STRIPA PROJECT 87-14

Annual Report
1986

August 1987

TECHNICAL REPORT

An OECD/NEA International project managed by:
SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO
Division of Research and Development

STRIPA PROJECT

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THE STRIPA PROJECT
ANNUAL REPORT
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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 1986.

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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.

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

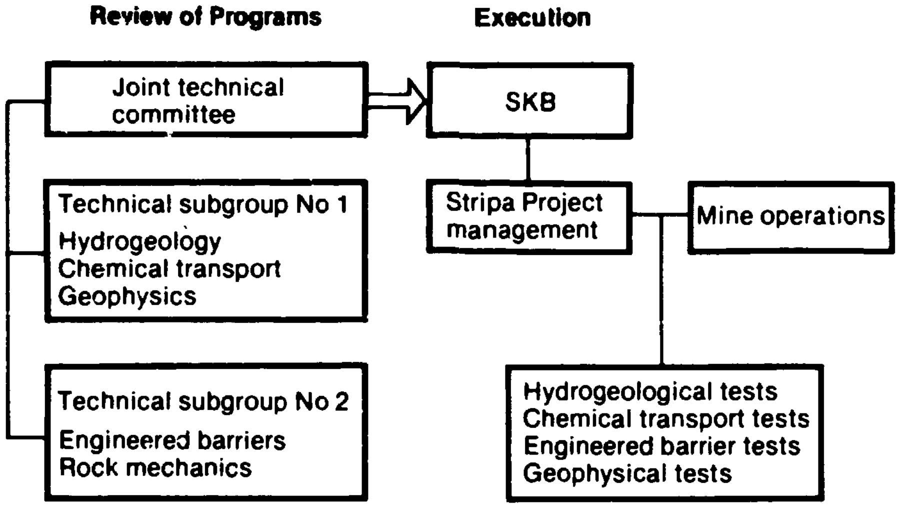

Figure 1-2. Organization of the Stripa Project.

The second phase of the Stripa Project, which has also been joined by Spain and the United Kingdom, started in 1983 and is currently scheduled for completion in 1987, with the exception of additional water sampling in the hydrogeochemistry program which will extend until mid 1988. The estimated total cost is 65 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, a shaft and a tunnel using highly compacted bentonite,
- hydrogeological characterization of the Stripa site based on data from the Swedish-American co-operative (SAC) project, and
- isotopic characterization of the origin and geochemical interactions of the Stripa groundwaters.

A decision was taken in principale, during 1986, for an extension of the project into a third phase. A formal agreement will be signed in 1987.

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 Sub-groups (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 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 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 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 1 and 2 met in parallel sessions on March 3-5, 1986 in Stockholm, Sweden. 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 and discuss the progress of the technical planning on Phase 3 of the Stripa Project. A visit to the Stripa Mine was arranged in conjunction with the meetings.

A JTC-meeting was held at the Castle of Lejondal, Sweden, on May 20-21, 1986. The management of the ongoing activities as well as possible future co-operation at Stripa were discussed. The technical and financial conditions of the proposed Phase 3 of the Stripa Project was approved by the seven JTC members in attendance, Canada, Finland, Japan, Sweden, Switzerland, the United Kingdom and the United States.

The Stripa Phase 3 contract was to be distributed by NEA before June 23, 1986 to potential member countries. A "letter of intent" regarding participation on the terms and conditions outlined in the contract was to reach the NEA before August 1, 1986. The Phase 3 activities would start as soon as these "letter of intent" had been received by the NEA. The funding needed to accomplish the Phase 3 work as presented in the contract will be given in price level January 1986 with an index formula for cost escalation.

Notes from all meetings have been distributed separately.

2.2 Extension of investigations

In an unprecedented investigation, the Hydrogeochemistry Advisory Group (HAG), has documented the rapid flow of shallow groundwaters (or surface waters) to depths of over 300 meters in a crystalline rock terrain during a peroid of only a few years.

Accompanying this movement is the occurrence of an anthropogenic compound of unknown origin, rapid redox changes in time and location as reflected in the uranium, iron and sulfur determinations and additional complications with C-14 age dating. The main objective for the Phase 2 extension program is to continue monitoring the M3, V1 and V2 boreholes with special emphasis on the organic chemistry and carbon isotopes in order to better document and to interpret the occurrence of young groundwaters at repository depths and what factors and/or processes may control their chemical behavior.

2.3 The Stripa Project Phase 3

Phase 3 of the program started as of September 1, 1986 and will be carried out during the period 1986-1991. Seven countries (Canada, Finland, Japan, Sweden, Switzerland, United Kingdom and USA) have confirmed their participation in Phase 3.

The Program for Phase 3 of the Stripa Project is a direct continuation and is based on the work carried out within Phases 1 and 2, but new research activities will also enter in. An undisturbed granitic rock volume (approx 125 m x 125 m x 50 m) will be investigated. A schematic illustration of the test area is shown in Figure 2-1. A mathematical model for groundwater flow will be developed and compared with values measured in the field. Previously obtained results show that models that treat the rock as a porous medium cannot describe in detail the conditions prevailing in a fractured granitic rock volume of the size in question. The mathematical model to be tested is based on a combined deterministic and statistical description of the groundwater flow in a discrete fracture pattern in three dimensions.

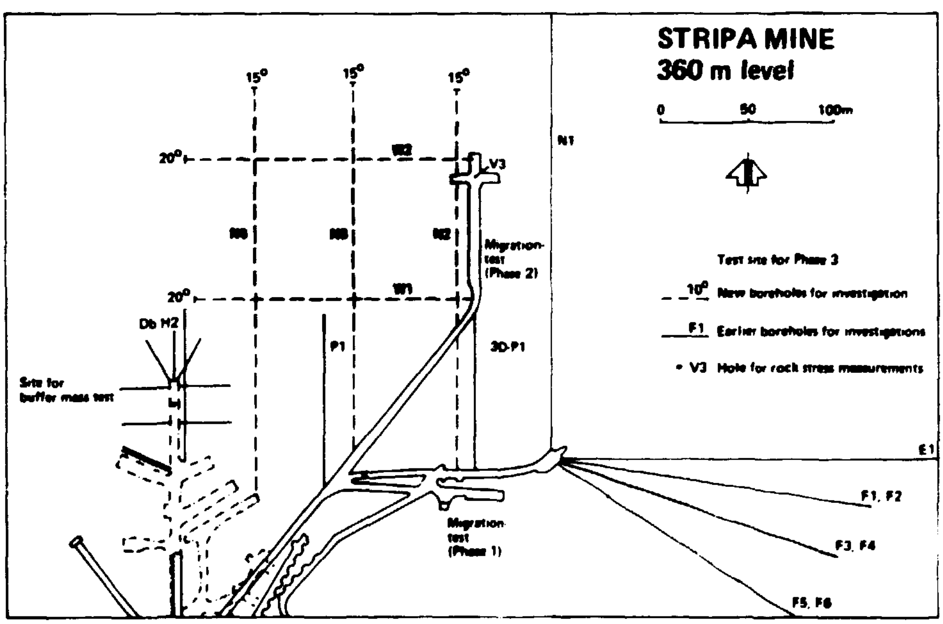

Figure 2-1. Schematic illustration showing the test site for the investigations of Phase 3.

The investigations at Stripe have shown that it is not realistic to describe a fracture as an aperture of constant width between two plane-parallel surfaces. Instead, it appears as if the water runs through randomly oriented channels in the fracture. The prevailing hypothesis today when it comes to channelling is that water in one channel mixes with water from other channels in an irregular pattern and that there exist zones with stagnant or nearly stagnant water where diffusion is the dominant transport mechanism. Phase 3 includes a continuation of the tracer tests from Phase 2 for the purpose of investigating the water flow in fractures in greater detail and thereby shedding more light on the phenomenon of channelling. These tests will be concluded with a large-scale tracer test in the aforementioned undisturbed rock volume. The results of these investigations will also be compared with calculated values.

The development of advanced measurement methods and instruments for rock investigations will continue during Phase 3. The work pertains to a high-resolution and direction-sensing borehole radar and improved technology for high-resolution seismics in boreholes.

A new research field in Phase 3 is technology for measuring the hydraulic length and width of fractures. These measurements are intended to complement the fracture mapping that is being carried out in connection with the excavation of a tunnel through the test site. This information is important for the modelling of the flow of water in the rock and the optimization of the technical design.

Of importance for the technical design of the final repository is also the use of sealant materials limit or prevent the migration of radionuclides from the repository. Phase 3 includes an extensive research effort. Among other things, the properties of different materials for injection grouting of rock will be studied. A large-scale grouting test will probably be carried out. Of particular importance is long-term stability in the expected environment around a final repository.

There will be only 1 (one) Technical Subgroup covering all areas of research within the Phase 3. The future TSG meetings will be chaired by Drs. Rudi Beck, Switzerland and Paul Gnirk, USA. The participating countries are allowed to send a maximum of 2 representatives and 2 observers to these meetings.

A "Task Force" on Sealing Materials and Techniques will form an ad hoc group to the project where the JTC may nominate a maximum of 2 representatives. This ad hoc group should report to the TSG on their activities. As for the "Site Characterization and Validation" program the project manager will be supported by two Scientific Coordinators, John Black of BGS and Olle Olsson of SGAB both with long experience in the Stripa Project. The "Site Characterization and Validation" program will both in its phase of practical work in the Stripa mine and in the stages of data evaluation and reporting, call for extensive co-ordination between different groups of investigators. A detailed technical knowledge of the work within the program is then necessary.

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

Results of Phase 3 work will be reported in forthcoming Annual Reports of SKB.

3 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".

3.1 Crosshole techniques for the detection and characterization of fracture zones

3.1.1 General

The purpose of this investigation is to develop crosshole electromagnetic (radar), seismic, and hydraulic methods for bedrock investigation which may determine the location, extent, thickness and physical properties of fracture zones. For each of these methods new equipment has been developed, field tests have been performed, interpretation techniques have been developed and tested on the obtained data. Most of the field tests have been performed at a specially prepared test site in the Stripa Mine named the Crosshole Site (Figure 3-1).

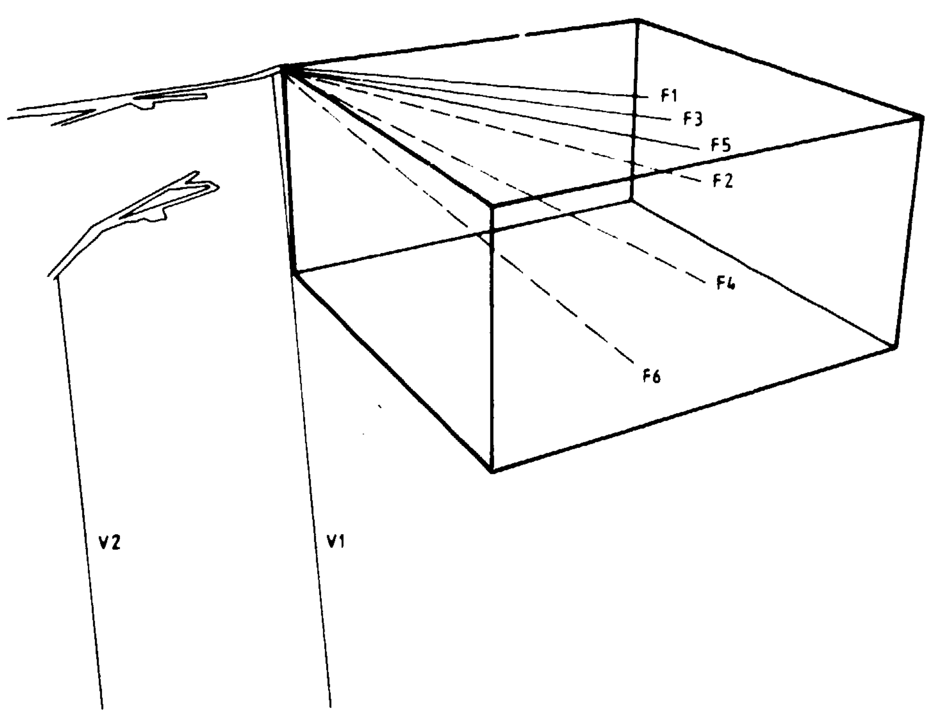

Figure 3-1. Perspective view for the boreholes at the Crosshole site.

