Nagra
Nationale
Genossenschaft
für die Lagerung
radioaktiver Abfälle

Cédra
Société coopérative
nationale
pour l'entreposage
de déchets radioactifs

Cisra
Società cooperativa
nazionale
per l'immagazzinamento
di scorie radioattive

TECHNICAL REPORT 86-20

THE STRIPA PROJECT

Annual Report 1985

August 1986

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

Nagra
Nationale
Genossenschaft
für die Lagerung
radioaktiver Abfälle

Cédra
Société coopérative
nationale
pour l'entreposage
de déchets radioactifs

Cisra
Società cooperativa
nazionale
per l'immagazzinamento
di scorie radioattive

TECHNICAL REPORT 86-20

THE STRIPA PROJECT

Annual Report 1985

August 1986

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

Das Stripa-Projekt ist ein Projekt der Nuklearagentur der OECD. Unter internationaler Beteiligung werden von 1980-86 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
- Verhalten von Materialien, welche zur Verfüllung und Versiegelung von Endlagern eingesetzt werden sollen
- Methoden zur zerstörungsfreien Ortung von Störzonen im Fels

Seitens der Schweiz beteiligt sich die Nagra an diesen Untersuchungen. Die technischen Berichte aus dem Stripa-Projekt erscheinen gleichzeitig in der NTB-Serie der Nagra.

The Stripa Project is organised as an autonomous project of the Nuclear Energy Agency of the OECD. In the period from 1980-86, 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
- behaviour of backfilling and sealing materials in a real geological environment
- non-destructive methods for location of disturbed zones in the rock

Switzerland is represented in the Stripa Project by Nagra and the Stripa Project technical reports appear in the Nagra NTB series.

Le projet Stripa est un projet autonome de l'Agence de l'OCDE pour l'Energie Nucléaire. Il s'agit d'un programme de recherche avec participation internationale, qui sera réalisé entre 1980 et 1986 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 puits de forage
- chimie des eaux souterraines à grande profondeur
- écoulement des eaux souterraines et transport des radionucléides dans les roches fracturées
- comportement des matériaux de colmatage et de scellement des dépôt finals
- méthodes de localisation non destructive des zones de perturbation de la roche

La Suisse est représentée dans le projet Stripa par la Cédra. Les rapports techniques du projet Stripa sont publiés dans la série des rapports techniques de la Cédra (NTB).

THE STRIPA PROJECT ANNUAL REPORT 1985

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 in 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 1985.

Stockholm
August 1986

Content

1 Introduction

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. 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, completed in 1985 at a total cost of approximately 47 MSEK, consisted 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.

The second phase of the Stripa Project, which has also been joined by Spain and the United Kingdom, started in 1983 and is scheduled for completion in 1986. The estimated total cost is 60 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.

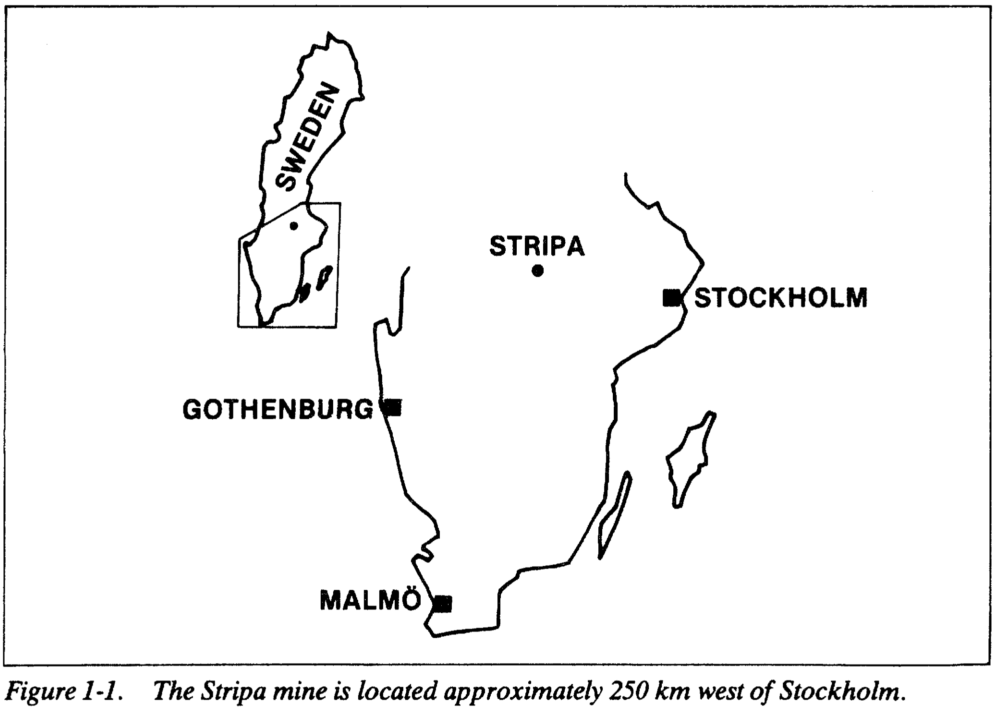

Figure 1-1. The Stripa mine is located approximately 250 km west of Stockholm.

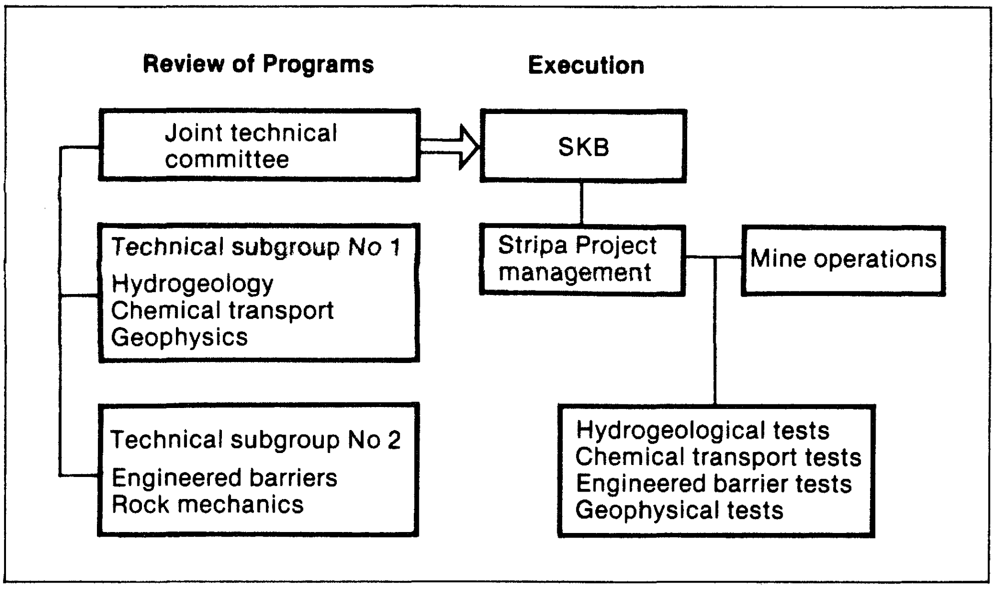

Figure 1-2. Organization of the Stripa Project.

Negotiations for an extension of the project into a third phase were in progress at the end of 1985.

The conditions of participation in the Stripa Project are covered by two separate agreements for Phase 1 and Phase 2, although both phases share the same management structure. 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.

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 realization, are periodically reviewed by two Technical Subgroups (TSGs). These subgroups 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 Research and Development Division of the Swedish Nuclear Fuel and Waste Management Company (SKB) acts as the host organization, and provides 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 Subgroups, 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 activities 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 (IVO)
France	Commissariat á l'Energie Atomique (CEA); Agence Nationale pour la Gestion des Dàchets Radioactifs (ANDRA)

Japan	Power Reactor and Nuclear Fuel Development Corporation (PNC)
Spain (Phase 2 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 2 only)	Department of the Environment (UK DOE)
United States	Department of Energy (US DOE)

2 General

2.1 Meetings

Technical Subgroup no 1 and 2 met in parallel sessions on March 26-28, 1985 in Switzerland. TSG-1 met to review the technical progress of the experiments related to hydrogeology, hydrogeochemistry, geophysics and chemical transport whereas TSG-2 met to review the progress on the work on engineered barriers. The TSGs also met jointly to review the progress of the technical planning on phase 3 of the Stripa Project. A visit to the Grimsel Rock Laboratory was arranged in conjunction with the meetings.

A Stripa Symposium, jointly organized by OECD/NEA and SKB, was held on June 4-5, 1985 in Stockholm and was followed by a field trip to Stripa on June 6. About 110 participants from 11 countries attended the symposium. Fifteen papers on the research at Stripa were given. Proceedings, including an executive summary of the presentations, may be ordered from the OECD/NEA.

A JTC-meeting was held in Grythyttan, Sweden, on June 7, 1985. The management of the ongoing activities as well as possible future co-operation at Stripa were discussed. The JTC expressed a general interest in a continuation of the project in a five year program and a planning program for the tentative phase 3 of the Stripa project was agreed upon.

Notes from all meetings have been distributed separately.

2.2 New investigations

The investigation "Hydrogeological Characterization of the Ventilation Drift Area, part 2", by prof. John Gale, University of Newfoundland, Canada, was approved by the JTC in late 1985.

The study aims at investigating the distinction between effective and total porosity when interpreting groundwater movements and nuclide migration in fractured rock masses, or in other words to study channeling. The determinations will be done on large core samples using a resin injection technique under either uniaxial or triaxial test conditions. Once these parameters have been determined they will be combined with the basic fracture statistics obtained in part 1 of this study. Fracture roughness will be determined on the core samples. The information gained from this work will aid the interpretation of the groundwater chemistry and close co-operation will be held with the Hydrogeochemistry Advisory Group (HAG).

The study will also include a calculation on the directional permeability at Stripa using existing data from all surface and subsurface boreholes. An attempt will also be made to calculate the 3-dimensional regional and local flow by integrating the obtained hydrogeological, geochemical and isotopic data. Again, close co-operation with the HAG is foreseen.

2.3 The Stripa project phase 3

The planning for phase 3 of the Stripa Project continued throughout 1985 and resulted in a tentative program that was distributed in early 1986 to the member countries for final approval.

The phase 3 program continues and builds on the work carried out under Phases 1 and 2 and also develops new areas of research. An unexplored volume of granite (about 125 m x 125 m x 50 m) will be studied for which a combined deterministic/statistical flow model will be developed and compared with data from field measurements. This modelling approach will be used because previous investigations have shown that an equivalent porous media model is considered inappropriate for similar volumes of fissured crystalline granitic rock. If successful, this will significantly enhance the confidence in the application of predictive mathematical models to site specific conditions.

The further development of the high resolution and directional radar (the Stripa Project is already considered to be at the forefront of the development of this tool), together with high resolution borehole seismics, will ensure the transformation of these research tools to full-fledged site investigation techniques. It must be emphasized that such nondestructive crosshole measurement techniques will be indispensable when investigations of actual disposal sites are proposed such that there must be as little disturbance of the host medium as possible and yet yield sufficient information to satisfy the needs of safety assessments and engineering design.

Observations at Stripa on flow in fractures have revealed that it is not realistic to treat a fracture as two planar parallel surfaces with constant width. Rather, what appear to be randomly distributed channels are thought to exist. The present concept of these channels suggests that mixing of waters occurs irregularly and that zones of stagnant or near-stagnant water are present where diffusion controlled transport dominates. Phase 3 includes provision for the continuation of tracer experiments to investigate flow in fractures so that this important phenomenon, "channeling", can be more fully understood. The culmination of this will be a large scale tracer experiment as part of the phase 3 investigation of the unexplored volume of granite. Comparison of the results with mathematical predictions will be made in a further validation exercise.

New work on the estimation of fracture length and aperture using hydraulic measurement techniques will yield a tool to complement fracture analysis carried out in tunnel excavations. Again this is important in predicting water flow and in optimizing the engineering design. Also of importance in engineering is the use of sealing materials to restrict the migration of radionuclides from a repository. A project is included which comprehensively evaluates available sealants for use in the optimization of a repository.

The total estimated cost for the five-year project is MSEK 112 in January 1986 prices.

