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# TECHNICAL REPORT 85-13

## STRIPA PROJECT

## ANNUAL REPORT 1984

JUNE 1985

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

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Das Stripa-Projekt ist ein Projekt der Nuklearagentur der OECD. Unter internationaler Beteiligung werden von 1980-84 Forschungsarbeiten in einem unterirdischen Felslabor in Schweden durchgeführt. Diese sollen die Kenntnisse auf folgenden Gebieten erweitern:

- hydrogeologische und geochemische Messungen in Bohrlöchern
- Ausbreitung des Grundwassers und Transport von Radionukliden durch Klüfte im Gestein
- Chemische Zusammensetzung des Grundwassers in grosser Tiefe
- Verhalten von Materialien, welche zur Abdichtung von Endlagern eingesetzt werden sollen

Seitens der Schweiz beteiligt sich die Nagra an diesen Untersuchungen.

The Stripa Project is organized as an autonomous project of the Nuclear Energy Agency of the OECD. In the period from 1980-84 an international cooperative programme of investigations is being carried out in an underground rock laboratory in Sweden. The aim of the work is to improve our knowledge in the following areas:

- hydrogeological and geochemical measurement methods in boreholes
- flow of groundwater and transport of radionuclides in fissured rock
- geochemistry of groundwater at great depths
- behaviour of backfill material in a real geological environment

Switzerland is represented in the Stripa Project by Nagra.

Le projet Stripa est un projet autonome de l'Agence pour l'Energie Nucléaire de l'OCDE. Il s'agit d'un programme de recherche avec participation internationale qui sera effectué entre 1980 et 1984 dans un laboratoire souterrain en Suède. Le but de ces travaux est d'améliorer et d'étendre les connaissances dans les domaines suivants:

- mesures hydrogéologiques et géochimiques dans les trous de forage
- écoulement des eaux souterraines et transport des radionucléides dans les roches fracturées
- chimie des eaux souterraines à grande profondeur
- comportement dans un environnement réel des matériaux de bourrage pour dépôts de déchets radioactifs

La Suisse est représentée dans le projet Stripa par la Cédra.

# THE STRIPA PROJECT

# ANNUAL REPORT 1984

The Stripa Project is an international project being performed under the sponsorship of the OECD Nuclear Energy Agency (NEA). The Project concerns research related to the disposal of highly radioactive waste into crystalline rock. The Research and Development Division of the Swedish Nuclear Fuel and Waste Management Company (SKB) has been entrusted with the management of the Project, under the direction of representatives from each participating country.

The aim of this report is to inform the OECD Nuclear Energy Agency and the participants in the Project about the general progress of work during 1984.

Stockholm, June 1985

Hans S Carlsson
Project Manager

# PREFACE

An autonomous OECD/NEA Project relating to the final disposal of highly radioactive waste from nuclear power generation is currently under way in an abandoned iron ore mine at Stripa, in central Sweden, see Figure 1.1. Research is being performed in a granite formation 350 meters below the ground surface. The stripa Project was started in 1980, in co-operation with Canada, Finland, France, Japan, Sweden, Switzerland, and the United States. The first phase of the project, scheduled for completion in mid 1985 at a total cost of approximately 50 MSEK, consists essentially of three parts:

- hydrogeological and hydrogeochemical investigations in boreholes down to a depth of 1230 metres below the ground surface,
- tracer migration tests to study radionuclide transport mechanisms in the rock fractures, and
- large-scale tests of the behaviour of backfill material in deposition holes and tunnels.

Preparations for an agreement between the participants covering a second phase of the Stripa Project were completed during 1982. The second phase, which

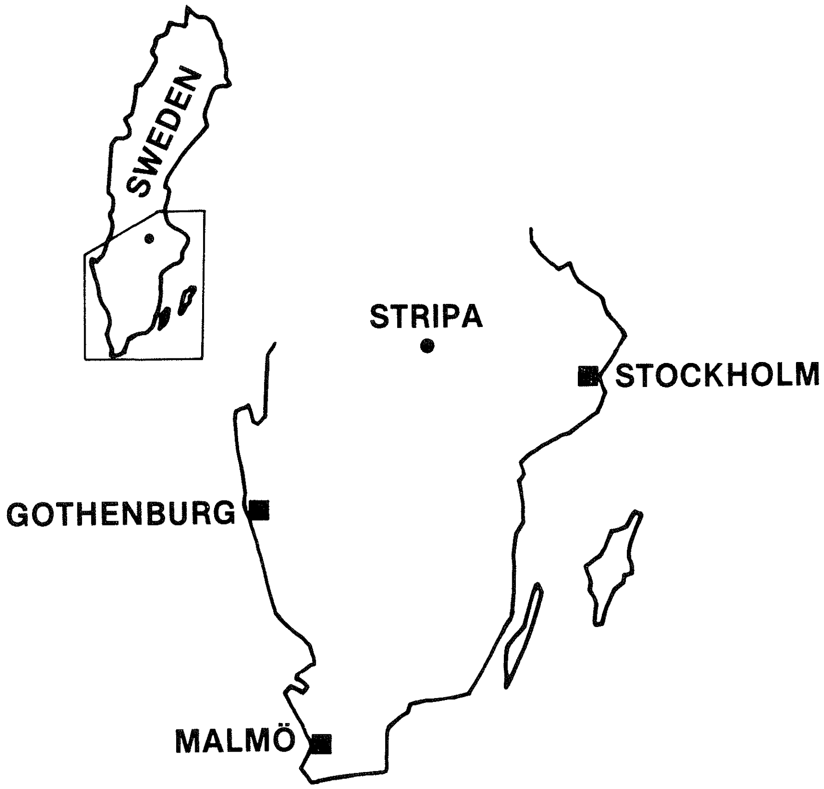


Figure 1.1. The Stripa Mine is located approximately 250 km west of Stockholm.

has been joined also by Spain and the United Kingdom started in 1983 and is scheduled for completion in 1986. The estimated total cost is 61 MSEK. The investigations included in the second phase are:

- the development of crosshole geophysical and hydraulic methods for the detection and characterization of fracture zones,
- extended tracer experiments in fractured granite
- the sealing of boreholes and shafts, using highly compacted bentonite,
- hydrogeological characterization of the Stripa site based on data from the Swedish-American cooperative (SAC) project, and
- isotopic characterization of the origin and geochemical interactions of the Stripa groundwaters.

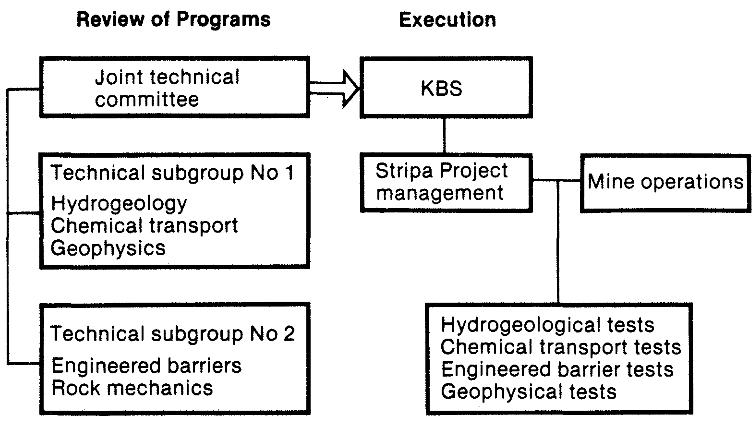


Figure 1.2. Organization of the Stripa Project.

The conditions of participation in the Stripa Project are covered by two separate agreements for Phase I and Phase II, although both phases share the same management structure, see Figure 1.2 The project is jointly funded by the organizations listed below. Responsibility for supervision of the research programme and for its finance resides with the Joint Technical Committee (JTC). This is composed of representatives from each of the national organizations. It also provides information on the general progress of work to the OECD Steering Committee for Nuclear Energy, through the NEA Committee on Radioactive Waste Management and its Co-ordinating Group on Geological Disposal.

Each research activity is assigned to a principal investigator, a scientist with particular expertise in the research field in question. The conception of the experiments, and their realisation, are periodically reviewed by two Technical Subgroups (TSGs). These sub-groups are composed of scientists from the participating countries. The first deals with hydrogeology, chemical transport and geophysics, the second with engineered barriers and rock mechanics.

The Division Research and Development of the Swedish Nuclear Fuel and Waste Management Company (SKB) acts as the host organization, and provides the management for the Project. It is responsible for mine operations, and for the procurement of equipment and material for experimental work. Meetings of the Technical Sub-groups, the Joint Technical Committee, the principal investigators and the project management are held on a regular basis to review the progress of the Project.

A representative of the OECD Nuclear Energy Agency takes part in the meetings of the Joint Technical Committee in an advisory capacity. The nuclear Energy Agency continues to foster the broadest possible participation in this and other Projects by its member countries, and ensures co-ordination of the Project with its other activites in the field of radioactive waste management.

The following organizations are participating in the Stripa Project:

| | |
|---|---|
| Canada | Atomic Energy of Canada Ltd (AECL) |
| Finland | Industrial Power Company Limited (TVO) Ministry of Trade and Industry; Imatra Power Company |
| France | Commissariat à l'Energie Atomique (CEA); Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA) |
| Japan | Power Reactor and Nuclear Fuel Development Corporation (PNC) |
| Spain (Phase II only) | Junta de Energia Nuclear (JEN) |
| Sweden | Swedish Nuclear Fuel and Waste Management Co |

| | |
|---|---|
| Switzerland | National Co-operative for the Storage of Radioactive Waste (NAGRA) |
| United Kingdom (Phase II only) | Department of the Environment (UK DOE) |
| United States | Department of Energy (US DOE) |

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# 1 GENERAL

## 1.1 MEETINGS

The Joint Technical Committee met in Stockholm on February 8-9, 1984, to discuss the technical progress and financial situation of the project. A large portion of the meeting was taken up by discussions on the recommendations from the Technical Subgroups regarding additional work at Stripa.

Technical Subgroup no 1 met in Stockholm and Kopparberg on September 24-27, 1984, to review the technical progress of the experiments related to hydrogeology, hydrogeochemistry, geophysics and chemical transport. In addition, the future work was discussed which resulted in a recommendation to the JTC to continue the Stripa project in a phase III.

Technical Subgroup no 2 met in Stockholm and Kopparberg on September 24-26, 1984, to discuss the progress of the experiments related to engineered barriers.

All meetings have included a visit to Stripa. Notes from the meetings have been distributed separately.

## 1.2 NEW INVESTIGATIONS

The following new investigations were approved by the JTC at their meeting in February 1985.

<u>Hydrogeological characterization of the Stripa site based on data from the Swedish-American co-operative project. Part 1.</u>

Proposed by Sweden through professor John Gale, University of Newfoundland, Canada.

Data obtained in the previous Swedish-American Cooperative Project will be used to establish any general correlations between fracture frequency, fracture orientation and fracture permeabilities. The bulk flow rates from a two-dimensional simulated fracture network, into the drift where the Buffer Mass Test is carried out, will be calculated. The calculated data will be compared with the actual data from the previous macropermeability experiment, carried out in the same drift.

<u>Additional crosshole seismic investigations at Stripa</u>

Proposed by Finland through dr Calin Cosma, Geoseismo OY, Finland

An equipment for crosshole seismic investigations developed in Finland will be used at the small scale crosshole site at Stripa. The results will be compared with other crosshole measurements from the same site.

