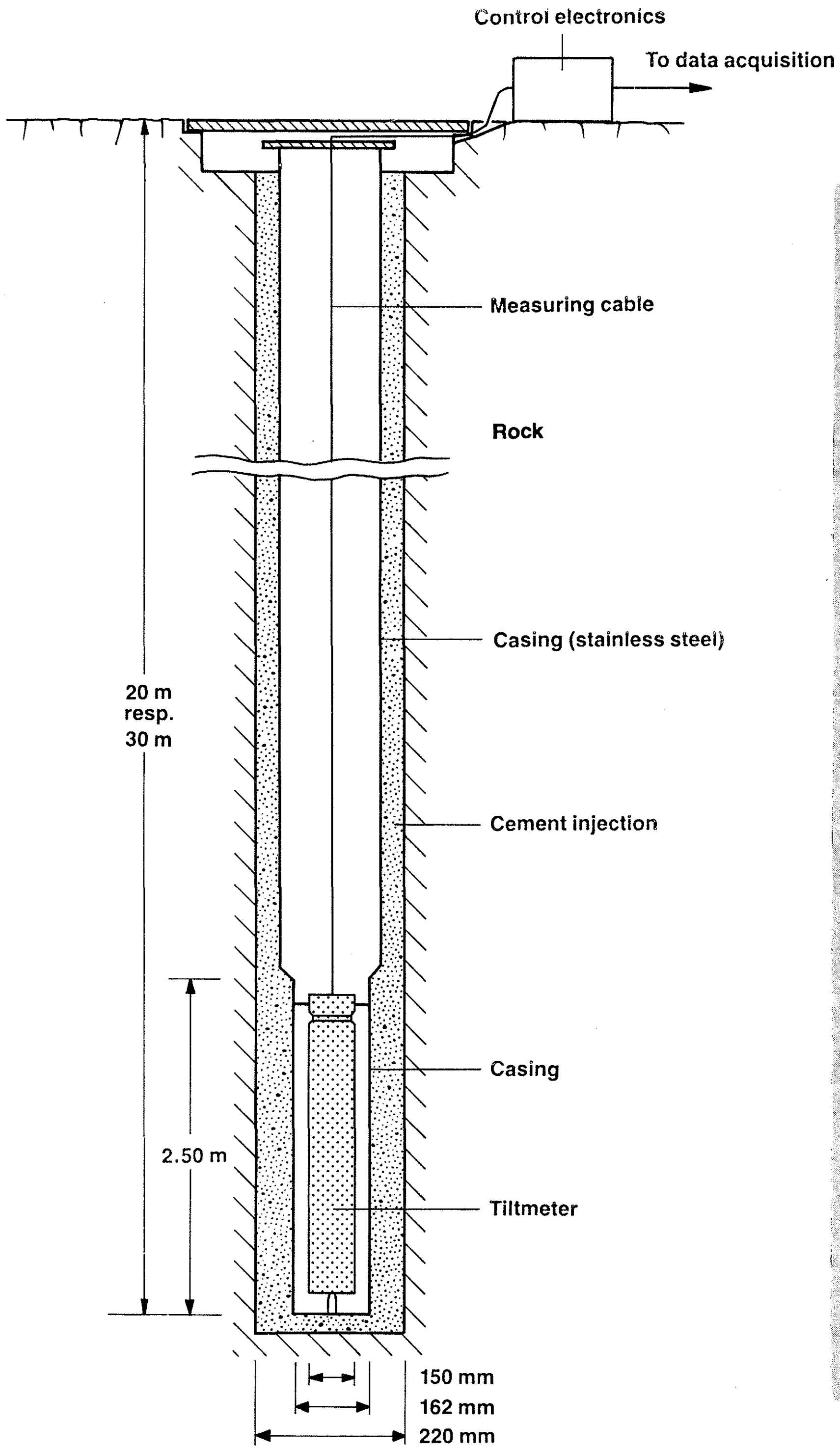
A Nova 4/X computer with 128 KW storage capacity is used to coordinate the entire measuring sequence and to control various other processes. The unit can be operated via the Remote Control Interface and a Modem. A Nova 4/C computer with 32 KW storage capacity is foreseen for the detection and data acquisition (acceleration tests) for seismic events.

For the evaluation of the measured data, two basically different methods, as described briefly below, will be used:

a) First, the known signals (e.g. earth tides) are subtracted from the measured data. The remaining signal (residual curve) is then analysed with statistical examinations and model calculations. For example, the residual curve so obtained, is examined for possible relationships with meteorological data and the levels of the reservoirs. If relationships are suspected, model calculations with finite elements are used to explain more closely the physics of these relationships and to quantify the interaction

b) In the case of causal relationships, the measured tilt curve is determined by the transmission function of the rock. If the transmission function is subject to time-based change caused, for example, by heating, the type of change and the magnitude of the changed volume must be determined in detail by using inversion calculation

The emphasis for the modelling lies on the one hand in determining the boundary area to the lamprophyre, and on the other hand in truly representing the tunnel system. In addition, FE calculations are made for tunnel convergence, first cylinder-symmetrical, then in a 3-D model. These calculations provide information on convergence movements at large depths, which influence the tilt measurement.



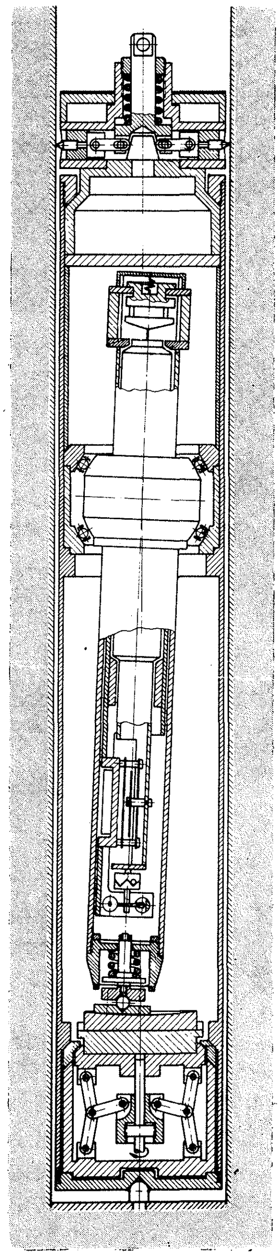


Fig. 14: Installation of tiltmeters

Fig. 15: Cross-section through the Askania tiltmeter GBP 10

5.5 Fracture System Flow Test (FF)

5.5.1 Basis

Assuming that the containers of contaminated substances disposed of in openings excavated for this purpose in rock bodies will ultimately leak, rock-mechanic studies are necessary so that the spreading processes can be assessed. Tests must be made to trace the water paths in joints and faults in a largely impermeable rock matrix. In addition to the natural fracturing in the rock, the mining of the caverns and tunnels may cause further fracturing or alter the primary joint systems.

It is necessary to determine the permeability of certain regions of rock as a function of direction and to quantify the hydraulic properties of the individual fracture systems or of several large fractures. Pressure tests are used for this purpose.

The predecessor of the present testing installation was used in granite and in Bunter sandstone. The BGR had to draw up engineering-geological and rock-mechanical criteria for evaluating sites for underground nuclear power stations. The results of the flow tests (about 355 tests) can be summarized as follows:

- Water passage occurs only in the fractures

- The permeability of the fractures is 100 to 1000 times greater than that of the rock

- The pressure produced in the granite and Bunter sandstone decreases to nearly normal within 50 to 100 m of the point of injection

- The spreading velocity in the fractured rock can, under unfavourable geological conditions, be 2 to 3 orders of magnitude greater than that in unconsolidated rock with the same permeability

- The size and nature of the fractures (e.g. width of opening, roughness, degree of separation) can vary greatly from one fracture to another, even in rock with apparently regular fracturing, so that there are large differences in permeability between fractures

- Boreholes provide a large number of possible pathways for water in the rock. These pathways must be closed, e.g. by filling the borehole with cement or bentonite.

5.5.2 Investigation Targets (FF)

In addition to the targets mentioned for the Basic Program of the GTS as a whole, all of the measuring equipment must be tested for its usefulness in the investigation of sites in crystalline rock being considered for permanent repositories.

Moreover, the results of the in situ measurements should be compared with those obtained from model calculations to establish whether model calculations can be used to determine the flow conditions in a geologically well-known fracture system, possibly aided by key measurements made in a few boreholes.

5.5.3 Test Arrangements (FF)

A special cavern was excavated for the FF test. Ten to twenty observation boreholes will be drilled around a central injection borehole. The diameter of all the boreholes is 86 mm. The geological conditions prevailing in the area of the RS/FF cavern are described in detail in section 7.7.5. The corresponding geological section is shown in Appendix 7.

The test is carried out in three phases in such a way that hydromechanical changes in the fractures are avoided. Each phase includes the following steps:

- Obtaining new knowledge of the geological structure (by examination of the drilling cores)
- Determination of existing hydraulic conditions (e.g pressure, flow)
- Flow tests
- Planning of the next phase.

Depending on the results of the preliminary tests, the flow tests are carried out by controlling the pressure or quantity of the injected water. If possible the boreholes are so arranged that a closed water system is tested. To determine whether such a system is present, an exact geological mapping of the surface area is made, possibly supplemented with aerial photographs.

The interpretation of the injection tests is done on the basis of the pressure-volume ratio. In the injection borehole, the injection segment is sealed off using a pneumatic quadruple packer with segment lengths of about 2 m (Fig. 17) and, if necessary, a hydraulic double packer with a segment length of about 1 m. The observation boreholes are subdivided into individual segments by pneumatic packers and several probes.

A schematic of the test arrangement is shown in Fig. 16.

5.5.4 Data Acquisition and Evaluation (FF)

The measurements obtained from the individual probes are transmitted to a computer (DEC or HP 98365 and HP Multi-programmer 4942A) and stored on discs.

The evaluation consists essentially of a comparison of the measured data with the results of the model calculations. These calculations are carried out using the finite-element method (FE) and other methods. Closed solutions, however, can provide only a rough indication of the permeability of the rock. The FE calculations assume an approximate, anisotropic continuum and a discontinuum. The FE models must be calibrated using simple in situ and laboratory tests.

Since the permeability of the rock under certain circumstances is higly dependent on the pressure in the fracture fill, the permeability calculation must be preceded by calculation of the stress and strain. This will provide an indication of the width of the fractures after opening by the injected fluid. Additional tests in the rock mechanics laboratory are necessary for this.

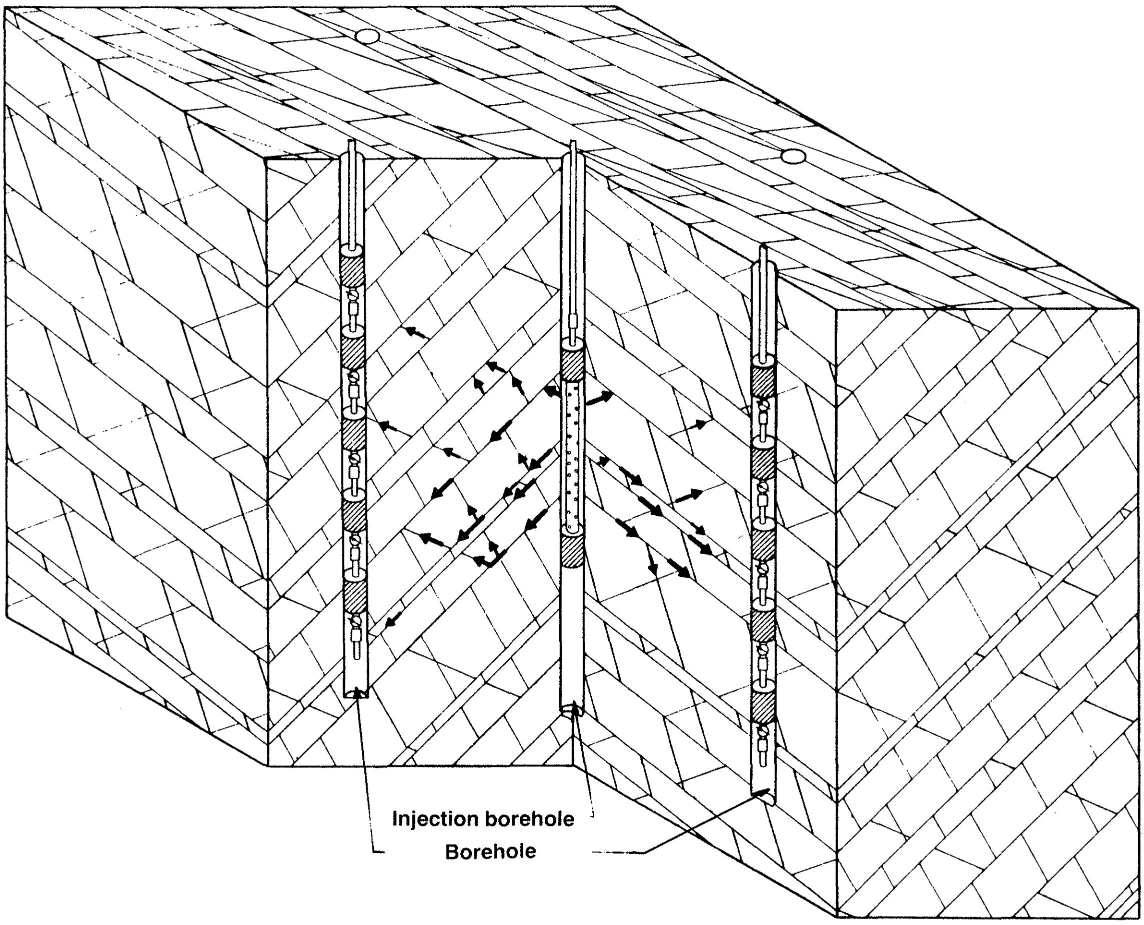


Fig. 16: Principle of the fracture system flow test (FF)

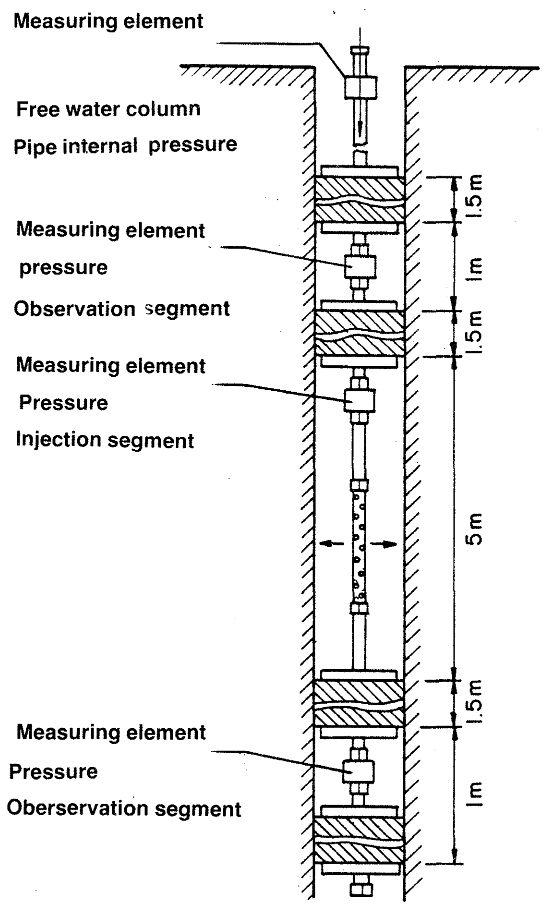


Fig. 17:
Quadruple packer (FF)

5.6 Ventilation Test (VE)

5.6.1 Basis

The hydrogeological conditions of the rock formation are of decisive importance for judging the long-term safety of a final repository for radioactive waste in geological formations.

Assuming that rocks with an appreciable and measurable water conductivity can never be considered for the final disposal of radionuclides with long half-lives, the measurement of low and very low rock moisture quantities, including the investigation of their pathways and mechanisms of spreading, becomes the centre of main interest of the hydrogeological investigation of any final repository site.

A ventilation test was first conceived and developed in Stripa, and carried out between October 1978 and September 1980. As a result, important hydrogeological parameters were determined in a dense and large-volume rock body. However, because of the relatively short time over which the test was run, the measurements give little information about the hydrogeological long-term behaviour of the granite.

Based on the experience gained at Stripa, perparatory work was started in 1980 for a ventilation test in the Konrad mine which, after some test runs, has been in operation since January, 1984. Here, the test concept was basically the same as in Stripa, but the accompanying measurements were adapted to suit the different hydrogeological conditions of the sedimentary iron ore.

Although the investigation areas in Stripa and at the Grimsel both lie in granite, the hydrogeological conditions are very different. In Stripa the water conductivity is related to a communicating fracture system, while at the Grimsel, the water appears only in a part of the fractures, and partly with different pressures. Furthermore, at the Grimsel there is a certain amount of water held in strongly schistous zones in the Grimsel granodiorite. The measuring techniques were adapted to suit these specific conditions.

By boring the testing tunnel with a tunneling machine, the disturbance of the surrounding rock caused by excavation was reduced to a minimum. Maintaining an almost circular cross-section ensures simple geometrical conditions in the ventilation tunnel which benefits the measurement of rock parameters and characteristics, as well as the subsequent data interpretation and the model considerations. Thus, the test at the Grimsel also represents a further development in this respect.

5.6.2 Investigation Targets (VE)

Through a series of individual tests and measurements, an adequate basis of measuring data must be procured to permit the determination of the macro-permeability of the rock and the modelling of the flow potential in a larger volume of rock with the aid of numerical methods. This does not only concern the determination of the present condition, but also the forecast of the long-term rock behaviour, which is important for the safety of the final repository.

A whole series of further developments in testing technology must be tried out. For example, it should be possible, by using flexible (inflatable) isolating "walls", to partition off gas-tightly the actual measuring area, in order to separate sections of rock of evident permeability from other sections which can be regarded as tight in the technical sense. This will considerably increase the informative capacity of the measurements. Using a closed circulation system with a built-in cooling trap will ensure almost total independence from the climatic conditions existing in the other tunnel systems.

The information capacity of the measured data must be increased by carrying out a number of accompanying measurements such as geophysical borehole logging (electric-log, sonic-log, etc.) and cavity deformation measurements (precision convergence measurements) on a selected profile cross-section, a number of laboratory tests on drilling cores and possibly geoelectrical measurements according to methods developed in the Konrad mine.

5.6.3 Test Arrangements (VE)

A tunnel (3,5 m dia.) approx. 70 m long was machine bored for the ventilation test. Using (movable) isolating walls, this length of tunnel was subdivided into a 30 m long front portion with fractured and humid rock, and a rear portion with less fractured and relatively dry rock (about 40 m). The geological situation of the VE test area is described in section 7.7.2. Appendix 4 shows the corresponding geological sections.