The field work and the associated data collection to be performed within this investigation program was completed early 1986. The efforts during 1986 have concentrated on the analysis and reporting of the obtained results.

3.1.2 Radar

A new borehole radar system was designed during the first stage of the Crosshole program. The radar system is a short pulse system operating in the frequency range 20 to 60 MHz. The system consists of borehole transmitter and receiver probes which are connected to a signal control unit by optical fibers. The signal control unit is used for communication with the borehole probes and for control of the measurement. A field computer unit is used for display on a colour screen, storage, processing and printout of the recorded data. The borehole radar system is designed to be used both in singlehole and crosshole measurements.

In a singlehole reflection measurement the transmitter and receiver are moved along the same hole at a fixed separation distance and the propagation time of reflected pulses is measured. When the transmitter and receiver are moved along the hole a characteristic pattern is generated on the radar maps depending on the geometry of the reflectors. Point reflectors give rise to hyperbolas while fracture planes are represented by lines. Reflections are generated by discontinuities in the electric properties of the rock. At Stripa the majority of the reflections have been caused by fracture zones.

The borehole geometry has made it necessary to use dipole antennas which make the radar images axially symmetric. Consequently the complete orientation of a fracture plane can not be determined from one borehole. However, by combining results from several holes a unique determination may be obtained. A technique has been developed which is based on representing the possible orientations in a Wulff projection. The technique has been applied at the Crosshole site where the predictions have been shown to agree with observed positions of fracture zones in the drift and in the boreholes.

In the singlehole reflection measurements fracture zones have been observed at distances of 115 m from the borehole at a frequency of 22 MHz (Figure 3-2). If the frequency is increased to 60 MHz the range is roughly halved but the resolution is considerably increased.

Reflections are also observed in crosshole measurements. The reflection geometry is different compared to the singlehole measurements and the data have to be analysed in a different fashion. A new technique has been developed for analysis of crosshole reflection data which in principle allows the orientation of a fracture plane to be determined uniquely if the boreholes are not in the same plane. If the holes are in the same plane there appears an ambiguity between two possible orientations.

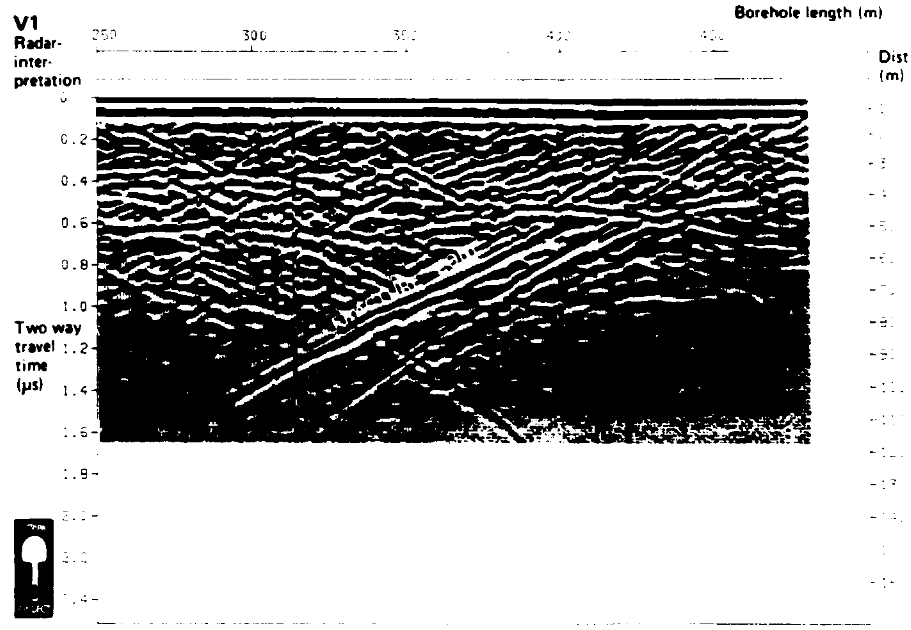

Figure 3-2. Radar reflection map from the borehole V1 measured with a centre frequency of 22 MHz.

In crosshole measurements the travel time and the amplitude of the first arrival have been determined. Tomographic inversion has then been made using both travel times and amplitudes. The measurements were made in such a way as to provide an even distribution of rays in the plane between two boreholes and a high ray density. Six tomographic sections were measured, each containing almost 1500 rays.

The travel time and the amplitude of the first arrival have been extracted by an automatic procedure. The data have been converted to residual travel and amplitudes after integration with borehole coordinate information. The outcome of a tomographic inversion has turned out to be sensitive to errors in the input data, e.g. coordinate errors and offset errors. Procedures have been developed to identify such errors and correct for them.

The tomograms provide a map of the distribution of radar velocity and attenuation in plane sections between the boreholes. A number of features (fracture zones) characterized by low velocity and high attenuation have been identified (Figure 3-3). These features appear in the same locations both in travel time and amplitude tomograms. For intersecting crosshole sections the features appear in the same position at the intersection lines. The consistency of the results is a clear indication that the tomograms represent the physical properties of the rock and not some artifact produced by the equipment or the inversion procedure.

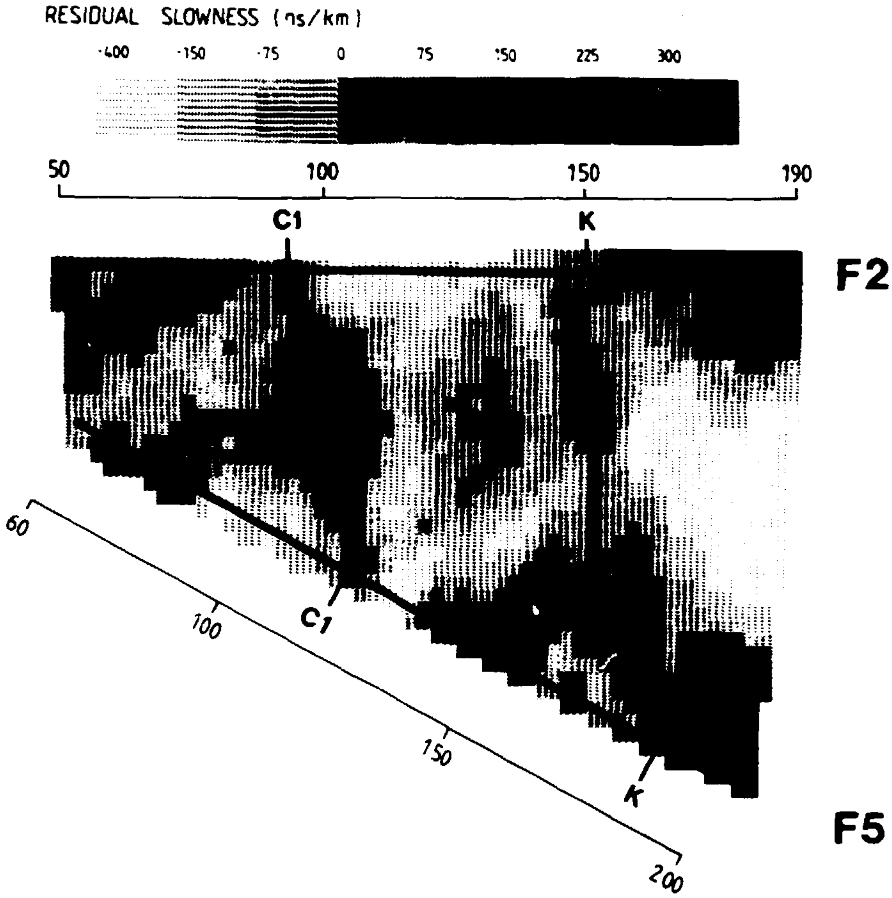

Figure 3-3. Crosshole radar tomography. Slowness distribution of the borehole section F2-F5 based on residual travel time data. Centre frequency 22 MHz.

A three dimensional model describing the geometry of fracture zones has been constructed of the experimental site in the Stripa Mine. The model is based on results from singlehole reflection, crosshole reflection and crosshole tomography. Four major zones have been identified and also some zones of smaller magnitude. The zones are found to be roughly planar but there are undulations from the average plane. Variations in thickness and electrical properties of the zones have also been noticed. The zones identified at the site belong to two different sets with different orientations. The fracture zones within each set have roughly the same orientation.

The development of the radar technique has opened new possibilities for the investigation of crystalline rock. The investigations at Stripa have demonstrated that radar is an efficient instrument for the location and characterization of fracture zones. The radar is unique in that it combines a resolution on the order of meters with investigation ranges on the order of hundreds of meters. The flexibility of the Stripa radar system, which makes it possible to apply the system in three different investigation modes, has made it possible to construct detailed and reliable three dimensional models of these extent and properties of fracture zones. The velocity and attenuation variations directly measured by radar have been shown to be related to the fracturing and water content of the Stripa granite.

3.1.3 Crosshole seismics

The field tests of the crosshole seismics program were completed early 1986. A total of five crosshole sections had then been completed at the Crosshoie site, each containing 300-400 rays.

A substantial part of the program has been devoted to the development of theories of tomographic analysis. Theoretical proofs of uniqueness have been found, showing that with ideal data sets the crosshole method can indeed provide an unambiguous picture of the area under study.

The tomographic analysis is very intensive computationally unless special care is taken. A substantial part of the work during the project has been the development of new fast numerical algorithms for tomographic inversion. A twenty-fold increase in the rate of convergence has been obtained. With the new computer programs it is now possible to analyse a large data set in half an hour on a mini computer.

For the small scale tests at the Crosshole site the tomographic analysis has provided detailed and encouraging results (Figure 3-4). By combining the information from all sections the positions of the identified fracture zones have been defined in three dimensions. The results obtained from P and S waves are in good agreement with each other but the S-wave velocity distributions display a higher noise.

The tomographic technique has been found to be very sensitive to noise in the input data. Especially, the position of the boreholes and the travel times have to be determined with great accuracy. The computer programs have been adapted for identification of different types of errors and for corrections of them.

At the TSG-meeting in March 1986 it was decided to include also an analysis of reflections and tube waves in the seismic program. It was found that the existing data set, which had been optimized for tomographic analysis, could only be used to a limited extent as reflection analysis requires a more dense detector coverage. Nevertheless two reflectors were compared to the existing crosshole model and proved to correlate well.

For the tubewave analysis almost all crosshole seismic data could be used. By comparing results with previous hydraulic tests, it was found that tube wave sources and hydraulically conductive zones are in concordance. All previously defined zones but one could be detected.