<u>Isotopic characterization of the origin and geochemical interactions of the Stripa groundwaters</u>

Proposed by the Hydrogeochemistry Advisory Group (HAG) within the Stripa Project.

The purpose of this program is to use and test different techniques in order to characterize the chemical quality of deep groundwaters. This is important for the prediction of future chemical reactions which may take place in and near the repository, particularly those involving corrosion of the waste canister and the waste itself. Secondly, the project aims at understanding the history of the water by using isotopic ($^{36}Cl$, $^{39}Ar$, $^{85}Kr$, $^{81}Kr$ etc) and standard chemical information. This information will also give some idea of the age of the water.

At the TSG-1 meeting in September it was recommended that a small group of experts familiar with the experiments at Stripa should prepare a tentative outline of an interdisciplinary research project to be accomplished in a tentative phase III of the Stripa Project. The aim of the proposed project should be to increase the knowledge on fracture flow in a crystalline medium using geophysical, hydrogeological and hydrogeochemical methods as well as methods for migration studies developed so far. The proposal was approved by the JTC and the formulation of the tentative outline was in progress by the end of the year.

If possible, research related to engineered barriers and rock mechanics will also be included in the program.

## 1.3 INFORMATION

The preparation of the second film as well as an updated brochure regarding the activities at Stripa was in progress by the end of the year. The film and the brochure will be completed in early 1985.

Preparations for a Stripa Information Symposium started in late 1984. The Symposium will be held on June 4 and 5, 1985, in Stockholm, followed by a visit to Stripa on June 6. The purpose of the Symposium is to present the results and conclusions from the phase I experiments as well as the progress of the phase II experiments.

## 1.4 REPORTING

The progress of the project has been presented in detail in quaterly reports. A list of internal and technical reports published during 1984 and previously is given in Chapter 12.

# PHASE I

A summary of the progress of the Stripa Project, Phase I, is given below. More detailed information is given in the reports listed in Chapter 12.

## 2 HYDROGEOLOGICAL AND HYDROGEOCHEMICAL INVESTIGATIONS IN BOREHOLES

The principal investigators for this part of the project are drs Leif Carlsson, Swedish Geological Co (SGAB), and Tommy Olsson, Geosystem AB, Sweden. The technical content and progress of the investigation is reported in /1/ and /34/.

### 2.1 GENERAL

All field work was completed during 1984 and the evaluation and interpretation of the final results began.

### 2.2 HYDRAULIC TESTING

An interference test between boreholes V1, V2, N1 and E1 was carried out during 1984. Borehole V1 acted as the transmitter hole and the pressure interferences were measured in four individual sections in each of the remaining boreholes.

All boreholes were in a pressure build-up stage for about 100 days. Borehole V1 was then turned into a controlled flowing condition with a constant flow-rate of 7 l/min. During this flowing stage, the pressure responses in the sealed-off sections were continuously recorded.

A clear pressure interference was noted between boreholes V1 and V2. A less clear response was noted in borehole N1. Borehole E1 was not affected at all from the pressure drop in V1.

After the free-flowing stage, borehole V1 was again sealed off and the recovery was recorded.

The final hydraulic measurements within this program were the water injection tests in ten meter sections in boreholes E1, N1 and V1. The applied excess pressure was 100 meter above the water head obtained after sealing the packers. The tests were performed with two hours of injection followed by a fall-off period of the same duration or longer. In total, 110 sections were tested.

In summary, the following hydraulic tests were carried out within this program during 1981-1984:

<u>Single-hole tests</u>

- Water injection tests in ten meter sections in boreholes E1, N1 and V1.

- Pressure build-up tests in selected two meter sections in boreholes E1 and N1.

- Pressure build-up tests in the crushed zone in borehole V1.

Interference tests

- Interference test between the crushed zone in borehole V1 and borehole V2.
- Interference test between borehole N1 and the boreholes in the Buffer Mass Test area.
- Interference test between borehole V1 and boreholes E1, N1 and V2.

## 2.3 HYDROGEOCHEMICAL INVESTIGATIONS

The major part of 1984 was used up for evaluation, interpretation and coordination of results obtained from the analyses carried out within Phase I of the project. However, some additional sampling were taken.

Samples for $C^{14}$-analyses were taken from boreholes in the mine as well as in some private wells included in the regional survey of saline waters. Neutron flux measurements at six different locations in the mine, both in boreholes and in the drifts. On average, 6.9 counts per minute were obtained which agrees very well with the calculations previously made.

# 3 MIGRATION IN A SINGLE FRACTURE

The principal investigator for this study is professor Ivars Neretnieks, Royal Institute of Technology, Sweden. The technical content and progress of the investigation is presented in /1/ and /34/.

## 3.1 GENERAL

All field activities were completed by the end of the year. Compilation and the final evaluation of the obtained data started.

## 3.2 SUMMARY OF ACTIVITIES TO DATE

A total number of 16 main cores have been excavated along or parallel to the investigated fractures A and B. From these, more than 200 sample cores have been drilled. Most of the sample cores have been drilled close to the injection hole.

Approximately 300 Atomic Absorption analyses have been carried out on the sample cores for the purpose of determining the surface and depth concentration of Cs and Sr. In addition, around 55 sample cores have been analysed by neutron activation for the purpose of determining the surface and depth concentration of Cs, Eu, Nd, Th and U.

## 3.3 PRELIMINARY RESULTS

Some of the analysed surface concentration of Cs is shown in Figure 3.1 whereas the depth variation is shown in Figure 3.2.

Evaluation and interpretation of the data continued throughout 1984.

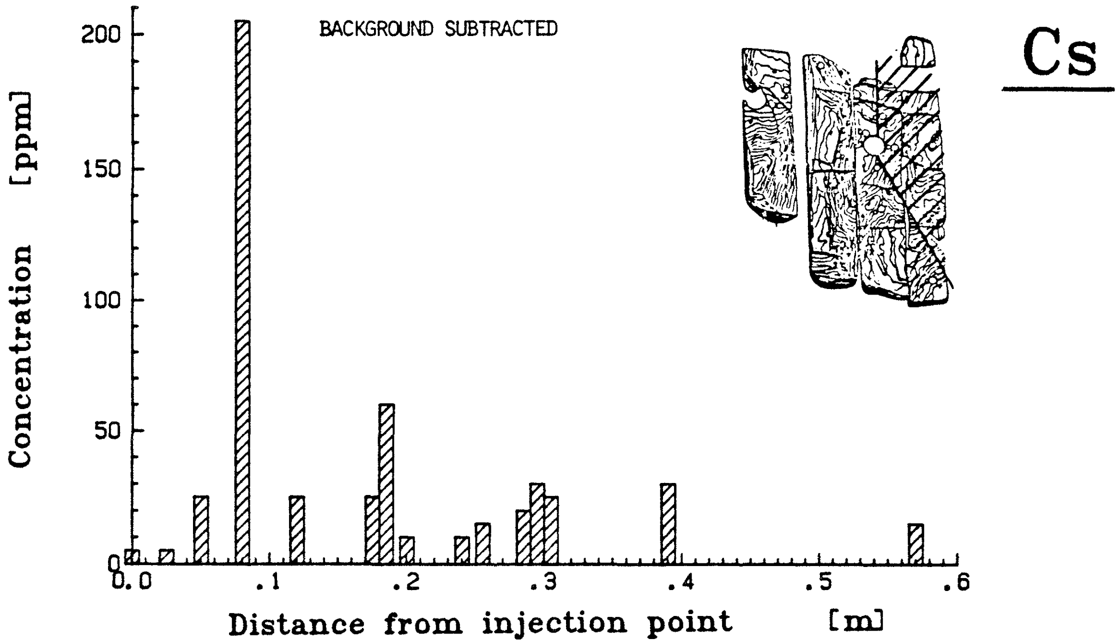


Figure 3.1. Example of Cs concentration as a function of distance from the injection hole.

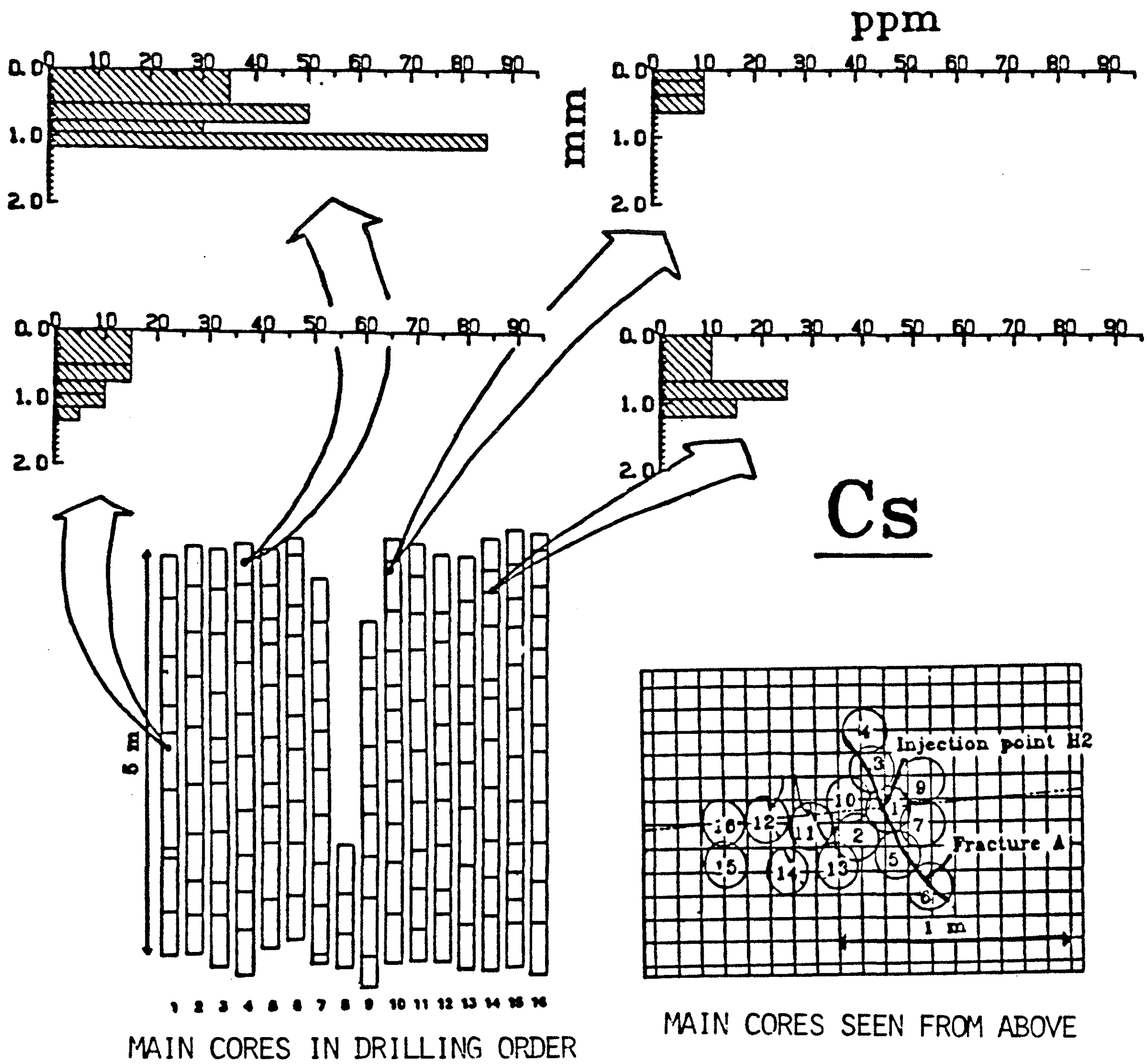


Figure 3.2. Example of Cs concentration as a function of depth.