From a cavern situated in front of the testing tunnel, two boreholes, approx. 110 m long (86 mm dia.), were drilled parallel to the testing tunnel, at distances of 1,75 m and 3,5 m from the tunnel wall. The exploratory boreholes EB 83.001 and EB 80.005, which cut across the near field of the ventilation tunnel, are also included in the test. Fig. 18 shows the basic principle of the test arrangement. In the boreholes, the existing fracture systems are closed off, where possible, by multi-packer systems in order to be able to observe pressure rises, pressure changes and the temperature of the inflowing formation water in these sections.

The data base to be produced consists of the following **individual measurements**:

- Determining the formation water inflow in the testing tunnel by measuring the condensate resulting from dehumidification
- Measurement of the temperature distribution along the tunnel wall
- Continuous measurement of the pressure and temperature of the formation water in different sections of the rock by measurements to be made in both parallel boreholes and in the two exploratory boreholes crossing the VE-area.

The following accompanying measurements will also be made:

- Continuous monitoring of the tunnel climate, with respect to humidity and temperature
- Measurement of the air exchange rate
- Continuous monitoring of both ventilating air currents, with respect to humidity and temperature.

When the installation and preliminary tests are completed, there will be three different test phases. During the first phase, lasting several weeks, a humidity/temperature balance must be obtained. In the second phase which, depending on the hydraulic rock conditions, can last until the second half of 1986, various ventilation tests will be carried out, at first in the front sections and later also in the rear section. The third phase is again a quiescent phase during which the rock, which has been partly dried out by the ventilation, can saturate again with water. From a comparison between the third and the first test phase, conclusions can be drawn about the hydraulic capacity of the rock mass.

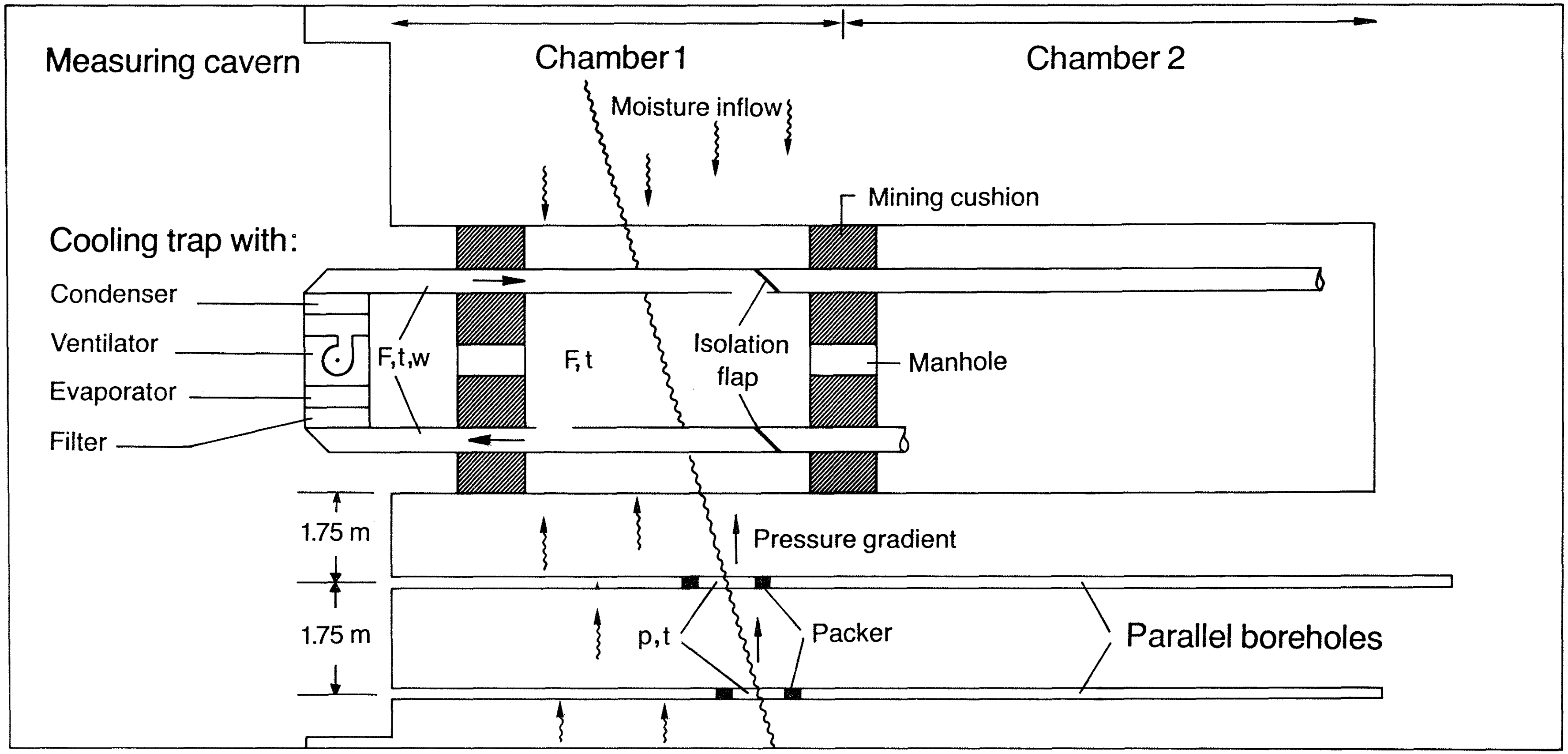
5.6.4 Data Acquisition and Evaluation (VE)

Data acquisition is carried out in the central EDP installation of the GSF (section 5.4.4). For the ventilation test the processing and transmission equipment for the measured values is mounted in a central panel. The input amplifiers are connected to the Multicon reader parts via cross-connection fields (distribution switches). In the main test field, the reader part consists of four basic units, each with 32 channels. There are two basic units, each with 32 channels available for the external measuring points. The information is transmitted to the computer station once every hour.

By using statistical methods such as, for example, regression analysis, intermediate evaluations are made for the individual tests and test phases, on the bases of which the further progress of the test is decided upon and controlled.

From a comparison of the ventilation tests to be carried out in the two ventilation tunnel sections, it is possible to make an estimation of the permeability of unfractured and fractured rocks (separately).

Provisional calculations are made according to the THIEM equation, which is applicable for modelling a radial water flow directed at the tunnel axis. It is intended to compare the test results with the results obtained from the Stripa and Konrad ventilation tests, to interpret the measured values in relation to the different types of rock conditions, and finally to use this comparison to prove the suitability of the test methods and the evaluating procedures.



Measured values

F: Relative humidity in %

t: Temperature in °C

w: Air flow in m/sec

p: Pressure in bar

Fig. 18: Schematic layout of the ventilation test

5.7 Excavation Effects (EX)

5.7.1 Basis

The excavation of rock cavities (tunnels, caverns, shafts) disturbs the original or "primary" state of stress in the rock formation; rearrangements of stress occur, which lead to deformations and, in many cases, to signs of fracturing. Not only these occurrences, which accompany the transition from the primary to a secondary state of equilibrium, but also the vibrations and gas pressures resulting from blasting operations, cause loosening up of the rock formation in the vicinity of the excavated area. These excavation effects can make themselves apparent in several ways:

- The displacements at the excavated soffit, and in the loosened-up zone behind it, might be greater than those which would be expected from conventional calculations

- Various geomechanical characteristic values, such as the compressive strength and the deformation module of the rock, as well as the propagation velocities of seismic are reduced as a result of the reduction in compactness of the rock.

- Existing and latent joint faces open up and increase the permeability of the excavation zone.

The intensity and the extent of the excavation effects which result from the construction of underground openings depend on a number of factors:

- Type and structure of rock formation, (size and shape of fractures, condition and filling of the joint faces), anisotropic compactness and deformation behaviour

- Primary state of stress of the virgin rock, including tectonic residual stresses,

- Mountain water conditions (pressure and flow conditions, flushing property of the fracture fillings)

- Cross-section (size, shape) and orientation of the underground opening

- Method of constructing the tunnel or cavern: excavation (tunnel boring machine or blasting operation) and supporting method (e.g. American steel shoring, new Austrian method of tunnel construction).

5.7.2 Investigation Targets (EX)

The aims of the test for excavation effects around underground openings can be subdivided into the following three groups:

- Physical signs: The different physical signs of the looseningup of the rock must be clearly defined, and criteria must be developed to be able to quantify them reproduceably. The signs of disturbance by tunneling must be measured. The low rock permeability and the careful excavation of a tunnel section with a tunnel boring machine places exceptional demands on the sensitivity and accuracy of the measuring method. Known methods must be tried out and partly developed further.

- Mathematical model: The results of the mechanical, physical and hydraulic investigations will be checked using calculation models, by means of which characteristic values of the corresponding rock formation can be back-calculated, partly conclusively and partly by tentative iteration. If necessary, the mathematical behaviour models must be varied until a satisfactory agreement with the measured results is achieved. For the future, such revised calculation models can then be used to forecast the behaviour of the rock, including the excavation zone.

- The search for correlations: Attempts must be made to find good correlations between characteristic values of the different rock formation in order to be able to make forecasts, if possible, in the future on the behaviour of the rock formation, based on fewer, more easily obtainable, rock parameters (e.g. sound propagation velocity). The costs of similar investigations in the future could then be considerably reduced.

5.7.3 Test Arrangements (EX)

The excavation effects testing area lies in the southern part of the Test Site, completely within the region of the Grimsel granodiorite. The general geological situation of the area through which the test tunnel was excavated by the tunnel boring machine is described in section 7.7.3. Appendix 5 shows the corresponding geological sections. The actual test areas for the boring and blasting sections are each 30 m long. Between these lies the measurement cavern from which an inclined shaft leads to the access tunnel and then to small measurement tunnels lying 12 m above the test area. Figs. 19 and 20 show the test arrangement, with the measurement boreholes, some of which cross through the excavation profile and some of which are parallel to the testing tunnel.

After the access shaft to the measurement cavern, the measurement cavern itself, and the measurement tunnel were excavated and the measurement boreholes made. The boring of the test tunnel was executed in about four weeks towards the end of 1983.

Very careful geological surveys were made before and during the tunnel boring, based on wall and drilling core mappings. Particular attention was given to the petrography, the structural elements (orientation of the joint face bands, degree of splitting, opening widths and fillings, roughness of the joint faces) and the water inflows (quantity, temperature, chemical composition). The results of these geological/hydrogeological surveys are summarized in chapter 7. In addition, geophysical surveys, mainly sonic-, gamma-, neutron- and resistivity-logs were made in selected transverse and longitudinal boreholes.

The individual measurements are described briefly in the following paragraphs:

Sliding micrometer measurements can be used in boreholes to measure the longitudinal displacement between two points lying 0,5 to 1,0 m apart, with an accuracy of $\pm$ 0,003 mm. The changes in the lengths of boreholes caused by tunnel construction give valuable information about the intensity of the loosening up of the rock and the depths of the area in which it occurred.

Convergence measurements between gauge pins placed in the tunnel walls, give information about the relative displacement of the tunnel walls. The accuracy is approx. $\pm$ 1 x 10^{-5} of the measured length, i.e. approx. $\pm$ 0,04 mm for a tunnel diameter of 3.50 m.

A **dilatometer probe** is used in different boreholes to determine the deformability of the rock formation; the area of rock covered by these measurements is about 0,1 m^3. Here too, the high values of the rock deformation module (guide value approx. 30 GPa) makes extreme demands on the measuring accuracy.

Using special **pressure cushions**, the deformability of the rock is measured additionally, in slots of about 1 m x 1 m cut from the testing tunnel with a special rock saw. This reduces the scale effect in comparison with borehole measurements. Also, an eventual anisotropy of the deformability can be determined by suitably arranging the slots in different directions.

The sound propagation velocity in the rock formation (p and s waves) is measured by a probe especially constructed for this test. The measurements are carried out mainly between parallel boreholes by the Crosshole method. In addition, the velocity of sound is also measured in function of the distance from the tunnel wall in a series of short, parallel boreholes drilled radially from the tunnel wall. Furthermore, refraction measurements are planned, in which the receivers are placed at various points on the tunnel wall and the transmitter in one of the radial boreholes. The sensitivity of the system is about 0,1 μs, the reproducibility $\pm$ 1 μs. Phase shift techniques might be used to increase the accuracy even more, if the excavation effects are minor.

The permeability of the rock formation is measured from boreholes, using water pressure tests. Because of the low rock permeability - many tests showed less than 2 cm^3 per minute at 1 MN/m^2 pressure - a special measuring device had to be developed and constructed. Since the water circulation in the type of rock present at the GTS occurs almost exclusively along joint faces and fractures, the arrangement of the tests was made in close cooperation with the geologist. The permeability measurements between slots allow to cover a rock volume of about 2 m^3, which already constitutes a representative sample for the tight to medium-tight fractured rock formation. Three vertical slots about 1 m wide by 1.20 m deep are cut from the tunnel floor perpendicular to the tunnel axis and 1 m apart. They are sealed off by a concrete stab. Water injected into the middle slot then flows mainly in the excavation zone from the middle to the two outer slots.

The primary stresses must be known in order to be able to interpret the displacement measurements and understand the stress rearrangements and loosening up of the rock caused by excavating the tunnels. They are determined in different boreholes by the overcoring method, using triaxial cells. The primary state of stress can also be concluded from the pressure cushion measurements in the slots and by calculating back from the displacement measurements.

Laboratory experiments on drilling cores are carried out in the rock mechanics laboratory of the ETHL. They shall show to what extent and under what conditions it will be possible to estimate the expected excavation effects on the basis of laboratory tests. Such tests could be less expensive and could be carried out at an earlier stage (i.e. during the boring phase). They include, among others, single and triaxial pressure tests, fissure tension tests, measurement of sound propagation velocity during the pressure tests, etc.

5.7.4 Data Acquisition and Evaluation (EX)

Data acquisition will be made on location, according to the individual testing arrangements.

For the stress and displacement investigations, a rock disc will be modeled to illustrate a typical cross-section through the testing tunnel, the access tunnel and the measuring tunnel. For the investigation of the hydraulic conditions in the rock formation, a hydraulic model will be made for determining the flow conditions in the surroundings of the testing tunnel. In particular, the gradients of the hydraulic potentials and water quantities will be examined for the case where water is injected in one of the horizontal boreholes. It is expected that they will be a function of the depth and of the permeability of the excavtion zone. An additional rock-mechanical and rock-hydraulic calculation model will be made for the surroundings of each slot.

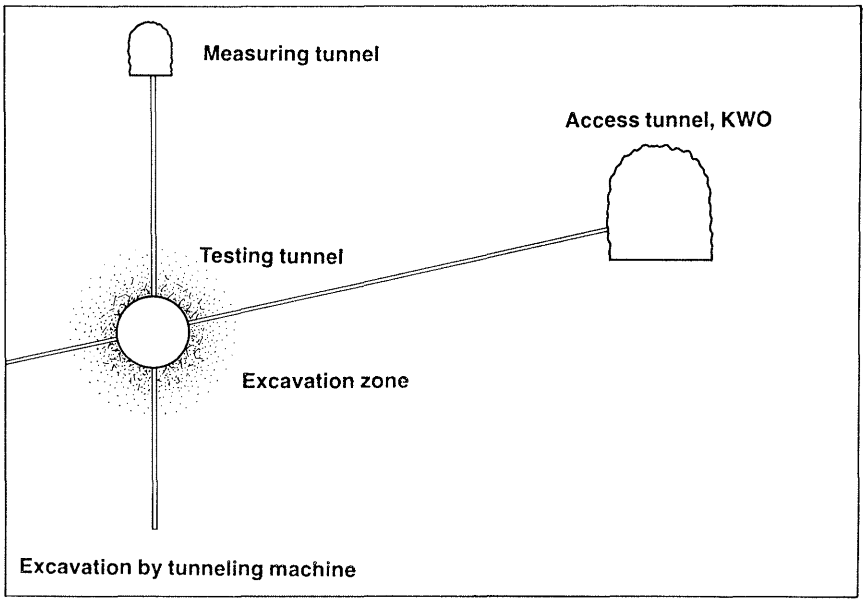


Fig. 19: Excavation test, cross-section

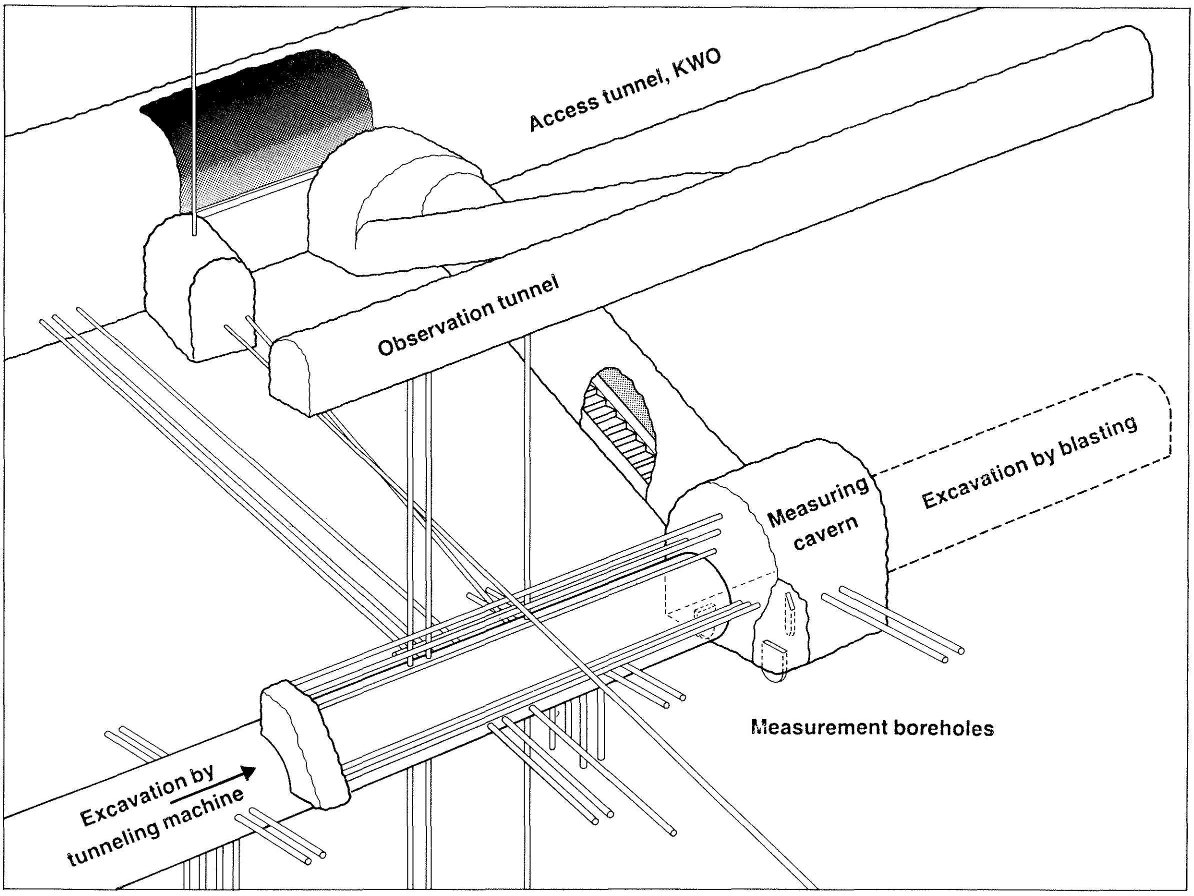


Fig. 20: Excavation test, perspective diagram

5.8 Rock Stress Measurements (RS)

5.8.1 Basis

The theoretical determination of the rock stresses in the crystalline rock formation, with its largely elastic material characteristics, would be possible on the basis of the continuum mechanics, if those stresses were only a function of the overburden weight and possibly of systematic anisotropies (e.g. pronounced schistosity). However, the primary stresses are also dependent on a number of other factors such as rock formation, acute tectonic stresses, residual stresses arising from earlier tectonic phenomena, and in particular also on fracturing of the rock massif. A knowledge of the primary state of the rock stress, which is basically important for the design of underground openings, can thus only be gained from in situ measurements.