2.4 Information

An updated brochure as well as a new film "Progress of the Stripa Project" were completed in early 1985. The brochure and the film, also available in a video version, may be ordered from SKB.

3 Phase 1

A summary of the progress of phase 1 of the Stripa Project is given below. More detailed information is given in the reports listed in the appendix "Stripa Project -Previously Published Reports".

3.1 Hydrogeological and hydrogeochemical investigations in boreholes

The principal investigators for this part of the project were drs Leif Carlsson, Swedish Geological Co, SGAB, and Tommy Olsson, Geosystem AB, Sweden.

3.1.1 General

All field work within this investigation was completed during 1984, while the evaluation and interpretation of the obtained data were completed in 1985. A brief summary of the results obtained during 1985 is given below.

3.1.2 Summary of results

Hydrogeological investigations
The different activities included in the current program have each provided valuable insight into the applicability, reliability and advantages of the techniques applied. Together, the activities have been used to achieve a sound program for hydrogeological, geological and geophysical testing of boreholes drilled from an underground site. As a supplement, data on the Stripa site have been obtained, thus increasing the huge stock of data and the understanding of an underground site in a crystalline plutonic rock.

From the drilling and core-logging procedure, the following conclusions were obtained:

- Drilling of subhorizontal boreholes of 300 m length can be carried out without serious difficulty. Longer boreholes could certainly be achieved without any anticipated problems.
- Drilling deviations for horizontal boreholes of 300 m length are comparatively small. In the vertical direction about one meter of deviation was obtained and in the horizontal direction almost nine meters.
- Total drilling cost is less for small diameter (56 mm) compared to large diameter boreholes (76 mm).
- The core-logging procedure should be as detailed as possible, and the data computerized for further treatment on a statistical basis.
- Orientation of cores should be performed and a technique which is also applicable in a vertical borehole should be used.

The rock stress measurements performed have given a three-dimensional picture of the stress field.

The applied standard geophysical borehole logging program has given valuable information on the penetrated bedrock. However, no single log will give a complete picture of the bedrock and an integrated logging program is necessary.

For geological and hydrogeological descriptions the following logs gave the most valuable information:

- natural gamma log
- point resistance log
- resistivity logs
- temperature and resistivity logs of the borehole fluid

Other logs not used in the program, such as neutron-neutron, gamma-gamma and tube wave seismics, would certainly have improved the knowledge of the penetrated bedrock. A combination of geological, geophysical and hydraulic logging methods will give the most integrated knowledge of a penetrated rock mass.

In the current program only the Mise a la masse method was used for geophysical crosshole investigation. Due to its simplicity it could easily be performed. However, the information gained had to be compared to a large number of possible models, which usually resulted in more than one possible explanation to the measured set of data. An improved use of non-destructing crosshole techniques for geometrical mapping of fractures and fracture zones is recommended for further studies.

An underground site will influence the groundwater head distribution around the site and create a high hydraulic gradient out in the bedrock. When the head distribution is measured in boreholes drilled from the site, consideration must be given to this gradient. In order to avoid large gradients along the boreholes, a straddle-packer system should be used. Further, groundwater head should be monitored in sections with increased hydraulic conductivity and the measurements should include a limited section length.

The hydraulic tests performed have utilized the hydraulic conditions created by the underground site. The shut-in tests have called for a very careful evaluation procedure. They are also rather time consuming when sections of very low hydraulic conductivity are considered. Consideration should be given to the borehole history when performing and evaluating the shut-in tests. In order to obtain an accurate interpretation of the data, due considerations should be taken to wellbore and skin.

The injection-recovery tests performed are a faster technique than the shut-in tests. However, the requirement of stable head conditions in the test section before the testing calls for a long stabilization period. This method also requires equipment which can withstand high pressure during the injection period. If the requirements of stable head conditions are not met, the tests are difficult to evaluate.

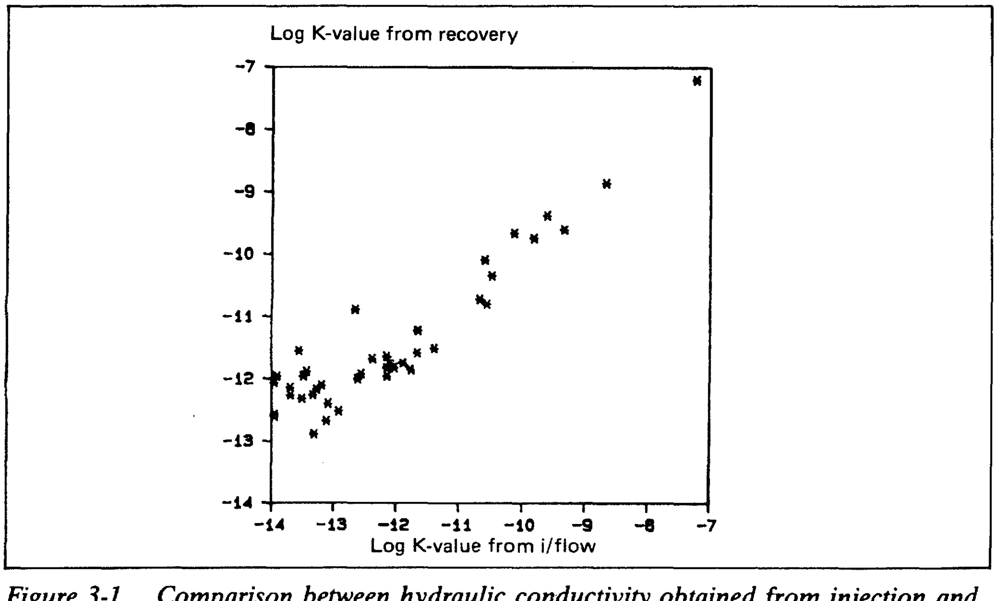

Figure 3-1. Comparison between hydraulic conductivity obtained from injection and recovery stages respectively. The reliability of the hydraulic conductivity values obtained from recovery tests are not good for values below 10^{-11} m/s.

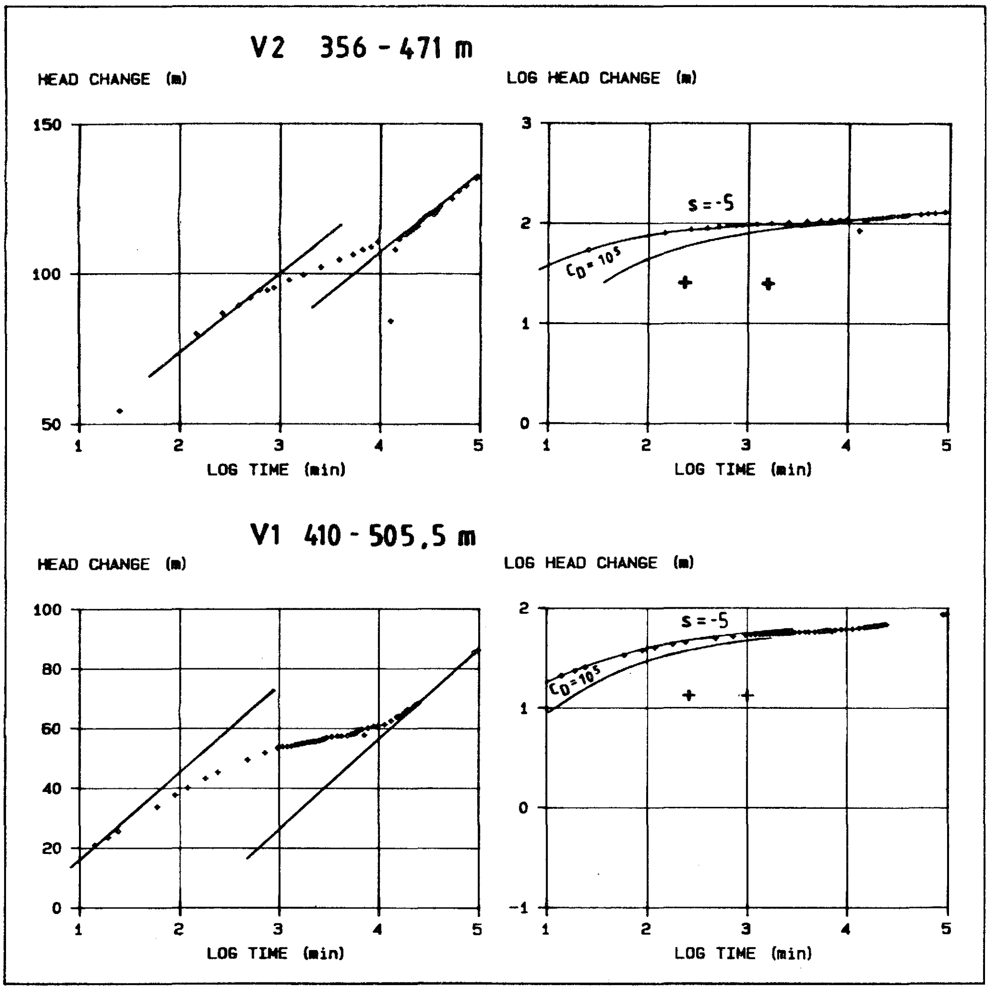

Figure 3-2. Graphs of pressure versus time from build-up tests showing double-porosity behaviour. Data from boreholes V1 and V2.

Hydraulic interference tests are preferably carried out using the natural hydraulic situation around an underground site. The tests will mainly be applied to sections of high hydraulic conductivity to locate connections between zones in different boreholes and to get values of directional hydraulic conductivity over large distances. In the evaluation process, consideration should be given to the double-porosity behaviour of the fractured formation.

In general, the shut-in tests give more accurate results as it is possible to obtain additional information on the hydraulic properties due to the long test time. On the other hand, this technique is very time consuming and should therefore only be used when special information is required. For an underground testing program in a potential repository site, different demands are to be fulfilled, and the most efficient way to obtain the proper information will be to combine different techniques which cover different degrees of accuracy, geometry and scale.

Hydrogeochemical investigations

The geochemistry of the groundwaters, bedrock and fracture mineralogy at the Stripa test site was investigated to gain an understanding of the origin and evolution of groundwaters in a granitic bedrock. Geochemical parameters provide an important constraint to the hydrogeologic properties of groundwater flow and complement physical investigations such as geophysical measurements of fractures, hydraulic testing and tracer migration studies. Geochemical studies provide the only measure of long-term migration of solutes and water in the subsurface environment. These investigations have contributed substantially to our understanding of geologically both old and modern water-rock-gas interactions occurring within crystalline bedrock.

Several lines of evidence strongly suggest that the groundwater system at Stripa has evolved from fresh meteoric waters, typical of central Sweden, interacting with the Proterozoic crystalline bedrock composed dominantly of feldspars and quartz and fracture-fill minerals, such as calcite, chlorite, epidote, sericite, pyrite, fluorite, and hematite. Several hypotheses may account for the source of the Na-Ca-Cl type water found at depth: (a) salt associated with the crystalline rock itself, i.e., fluid inclusions and associated grain boundary salts or salty fluids, (b) intrusion of old seawater and (c) leaching of salts of sedimentary origin. All of these hypotheses are given careful consideration. Many of the water-rock interactions can be related to weathering processes and solubility equilibria such that a firm basis for predicting the effect of perturbations, such as radioactive waste storage, can be made with greater reliability. For example, thermal stress will clearly affect the water chemistry and could actually increase chloride concentrations significantly in the near-field by extruding saline fluids from the micropores and/or microfracturing fluid inclusions. Increased salt concentrations can both increase and decrease the solubility of various minerals, depending on the mineral, the temperature, and the composition of the salt components. Changes in solubility can, in turn, affect the permeability of the bedrock.

Identification of active processes, such as calcite, fluorite, ferric hydroxide, and possibly barite precipitation, provides favorable conditions for radionuclide retardation in the far-field by coprecipitation or adsorption. When these processes are linked to other processes, such as silica dissolution and reprecipitation through a temperature gradient in the near-field, possible clay mineral formation, and the absorbing properties of the backfill, then the outlook for long-term radioactive waste storage looks even more favorable.

3.2 Migration in a single fracture

The principal investigator for this study was Prof. Ivars Neretnieks, Royal Institute of Technology, KTH, Sweden.