VIBROVISION job: F4F5P

GEOSEISMO	:	1986-05-17
Nmb. of rays	:	196
Nmb. of iterations	:	10
RMS error	:	.024623
Mean velocity	:	6139.
Cell size X,Y	:	5.00 5.00

6066 6076 6086 6097 6107 6117 6127 6138 6148

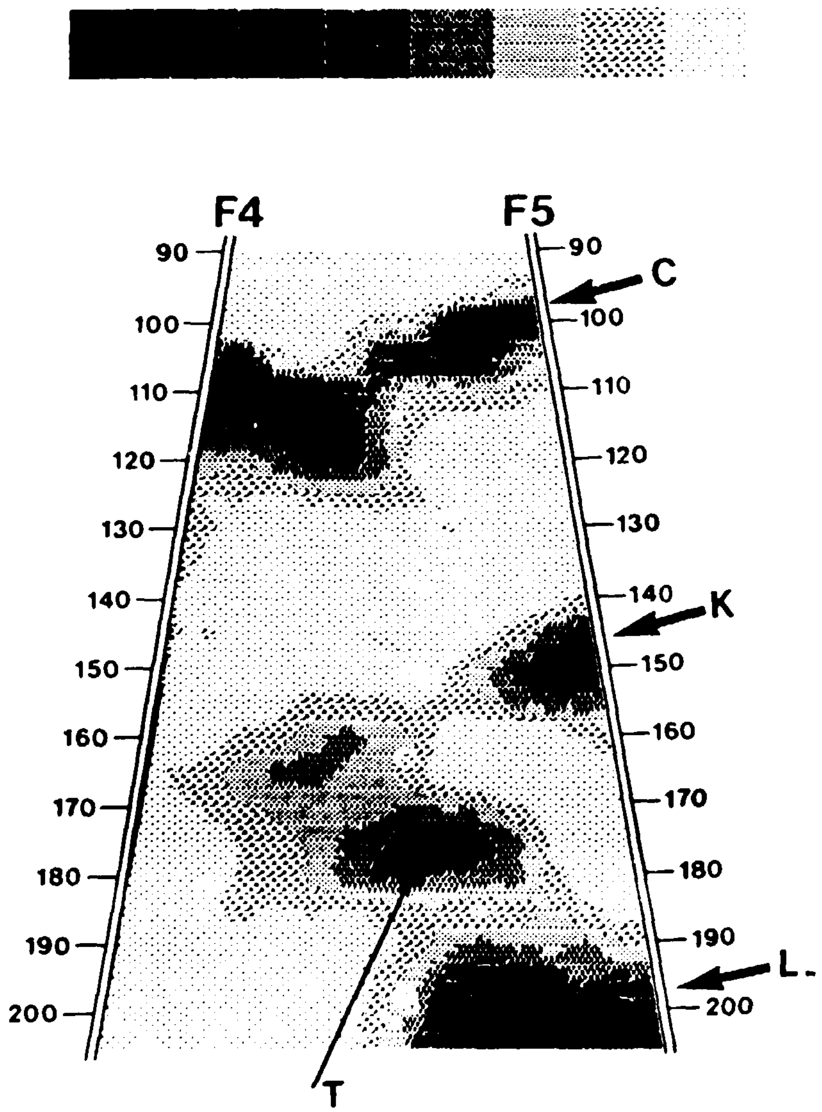

Figure 3-4. Crosshole seismic tomography. Velocity distribution for P-waves in the borehole section F4-F5.

3.1.4 Crosshole Hydraulics

The hydraulics testing programme was completed in January 1986. Since that time, effort has concentrated on the analysis and interpretation of the crosshole sinusoidal testing and the steady state head data. The hydraulics programme incorporates two novel features, namely the use of automatic testing equipment and the employment of a form of testing known as sinusoidal pressure tests.

The automatic equipment consists of a central microcomputer which not only records the data but also controls the test according to a series of instructions provided by the operator. This was designed originally in order to regularly carry out sinusoidal tests but also proved useful for more standard single borehole tests. One major aspect of the control is the ability of the system to sense that flow is leaking into other parts of the borehole around the straddle system and compensate for it. Hence the system has two pumps, on to create the pressure disturbance in the source zone and the other to control the pressure in the rest of the borehole. This has the overall effect of reducing the spread of the source and ensures that the test conditions more closely match the analytical assumptions than would otherwise be the case.

The sinusoidal pressure tests consists of creating a sinusoidally varying flow or pressure in a source zone and monitoring a number of receiver zones for the appearance of the signal. The hydrogeological properties of the rock between the sourc and receiver zones are derived from the attenuation of the peak amplitude and the lag of the signal at the receiver compared to that at the source. Tests can be carried out at a variety of frequencies and detailed information derived concerning the properties of the intervening rock.

Originally it was assumed that some relatively simple models of the hydraulic behaviour of the rock would suffice. Hence interpretation methods based on assuming simple geometries such as radial flow in a single planar fissure or ellipsoidal flow in a regularly fissured porous medium were devised. The results turned out not to fit these models at all well. For the most part signals were arriving too soon at the receiver zones compared to amount of attenuation which was observed. The basic lag and attenuation resulting from the finite dimensions of both receiver and source zones had already been taken into account. A further concept of flow geometry was tried based on flow in pipes. It was found that although it coincided with some aspects of the results, it usually produced a somewhat "extreme" result. It did however show the eventual route to a more adequate analysis procedure based on "fractional dimensions". In this concept the geometry becomes a variable ranging from 1 (i.e. pipe flow) to 3 (i.e. spherical flow). Generally the smaller dimensions would expect to be found at smaller testing scales, with long-term, large-scale tests yielding effectively 3-dimensional flow. Most single borehole tests are interpreted as being 2-dimensional. The result of applying this concept to Zone A is shown in Figure 3-5 which shows the hydraulic diffusivity derived from tests with 24 hour period. The results

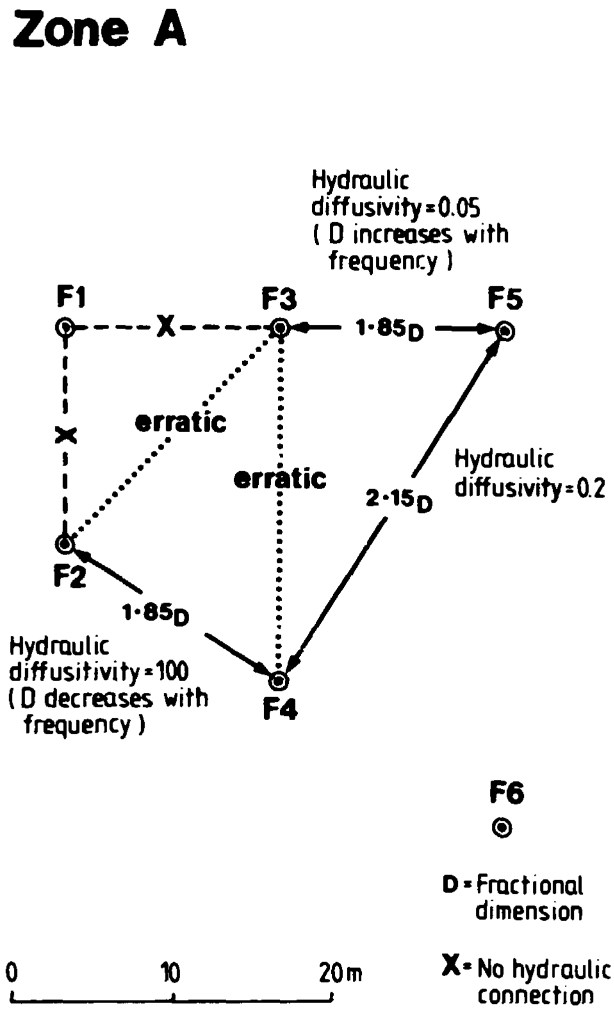

Figure 3-5. Values of hydraulic diffusivity and fractional dimension obtained from crosshole sinusoidal testing in Zone A.

with a dimension less than two imply a channelised system albeit within an identified fracture zone. When all the different hydraulic results are amalgamated for Zones A and C, it appears that where they cut the Crosshole Site they are bifurcating and disappearing. In both zones where crosshole sinusoid were employed quite intensively, it was found that the dimension varied with frequency sometimes rising with increasing frequency and sometimes falling. The meaning of the frequency dependent response has not yet been analysed in detail.

The exact meaning of fractional dimensions has not been evaluated in detail. It appears that sinusoidal tests are particularly sensitive to dimension probably due to the very specific frequencies at which they are carried out compared to the cocktail of frequencies involved in standard hydrogeological tests. However, interpretations of this form seem to present a generalised way of dealing with tests which contain channel networks. Tests on networks are being initiated outside the scope of the Stripa project.

The results of the sinusoidal testing together with those from more standard tests are being interpreted with respect to the basic geometrical model erected by the crosshole geophysics.

3.2 Hydrogeological characterization of the Stripa site Part II

The principal investigator was Professor John Gale, Department of Earth Sciences, Memorial University, St. John's, Nfld, Canada. Charlie Cole and Lance Vail of Batelle Pacific Norhwest Laboratory provided modelling support to this project.

3.2.1 General

This study was initiated in January, 1986, and finalized in March, 1987. Part I of this study was completed in February, 1986, and was published as TR-86-05. Part I consisted primarily of a detailed analysis of the borehole packer test data from the Buffer Mass Test area and the surface boreholes. This study, Part II, is a continuation of Part I.

The objectives of this study were to a) characterize the directional permeabilities of the rock mass in the Buffer Mass Test area at Stripa, b) determine the effective and total fracture porosity distributions based on field and laboratory data and c) determine the three dimensional configuration of the groundwater flow system at Stripa in order to properly interpret the hydrogeological, geochemical and isotopic data from the Stripa site.

3.2.2 Directional Permeabilities

The directional permeabilities of the rock mass in the Buffer Mass Test area were assessed by a) calculating the permeability tensor based on an equivalent porous media approach that combines each fracture intersecting the borehole with the aperture distribution determined from the borehole packer tests and then computing the principal permeabilities and their directions for each borehole and the rock mass, b) generating fracture networks for three orthogonal planes and determining the relative flux rates through these fracture networks for a full range of flow directions and c) measuring the change in flow through natural fractures from the Stripa granite as a function of normal stress under laboratory conditions.