For stress and deformation measurements in granite, i.e. in a relatively fine crystalline rock with pronounced elastic material characteristics, different measuring methods can generally be employed. For use in boreholes, these are: for stress measurements overcoring methods and hydraulic fracturing tests or flat jack tests, and for determination of the deformation behaviour e.g. hydraulic or mechanical borehole deformation tests.

Overcoring gauges and dilatometers have, however, been used by BGR in boreholes with a maximum depth of 50 m. In view of the investigations for deep storage of nuclear waste these measuring instruments have to be tested in much deeper boreholes filled with water.

The evaluation of the measurements is generally based on simple mechanical and geometrical models, with the help of which a mathematical interrelationship between the measured displacements and the stresses or the deformation moduli can be derived, e.g. for overcoring tests or borehole deformation tests. A rock anisotropy might also be taken into account, if the cores are properly orientated.

If discontinuities (fractures, fissures) are to be taken into account, closed-form analytical solutions cannot be used for the evaluation. In such cases numerical calculation methods, e.g. the method of finite elements must be used.

5.8.2 Investigation Targets (RS)

Behaviour/characteristics of the rock formation:

For the engineering-geological and geotechnical appraisal of the unfractured rock, different methods within the scope of stress and deformation measurements, shall be tested in a borehole of up to 200 m depth, in order to determine essential rock-mechanical parameters (initial state of stress, Young's modulus), without neither being affected by the disaggregation of rock nor influenced by the excavation of large underground openings.

Measuring methods and instrumentation:

Measuring methods such as overcoring tests with inductive displacement transducers or strain gauges, borehole deformation tests with a dilatometer, or direct stress measurements with hydraulic flat jacks, have generally been used in boreholes in the vicinity of cavities. At the Grimsel Test Site, an attempt will now be made to further develop, modify and test these well-known and proven methods for use in deeper boreholes.

The following investigations will be carried out:

- Borehole deformation tests with a dilatometer (BGR system) at depths of up to 200 m, as a pilot study for use in boreholes of up to approx. 1000 m depth

- Overcoring tests with measuring devices based on inductive displacement transducers (BGR system) or strain gauges at depths of up to 200 m, as a pilot study for use in boreholes deeper than 200 m

- Stress measurements using hydrofrac tests

- Long-term stress measurements for testing in deep boreholes of up to 200 m, and to compare with the results of above mentioned stress measurement methods.

5.8.3 Test Arrangements (RS)

For the tests with the individual instruments described below, one vertical borehole 200 m deep and one horizontal borehole (5° upward slope) of max. 20 m length will be made in the RS cavern. The geology in the RS region is described in section 7.7.5. Appendix 7 shows the corresponding geological sections. The geological basic surveys will be supplemented by special surveys on the drilling cores obtained during the RS tests.

The following measuring instruments will be used:

The borehole overcoring gauge, BGR system, (abbreviated, BGR gauge) consists mainly of an approx. 40 cm long stainless steel supporting body, in which displacement transducers are arranged radially at 45°, to measure independently from each other the radial displacements of the borehole wall over a range of 45 to 48 mm, with an accuracy of 0,001 mm. During the overcoring, the measured values are transmitted continuously to the recording unit. The measurement cable is led through the swivel with a special sealing. It is also possible to store the measured values in a digital cable-free data recording system directly in the borehole, at time intervals as desired.

With the existing BGR gauge, both principle stresses perpendicular to the axis of the borehole and their orientation can be detected. At an advanced phase of the test, a further developed version of this gauge will be tested which will allow to determine also the stress parallel to the borehole axis.

The CSIR triaxial cell consists of a plastic body in which three cylindrical bodies, angled at 120° to each other, are embedded. On the surface of each of these bodies are four strain gauges, displaced by 45°. The triaxial cell is installed in the borehole, aligned in direction and depth by a special rod, and affixed entirely to the borehole wall with an underwater plastic glue. The measurement of a total of 12 strain components permits the complete determination of the rock stress tensor and the orientation of the principle stress directions. The measurement of the strain at the borehole wall due to stress release can at present be made with the CSIR cell only before and after the overcoring process, but not during the overcoring process.

Dilatometer, BGR system. Three displacement transducers are spaced 120° apart inside the approx. 1 m long device. These transducers are the same as the ones in the BGR gauge described above, and can be used to measure the deformation of the rock through the rubber tube. By means of oil pressure in the rubber tube, the borehole is loaded in the radial direction. Simultaneous measurement of the deformations permits the determination of Young's modulus of the rock formation.

The concept for the hydrofrac tests and the longterm stress measurements is in preparation. The measurements at the RS test area take place mainly in the vertical borehole. As a supplement, additional overcoring tests are made in the horizontal borehole.

It was intended to carry out 33 overcoring tests with the BGR gauge and with a modified CSIR triaxial cell, 14 hydrofrac tests, 7 dilatometer tests and longterm measurements. The depths of the various tests are shown in Fig. 21. The final number of tests and their depths were determined during the execution of the tests, taking into account the geological data, the technical requirements for the tests and the results of the preceding tests.

5.8.4 Data Acquisition and Evaluation (RS)

The acquisition of the measured values for individual tests is made locally, either by reading the corresponding recorder units, or by automatic recording of the raw data. After irregularities in the raw data have been smoothed by graphical methods, the evaluation is made using different theoretical models. These models are: For the dilatometer tests, the infinitely extended disc with hole under internal load; for the BGR gauge, the disc with a hole in an infinite elastic-isotrope continuum; and for the triaxial cell, the hollow cylinder under triaxial stress.

If necessary, other analytical solutions will be drawn upon to take into account the rock-specific data (e.g. anisotropy) or test-technical data (e.g. axial stress-relief of the overcored core) and, if required, numerical calculations will be made to determine, for example, the discontinuities in the rock formation and their influences on the measured results.

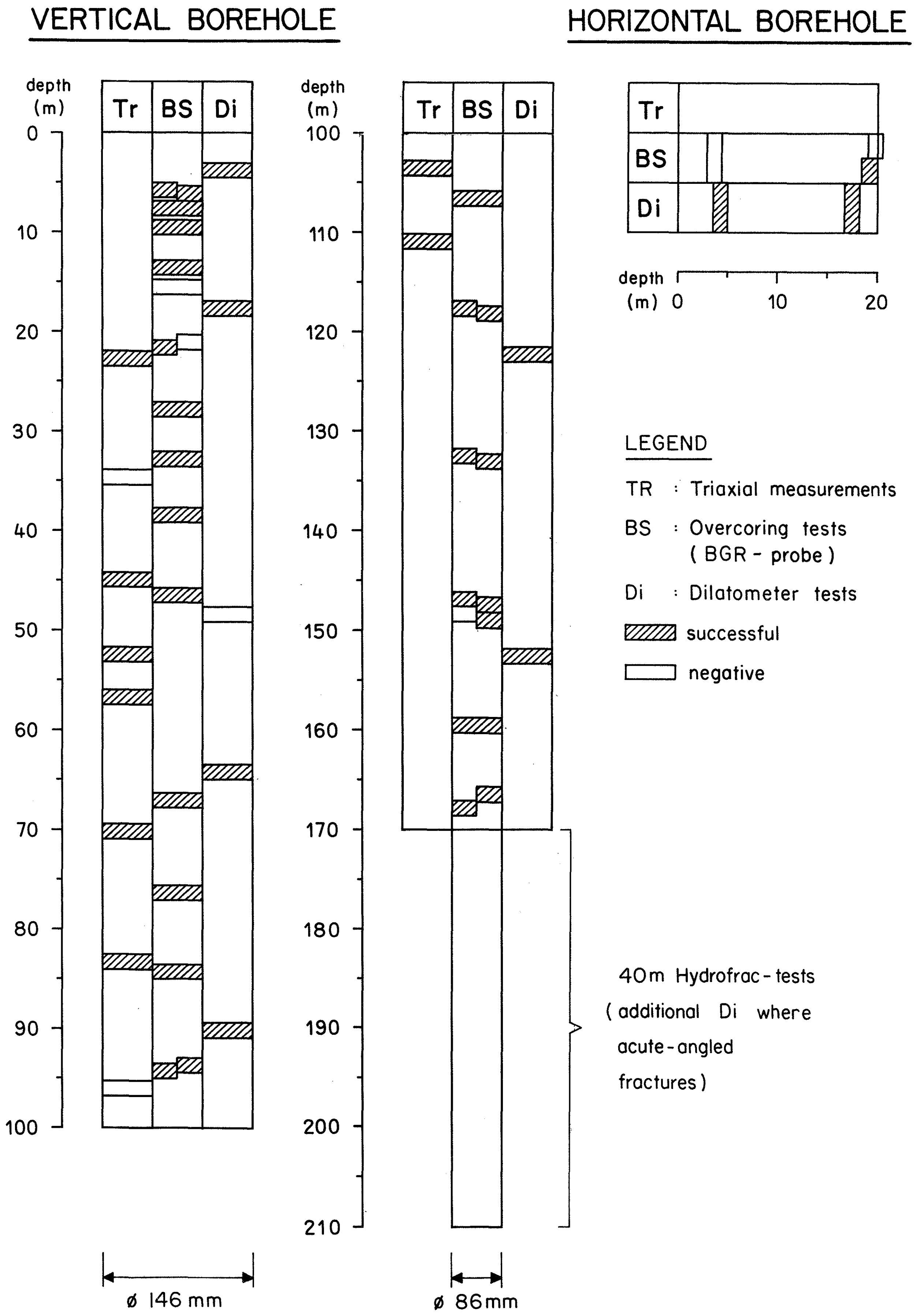


Fig. 21: Rock stress measurements, testing arrangement

5.9 Heat Test (HT)

5.9.1 Basis

The heat test being carried out at the Grimsel Test Site is a development of the heat tests already carried out at other sites. The test serves to research the reactions of the granitic host rock to a heat load such as that which would result from the disposal of radioactive waste. Of primary interest are the stresses, the deformations and the possible changes in the permeability of the rock induced by heat.

The numerous results on the properties of the granite obtained from the test carried out at Stripa, showed the way for the conceptional work on the Grimsel Project heat test. It must be noticed, however, that the types of rock at Stripa and Grimsel are basically different. Whereas the rock at Stripa is strongly fractured and wet, the Grimsel granite in the fractured zone, though saturated with water, has some almost unfractured areas which are nearly dry. Also, the test in Stripa was terminated at a relatively early stage. The experiences gained from the various heat tests conducted in salt by the GSF, serve as a valuable basis for the modelling and for the layout of the instrumentation, in particular of the heaters themselves.

FE calculations were made as the basis for the detailled planning of the heat test at the GTS. Simplified systems symmetric to an axis of rotation, were investigated in order to keep the effort within acceptable limits. Elastic properties were attributed to the rock, so that thermally induced states could be calculated independently of the primary (tectonics, overburden) and secondary (tunnel excavation, boreholes) states of stress and deformation.

In the FE calculations, the reactions of the rock formation to the influx of heat were first examined for a constant power output of 10 kW over a length of the heater of 6 m. . A cylindrical rock volume of 100 m diameter and 100 m height was modelled. These model calculations used the thermal and mechanic rock properties of the Grimsel granite and were based on the experience gained from Stripa about the behaviour of fractured granite under the influence of heat.

Some of the **most important results** of this preparatory modelling are:

- After one year there is no heating up noticeable outside a volume of rock approx. 20 m in diameter and 30 m in height

- Due to the embedding in a theoretically infinitely large massive body of rock, the local power input causes mainly an increase of stresses and only very small displacements even in highly fractured rock (in the order of max. 0.5 mm)

- At approx. 5 m distance from the heater, the rock has a temperature of only 10 % of the temperature at the wall of the heater borehole

- Open fractures with good heat conductance (e.g. water filled) at first will be closed as a result of the temperature extension of the rock. The water will be pressed out. Later they behave like closed fractures. At open fractures with pour heat conductance (e.g. air filled), there is a temperature jump which would lead to a corresponding jump in stress if the expansion was completely prevented

- After one year of heating at a constant temperature of 100° C at the surface of the heater, changes in stress outside a diameter of approx. 20 m are so small that they cannot be recorded by the conventional measuring equipment.

5.9.2 Aim of investigation (HT)

The calculations accompanying the tests will be continued on the basis of the preparatory calculations already mentioned, with updated parameters (constant temperature instead of constant power, heater geometry, thermal and mechanical properties of the granite, etc.). The calculated distributions of temperature, displacements and stresses will be compared with the measured ones. The actual aim of this test is to find those parameters which must be determined from in situ geotechnical investigations for the modelling of the heat test, such that the model describes accurately the properties and behaviour of the rock formation.

Contrary to Stripa, the heat test at the Grimsel Test Site will be run over a sufficiently long time (including the controlled cooling down) to be able to investigate the long-term behaviour of the rock under the influence of heat. Great attention must therefore also be paid to the long-term reliability of the instrumentation.

The behaviour of a fracture zone under the influence of heat is to be examined as comprehensively as possible.

5.9.3 Test Arrangements (HT)

The geological conditions during the heat test are described in section 7.7.4. Appendix 6 shows the corresponding geological sections. To investigate the effects of fractures on the thermally induced behaviour of the rock, one heater is placed directly beside the brittle, schistose transition between the Central Aaregranite and a lamprophyre vein. Thus, there are clearly definable conditions available between the compact granite and the distinct, continuous fault zone of poor rigidity (Fig. 22 and Appendix 6).

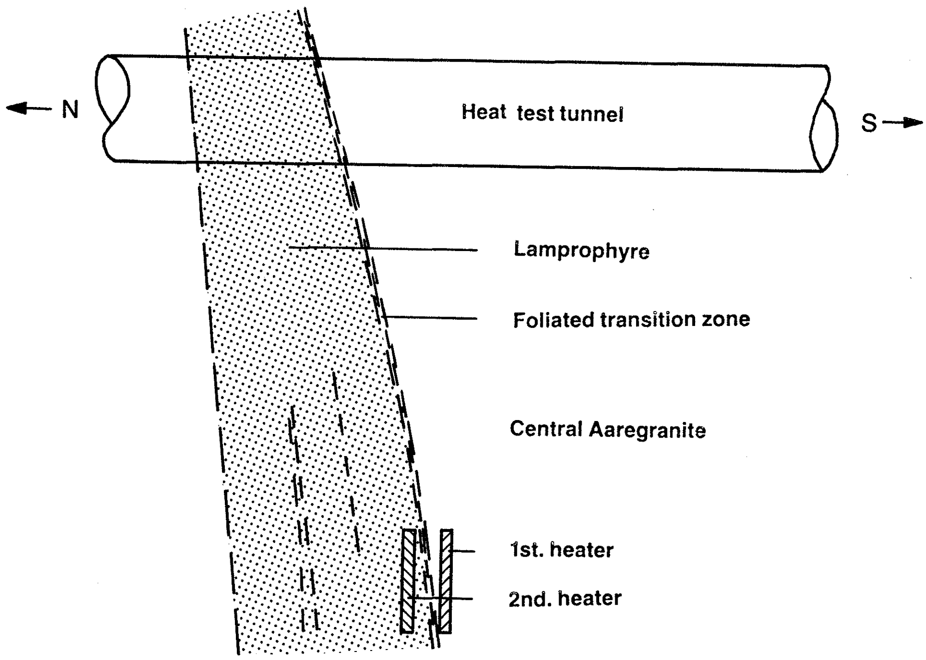


Fig. 22: Diagrammatic sketch of the heat test area (vertical section in tunnel axis)

Fig. 23 shows the arrangement of the heater and the instrument boreholes. The mid-point of the heater in borehole H 1 which will be operated at first, is the center of the heat test (15 m below tunnel soffit). Pre-calculations show that thermally induced events will not reach the tunnel.

Since the construction of the heaters and the equipment of the boreholes is of fundamental importance for the success of the heat test, they are described briefly below:

The heaters are 6 m long each and are designed for a power output of up to 4 kW/m. This means that a power output twice as much as in the comparable heat test in Stripa will be available. A very high degree of operating reliability is required of the heaters and their controls. Even very short failures can produce steep temperature gradients which could lead to fissures in the rock and thus could jeopardize the further suitability of the area. Therefore the heaters are designed for double redundancy. There is also a third heater at the test site provided for replacement.

The actual heating elements are conventional heating tubes. Short-circuit safety is doubly guaranteed by two steel casings insulated from each other and from the heating tubes. To ensure that the heaters can be recovered, both heater boreholes H 1 and H 2 are lined with a casing which is pressure-tight up to 3 bar. The annulus between casing and rock is injected with an expansive mortar with practically the same temperature conductivity as that of the granite.
The heat produced by each of the 2 m long heater sections can be controlled independently. Nine resistance thermometers fixed on the casing of each section serve as control sensors. The maximum operating temperature in the heater is 800° C. It is monitored by the automatic heater control system.

For the **stress measurement**, probes of a length of 2 m are cast with expansive mortar at a depth of 15 m in each of the three boreholes S 1, S 2 and S 3. Each probe consists of a concrete cylinder (120 mm dia.) in which eight flat jacks can register all main components of the 3-dimensional stress field. The radial and tangential stresses are measured twice. Resistance thermometers in the probes are installed for calculatory temperature compensation.

