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TECHNICAL REPORT 89-24

STRIPA PROJECT

ANNUAL REPORT 1988

MAY 1989

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

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Der vorliegende Bericht betrifft eine Studie, die für das Stripa-Projekt ausgeführt wurde. Die Autoren haben ihre eigenen Ansichten und Schlussfolgerungen dargestellt. Diese müssen nicht unbedingt mit denjenigen des Auftraggebers übereinstimmen.

Le présent rapport a été préparé pour le projet de Stripa. Les opinions et conclusions présentées sont celles des auteurs et ne correspondent pas nécessairement à ceux du client.

This report concerns a study which was conducted for the Stripa Project. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

Das Stripa-Projekt ist ein Projekt der Nuklearagentur der OECD. Unter internationaler Beteiligung werden im Rahmen einer 3. Phase dieses Projektes von 1986-1991 Forschungsarbeiten in einem unterirdischen Felslabor in Schweden durchgeführt. Unter Anwendung des in den vorhergehenden Phasen 1 und 2 Gelernten sollen folgende Arbeiten realisiert werden:
- Anwendung verschiedener Felduntersuchungs- und Berechnungsmethoden, um den Wasserfluss und Nuklidtransport in einem unbekannten Felsvolumen des Stripagranites vorherzusagen und anschliessend zu überprüfen
- Evaluation verschiedenster Materialien und Methoden zum Abdichten wasserführender Klüfte im Stripagranit

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. Over the time period 1986-1991 (Phase 3 of the Project), an international cooperative programme of investigations is being carried out in an underground rock laboratory in Sweden. Building on experience gained in Phases 1 and 2, the following research will be carried out:
- Application of various site characterisation techniques and analysis methods with a view to predicting and validating groundwater flow and nuclide transport in an unexplored volume of Stripa granite
- Verification of the use of different materials and techniques for sealing water-bearing fractures in the Stripa granite

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

Le projet de Stripa est un projet de l'Agence de l'OCDE pour l'Energie Nucléaire. C'est dans le cadre d'une troisième phase de ce projet allant de 1986 à 1991, que des travaux de recherches sont réalisés avec une participation internationale, dans un laboratoire souterrain de Suède. Il s'agit d'effectuer les travaux ci-dessous, en mettant en application ce que l'on a appris au cours des précédentes phases 1 et 2:
- Application de diverses méthodes de recherches sur le terrain et de calcul, pour prévoir puis contrôler l'écoulement de l'eau et le transport des nucléides dans un volume rocheux inconnu du granite de Stripa
- Evaluation des méthodes et des matériaux les plus divers, en vue de colmater des fractures aquifères du granite de Stripa

La Cédra participe à ces recherches pour la Suisse. Les rapports techniques rédigés à propos du projet de Stripa paraissent en même temps dans la série des Rapports Techniques de la Cédra (NTB).

THE STRIPA PROJECT
ANNUAL REPORT
1988

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 1988.

Stockholm
May 1989

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:

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

The second phase of the Stripa Project, which was joined by two additional countries, Spain and the United Kingdom, started in 1983. The second phase of the project was completed in 1988, at a total cost of approximately 65 MSEK. The investigations included in the second phase were:

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

The formal agreement for an extension of the project into a third phase was signed in 1987. Participating countries in the Phase 3 of the Stripa Project is Canada, Finland, Japan, Sweden, Switzerland, United Kingdom and the United States. The research activities in this third phase of the Stripa Project are carried out under two headings,

- Fracture Flow and Nuclide Transport; and
- Groundwater Flow Path Sealing.

Under the heading Fracture Flow and Nuclide Transport the main objectives are:

- to predict groundwater flow and nuclide transport in a specific unexplored volume of the Stripa granite and make a comparison with data from field measurements. The comparison will be made by means of an integrated approach with existing site characterization tools and methods, particularly those developed under Phases 1 and 2, this programme is referred to as the "Site Characterization and Validation" programme,

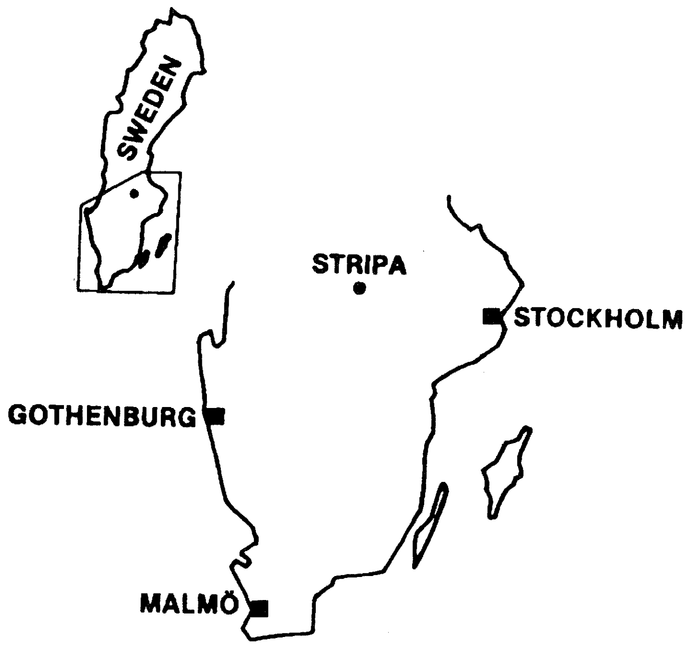


Figure 1-1. The Stripa mine is located approximately 250 km west of Stockholm.

– to continue the development of site assessment methods and strategies and, where found appropriate, apply them in later stages of the integrated site characterization exercise outlined above. This programme is referred to as "Improvement of Site Assessment Methods and Concepts".

Under the heading Groundwater Flow Path Sealing the principal objectives are:

– to identify, select and evaluate sealing substances which promise to possess long-term chemical and mechanical stability; and
– to demonstrate in field tests, by use of suitable methods and techniques, the effectiveness of such substances for the long-term sealing of groundwater flow paths in the Stripa granite. The total programme is referred to as "Sealing of Fractured Rock".

The conditions of participation in the Stripa Project are covered by separate agreements for Phase 1, Phase 2 and Phase 3, although all three 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 a Technical Sub-group (TSG). The sub-group is composed of scientists from the participating countries. It deals with geology, geophysics, hydrogeology, numerical modelling

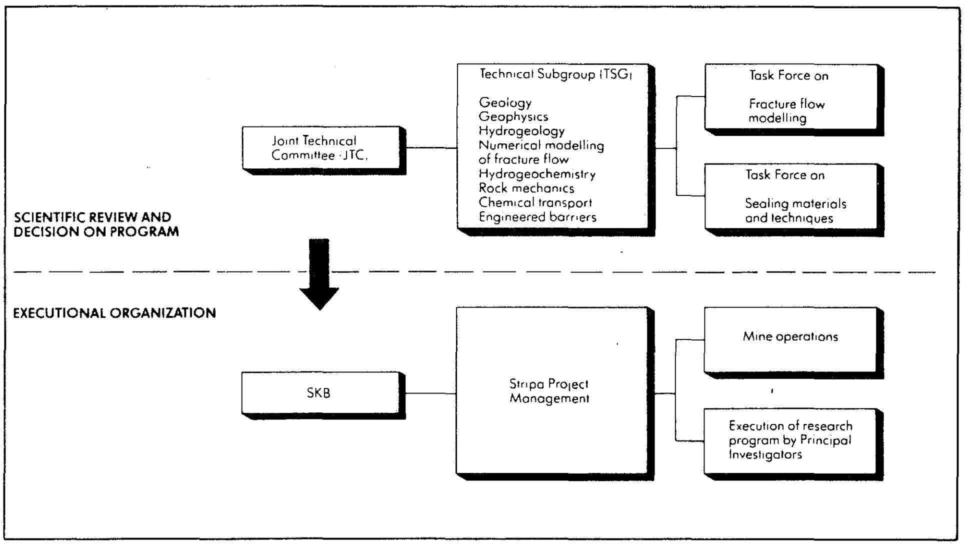


Figure 1-2. Organization of the Stripa Project.

Two "Task Force" groups one on Sealing Materials and Techniques and a second on Fracture Flow Modelling form ad hoc groups to the project. In each of the two groups the participating countries may assign a scientist with particular expertise in the research field considered. The ad hoc groups should report to the TSG on their activities.

As for the "Site Characterization and Validation" programme the project manager is supported by two Scientific Coordinators, John Black of Golders Associates and Olle Olsson of SGAB both with long experience in the Stripa Project. The "Site Characterization and Validation" programme 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 programme is then necessary.

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 Joint Technical Committee, the Technical Sub-group, the two Task Force groups, 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 (Phase 2 only)	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	Department of the Environment (UK DOE)
United States	Department of Energy (US DOE)

2 GENERAL

2.1 MEETINGS

The Technical Subgroup met on March 22—23, 1988 in Nottingham, England to summarize the technical results of the experiments of Phase 2 as well as to review and discuss the progress of Phase 3 of the Stripa Project. A visit to the Sellafield nuclear fuel re-processing plant and the Drigg low level waste disposal site was arranged on March 24 in conjunction with the meeting.

A JTC-meeting was held at Forsmarks Herrgård, Sweden on June 6—7, 1988. The management of the ongoing Stripa Project activities were discussed. The technical and financial status of Phase 2 and Phase 3 of the Stripa Project was also presented. Based on the recommendations made by the TSG the JTC made the following unanimous decisions:

- the formation of a Task Force on Fracture Flow Modelling with the responsibility as outlined in section 4.6.1 of the minutes from the meeting and the distribution of the charter as of January 19, 1988 to the Task Force members,

  Dr. Paul Gnirk was elected chairman of the Task Force on Fracture Flow Modelling,
- the extension of the water-head monitoring program to the boreholes of the SCV-site and the evaluation of the water-head data from all the monitored boreholes,
- complementary measurements of the in-situ rock stresses within the SCV-site, to perform a set of four large scale sealing tests in the Stripa Mine and continue the longevity study of the bentonite and cement based grouts, as defined in the program plan and recommended by the Task Force on Sealing Materials and Techniques,
- to extend the Phase 3 program time schedule from mid 1991 to the end of 1991, subject to the following conditions;
  - all test work in the mine shall be completed and all equipment retrieved by mid 1991,
  - all reporting shall be completed by the end of 1991,
  - no cost increase in the Phase 3 Program budget.

In a letter to the JTC chairman Dr. Rudi Beck had expressed his decision to resign as the co-chairman of the TSG. The JTC expressed its gratitude to Dr. Rudi Beck, and his sponsoring organization NAGRA of Switzerland, for his dedicated and conscientious service as chairman of the TSG 1 from 1980 to 1986 and as co-chairman of the TSG for Phase 3 since 1986.

As the successor for Dr. Rudi Beck, Dr. Neil Chapman from BGS, the British Geological Survey was proposed and elected in full agreement by the JTC.

A plan to arrange two workshops per year as a part of the technology transfer program was proposed by the Project Manager. The JTC decided that a fee is to be charged to the participants in the workshops to cover the costs associated with the workshops.

A visit to the nearby SFR repository site for low and intermediate level radioactive waste was arranged on June 8 in conjunction with the JTC-meeting.

The Task Force on Sealing Materials and Techniques and the Task Force on Fracture Flow Modelling both met twice to discuss and review the technical progress of respective programme.

Notes from all meetings have been distributed separately.

3 PHASE 3

3.1 SITE CHARACTERIZATION AND VALIDATION

3.1.1 Introduction

The Site Characterization and Validation (SCV) Project focusses on the techniques and approaches used in site characterization. The central aim of the programme is to predict groundwater flow in a specific volume of rock and to compare these predictions with data from field measurements. The distribution of water flow into a drift (tunnel) will be predicted, the drift will be excavated, the inflows will be measured and compared with prediction. Above and beyond the central aim there are a number of subsidiary aims such as assessment of channeling, the small scale hydrogeological effects of drift excavation and tracer tests in the fractured rock mass.

The Site Characterization and Validation programme is based around the idea of cycles of data-gathering, prediction, and validation. Hence the programme has stages of work which can be described in these terms. In fact, the programme contains two cycles of this type where predictions are checked against observation. It is therefore divided into five stages as follows:

Stage	Title of stage	Period	Type of work	Cycle
I	Preliminary site characterization	86-88	data gathering	first
II	Preliminary prediction	87-88	prediction	
III	Detailed characterization & preliminary validation	88-89	validation/ data gathering	
IV	Detailed predictions	89-90	prediction	second
V	Detailed evaluation	90-91	validation	

The programme of work contains a number of different techniques falling within the disciplines of structural geology, geology, geophysics, chemistry hydrogeology, and modelling. These have been combined so that predictions can be made and subsequently validated. The "cycles" of the programme envisage two modelling periods in which predictions would be made. These two periods are very different. In the first (Stage II), a conceptual model is made which is essentially geometrical with preliminary values of the important properties. Modelling at this stage will make primarily geometrical predictions. In the second (Stage IV), modelling will include the detailed properties and will include predictions of inflows to the test drift.

As can be seen Stage III fulfills two functions, that is the data gathered at this point in the programme will be compared against the preliminary predictions resulting from the Stage II work. They will also provide a basis for the detailed

3.1.2 Experimental Site

The project aims at characterizing in detail a volume of rock which is about 125 m by 125 m in plan and about 50 m deep. The SCV-site is located about 100 m north of the old mine workings (except for the 3D-migration drift) between the 360 and 410 m levels. The selected location made it possible to explore the rock volume through boreholes made from existing drifts. Although the volume to be investigated is comparatively small, it will eventually consist of a small region of well-characterized rock surrounded by a larger volume of rock which is less well known. This larger volume will probably have dimensions on the order of half a kilometre.

The location of the existing mine workings in relation to the site is important as they provide hydraulic boundaries of atmospheric pressure. All mine workings above the 435 m level are open and air filled. Figure 3-1 shows the location of the site in relation to the ore body and old mine workings.

Figure 3-2 shows the location of the SCV-site and its boreholes in a plan view. Five "boundary boreholes" have been drilled for preliminary characterization of the site: three holes towards the North (N2 — N4) of 200 m length and 60 m apart, and two towards the West (W1 — W2). These holes of 150 m length are roughly 70 m apart. A 50 meter long vertical hole (V3) has been drilled at the end of the 3D-migration drift mainly for the purpose of measuring rock stresses.

3.1.3 Conceptual Model of the SCV-site

The major effort during 1988 has been the compilation and integrated interpretation of the data collected during Stage I. The resulting interpretation has been presented in a report titled "Site Characterization and Validation Stage 2 — Preliminary Predictions" which is summarized below.

The rock type at the SCV-site is granite with small lithological variations. The granite is traversed by regionally visible fracture zones with spacings around a kilometre. This compares with the 125 m sides of the volume being investigated. The mine opening affects the regional hydrogeology and the regional stress field. It intercepts regional groundwater flow paths, some of which are up to 10 km in length, and over the period of mine operations it has reversed some flow away from the nearby Lake Råsvalen.