The permeability tensor approach assumes that each fracture is continuous to some flow or pressure boundary. Thus by combining fractures with different orientations, spacings and apertures one can produce a mathematical description of the

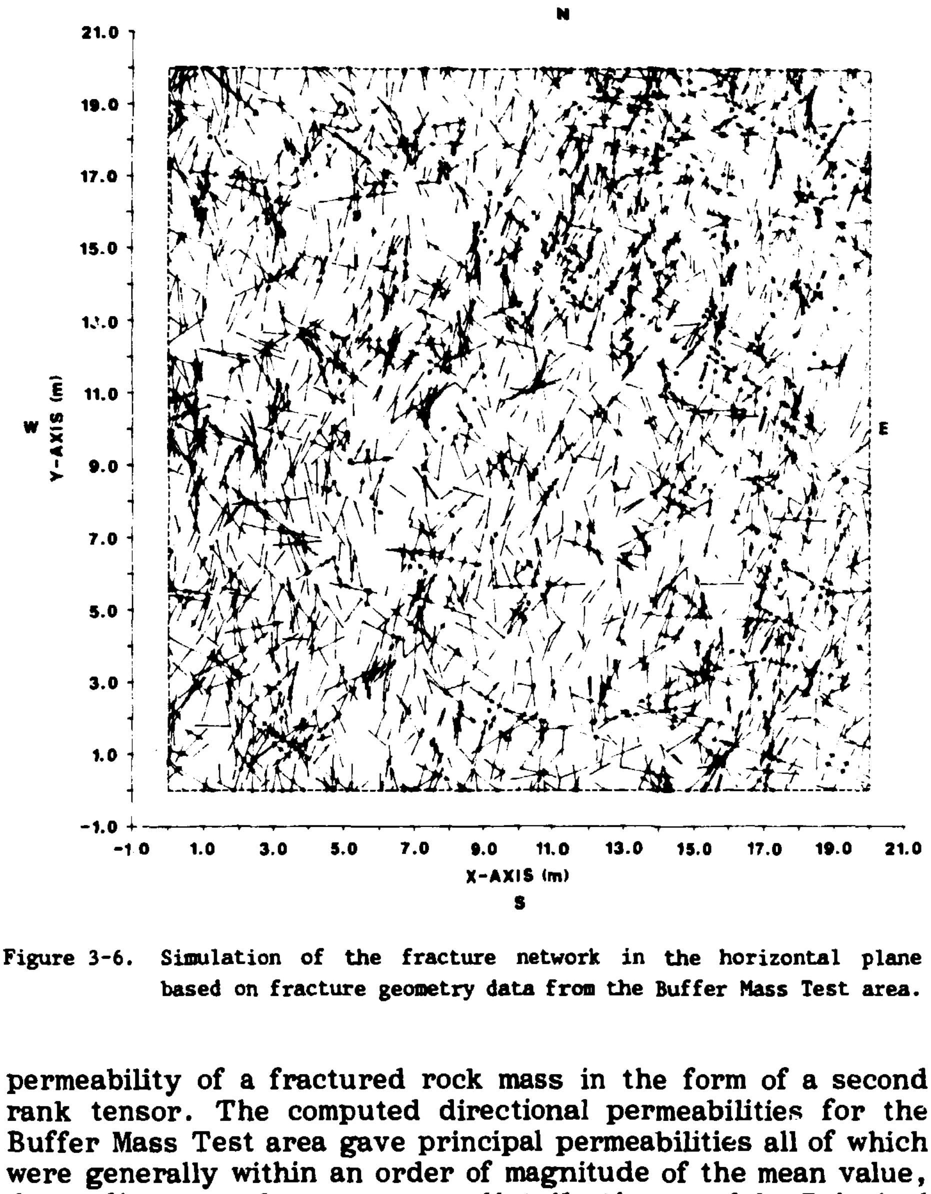

Figure 3-6. Simulation of the fracture network in the horizontal plane based on fracture geometry data from the Buffer Mass Test area.

permeability of a fractured rock mass in the form of a second rank tensor. The computed directional permeabilities for the Buffer Mass Test area gave principal permeabilities all of which were generally within an order of magnitude of the mean value, depending on the aperture distribution model. Principal permeabilities computed for the surface boreholes showed more variation; again the results were dependent on the aperture model used.

The fracture network generator used in this study is described in SKB - Stripa Project Technical Report 86-02. The fracture networks in three orthogonal planes were simulated, based on the measured fracture data (see TR 86-02), each representing an area 20 m by 20 m. The network for the horizontal plane is given in Figure 3-6. Flowrates were computed for each of the two orthogonal directions assuming a uniform fracture aperture. The mesh was then rotated in 15 degree increments and the flowrates recalculated to give a measure of the relative anisotropy to flow due to the fracture geometry. The relative flowrates, normalized to 5.0E-10 m^3/sec,

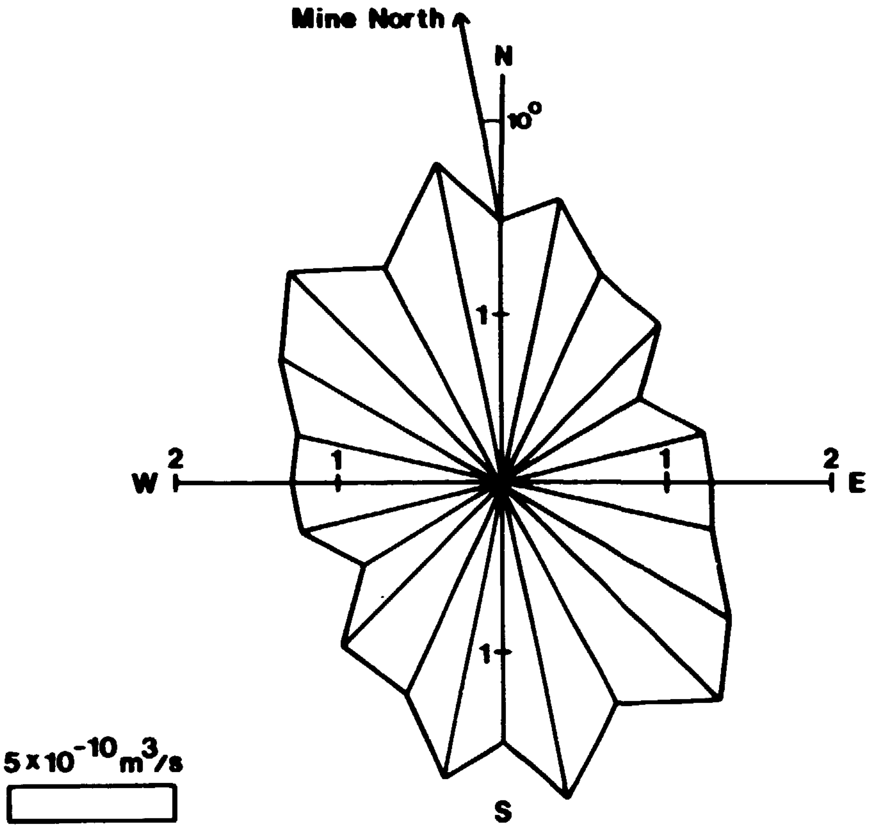

Figure 3-7. Relative flowrates for different directions of flow through the fracture network in Figure 3-6.

are plotted in Figure 3-7 and indicate an anisotropy to flow of a factor of two with the principal direction oriented NW-SE. Similar degrees of anisotropy were determined for the two vertical planes, of anisotropy were determined for the two vertical planes, the N-S and W-E planes, with the N-S plane having much lower fracture interconnection and hence lower overall flowrates.

Anisotropy to flow in the vertical direction must exist, since in-situ stresses increase with depth and we have measured a decrease in fracture permeability with increase in normal stress in the four samples containing natural fractures that were tested in the laboratory. In addition this dependency of fracture permeability on normal stress must produce significant anisotropy to flow in the horizontal plane, given the measured in-situ stress anisotropy, and hence must be superimposed on the directional permeabilities produced by the fracture geometry.

3.2.3 Porosity

One of the major problems in fracture hydrology is to determine the volume of pore space that controls fluid movement and how this pore space is distributed. This includes not only the "effective" or flow porosity but all fracture openings whether they contribute to the flow process or not, i.e. the total porosity.

The total and flow porosities of single fractures from Stripa have been determined in the laboratory using a resin impregnation technique Figure 3-8 shows the distribution of fracture apertures determined along a number of cross-sections through sample STR-2. The resin, injected while the fracture was under a given normal stress, has a mean thickness of 0.267 mm with a standard deviation of 2.92 mm and is thought to represent that part of the fracture plane that forms the flow porosity for this fracture. The total aperture has a mean value of 0.446 mm and a standard deviation of 2.64 mm. Both the resin thickness and the total aperture appear to be log-normally distributed and when combined with average fracture spacings give porosity values substantially higher than expected.

A second attempt at calculating the effective and total porosities consisted of combining the aperture data from both the field packer tests and the laboratory studies with the mean total porosities from 0.001 to 0.0001.

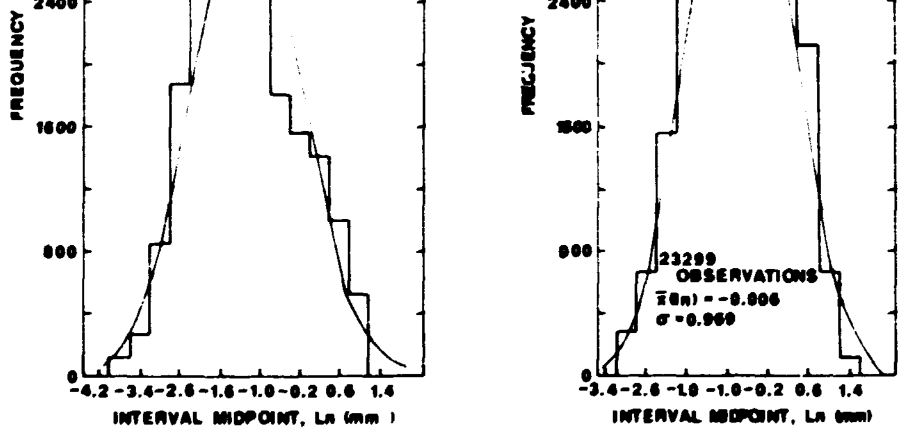

Figure 3-8. Frequency histograms for the natural logarithm of A) resin thickness and B) total aperture in mm for sample STR-2.

3.2.4 Flow System Analysis

The flow system analysis was conducted on two scales. The regional model (Figure 3-9) includes an area, defined by surface water drainage boundaries, of about 9 km by 12 km. The sub-model region (Figure 3-10) includes an area of about 4 km by 4 km centered on the Stripa mine. Each figure shows the distribution of lakes and fracture zones. The basic geology

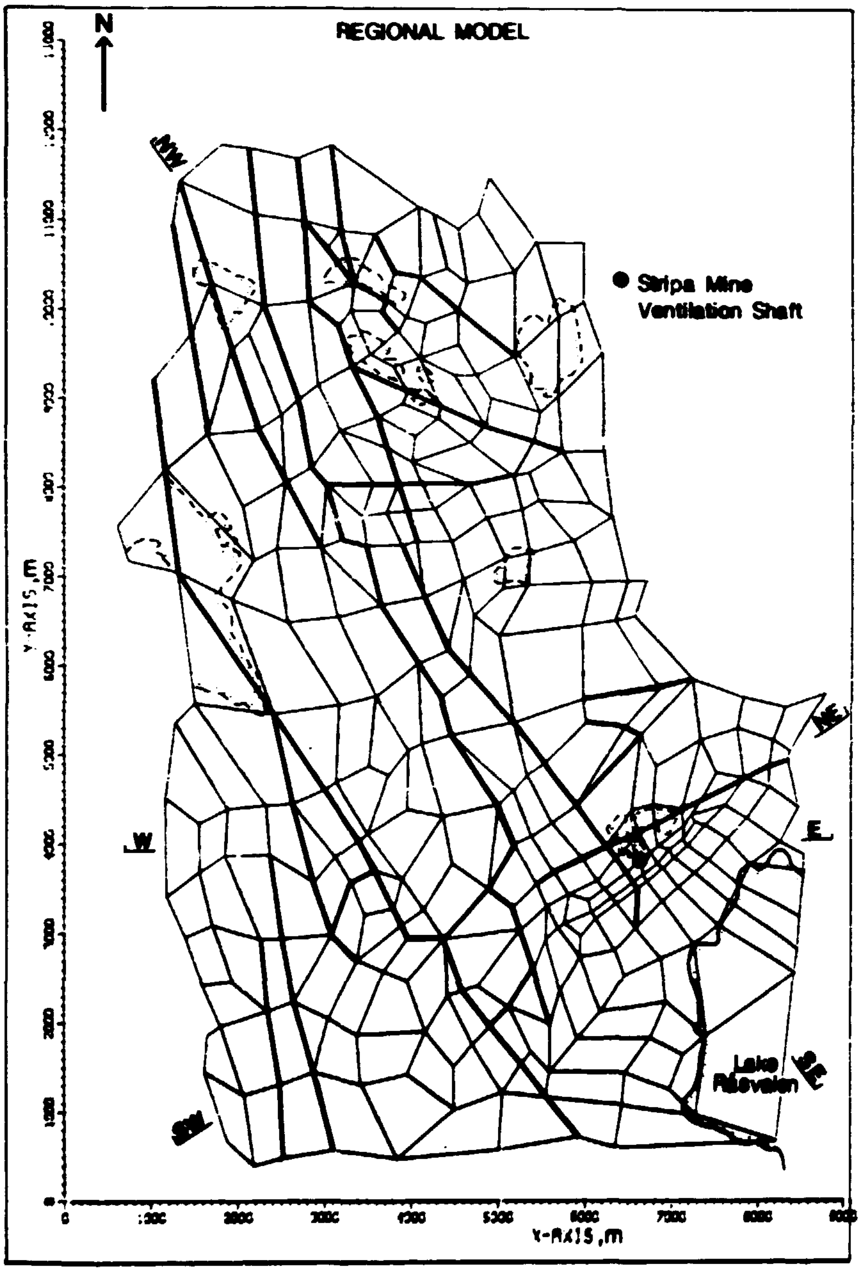

Figure 3-9. Finite element mesh for the regional model showing the location of the major lakes, fracture zones and the location of referenced cross-sections.