The **deformations** will be small and decrease with increasing distance from the heater. Multifold extensometers (measuring accuracy ± 0,05 mm) will be cemented into six boreholes (E 1 - E 6). An inclinometer probe in three boreholes (E 2, E 3, M 1) and an incremental extensometer (1'000 mm measuring basis, accuracy ± 0,005 mm) in one borehole (M 1) will be used additionally next to the heater.

Five geophones are used to record the elastic waves which may be produced by sudden relaxation of stresses due to the rise of fissures or the deplacements along fractures in the heated rock area. They are installed near the tiltmeters and in the center of the heat test (B 1 - B 5).

The convergences of the heat test tunnel in the area above the actual testing field are measured at five cross sections near and in the fault zone mentioned above (lamprophyre vein). Precision levelling is used to check whether deviations in the level of the reservoir lakes have any influence on the deformations during the heat test.

The **temperature measurements** in Stripa and Asse have shown that the temperature spread corresponds very well with the modelling. Thus for the Grimsel heat test the temperature field needs only to be verified at certain points. In all the equipped boreholes and in the special temperature measurement holes T 1 to T 4, a total of approx. 120 electrical resistance thermometers are arranged from 8 m to 22 m depth. They also allow temperature compensation of the measuring system.

In Stripa the **water discharge** was measured for each respective borehole as a whole. In the Grimsel heat test the waterflow into well-defined sections fixed according to the geological and hydraulic conditions of the boreholes will be investigated. For this purpose, the three boreholes W 1, W 2 and W 3 will be subdivided by packers into four to six measuring sections which will be drained by pneumatic pumps. Any water vapour will be condensed and led back into the corresponding sections. The water delivered from each section will be measured by electric flow meters. The dewatering system can also be used to measure the increase of pressure in the borehole sections sealed off.

The **test program** begins with the recording of the original state (without heating) for a period of at least three months. The first heating phase agrees with the Nagra concept for final disposal. This means in particular that the temperature at the surface of the heater must remain some degrees below the boiling point of water. This phase will last about half a year. When a sufficiently stationary state has been reached, the decision will be made on further test phases.

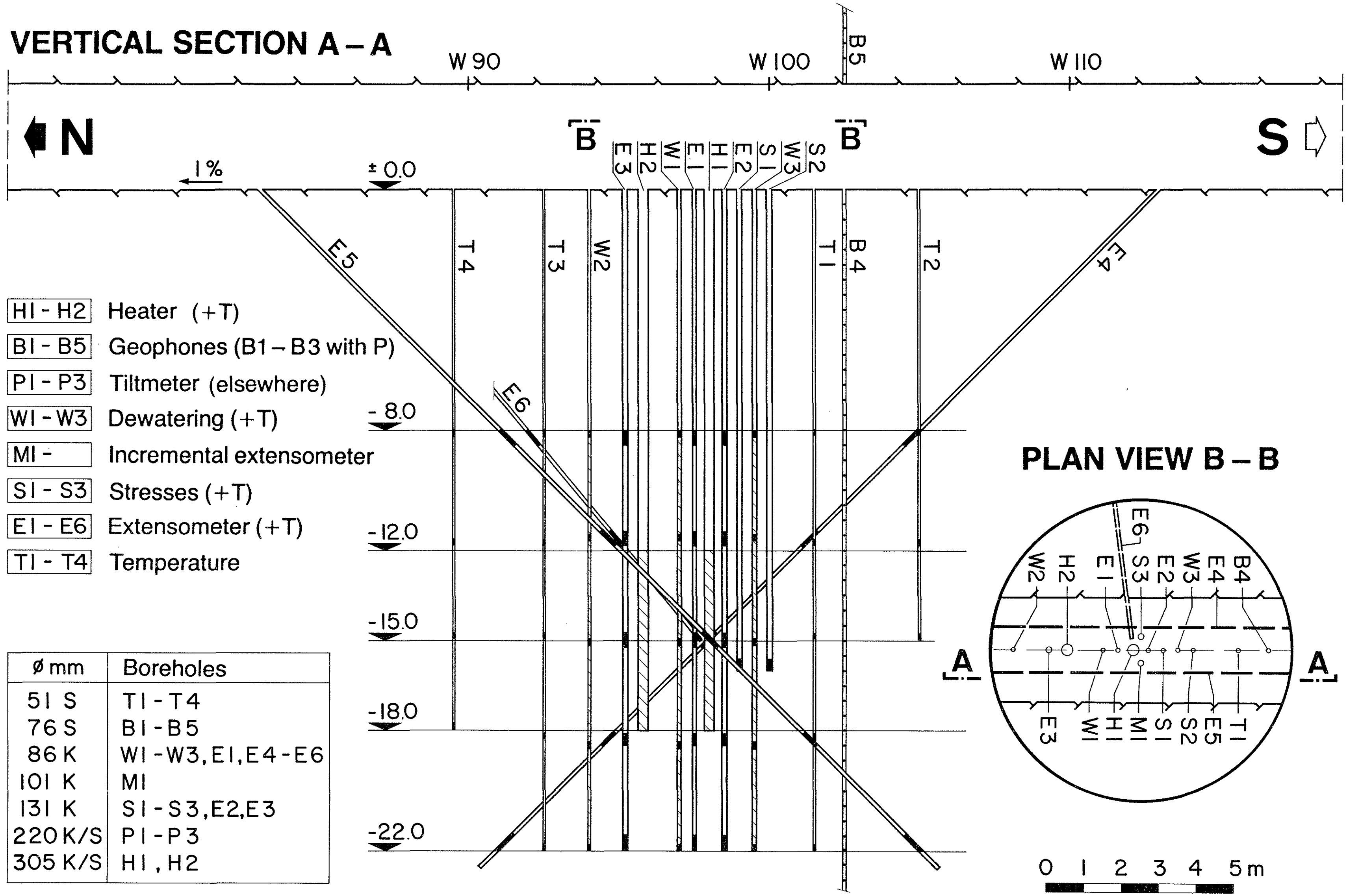
5.9.4 Data Acquisition and Evaluation (HT)

Data is acquired at the EDP installation in the central building (section 5.4.4). Eight basic units (Multicon 32), each with 32 channels (256 channels in all) are provided for the data acquisition of the heat test. Data is sampled once an hour and sent by a serial interface to the computer.

The heater temperature and heat output are controlled by a computerized control system. The flat jacks of the stress measuring probes are monitored by a computer-controlled measuring system, independently of the recording cycle of the central computer, and transmitted to this computer by a temporary store and a serial interface. The dewatering system also operates fully automatically by means of its own freely programmable process control system.

The cycles in which the EDP installation samples the measured values are adapted to the specific test phase. Certain measured values are pre-evaluated and passed to appropriate periphery units (e.g. printers) for immediate checking and, if necessary, alarming. Magnetic tapes are used to carry the data. At least eight selected measured values are transmitted daily to the principal investigator and compared immediately with the expected values so that control of the planned test run is guaranteed at all times.

Simultaneously with the evaluation of the measured values the separate phases of the heat test will be simulated with suitable calculation models on the basis of the thermal and mechanical properties of the rock obtained in laboratory tests or in situ. Analytical as well as FE models will be used. The calculations are at first based on the assumption of linear thermo-elasticity and temperature independent thermal and mechanical substance parameters.



ø mm	Boreholes
51 S	T1 - T4
76 S	B1 - B5
86 K	W1 - W3, E1, E4 - E6
101 K	M1
131 K	S1 - S3, E2, E3
220 K/S	P1 - P3
305 K/S	H1, H2

K = cored borehole   S = Percussion borehole

Fig. 23: Heat test, vertical section

6. STATE OF PROGRESS AND FURTHER PLANNING

The following is a summary of the progress of work and the status reached at the end of June, 1985, as well as a brief outlook on the planning of future investigations at the Grimsel Test Site.

6.1 Construction and Operation

The constructional phase described in section 4.3 was completed in the second quarter of 1984. The laboratory has thus been operational since the middle of May, 1984. The boreholes required for the tests already planned have been drilled, with the exception of those for the third phase of the fracture system flow test. For the latter, a further 300 m' of cored boreholes, 86 mm in diameter, will be drilled early in 1986. If and when the excavation work and boreholes for phase II (blasted) of the excavation test will be carried out, will be decided in 1986.

The first test at the GTS was phase I of the excavation test, which was carried out in the fourth quarter of 1983 while tunnel boring was still in progress. After suitable boreholes had been made, the electromagnetic high frequency measurements were also commenced already during the construction period.

On June 20th, 1984 the Grimsel Test Site was officially opened in the presence of representatives from the Swiss and German authorities.

The project organisation described in section 4.5.1 is working well. A small team of qualified and highly motivated personnel could be formed for the local operation of the GTS.

After the completion of the installation phase in most test programs, the local management of the GTS will now have to concentrate on gaining practical experience in the running of the individual test programs and in the acquisition and securing of raw data. Additionally, special attention will have to be paid to the applicability of experience and results gained at the GTS to other host rock formations, in view of Nagra's field investigation programs for a B-repository which are scheduled to commence in 1986.

6.2 Basic Geological Surveys

The basic geological, petrographical and hydrogeological surveys in the Juchlistock Test Site were completed in April, 1984. They are described with results in chapter 7 of this report. A detailed report on this will be prepared in 1986 as a NTB.

The detailed knowledge of the rocks and the rock massif in the closer and wider reaches of the Test Site, obtained from these surveys, will continuously be extended through the test-specific detailed mappings, the examination of the cores from further test borings and the evaluation of the results from the electromegnetic high frequency measurements and from the underground seismic testing. Such supplementary results will first be made available to the direct participants in the Grimsel project in the form of separate intermediate reports, and then be consolidated into the above mentioned NTB.

6.3 Investigation Programs

The twelve investigation programs of the Basic Program are at different stages of progress, as will be seen from the short overviews given below:

EM: The electromagnetic high frequency measurements are being conducted in a series of measuring campaigns of varying duration, at irregular intervals which are partly determined by the availability of boreholes. During the next two years there will be close correlation with the underground seismic testing programme.

US: The detailed planning, preliminary work, test measurements, model calculations and boreholes have been completed. The scanning now in progress will continue until late in 1985. Preliminary evaluation is made at site as soon as the appropriate scanning data becomes available. The final evaluation and the reporting will be completed at the end of 1986.

TM: All six tiltmeters are installed and connected to the EDP installation. The first model calculations have been made. The series of measurements planned for the next two years will be evaluated continuously with the aid of model calculations, taking into account the disturbance factors (meteorological data, lake level deviations, etc.)

ND: The investigation program "Locating of active neotectonic distrubance zones" is of low priority. It will only be planned and prepared at the earliest in 1986. The concept and execution period of these tests depend, among other things, on the results obtained from the tiltmeters (TM).

FF: The basic equipment arrangement for the fracture system flow test was assembled and tested during 1984 at the scale 1:1 in the BGR laboratory in Hannover. At the same time various model calculations were made. From January, 1985 to approx. mid 1986 some 15 boreholes will have been drilled and flow tests performed in three successive phases. Preliminary results will become available continuously from site computations but final evaluation and reporting will take at least one more year.

VE: Installation of the testing equipment is almost complete. The first tests will be made in the third quarter of 1985. The individual test phases will then be carried out between late 1985 and 1986. Model calculations will be made as soon as measured data are available in sufficient quantity.

HP: A sliding piezometer, developed by the ETH, Zürich, is now available for tests. The recently commenced detailed evaluation of hydrogeological raw data obtained by earlier measurements and supplementary detailed measurements in autumn 1985 will be the basis for conceiving the investigation program HP.

MI: Extensive theoretical investigations and a series of laboratory tests at the Swiss Reactor Research Institute (EIR) were carried out for the Project "Guarantee". Together with knowledge gained from the migration tests made in Sweden (among others, 3-D migration tests), they will form the basis for the concept of the in situ migration (and possibly sorption) test program to be prepared in the near future.

EX: After a number of preparatory calculations and measurements, the first phase of the tests for excavation effects reached its high point in November, 1983, with the excavation by the tunneling machine of the 30 m long test tunnel. The last measurements (slot tests) and the evaluation of this phase will be completed in July, 1985. The concept for phase II (excavation by blasting) will be revised on the bases of the positive results obtained from phase I and the knowledge gained during work on the project "Guarantee".

RS: The in situ measuring program for the rock stress test is based on a great deal of preparatory work (calculations, development of instruments). It started in the middle of May, 1984 and, with the exception of the hydrofrac tests (1985), was completed 6 1/2 months later. A depth of 171 m was reached. The test runs were positive, with only a few exceptions. The first evaluations proved that the instruments used by the BGR were reliable. The final evaluation will last for about one more year, including the further development of the instruments. Instrumentation for long-term tests will be installed in the existing RS borehole late in 1985.

HT: The procurement and installation of the large number of apparatus and instruments for the heat test was much more time-consuming than originally planned, but is now almost completed. Cold equipment trial runs started in March, 1985 and will last for about four to five months. If the results are positive, the first heater can be operated at approx. 90°C in the 3rd quarter of 1985. The subsequent program must then be determined on the basis of the results from the first heating phase.

KO: A concept for convection tests may only be prepared in one or two years, based on refined safety considerations (optimisation).

LU: A series of tests on drilling cores and hand pieces have already been carried out at the rock-mechanics laboratory of the ETH in Lausanne, the BGR and the GSF. Others will follow, to correspond with the requirements and the progress of the individual in situ tests and their evaluation.

6.4 Future Plans

In one or two years, the execution and evaluation of most of the investigations will be sufficiently advanced, so that each test concept can be judged on its capability to resolve the respective problem.

Consideration will therefore have to be given in 1986/87 to a continuation or extension of the present Basic Program for the Grimsel Test Site.

7. GEOLOGY AND HYDROGEOLOGY OF THE GRIMSEL TEST SITE

7.1 Scope of investigations

In addition to the hydrogeological targets formulated in the Basic Program (page 8), the geological-hydrogeological investigations at the GTS served

- to obtain basic data for selecting the location of the Test Site as a whole, as well as for determining the best places for the individual tests (preliminary investigations)
- as bases for the detailed planning and interpretation of the different investigation programs.

7.2 Investigations carried out to date

7.2.1 Preliminary investigations in 1980

The geological-hydrogeological investigations carried out till the end of December, 1980 with regard to the Grimsel Test Site are described in detail in the Nagra Report NTB 81-07 "Sondierbohrungen Juchlistock, Grimsel" (exploratory boreholes, Juchlistock, Grimsel). These preliminary investigations essentially comprised:

- Sifting and evaluating existing data (e.g. KWO investigations) with regard to the GTS
- Geological surface mapping
- Geological mapping of the access tunnel to the KWO Grimsel II hydropower station
- 6 exploratory boreholes, bored from the access tunnel (EB 80.001 - EB 80.006, in short EB 1 - EB 6)
- mineralogical investigations
- borehole geophysics.

The boreholes EB 1 - EB 6 are each 100 m long, slope slightly (2°) upwards and have a diameter of 86 mm (Fig. 1, page 3). The cores, which were recovered almost without loss, were examined with regard to petrography, fractures and (partly) rock mechanics.

The main **results of these early investigations** are summarized briefly below. They are still valid.

The investigated region contains granites and granodiorites with either a low or high content of biotite. They are penetrated locally by lamprophyres and aplites. Most of the rock formation investigated consists of massive rock with very little fracturing. An average of 80 % of the cores have no open fractures; these occur more frequently in EB 1 and EB 5.

For water injection tests, pressures of more than 10 bar were generally necessary in order to press measurable quantities of water into the rock. The injectable quantities of water were consistently small. The estimated rock permeability for the fractured regions was approx. 10^{-9} to 10^{-12} m/s. Tritium measurements showed that the groundwaters of the exploratory boreholes EB 1 to EB 6 are older than 30 years (Appendix 3).

Investigations of temperature, chemical composition and hydrostatic pressure, which also included 27 water inflows to the access tunnel, indicate that the water circulation in the rock formation results from joint or fracture systems which are partly independent of each other.

The velocities of the compression waves in massive rock formations, measured with the acoustic log, have an average value of 5600 m/s. They are 70 to 80 % higher than the values measured on drill cores under laboratory conditions.

Porosity values of 0 to 5 % were determined for the investigated rock body, depending on the degree of fracturing. In the rarely occurring hydrothermally decomposed granites and granodiorites, the porosities reach 10 %.

7.2.2 Investigations 1981 to mid 1985

After the site had definitely been selected, further general investigations and detailed geological mappings were carried out at the various individual sites, some commissioned by Nagra and some directly by BGR (especially for the rock stress test and fracture system flow test) and by GSF. In addition to the 600 m' of exploratory boreholes, the geological evaluation included about 2'600 m' of cored boreholes having diameters of 56 mm to 146 mm (mostly 86 mm) and lengths between 1 m and 191 m. The approx. 900 m' of tunnels and the various caverns were also meticulously geologically mapped. The investigations essentially comprised careful monitoring during drilling, core mapping, geophysical borehole logging, analysis of the cutting rate of the tunnelling machine, observation of the water outflows and the hydrostatic pressures, hydrochemical investigations and isotope measurements.

7.3 General Geology and Mineralogy

The Grimsel Test Site lies in the Aar Massif, the largest massif of the Swiss Alps. The main rocks of the Juchlistock are about 280 million years old granites (Central Aaregranite and Grimsel-Granodiorite). Shortly after their cristallization, dikes of lamprophyres and aplites intruded into the granites. All rocks were metamorphosed several times by the hercynic and alpine orogenesis and are today in a polymetamorphic state. The youngest features are the alpine tension fissures which were formed some 15 million years ago. They are accompanied by local hydrothermal leaching of the host rock. The mineralogy and petrography of the Juchlistock have been described in detail by STALDER (1964).

The relatively rare aplite dikes have a mineralogy similar to granite, but contain less biotite. Their compressive strength of 225 MN/m^2 is distinctly higher than the strength of the other rocks at the GTS.

Rock	Central Aare-granite	Grimsel Grano-diorite	Lamprophyre (K=Kersantite) (S=Spessartite)		Hydrothermally altered rocks
Occurrence, special properties	Main types of rock blend smoothly into each other		Veins, 0.1 - 3 m thick, mostly in steeply dipping parallel sets/clusters		Local zones of limited extension in connection with tension fissures and quartz veins. Increased porosity caused by leaching
Mineralogy			K	S	Change in the host rock due to dissolution of quartz and biotite
Quartz	33	28			
Potash feldspar	34	24	0-10	5-10	
Plagioclase	21	29	10-25	40-60	
Biotite and Mica	7	11	50-70	10-20	
Amphibole	1	3		15-30	
Epidote	2	2	10-20		
Density (kg/m^3)	2650	2700	2910		2400 - 2600
Compressive strength (MN/m^2)	170	115	125		
p-wave velocity (km/s)					
- in situ	5.6	5.7	6		5 - 5.4
- drill core	3.1	3.7	3.9		2.1

Table 2: Mineralogical and physical properties of the Juchlistock rock

7.4 Rock Structure and Joints

The rock structure of the Aar Massif is regarded (LABHARDT, 1966; STECK, 1966) as the product of multiphase tectonic activity. The deformations started during the hercynic orogenesis and lasted until recent times. The joints parallel to the valley slopes (called "Talklüfte") are considered as synglacial to postglacial and were probably caused by pressure release (STALDER, 1964). The "Talklüfte", however, are limited to the near-surface zones (maximum depth 200 m).