The SCV site lies within a local groundwater flow system where the mine acts as a sink. In this system "young" low salinity groundwater flows downward towards the mine and mixes with "older" more saline water flowing upwards from depth. Near the surface, waters are almost exclusively "young", whilst at depth (i.e. >400 m) waters are "old". The site therefore lies within a zone of mixing between about 200 and 400 m below ground. This is reflected in the hydrochemistry of the site. The SCV site also lies within a region of stress realignment with more or less unmodified regional stress in the northern half of the site and about 30° realignment in the south.

The predictions concerning water inflows will be based on a numerical model of the mine. In reality, this is a set of 4 models at increasing detail; a regional model, a sub-region model, a "mine" model, and a "site" model. The first two parts were completed during the previous phase of the Stripa Project. The large region model assumes boundary conditions such as the topography of the water table and surrounding impermeable borders. The head and flow distribution is then calculated within the modelled region. The boundary heads and flows for the three more detailed models are all based on the results obtained from the model "next up" in the series. All of these models are finite element equivalent

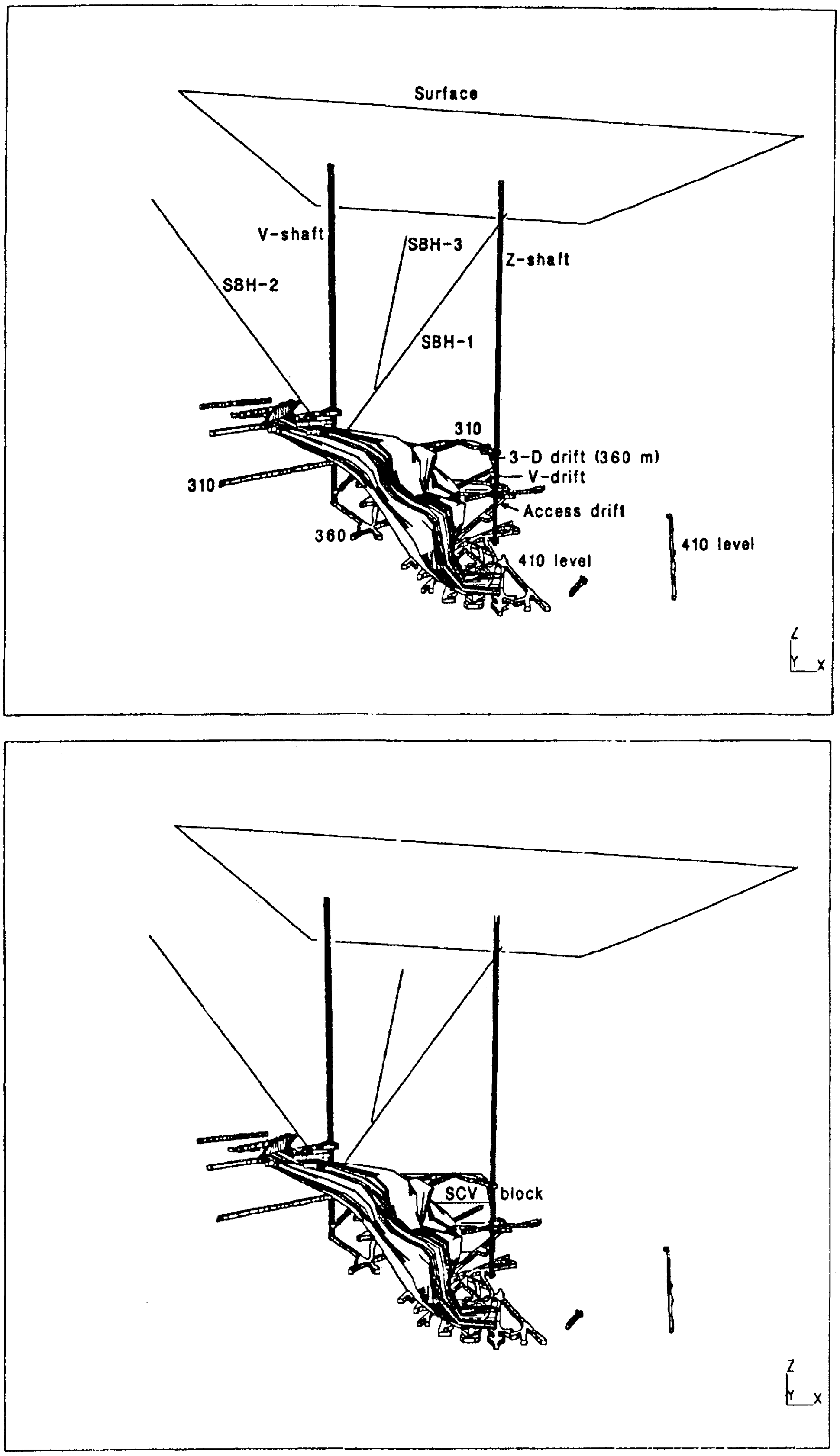


Figure 3-1. Perspective view of mined out area in relation to the SCV-site.

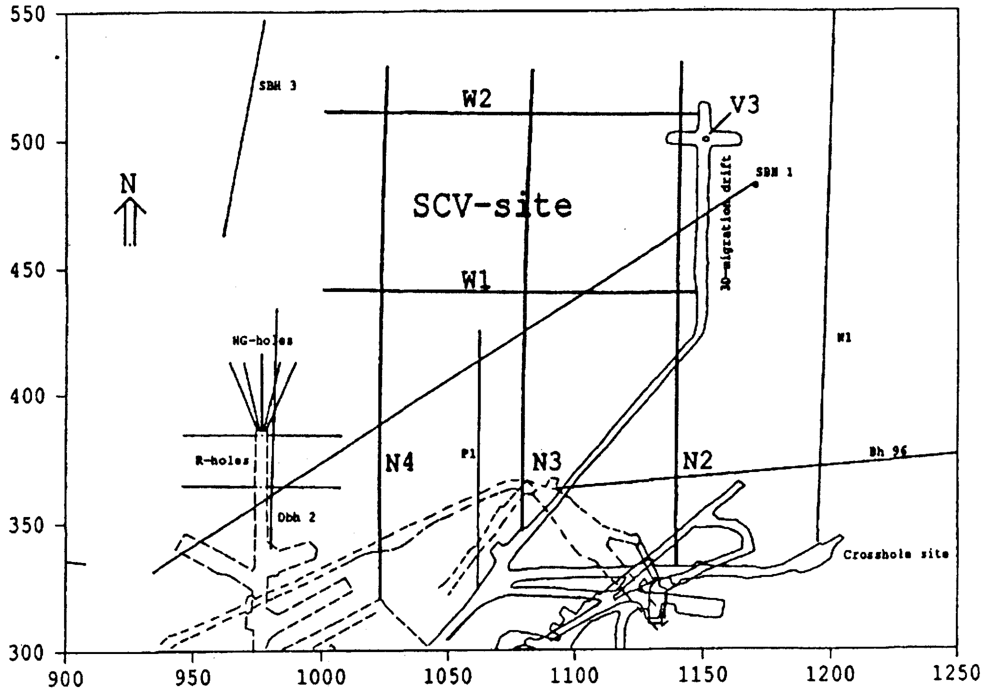


Figure 3-2. Map of the SCV-site indicating the location of the "boundary boreholes", boreholes drilled prior to the start of the SCV Project, and existing mine workings. Dashed 310 and 335 m levels, solid 360 and 410 m levels.

porous medium models. However, at the most detailed level, the "site" model, a region will be modelled using a fracture network approach. This is the region of the proposed validation drift. At all stages in the modelling some fracture zones will be included explicitly as regions of distinctly different properties. Hence, the site needs to be characterized in terms of highly transmissive "fracture zones" and "background rock".

The major structural features within the SCV site have been identified, within this phase of work, primarily on the basis of geophysical remote sensing (i.e. single borehole radar and crosshole radar and seismics). Major features have been selected mainly on how extensive they are as observed in tomograms. It has also been found that there is a general correlation between radar "slowness" tomograms and transmissivity. Using this geophysical information 5 "fracture zones" have been identified, named GA, GB, GC, GH, and GI. They all extend across the entire SCV site. They are basically in two groups (GA, GB, GC and GH, GI). The first group are aligned N40°E with a dip of 35° to the south. The second group are aligned approximately N10°W dipping 60°E. Both sets are in the order of 50 m apart but there are also other minor features in between. Figure 3-3 shows a perspective view from northeast of the major features within the SCV block.

Of the two groups, the second more steeply dipping set (i.e. GH and GI) are more extensive and more continuous. There are other features with a northwesterly strike but they are less extensive and have not been included deterministically in the conceptual model. All features are irregular and appear

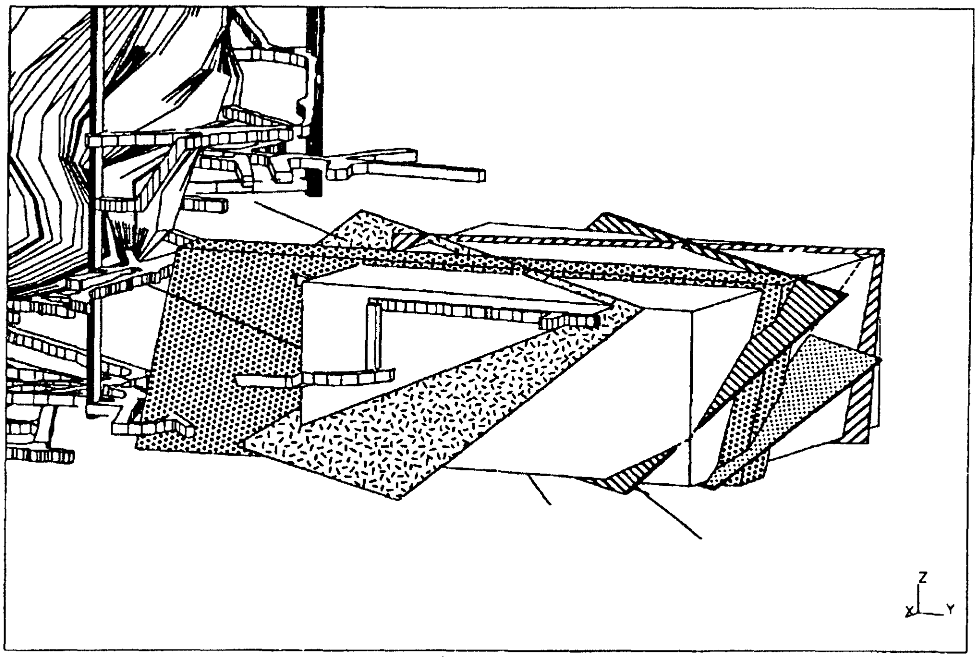


Figure 3-3. Perspective view of main features in relation to C boreholes and the access and validation drifts.

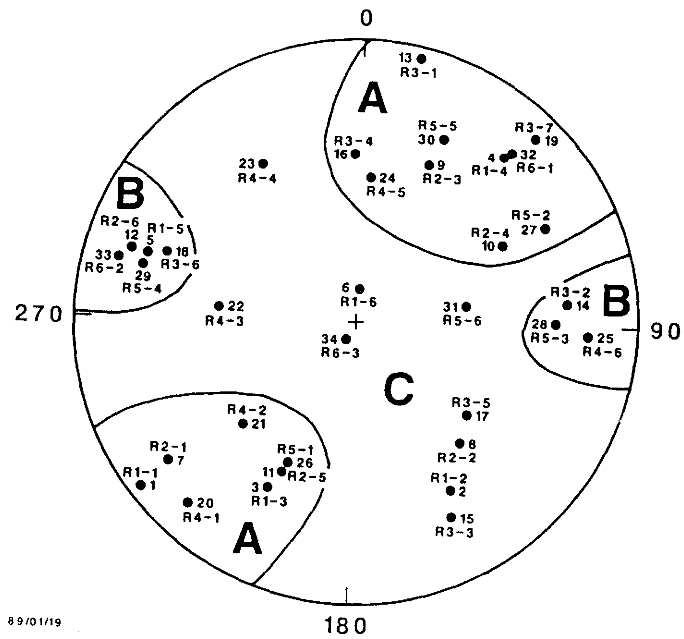
in the tomograms as series of connected patches rather than as well-defined planar zones.

The rest of the rock has been characterized in terms of the occurrence of fractures. Their geometric properties (spacing, orientation, and trace length) have been measured both along scan lines in the drifts as well as in the core from the boreholes. Their hydraulic properties have been measured in the boreholes.

It is clear that there are several biases in the data. Firstly, there are two subhorizontal borehole orientations which do not sample the vertical direction very well. Secondly the drifts have a limited dimension which censors the data on trace lengths. However, although there are detailed systematic variations across the site there are essentially two well measured clusters (Clusters A and B) and a third poorly measured group (Cluster C, Figure 3-4). The fractures of Cluster A have a wide range of orientations with an average strike orientation of about N45W and the fractures are steeply dipping in either the northeasterly or the southwesterly direction. The fractures in Cluster B have either easterly or westerly dips that are practically vertical with a strike of about N10 degrees. The third group, Cluster C, are subhorizontal and not very well-measured. The trace length data are strongly affected by censoring and truncation and it was only possible to make the necessary correction for Cluster C. The spacings between the clusters vary and these differences are easily seen in the different number of fractures intercepted by the boreholes of westerly and northerly orientation.

The hydraulics of the fractures vary depending on orientation and it seems that the mean aperture of the fractures penetrated by the W boreholes is larger than that penetrated by the N boreholes. Interpretation according to the Clusters A, B, and C is not completed.

The accurate prediction of water inflows, based on geophysical remote sensing, is dependent on the correlation between significant geophysical features and hydrogeological features. Unfortunately major geophysical features are defined by their extensiveness whilst hydraulic features result from single borehole tests. Single borehole hydraulic tests measure the hydraulic properties



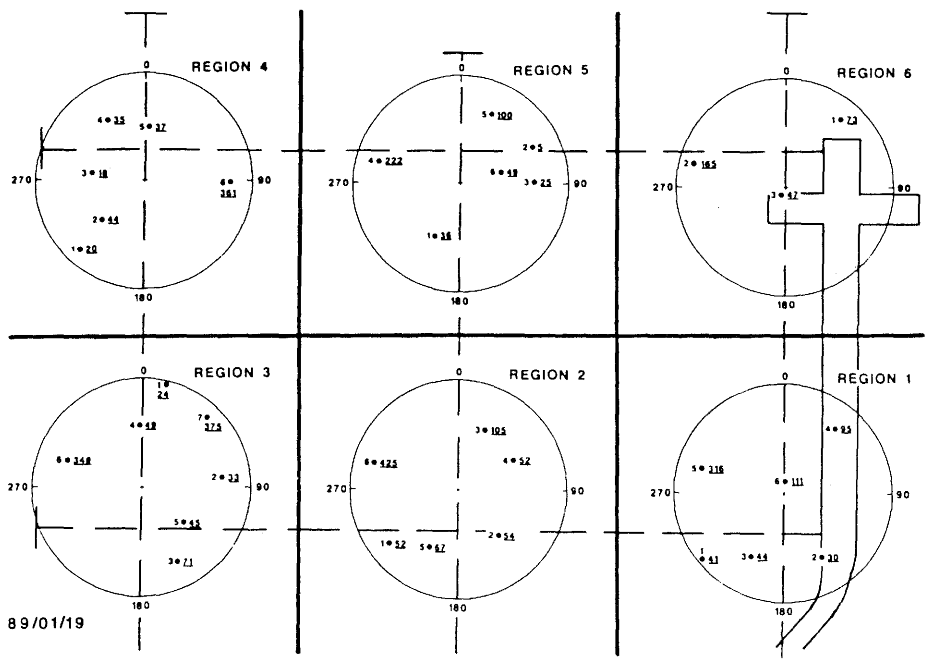


Figure 3-4. Plot of the mean pole directions for (a) all of the clusters in the SCV block and (b) the clusters in each of the sub-regions.

immediately surrounding the test borehole. In contrast it is known that significant extensive geophysical features are patchy. Hence it can be expected that identification of major geophysical features is a reasonable prediction of single borehole performance but a better prediction of whole drift performance (where the effect of patchiness (or channeling) is reduced).