# 4 BUFFER MASS TEST

The principal investigator for this investigation is professor Roland Pusch, Swedish Geological, Sweden. The technical content and progress of the investigation is presented in /1/ and /34/.

## 4.1 FIELD ACTIVITIES

Early in the year, the power content of heater no 1 and 3 were increased to 1400 W and 1800 W respectively. This was done in order to investigate the heat and water distributions at higher temperatures. Deposition hole no 3 was excavated in mid May whereas heater no 1 continued to operate at 1400 W output throughout the year.

Deposition hole number 6 was excavated in early April after approximately 25 months of testing at a power output of 600 W and deposition hole number 5 was excavated in early June after approximately 27 months of testing at the same power output.

Finally, the excavation of the outer half of the tunnel backfill and deposition no 2 began in early October and was completed approximately 1 month later. The tunnel backfill was removed step-wise with samples taken in regular network patterns over the steeply inclined, exposed surface. Heater hole no 2 was sampled in the same manner as the previously excavated heater holes.

## 4.2 PRELIMINARY RESULTS

Below some of the results obtained are presented. Final evaluation and interpretation for the final report began by the end of the year.

Deposition hole no 5

This "wet" hole was excavated after 27 months of testing at a power output of 600 W.

The maximum recorded temperature shortly before turn-off was 63°C. A high degree of water saturation to within a couple of centimeters from the heater surface was obtained from the sampling. The joints between the original blocks could not be identified at the sampling. The swelling pressure development is shown in Figure 4.1. Maximum water pressure recorded just before turn-off was 27 kPa.

Deposition hole no 1

The heater in deposition hole no 1 has been running at 1400 W power output since mid March, 1984.

The maximum recorded heater temperature was close to 125°C in late December, 1984, while the temperature at the rock/bentonite interface at the same level (mid-height) was around 72°C. Figure 4.2 shows the temperature development during July through December, 1985.

Preliminary data indicate a high degree of water saturation in hole no 1 since the maximum swelling pressure were almost constant at 8 MPa during the last three months of 1984, see Figure 4.3. The water pressure at the base of hole no 1 increased from 744 kPa to 770 kPa by the end of the year despite the fact that the back-fill had been removed. This shows that there are no effective flow paths or hydraulic connections between the lower part of holes no 1 and 2 and the pervious tunnel floor.

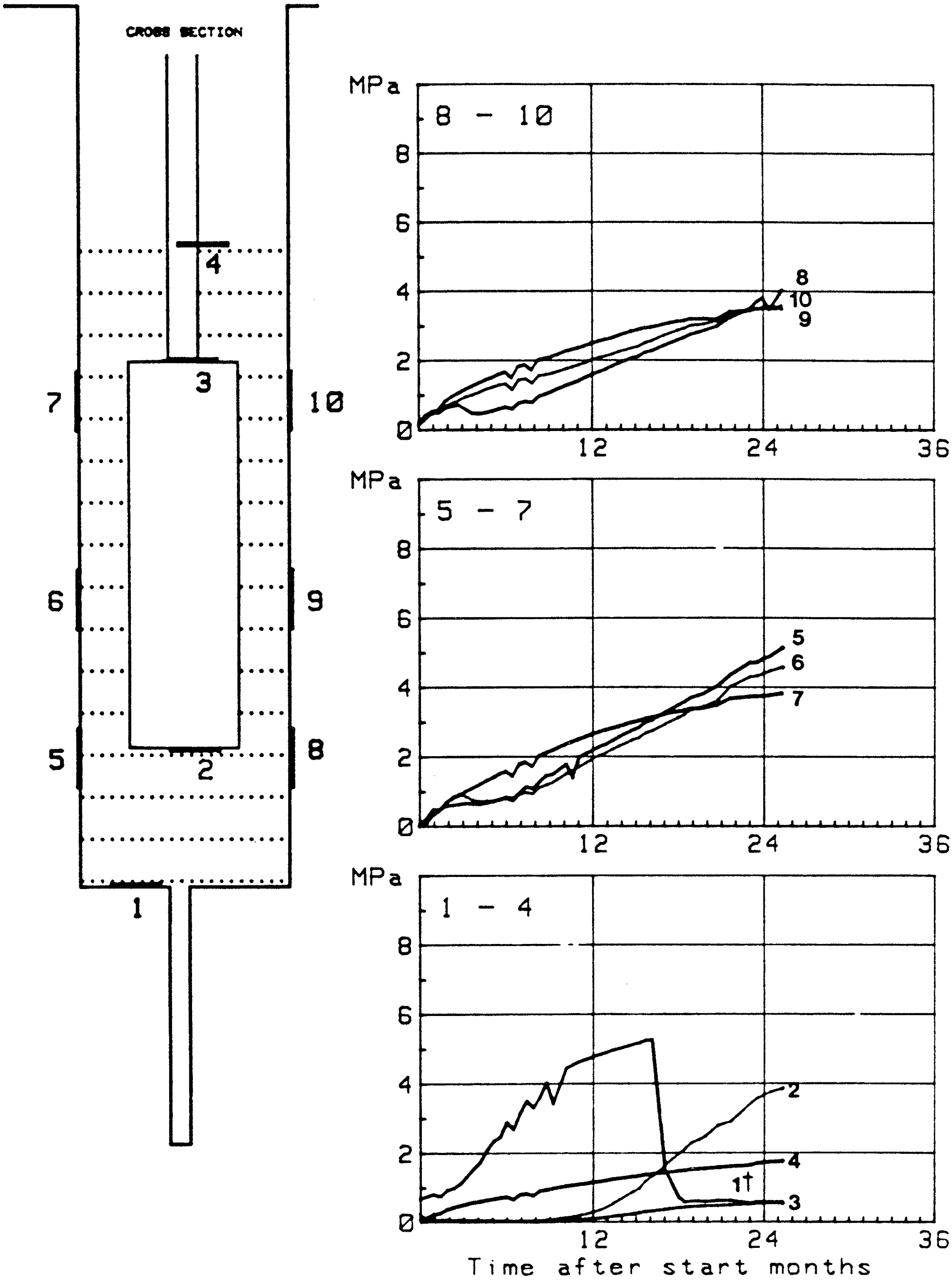


Figure 4.1. Swelling pressure development in hole no 5. Heater power output 600 W.

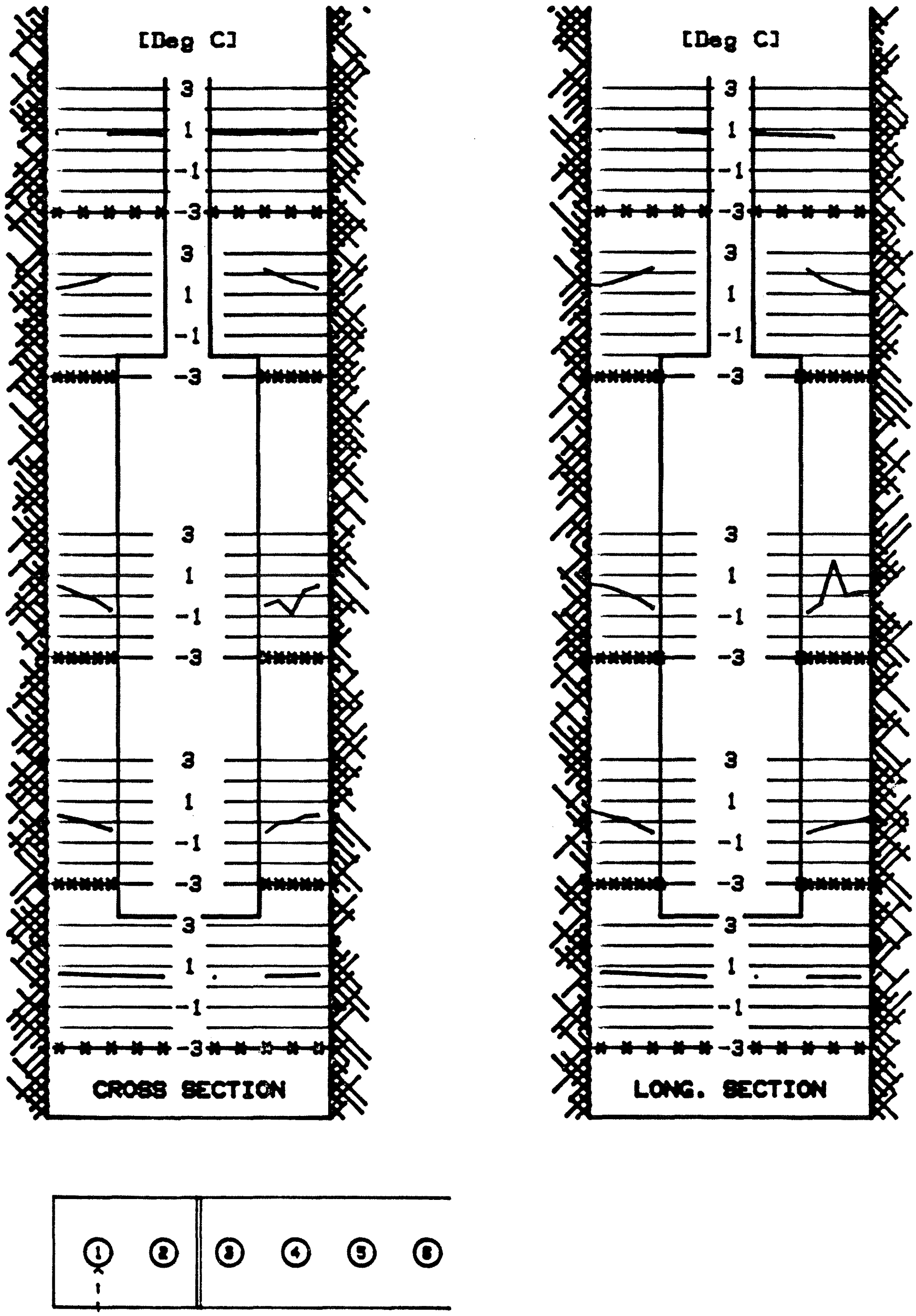


Figure 4.2. Temperature change in hole no 1 during July through December, 1984. Heater power output 1400 W.