3.2.1 General

All field work within this investigation was completed during 1984 while the evaluation and interpretation of the obtained data were completed during 1985. A brief summary of the results obtained during 1985 is given below.

3.2.2 Summary of results

Experimental design and instrumentation
The equipment has worked very well with the exception of the variations of the injection flow rates. The tracers Uranine and Iodine were injected simultaneously in the same flow path. They behaved identically, indicating that they do not react with the rock. All the dyes except Uranine coloured the nylon tubing used in the experiment but the loss due to this effect is insignificant.

Hydraulic pulse testing
The hydraulic pulse testing has shown that even though some of the injection holes were separated only 0.5 m the response to the pressure pulses could vary considerably. This clearly shows that fracture properties are not constant over the fracture plane.

Water flow monitoring
The water flow was monitored in three fissures at a total of some 40 sections. Water flowed only in a minor part of the sections. Flowing parts were divided

from each other by non-flowing parts. These channels make up between 5 and 20% of the fissures.

Conservative tracer injections
The breakthrough curves also show that several distinct channels are present. This information and the information from the monitoring of the water flow rates from the fractures used, in the preliminary and the main experiment, clearly show that channeling within a single fracture exists.

Fracture widths
The hydraulic pulse testing, water flow monitoring and observations of the tracer residence times show that the fracture width determined from water residence times and flow rates is much larger (order(s) of magnitude) than the equivalent fracture width which would cause the pressure drop in laminar flow in a slit. Hydraulic tests will thus not give any direct information on actual flow porosity.

Flow geometry within a single fracture
The flow is very unevenly distributed along the fissure planes investigated. Large areas do not carry any water. The water flows in channels which seem to be 10-100 cm wide. The channels make up only 5-20% of the fracture plane. There was at least one connection between two of the channels investigated over a distance of 4.5 m. Channel widths (openings) are considerably larger than the equivalent channel width for pressure drop between two parallel plates.

Sorbing tracer movement
Elevated concentrations of the sorbing tracers Cs, Sr, Eu, Nd and U have been found on the fracture surface as well as in depth in the adjacent rock matrix (Cs, Sr, Eu, Nd). The concentration was highest near the injection hole. The obtained concentration profiles in depth may to some extent be due to a rough fracture surface. The penetration depths found for Cs and Sr go much deeper than the surface roughness. This indicates that the retarding mechanisms, such as matrix diffusion and sorption, found in laboratory experiments also exist in a real environment. It has not been possible to fully quantify these retarding mechanisms in this experiment but the results are consistent with the results from the laboratory experiments. The retardation of Sr was stronger than originally expected. This could be due to higher K_d values than expected or due to a much larger surface area in contact with the flowing water. This enlargement of the surface could be due to clay infillings in the fracture or because the fracture has split up to several thinner fractures which are joined together again before entering the drift.

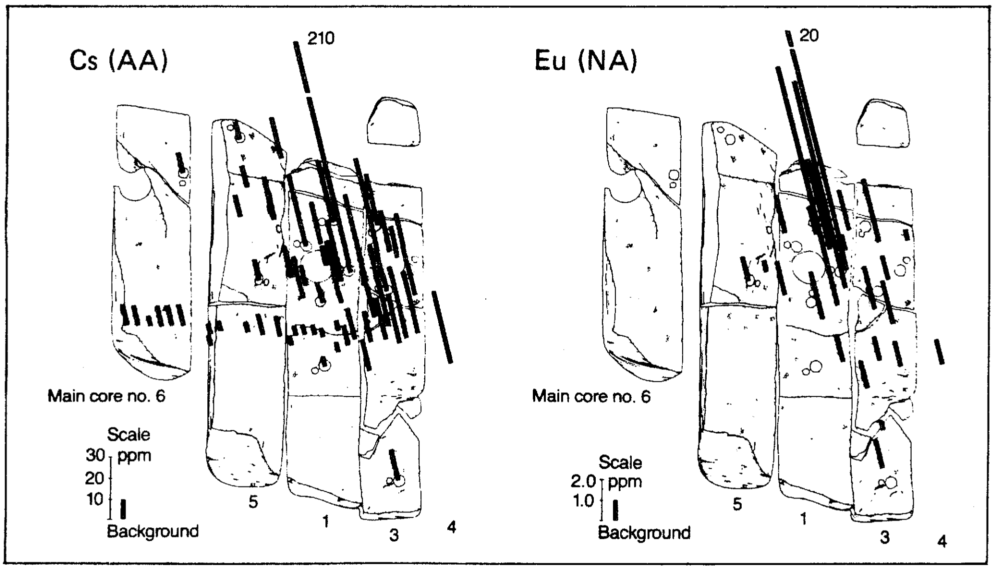

Figure 3-3. Examples of obtained surface concentrations.

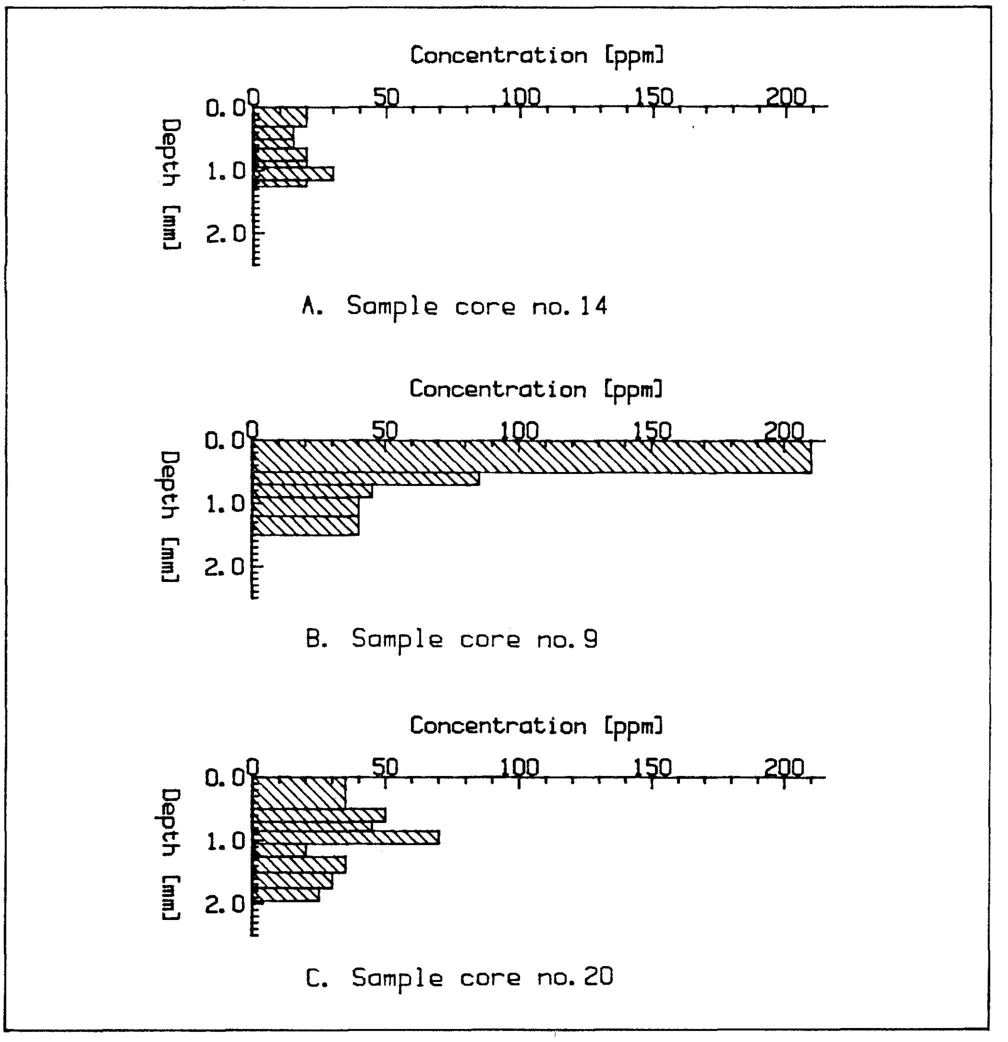

Figure 3-4. Three major patterns of concentration variation with depth were found, exemplified with Cs from atomic absorption analyses.

Modelling

The output from a model is very dependent on the assumed flow geometry of the fracture. Trying to add channeling to the model without the possibility to determine these extra parameters by independent means will just give a better fit of the model to the experimental data without adding any useful information. The fracture "width" can be varied by assuming different breadth of the channel/s. All the modeling is based on the assumption that the injected tracers are mixed with all the water flow at the injection point and not somewhere between injection point and sampling point. This, together with the fact that the fracture breadth is unknown along the flow path, makes the determination of actual fracture widths inaccurate.

Of the three different models tested for tracer transport the one which does not account for matrix diffusion cannot explain the observed penetration in depth of the sorbing tracers. The two other models differ mainly in the way they account for dispersion. One assumes Fickian dispersion, the other assumes pure channeling, but both include matrix diffusion. Available data are not sufficient to firmly conclude which of the mechanisms is mainly responsible for dispersion. The presence of channels does, however, indicate that "channeling dispersion" may not be negligible.

It has not been possible to quantitatively fit the models to the observed data because of the large variations in sorbed concentration over the fissure surface. The variation is due to channeling as well as to variations in mineralogy of the surface. The observed data fall within those which may be expected from independent laboratory investigations and do not contradict previous results.

3.3 Buffer mass test

The principal investigator for this study was Prof. Roland Pusch, Swedish Geological Co, SGAB.

3.3.1 General

The field work of the Buffer Mass Test was completed during 1985 by excavating the inner half of the tunnel backfill as well as heater hole no. 1. The excavated buffer and backfill material was sampled for water content determination. The remaining activities included the start and completion of the mineralogical studies of the bentonite from heater hole no. 1. The results from the entire project were evaluated and interpreted during 1985 and a brief summary is given below.

3.3.2 Summary of results

The general objective of the Buffer Mass Test was to check the function of highly compacted Na bentonite as canister overpack and sand/bentonite mixtures as tunnel backfill. It involved prediction of the temperatures and swelling pressures and measuring of these quantities. Since they were expected to be functions of the water content it was required to make predictions and conduct measuring of the uptake and redistribution of water in the buffer materials. Experience shows that recording of water contents by use of moisture sensors is not very accurate, which called for comprehensive sampling of the clay materials for direct determination of the water content at suitable time intervals. These were chosen so as to give information on the rate and uniformity of the moistening in the three "wet" holes no 1, 2 and 5, and in the three "dry" holes no 3, 4 and 6, which required the stopping of certain tests after about one year and comprehensive sampling and laboratory testing in connection with these terminations.

The prediction of temperatures was based on FEM calculation and application of laboratory-derived thermal data. It showed that the temperatures at the heater surfaces would not exceed about 80°C at the end of the test period when the heater power was 600 W and about 184°C at 1800 W power, which was also confirmed by the tests. The initial temperatures, soon after the onset of the power, turned out to be higher than expected in most cases but they dropped in the course of the tests, which was explained by temporary drying close to the heaters followed by uptake of water from the rock. This uptake was well manifested by the successively increasing swelling pressures, which were predicted to be 10 MPa at maximum in the "wet" holes. The moisture sensors did not give a reliable picture of the moisture distribution in the heater holes or in the tunnel backfill.

At the excavation of each heater hole about 2500 samples were taken to determine the true water content. The highly compacted bentonite in the "wet" holes had become completely or almost fully saturated after about 2 years, while it showed a moisture gradient and relatively dry conditions close to the heaters in the "dry" holes. The tangential distribution of water at various radial distances turned out to be very uniform, however, which was explained mainly by the ability of dense bentonite to seal off water-bearing fractures. Through this, inflowing water was directed to adjacent, finely fractured rock areas and was thus taken up uniformly by the bentonite. Also, the initial thermally induced redistribution of the original pore water contributed to the uniform wetting. Even in the dry holes complete saturation was obtained in the peripheral part of the bentonite.