The various joints and fractures found in the Grimsel rocks can be classified as follows:

Schistosities (s): Characterized by the orientation of rock-forming minerals

Fractures (k): usually more or less plane surfaces disrupting the rock structure

Rock boundaries (ℓ): Mainly contacts between lamprophyres and the host rock.

Alpine tension fissures (z): Elongated, flat-lying cavities of small extent, frequently open or filled with quartz and chlorite.

In the following, the designations s, k, ℓ and z are used purely in the sense of the mode of origin of the structural elements, i.e. independent of subsequent reactions on joint-surfaces, such as shearing, fissure mineral formation, etc.

Till now,

3 schistosities $s_1 - s_3$,

6 fracture systems $k_1 - k_6$ (incl. z),

2 lamprophyre directions $\ell_1 - \ell_2$

could be identified. It is possible that other joint-systems will be found during further investigations, but they will probably be of lesser significance.

The distributions of the joint faces are very similar in all systems; they follow the Poisson distribution. This means that the fractures occur characteristically bundled into clusters. With respect to frequency, the systems s and ℓ clearly dominate. For these, and in k_1, the average two-dimensional degree of separation, relative to the tunnel cross-section, is high (mostly over 75 %). The lamprophyres and the schistosities s_1 and s_2 can be traced in a horizontal direction for more than 150 m and vertically up to the surface of the terrain (approx. 450 m).

The genetic interpretation (age) of the individual fabric systems is essential because young joint faces usually have higher degrees of separation and can replace older systems. It can therefore be assumed that young systems play a more important role than the older systems from the point of view of water circulation. In the case of fractures which have been healed by subsequent mineralization, it must be taken into account that the fissure mineral aggregates (especially quartz, feldspar, epidot, calcite) are usually more porous than the host rock.

System	Average direction of dipping/dip angle	Number of fabric elements considered	Characteristics	Genetic interpretation
s_1	142/77	639	- Alignment of the rock-forming minerals (stratification of matter) - Shear zones	Youngest, alpine schistosity
s_2	157/75	519		Older schistosity, possibly early alpine
s_3	183/65	271	- Generally rare, readjustment of mica Shear zone in SB 5	Oldest schistosity, possibly hercynian
k_1	53 + 233/80	292		Most important lateral fracture system (age uncertain, alpine and hercynian
k_2	19 + 199/78	124	Rare joints with biotite and chlorite	Possibly hercynian fracture system
k_3	264/84	144	Relatively rare. Joint planes with high degree of separation. Mostly coated with fissure-chlorite	Probably hercynian lateral fracture system
k_4	297 + 117/62	163		
k_5	336/42	singly	Relatively rare, mainly observed at the surface	
k_6/z	subhorizontal	73	Alpine tension fissures partly developed as thin quartz veins (15/20)	Youngest mineral formation +/- 13 mio. years ago at temperatures of 350° - 400° C
ℓ	216/80 and 242/80	186	Lamprophyre contacts	Parallel to k_1, poss. k_2
t	no systematic direction	-	Stress relaxation joints observed to 150 m below ground surface	Youngest fractures caused by stress relaxation

Table 3: Joint systems of the Juchlistock granite

With the exception of k_5 and z (= k_6), all the joint systems are steeply inclined. Fig. 24 illustrates the spatial positions of the joint planes.

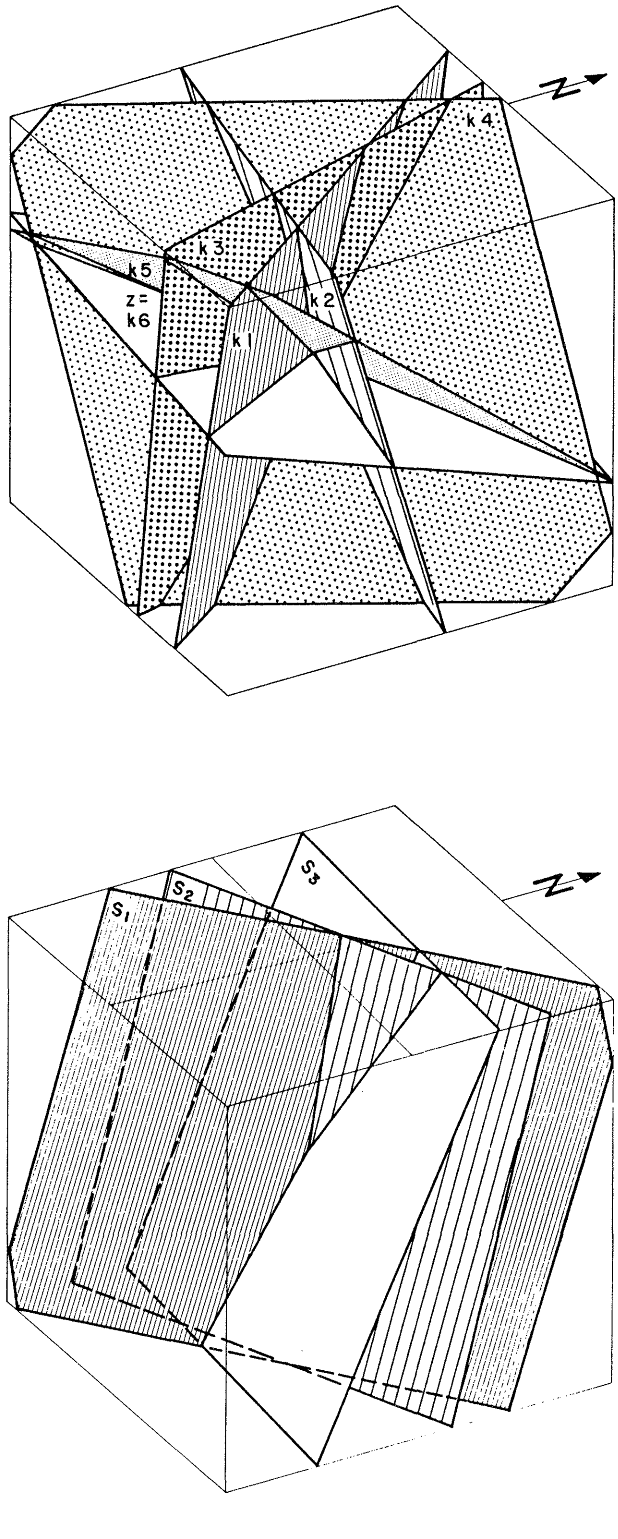


Fig. 24: Positions of the joint planes in the GTS (without lamprophyre)

7.5 Groundwater Conditions

7.5.1 Circulation of water

The circulation paths of the water can be observed very clearly in the machine excavated testing tunnel. A large portion of the water circulation is concentrated on the joint systems s_1, s_2 and ℓ. Almost no water was found on k_1, k_2 and k_3. In addition to the water bearing joints, there are areas where the water diffuses through the rock. Such zones must have high porosity resulting from microfissures or pores (caused by alpine leaching).

A surprising fact is that tension fissures, which are of limited extension, very often bear water. One explanation could be that the tension joints often occur in greater numbers in the vicinity of lamprophyre dikes. The contact area between these dikes and the host rock was highly stressed during the alpine orogenesis and had or still has a higher water conductivity than the rock matrix.

Observed at	Total examined tunnel/caverns		Number of joint planes considered	Number of waterbearing joint planes		Number of waterbearing joint planes in s_1, s_2, ℓ	
	length m'	visible Area m^2		Total	per m^2 of visible area	Total	percentage of water bearing joint faces
Testing tunnel (machine excavated)	773	8500	320	114 (35%)	0.013	91 (28%)	80%
Caverns *) FF/RS (blasted)	65	820	175	11 (6%)	0.013	8 (4.5%)	73%

*) Mapped by BGR

Table 4: Water bearing of joint planes in the testing tunnel

7.5.2 Water discharges

Appendix 3 shows clearly that the Grimsel Test Site lies in a relatively "dry" zone of the Juchlistock, as was foreseen during the planning stage. Large water discharges were found in the main access tunnel, especially near Lake Grimsel, where the rock mass is intersected by numerous disturbance zones. The water discharges into the main access tunnel have been under observation since 1980. They are mostly constant, but large variations occur at Tm 708 and Tm 2078. This may be caused by climatic conditions.

Table 5 contains information on the discharges which were observed in the various areas of the GTS over periods of 1 1/2 to 2 years each between 1980 and 1985. The following observations are noteworthy:

a) As expected, the discharges depend on the fracture frequency

b) There are two wet zones in the GTS area:

- **The excavation and ventilation testing areas**, with a water circulation mainly in shear zones of the schistosity systems s_1, s_2 and s_3 (increased fracture frequency). The estimated water discharge into the existing tunnels and boreholes is approx. 0.5 to 1 l/min.

- **The fracture system flow testing area**, with a water circulation mainly in shear zones of s_1, s_2 and k_4 (increased fracture frequency). The estimated water discharge into the opening of the GTS is approx. 2.5 - 3 l/min.

The discharges in the GTS have remained practically constant over the last 3 years. Only in EB 1 there was a distinct drop from an initial rate of 3.5 l/min. to 2.0 l/min.

The mean discharges are:

Per m' of borehole:	0.004 l/min. x m'
Per open joint plane in the borehole:	0.007 l/min.
Total in the GTS (tunnels and boreholes): approx.	4 l/min.

GTS region	Borehole	Tunnel	Metre	Discharge l/min.	Specific discharge l/min. pro m'	Specific discharge l/min. per open joint plane
Fracture System flow test		FF		1.4		
	SB1		0-80	0.03	0.0003	
			80-85	0.07	0.014	0.004
			85-90	0.02	0.0045	0.006
			90-95	1.4	0.28	0.05
			95-100	0.65	0.13	0.04
	Total		0-100	2.15	0.02	0.01
Heat test	SB2		0-100	0.04	0.0004	0.0007
	SB3		0-100	0.08	0.0008	0.004
	SB4		0-100	0.06	0.0006	0.003
Excavation test		EX		0.25		
Ventilation test	SB5 Total		0-100	0.17	0.0017	0.0017
	SB6		65-75	0.003		
			75-85	0.0016		
			85-95	0.0003		
			175-185	0.0125		
			185-195	0.023		
	Total		0-195	0.05	0.0003	0.001
	83.01		30-40	0.0001		
			45-55	0.0005		
			90-100	0.0001		
			130-140	0.45	0.045	0.016
	Total		0-140	0.5	0.0035	0.007

Table 5: Water discharges in the testing tunnel and in individual borehole sections

7.5.3 Chemistry and temperatures

Chemical analyses of the ground and surface waters in the region of the Grimsel Test Site were carried out by the Cantonal Chemist and by the University of Kiel. The characterization of these waters can be summarized as follows:

- Chemically, the ground water of the GTS shows low mineralization

- The degree of chemical saturation of the ground water is clearly different from that of the surface waters in the Juchlistock region

- Within the rock formation, there is obviously sufficient time and surface available to the ground water to reach the state of thermodynamic equilibrium with the minerals calcite, fluorite and hornblende-asbestos. Special attention must be drawn to the high content of fluorine. The solubility of fluorite increases strongly in the basic environment ($>$ pH 9). This explains the observation made on the Grimsel, that the fluorites which are frequently present in the tension joints, are more or less corroded.

- Regarding the other rock-forming minerals such as quartz, feldspar and mica, there is an approximation to the saturated state in the ground water

- The oxygen contents are reduced. Some H_2S was found. The environment seems to be reducing

- The waters are remarkably low in K^+ and Mg^{++} ions. It is possible that there is an absorbtion of these ions or a formation of new clay minerals inside the rock formation.

Further details can be found in the NTB 81-07.

Trace analyses of water samples will be made to differentiate between waters circulating independently of each other in the rock formation.

The temperatures of the waters in the GTS region range between 10.0 and 11.6° C. To the south, in the direction of Lake Grimsel, the water temperatures become successively lower, in accordance with the decreasing thickness of the overburden.

Appendix 3 shows the tritium contents and the temperatures of the ground waters.

7.5.4 Hydrostatic pressures and permeability

Since December, 1980, systematic observations have been made of the hydrostatic pressures in the 6 exploratory boreholes. Before machine excavation started (May, 1983), all exploratory boreholes were closed in order to determine the hydraulic connections to the testing tunnel which passes a few metres below the boreholes.

As shown in Fig. 25, there are significant pressure differences between the exploratory boreholes, which are only 80 - 100 m apart. Observations made till now give no indication that these pressures tend to equalize. Also, no dependence of the water heads in the mountain on the water levels of lakes Grimsel and Räterichsboden could be found. Pressures in EB 1, EB 2 and EB 4 did not react to the tunnel excavation, but there was a clear pressure drop in EB 3. Pressures in EB 5 and EB 6 were disturbed prior to the tunnel boring machine reaching their area.

Hydrostatic pressure tests (Lugeon) in the exploratory boreholes indicated rock permeabilities in the order of 10^{-7} m/s in the area of the fracture system flow test, and generally 10^{-11} to 10^{-12} m/s at the other test sites.

In the majority of the fractures, the water is retained by capillary and other forces (pendular water). From the other discontinuities the water drained when they were tapped.

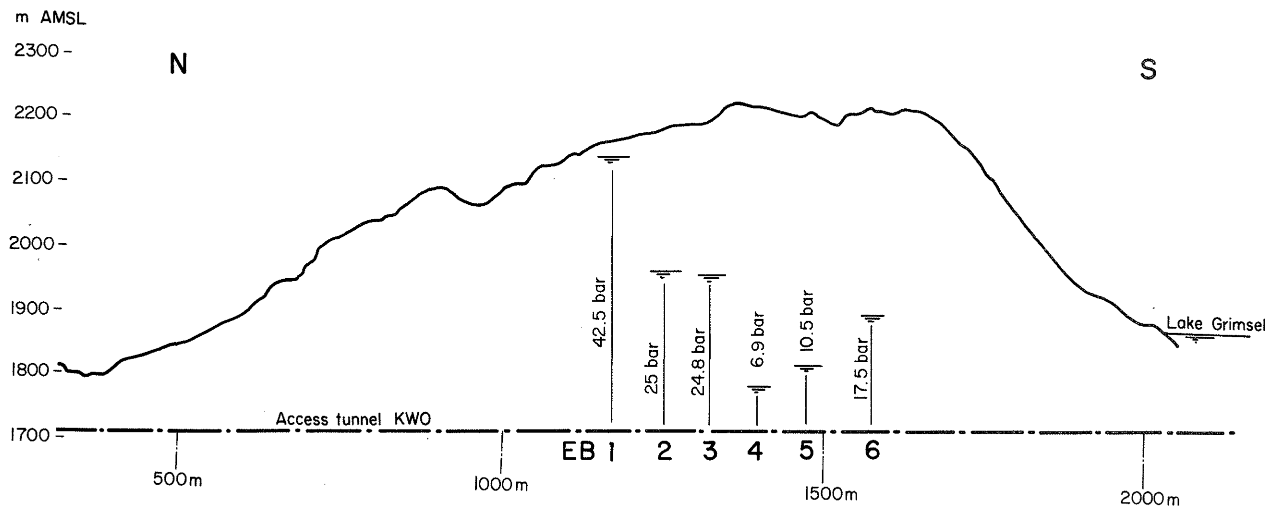


Fig. 25: Maximum hydrostatic pressures in the exploratory boreholes.

7.6 Hydrogeological Model of the Juchlistock

The evaluation of the data compiled on the structure and texture of the rock is still proceeding. The results of additional hydrogeological investigations and evaluations will be available by the end of 1985. However, important information for characterizing the hydrogeological model of the Juchlistock massif is already available.

7.6.1 Geometry

Of the 10 to 11 joint systems known today, only a few play an important hydrogeological role, viz. s_1, s_2, k_1 (k_4 only locally) and ℓ (lamprophyre). The other systems are less important hydrogeologically because they occur only rarely and have a low degree of separation.

The dominant systems are characterized by their **steeply dipping fracture clusters.** These clusters cause a distinctly **sub-vertical structuring** of the rock body (Fig. 26). Completely compact, mostly fractureless volumes of rock are intersected at certain distances by fractured zones.

7.6.2 Water conductivity

As indicated already, water circulation in the rock formation is concentrated on the systems s_1, s_2, k_1 (k_4 locally) and ℓ (lamprophyre). The frequently observed water bearing of the tension fissures is probably of a secondary nature. Its likely cause is the usually coupled occurrence of the tension fissures with lamprophyres.

The questions of the permeability and storage coefficients of these clusters of fissures and the flow velocities of the water circulating therein are yet to be clarified.

7.6.3 Hydraulic potentials

Observations made so far, though in only a few boreholes, indicate that there are a large number of significantly differing hydraulic potentials in the rock formation. The marked pressure differences within short distances are best explained by flow processes along steep disturbance zones. For areas of compact rock, it seems that there are practically no connections between these disturbance zones. The horizontal joint planes appear to be of minor hydraulic significance. This is consistent with the abovementioned vertical structuring of the rock body.

7.6.4 Comparison with Stripa and URL

The nearly vertical hydrogeological rock structuring at the Grimsel Test Site differs significantly from that at the sites in Stripa which show a pronounced horizontal structuring due to flat-laying, hydraulically important disturbance zones.