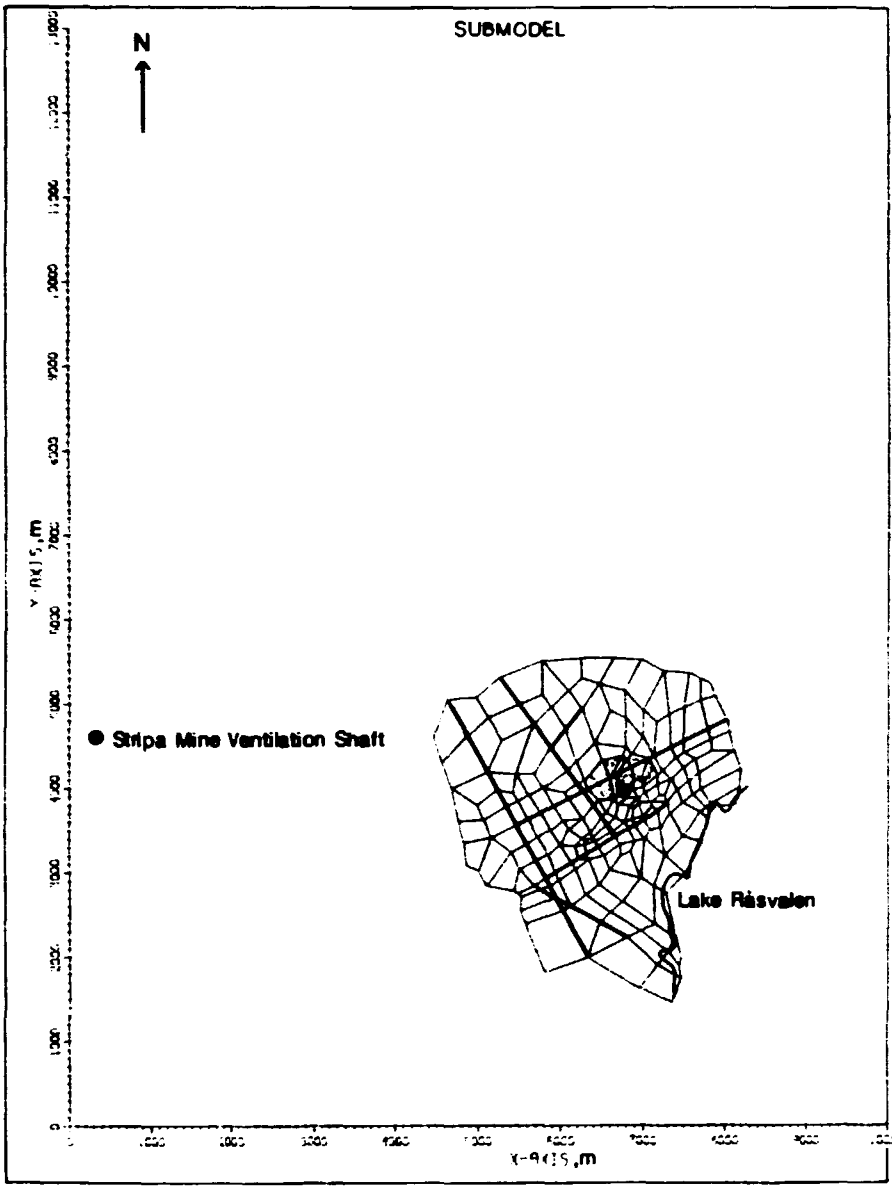

Figure 3-10. Finite element mesh for the sub-regional model showing the mine tailings pond and fracture zones.

consisting of granite, leptite, metasediments and the two sets of major fracture zones were incorporated in each model. The regional model was first analyzed as a 7 layer case extending to 5000 m and then as a 5 layer case extending to 3000 m. The sub-model was divided into 12 layers, extending to about 3000 meters with the hydraulic head boundary conditions being obtained from the regional model. The permeability and porosity input parameters for each model were developed by averaging the existing data base from Stripa and using the mine discharge rates to provide a constraining boundary condition. The water table was developed from the lake levels and by fitting a smoothed surface to the surface topography.

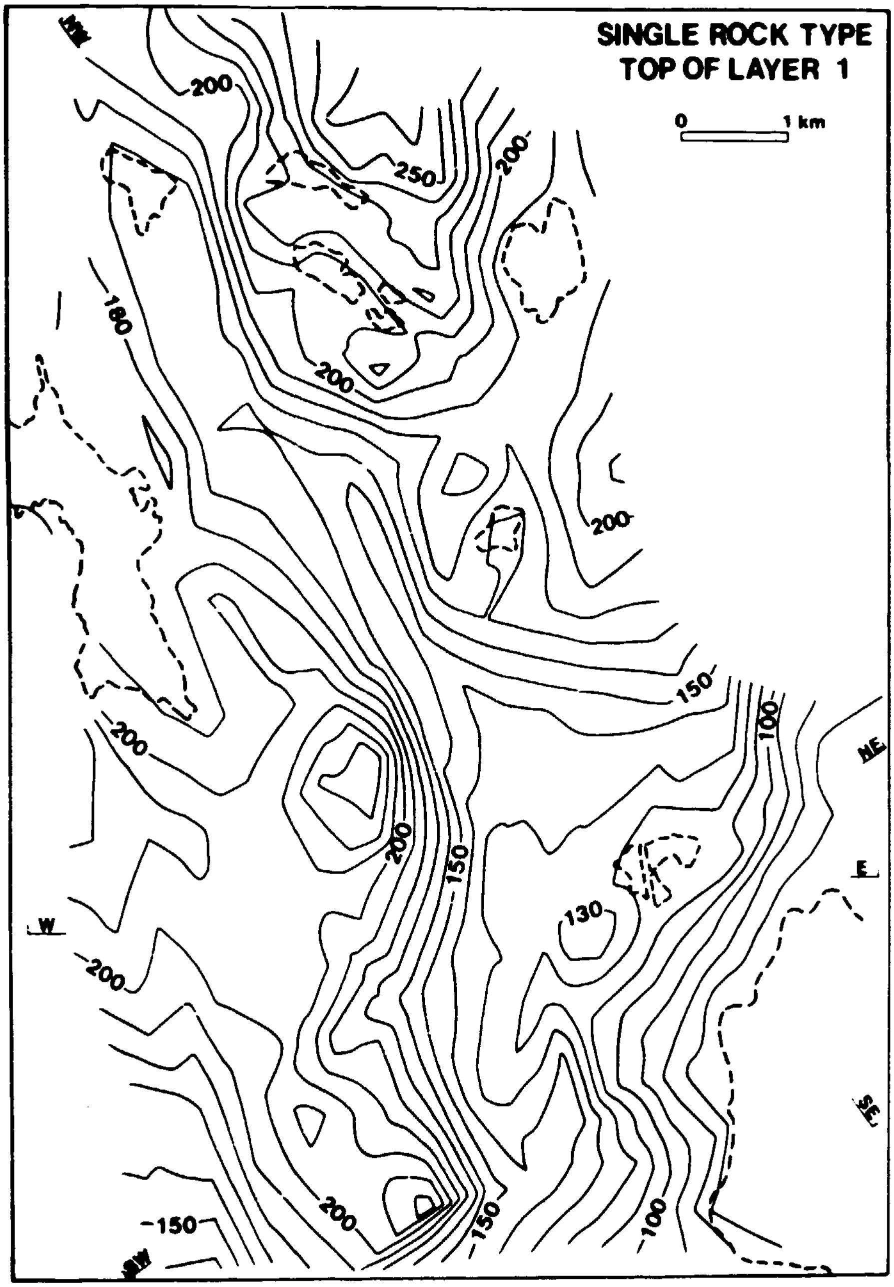

Figure 3-11. Contour map of the hydraulic head distribution on the top of the layer 1 (water table), regional model.

Figure 3-11 shows the distribution of hydraulic heads at the top of layer 1 in the regional model. This represents a contoured map of the water table. In this particular model the same permeability and porosity is used in each layer including the fracture zones. In addition the same relationship between permeability and porosity with depth was used to assign flow properties to the different layers in the model. This uniform geology case resulted in a smoothing of the hydraulic head contours with depth as is evidenced by the hydraulic head contours at the top of layer 6 (Figure 3-12) which is located about 600 m below sea level.

The three-dimensional numerical model gave mine inflows of about 75 to 100 l/min when a single hydraulic conductivity of 1.0E-09 m/s was used for all rock types and all layers. Using hydraulic conductivity averages that approximated the geometric mean of the permeabilities and the depth-permeability relationships observed in the three surface boreholes gave mine inflows