It was concluded that the backfill interacted with the rock in much the same way as the heater overpacks. Thus, the large variation in distribution of the

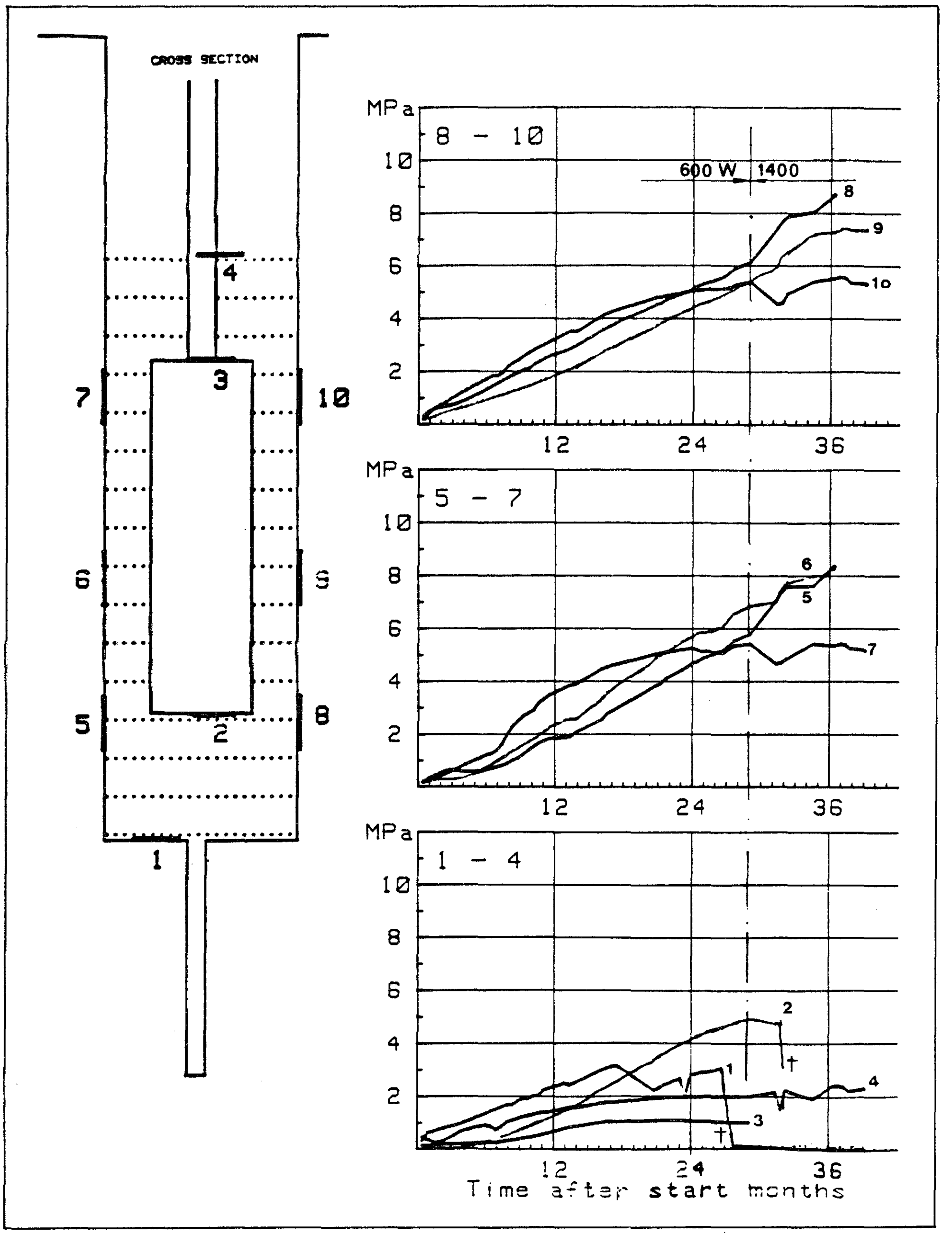

Figure 3-5. Recorded swelling pressures in heater hole no. 1 (600 and 1400 W).

inflowing water immediately after the application of the backfill led to local sealing and redistribution to initially dry areas and thereby to a uniform wetting of the backfill. The water pressure at the rock/backfill interface was expected to be increased considerably when the peripheral part of the backfill had been saturated. This stage was reached in about one year but it was not accompanied by any significant piezometric rise. The reason for this was partly that the water was discharged through the rock which had experienced an increased hydraulic conductivity through the blasting and stress redistribution, and partly that practically all the water that flowed into the tunnel was absorbed by the backfill. Thus, large parts of it turned out to be saturated, the main water-driving mechanism probably being capillary suction due to the low initial water content of the sand/bentonite material.

A general conclusion from the BMT project is that the basic information that was asked for at the planning stage was actually obtained. Thus, the physical processes involved in the moistening and maturation of the buffer materials under repository conditions in crystalline rock are understood in principle and

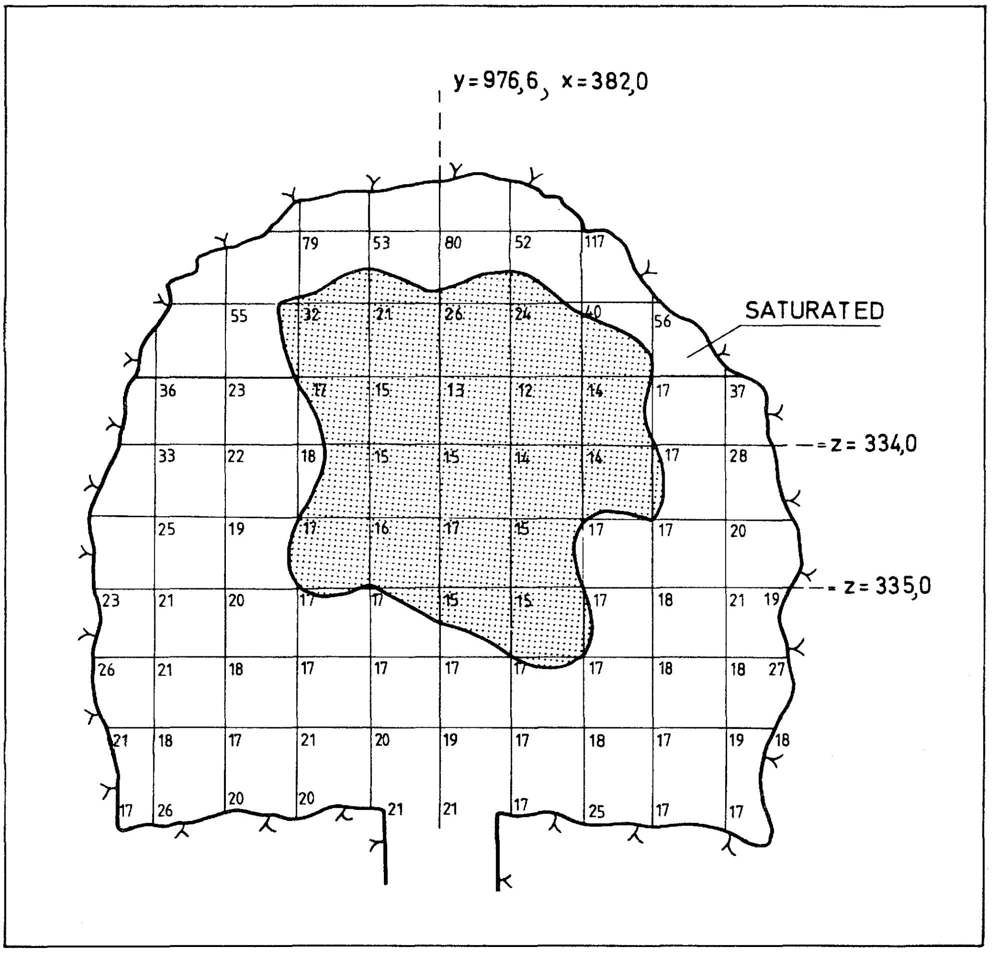

Figure 3-6. Water content distribution in the tunnel backfill in a cross section through heater hole no. 1 appr. 3 years after application. Dotted area is nonsaturated.

their ultimate physical state and functions can be safely predicted. Also, the preparation and practical applicability of the various buffer materials were amply demonstrated, indicating the feasibility of bentonite-based isolation techniques in general and the KBS 3 concept in particular.

In addition to the initial objective of the Buffer Mass Test to check the function of bentonite-based materials as barriers, it appeared to be possible to investigate whether chemical changes of the smectite component took place in an experiment where water-saturated bentonite was heated to 125°C for about one year. Observations could also be made to find out whether groundwater erosion had taken place in the heater holes and tunnel.

Literature provides data which indicate that two major heat-induced effects can be expected at increased temperature. The first is a charge change caused by replacement of tetrahedral silica by aluminum and associated liberation and precipitation of silica compounds, the second is uptake and fixation of potassium by which the smectite is transformed to illite. The charge change, which is a necessary prerequisite of the illitization, was the only process expected to take place in the heater hole experiment, provided that the temperature was high enough. It cannot be unanimously decided from a theoretical point of view whether the charge change is a true kinetic Arrhenius-type process that takes place at any temperature, or if a critical threshold temperature must be exceeded, but both explanations would yield measurable alterations at about 125 °C in one year.

The analyses comprised X-ray diffraction tests and chemical analyses as well as electron microscopy and determination of two characteristic physical properties, namely the swelling pressure and the hydraulic conductivity. The test results showed no clearly identified alterations except for a slight tendency toward precipitation of supposed silica compounds and a possible indication of mixed-layer formation. The physical tests gave the same results as those obtained from non-heated samples.

The erodibility of smectite gels emerging from heater holes and propagating into water-percolated fractures was found to be less than expected. The explanation may be that the soft gel front exposed to the flowing water consisted of cohering flocks rather than of discrete, easily disrupted particles. The tunnel backfill consisting of sand/bentonite mixtures did not exhibit any sign of erosion at all, which is partly explained by the filter-type composition of this material.

3.4 Economy

The total cost of the Stripa Project phase 1 is given in Table 3-1. The project resulted in a surplus, now transferred to phase 2 of the Stripa Project.

Table 3-1. Stripa Project phase 1 – Summary of costs. All figures in SEK.

Program	Original budget price level 1979/80	Revised budget March 31, 1985 incl 10% annual escalation	Final cost	Surplus/ Deficiency
Project management	3 100 000	2 650 000	2 666 597	–16 597
Mine operations	12 000 000	9 540 000	8 834 705	705 295
Hydrogeological and hydrogeochemical investigations	6 500 000	8 630 000	8 727 145	–97 145
Migration in a single fracture	4 150 000	5 460 000	5 485 897	–25 897
Buffer mass test	14 000 000	21 600 000	21 544 550	55 450
Total	40 750 000	47 880 000	47 258 894	621 106

4 Phase 2

A summary of the progress of the Stripa Project phase 2 is given below. More detailed information is given in the reports listed in the appendix "Stripa Project Previously Published Reports".

4.1 Crosshole techniques for the detection and characterization of fracture zones

The crosshole investigations have been set up in cooperation between the Swedish Geological Co, SGAB, the Swedish National Research Defense Institute, FOA, the British Geological Survey, BGS, and Geoseismo OY, Finland. The principal coordinator is Dr. Olle Olsson, SGAB.

4.1.1 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 is also 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 suitable. 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.

4.1.2 Radar

The experimental part of the radar program was completed during 1985. The work has been devoted to improving the system performance and testing different antenna designs. An example of the results obtained with the improved antenna design is shown in Figures 4-1 and 4-2. Both figures show reflection measurements in borehole F3 but with different transmitter-receiver spacing and antenna frequency. In Figure 4-2 the boreholes surrounding F3 can be seen out to a distance of at least 35 m from the hole. It should be noted that the boreholes are only 76 mm in diameter, which is small compared to the wavelength of approximately 2 m, and that the boreholes only contain their natural groundwater, which has a resistivity of about 50 ohm. This implies that the system is also sensitive to low contrast features in the rock. It is also interesting to observe that the water-filled boreholes are seen quite clearly at radar frequencies of 60 MHz but not at all at the most commonly used frequency, 22 MHz. This implies that information obtained from a radar survey is quite sensitive to the frequency applied. Thus the frequency should be carefully selected in relation to the objective of the survey.