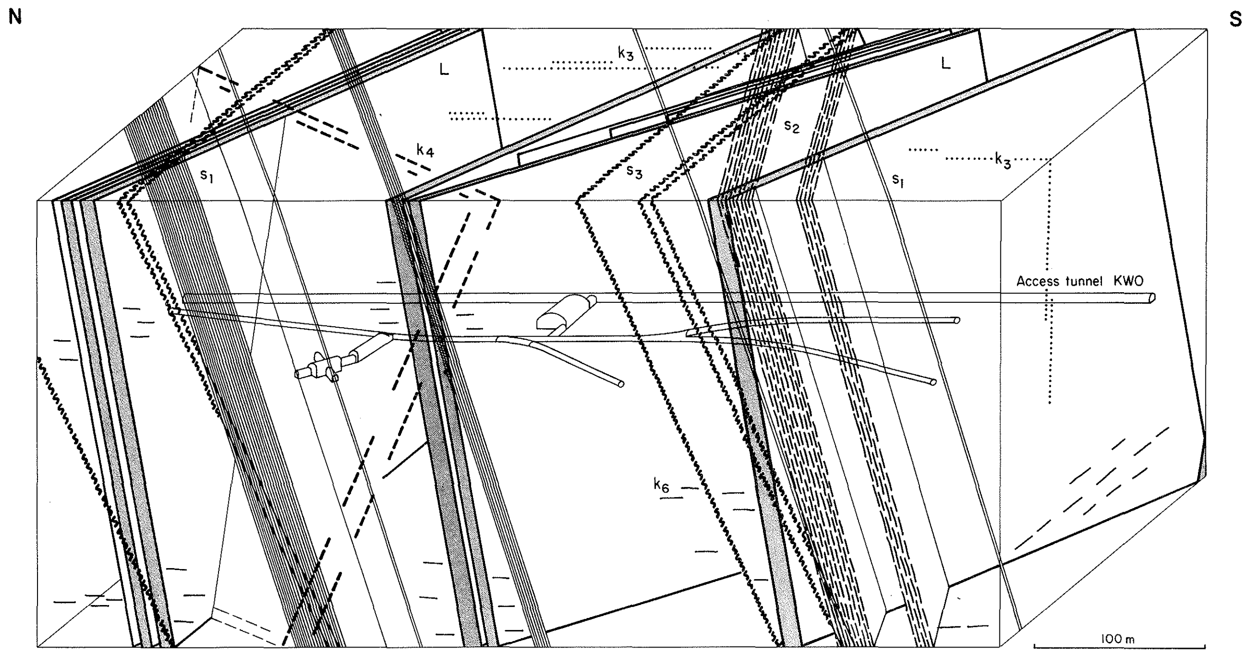


Fig. 26: Hydrogeological rock model in the GTS area

7.7 Geology of the Individual Test Sites

7.7.1 Selection of the test sites according to geological criteria

The selection of the sites for the eight investigation programs already under way was made on the bases of the results obtained from the preliminary investigations (section 7.3.1) and some additional clarifications. Table 6 shows the different requirements of the various projects.

Test Program	Desired geological conditions
Excavation test EX	Relatively fractured rock
Ventilation test VE	Uniformly moist rock. Little local water circulation. No free-flowing water.
Fracture system flow test FF	Fractured rock with relatively high overall permeability
Heat test HT	Homogeneous rock with one fracture zone only
Tiltmeter TM	Large rock bodies separated from each other by discontinuities (shear zones)
Migration MI	Hydrogeologically well defined rock bodies (rocks with known single fracture or several fracture systems; proven hydraulic connections, if possible)
Borehole radar EM. Underground seismic testing US	Geologically well defined rock bodies with known discontinuities

Table 6: Desired geological conditions for the investigation projects.

The excavation of the testing tunnels and the subsequent geological mapping have confirmed that the choice of the test sites was appropriate and that the geological requirements of the various investigation programs are met. This is of particular importance for the two programs for the direct determination of permeabilities of entire rock bodies, viz. the fracture system flow test (FF) and the ventilation test (VE) which were to be arranged in areas of substantially different water conductivity.

7.7.2 Geology for the ventilation test (VE)

Appendix 4 shows the general geological situation for the ventilation test, which is being carried out in the Grimsel-Granodiorite. Between Tunnel Meter (Tm) L 420 - L 435 and L 446 - L 473, the rock formation varies from a distinctly parallel textured to schistose rock, with many open fractures and some shear zones in s_1 and s_2. The southern disturbance zone was clearly recognized again in the two parallel boreholes BOVE 84.011 and 84.018.

In the actual testing tunnel south of the VE cavern, a total of five lamprophyres are located, the three at the south end are displaced by s_1. Other displacements of less than 1.0 m were found along the flat dipping system k_6. Several quartz veins and alpine tension joints indicate increased hydrothermal activity in th southern part of the testing tunnel.

Water conductivity in the entire VE area is low. Water outflows were found mainly at the lamprophyre contacts, shear zones and open fractures in s_1 and s_2. There are also isolated water outflows from tension fissures. The water outflows from the lamprophyres themselves frequently occur from transverse fractures confined to the lamprophyres. Isolated wet areas are also observed in the higly schistose part with no visible open fractures.

The water ingress into the test section of the ventilation tunnel is limited to wet areas on the tunnel surface and dripping; there are no measurable outflows.

The 40 water or moisture ingresses observed in the VE area can be allocated to the following joint systems:

Open fractures in lamprophyres	7
Lamprophyre contacts	16
Shear zones in s_1, s_2 and s_3	4
Open fractures (mainly in s_3)	6
Alpine tension fissures (k_6)	2
Highly schistose rock zones (s_3)	5

7.7.3 Geology for the excavation test (EX)

Appendix 5 shows the general geological situation of the test area for excavation effects. The following description is relevant mainly to the part of the tunnel which has already been machine-excavated. The site EX lies completely in the region of the Grimsel-Granodiorite. The rock in the northern section of the tunnel (Tm EX 40 - 120) is somewhat, the one in the southern section distinctly parallel-textured. This distinct change from north to south is accompanied by an increase in open fractures and three prominent shear zones.

Eleven lamprophyres cut across the EX site. Consistent with the parallel texturing of the granodiorite, the lamprophyres are more or less compact in the northern section of the tunnel while they have been converted into friable biotite schists in the southern tunnel area, similar to the two lamprophyres in the observation tunnel. At certain places, squeezing of lamprophyres was even observed.

The presence of many small tension fissures and quartz veins indicates higher hydrothermal activity in the regions Tm E 40 to E 70 and E 120 to the end of the EX cavern. Directly at the beginning of the southern branch of the observation tunnel there is an approx. 6 m long alpine tension fissure at the west side. Its hydrothermally altered zone has a thickness of at least 2 m in the region of the observation tunnel. It can be correlated with a similar zone of approx. 1 m thickness observed in the measurement cavern. These observations, as well as electromagnetic reflection measurements, point to the presence of a large (several m^3) alpine tension fissure.

Water conductivity in the EX area is low. Several insignificant water outflows have been observed along the shear zones and at the lamprophyre contacts. The main water outflow of approx. 0.25 l/min. at Tm E 95 originates from an open fracture in s_1.

The approx. 17 water or moisture ingresses observed in the EX area, can be allocated to the following joint systems:

Lamprophyre and lamprophyre contacts	5
Shear zones s_1 and s_3	4
Open fractures (s_2 and s_3)	4
Geologically not identifiable	4
Tension fissures and hydrothermally altered zones	1 (cavern EX).

7.7.4 Geology for the heat test (HT)

The HT area is in the Central Aaregranite region (Appendix 6). From Tm H 130 onward, the biotite content increases, manifested by the darker colour and the more pronounced parallel-texturing. Apart from this, the rock in this region has a relatively weak to medium parallel texture. Various aplite and aplitic veins intersect the rock, concordant to s_2.

Directly south of the branching off of the HT tunnel several chlorite-filled fractures in k_3 were observed. The same fractures could be seen partly in the testing tunnel and in EB 3. This indicates horizontal extents of up to 140 m and more for individual chlorite fractures. Several fractures of k_3 were also observed at Tm H 109 between two lamprophyres; their continuation outside the pair of lamprophyres could, however, not be established. Obviously, the granite body between the two lamprophyres had been displaced along them. A total of 11 lamprophyres were located in the heat test area, of which three are completely wedged out at certain places, so that the only evidence of their continuation is a fine fracture.

The tunnel section for the heat test, between Tm H 75 and H 85, is the only place in the entire GTS area where a certain amount of rock burst occurred. Shortly after excavation, the rock started to exfoliate parallel to s_1. This process is still continuing almost one year after tunnel excavation. It is unclear whether this rock spalling is due to locally increased stresses or only to the fact that the excavation runs parallel to the schistosity s_1. Nonetheless, the intensive "disking" (disintegration of the drilling core into 1 - 2 cm thick disks) observed in some boreholes of the heat test indicates increased stresses.

The **water conductivity** in the heat test area is limited mainly to the lamprophyres and the lamprophyre contacts. Some isolated moist areas or minor dripping of water was observed from fractures in s_1.

The 30 water or moisture ingresses observed in the HT area can be allocated as follows:

Open fractures in lamprophyre	8
Lamprophyre contacts	11
Open fractures in s_1	11

7.7.5 Geology for the rock stress measurements (RS) and the fracture system flow test (FF)

Appendix 7 shows the general geological situation in the area of the rock stress measurements and the fracture system flow test. The detailed geological mapping of the tunnel and cavern RS/FF was made in 1983 by BGR.

The RS and FF test sites lie in the Central Aaregranite (CAGr) region of the GTS. Whereas the granite in the RS cavern is dark, rich in biotite and clearly parallel textured, the FF cavern shows a brighter and more massive variety of the CAGr.

The main schistosity in **the RS cavern** is s_2. At the entrance to the cavern, there are several open fractures in s_3, directly related to a shear zone (biotite schist) there. In the western part of the cavern, mainly k_2 is found in addition to s_2. The other systems are of minor importance.

In the short connecting tunnel and in **the BK cavern,** s_2 is also the main schistosity system. Apart from this, the two systems k_1 and k_4 are predominant, with k_4 dipping to the WNW and also the ESE directions. k_3 appears insignificantly. However, there is another flat system dipping in the NE direction.

From the exploratory borehole EB 1, it is known that there are prominent disturbance zones in s_1 and k_4 in the west of the cavern. The shear zones in s_1 can be correlated with those in the testing tunnel at Tm L 70. The disturbances in k_4 are possibly associated with the water bearing fracture in the main access tunnel at Tm 927.

The water conductivity in the RS-FF area varies considerably. Whereas the RS cavern is practically dry, different water inflows in the form of heavy dripping are observed in the cavern FF. They are limited to the systems s_2, k_1 and k_4, and (minor only) s_1.

The schistosity s_1 and the fracture system k_4 are of much greater importance as water-conducting zones in the rock zone behind (west of) the cavern, from where substantial water discharges were observed in borehole EB 1. This was confirmed during excavation of the FF cavern by the fact that the additional (abandoned) blast holes of 2.5 m length which were drilled westwards from the present, westernmost face of the FF cavern obviously penetrated and (at least partly) drained the first prominent disturbance zone (k_4) behind the cavern. The entire discharge from the blast holes was approx. 3.5 l/min. at the beginning, decreasing gradually to approx. 1.4 l/min. after one year.

Observations of the hydrostatic pressures further indicated that there is a larger drainable rock cavity directly to the west of the FF cavern. This cavity is probably formed mainly by clusters of fractures in k_4 and s_1. The local permeability of $K=10^{-7}$ - 10^{-8} m/s is abnormally high for GTS conditions.

The observed hydrostatic pressure indicates a hydraulic connection to the surface. The most likely source area is the prominent fault of the "Strahlchäle" which extends to the north of the Juchlistock in the direction of Lake Räterichsboden. This disturbance zone lies in the lamprophyre dikes north of the FF cavern, and intersects the k_4, or possibly the s_1 and s_2 systems at several places.

At a height of 2218 m above sea level, there is a marked funnel-shaped depression in the "Strahlchäle" which could be caused by such an intersection of several disturbance zones. It is possible that surface water infiltrates here and reaches the area of the FF cavern via fracture systems which are not yet identified.

It is remarkable that the fault of the "Strahlchäle" which extends to Lake Räterichsboden (1767 m above sea level), is not able to drain this rock body. It can therefore be assumed that there is a steep permeable zone (possibly caused by the aforementioned intersection of several fracture systems) present which forms a limited chimney-like water way. However, the flow velocities must be very low, since the ground water in the FF area is more than 30 years old. As a result of the drainage of the disturbance zones, caused by the excavation of the FF cavern, the flow velocities in the rock formation could increase. It will be interesting to discover if, and how soon, this drainage leads to a flow of recent water with high tritium content into the FF cavern.

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LIST OF ABBREVIATIONS USED

AECL	Atomic Energy of Canada Ltd., Pinawa, Manitoba
B 1/BO 1	Boring 1
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover (Federal Institute for Geoscience and Natural Resources)
B-repository	Final repository of Nagra for intermediate- and lowlevel waste (ILW/LLW)
BMFT	Bundesministerium für Forschung und Technologie, Bonn (German Federal Ministry for Research and Technology)
CAGr	Central Aaregranite
CB	Central Facilities, GTS
CEN	Centre d'Etudes de l'Energie Nucléaire, Mol, Belgien
CO	Convection Tests
C-repository	Final repository of Nagra for highlevel waste (HLW)
3-D	Three-dimensional
EB 80 002; EB 2	Exploratory Boring Nr. 2, bored 1980
EIR	Swiss Reactor Research Institute, Würenlingen
EM	Electromagnetic High Frequency (HF) Measurements
EMA	Electromagnetic High Frequency (HF) Measurements, Absorption
EMR	Electromagnetic High Frequency (HF) Measurements, Reflexion
ETH/Z-L	Eidgenössische Technische Hochschule Zürich/ Lausanne (Swiss Federal Institute of Technology)
EX	Tests for excavation effects in the vicinity of underground openings
FE	Finite Elements
FF	Fracture System Flow Test
Fig.	Figure

GrGr	Grimsel-Granodiorite
GSF	Gesellschaft für Strahlen- und Umweltforschung, Institut für Tieflagerung, Braunschweig (Research Centre for Environmental Sciences, Institute for Deep Storage)
HP	Tests of Hydraulic Potential
HT	Heat Test
IUB	Ingenieurunternehmung AG, Bern (Engineering Consultants)
k	Fractures (page 95)
KBS	Nuclear Fuel Safety Program (of SKB)
kW	Kilowatt
KW	Kilo-words (Computer capacity)
KWO	Kraftwerke Oberhasli AG (Oberhasli Power Station Company)
ℓ	Rock boundaries (page 95)
LBL	Lawrence Berkeley Laboratory
LT	Laboratory Test
MI	Migration Test
ND	Tests for Locating Active Neotectonic Disturbance Zones
NEA	Nuclear Energy Agency (of the OECD)
NTB	Nagra Technischer Bericht (Nagra Technical report)
OECD	Organisation for Economic Co-operation and Development
RS	Rock Stress Measurements
s	Schistosities (page 95)
SKB	Swedish Nuclear Fuel and Waste Management Co.

TBM	Tunnel Boring Machine
TGS	Grimsel Test Site
TM	Tiltmeter Test
Tm	Tunnel meter
Tu	Tritium units
URL	Underground Research Laboratory (of AECL)
US	Underground Seismic Testing
VE	Ventilation Test
z	Alpine tension fissure /page 95)
∅	Diameter

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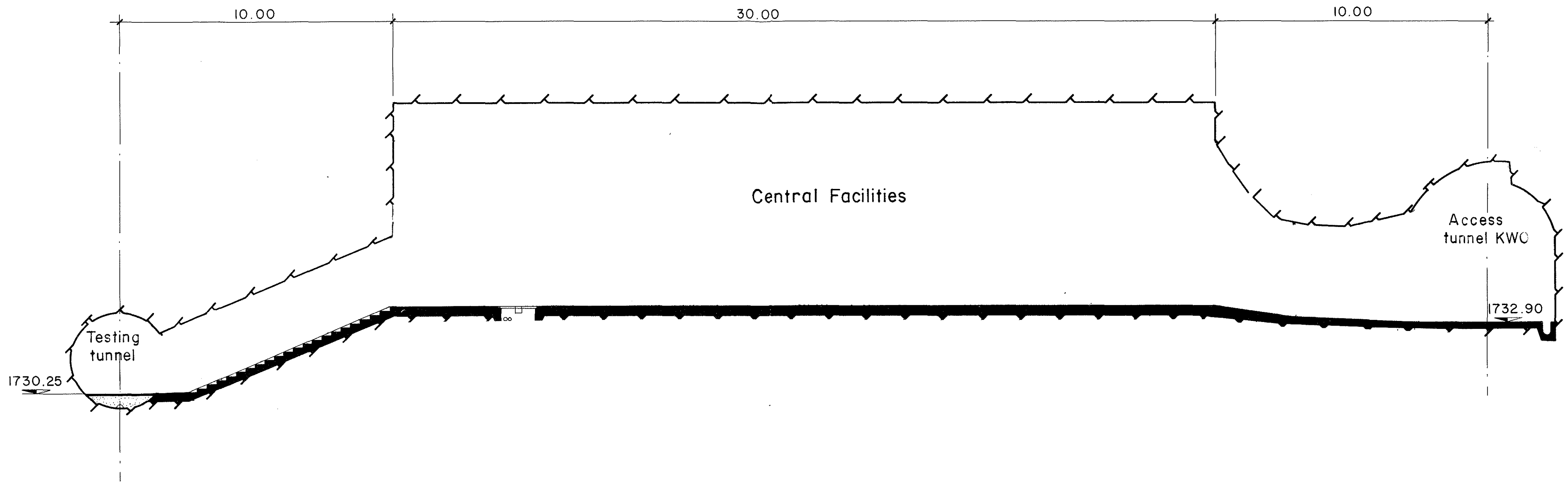