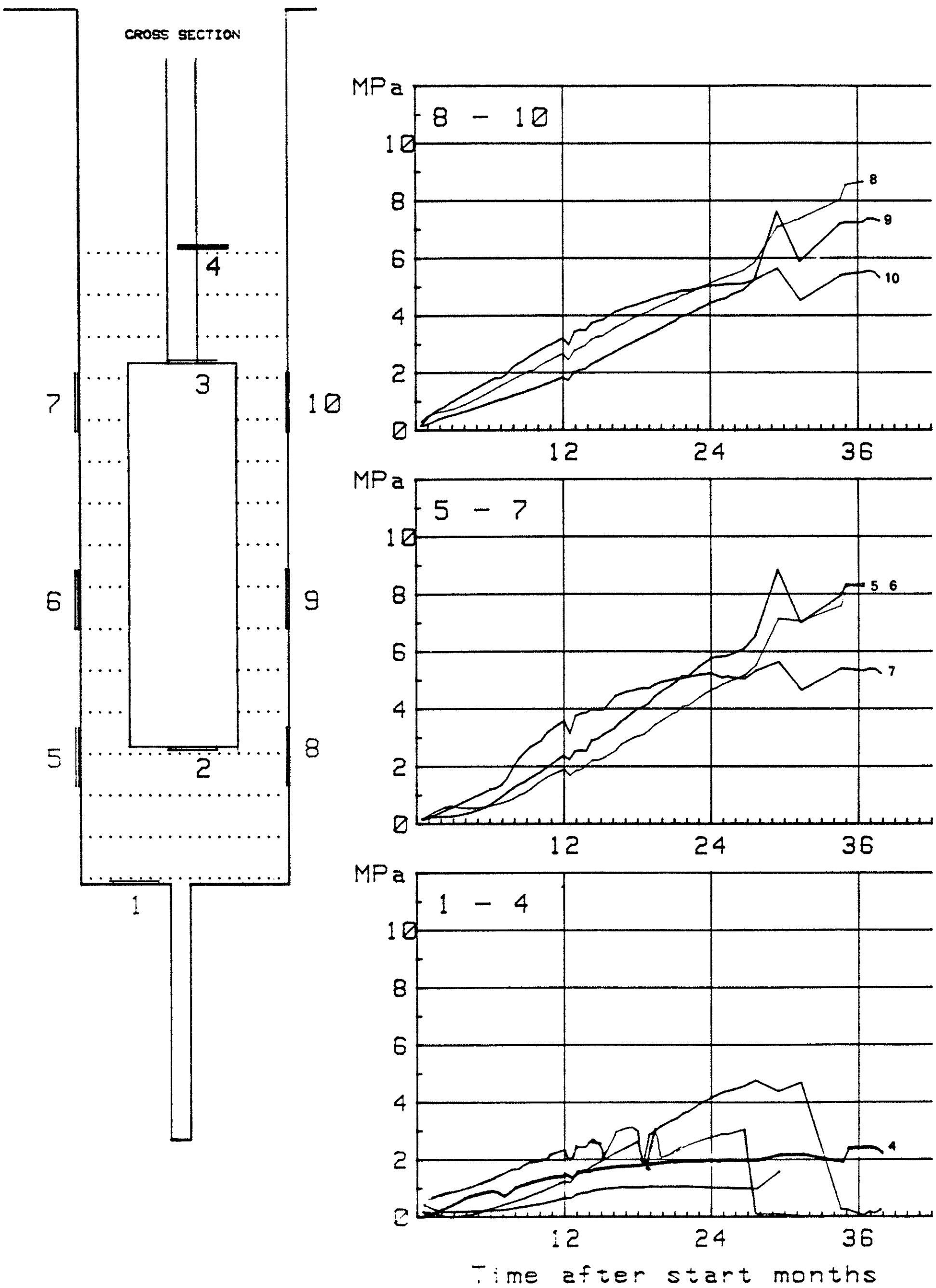


Figure 4.3. Swelling pressures in heater hole no 1.
Heater power output 1400 W.

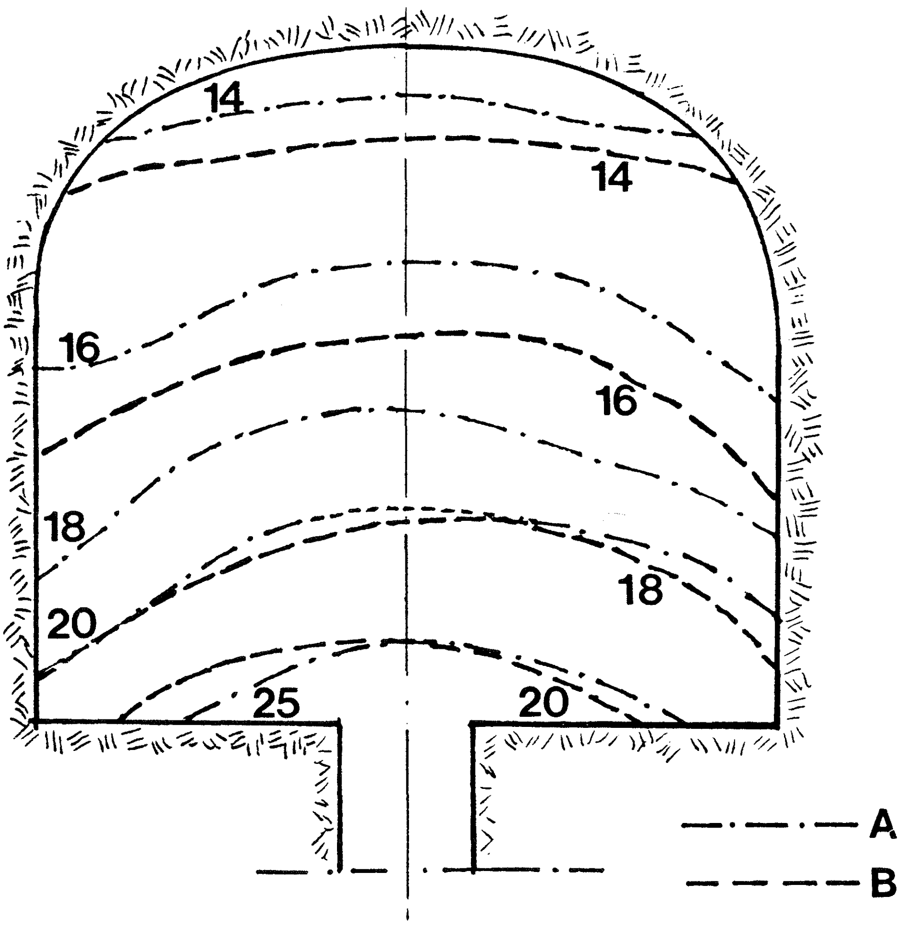


Figure 4.4. Isotherms (centigrades) in the tunnel backfill in mid September, 1984. **A** represents the section through hole no 1 (1400 W) and **B** that through hole no 2 (600 W).

Tunnel backfill

The following results were obtained after approximately 3 months of testing.

The backfill temperature above holes no 1 and 3 increased slowly and measured temperature profiles are shown in Figure 4.4. The degree of saturation was surprisingly high, i.e. about 75% as an average. The 10/90 backfill was completely saturated to about 2 m from the tunnel floor, which indicated that the ability of the backfill to absorb water has consistently been higher than the capacity of the rock to give off water. This explains why the water pressures at the rock/backfill interface have remained quite low.

## 5 ECONOMY

A summary of the budget and accumulated cost as per December 31, 1984, is given below.

No overrun of the grand total budget is expected.

| | Original budget Price level Jan 1, 1980 | Revised budget 840123 incl 10% annual escalation | Accumulated | Estimated Remaining |
|---|---|---|---|---|
| Project Management | 3.100.000 | 2.650.000 | 2.599.866 | 50.134 |
| Stripa General | 13.000.000 | 10.140.000 | 8.824.313 | 1.315.687 |
| Hydrogeological Investigations | 6.500.000 | 8.230.000 | 8.010.833 | 219.167 |
| Buffer Mass Test | 14.000.000 | 21.400.000 | 20.643.941 | 756.059 |
| Migration in a Single Fracture | 4.150.000 | 5.460.000 | 5.113.417 | 346.583 |
| TOTAL | 40.750.000 | 47.880.000 | 45.192.370 | 2.687.630 |

# PHASE II

A summary of the progress of the Stripa Project, Phase II, is given below. More detailed information is given in the reports listed in Chapter 12.

## 6 THE DEVELOPMENT OF GEOPHYSICAL AND HYDRAULIC CROSS-HOLE TECHNIQUES

The current investigation has been set up in cooperation between the Swedish Geological Co (SGAB), the Swedish National Research Defence Institute (FOA), the British Geological Survey (BGS) and Geoseismo OY, Finland. The principal coordinator is dr Olle Olsson, SGAB. The technical content and the progress of the investigation is presented in /35/ and /34/.

### 6.1 GENERAL

The purpose of this investigation is to develop crosshole electromagnetic (radar), seismic and hydraulic (sinusoidal) methods for bedrock investigations which may determine the location, extent, thickness, and physical properties of fracture zones. The radar and sinusoidal methods are tested in a specially designed borehole configuration at Stripa whereas the seismic method also is tested at Gideå, located in northern Sweden. The distance between transmitter and receiver when performing crosshole seismic investigations may be up to 1000 meters or more making the Stripa mine less preferable. The geology of the Gideå site has been carefully investigated by SKB within their program for selection and investigation of potential sites for a repository for spent nuclear fuel.

## 6.2 SITE PREPARATION

The suitability of the crosshole site at Stripa has been progressively investigated by a step-by-step approach and the field work was completed during 1984. The interpreted extension of the major units which have been correlated between the boreholes are shown in Figure 6.1. The borehole investigation program has comprised mapping of the core, TV-inspection and geophysical borehole measurements; resistivity, single-point resistance, sonic, gamma-gamma, neutron, self-potential, natural gamma, magnetic susceptibility, temperature and salinity of the borehole water. Water injection tests have been performed in two boreholes (F1 and F2).

The crosshole site contains suitable targets for the crosshole investigations such as one or more water yielding fracture zones. The specific geological and geophysical character of the deformed units enable correlation of the units between the boreholes. Thus, the extension of seven units has been determined and four of these units have been encountered in all six boreholes. The extension and the direction of correlated units has been calculated by a computer program. The units constitute planar structures and the computed and correlated borehole positions only depart with a couple of meters. The TV-oriented fractures in the units often are subparallel with the calculated orientation of the units. The TV-oriented fractures and the units generally have a strike direction of about NNE-NE and are steeply dipping towards NW or SE.

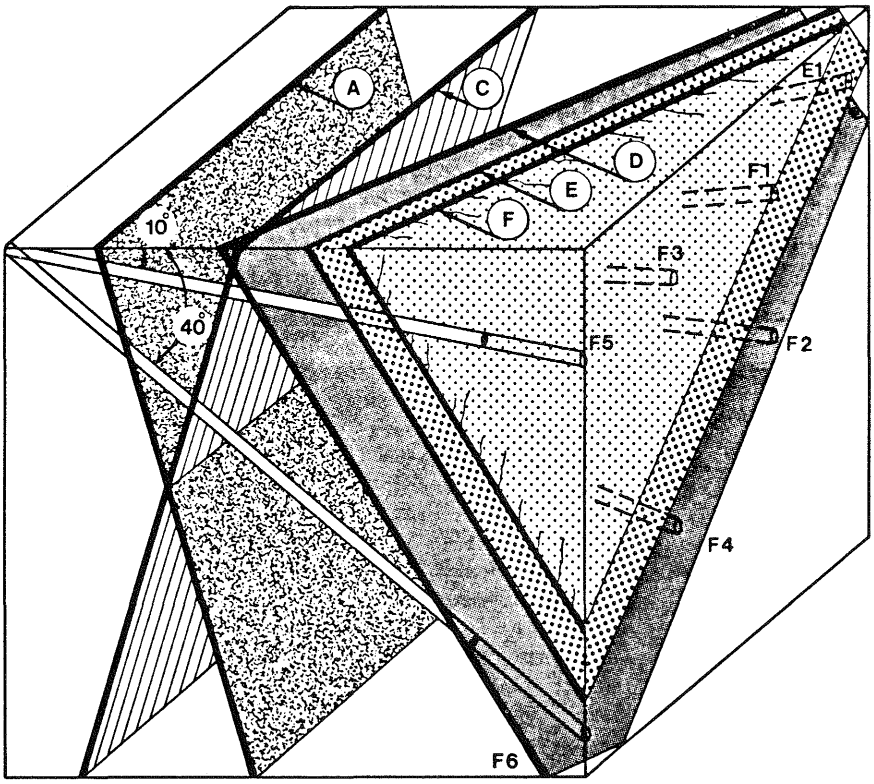


Figure 6.1. Block diagram showing the interpreted extension of some major units which have been correlated between the boreholes.