Examining the correlation between the identified geophysical features and single borehole hydraulic results shows some interesting features. Firstly the five major features are identified as having a thickness between 3 and 8 metres where they cross the five N and W boreholes. This accounts for 93 m of the 868 m of tested borehole. This 11 % of the boreholes contains 57 % of the total borehole transmissivity. However, the transmissivity is much more unevenly distributed with 94 % of the transmissivity measured in 32 one metre sections (i.e. 4 % of the measured length). Two of the most transmissive sections accounting for 33 % of the measured transmissivity were close to but not contained within geophysical features. If these are included within the zones to which they are adjacent then geophysical features account for 90 % of the measured transmissivity. The idea of proximity is inexact but should be justified when considering inflows to a drift.

There is at present limited evidence of crosshole responses between the boreholes of the SCV site. However, if this is combined with the head data gathered during the single borehole testing and with the long term Piezomac (head) data some factors are clear. First of all there are rapid pressure responses right across the site with speeds up to 14 metres per minute seen in one zone. Secondly there seems to be a general flow of water from the north (to the NW of the 3D Drift) towards the south and southwest. A large region of low head is found in northwest (i.e. the furthest ends of W2 and N4). The explanation for this large region of reduced heads at some distance from the mine must lie in the presence of at least one highly transmissive feature draining towards the mined cavity and probably oriented subhorizontally. This is not an orientation which is well sampled by the existing borehole layout. This also presents a prediction problem since small errors in orientation will result in large differences in intersection position.

A series of predictions are put forward in the Preliminary Prediction report. These include:

- the intersection of major features with the "C" and "D" boreholes and the access drift,
- the geological characteristics of these features where observed,
- the fracture characteristics sampled by the new boreholes and drifts,
- the hydraulic properties of the new boreholes,
- the head gradients likely to be measured in the new boreholes.

3.1.4 Current Status of Investigation Programme

The conceptual model as presented above has been the basis for locating the access drift and the C and D boreholes.

The main objective of the C-holes is to characterize a smaller volume around the validation drift in more detail. Two of the most significant zones at the SCV-site are GB and GH. These zones are likely to control the hydraulics in the central portions of the site and they have to be checked with respect to location and properties. The circular feature RQ is also an anomaly of interest and an attempt has been made to locate the boreholes so that this feature is included in the Stage III investigations. The location of the validation drift has been

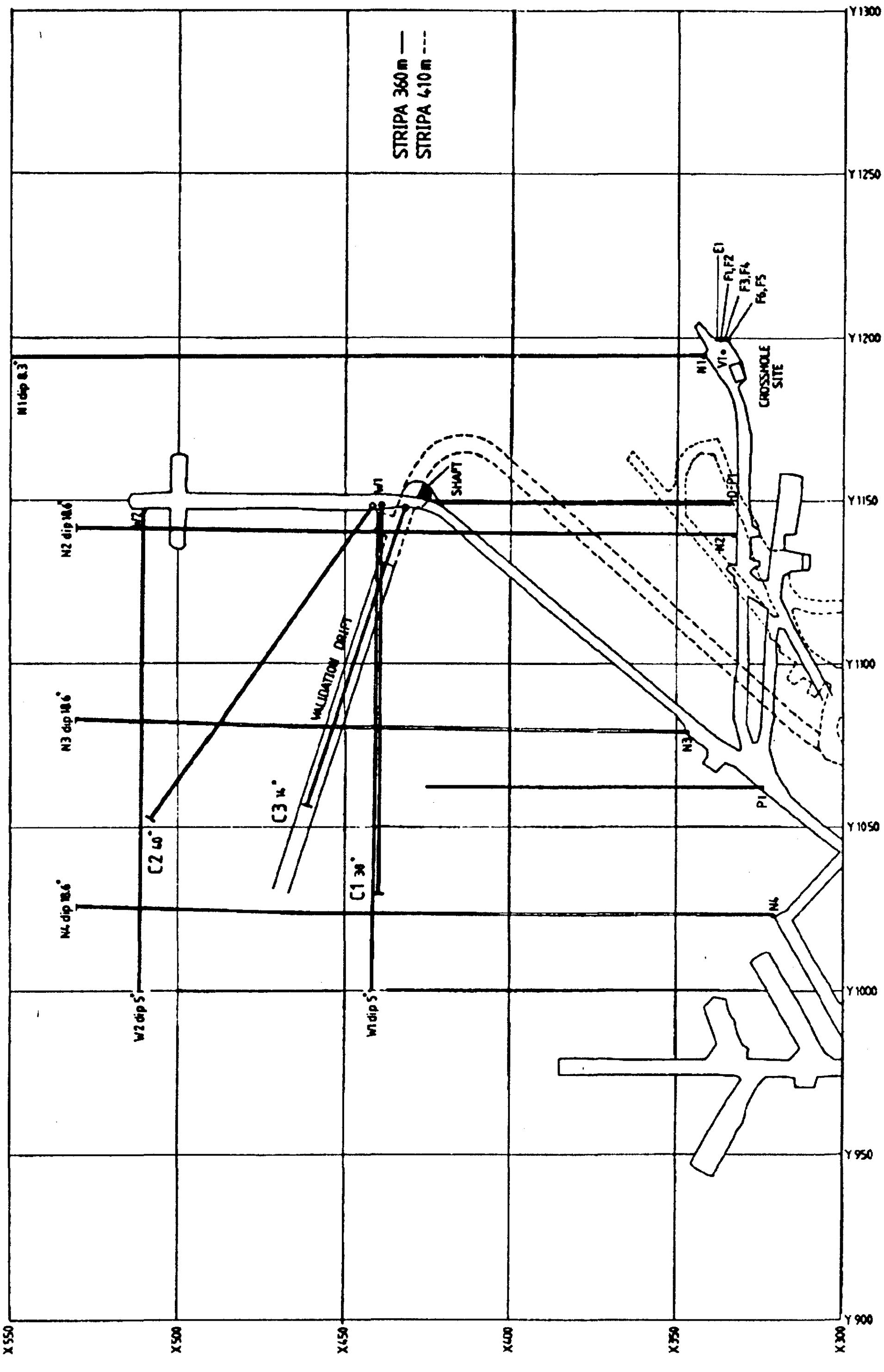


Figure 3-5. Location of C-boreholes, access drift, and validation drift. Solid; 360 m level, dashed; 410 m level.

changed compared to original plans in order to intersect both GB and GH and to make the intersection as perpendicular as possible.

The boreholes have been located in such a way that they originate from essentially the same point (close to the beginning of W1). In this way each pair of boreholes will define a plane and tomographic surveys between the holes will be possible. The two major zones will be intersected by a large number of boreholes which will facilitate detailed crosshole hydraulic testing of the zones.

Two of the boreholes were given a steep dip in order to provide better sampling in the vertical direction compared to what has been obtained from the boreholes drilled so far.

The validation drift will intersect zones GB and GH at a relatively steep angle. The validation drift has been oriented in order to minimize the risk of it being nearly parallel to a major zone. The validation drift will be located at the 385 m level of the mine which is approximately in the middle of the investigated volume.

The D-boreholes will outline the validation drift. There will be 6 boreholes, one in the centre surrounded by five symmetrically placed boreholes. The radius of the perimeter where the boreholes will be located will be 1.2 m. The intention is that the validation drift should have a diameter of 3 m which would make it possible to contain the boreholes within the diameter of the drift.

The location of the new boreholes, access and validation drift in relation to the mine workings and the existing boreholes are shown in Figure 3-5. Figure 3-6 shows the zones with existing and new boreholes in a vertical section at the X-coordinate 440, i.e. the vertical plane of borehole W1.

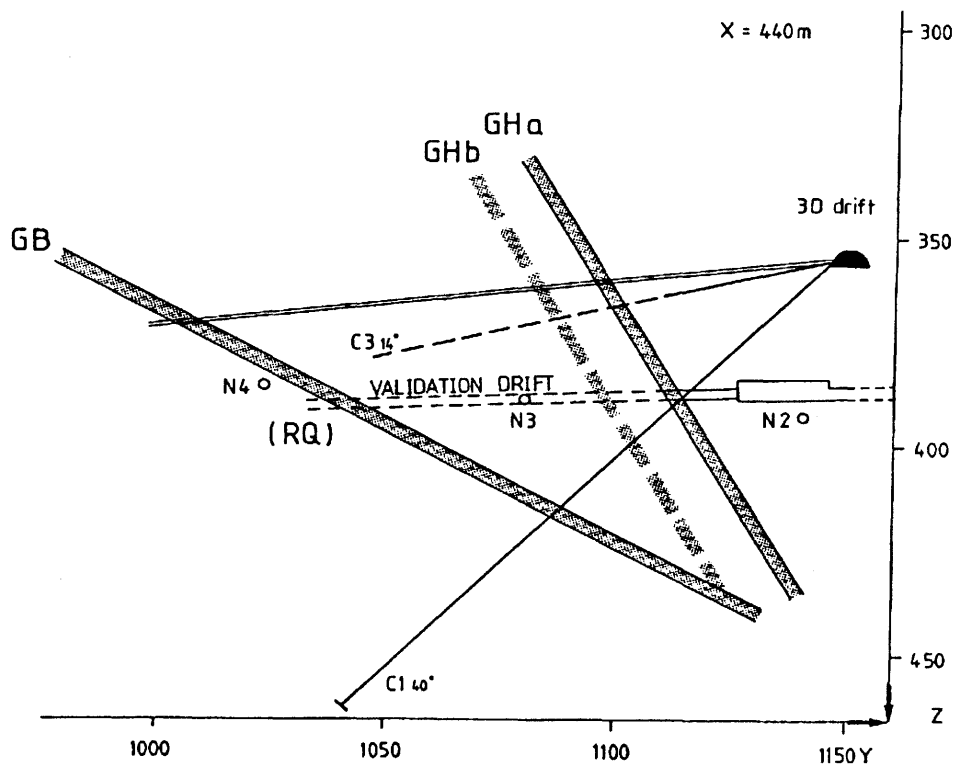


Figure 3-6. Vertical section at the coordinate X=440 m in the mine system. Location of C-holes, validation and access drift are indicated in relation to the major features GB and GH.

3.1.5 Rock Mechanics Characterization of the Stripa Joints

General

The ultimate purpose of the rock mechanics test programme is to be able to predict the effect of the disturbed zone surrounding the validation drift. Tunnel driving causes stress relief and redistribution of the stress. Joints are opened, closed further, or slightly sheared in the process of tunnel excavation. Joint apertures may be strongly affected, and as a result of the cubic relationships between aperture and flow, the validation drift is likely to demonstrate strong variations in inflows. Joint characterization is required in order to predict the mechanical response of joints to the excavation process.

Scale Effects on Joint Characterization

The five stages of the rock mechanics test programme are represented graphically in Figure 3-7. Joints are characterised at successively larger scales and in smaller numbers, as Stage 1 passes into Stage 3.

o Stage 1	174 joints from	100 mm diameter core
o Stage 3	5 joints from	200 mm core
o Stage 3	1 joint in	1000 x 1000 mm block test

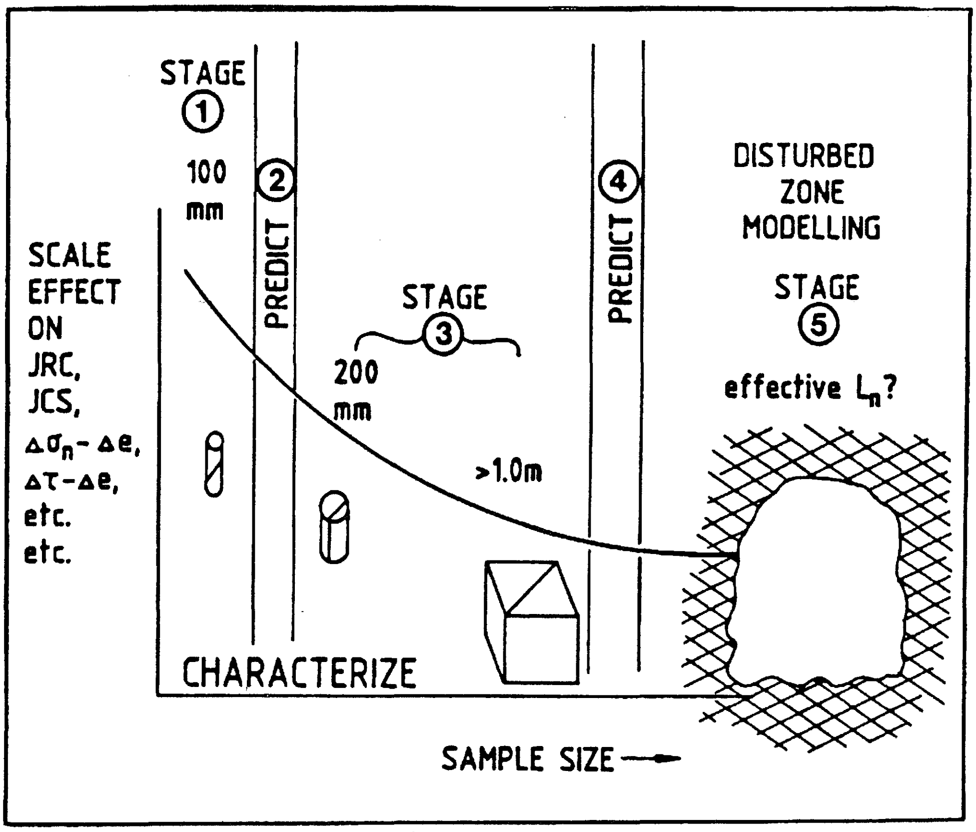


Figure 3-7. Rock joint shear strength parameters JRC and JCS, and flowstress coupling show sample size effects. The ultimate joint sample size is defined by the natural block size in the disturbed zone surrounding the validation drift.

The Stage 1 tests have been purely mechanical; utilizing tilt (low stress) shear tests to characterize joint roughness (JRC), and Schmidt hammer rebound testing to characterize joint wall strength (JCS). As indicated in Figure 3-7, these parameters are sample size dependent, declining in value as block size or joint length is increased.

Stage 3 tests on the larger joint samples consist of flow testing in combination with mechanical loading. Changes of normal stress ($\Delta\sigma_n$) and changes of shear stress ($\Delta\tau$) cause changes of conducting aperture (Δe) which are of consequence in the final modelling of disturbed zone effects on measured inflows. A sample size effect on all these parameters must be anticipated. The ultimate scale of testing in Stage 3 is the in situ block test which is being conducted on a jointed block of natural size in the floor of the 3D drift.