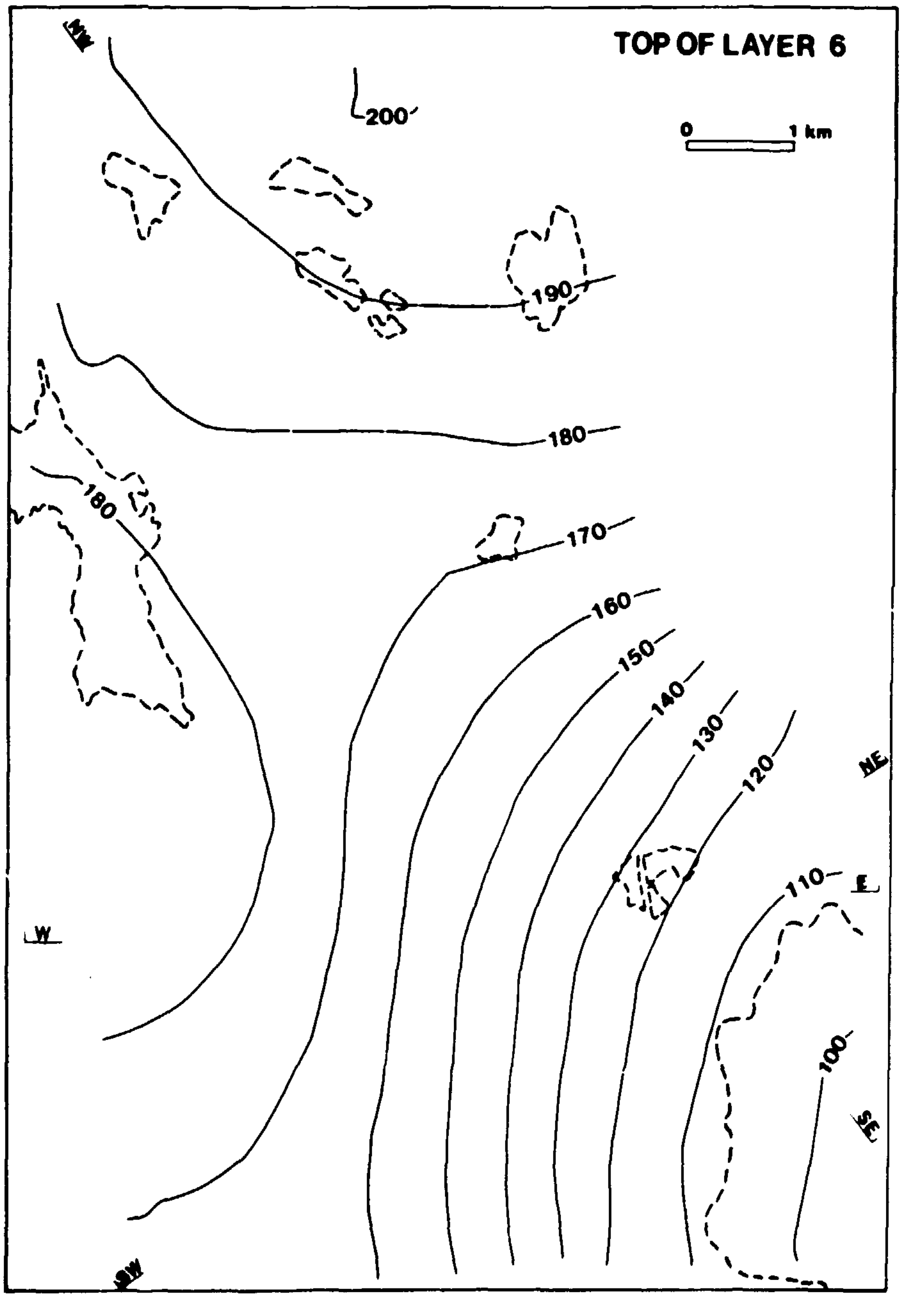

Figure 3-12. Contour map of the hydraulic head distribution on the top of layer 6, regional model.

of about 500 l/min which closely approximates the average discharge from the mine. Transit times predicted from the flow tube calculations were much shorter than predicted from the existing geochemical and isotopic data for the range of porosities and permeabilities used in the flow model calculations. The effects of the dewatering produced by the excavation of the mine on the hydraulic head distribution and hence the flowlines are shown by the cross-sections in Figures 3-13 and 3-14. The zone of low hydraulic head in the middle of both cross-sections is due to the presence of several large fracture zones that have been assigned permeabilities that are from 0.5 to 1.0 order of magnitude greater than those assigned to the adjoining rock mass.

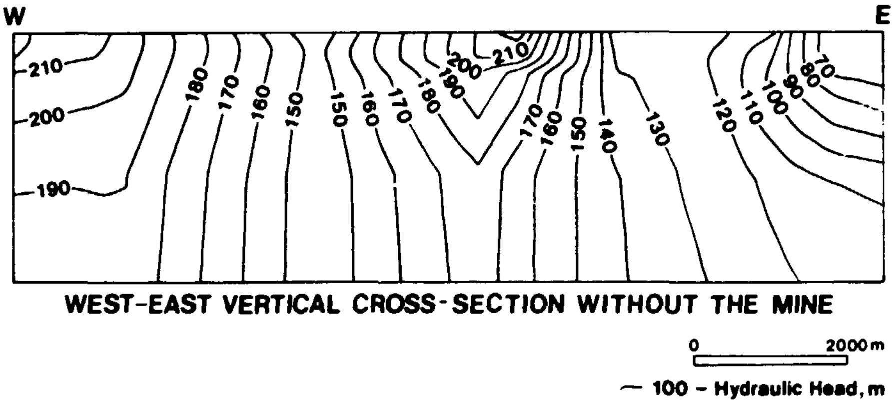

Figure 3-13. A west to east vertical cross-section (see Figure 3-9 for location) showing the distribution ot hydraulic heads for the 3-D model with fracture zones but without simulating the effects of the mine.

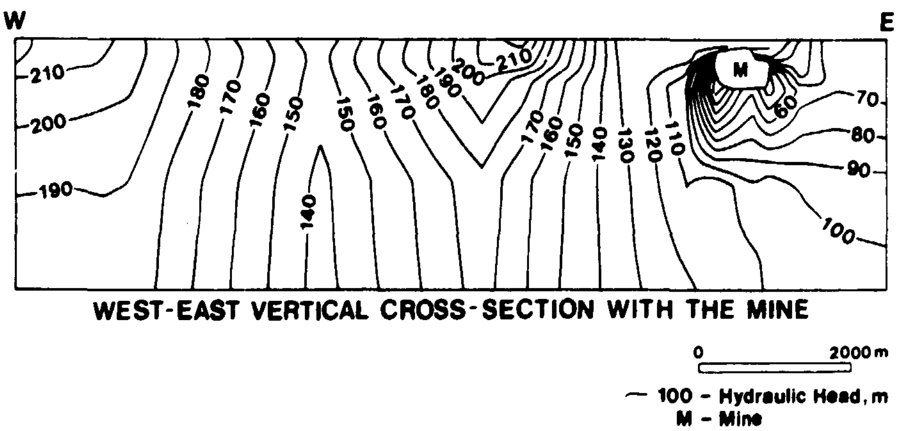

Figure 3-14. The same cross-section as shown in Figure 3-13 but including the dewatering effects produced by the mine on the hydraulic head distribution.

3.3 Three-dimensional migration experiment

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

3.3.1 General

The general objectives of the experiment are to:

* study longitudinal and transverse dispersion in fissured rock.

* determine flow porosity.

* study channelling.

* obtain data for model verification and/or modification.

* develop techniques for large scale tracer experiments in low permeability fissured rock.

3.3.2 Experimental Design

Since the object is to study migration flow paths over distances up to 50 m, the effects of adjacent hydraulic sinks such as drifts and boreholes can be large. Due to this, the test site was excavated in an "undisturbed" but geologically well known part of the mine, see Figure 3-15.

The upper part of the test site has been covered with plastic sheets, each sheet with an area of ~ 2 m^2, see Figure 3-16.

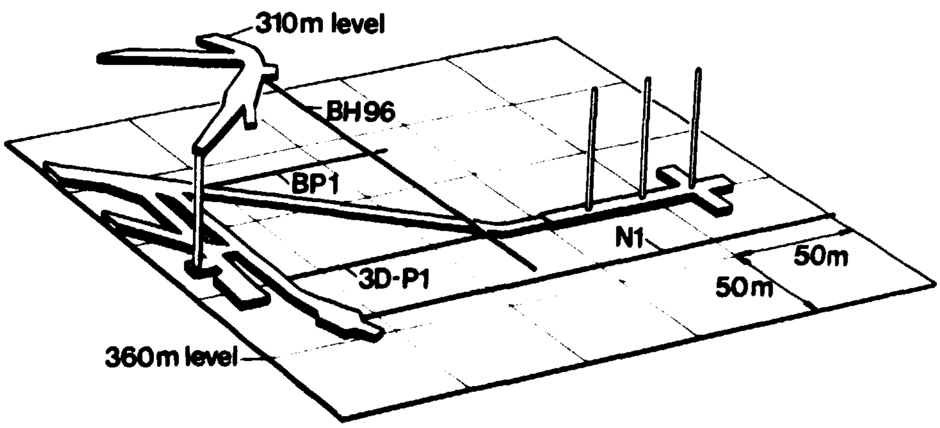

Figure 3-15. Location of the 3-D test site within the Stripa Mine.

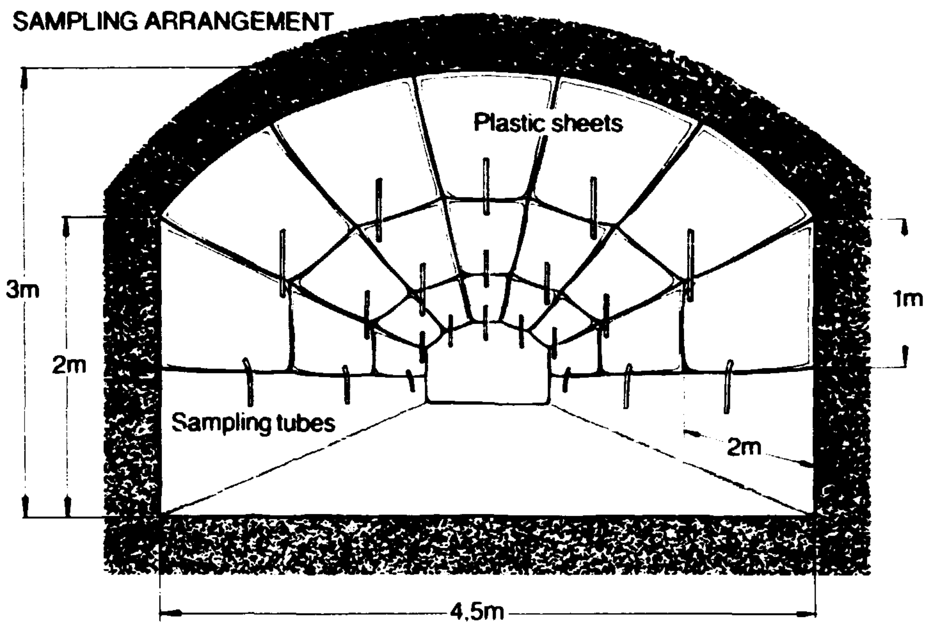

Figure 3-16. Sampling arrangement in the 3-D test site.

A total number of about 350 sheets serves as sampling areas for water emerging in the upper part of the test site. This sampling arrangement completely covers an area of ~ 700 m^2. When sampling over an area and not just at distinct points, the spatial distribution of water flow paths can be obtained. The layout of the test site as a cross increases the resolution of the three-dimensional distribution of the tracers in that part of the test site.

Water inflow monitoring started directly after the covering of the upper part of the test site. A compilation of the results is given in Figure 3-17. From Figure 3-17 it can be clearly seen that water does not flow uniformly in the rock over the scale considered (~ 700 m^2), but seems to be localized to wet areas with large dry areas in between. Measurable amounts of water emerge into just one third of the 350 sampling areas. 10 % of these "wet" sampling areas give more than 50 % of the total water inflow. The total measured water inflow rate was ~ 700 ml/h.

From the test site which has a total length of 100 m, three vertical holes (length 70 m) were drilled. Within these three holes, 9 different injection zones (each 2.5 m in length) were located. The location of the injection zones within the holes were based on the results from inflow measurements over 2 m sections as well as radar measurements. The space between the injection zones were sealed off with compacted bentonite.

Table 3-1 gives the locations of the injection zones, injected tracer and if the tracer has emerged into the test site.

The tracers were continuously injected during 20 months using a small over-pressure. The total injection inflow rates were ~ 10 % of the total water inflow rate into the upper part of the test site.