Revised circuit cards of the radar system have been tested during 1985 and were found to improve the system. Tests have also been made of some signal processing algorithms. One type of "pulse compression" filter was found to improve the resolution of the radar plots considerably, especially at larger distances.

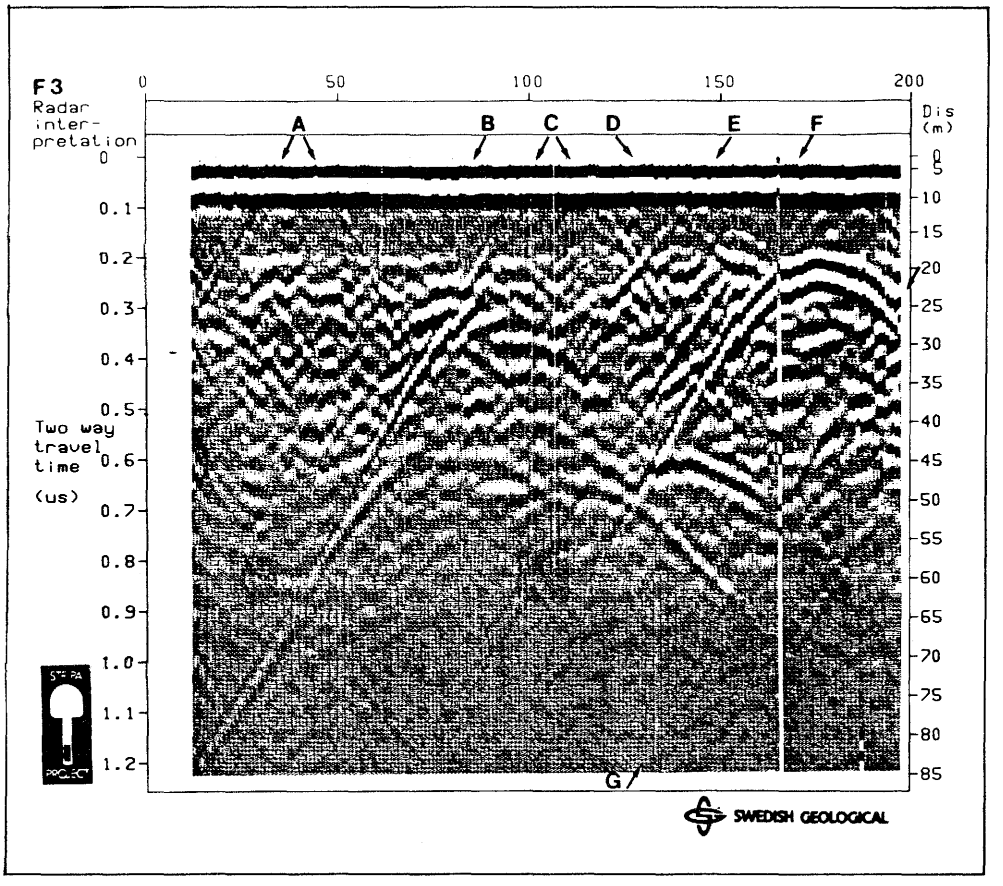

Figure 4-1. *Radar reflection map from borehole F3. Transmitter-receiver spacing 14 m and 22 MHz center frequency.*

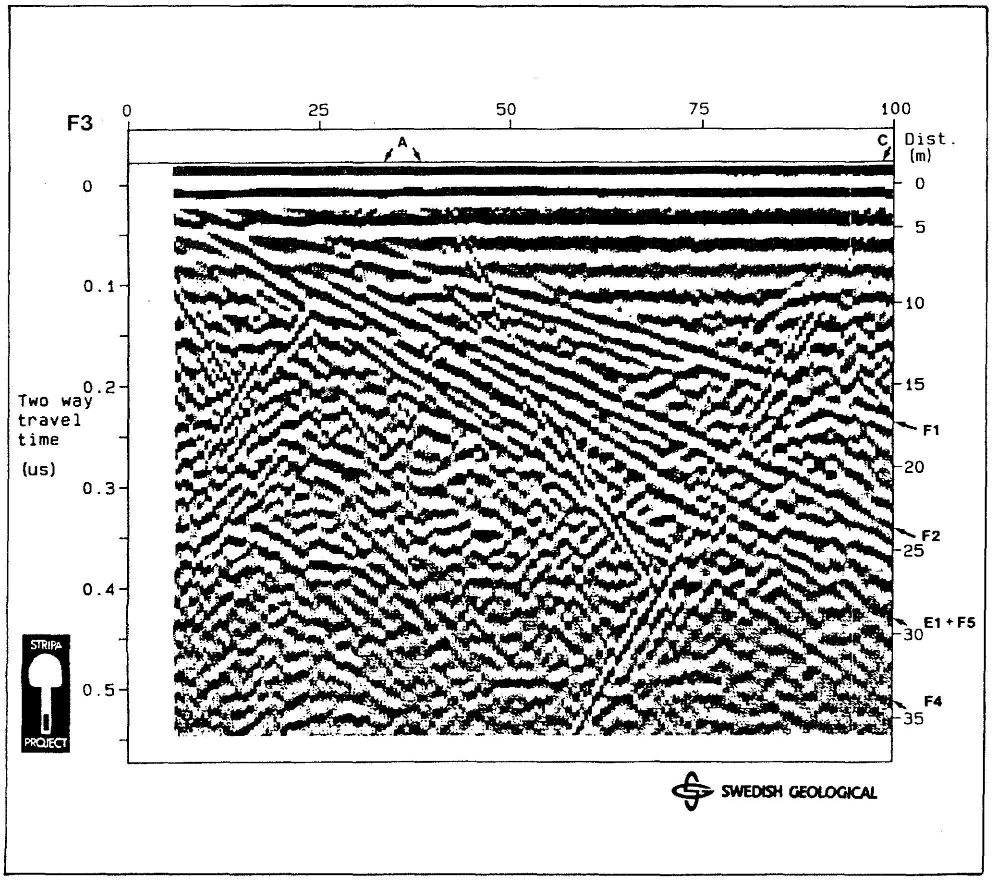

Figure 4-2. *Radar reflection map from borehole F3. Transmitter-receiver spacing 7.1 m and 60 MHz center frequency.*

4.1.3 Crosshole seismics

The analysis of the large scale experiment at Gideå by FOA was successfully completed in early 1985. The technique using measurements in three boreholes simultaneously was working well, giving a true three-dimensional coverage of the volume under study.

More than 300 shots were fired in the experiment, giving around 8000 signal traces corresponding to about 3000 travel times. A 3-D inversion has been made. A coarse structure can be seen, but the residual errors are quite large, making detailed interpretations difficult. Closer interpretations have been performed using 2-D inversions. Model calculations using an anisotropic velocity distribution show agreement for most features which were suggested by previous geophysical investigations. No new major fracture zones were found. The VSP (Vertical Seismic Profile) 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.

Some theories showing the uniqueness of tomographic inversion have been developed. It can be proved that the obtained result is unique even if not all points on the circumference are covered. Especially the VSP measurement configuration gives unique results.

Two new programs for output of tomographic maps have been written. Both use a multi-colour pen plotter to draw isovels, i.e. lines of the same velocity. A bilinear interpolation formula is used to find the isovels. One program outputs 2-D maps, whereas the other gives a 3-D presentation from an arbitrarily chosen viewpoint.

At the crosshole site in Stripa more seismic tests were carried out by Geoseismo OY. The pair of boreholes F4-F6 was investigated with a higher ray density (5 m steps for the source and 2.5 m steps for the detectors). A lighter version of the BHS-56 system was used for these tests. The emphasis was placed on detection of late arrivals.

The processing of the data recorded during Fall 1984 has continued. A systematic dependence of the velocity was found with respect to the path inclination, interpreted as anisotropy. The magnitude of this effect (2-4%) is comparable with the overall contrast and therefore has a strong influence on the resolution. A routine for compensation of the anisotropic behavior was applied and linear low velocity features clearly appeared.

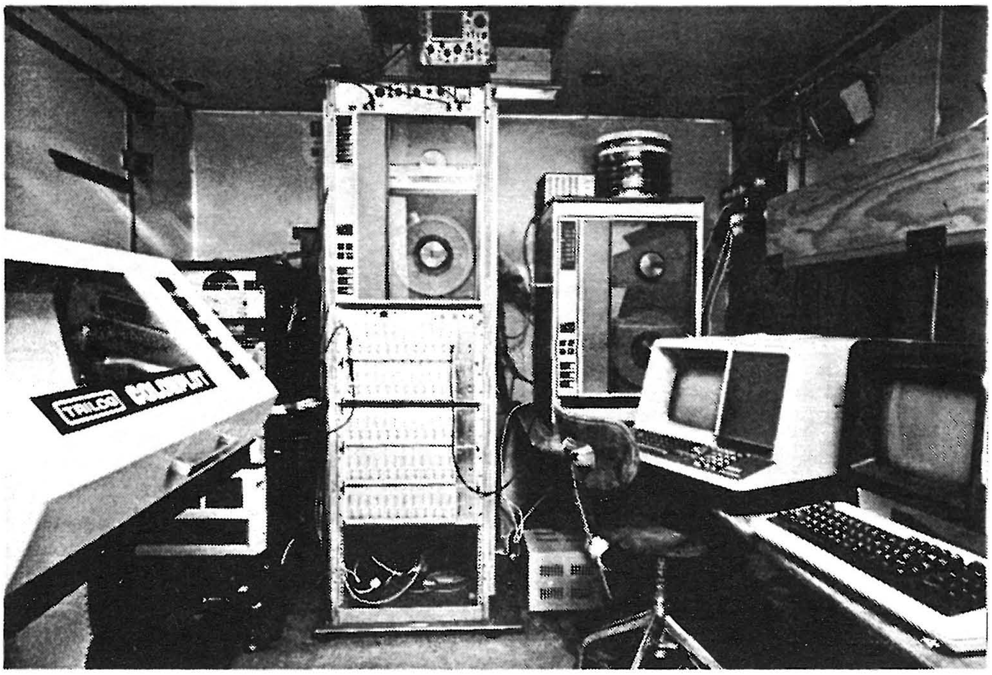

Figure 4-3. The Mobile Seismic System (MOSES) set up in the laboratory van.

4.1.4 Crosshole hydraulics

Single hole tests were completed in early 1985 in all the "fan-array" boreholes. These have consisted of constant pressure and constant flow injection tests as well as slug and pulse tests. All tests have been conducted with careful attention to the attainment of pseudo-equilibrium pressure. Hydraulic conductivity ranges from values appropriate for unfractured granite (i.e. $K = 2x10^{-13}$ m/s) to rather high values ($K = 5x10^{-7}$ m/s) at the far end of borehole F6. Within each borehole K varies abruptly as would be expected in fractured crystalline rock but bears no particular correlation with mapped fracture frequency. Similarly, the occurrence of zones of high K, measured on a single hole basis, bear no obvious correlation with the zones defined by standard single borehole geological or geophysical logging.

A strategy of increasing frequency sinusoidal crosshole measurements was adopted. The periods ranged from a day to a few minutes. The idea of the changing frequency was to identify the frequency of transition from a whole-rock response to a fissures-only response. This point should then yield information on the hydraulic properties of the rock matrix immediately adjacent to the fissures.

The early crosshole testing program was concentrated to the central part of the "fan array" since this holds the key to transmission of signals across the full width of the rock volume under consideration. Some very direct borehole-to-borehole connections have been observed, such as between F2 and F3 where no equivalent F1 to F3 connections were seen.

The program investigators met in October to discuss strategy for the remainder of the program. It was decided that, because of the limited time available, the hydraulic investigations should concentrate on the detection of major pathways together with a detailed characterization of zones A and C in all the boreholes.

Field work during late 1985 has concentrated on using the sinusoidal pressure system as a "hydraulic tracer" to detect pathways in the more remote parts of the "fan array" boreholes, where the separation distances are greatest. Twenty four hours period signals have been used and some pathways located, although the majority of tests have proved negative. Boreholes F3 and F2 are hydraulically linked between approximately 180 and 200 metres, as are F3 and F5 at similar depths. A good connection has been found joining the bottoms of F6, F4 and F2.