Stage 1 Characterization

Joints recovered in drillcore from holes W1, W2 and N3 were selected for characterization. One hundred and twenty two joints represented the N-S trending set #2, while fifty two joints represented the NW-SE trending set #1. A further twenty seven joints were tested that were not matched with one of the sets identified by J. Gale.

The methods of characterization were based on Barton and Choubey (1977) tilt testing and Schmidt hammer testing, to obtain the three parameters required for joint shear strength description, where peak friction angles (Φ) are given by

$$\Phi = \text{JRC} \log (\text{JCS}/\sigma_n) + \Phi_r$$

where JRC = joint roughness coefficient
JCS = joint wall compression strength
Φ_r = residual friction angle

Figures 3-8 and 3-9 show histograms of the measured data. Table 3-1 gives median values of these key joint strength parameters with example values of peak friction for assumed normal stress levels of 5 and 25 MPa ($\Phi_5°$ and $\Phi_{25}°$).

Table 3-1. Median values of joint strength parameters for Stripa joints.

JOINT SET	JRC	JCS	$\Phi_r°$	$\Phi_5°$	$\Phi_{25}°$
#1 NW-SE	7.1	120	24.3°	34.1°	29.1°
#2 N-S	6.9	140	25.5°	35.5°	30.7°

The wide range of JCS and Φ_r values reflect the effect of several mineral fillings in the various sets. In general, joint roughness showed more consistent trends.

Stage 2 Prediction

The above joint parameters are relevant to small scale samples recovered from 100 mm diameter drill core. Scaling rules developed by Barton and Bandis (1982) were used to predict relevant values of JRC and JRC for natural size jointed blocks, where in the first instance a mean block size of 0.5 m was

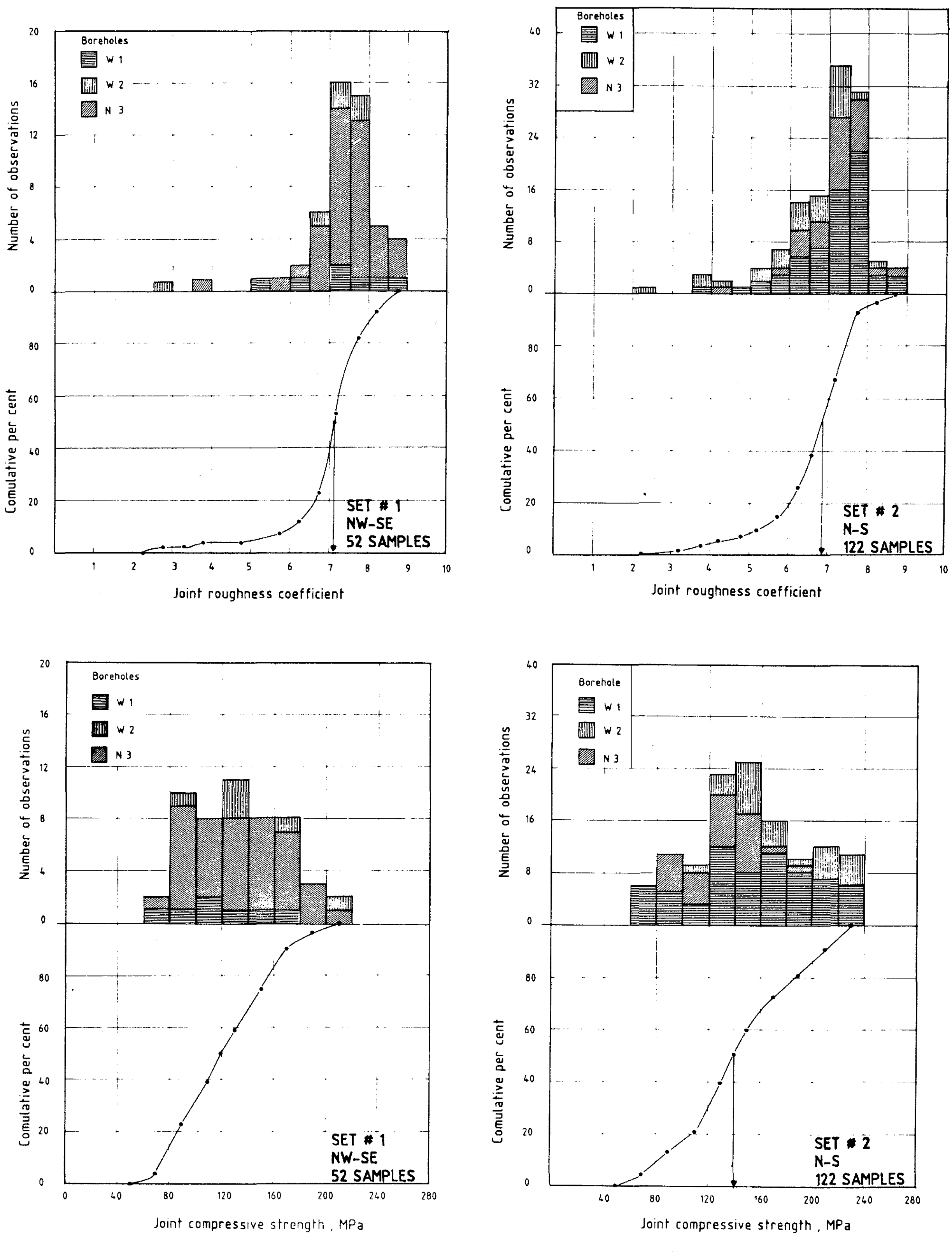


Figure 3-8. Histograms of joint roughness coefficient (JRC) and joint wall compressive strength (JCS) for the NW-SE and N-S trending joint sets.

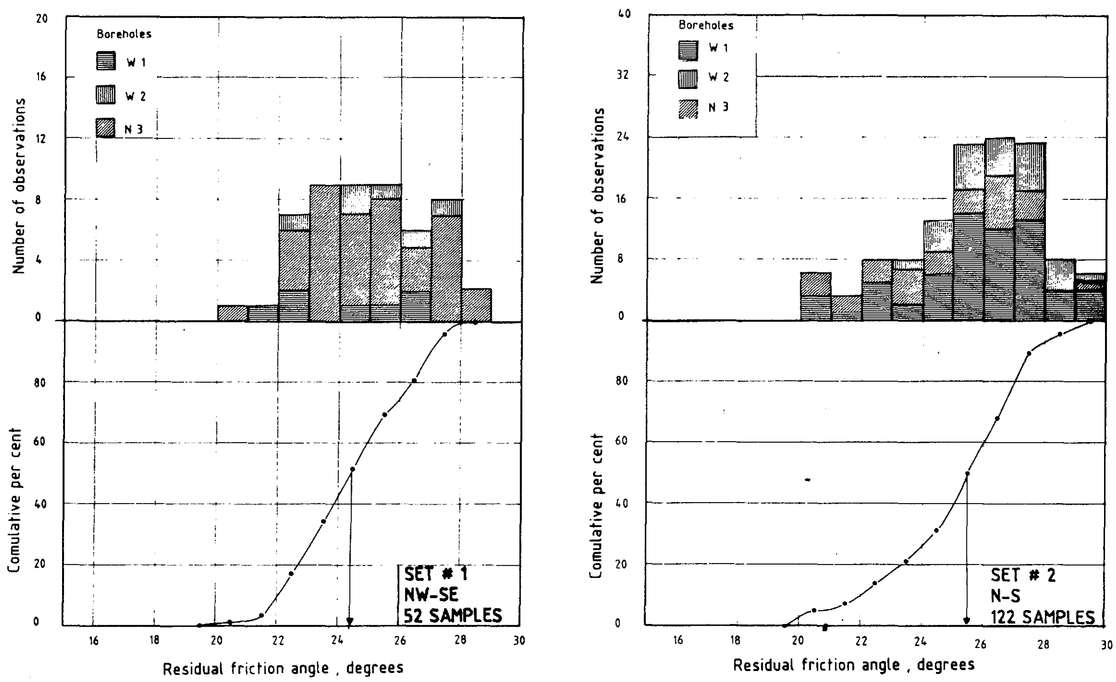


Figure 3-9. Histograms of residual friction angle (Φ_r) for the NW-SE and N-S trending joint sets.

assumed. This value will be modified by input from other research groups, when Stage 4 predictions are made. With the assumed block size, corrected "full-scale" values for JRC were 5.4 and 5.3, while "full-scale" values of JCS were 80 and 95 MPa for sets 1 and 2 respectively.

The above input data was used in the Barton-Bandis joint sub-routine in the discrete model μDEC-BB to generate sets of joint behaviour curves for the following variables:

- o shear strength — displacement
- o dilation — displacement
- o conductivity — displacement
- o normal stress — closure
- o normal stress — conductivity

Predicted behaviour is reported in Stripa Project report IR 88-08.

Stage 3 Characterization

Tests on larger joint samples, with coupling of fluid flow and joint deformation, form the basis for Stage 3 characterization. Figure 3-7 indicates that 200 mm core and a 1 x 1 meter block will be utilized for this characterization, which is ongoing. The objective is to measure the coupled hydromechanical behaviour on large scale joint surfaces, in order to have closer correspondence to joint behaviour in the disturbed zone around the future validation drift. Cycles of normal load and unloading are followed by limited shearing during simultaneous measurement of joint conductivity. Results will be compared with Stage 2 predictions, and will be used as a basis for Stage 4 predictions of disturbed zone effects.

Supplementary work under Stage 3 characterization has been conducted at the Rock Mechanics Department of the University of Luleå. Eva Hakami has produced an original study of "Water Flow in Single Rock Joints" for a Licenciate Thesis (1988: II L), under the supervision of N. Barton (NGI's PI).

The work has consisted of aperture mapping and flow velocity measurements in transparent epoxy replicas of five rock joints, three of which were cast on Stripa joints that were previously recovered from the N-S set # 2 in the 2D drift by Chemflow. The Stripa joints were fully disturbed and they were rather planar (JRC = 3) and mated poorly. Apertures were correspondingly large. The techniques developed by Hakami can be used in the future on less disturbed joints recovered in the SCV programme.

Figures 3-10 and 3-11 illustrate one set of data from sample "S4" from the Stripa 2D drift. Aperture dimensions were measured by a photographic technique using minute drops of liquid pressed between the transparent mating joint replica walls. The median value of physical aperture (E) was approximately 200 microns. The TERMOS digital 3D terrain model shows peaks that represent maximum aperture, which correspond to the contoured plan view of the joint aperture distribution. Flow experiments with injected colour tracer provided streamline data and velocity distributions as shown in Figure 3-11.

Due to the disturbed nature of these samples compared to nonsampled joints in situ, care must be exercised when evaluating the results. The tests do, however, demonstrate useful techniques for investigating and interpreting channelling phenomena, and could be used in conjunction with SCV channelling experiments.

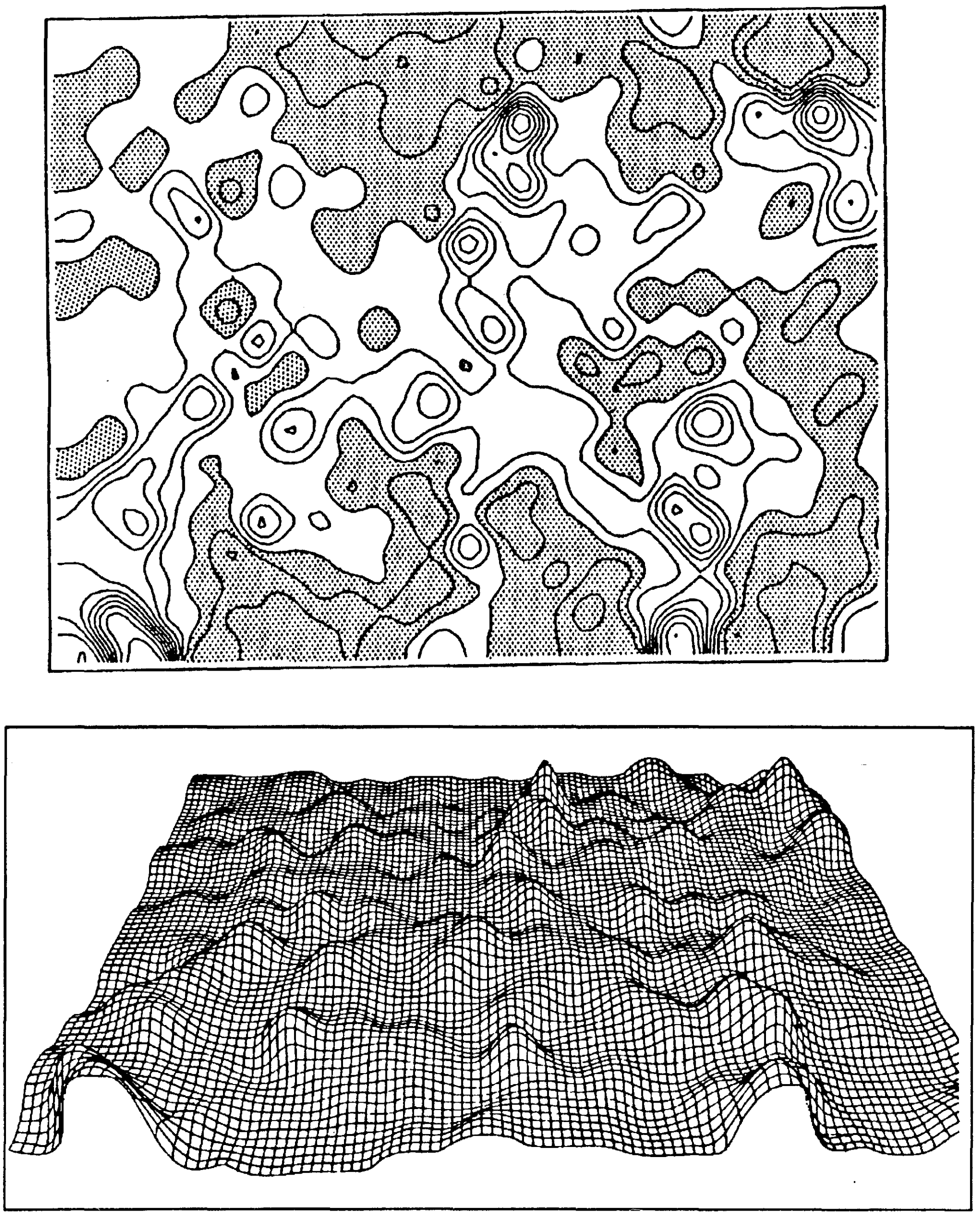


Figure 3-10. Joint aperture contours obtained from an epoxy replica of a disturbed planar Stripa joint. The hatched areas correspond to apertures smaller than 250 μm. /E Hakami 1988/