No site preparation work was needed at Gideå.

## 6.3 BOREHOLE RADAR

The construction of the new borehole radar system is now completed and the system performance has been tested extensively.

Significant improvements have been made to reduce the ringing in the system. New antennas of the resistively loaded type have been designed and in combination with an improved impedance matching between antennas and electronics a well defined pulse has been obtained. The ringing is now reduced to acceptable levels and consequently very good results can be obtained in single-hole reflection measurements.

Single-hole reflection measurements have been made in all F-holes, E1, N1, V1, 3DP1, 3DH1, 3DH2 and 3DH3 (3D indicates boreholes in the 3D migration drift). Crosshole measurements have been performed between boreholes E1 and N1 as well as between F2 and E1. In the latter survey, the transmitter was placed in F2 and moved in 10 m steps. For each transmitter position the receiver was moved in E1 in 2 m steps. The crosshole survey resulted in a total of 1065 rays covering the plane between the boreholes. The equipment worked very well during these tests and the work performed corresponds to approximately 3.7 km of measured borehole.

The attenuation of radar waves in the Stripa granite is 28 dB/100 m and the velocity is 128 000 km/s. The high attenuation limits the range of the radar system which presently is 100 m for reflection measurements and 250 m for crosshole measurements. An increase in range will require a considerable increase in dynamic range due to the high attenuation. On the other hand if measurements are made in a rock with less attenuation significant increases in range are expected.

The single-hole reflection measurements obtained have good quality and give detailed information on the geometry of fracture zones. Fracture zones intersecting the borehole may be followed to distances of up to 100 m from the borehole. In some cases it is also possible to see evidence of faulting of the fracture zones. It is interesting to note that reflections are also clearly seen in crosshole measurements opening new possibilities for obtaining data on the properties of fracture zones.

## 6.4 CROSSHOLE SEISMICS

A large scale crosshole seismic survey was carried out at the study site Gideå. Three cored boreholes and two percussion drilled boreholes were used. The maximum depth of the holes is 700 m and 150 m respectively. The maximumn horizontal distance between the top of the recording holes was around 1000 m and the size of the test area was around 0.4 $km^2$.

The experimental layout gave a true three-dimensional coverage of the volume under study. In the experiment over 300 shots were fired, giving around 8000 signal traces corresponding to about 3000 traveltimes. A 3-D inversion was made. A coarse structure could be seen, but the residual errors were quite large, making detailed interpretations difficult. Closer interpretations will be performed using 2-D inversions.

Model calculations using an anisotropic velocity distribution were in agreement for most features which were suggested by previous geophysical investigations. No new major fracture zones were found.

The VSP (Vertical Seismic Profiling) technique, using shots at the surface and receivers in a single borehole is a viable alternative to the standard crosshole measurements. The main advantages are lower cost due to increased shooting rate and that only one deep borehole is needed. The disadvantage is a poorer ray coverage of the bottom half of the section.

A crosshole seismic survey was also performed at Stripa by Geoseismo OY using the system BHS-56 designed by them.

The pulse generator was placed in borehole F4 and the 3D detectors in each of the other holes. Sections F4-F6 and F4-F2 were surveyed with geophone probes. Accelerometric probes were used for the other three sections. The step between measuring

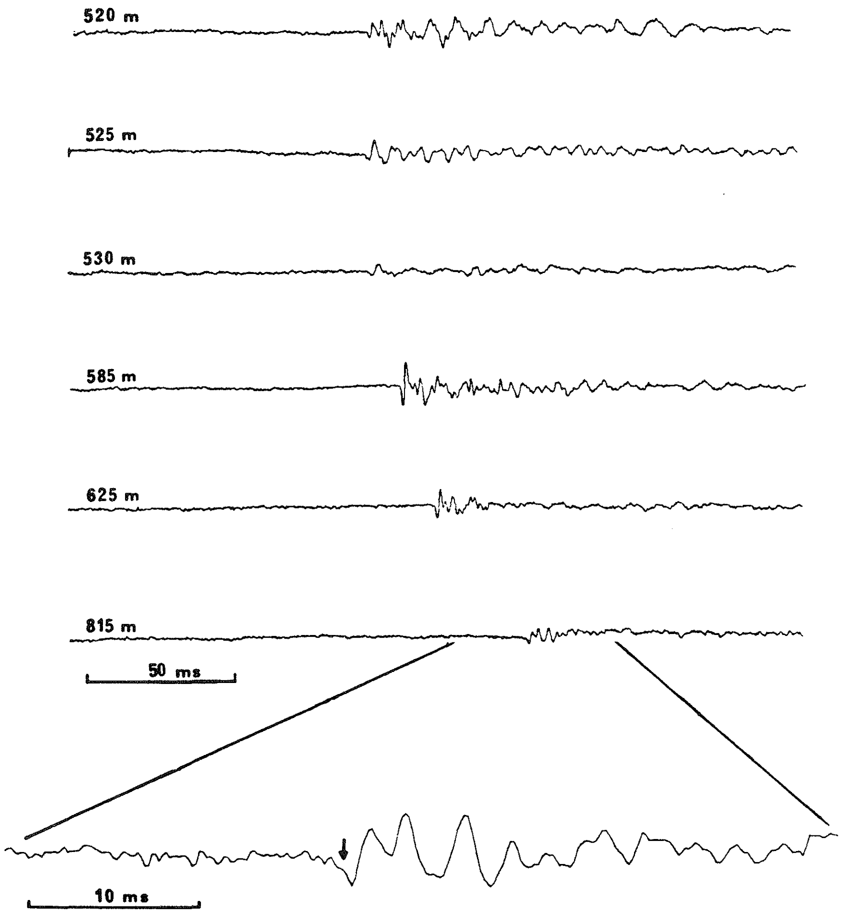


Figure 6.2. Recordings at a depth of 520 m in Gi2, (horizontal component), from surface shots at different positions along line Gi1 - Gi2. The shot at 815 m is shown in both normal and expanded scale.

points was typically 5 m and some 300 rays were recorded for each section. The ray net was chosen in such a way as to keep an even ray density throughout the whole field. The measurements were done between 60 m and 200 m in every borehole.

A first attempt of tomographic inversion was done using the depth in the borehole and the pre-established borehole coordinates as a base for measuring point positions. This approach cannot be considered reliable because the boreholes are expected to deviate from the initial direction. The measured coordinates were used afterwards but still the error in position determination was greater than the error in travel time. In order to get a consistent error level the accuracy of positioning should be within ±0.3 m at any depth.

Evaluation of the results were in progress by the end of the year.

## 6.5 CROSSHOLE HYDRAULICS

The construction of the equipment for carrying out the hydraulic testing programme was completed and tested at Stripa.

The system is designed to perform a variety of different hydraulic tests (constant rate tests, transient tests, and sinusoidal tests) at the touch of a button. It consists of comparatively normal borehole hardware with a complex system of pumps and valves located in the drift which are controlled by a micro-computer. The micro-computer controls the functions of the hardware to create the source-zone signal and measure the resulting fluctuations using specially written software.

The testing system which is central to carrying out the hydraulic programme is an advanced hydrogeological testing system and has met all performance criteria. It has proved very reliable and has a versatility unknown in simpler systems. Particular innovations are the borehole pumps, seals and the mechanised system of valves, differential pressure transducers and reference pressure.

Using the system is quick and once more tests have been carried out an optimum testing mixture of transient and steady state tests will be evolved. Initial single borehole and interference tests have yielded results within the range expected for the Stripa Mine. More surprising is the range in hydraulic heads which are present within short distances from the drift wall.

An example of obtained results are shown in Figure 6.3.

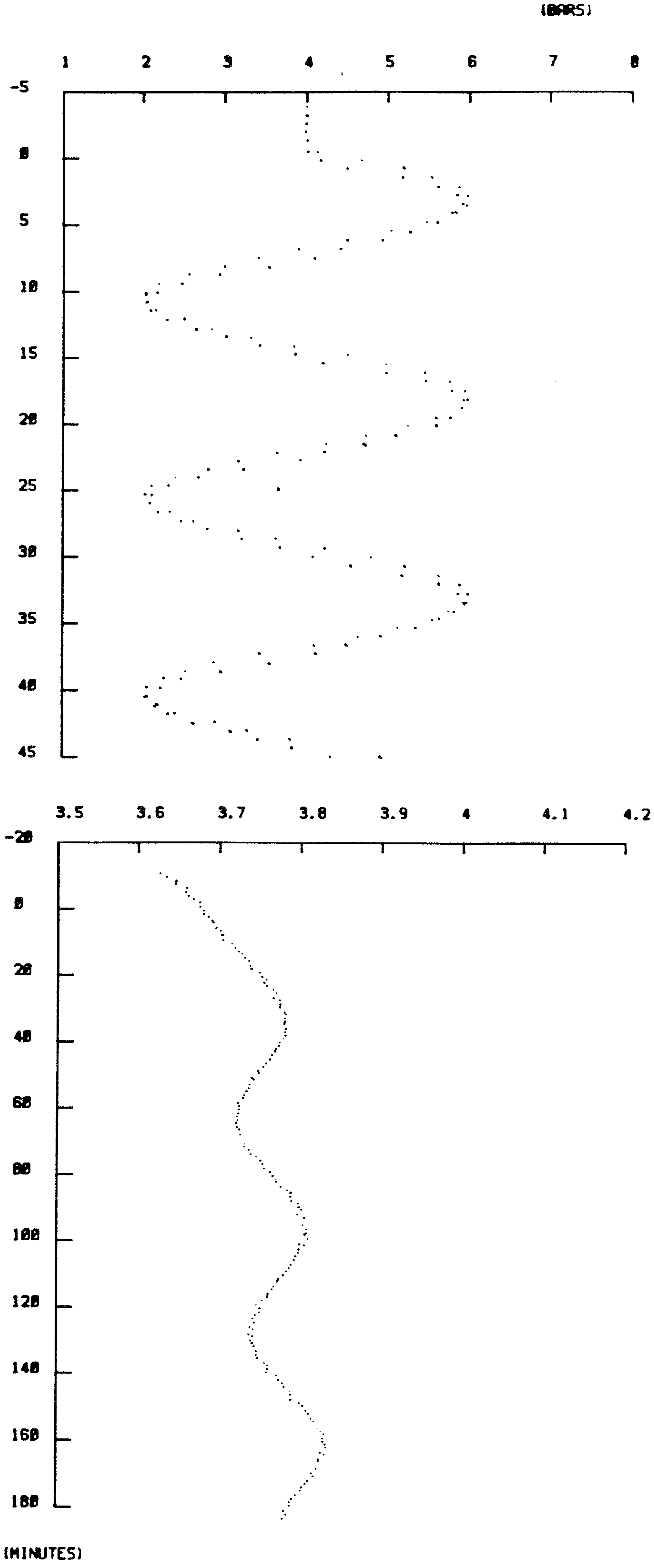


Figure 6.3 Above - Sinusoidal signal in source borehole (calculated and measured). Below - Example of received sinusoidal signal.