The crosshole testing produces single borehole results as a byproduct. These tests are at a finer scale than the original "site investigation" type tests so that the definition of the position of "active" zones is being improved all the time. It is still the case that the fracture zones defined by the various geological and geophysical approaches do not encompass all the zones of significant hydraulic transmissivity. However, it is often the case that where "identified" fracture zones lack transmissivity an adjacent zone is highly conductive. This idea of a fracture zone consisting of a "linear swarm" of sub-parallel fractures is geologically attractive and may have a characteristic geophysical signature.

4.2 Hydrogeological characterization of the ventilation drift area

The principal investigator for this study was Prof. John Gale, Memorial University, Nfld, Canada.

4.2.1 General

This study was initiated in September 1984 and finalized in late 1985.

The initial KBS-LBL fracture hydrology program at Stripa included the collection of considerable data on the geometry and hydrogeology characteristics of the fracture system at Stripa. In an earlier study the fracture data collected from the immediate area of the ventilation drift were analyzed. This analysis defined four distinct fracture sets in the rock mass surrounding the ventilation drift. The distributions of trace length and spacing data were analyzed in this earlier work and the statistical parameters for the lognormal, Weibull and exponential models were determined for each fracture set. However, while considerable hydrogeologic data were collected at Stripa during this early program, only the data collection procedures and part of the raw data, in an unchecked form, were tabulated with only a very limited analysis of the data being completed.

The objectives of this study were (1) to determine how much of the existing hydrogeologic data, primarily the borehole packer test data, were acceptable and could be analyzed to determine the distribution of permeabilities and fracture apertures in specific areas of the Stripa rock mass, (2) to determine the statistical models that best represent these permeability and aperture distributions and their distribution parameters, (3) to determine if a relationship exists between (a) the measured permeabilities and fracture frequency and (b) between permeability and depth, and (4) to numerically simulate the fracture network surrounding the ventilation drift (Buffer Mass Test area) and to calculate the flow through the simulated network into the drift, and compare the computed flow rates with those measured during the macropermeability experiment in the ventilation drift.

4.2.2 Summary of results

A total of 766 injection and withdrawal packer tests, completed in the 1977 to 1981 period in 3 surface (SBH) and 15 subsurface (HG and R) boreholes, were reviewed in this study. This review showed that, in the three SBH surface boreholes successful injection tests were completed in (a) 450 2 m long packer intervals, (b) 60 short intervals, each less than 0.8 m long, each containing one fracture, and (c) 23 packer intervals, each between 6 and 7 metres in length. In the subsurface HG and R boreholes 84 single fractures were successfully tested under both withdrawal and injection test conditions. In the same boreholes 149 injection tests were completed in 2 m and 4 m intervals, and 100 withdrawal tests were completed in 2 m packer intervals. A number of additional intervals were tested but the data were rejected during this review and analysis, due to either incomplete test data or faulty test equipment.

Analysis of the permeability data from the surface boreholes showed a general decrease of permeability with depth. This is much more pronounced over the first 100 m of depth than it is for the lower 180 m of depth. The lower 180 m of depth in SBH-2 shows no decrease of permeability with depth. This change in trend of the permeability - depth relationship may be an artifact of the flow rate measurement limit. However, the wide scatter in the measured permeabilities at this level does not support this conclusion. Also, an analysis of fracture frequency versus depth in the surface boreholes does not show any significant change in fracture frequency with depth that would correspond to the observed variation in permeability with depth. Since the HG and R boreholes are all located within a 60 m depth interval, we examined the relationship between fracture frequency and permeability in these boreholes. A moderate to weak correlation was found between the total number of fractures in each test interval and permeability but very little to no correlation was found between the number of fractures of each set in each test interval and permeability. It is possible that stress changes due to the excavation of the drift may have effectively hidden any existing relationships between fracture frequency and permeability. Laboratory data on flow in single natural fractures from Stripa show a strong relationship of decreasing fracture permeability with increasing normal stress.

Determining the parameters of the theoretical distribution that best fits the permeability and aperture data from the HG and R boreholes is difficult since

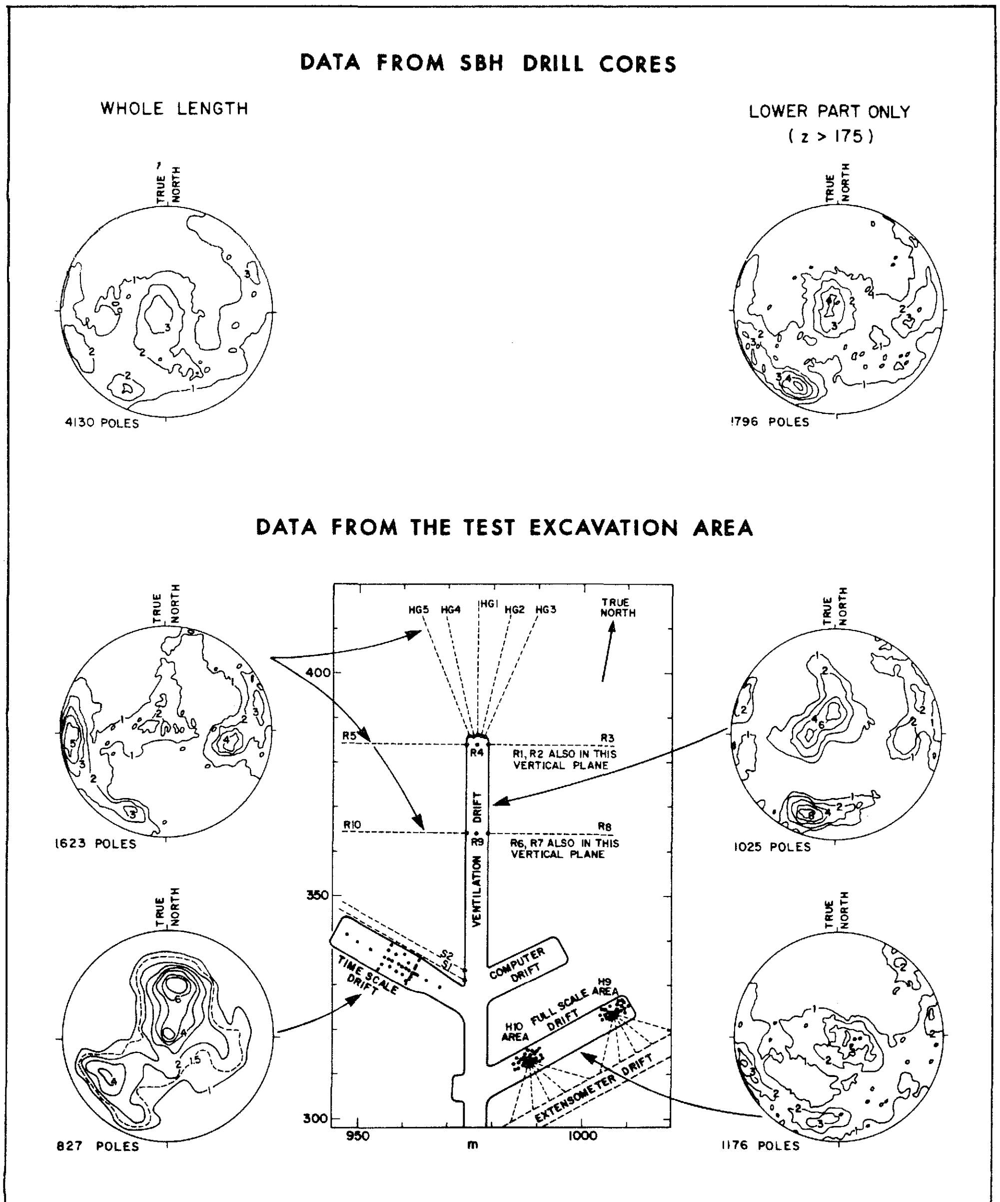

Figure 4-4. Contoured stereonets of poles to joint planes showing variations in orientation in the area of the test excavations. The contoured values are in percent of points per 1% surface area.

up to 46.4% of the single fracture tests and 7.4% of the fixed interval tests had flow rates that were lower than that which could be measured with the available packer test equipment. Since we were not aware of any theoretical method to correct a highly truncated data set or conduct goodness-of-fit tests, with respect to different distribution models, on such truncated data sets we have made empirical corrections by plotting the permeability and aperture data on cumulative probability paper for the lognormal, Weibull and exponential distributions. These plots have been used to develop empirical measures of the parameters of each distribution model and to obtain an estimate of how well the data fits each of the models examined.

The lognormal distribution parameters for fracture trace lengths, spacings and densities for each set were used as input for the generation of fracture networks for the Ventilation drift area. For symmetry reasons we simulated both the east (first) quadrant and the west (second) quadrant. The total flow rates computed for these fracture networks, based on field-defined hydraulic boundary conditions, agreed very closely with the measured flow rates when the mean fracture aperture used in the fracture network flow model was approximately equal to the mean aperture determined from the borehole packer injection tests on single fractures in the HG and R boreholes.

This study has shown that detailed fracture geometry and fracture hydrology data can be collected and analyzed to provide needed insight into the relationships between fracture geometry, permeability, apertures and normal stress. The fracture and hydrology data base has been sufficient to define the parameters of the statistical distributions of permeability and apertures. The current analysis shows clearly the need to correct data distributions for truncation and censoring errors and the need for theoretical corrections that will enable one to conduct rigorous "goodness of fit" tests to determine which statistical model best fits the data distribution. In addition analysis of the hydrology data base has clearly shown the minimum permeability measurement limit needed to completely characterize the permeability and aperture distributions. This conclusion has the potential of saving considerable time in future field testing programs without compromising the completeness of the data set.

In this study, it has also been shown that we can combine the statistics of fracture geometry and hydrology to study flow through fracture networks. The good agreement obtained between computed flowrates, measured flowrates and fracture apertures, determined from field tests, indicates that discrete network modelling will be a powerful tool in predicting and describing velocity distribution and fluid pathways in fractured rocks. Fundamental to these predictions will be the empirical formulation of the correct constitutive relationship for flow in rough fractures whose walls are in intimate contact.

4.3 Three-dimensional migration experiment

The principal investigator for this experiment is Prof. Ivars Neretnieks, Royal Institute of Technology, KTH, Sweden.

4.3.1 General

The general objectives of the experiment 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.

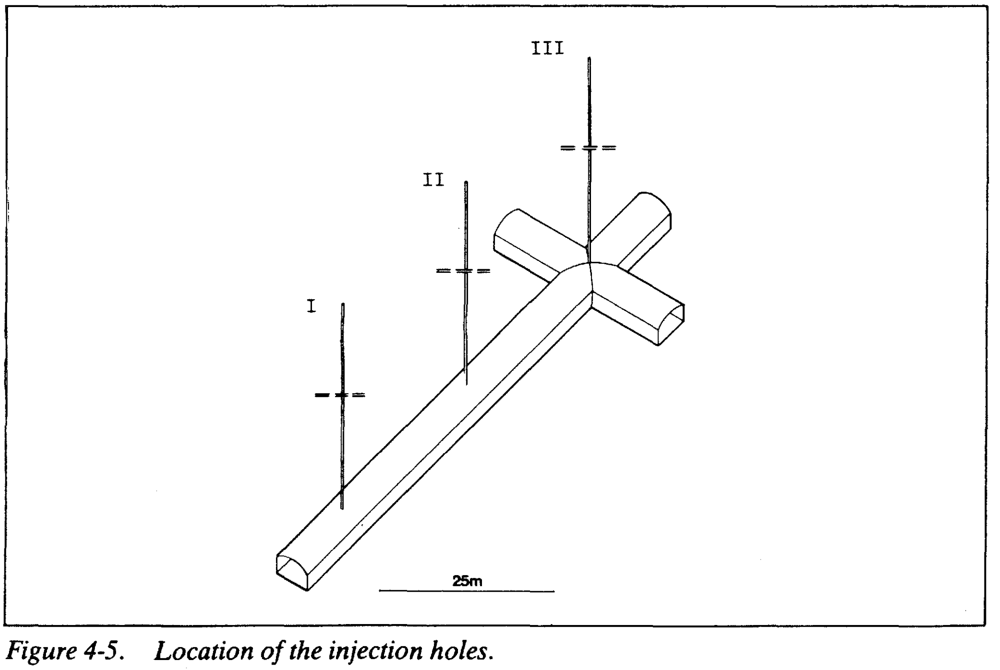

Figure 4-5. Location of the injection holes.