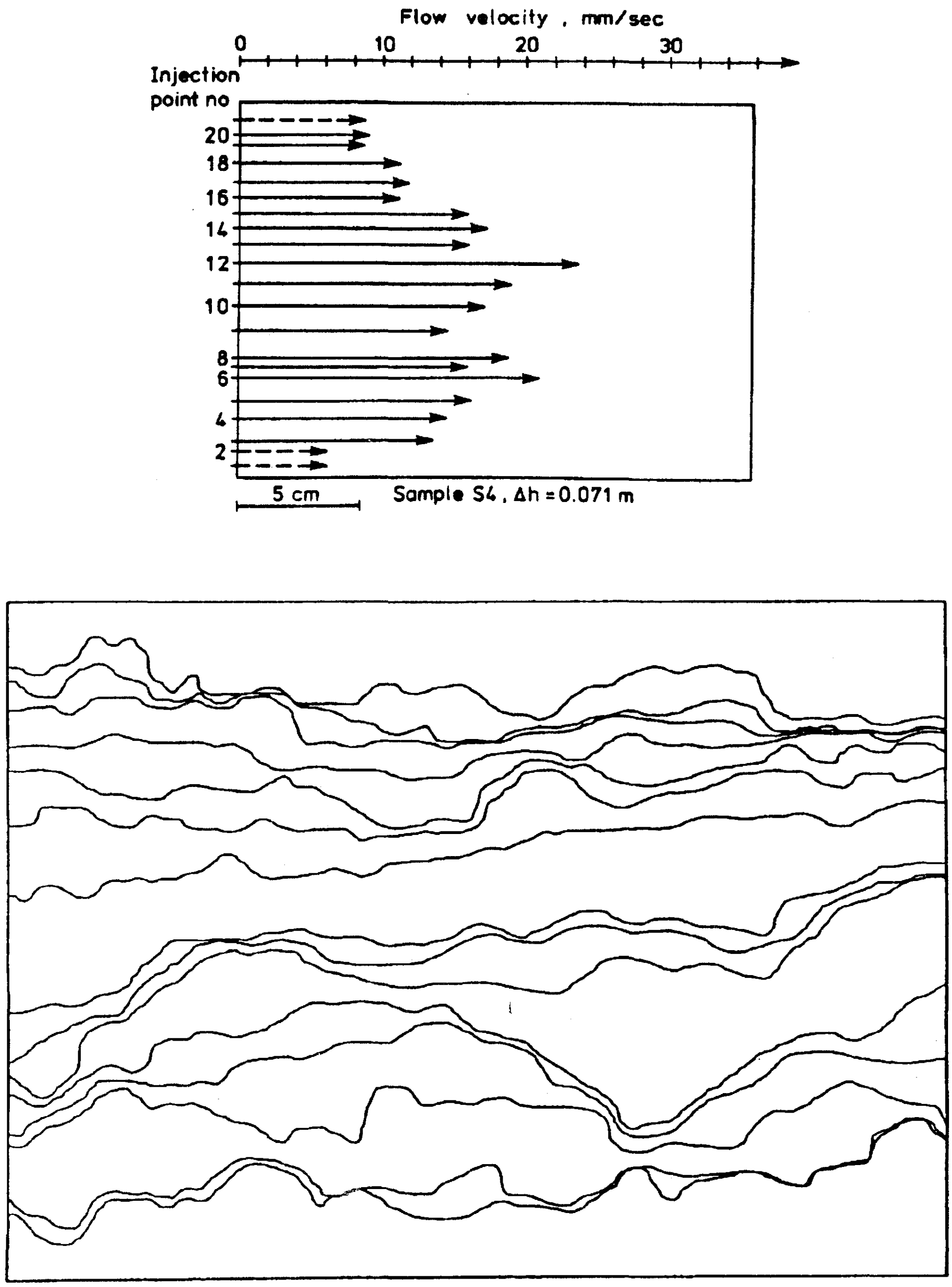


Figure 3-11. Streamline paths and corresponding average velocities of flow measured in an epoxy replica of a disturbed planar Stripa joint. /E Hakami, 1988/

3.2 DEVELOPMENT OF HIGH RESOLUTION AND DIRECTIONAL RADAR

3.2.1 Previous Work

The theoretical analysis has demonstrated that there are two possible concepts for a directional antenna: either a simple antenna that would be rotated mechanically in the borehole or a more complicated system, where the rotation is digitally synthesized from several measurements. The second possibility was preferred, since it will simplify measurements, although the concept contains some difficult points.

The directional antenna has been constructed as an extension of the existing radar system in order to facilitate the development and avoid extra work. The main novelties are

1) a direction indicator to measure the position of the antenna in the borehole;

2) a fourth optical fibre communicating in both directions with the direction indicator and the switches to the antennas;

3) a directional antenna with four antenna ports providing independent information about the incident waves.

New amplifiers and a new sampler have improved the signals, particularly at high frequencies.

3.2.2 Antenna Tests and Calibration

The directional antenna has been tested mainly in the Crosshole Site in Stripa. This site is known in detail after the work performed during phase 2 of the Stripa project and there are many possibilities for checking the results both on reflections from fracture zones and boreholes.

Initially the measurements suffered from poor electric contacts in the antenna. This experience demonstrated the need for internal tests that continuously check the performance of the system. Electronic errors often appear during transport or reconstruction of the antenna but it would be disastrous if a system failure went unnoticed during a measurements. Such a check is possible because there are four antenna signals but only three independent components. A checksum can be defined which will be zero if all antennas work perfectly. The checksum provides both a check of the system and a measure of the quality of the data.

The three independent signal components correspond to the three possible modes of a slim borehole antenna: an electric dipole, which can be thought of as a single wire placed in the borehole, and two magnetic dipoles, which can be viewed as current loops placed at right angles to each other. The magnetic dipoles provide the directional information, which is extracted by linear combination of the signals.

The performance of the system is also tested by direct calibration. The antenna is rotated manually in a borehole, while the transmitter is held in a fixed position. The signal from each antenna port is then compared with the theoretical formula. Any transmitter signal can be used in calibration tests and it does not matter whether there are any reflections from walls etc. Calibrations can be performed directly in a laboratory, which is a great advantage compared with radar measurements which are restricted to boreholes.

The radar antenna was tested in this way after the first measurements and some poor contacts were immediately discovered. After adjustments the directional components from two antenna ports were almost perfectly out of phase as shown in Figure 3-12. Furthermore the electric dipole signals of all antennas were almost identical, which is a necessary condition for calculating the directional components.

3.2.3 Radar Performance

The time of measurement has increased since at each point four signals are registered rather than one. This increase is compensated by the fact that an electric dipole measurement is obtained simultaneously with the directional components. There are thus three independent radar pictures available from a single measurement. The interpreter must learn to combine the results of these three pictures, since they often contain different information.

The radar range is reduced for directional antennas, but the loss is not excessive and it is still possible to observe fracture zones far from the boreholes. It is sometimes an advantage that the radiation pattern of the directional antenna is different from that of an electric dipole: fracture zones that run orthogonally to the borehole have traditionally been difficult to detect, but they are now often clearly visible. The reflections obtained with the directional antenna are in many cases sharper than those created by an electric dipole because the directional antenna is very broadband in frequency and does not deform the pulse.

The antenna has recently been improved by reducing the electric dipole field to half its previous value. The directional and electric dipole components are now of similar magnitude, which simplifies the separation of the signals. The dipole component is caused by an unbalance of the antenna feed relative to the electronic section; the balance has been improved by modifying the feed.

3.2.4 Analysis of Data

Much analysis has been devoted to displaying radar data in a clear way. The analysis of directional radar data is illustrated in Figures 3-13 — 3-15. The problem depends on the type of reflector. It is simplest to solve for fracture zones, which often behave as plane mirrors.

The signal of an ideal directional antenna rotated through an arbitrary angle can be calculated from the two directional components. Figure 3-13 shows a measurement containing reflections from several adjacent boreholes. As the antenna is rotated the reflected signals pass between minima and maxima. The direction is determined from a minimum since a maximum becomes very wide in grey scale maps.

Figure 3-14 shows a directional radar picture containing some prominent fracture zones. The orientation of fracture zone C is estimated in Figure 3-15 where a minimum is observed near an angle of 120°. One can successively close in on this minimum which is approximately located at 125° ± 5°. This result is quite good considering that this value includes both uncertainties in the directional antenna and the fact that a real fracture zone is a complicated scatterer.

The directional information and the angle of intersection with the borehole is sufficient to determine the orientation of the fracture zone in a single measurement. This is a great advantage compared with previous methods, where results from different boreholes had to be combined. The calculated orientation of zone C is shown in a Wulff diagram in Figure 3-16. The intersection between the two curves is quite close to the orientation derived by combining geophysical and geological data from the seven boreholes intersecting the zone. The final ambiguity caused by the two intersections between the curves can be removed by a careful analysis of the phase of the measured signals.

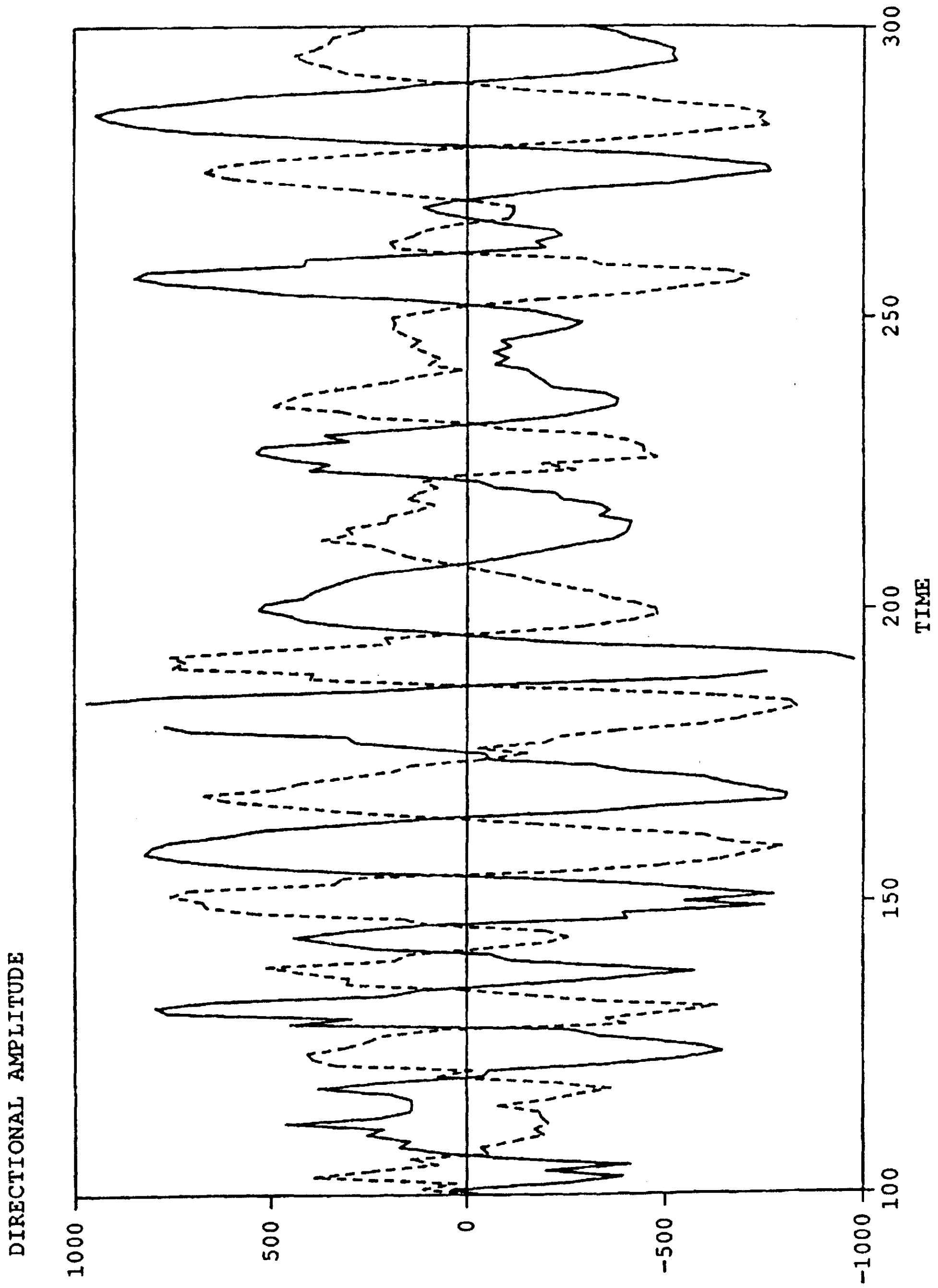


Figure 3-12. The directional signal from two opposite antenna ports in a calibration measurement performed in the laboratory. The ringing is caused by multiple reflections from the walls.

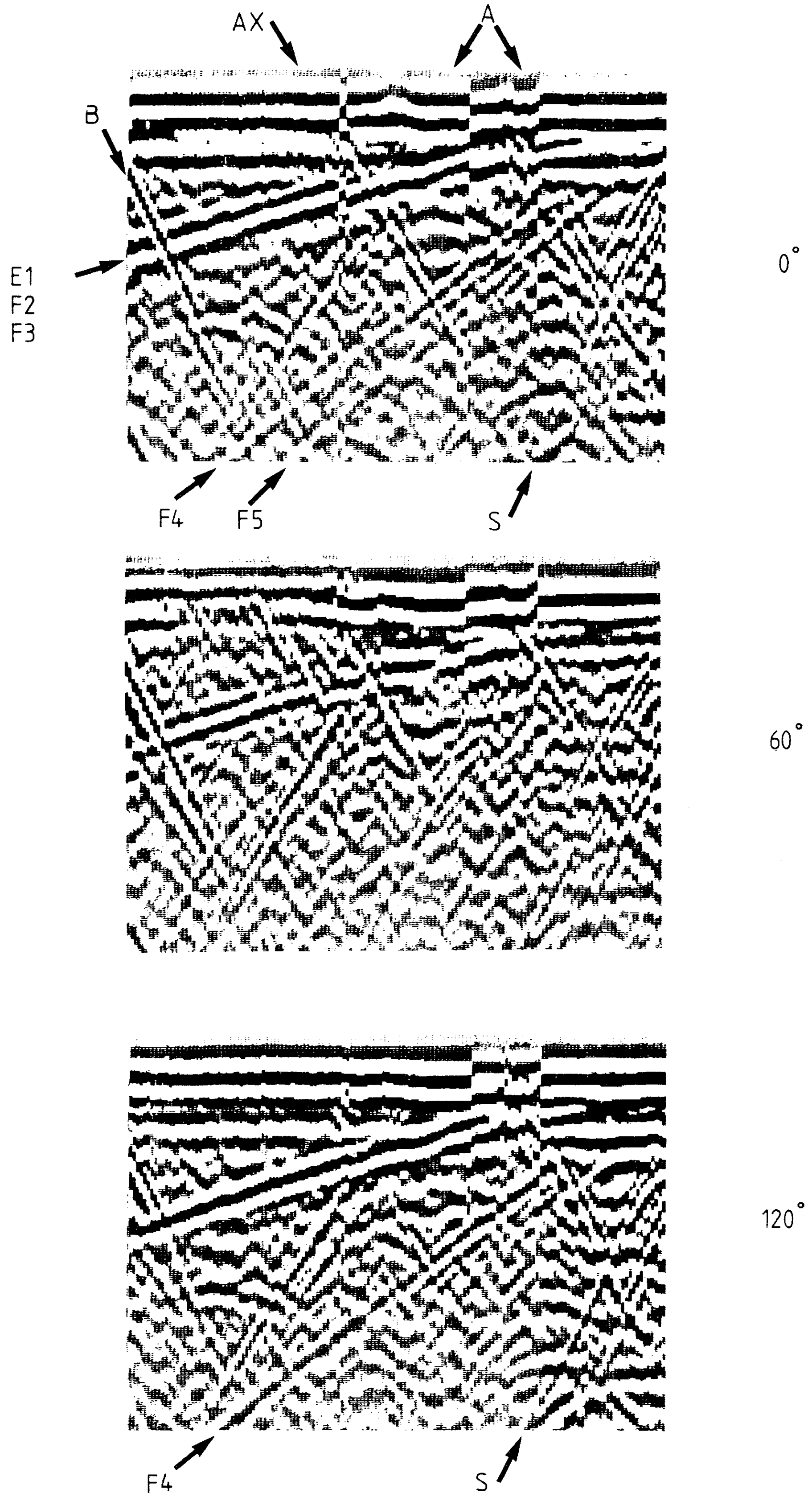


Figure 3-13. The signal of an idealised directional antenna calculated for three different orientations in borehole F1 in Stripa. Several boreholes (E1, F2, F3, F4, F5) and fracture zones (A, AX, B, S) are visible.