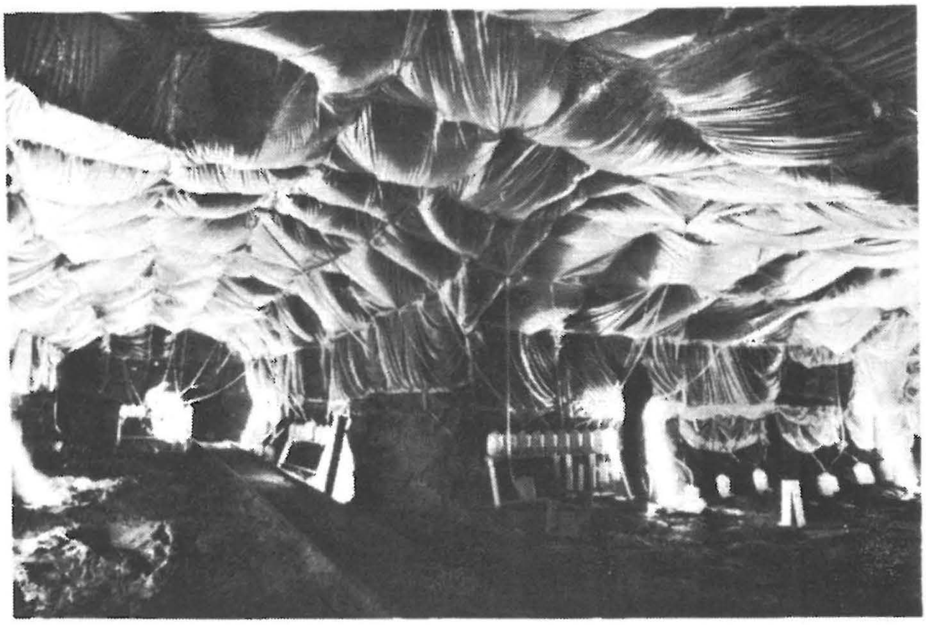

Figure 7.1. Part of the experimental drift used in the 3D migration experiment and covered with plastic sheets.

# 7 THREE-DIMENSIONAL MIGRATION EXPERIMENT

The principal investigator for this experiment is Professor Ivars Neretnieks, Royal Institute of Technology (KTH), Sweden. The technical content and progress of the investigation is given in /35/ and /34/.

## 7.1 GENERAL

The general objectives of the 3D Migration Test are to study longitudinal and transverse dispersion in fissured rock, to determine flow porosity, to study channeling, to obtain data for model verification and/or modification and finally to develop techniques for large scale tracer experiments in low permeable fissured rock.

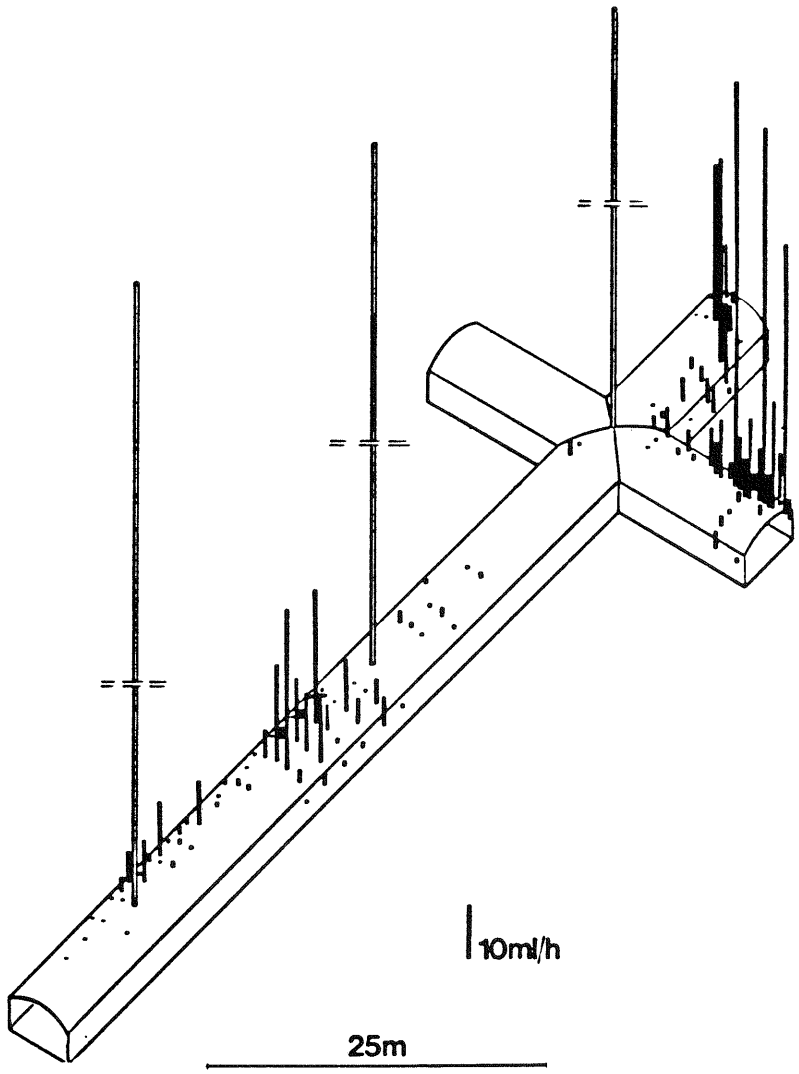


Figure 7.2. Water flow rates into the test site after appr. 1 year of measurements.

## 7.2 SITE PREPARATION

The covering of the roof and part of the walls with plastic sheets were completed early in the year. In total, the 350-400 sheets cover around 700 $m^2$ of rock, see Figure 7.1. The total inflow of water to the sheets was around 800 ml/h and the distribution of the flow is shown in Figure 7.2. Water was found in only 1/3 of the total number of sheets. 10% out of these "wet" sheets gave more than 50% of the total water volume flowing in to the drift.

Three vertical injection holes were diamond drilled to a length of 70 m, see Figure 7.2. The inflow in to the holes was measured in 2 m sections and the highest flowing zones were selected for tracer injections. In total, 9 different tracers were injected according to the following table:

| Hole | Level above the ceiling | Tracer |
|---|---|---|
| I | 31-33 m | Uranine |
| | 17-19 m | Eosin yellowish |
| II | 55-57 m | Phloxine B |
| | 33-35 m | Rose Bengal |
| | 9-11 | Elbenyl br. flavine |
| III | 36-38 m | Duasyn acid green |
| | 28-30 m | Iodide |
| | 18-20 | Eosin blueish |
| | 12-14 m | Bromide |

## 7.3 TRACER INJECTION

All tracers will be injected continuously in 2 meter packed-off sections and with a "constant" overpressure of approximately 10-15% over the natural pressure.

Before injection, all nine tracers were tested in laboratory experiments where they were found to be stable with time and non-sorbing on crushed granite as well as on the materials used in the equipment. Seven of the tracers are dyes (i.e. coloured tracers), while the two remaining tracers are salts (iodide and bromide). The injection concentrations are between 1000 and 2000 ppm, and the injection flow rates are 1-20 ml/h.

Approximately 100 samples/day are taken for analysis from the water that enters the plastic sheets.

## 7.4 PRELIMINARY RESULTS

At the end of 1984 and after 2 months of injection tracers from the zone located 9-11 m above the ceiling in hole II were seen in approximately 10 plastic sheets.

# 8 BOREHOLE AND SHAFT SEALING TESTS

The principal investigator for this study is Professor Roland Pusch, Swedish Geological Co, Sweden. The technical content and progress of the project are given in /35/ and /34/.

## 8.1 GENERAL

The general objective of the Borehole and Shaft Sealing Test is to demonstrate the construction phase of borehole, shaft, and tunnel plugs, as well as to determine the sealing effects of such plugs using highly compacted bentonite.

## 8.2 BOREHOLE PLUGGING

Highly compacted bentonite surrounded by perforated copper tube was used to plug approximately 95 meters of borehole DBH 2 which run parallel to the Buffer Mass Test drift. Water is injected through filters along the borehole in order to test the sealing function of the bentonite. The pressure increased slowly during the year (max. 800 kPa) but was also affected by the activities in the Buffer Mass Test. The plug was left to mature and excavation will be carried out during 1985.

A duplicate test using highly compacted bentonite surrounded by a perforated coper tube and a steel mesh respectively was initiated in late 1983. The water pressures in the surrounding rock were low and water was therefore not effectively driven to the clay core resulting in a slow maturation process. Water saturation was increased by increasing the injection pressure as a preparation for the future determination of the "bond strength" of the clay plugs.

## 8.3 SHAFT SEALING TEST

A schematic layout of the test is shown in figure 8.1.

The completion of the reference test was delayed due to a replacement of the backfill between the concrete plugs.

The preparation of the site for the main test with bentonite plugs included cutting of a 25 cm high and 25-30 cm deep slot around the lower clay plug, and the application of beams, and steel plates for the bentonite "brickwork". After the completion of the lower clay plug, 0.5-2.0 mm sand with no fines was sedimented and compacted on top of it and the upper clay plug was then built. The same type of water inlet arrangement in the sand chamber of the reference test was used in the main test.

## 8.4 TUNNEL SEALING

The purpose of this subproject is to investigate the suitability of using highly compacted bentonite for sealing a highly fractured waterbearing zone crossing a drift. In the actual experiment at Stripa an artificial zone is created using perforated pipes around the periphery of the tunnel.

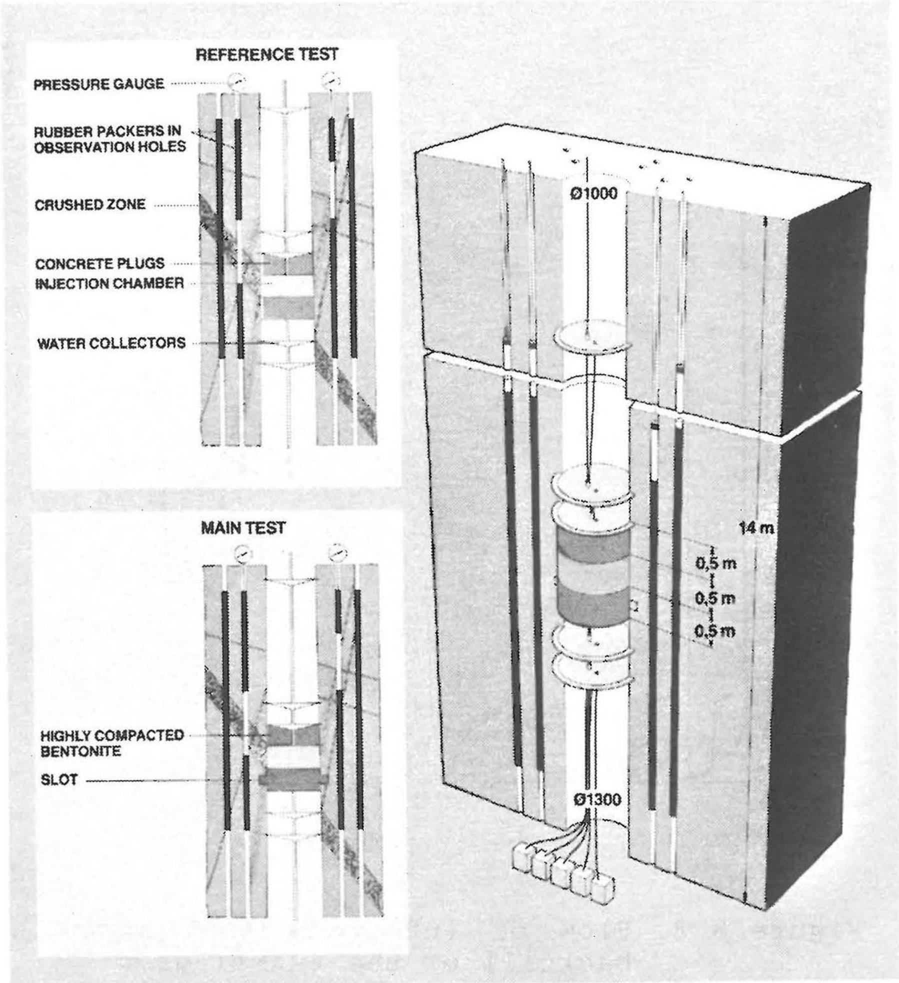


Figure 8.1. Schematic layout of the vertical shaft sealing experiment.