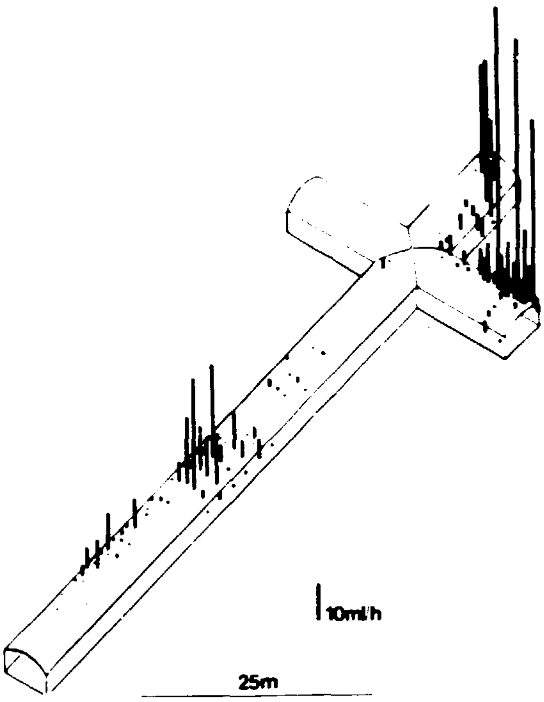

Figure 3-17. Water inflow rates into the upper part of the drift.

Table 3-1. Location of injection zones and used tracers.

Hole	Level (m)	Tracer	Emerged
I	31-33	Uranin [1], STR-7 [2], F^-	Uranin
	17-19	Eosin yellowish [1]	Yes
II	55-57	Phloxine B [1]	No
	33-35	Rose Bengal [1]	No
	9-11	Elbenyl Br. Fl. [1]	Yes
III	36-38	Duasyn Acid Gr. [1]	Yes
	28-30	Iodide	Yes
	18-20	Eosin bluish [1]	Yes
	12-14	Bromide	Yes

1) Dyes, molecular weight ~ 200 - 500
2) Large Molecular tracer ~ 15000

Before injection, all 11 tracers were tested in the laboratory and found to be stable with time and "non-sorbing" on crushed granite as well as on the materials used in the equipment. Of these 11 tracers, all conservative, 7 were dyes, 3 were salts and the last one was a large molecular weight tracer. The 7 dyes were selected based on tests of ~ 100 different dyes.

From the most water conductive sampling areas (65 areas) water samples were taken every 16 hour. Samples were also taken from another 80 places, such as sampling areas with low water flow rates, wet spots on the floor, adjacent boreholes and drifts. The time intervals between samples from these places were 1-5 weeks, depending on the water flow rates. The water sampling continued 6 months after the end of injection.

3.3.3 Results

Of the 11 injected tracers, 7 have reached test site within the time of the experiment. Out of 145 water bearing sampling areas, tracers have emerged in ~ 60. The tracers injected close to the right arm of the cross, which is the wettest area in the test site, did not appear there, but emerged 30 m away, in the middle part of the long drift, see Figure 3-18. In some sampling sheets in this part of the test site, all 7 tracers appear. The first appearance of tracers was after 3 weeks. The last of the 7 tracers to appear (Duasyn) emerged after about 20 months. This appearance coincided with the work done (excavations and drillings) in preparation for the Stripa Project Phase 3.

The obtained breakthrough curves are evaluated using the Advection-Dispersion-Matrix diffusion model, which gives the mean residence time, Pe number (Longitudinal dispersion), interaction with the rock matrix (diffusion into the porous matrix) and the dilution factor.

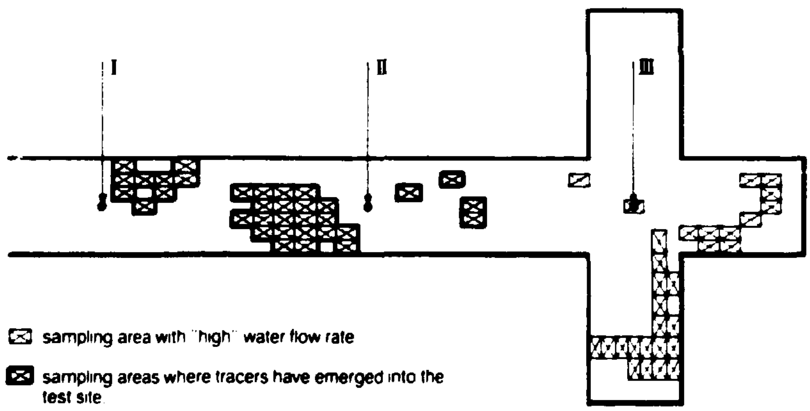

Figure 3-18. Tracer distribution.

3.3.4 Summary at a glance

* 9 different injection zones
* 11 different tracers
* Deepest injection zone 55 mm
* Closest injection zone 9 m
* Continuous injection for 20 months
* Water sampling 20 months + 6 months after end of injection
* Water found in 1/3 of the 350 sampling sheets
* Total flow to the sampling sheets ~ 700 ml/h
* Tracers found in 65 out of 145 wet sampling points
* First arrival 3 weeks after start of injection
* Latest arrival 20 months after start of injection
* 7 out of 11 injected tracers have emerged at the test site

3.4 Borehole, shaft and tunnel sealing

3.4.1 General

The field activities were finished in 1986, the last part being the excavation of the tunnel plug for comprehensive clay sampling. This gave a true picture of the distribution of absorbed water in the bentonite clay and of the clay/rock interaction, by which the sealing function of the plug became fully understood.

All three tests, i.e. the borehole, shaft, and tunnel sealing tests were evaluated and reported in the course of 1986, a brief summary being given in the subsequent text.

3.4.2 Scope of tests

The general objective of the tests was to investigate the sealing power of highly compacted sodium bentonite. The clay was applied in the form of dense blocks of compacted commercial MX-80 powder, the major item being to measure how fast the clay absorbed water and swelled to form tight plugs.

3.4.3 Borehole plugging test

The Borehole Plugging Experiment comprised three field tests, in which the function and practicality in handling and application of such plugs were tested under real conditions. The design principle was that cylindrical blocks of compacted clay powder were contained in perforated casings of copper. After insertion in the boreholes, which were water-filled from the start, the clay was expected to absorb water and swell out through the perforation. Laboratory tests and pilot field tests had indicated that the expansion of the clay leads to complete embedding of the casing if there is sufficient access to water (Figure 3-19). The main purpose of the field tests was to investigate the rate and uniformity of the water uptake.

The plugging of a 100 m long, 56 mm diameter, almost horizontal borehole demonstrated the practicality of this plugging technique also in very long holes and this test also showed that the maturation of the plugs was sufficiently fast to resist piping or distortion by high hydraulic gradients already after about one week. The uniformity of the water content of a recovered section was determined after about 2,5 years and it was found to be very high. The clay was completely water saturated despite the large variation in fracture frequency of the rock, which indicates that water had passed through frequent fine fissures in the confining rock, leading to uniform uptake over the entire clay/rock interface.

The same observation was made in the testing of two 14 m long 76 mm diameter holes with plugs that were equipped with soil pressure and pore pressure cells for recording the successive build-up of internal pressures. The latter two plugs, which had different porosities of their casings, were extruded from their holes at the end of the tests for determination of the bond strength. The required force to extrude each of the 4 m long plugs was 8-10 tons, corresponding to a bond strength of about 100 kPa. Expressing this shear resistance as the product of the swelling pressure and the angle of wall friction, the latter turns out to be about 10^{o}. The last-mentioned plugs had matured for slightly less than one year.

Figure 3-19.

Example of extruded, matured borehole plug. Bentonite has expanded through the perforation of the casing and formed a largely uniform "skin" between the casing and the borehole. Part of this skin has been removed here to show the uniform, dense character of the clay that had passed through the perforation.

3.4.4 Shaft plugging test

The Shaft Plugging Test comprised determination of the sealing effect of sodium bentonite by comparing it with expansive concrete. This was made by first conducting a reference test in a 14 m long and 1-1.3 m diameter shaft, with two concrete plugs separated by a sand-filled injection chamber, and then running a main test in which the concrete was replaced by blocks of highly compacted sodium bentonite.

The rock structure was carefully investigated in order to identify major potential passage-ways for the injected water and both tests confirmed that some of the identified structures discharged water from the injection chamber. Most of the outflow took place along the plug/rock interface in the reference test, while this contact turned out to be perfectly tight in the main test. This gave largely different outflow rates: about 8 litres per hour in the reference test and only a few per cent of this value when the clay plugs were in position and had partly matured.

The swelling pressure was measured in the test and values of up to about 3 MPa were recorded indicating that the clay interacted strongly with the surrounding rock. This must have contributed to the sealing effect by tending to close some of the water-bearing structures, although this effect was less important than the elimination of water flow along the rock/plug interface by the development of an impervious clay-infiltrated rock matrix at the interface.

A comprehensive determination of the water uptake was made at the end of the field test. It demonstrated that the general model of diffusion-type migration of water applied well to the part of the clay that was furnished with water from the pressurized sand fill. However, the water uptake appeared to have been retarded locally at the rock/clay interface, which was obviously related to a limited access to water in certain, fracture-poor parts. It was concluded that this was due to the low water pressures at the test site, which had been drained for a long time before the test began. The injection pressures were also too low to drive water through finer fractures and fissures to the shaft.

3.4.5 Tunnel plugging test

The test arrangement consisted of a 9 m long and 1.5 m diameter steel tube, surrounded by sand and cast in concrete plugs at each end. These plugs contained bentonite blocks arranged in the form of "O-ring" sealings at the rock/concrete interface (Figure 3-20). This simulated a temporary sealing of a water-bearing rock zone penetrated by a repository tunnel, allowing for transports through the plug construction while minimizing the water inflow into the tunnel. The water pressure in the sand fill was raised to 3 MPa in the course of the test and the associated inflow and leakage were accurately measured by flow meters and by collecting water that leaked

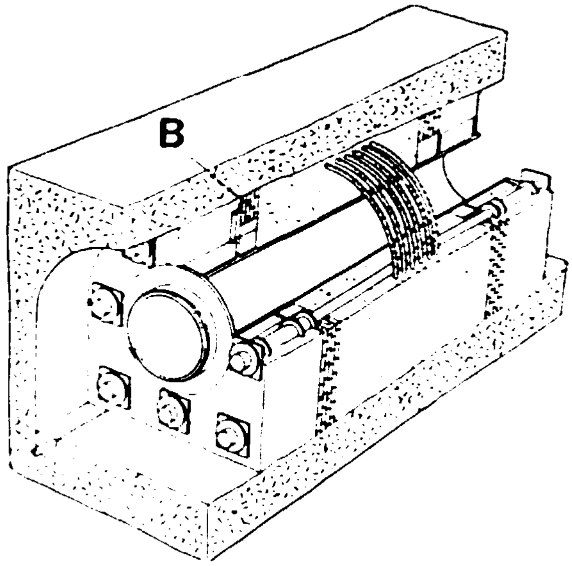

Figure 3-20. General view of the test arrangement with the central steel casing and tie-rods passing through the concrete plugs with bentonite sealings (B) at the ends and the sand-filled chamber. The latter simulated a richly water-bearing rock zone.

from the plug. The swelling pressure exerted on the rock and on the sand by the expanding bentonite was measured by Gloetzl cells, and the deformation and displacement of the plug components recorded by use of extensometers.

The predicted outflow from the sand-filled injection chamber was about 1000 l/hour if no bentonite sealings had been applied, and 60-600 l/hour at 3 MPa water pressure at the end of the test with the tested, bentonite-equipped plug construction.