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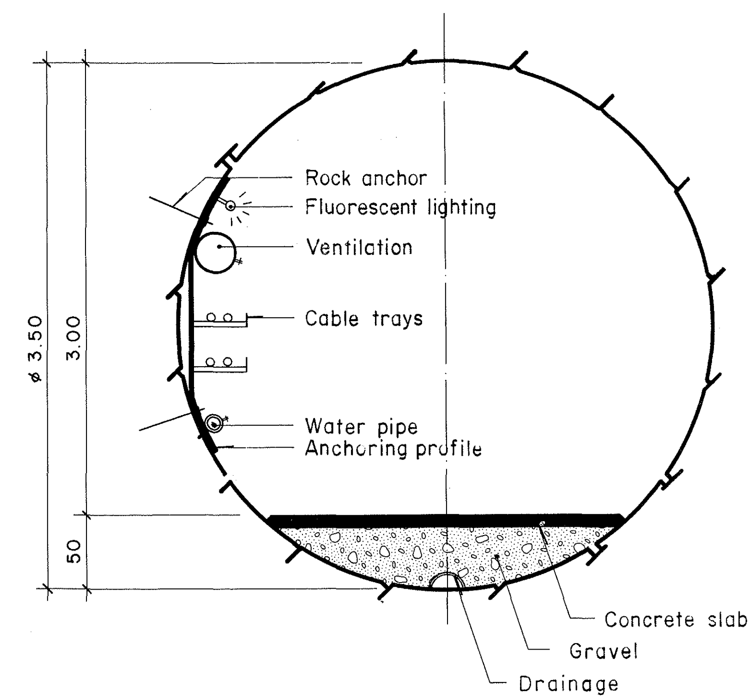
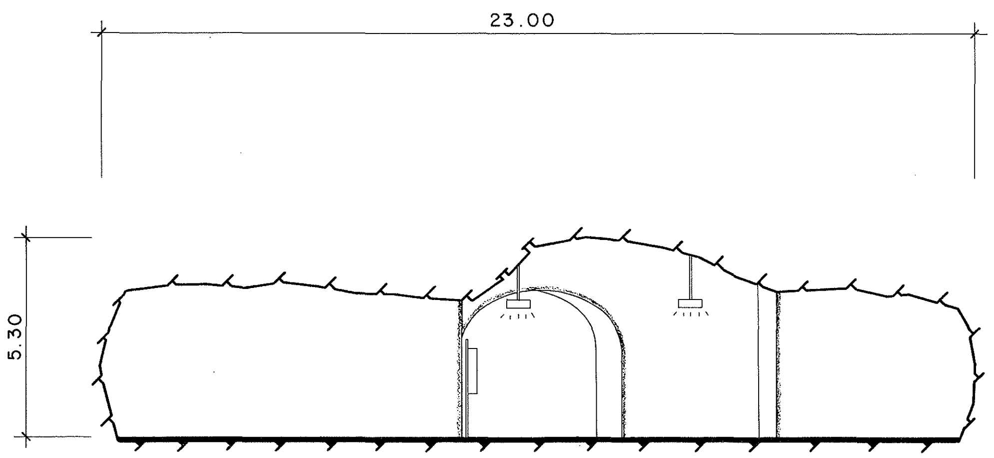
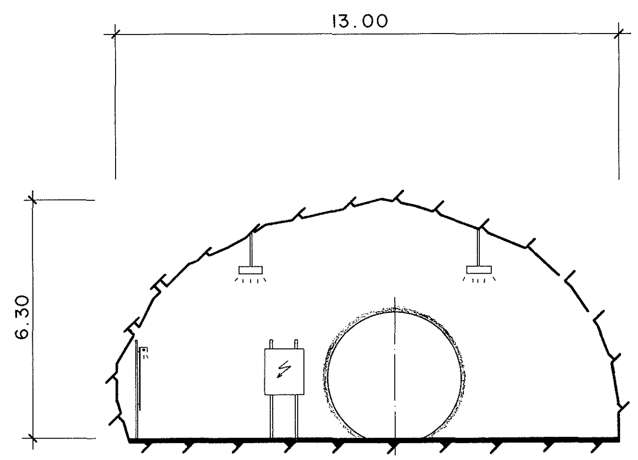


Cavern FF 1:200



Cavern VE 1:200



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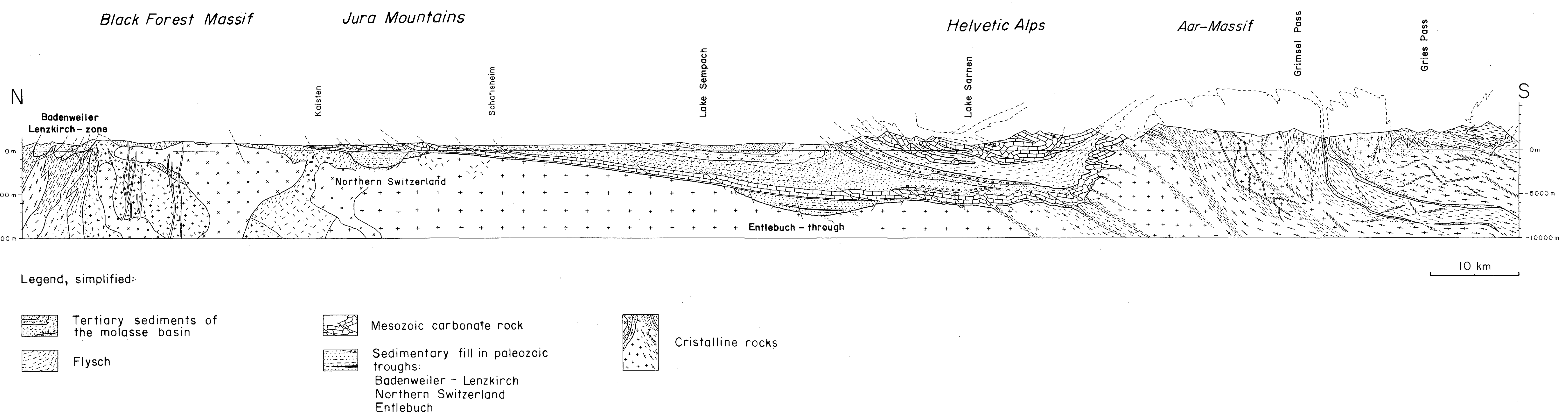
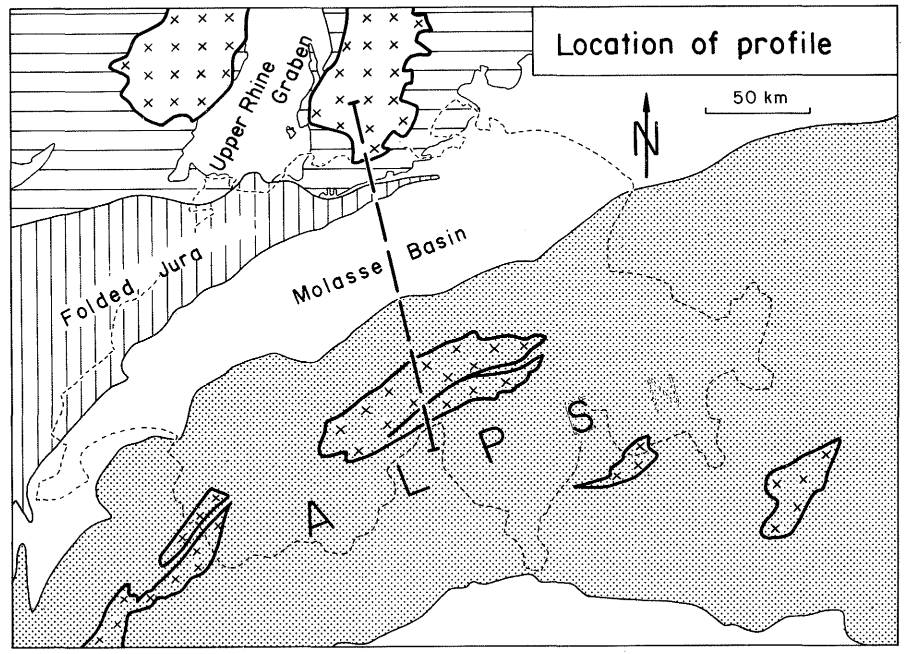
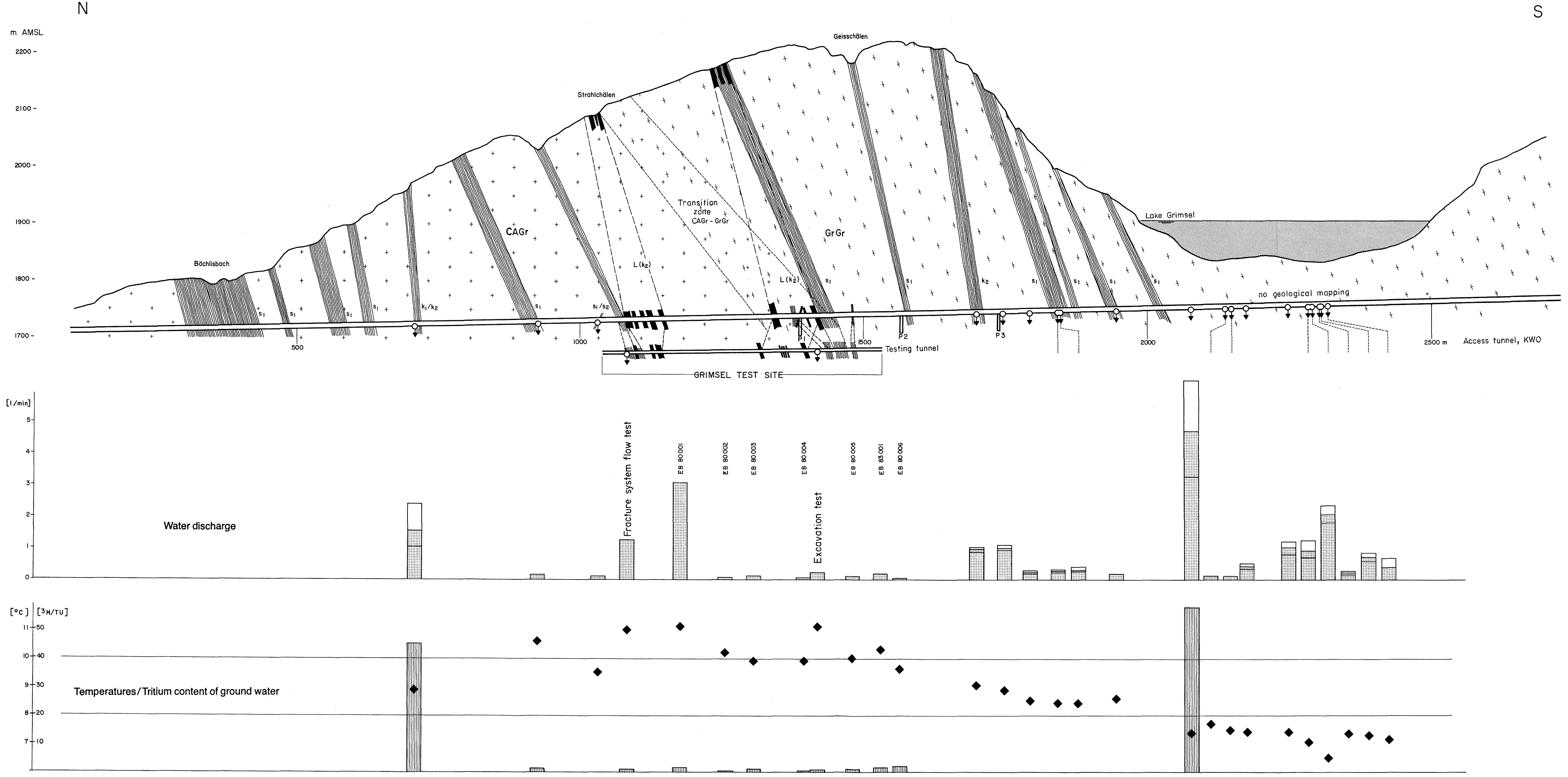
SECTION OF TESTING TUNNEL AND CAVERNS

GRIMSEL TEST SITE DAT.: 12. 7. 85 **ENCLOSURE 1**





NAGRA	TECHNICAL REPORT NTB 85-46
GEOLOGICAL N – S PROFILE OF SWITZERLAND	
GRIMSEL TEST SITE	DAT.: 12-07-85 · **ENCLOSURE 2**



Legend

Central Aaregranite, CAGr

Grimsel Granodiorite, GrGr

Lamprophyre

Disturbance zone observed at the surface, in the access tunnel and in the testing tunnels.

Significant water outflows in the access and testing tunnels.

Water discharge

Water temperature

Tritium content of outflowing water

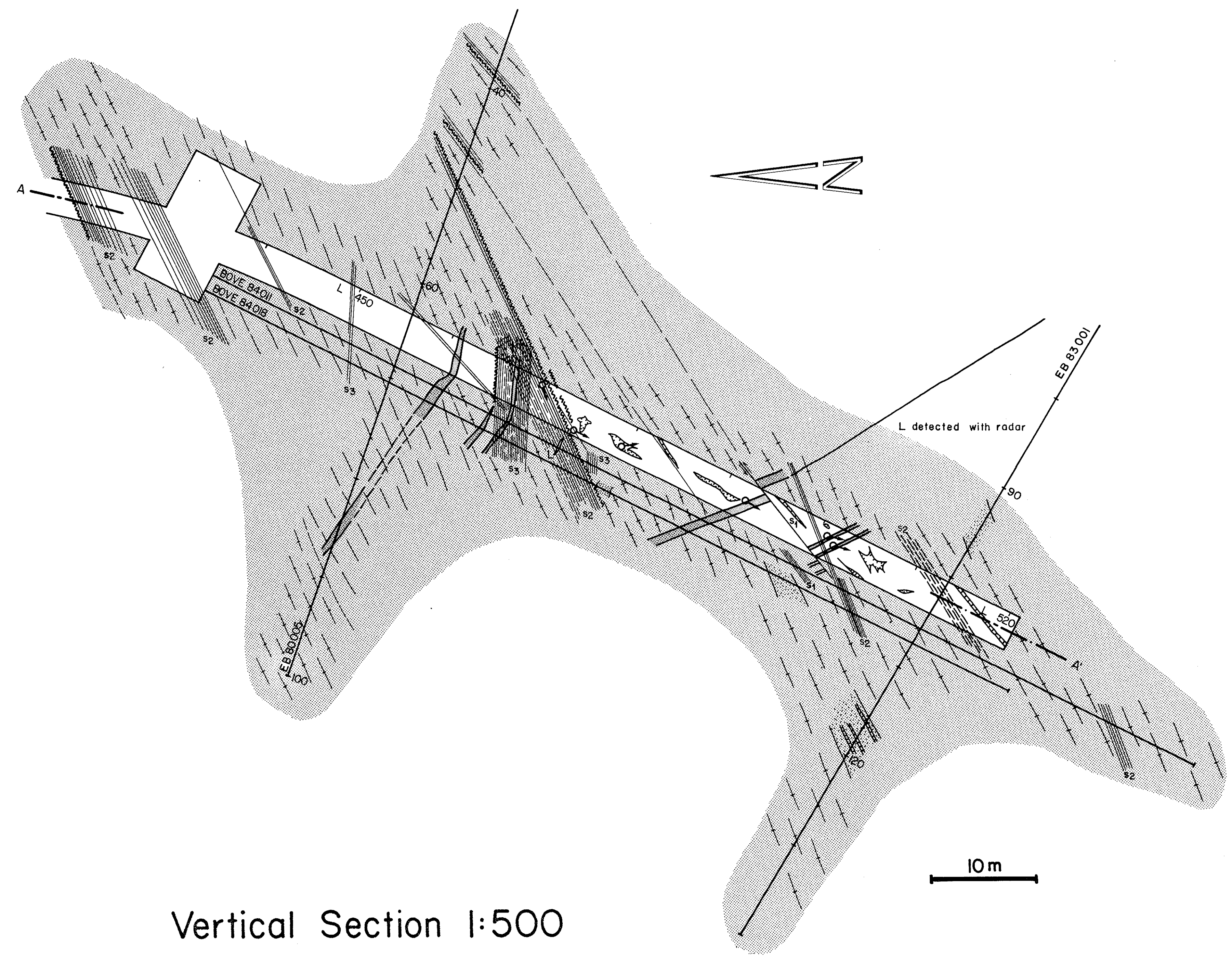
Neotectonic tiltmeter

1:5000

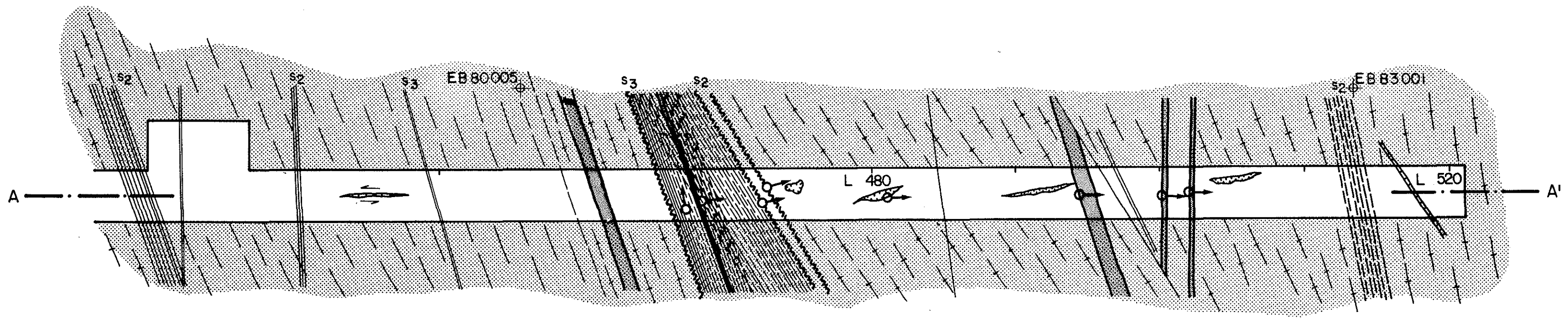
0 250 500m

NAGRA	**TECHNICAL REPORT NTB 85-46**
GEOLOGICAL PROFILE 1 KM EAST OF THE JUCHLISTOCK	
GRIMSEL TEST SITE DAT.: 12. 7. 85	**ENCLOSURE 3**