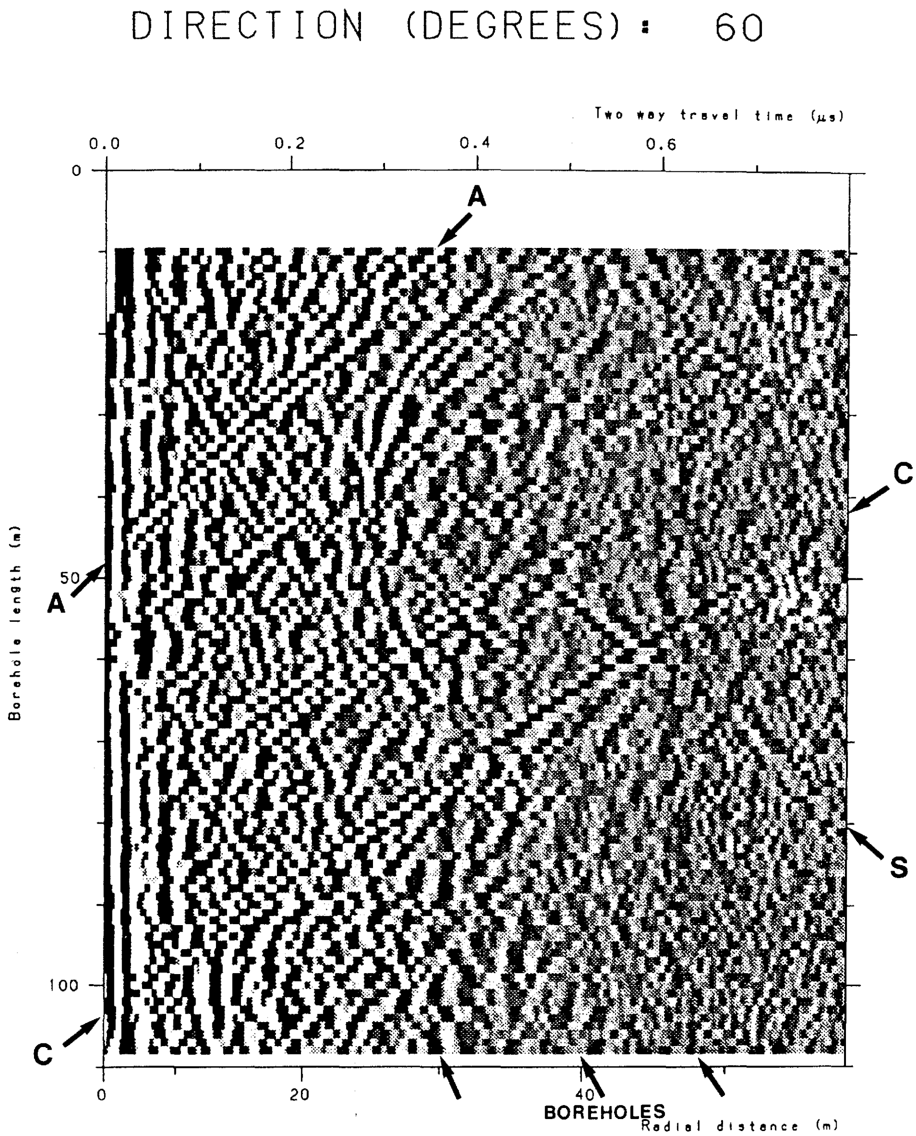


Figure 3-14. The directional signal measured in borehole F4 displayed for an angle of 60° on the direction indicator.

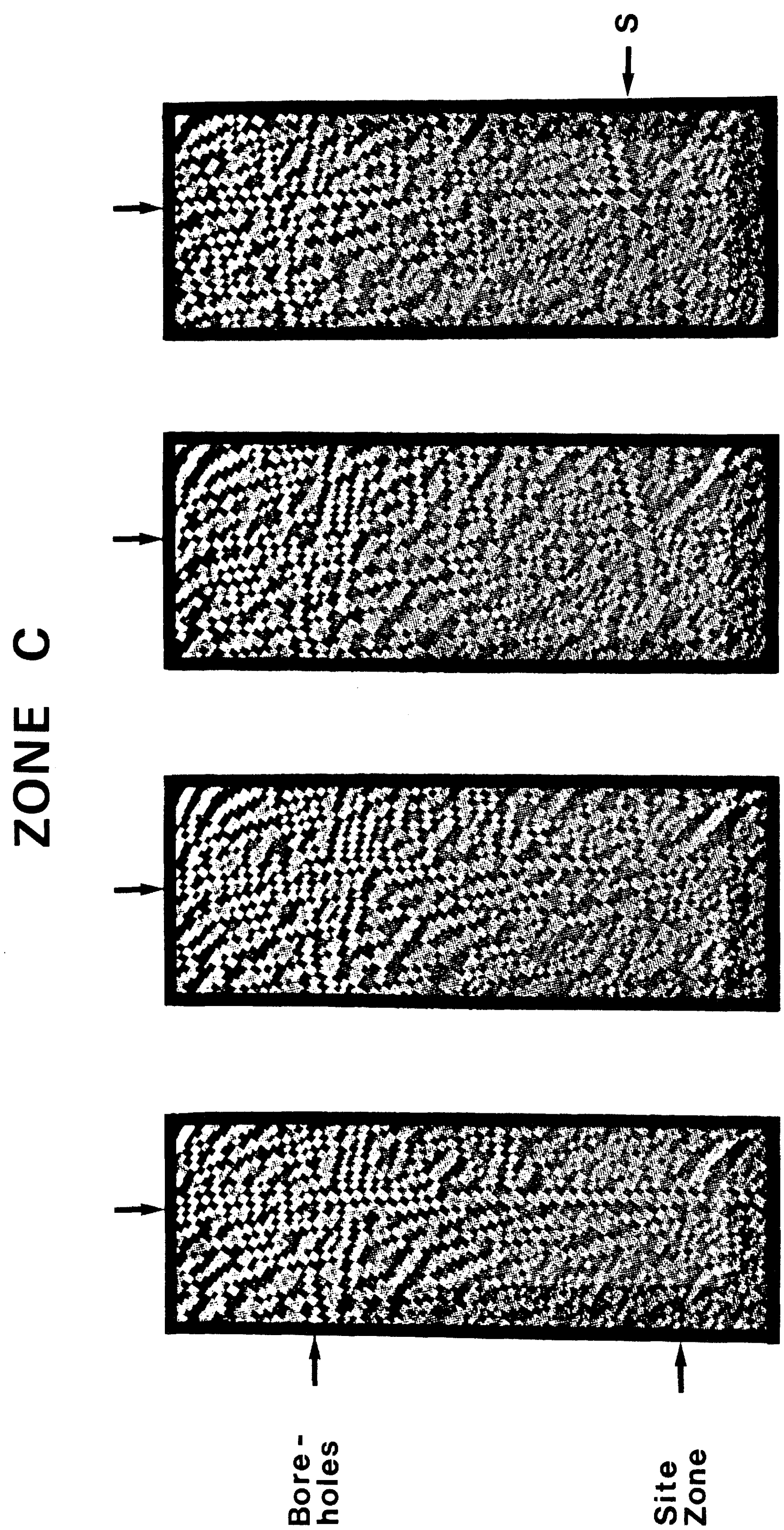


Figure 3-15. Radar pictures showing the variation in reflection strength when the antenna is rotated numerically. Zone C is the vertical reflection indicated by arrows. It is intersected by horizontal reflections from boreholes and the S zone.

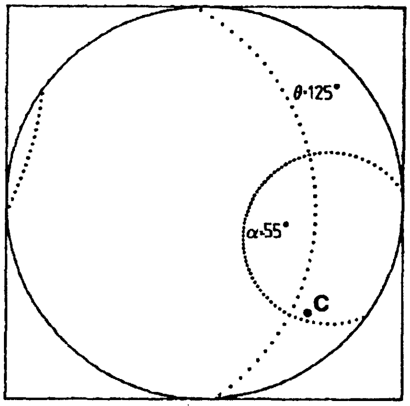


Figure 3-16. The orientation of zone C determined from directional (θ = 125°) and geometrical (α = 55°) data. The orientation derived from logging and core data is indicated by a point.

3.3 IMPROVEMENT OF TECHNIQUES FOR HIGH RESOLUTION BOREHOLE SEISMICS

3.3.1 The Coherent Source

A prototype of the coherent seismic source had been constructed and tested in Stripa already during 1987. The design of this prototype was extremely simple, the main role of this unit being to verify the applicability of the concept of coherent seismic emission. The tests had proven that using high frequency coherent signals is feasible in practice and leads to the increase of resolution of the seismic measurements. This first prototype was not meant to be used for a large volume of measurements.

To cover this requirement, it was necessary during the present reporting period to put efforts into a functional and reliable design of the source itself and to construct a system of accessories which would be both safe and handy to use in a real site environment.

Figure 3-17 shows the new model of coherent source used for the tests at Stripa. The minimum borehole diameter is 56 mm. The principle of construction is presented in Figure 3-18. Two piezoelectric transducers (5) face each other along the axis of the hole. They delimitate a water filled borehole segment (6) of a length adjustable by an electric motor (9) turning a screw (7) attached to one of the transducers. The frequency of the voltage which drives the transducers can be controlled from the surface. It is thus possible to achieve a resonance condition and the energy is conveyed to the rock with a high efficiency rate. If the segment of borehole in which the source is placed is not naturally water filled, one can use a packer.

A field data acquisition and processing unit had also been assembled during the previous reporting period around an industry (IBM) standard personal computer. This solution had been chosen considering the rapid development of this type of machines, the increasing number of hardware options and their wide availability.

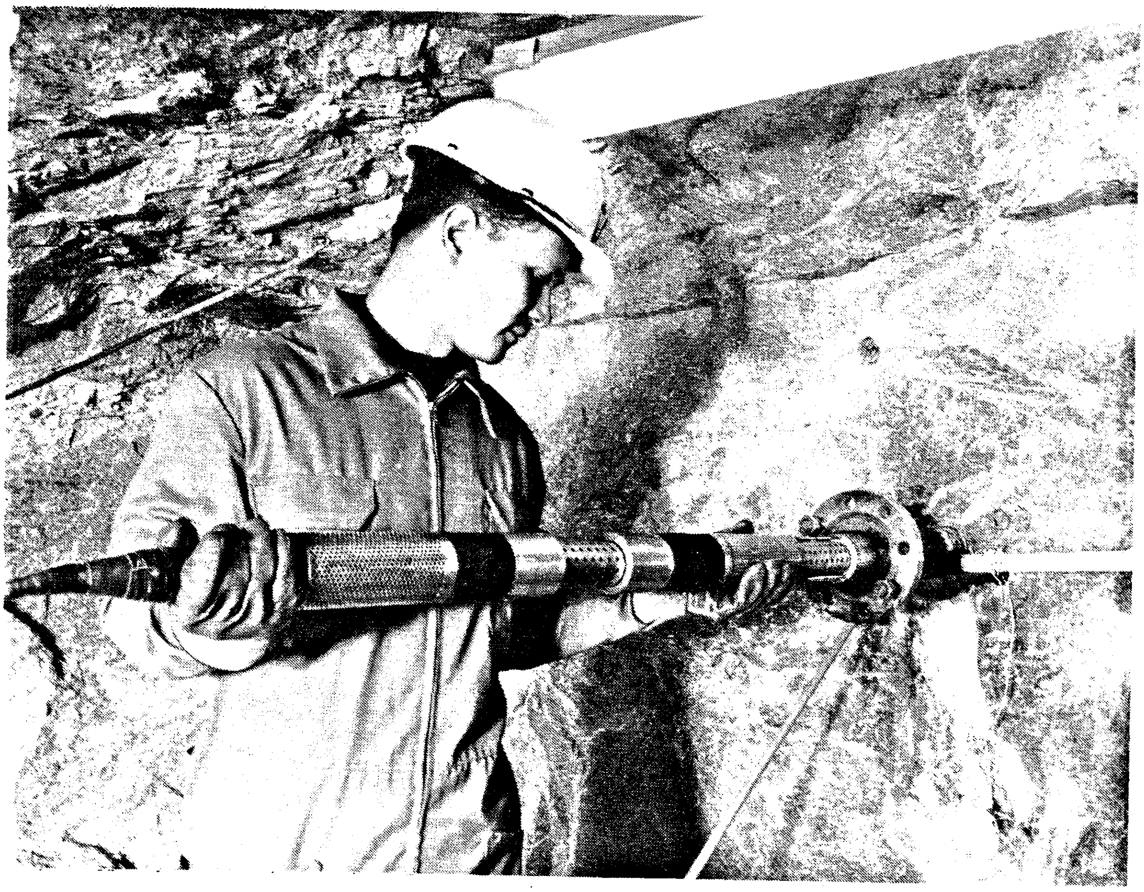


Figure 3-17. Coherent Source during Tests.

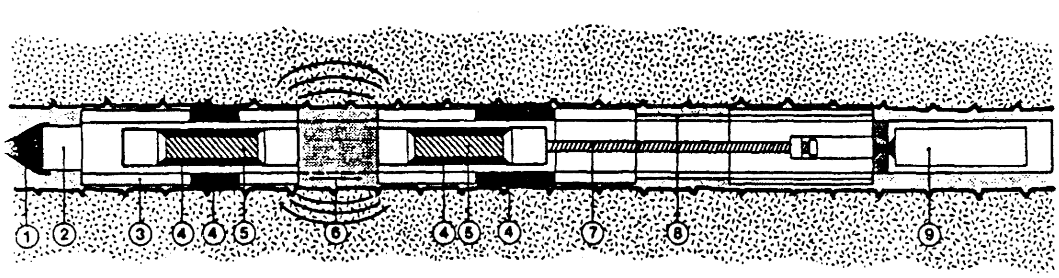


Figure 3-18. Principle of Construction.