The construction phase was completed in early 1984 and a stepwise pressure increase by water injection started. The flow/time relation is shown in Figure 8.2 both for the injected water and the water that is being collected immediately outside the ends of the plug. The close resemblance of the two curves indicates that practically all the injected water flows through the rock adjacent to the plugs. The last pressure step (3 MPa) obviously increased the flow considerably, which possibly indicates flow paths deeper into the rock. An additional explanation may be that the increased pressure affected the aperture of the fractures.

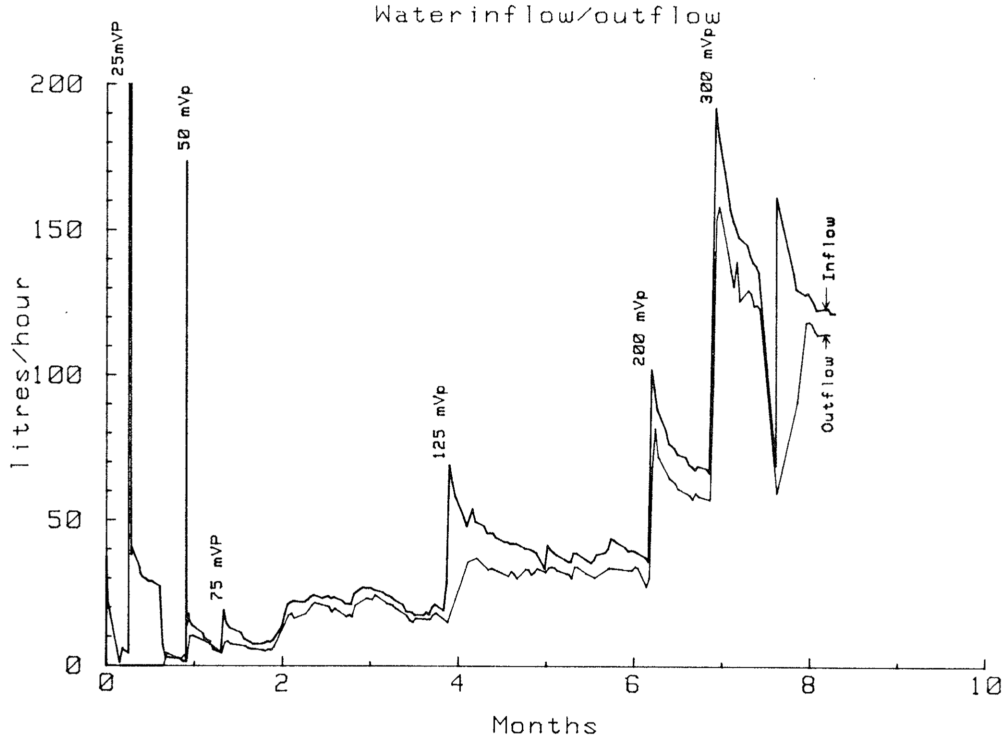


Figure 8.2. Flow of injected water into the sandy backfill of the tunnel plug.

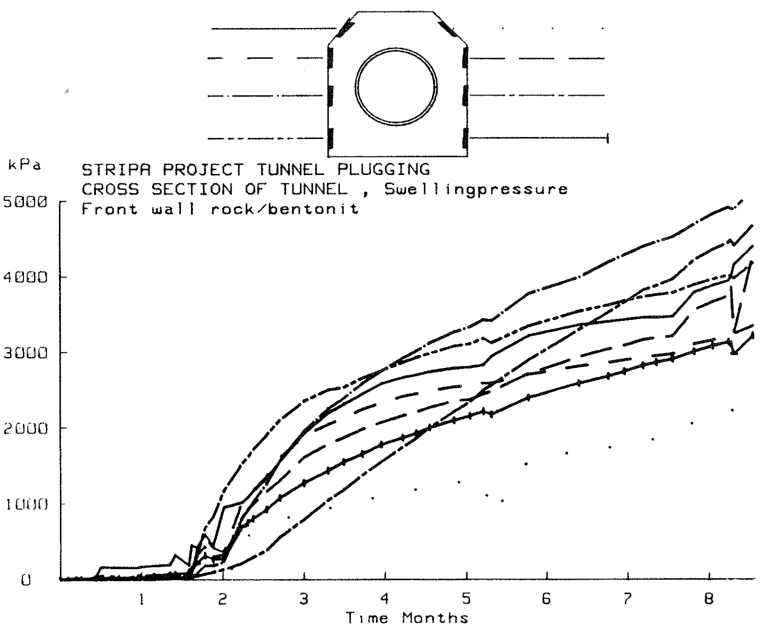


Figure 8.3. Total pressures at the front wall of the tunnel plugs. The cells are located at the rock/bentonite interface.

The measurement of the total pressures at the interface between rock and bentonite has proceeded. The pressures tend to increase at a constant rate and are now in the range of 2-5 MPa (Figure 8.3). Since the water pressure now amounts to 3 MPa it is clear that arching effects in the system of bentonite blocks still prevent the swellling and water pressures to be completely transferred to the gauges. The degree of maturation of the bentonite is consequently not complete.

# 9 HYDROGEOLOGICAL CHARACTERIZATION OF THE STRIPA SITE - PART 1

The principal investigator for this project is Professor John E Gale, Memorial University of Newfoundland, Canada. The technical content and the progress of the study are given in /35/ and /34/.

## 9.1 OBJECTIVES

This study has the following main objectives:

- to review the borehole packer test data collected during the LBL-KBS cooperative program
- to tabulate and characterize the distributions of permeabilities determined from the usable borehole packer test data
- to determine the degree of correlation between the calculated fracture permeabilities and the frequency of each fracture set in each test interval
- to characterize the distribution of fracture apertures for each fracture set in terms of (a) individual fractures, and (b) effective conduits

- to compare measured inflows to the macropermeability drift at Stripa to those calculated for flow through generated fracture networks using various fracture aperture models.

## 9.2 PROGRESS OF THE WORK

This study was initiated on September 1, 1984. By the end of the year the packer test data files were reviewed and reconstructed as necessary. The fracture network generator code was revised and implemented on the VAX-780 at Memorial University. An example of the type of fracture network that is generated by the network program for one quarter at a circle orientated perpendicular to the macropermeability drift is given in Figure 9.1. The fracture network has been generated using the fracture data from the macropermeability drift. In order to study

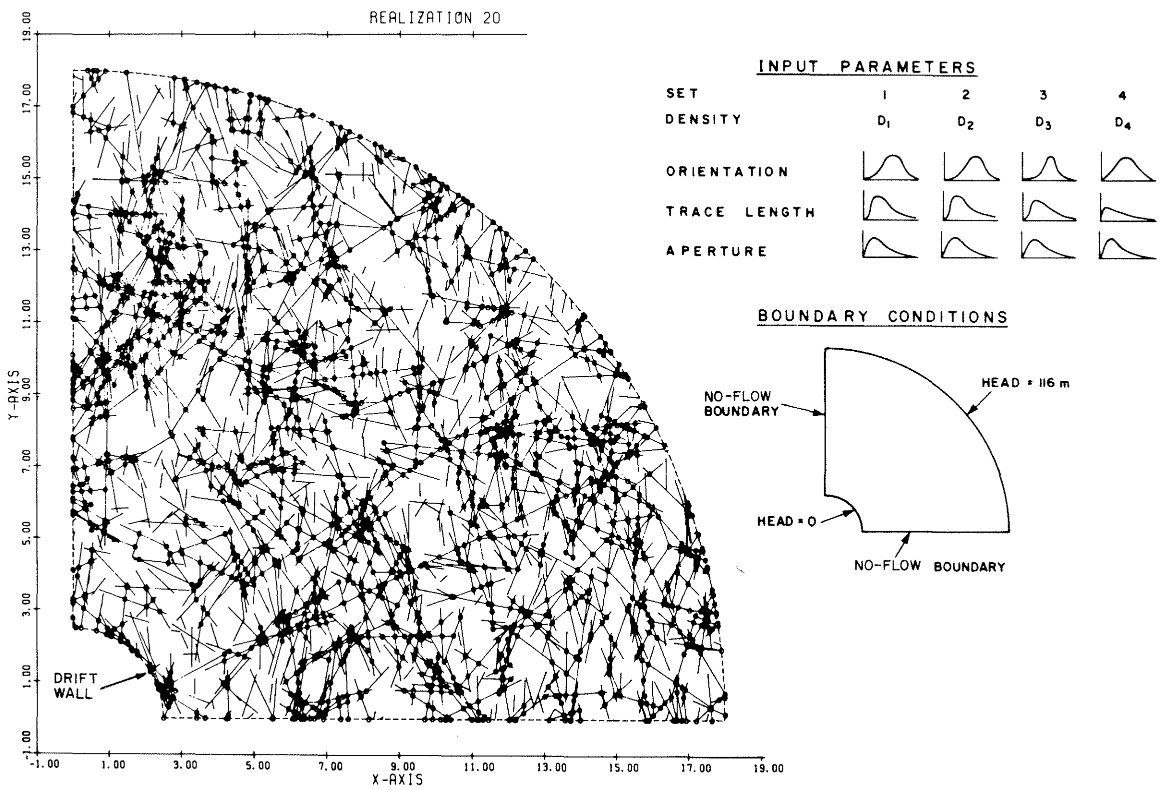


Figure 9.1. Example of the fracture network generated using the fracture generator code. The fracture network is based on the field data from Stripa and represents one quarter of a plane perpendicular to the macropermeability drift.

the effect of different fracture apertures (aperture distribution models) the network generator code has been modified so that different apertures can be assigned to the same fracture network. Hence for each fracture network the flow through the fractures for a number of different aperture models will be calculated. This requires consideration to which fracture set each fracture belongs to and the strike and dip of each fracture in order to determine the normal stress component acting across the fracture.

## 10 HYDROCHEMICAL CHARACTERIZATION OF THE STRIPA GROUNDWATERS

This project is carried out by the members in the Hydrogeochemistry Advisory Group (HAG) chaired by Professor Kirk Nordstrom, USGS, USA. The members are

John Andrews, UK
Werner Balderer, Switzerland
Stanley Davis, USA
Erik Eriksson, Sweden
Bryan R Payne, IAEA
Jean-Charles Fontes, France
Bertrand Fritz, France
Peter Fritz, Canada
Heinz Loosli, Switzerland
Heribert Moser, W. Germany
Kirk Nordstrom, USA, Chairman
Tommy Olsson, Sweden

The technical content and the progress of the study are presented in /35/ and /34/.