Figure 4-6. View of the experimental site.

Tracers have continuously been injected since October/November 1984. The injections are carried out with a "constant" overpressure, approximately 10-15% above the natural pressure. The concentrations of the injected tracers are between 1000 and 2000 ppm, and the different injection flow rates are between 1 and 20 ml/h.

Before injection, all 11 tracers (including the high molecular weight tracer, STR-7,) were tested in the laboratory and found to be stable with time and "nonsorbing" on crushed granite as well as on the materials used in the equipment. 8 of the 11 tracers used are dyes, the three remaining tracers are iodide, bromide and fluoride.

From the 65 most water-conductive sampling areas, samples are taken every 16 hours. Samples are also taken from another 80 places, such as sampling areas with low water flow rates, wet spots at the floor, pilot hole, access drift, drifts at the 310 m level etc. The time intervals between samples from these places are 1-5 weeks, depending on the water flow rates.

4.3.2 Preliminary results

After 14 months of injection (December 1985), tracers from six injection zones were seen in about 50 of the 145 sampling areas. Analysis done during late 1985 clearly showed that iodide, injected 28-30 m above the ceiling in hole III, was found in the test site.

The tracers emerging in the area between holes II and III are only those injected in hole III. In the area closest to injection hole I only tracers injected from this hole appear, while all six tracers appear together in the central part of the test site.

Looking at Figures 4-7 and 4-8 it is remarkable that the three tracers injected in hole III have not yet been found in any of the closest sampling areas, but have been found in many of the sampling areas around hole II.

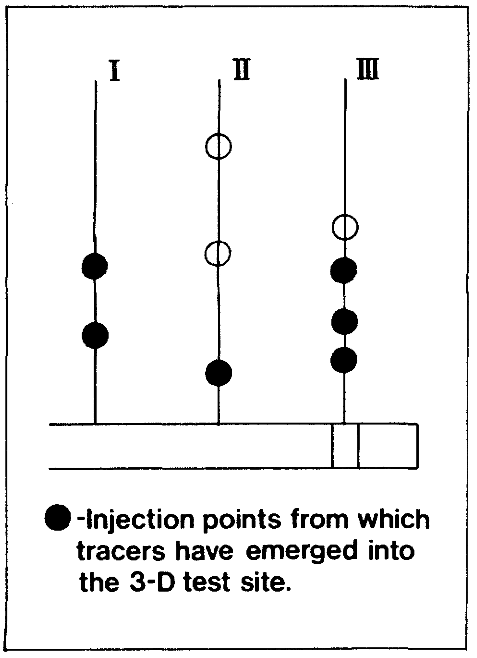

Figure 4-7. Location of injection zones and from which tracers have emerged (December 1985).

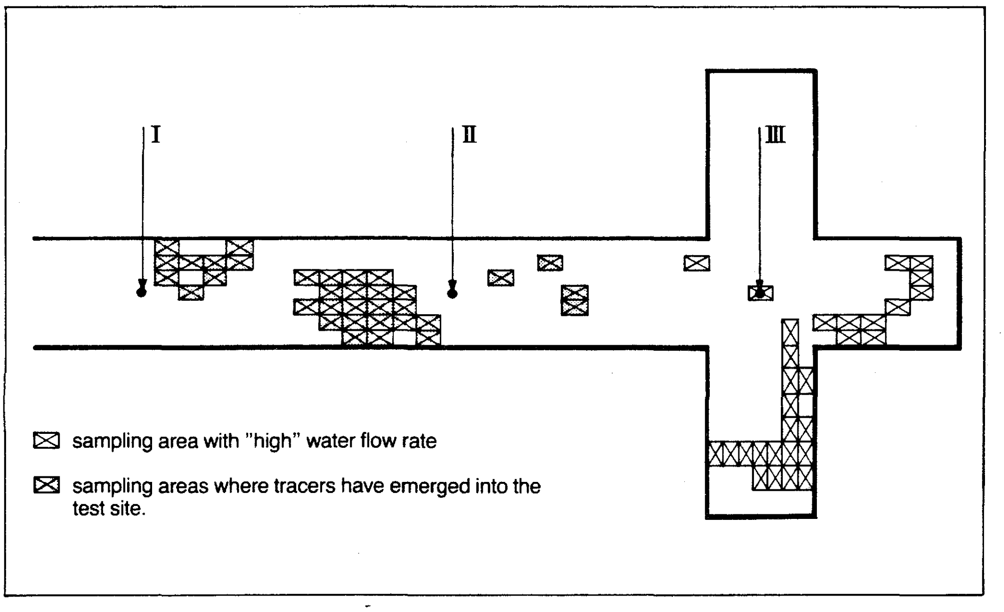

Figure 4-8. Tracer distribution (December 1985).

4.4 Borehole and shaft sealing test

The principal investigator for this study is Prof. Roland Pusch, Swedish Geological Co, SGAB.

4.4.1 General

The general objective of the Borehole and Shaft Sealing Test is to test and demonstrate various ways of plugging boreholes, shafts and tunnels by use of highly compacted sodium bentonite, as well as to determine their sealing effect with special respect to clay/rock interaction phenomena.

Recording, evaluation and interpretation of results were the main activities during 1985.

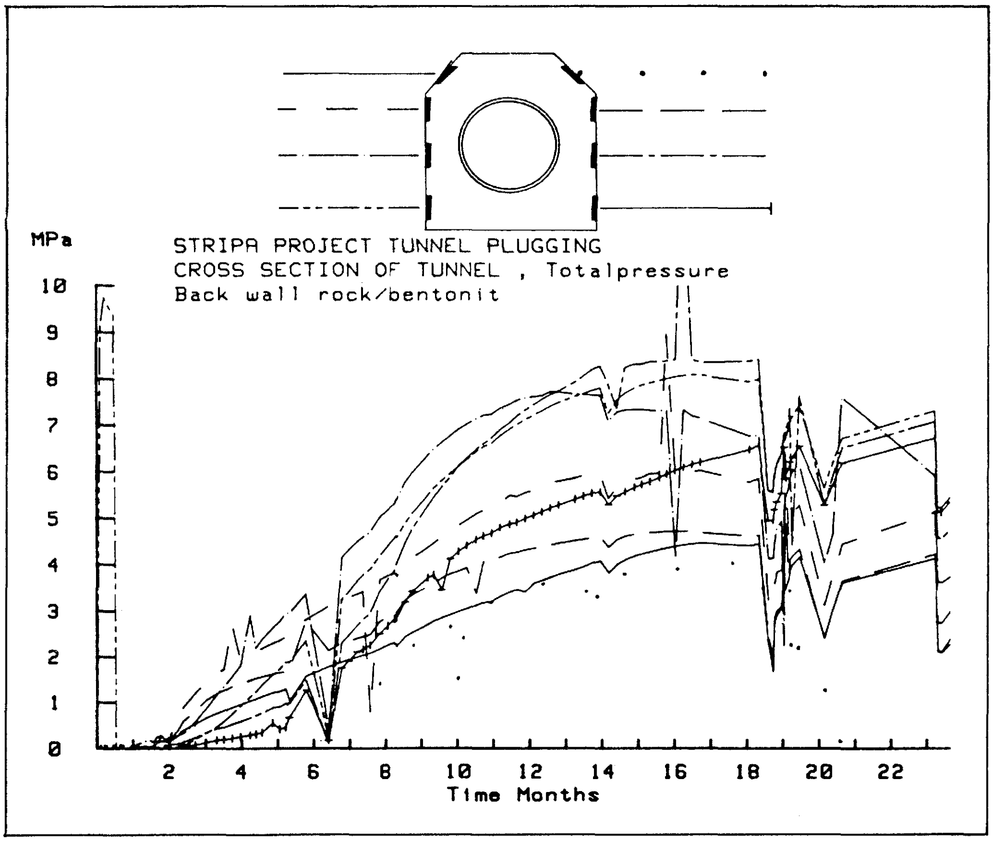

Figure 4-9. Total pressure recorded at the rock/bentonite interface at the back wall.

4.4.2 Tunnel plug

In December 1985 the plug had been in operation for about 20 months, the pressure being held at 3 MPa in the last year. During this pressure stage the flow had decreased from initially almost 200 liters per hour to a value varying between 85 and 100 liters per hour. While the flow tended to correspond to the lower of these figures for quite long periods of time, it changed abruptly to the higher value a few times. This was ascribed to temporary power breakdowns, the probable explanation being that the associated pressure drop resulted in a contraction of the plug which is held together by prestressed tie-rods. An alternative explanation may be that pressure-induced creep in the rock at the highly stressed ends of the plug yields local critical stress conditions, which produces displacements along existing joints and fractures, or propagation and generation of such discontinuities.

The development of swelling pressures has continued but the Gloetzl pressure recording system has successively deteriorated through leakage of the plastic tubing. However, the pressures recorded at the rock/bentonite interface of the back wall of the plug appear to be accurate (cf Figure 4-9) and they indicate that the present swelling pressure, i.e. the total recorded pressure minus the water pressure is in the interval 2-6 MPa, as demonstrated by the recordings about 18.3 months after test start when the water pressure was only 0.25 MPa. This demonstrates an average degree of water saturation of 70-90%, which is in good agreement with the predictions.

4.4.3 Vertical shaft plug

The 100 kPa water pressure in the injection chamber was maintained during 1985 until December 4 when it was increased to 200 kPa. The initial leakage was more than 30 liters per day but it dropped to 10 liters per day after one week and to about 6 liters per day after one month, which is less than the recorded leakage one month after the application of the preceding 100 kPa pressure, see Figure 4-10. This confirms the expected increase in sealing power of the bentonite through the successively built-up swelling pressure and possibly also through its penetration into major fractures.

The swelling pressure continued to increase in the reporting period with the highest value, about 2.7 MPa, being recorded for one of the cells in the rock slot, see Figure 4-11. The gauges which record the vertical swelling pressure in the centers of the plug halves (2 and 4) showed a pressure of only 1.5 MPa in late 1985. This was due to the vertical expansion and associated drop in bulk density of the clay. The expansion is due to compression of the sand and elongation of the bolts that keep the plug units together.

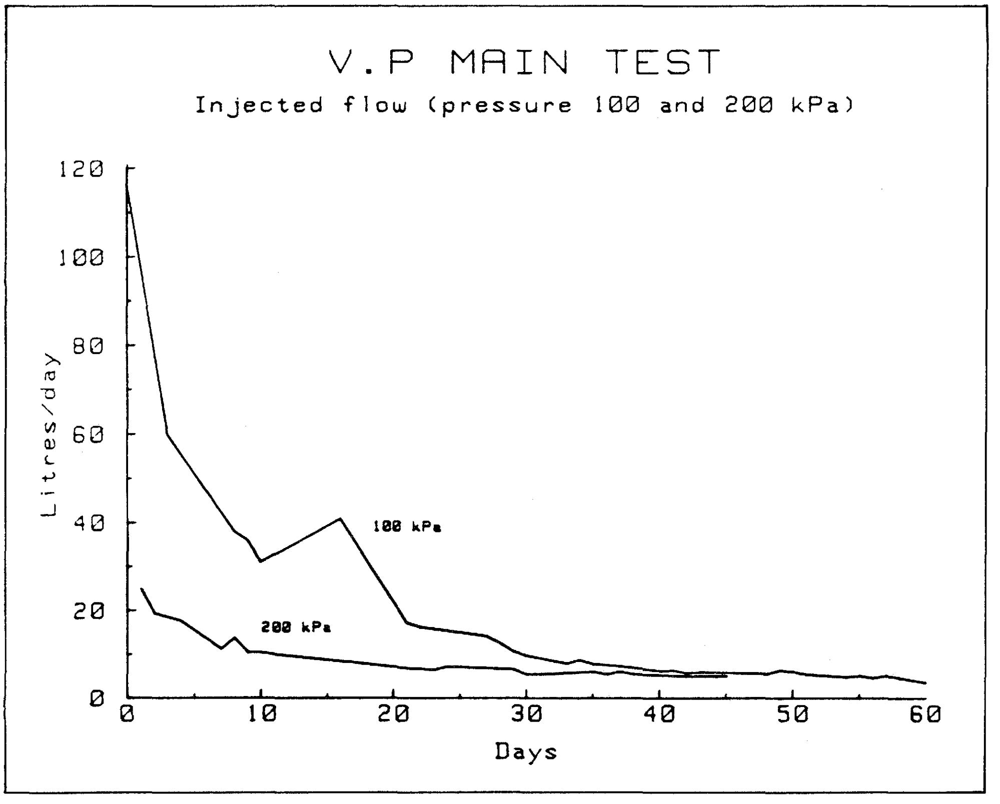

Figure 4-10. Leakage from the injection chamber of the shaft plug at 200 kPa pressure compared to that at 100 kPa. Both refer to the start of the respective tests.