1. Cable
2. Connector
3. Sleeveec
4. Rubber
5. Piezoelectric transducer
6. Resonant cavity
7. Screw
8. Adjustment screws
9. Electric motor

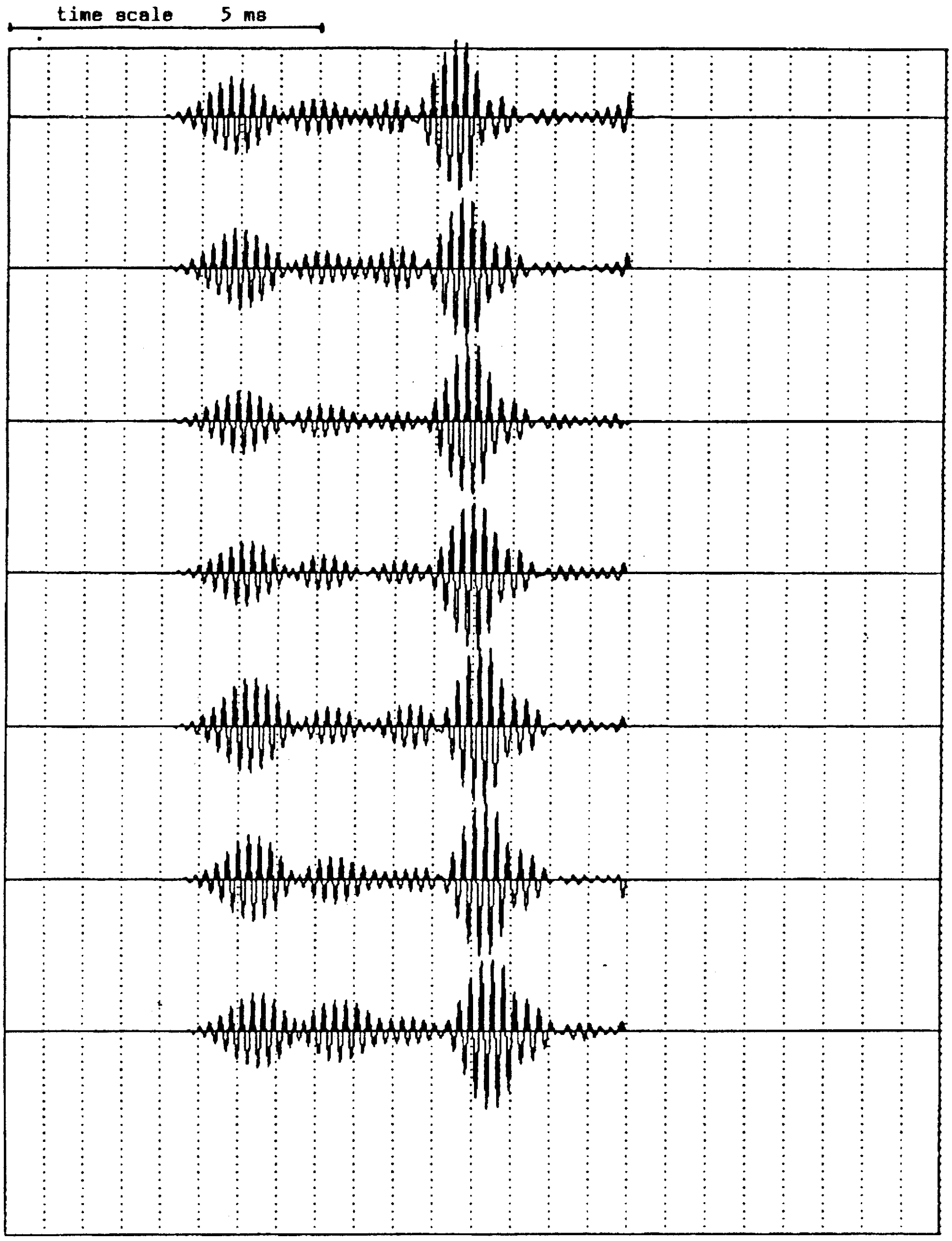


Figure 3-19. Seismogram signals.

It was thus possible during 1988 to add to the system a vector processor which increased the computational speed considerably. The increase of speed is necessary if data processing at site is to become a realistic option.

The data used previously to test and calibrate the software had mostly been borehole hammer data. The coherent source data, obtained during 1988, revealed new possibilities of using the higher frequencies and the stability of the source signal.

Figure 3-19 shows a set of seismograms recorded at Stripa by sliding the source in the borehole at a 0.5 m increment. The high frequency (6 kHz) gives a

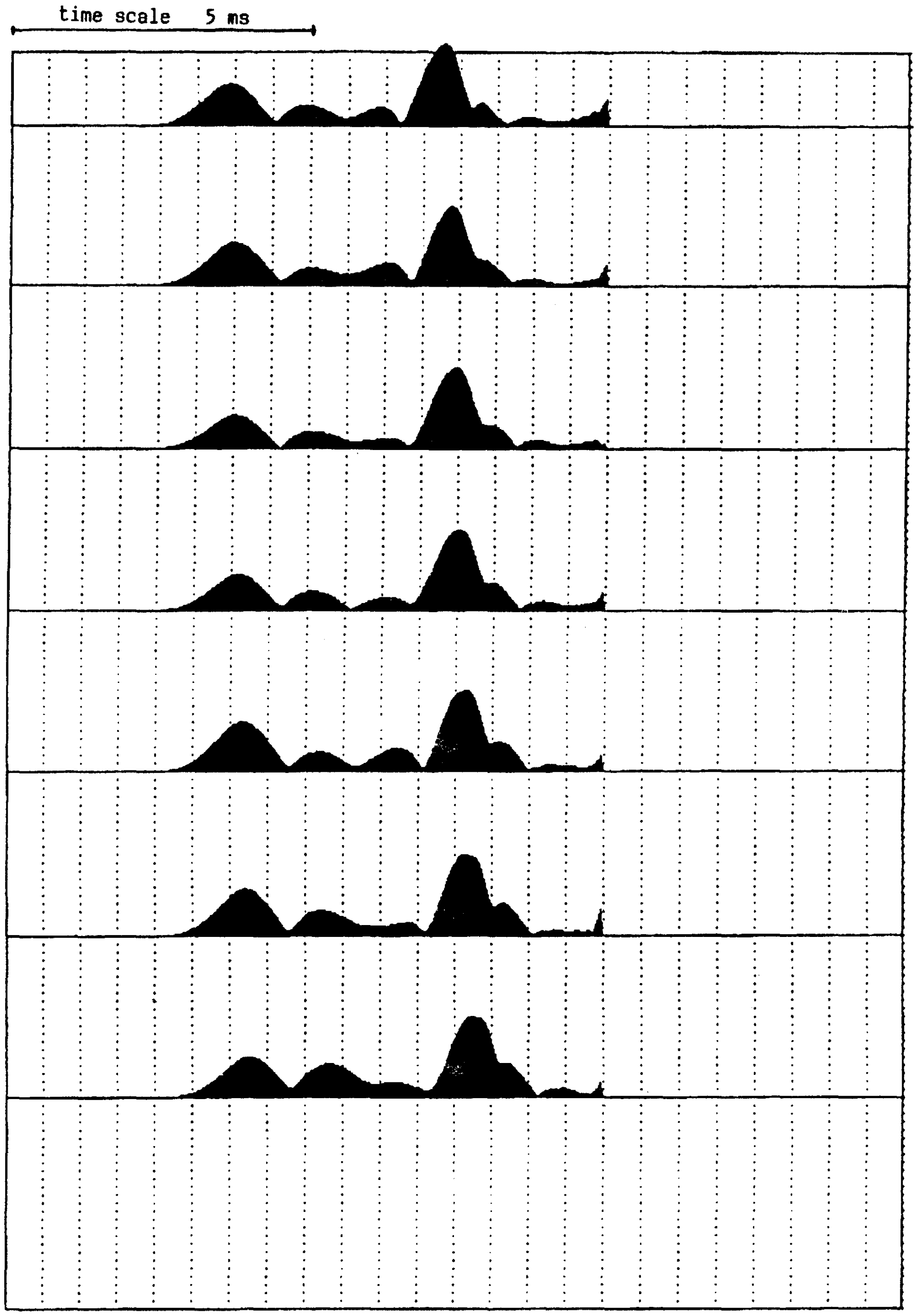


Figure 3-20. Envelopes of signals.

reliable travel time pick, the error being less than 0.05 % over a 200 m distance from source to receiver. This represents roughly a tenfold increase of accuracy with respect to the previously used techniques, which may lead to an important increase of resolution of velocity tomographic surveys. Figure 3-20 shows the calculated envelopes of the same signals. The energy traveling as p-wave can be accurately estimated, which opens the way towards seismic amplitude tomography.

3.3.2 Processing and Interpretation Routines

The software developed till the beginning of the present reporting period had been centered on an inversion procedure based on the P-Tau Transform. This approach produced good results in enhancing weak reflected events from features with very diverse positions and orientations in space. This had been an important obstacle to overcome, because the seismic industry had few established procedures applicable in crystalline rockmass. The work done during 1988 was aimed at refining the algorithms and rewriting the code for use on vector processors.

3.4 FRACTURE NETWORK MODELLING

3.4.1 General

Phase 3 of the Stripa project provides an opportunity to study a previously undisturbed volume of Stripa granite in great detail. It is important to understand groundwater flow and transport through such rock, since hard, fractured rocks provide possible locations for radioactive waste disposal sites. Field experiments involving tracer transport in fractured rocks have not been fully explained using conventional continuum approximations such as Darcy's law. In these rocks, groundwater flow and transport takes place primarily through a network of connected fractures and it is hoped that a more direct model might build understanding. One of the goals of Phase 3 of the Stripa project is to validate the fracture network approach. In this approach we calculate flow and transport through fracture networks, which are generated numerically to exhibit the same statistical properties as those measured in the rock. We must show that important properties of the flow field depend only on these statistics and are independent of details of the individual fractures which make up the network. Further, we must show that all the necessary input data for the models can be collected and that the results we calculate are accurate and in agreement with the field measurements.

The Stripa project sponsors the fracture network modelling work carried out by the Harwell Laboratory of the U.K.A.E.A; a collaborative effort is provided by the U.S. Department of Energy — at Lawrence Berkeley Laboratory and Golder Associates. At the 1988 Joint Technical Committee meeting, a Modelling Task Force was set up. This forum aims to coordinate the work of the three modelling groups, recommend criteria for the verification and validation of their numerical models, and to facilitate the wider dissemination of progress in the development of this approach amongst the countries participating in the Stripa project. The first two meetings of this group took place in California and Kyoto, and have already led to a much better understanding between the groups and a coordinated research programme. The following sections describe the progress we have made in developing our numerical models and in applying them to the Stripa site. We conclude with a description of the preliminary work that will lead to our predictions of the experimental results. This prediction will form the basis of the validation of our approach.

3.4.2 Development of Computer Codes

The Stripa project funds the development of the NAPSAC computer code at Harwell. During 1988, NAPSAC has been extended from what was primarily a research tool, into a computer code that can be used to simulate real experimental sites. This has involved a significant enhancement of the data structure of the computer code. NAPSAC can now simulate flow through quite general geometrical regions composed of a number of distorted cuboids. This particular geometry was chosen so as to facilitate the interface between regional simulations using finite-element models, and the boundaries of NAPSAC models which, because of their numerical complexity, must generally simulate relatively small regions. Within this new data structure, we have considerably extended the range of output options. These include options to perform trace mapping and core logging within the numerically generated networks. This will enable us to check the consistency of the fracture data interpretation techniques. We can also plot contours of the pressure head on selected planes in the network: a first step towards visualising the calculated flow fields. Two simple examples used to test the new features are shown in Figure 3-21.

We have begun the documentation of NAPSAC and have demonstrated the portability of the NAPSAC package by installing it on a Convex computer at Lawrence Berkeley Laboratories and on a Cray XMP system. These two tasks are required if we are to transfer the technology we are developing to the countries participating in the Stripa project.

Golder Associates use their PC based interactive fracture network generation code, Frac Man; and a fracture-water flow and solute transport code, MAFIC/T. Their development work related to the Stripa project has focussed on developing more realistic fracture network generation schemes. These include schemes which model fracture termination modes, and also allow correlations in the fracture locations. This allows for the stochastic generation of fracture clustering and of fracture zones.

Lawrence Berkeley Laboratory have focussed their model development on an inverse approach, as opposed to the forward modelling of the other two groups. They have developed an annealing algorithm which they have applied to their hydrological modelling codes. The scheme first generates a very general 'template' model and then automatically constrains this network using hydraulic, geophysical and geological data.

The inverse approach requires cross-hole data, spanning the modelled region. Where this is available, the algorithm developed by Lawrence Berkeley Laboratories provides a very elegant scheme for fully utilising data directly from hydraulic and geophysical experiments.

Finally, as part of our computer code development, the three groups have prepared a report defining a plan to verify their respective computer codes. The plan includes test cases to verify the accuracy of the network generation schemes and of the flow calculations, using a mixture of analytical results and cross comparison between the independent compute codes. Preliminary results, prior to the final definition of the test cases, indicate broad agreement between the programs although they have served to highlight the approximations used by the three computer codes.

3.4.3 Data Interpretation and Experimental Support

Network models have quite different data needs to more conventional models. The data to be used is mainly in the form of probability distributions of local properties of the fractures. Whilst such local properties are more amenable to measurement than bulk properties of fractured rock; the models require a great deal of data and the parameters of the probability distributions must be inferred from the measured quantities.