### 10.1 SCOPE

The overall purpose of the hydrogeochemical program is to determine the origin and evolution of deep groundwaters within the Stripa granite. Numerous chemical and isotope techniques have been proposed, but many of them have been untested or unverified for crystalline bedrock. The Stripa hydrogeochemical studies have been undertaken to apply such techniques, to determine the most suitable ones and to find the most reliable methods, strategy, and interpretations for groundwater-granite interactions. These results will greatly enhance our ability to predict geochemical processes affecting a high-level radioactive waste repository in granitic bedrock.

## 10.2 PROGRESS OF THE WORK

The study started late in 1984 and only a few results were available at the end of the year. Some examples of obtained results are given below.

- Mineral separations have been made for some of the fracture-fill minerals. Laumontite has been identified for the first time in one of the deep cores.
- Preliminary organic carbon analyses indicate that there is more dissolved organic carbon than dissolved inorganic carbon in three of the V2 borehole intervals. The highest value of DOC from Stripa of 70 mg/L has been reported for the first time from the bottommost interval in V2. These results indicate the need for continued monitoring of DOC in V2.
- Preliminary $^{36}Cl$ results are generally in agreement with the earlier data in the final report of Phase I activities, except that the one high value of about 200 x $10^{-15}$ for $^{36}CL/CL$ has not been found in any of the new data. All values are less than 100 x $10^{-15}$. Values from N1 and V1 appear to be in agreement, but about half of most of the values from V2.

- All groundwater samples for $^{36}Cl$, $^{37}Cl/^{35}Cl$ and $^{129}I$ determinations have been processed by either direct precipitation as AgCL or AgI or by ion-exchange extraction. Where halide concentrations were low, a preconcentration step was employed by sub-boiling evaporation.

- $^{39}Ar$ and $^{85}Kr$ have been measured and, as expected, subsurface production of $^{39}Ar$ has been found. Also, due to rapid processing of the samples, $^{37}Ar$ has been measured for the first time in groundwater. Calibration measurements are in progress for data reduction.

## 11 ECONOMY

A summary of the budget and accumulated costs as per December 31, 1985, is given below. All figures are in SEK.

| Programme | Budget including 10% annual escalation | Accumulated costs | Estimated remaining funds |
|---|---|---|---|
| Project Management | 3 700 000 | 1 231 319 | 2 468 681 |
| Stripa Generally | 14 150 000 | 4 003 849 | 10 146 151 |
| Crosshole Techniques | 22 400 000 | 11 735 061 | 10 664 939 |
| 3D Migration Experiment | 8 350 000 | 5 896 262 | 2 453 738 |
| Borehole Sealing | 10 200 000 | 7 317 341 | 2 882 659 |
| Hydrogeological Characterization | 260 000 | 28 | 798 231 202 |
| Hydrochemistry | 1 400 000 | 404 | 517 995 483 |
| Seismic Crosshole | 700 000 | | 700 000 |
| TOTAL | 61 160 000 | 30 617 147 | 30 542 853 |

## 12 REFERENCES AND PUBLISHED REPORTS FROM THE STRIPA PROJECT

*1980*

/1/ TR 81–01
**"Summary of defined programs"**
L Carlsson and T Olsson
Geological Survey of Sweden, Uppsala
I Neretnieks
Royal Institute of Technology, Stockholm
R Pusch
University of Luleå
Sweden November 1980

*1981*

/2/ TR 81–02
**"Annual Report 1980"**
Swedish Nuclear Fuel Supply Co/Division KBS
Stockholm, Sweden 1981

/3/ IR 81–03
**"Migration in a single fracture Preliminary experiments in Stripa"**
Harald Abelin, Ivars Neretnieks
Royal Institute of Technology
Stockholm, Sweden April 1981

/4/ IR 81–04
**"Equipment for hydraulic testing"**
Lars Jacobsson, Henrik Norlander
Ställbergs Grufve AB
Stripa, Sweden July 1981

/5/ IR 81–05
**Part I "Core-logs of borehole VI down to 505 m"**
L Carlsson, V Stejskal
Geological Survey of Sweden, Uppsala
T Olsson
K-Konsult, Stockholm

**Part II "Measurement of Triaxial rock stresses in borehole VI"**
L Strindell, M Andersson
Swedish State Power Board, Stockholm
Sweden July 1981

*1982*

/6/ TR 82–01
**"Annual Report 1981"**
Swedish Nuclear Fuel Supply Co/Division KBS
Stockholm, Sweden February 1982

/7/ IR 82–02
**"Buffer Mass Test – Data Acquisition and Data Processing Systems"**
B Hagvall
University of Luleå, Sweden August 1982

/8/ IR 82–03
**"Buffer Mass Test – Software for the Data Acquisition System"**
B Hagvall
University of Luleå, Sweden August 1982

/9/ IR 82–04
**"Core-logs of the Subhorizontal Boreholes N1 and E1"**
L Carlsson, V Stejskal
Geological Survey of Sweden, Uppsala
T Olsson
K-Konsult, Engineers and Architects, Stockholm
Sweden August 1982

/10/ IR 82–05
**"Core-logs of the Vertical Borehole V2"**
L Carlsson, T Eggert, B Westlund
Geological Survey of Sweden, Uppsala
T Olsson
K-Konsult, Engineers and Architects, Stockholm
Sweden August 1982

/11/ IR 82–06
**"Buffer Mass Test – Buffer Materials"**
R Pusch, L Börgesson
University of Luleå
J Nilsson
AB Jacobson & Widmark, Luleå
Sweden August 1982

/12/ IR 82–07
**"Buffer Mass Test – Rock Drilling and Civil Engineering"**
R Pusch
University of Luleå
J Nilsson
AB Jacobson & Widmark, Luleå
Sweden September 1982

/13/ IR 82–08
**"Buffer Mass Test – Predicitions of the behaviour of the bentonite-based buffer materials"**
L Börgesson
University of Luleå
Sweden August 1982

*1983*

/14/ IR 83–01
**"Geochemical and isotope characterization of the Stripa groundwaters – Progress report"**
Leif Carlsson,
Swedish Geological, Göteborg
Tommy Olsson,
Geological Survey of Sweden, Uppsala
John Andrews,
University of Bath, UK
Jean-Charles Fontes,
Université, Paris-Sud, Paris, France
Jean L Michelot,
Université, Paris-Sud, Paris, France
Kirk Nordstrom,
United states Geological Survey, Menlo Park
California, USA
February 1983

/15/ TR 83–02
**"Annual Report 1982"**
Swedish Nuclear Fuel Supply Co/ Division KBS
Stockholm, Sweden April 1983

/16/ IR 83–03
**"Buffer Mass Test – Thermal calculations for the high temperature test"**
Sven Knutsson
University of Luleå
Sweden May.1983

/17/ IR 83–04
**"Buffer Mass Test – Site Documentation"**
Roland Pusch
Univeristy of Luleå and Swedish State Power Board
Jan Nilsson
AB Jacobson & Widmark, Luleå,
Sweden October 1983

/18/ IR 83–05
**"Buffer Mass Test – Improved Models for Water Uptake and Redistribution in the Heater Holes and Tunnel Backfill"**
R Pusch
Swedish State Power Board
L Börgesson, S Knutsson
University of Luleå
Sweden, October 1983

/19/ IR 83-06
**"Crosshole Investigations — The Use of Borehole Radar for the Detection of Fracture Zones in Crystalline Rock"**
Olle Olsson
Erik Sandberg
Swedish Geological
Bruno Nilsson
Boliden Mineral AB, Sweden
October 1983

*1984*

/20/ TR 84-01
**"Annual Report 1983"**
Swedish Nuclear Fuel Supply Co/Division KBS
Stockholm, Sweden, May 1984.

/21/ IR 84-02
**"Buffer Mass Test — Heater Design and Operation"**
Jan Nilsson
Swedish Geological Co
Gunnar Ramqvist
El-tekno AB
Roland Pusch
Swedish State Power Board
June 1984

/22/ IR 84-03
**"Hydrogeological and Hydrogeochemical Investigations—Geophysical Borehole Measurements"**
Olle Olsson
Ante Jämtlid
Swedish Geological Co.
August 1984

/23/ IR 84-04
**"Crosshole Investigations—Preliminary Design of a New Borehole Radar System"**
O. Olsson
E. Sandberg
Swedish Geological Co.
August 1984

/24/ IR 84-05
**"Crosshole Investigations—Equipment Design Considerations for Sinusoidal Pressure Tests"**
David C. Holmes
British Geological Survey
September 1984

/25/ IR 84-06
**"Buffer Mass Test — Instrumentation"**
Roland Pusch, Thomas Forsberg
University of Luleå, Sweden
Jan Nilsson
Swedish Geological, Luleå
Gunnar Ramqvist, Sven-Erik Tegelmark
Stripa Mine Service, Storå
September 1984

/26/ IR 84-07
**"Hydrogeological and Hydrogeochemical" Investigations in Boreholes — Fluid Inclusion Studies in the Stripa Granite**
Sten Lindblom
Stockholm University, Sweden
October 1984

/27/ IR 84-08
**"Crosshole investigations — Tomography and its Application to Crosshole Seismic Measurements"**
Sven Ivansson
National Defence Research Institute, Sweden
November 1984

*1985*

/28/ IR 85-01
**"Borehole and Shaft Sealing — Site documentation"**
Roland Pusch
Jan Nilsson
Swedish Geological Co
Gunnar Ramqvist
Eltekno AB
Sweden
February 1985

/29/ IR 85-02
**"Migration in a Single Fracture — Instrumentation and site description"**
Harald Abelin
Jard Gidlund
Royal Institute of Technology
Stockholm, Sweden
February 1985

/30/ TR 85-03
**"Final Report of the Migration in a Single Fracture — Experimental results and evaluation"**
H. Abelin
I. Neretnieks
S. Tunbrant
L. Moreno
Royal Institute of Technology
Stockholm, Sweden
May 1985

/31/ IR 85-04
**"Hydrogeological and Hydrogeochemical Investigations in Boreholes — Compilation of geological data"**
Seje Carlsten
Swedish Geological Co
Uppsala, Sweden
June 1985

/32/ IR 85-05
**"Crosshole Investigations — Description of the small scale site"**
Seje Carlsten
Kurt-Åke Magnusson
Olle Olsson
Swedish Geological Co
Uppsala, Sweden
June 1985

/33/ TR 85-06
**"Hydrogeological and Hydrogeochemical Investigations in Boreholes — Final report of the phase I geochemical investigations of the Stripa groundwaters"**
D.K. Nordstrom, US Geological Survey, USA
J.N. Andrews, University of Bath, United Kingdom
L Carlsson, Swedish Geological Co, Sweden
J-C. Fontes, Universite Paris-Sud, France
P. Fritz, University of Waterloo, Canada
H. Moser. Gesellschaft für Strahlen- und Umweltforschung, West Germany
T. Olsson, Geosystem AB, Sweden
July 1985

/34/ **"Stripa Project. Quarterly Progress Reports"**
Compiled by SKB
Stockholm, Sweden

/35/ TR
**"Summary of Defined Programs — Phase II"**
In preparation