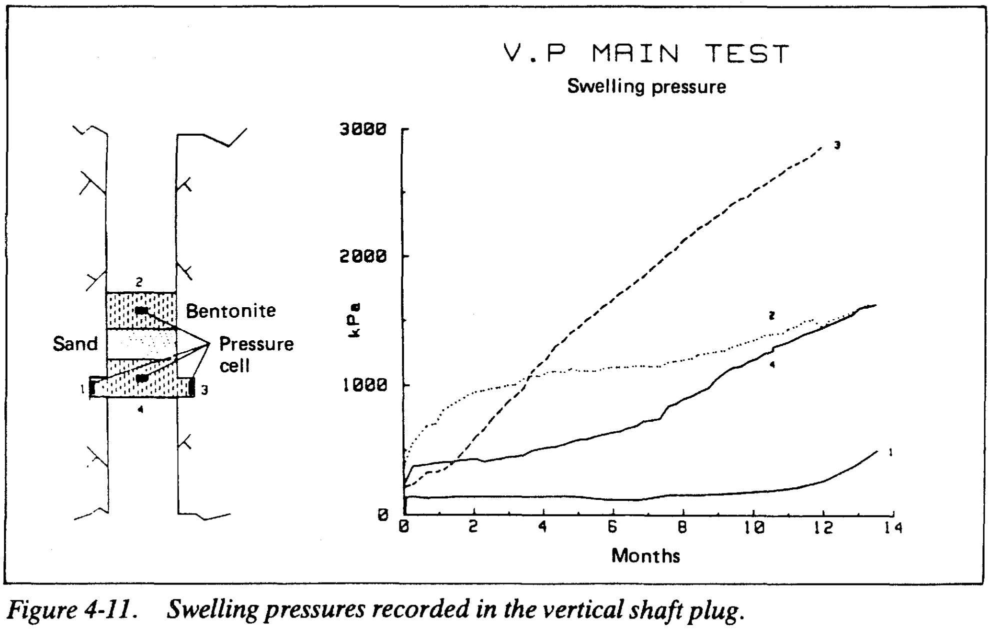

Figure 4-11. Swelling pressures recorded in the vertical shaft plug.

4.4.4 Borehole plugging

The DbH2 borehole

The water pressures in the four filters remained nearly constant during 1985 despite the almost 12 months that have passed since the nearby tunnel backfill was removed. This makes it clear that this borehole is located in rock which is not effectively drained to the tunnel although the distance between the hole and the tunnel is only slightly more than one meter. It is concluded that the rock which constitutes the walls of the tunnel is not fractured to more than a few decimeters from the periphery.

Ø 76 mm borehole plugs

The extrusion of the plugs was made in summer 1985 by use of mechanical jacks applied to the lower ends of the plugs via a number of rigid steel tube sections. Previous shear tests in the laboratory had also shown that largely different shear strain rates did not result in a significant change in peak shear strength, and a rather high expulsion rate, i.e. about 0.1 mm/s, was therefore applied in the test.

A maximum force of 8.7 tons (87 KN) was reached after about 36 mm displacement of the lower end of the Swedish plug in hole Ib, while the corresponding force was 8.7 tons (87 KN) at about 70 mm displacement of the lower end in the Swiss hole (Ic). This indicates that the two plugs had maturated to approximately the same state despite the different porosity of their casings. The larger displacement of the Swiss plug before it was sheared off from the rock, was due to deformation of the weak central tube which initially took all the load.

The pursued extrusion of the Swedish plug led to a drop in extrusion force to about 70% of the peak value, while the force required to push out the Swiss plug first reached a maximum of about 87 KN and finally rose to 100 KN, after which it again dropped to about 87 KN. The bond strength of both plugs was thus slightly less than 45 kPa, which corresponds fairly well to the shear strength of saturated MX-80 clay with a water content of about 50-70%.

After the complete recovery of the plugs it was found that the Swedish copper casing was compressed by about 20 mm over the lower 500 mm length, which is a strain that hardly influenced the recorded extrusion force. The wire net and the central tube of the Swiss hole were very much distorted, on the other hand. The total axial compression of these units, which had the form of z-shaped folds, was estimated at 450 mm. This severe deformation was probably responsible for the increase in force in excess of 8.7 tons that was required to push out this plug.

It was expected before the excavation that both plugs should exhibit similar water contents and a fairly uniform wetting, the bulk density ranging between 1.4 and 1.8 t/m^3, corresponding to the water content interval 40-150%.

After the extrusion of the plugs, which showed no voids or incomplete clay filling, samples of clay were taken to determine the average water content of each 5 cm interval in the axial direction of the plugs, distinction being made between the peripheral clay, i.e. the clay located between the casing and the rock (Zone A), and Zones B and C as defined in Figure 4-12. The conclusion from these data is that the wetting of the clay at the pressure gauges, i.e. where the clay had to expand very much to fill up the initially open space, had led to approximately the expected density conditions in the Swedish hole, while the clay in the Swiss hole turned out to be somewhat stiffer. Both plugs had reached a water content of about 35 to about 50% over the rest of their length. The initial water content was about 10% in both cases, meaning that the redistribution even to the inner part of the clay cores had been very effective. It is clear that water and clay redistributions were more effective close to the gauges in the Swiss hole than in the Swedish hole, but the difference is relatively moderate.

An important conclusion is that no correlation exists between the location of strongly water-bearing joints or fractures in the rock and the occurrence of high water contents. This supports the conclusion from the Buffer Mass Test that

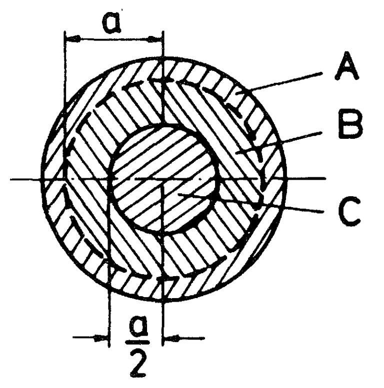

Figure 4-12. Definition of clay zones A, B and C for the water content determination.

strongly water-bearing joints are sealed early by penetrating bentonite, by which "second order" fissures in the rock are the ones that determine the rate of water uptake by the bentonite over longer periods of time.

4.5 Hydrogeochemical characterization of the Stripa groundwaters

This project is carried out by the members in the Hydrogeochemistry Advisory Group (HAG) chaired by Prof. 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

4.5.1 General

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.

4.5.2 Preliminary results

A summary of some of the major results obtained during 1985 is presented below.

4.5.3 Water chemistry

Changes in chemistry during free flow

Results are now available from the continued monitoring of water chemistry during free flow in the two deep vertical boreholes V1 and V2, and the horizontal borehole, M3. Samples have been taken regularly since the 1st of May, 1985. There is no notable variation in chloride or other major ion concentrations in V1 and V2. The chloride concentration in M3 is still going down since the abrupt change in water chemistry during the heater experiment close to M3 in 1978.

Redox conditions

The iron content is, in general, very low and the concentration of Fe^{3+} is close to saturation for ferric hydroxide. This has been reconfirmed by new, more accurate, analyses performed at IVL (Sweden) and USGS. There is in general more total iron than $Fe^{2}+$ except in sulphide-containing waters where they have equal concentrations (deepest part of V2).

4.5.4 Oxygen-18 and deuterium in water

From these data it can be concluded that the Stripa groundwaters are normal meteoric waters. The lower oxygen-18 and deuterium contents of deep waters indicate that infiltration in this area has occurred during a cooler climate than today.

The oxygen-18 values are remarkably stable even where large amounts of water have been extracted from the sampling section. There is also no apparent connection between oxygen-18 and chloride concentration. In other words: water and chloride seem not to be related.

4.5.5 Carbon-14 in dissolved carbonates

Samples have been taken for analyses of carbon-14 content in the dissolved carbonates using the accelerator technique. This method is necessary due to the very low alkalinity of some of the Stripa waters (V1 and V2). All samples have not been analysed yet and others have to be resampled due to atmosphere contamination.

4.5.6 Sulphur-34 and oxygen-18 in dissolved sulphate

The correlation of these stable isotopes in V1 and V2 is such that an active redox process involving sulphate is indicated. The general water chemistry lends some support to that observation, which is of course important for the availability of sulphide and the redox properties of the groundwater. The sulphate reduction will most probably involve organic matter and bacteria.

4.5.7 Chlorine isotopes and iodine-129

Chlorine-37

Water and rock-leachate samples have been analyzed for the ratio of stable isotopes chlorine-37 to chlorine35. The values are above what is obtained for normal seawater by 0.2 - 1.4‰.

Chlorine-36

Water and rock-leachate samples have been prepared for measurement of the radioisotope chlorine-36. A predicted equilibrium value of about (200 to 400) x 10^{-15} (chlorine-36 to stable chlorine) has been calculated for granite and (48 to 58) x 10^{-15} in leptite. Measured values so far are between (49 to 135) x 10^{-15} for granitic groundwater, (142 to 220) x 10^{-15} in granite leachates and about 172 x 10^{-15} in leptite leachates. These calculations are based on measurements of natural neutron flux etc.

4.5.8 Fluid inclusion

The fluid inclusions of calcites in fractures have been carefully investigated. The main conclusions from this study can be summarized as follows:

- The variation in fluid inclusion size is very irregular and about 1 to 200 μm.
- Two types of fractures have been observed
  a. 1-5 mm wide with quartz, calcite, chlorite, epidote, prehnite, sericit and fluorite.
  b. <0.5 mm wide, mostly monomineralic, with calcite, chlorite or epidote.
- Homogenization temperature of the calcite fluid inclusions 80 - 220°C.
- Highly saline population around 85°C.
- A trend toward higher salinity of the calcite inclusions at depth.
- Most of the fracturing took place at the late stage cooling of the pluton.
- Many of the more saline inclusions indicate calcium enrichment.
- The volume of fluid inclusions in calcite is around 0.9%.
- There is enough and relatively accessible salinity in the calcites to contribute significant amounts of salt to the groundwaters.

Three kinds of porosities have been identified:

- Fracture flow porosity, about 0.001 - 0.01%
- Connected microfracture porosity, about 0.1 - 0.3%
- Closed microporosity, about 1-2%.

4.6 Economy

The total cost of the Stripa Project phase 2 as of December 31, 1985 is given in Table 4-1 below.

Table 4-1. Stripa Project phase 2 – Summary of costs as per December 31, 1985. All figures in SEK.

	Total program			
Program	Original budget incl 10% annual esc.	Rev budget Now 30, 1985 incl 10% annual esc.	Accumu-lated	Estimated Remaining
Project management	3 700 000	3 700 000	2 279 500	1 420 500
Mine operatisons	14 150 000	13 205 000	7 383 026	5 821 974
Crosshole techniques	22 400 000	22 400 000	17 849 926	4 550 074
3-D tracer experiment	8 350 000	8 550 000	7 060 522	1 489 478
Sealing test	10 200 000	10 200 000	8 253 875	1 946 125
Hydrogeological characterization, Part 1	260 000	260 000	174 053	85 947
Hydrogeological characterization, Part 2	0	745 000	0	745 000
Hydrochemistry	1 400 000	2 460 000	1 717 228	742 772
Seismic crosshole	700 000	700 000	681 763	18 237
Total	61 160 000	62 220 000	45 399 893	16 820 107