Horizontal Section 1:500



Vertical Section 1:500



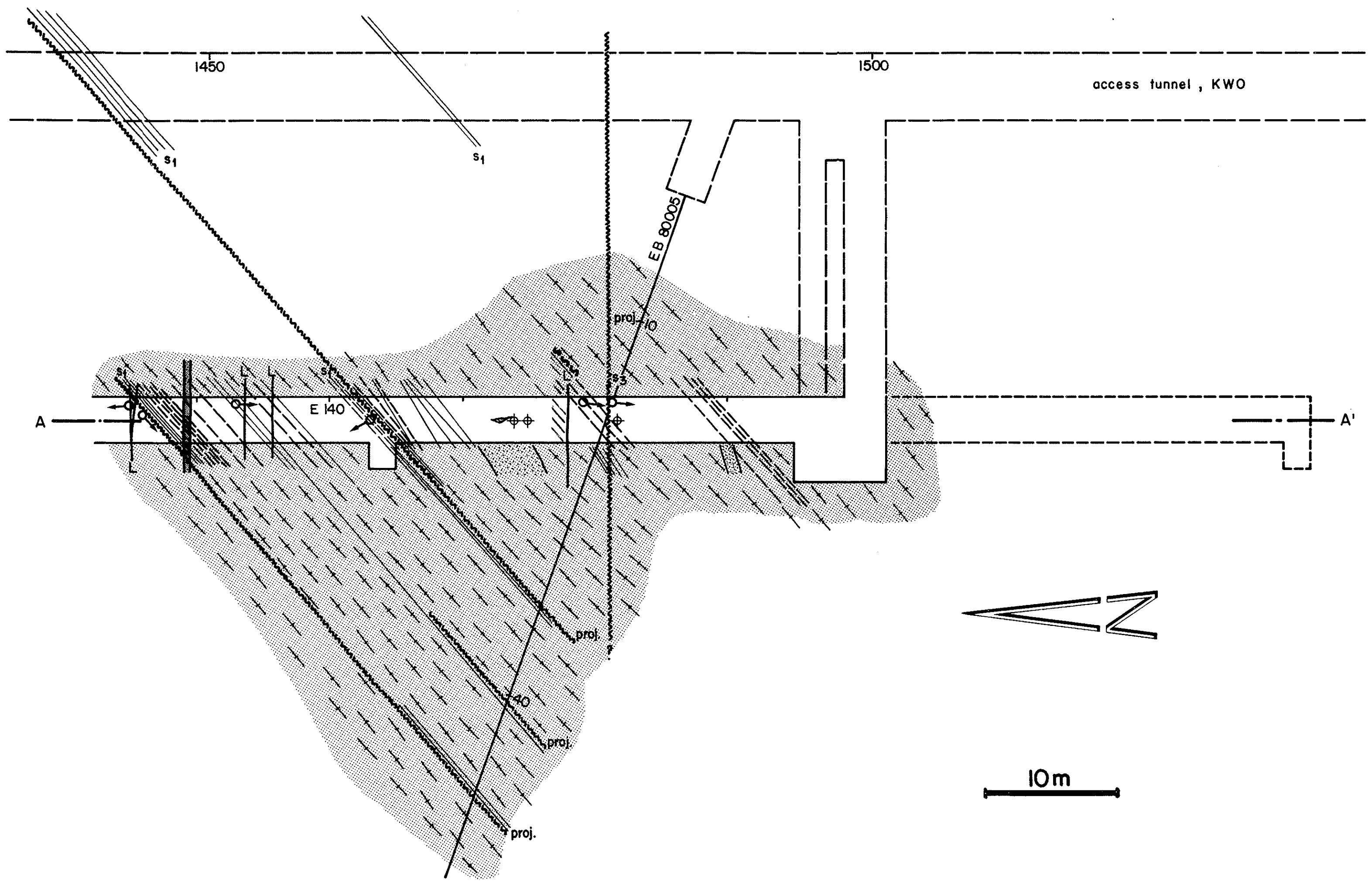
LEGEND

- Central Aaregranite, CAGr
- CAGr with high content of Biotite, parallel textured
- Grimsel Granodiorite, GrGr
- GrGr markedly parallel textured
- Lamprophyre
- Aplite
- hydrothermaly decomposed zone
- alpine tension fissure
- Quartz vein
- open fractures, fractured zone
- shear zone
- tectonic dislocation with direction of movement
- Water outflow
- Borehole

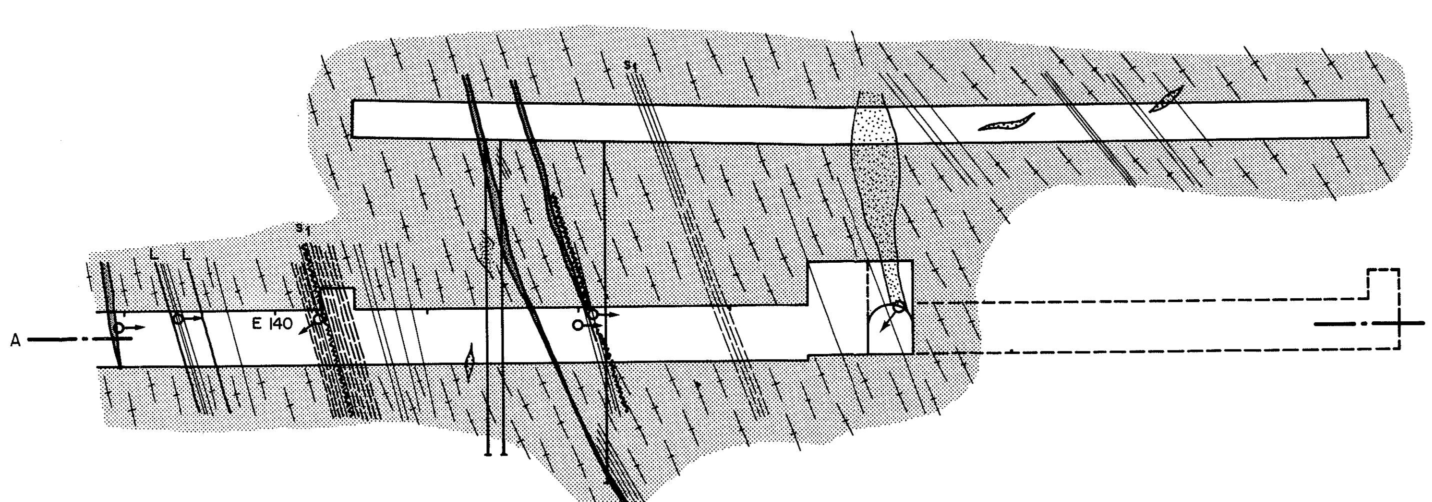
(The geology has been simplified, partly projected, shown in the plane through the tunnel axis)

NAGRA	TECHNICAL REPORT NTB 85-46
VENTILATION TEST, GEOLOGY	
GRIMSEL TEST SITE	DAT.: 12.07.85 — ENCLOSURE 4

Horizontal Section 1:500



Vertical Section 1:500



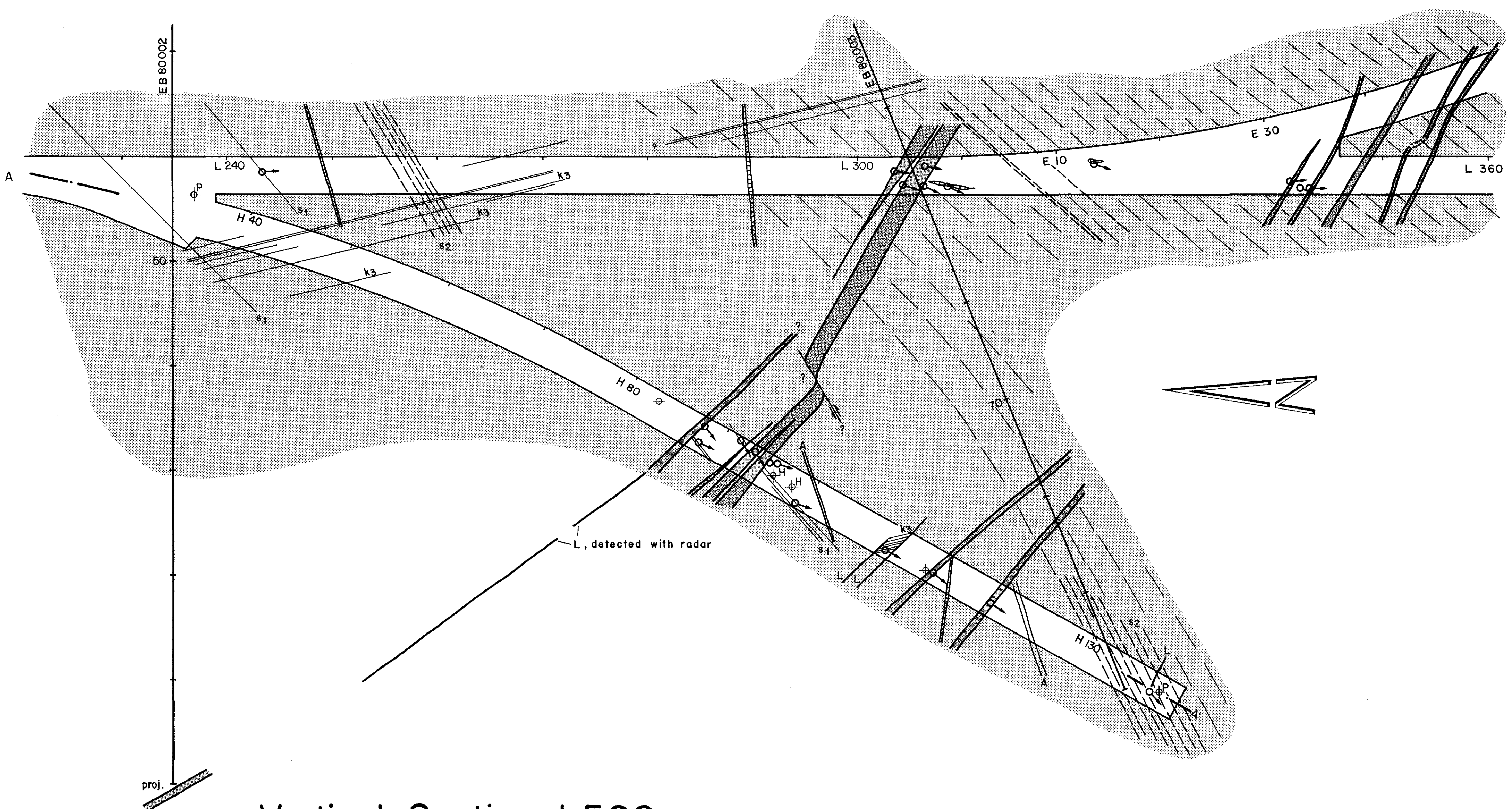
LEGEND

- Central Aaregranite, CAGr
  CAGr with high content of Biotite, parallel textured
- Grimsel Granodiorite. GrGr
  GrGr markedly parallel textured
- Lamprophyre
- Aplite
- hydrothermaly decomposed zone
- alpine tension fissure
- Quartz vein
- open fractures, fractured zone
- shear zone
- tectonic dislocation with direction of movement
- Water outflow
- Borehole

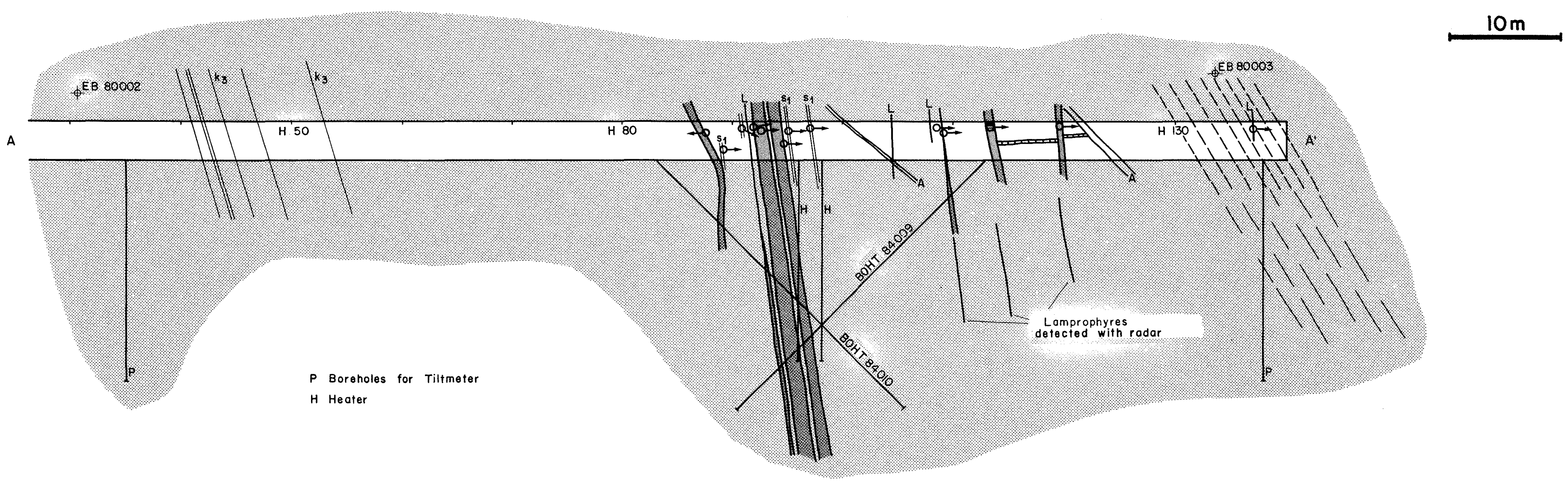
(The geology has been simplified, partly projected, shown in the plane through the tunnel axis)

NAGRA	TECHNICAL REPORT NTB 85-46	
EXCAVATION TEST, GEOLOGY		
GRIMSEL TEST SITE	DAT.: 12.07.85	ENCLOSURE 5

Horizontal Section 1:500



Vertical Section 1:500



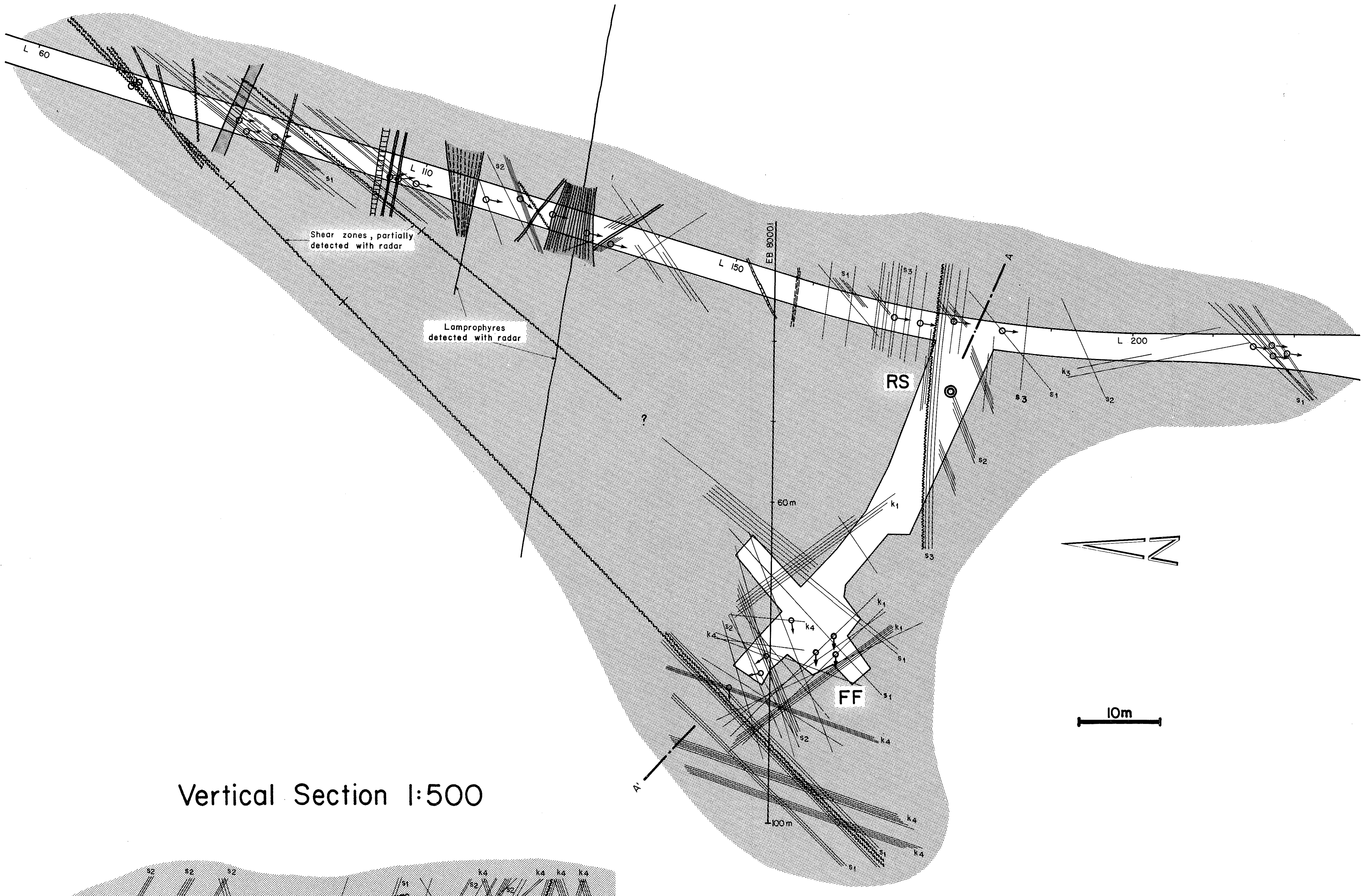
LEGEND

- Central Aaregranite, CAGr
- CAGr with high content of Biotite, parallel textured
- Grimsel Granodiorite, GrGr
- GrGr markedly parallel textured
- Lamprophyre
- Aplite
- hydrothermaly decomposed zone
- alpine tension fissure
- Quartz vein
- open fractures, fractured zone
- shear zone
- tectonic dislocation with direction of movement
- Water outflow
- Borehole

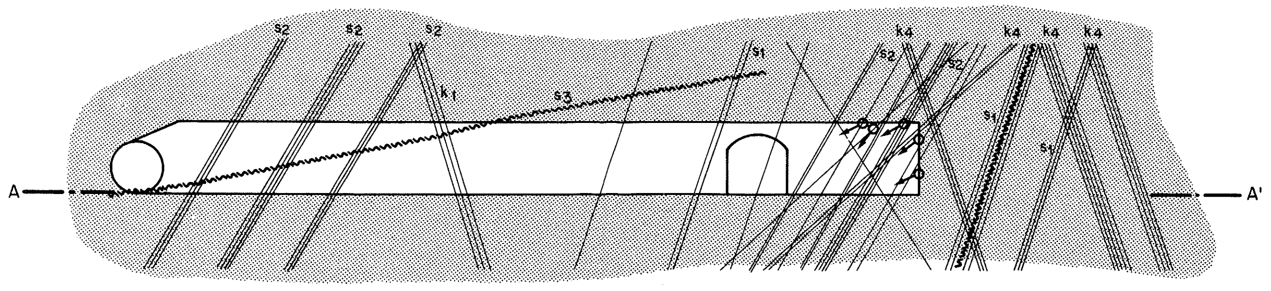
(The geology has been simplified, partly projected, shown in the plane through the tunnel axis)

NAGRA	**TECHNICAL REPORT NTB 85-46**
HEAT TEST, GEOLOGY	
GRIMSEL TEST SITE	DAT.: 12.07.85 — **ENCLOSURE 6**

Horizontal Section 1:500



Vertical Section 1:500



LEGEND

- Central Aaregranite, CAGr
  CAGr with high content of Biotite, parallel textured
- Grimsel Granodiorite, GrGr
  GrGr markedly parallel textured
- Lamprophyre
- Aplite
- hydrothermaly decomposed zone
- alpine tension fissure
- Quartz vein
- open fractures, fractured zone
- shear zone
- tectonic dislocation with direction of movement
- Water outflow
- Borehole

(The geology has been simplified, partly projected, shown in the plane through the tunnel axis)

NAGRA	TECHNICAL REPORT NTB 85-46
ROCK STRESS MEASUREMENTS, FRACTURE SYSTEM FLOW TEST GEOLOGY	
GRIMSEL TEST SITE	DAT.: 12.07.85 — ENCLOSURE 7