The actual leakage turned out to be about 200 l/hour at 100 kPa water pressure early in the test but it dropped successively in the course of the test and became 75 l/hour at 3 MPa pressure at the end of the about 20 months long test. During the 3 MPa pressure period, which lasted for about 10 months, the leakage dropped from about 200 l/hours to 75 l/hours (Figure 3-21) and this very significant reduction was found to be caused by three effects. The major one was the establishment of a very tight contact between the rock and the bentonite, while the flow-reducing influence of the swelling pressure on certain rock fractures and the penetration of bentonite into certain wider fractures were less important but still of some significance.

It was expected that some erosion of the bentonite would take place in the early part of the test when the flow rate of leaking water along the rock/clay contact was very high. No such effect appeared, however. The physical stability of the bentonite and its excellent sealing efficiency over long periods of time were thereby demonstrated.

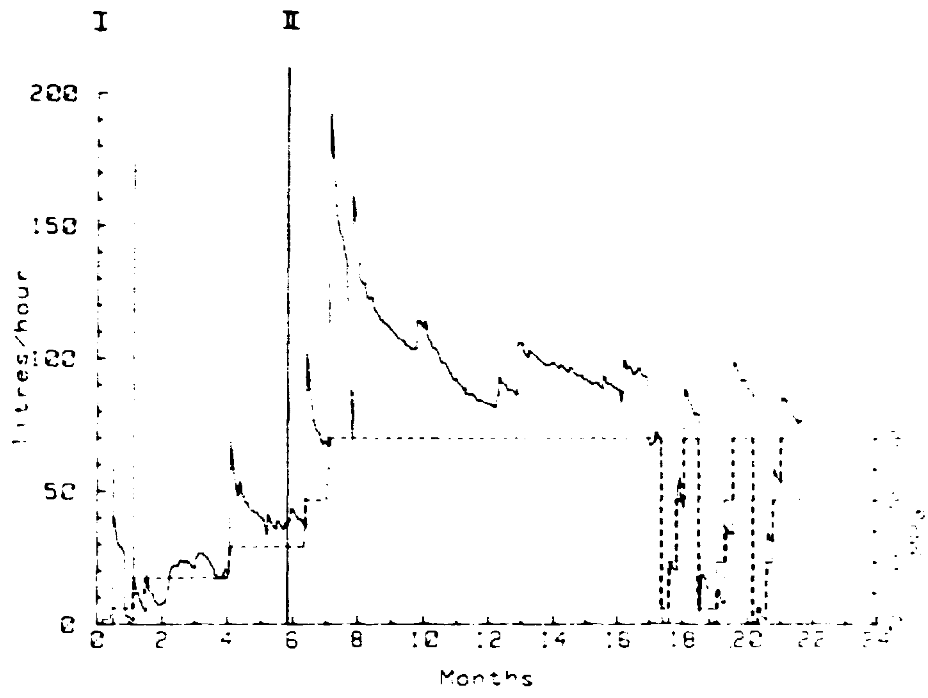

Figure 3-21. Leakage of injected water.

3.5 Hydrogeochemical charaterization of the Stripa groundwaters

3.5.1 General

The overall purpose of the hydrochemical 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 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.

3.5.2 Sampling program during Phase 2

In late 1984 a packer system was constructed to obtain separate discharges from five fracture zones in the V2 borehole (at depths from surface of 800 m - 1230 m). Each interval was about 8 meters in length except for the bottom of the hole which was sampled over a 263 m interval due to low discharges of only 10-15 ml/min. Water samples were also collected from the bottom 75 meters of the V1 borehole and from the M3 borehole. Samples were collected in November, 1984, for organic fractionation analysis, chlorine-36, chlorine-37/35 and iodine-129. Beginning in May, 1985, a regular sampling program was operated to collect samples for major ions, tritium and O-18/16 and H-2/1 every one to three months. Additional samples were collected as possible for other stable and radioactive isotopes. All sampling tubing in the V2 borehole was made of nylon except the first (most shallow) interval which was teflon tubing. Water was allowed to discharge freely without interruption. This sampling program ended with the April, 1986, sample collection. In September, 1986, the packer system was rearranged to only sample three zones in the V2 borehole every three months but using teflon tubing throughout because of the problem with organic leachates contaminating samples for organic fractionation analysis.

3.5.3 Water chemistry

Major ion concentrations for V1 and V2 water samples have remained nearly constant since May, 1985. The M3 water chemistry, however, appears to have leveled out after eight years of a steadily decreasing total solute concentrations following the heater experiment perturbations of 1978. Any chemical changes resulting from the recent heater experiments starting in early fall, 1986, have not been noticed but this may be due to shut-down of the flow.

Equilibrium computations using WATEQ4F and time series plots of individual parameters have provided valuable information on the sensitivity of computational results (such as saturation indices) to errors in field measurements and in analytical accuracy and precision. Saturation to supersaturation with respect to calcite, fluorite, barite and ferric hydroxide is still maintained for all intermediate to deep groundwaters. All waters are slightly oxidizing except for the bottom drainage in V2 which continues to give about 1 mg/L dissolved sulfide. This value is the highest concentration of sulfide yet found anywhere at Stripa. On the basis of total concentration and ion ratios the water discharging into section V2:4 (at 810-818 m depth) appears to be most similar to the V1 deep groundwater. The slightly higher tritium content and the lower chloride content of the V1 water would suggest that either (1) a larger amount of a younger water is mixing into the V1 fracture zone than at V2:4 or that (2) the water flows from V1 to V2:4 through such a tortuous route that it loses tritium by decay and gains chloride by rock leaching (from fluid inclusions). The Cl-36/Cl and I-229/I ratios are also very similar for these two samples which supports the idea of hydraulic connection.

3.5.4 Oxygen-18, deuterium and tritium

Analyses for H-2/H-1, O-18/O-16 and tritium show that groundwaters at Stripa are of meteoric origin and not affected by secondary isotope effects (evaporation or isotopic exchange). Deep groundwaters have lower O-18 and H-2 contents than recent, shallow groundwaters. If the deep waters have a local origin, then the differences in heavy isotope contents could indicate infiltration during cooler climatic conditions, possibly before the beginning of the Holocene. However, if regional flow systems exist, then the difference could be explained by altitude effects and the mean residence time of the deep groundwaters could be much shorter.

The lowest O-18 values correspond to the waters with the higher chloride (and major solute) concentrations although there is little change in O-18 for a wide range of chloride. The presence of young groundwaters down to the 300 m level of the mine is evident by the tritium content of the groundwaters. Low but detectable tritium in V1 and sections of V2 may be either subsurface production or a mixture of old groundwater with small amounts of much younger water (<35 years).

3.5.5 Sulfur-34 and oxygen-18 in dissolved sulphate

Sulfur-34 and oxygen-18 in dissolved sulphate indicates that bacterial sulphate reduction is an important process in the deep groundwaters. The original sulphate (prior to reduction) could be a brine from either a sedimentary origin or crystalline rock origin.

3.5.6 Carbon geochemistry

The carbon isotopes indicate that there are both organic and inorganic sources of carbon in the deep ground waters. Calcite dissolution and precipitation is the dominant inorganic source and dissolved organic carbon participating in bacterial sulphate reduction is the likely organic source. Organic fractionation analyses have been greatly hindered by the contamination from an organic filler. N-butylbenzenesulfonamide leaching from the nylon sampling line has contributed 50-100 percent of the DOC in the groundwaters. True DOC concentrations in Stripa groundwaters appear to be about 0.2 mg/L based on the DOC found from the teflon sampling tubing. Natural organics include long chain fatty acids, fulvic acid and cyclic hydrocarbons of low molecular weight The C-14 values for the DOC are generally lower than that for the DIC. Two alternative hypotheses are offered for this difference: either subsurface production increasing the DIC-14 or mixing of dead carbon with young carbon to reduce the DOC-14.

3.5.7 Natural radioelements

Uranium concentrations and U-234/U-238 activity ratios reflect active leaching at shallow depths plus enhanced U-234 by alpha-recoil at the 300-400 m level. Deeper groundwaters reflect the more reduced redox conditions and estimated residence times from alpha-recoil aided ingrowth of U-234 indicate less than 20 000 years.

Estimates of fracture widths deduced from Rn-222 contents range from 20-300 micrometers which would allow penetration of shallow groundwaters to the deepest boreholes within short time periods (tens of years). Mean residence times of natural actinides are very short (hours to days) indicating considerable retardation under current conditions. However, Ra-226 correlates strongly with salinity and suggests that the fission product Sr-90 could be very mobile in the more saline groundwaters.

3.5.8 In-situ production of radioisotopes

The neutron flux has been calculated and measured in the Stripa granite and the agreement is quite good (±15%). Estimated groundwater concentrations for in-situ produced tritium and C-14 are close to the present detection limits. Measurements of Cl-36 have proven useful in determining the origin of the chloride in the groundwaters but they are not definitive for age dating the groundwater. The Cl-36 results demonstrate that a substantial portion of the chloride must be coming from outside the granite and from a relatively low radioactive environment. Results from I-129 measurements reflect a considerable amount of subsurface production by spontaneous fission of U-238 but secular equilibrium has not been reached. In-situ production of Ar-39 reflects loss from potassium sites (feldspars and micas) whereas Ar-37 production reflects loss from calcite fracture-fill minerals. Kr-85 production occurs at uranium sites in both fracture-fill minerals and microfractures in the rock matrix. Although age dating is not possible with most of these radioisotopes, the results do lead to a better understanding of the mechanisms for their release into the groundwaters.

3.6 Economy

The total cost of the Stripa Project Phase 2 as of December 31, 1986 is given in the Table 3-2 below.

Table 3-2. Stripa Project Phase 2 - Summary of costs as per December 31, 1986. All figures in SEK.

	TOTAL PROGRAM			
Program	Original budget incl 10% annual esc.	Rev budget 1986 incl 10% annual esc.	Accumulated	Estimated Remaining
Project management	3 700 000	4 200 000	2 765 692	1 434 308
Mine operations	14 150 000	12 200 000	11 021 405	1 178 595
Crosshole techniques	22 400 000	22 565 000	22 116 847	448 153
3-D tracer experiment	8 350 000	9 250 000	8 223 507	1 026 493
Sealing test	10 200 000	9 700 000	9 825 699	- 125 699
Hydrogeological characterization, Part 1 and 2	260 000	1 005 000	629 522	375 478
Hydrochemistry	1 400 000	2 830 000	2 733 057	96 943
Seismic crosshole	700 000	840 000	859 482	- 19 482
Total	61 160 000	62 590 000	58 175 211	4 414 789

Stripa Project – Previously Published Reports

1980

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

TR 81–02

"Annual Report 1980"
Swedish Nuclear Fuel Supply Co/Division KBS
Stockholm, Sweden 1981

IR 81–03

"Migration in a single fracture Preliminary experiments in Stripa"
Harald Abelin, Ivars Neretnieks
Royal Institute of Technology
Stockholm, Sweden April 1981

IR 81–04

"Equipment for hydraulic testing"
Lars Jacobsson, Henrik Norlander
Ställbergs Grufve AB
Stripa, Sweden July 1981

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

TR 82–01

"Annual Report 1981"
Swedish Nuclear Fuel Supply Co/Division KBS
Stockholm, Sweden February 1982

IR 82–02

"Buffer Mass Test – Data Acquisition and Data Processing Systems"
B Hagvall
University of Luleå, Sweden August 1982

IR 82–03

"Buffer Mass Test – Software for the Data Acquisition System"
B Hagvall
University of Luleå, Sweden August 1982

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

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

IR 82–06

"Buffer Mass Test – Buffer Materials"
R Pusch, L Börgesson
University of Luleå
J Nilsson
AB Jacobson & Widmark, Luleå
Sweden August 1982

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

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
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

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

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

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

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

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

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
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