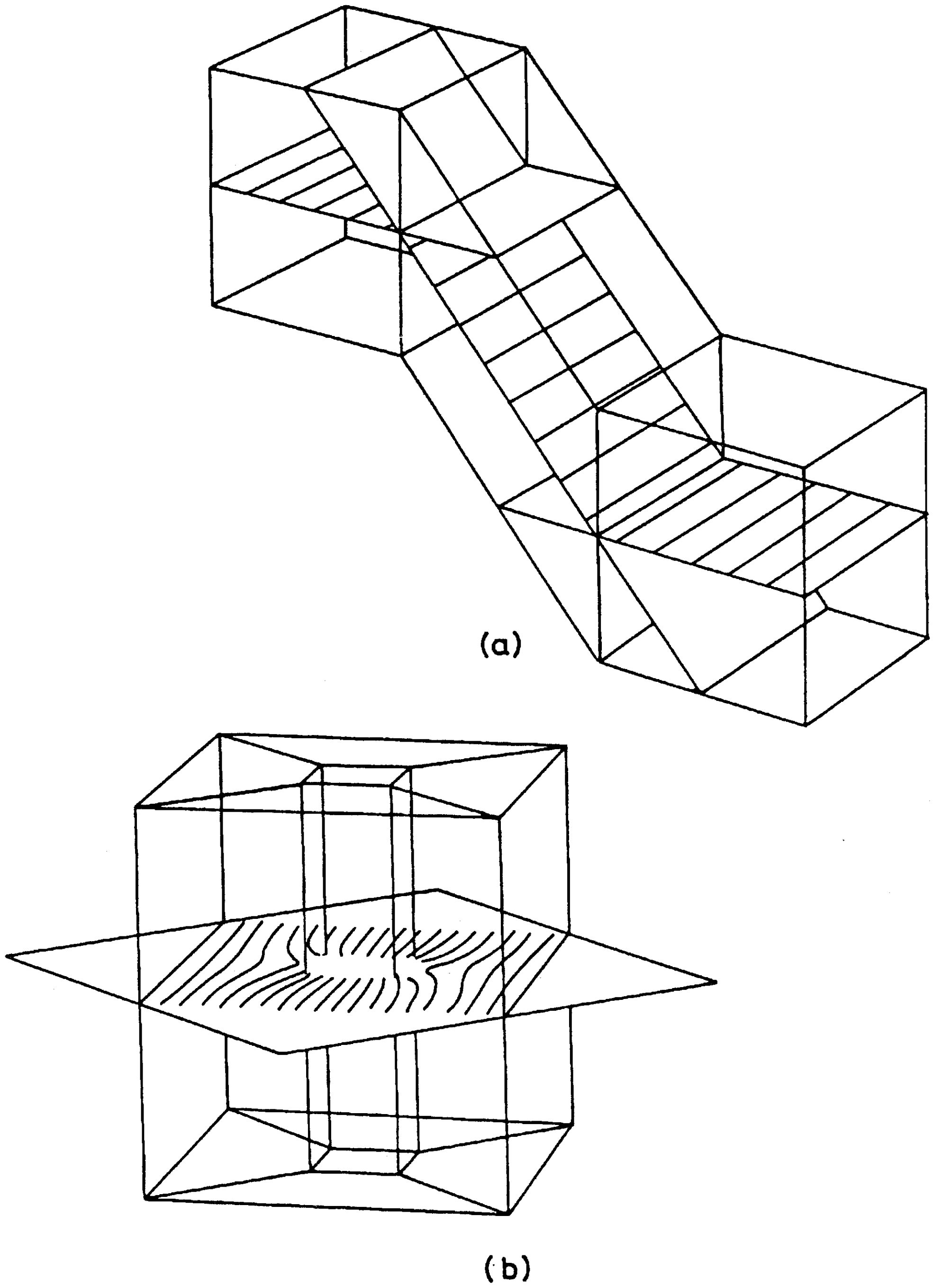


Figure 3-21. Two test cases illustrating pressure head contours on fractures within complex regions.

The hydraulic tests have been interpreted by experimental groups to give a transmissivity for each tested interval. Such intervals may contain several distinct fractures. Harwell and Lawrence Berkeley Laboratory have written a small program to calculate maximum-likelihood estimates of the parameters for the effective hydraulic transmissivity distribution. The program is based on the assumptions that the fractures intersecting a given measurement interval are independent and that all fracture transmissivities belong to a single gamma or lognormal distribution. Neither of these assumptions are strictly true; however, of more concern is the assumption of two-dimensional plate flow. If we use such a model, then we require an effective 'cross fracture' transmissivity. Golder Associates have performed numerical experiments, analogous to those performed in the mine, with different forms of aperture variation over the fracture plane. The results suggest that what has been measured is the transmissivity of the part of the fracture plane adjacent to the borehole. This may be quite different to the effective transmissivity of the plane as a whole. Their results emphasize the importance of having a conceptual model for the fracture which accounts for transmissivity variation or channelling. Lawrence Berkeley Laboratory, too, have been investigating the interpretation of transient well tests, proposing a fractal model. The modelling teams are actively involved in supporting the design and interpretation of the channelling experiments performed by Professor Neretnieks.

Example results, calculated by Golder Associates for two alternative conceptual models of the channelling experiment, are compared to preliminary experimental results in Figure 3-22.

As well as hydraulic tests in the averagely fractured rock, there are a number of cross-hole tests proposed to study flow in the fracture zones identified by geophysics experiments. Lawrence Berkeley in particular are developing models of these zones based on geophysical and geomechanical evidence. Their inverse approach will be particularly useful when interpreting the hydraulic results, and they are supporting the experimental design.

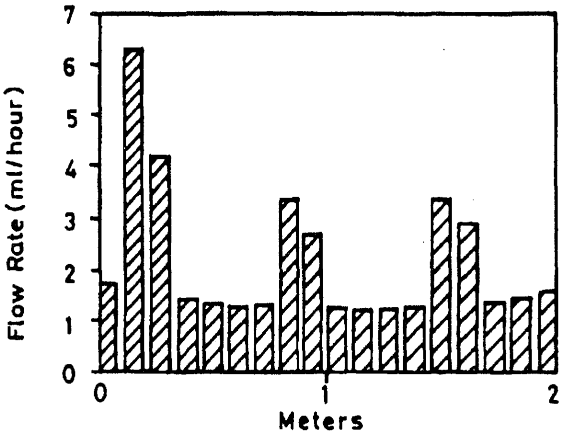
Lawrence Berkeley Laboratory have also been considering the difficulties of deriving fracture length data from distributions of fracture trace lengths observed on tunnel walls. As they show in Figure 3-23, very different length scale distributions may produce indistinguishable trace length distributions. To obtain the fracture length distribution from fracture trace maps, we will have to make a number of assumptions about the form of distribution.

A final area of concern which we have studied is the possibility of measuring correlations between the fracture data distributions. Auto correlations of orientation and of location are observed. A correlation between fracture aperture and length might significantly affect the predicted flows. One experiment where we hoped to measure this involved measuring fluxes into intervals along the D-holes and subsequently identifying the traces of flow-conducting fractures on the validation drift walls. Numerical simulation of this experiment by a Harwell and Lawrence Berkeley Laboratory team, and also by Golder Associates, indicated that the results for this experiment may be inconclusive. To get even a qualitative result would require a reduction in the interval size of the flow tests. Such a reduction is included in the latest plans and the data will, in any case, be collected, but our expectations for evaluating correlations are low.

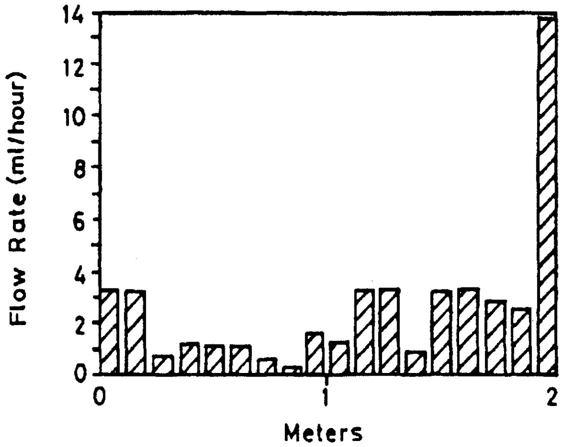
3.4.4 Predictive Modelling

The data required for our network models of the SCV-site was not yet available at the end of 1988 and so models were being constructed with preliminary datasets. It became clear that major revisions would be required to these datasets and so, for economic reasons, work with preliminary datasets was restricted.

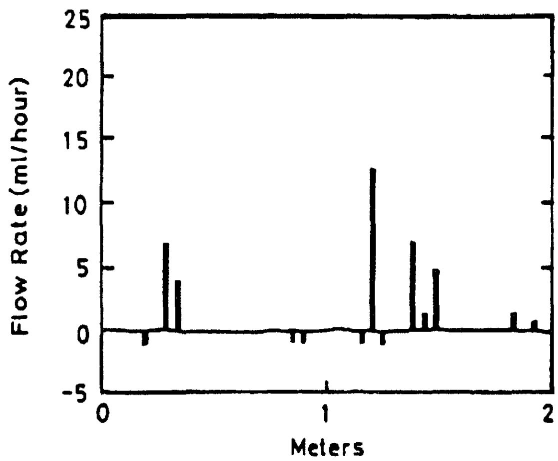
Harwell's work on the preliminary dataset was restricted to considering representative volumes of rock containing networks realising the observed fracture property distributions. Not all fractures could be accommodated within our net-



(a) Simulated Flow Distribution, Strong Linear Channels

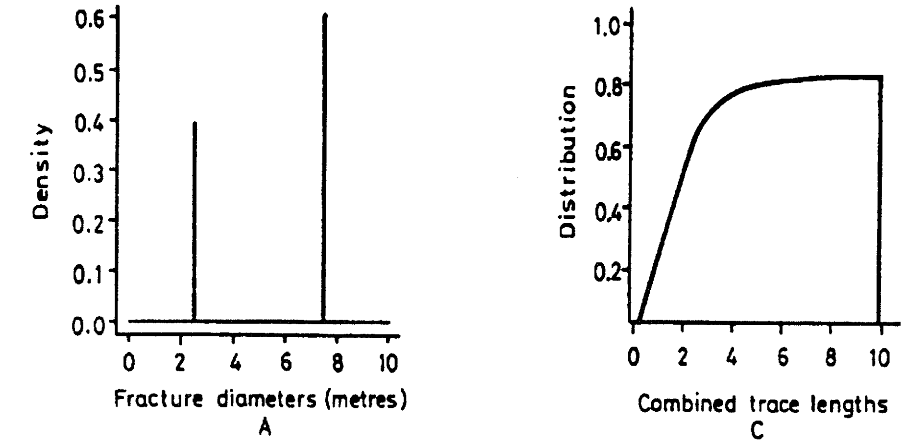


(b) Simulated Flow Distribution, Random Transmissivity Distribution

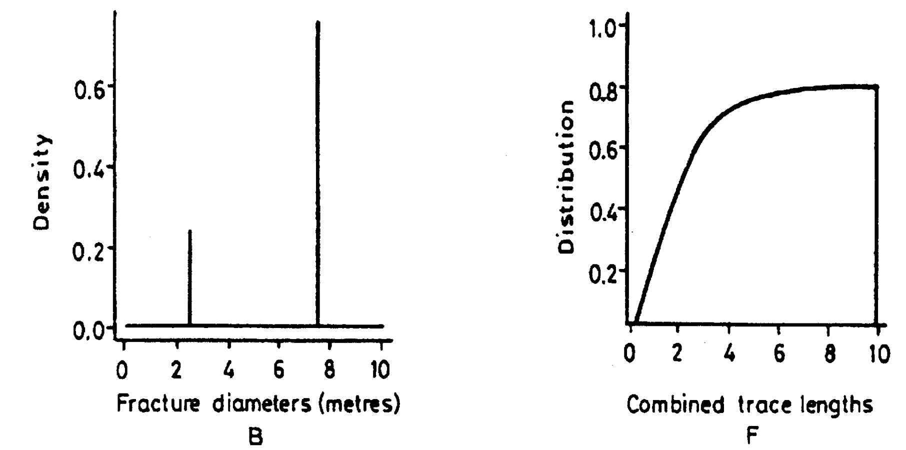


(c) Example Experimental Flow Distribution

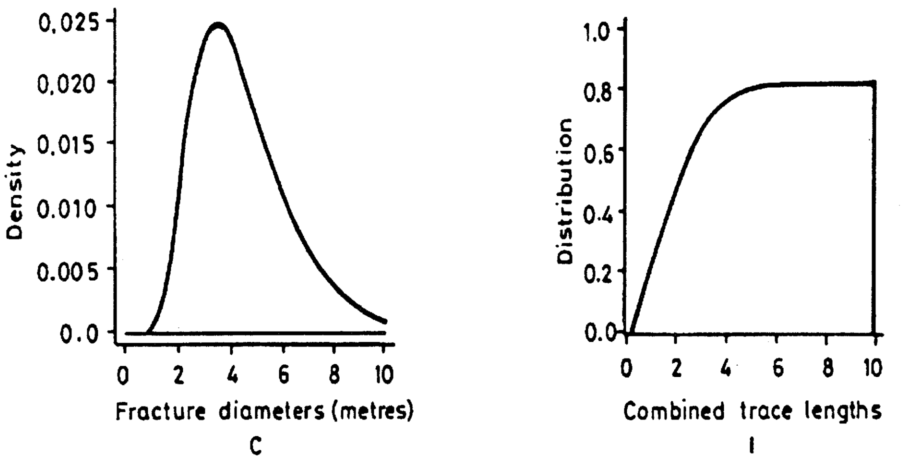
Figure 3-22. Comparison of numerical simulation and experimental results for the channelling experiments.



a) Trace Length Distribution, from a Fracture Set With 40% of the Diameters Equal to 2.5 Meters, and 60% of the Diameters Equal to 7.5 Meters.



b) Trace Length Distribution, from a Fracture Set With 24% of the Diameters Equal to 2.5 Meters, and 76% of the Diameters Equal to 7.5 Meters.



c) Trace Length Distribution, from a Lognormal Fracture Set With a Mean Diameter of 4.5 meters.

Figure 3-23. Three very different fracture length distributions and the corresponding trace length distribution.

work models, and indeed it is inefficient to model the many fractures that play an insignificant role in the groundwater flow system. We therefore aimed to assess the effect of truncating the observed transmissivity or length scale distributions, so as to include only the most transmissive or the longest fractures in our models. This approach depends upon sensitivity studies demonstrating that we are including sufficiently many fractures to account for the bulk permeability of the rock. Sensitivity studies were carried out which indicated that choosing the longest, and so most highly connected, fractures led to an excessively complicated numerical problem. NAPSAC could only include some 3000 fractures: far too few. When considering the most conductive fractures, results were more promising. With some 10,000 fractures in the model we could accommodate nearly 2% of the fractures in a 50 m cube of rock based upon the preliminary dataset. This was still too few. However, in the latest dataset there is a lower fracture density, and we are optimistic that we can accommodate more than 5% of the fractures. Harwell estimates that this proportion of the fractures will carry the bulk of the flowing groundwater. A further outcome of this study was that an unphysically large permeability was predicted when fracture aperture was correlated with fracture length-scale. This does not entirely rule out such a correlation since the assumption of parallel-plate flow most likely implies an unphysically high connectivity in the network. However, this interpretation of transmissivity is consistent with the parallel-plate flow assumption and for the present we shall continue with this approach, and also assume that apertures and lengths are uncorrelated.

The boundary conditions for our network models will need to be specified around the edges of the SCV-site. There are no 'natural' boundary conditions here and so they will be provided by a continuum, porous medium, 'mine' model which extends to include the mine workings which are at fixed atmospheric pressure. This model, in turn, takes some of its boundary conditions from a more regional model which extends out to natural flow boundaries. The mine model has been constructed by Professor Gale, and, since it contains a number of elements around the validation drift, can be used as a predictive tool itself. The geophysically identified fracture zones are presently being properly incorporated in the model. Flux predictions and boundary conditions for network modelling will shortly be available.

The other two groups have also been awaiting data for their models, and in the meantime have been considering alternative approaches. Golder Associates have developed a stochastic continuum model of the region surrounding the drift, accounting for heterogeneity of the medium by a stochastic variation of finite-element block permeability. The stochastic properties of these blocks can be derived from smaller scale discrete fracture simulation or from conventional hydrologic approaches. This model can make predictions of flow distributions in the same was as a network model. Finally, Lawrence Berkeley Laboratory have started to develop a hydrologic model of the SCV-site, in which 80% of flow is modelled by only 7 heterogeneous, planar features representing major fracture zones. These major features are based upon, but not identical to, zones defined by current geophysical interpretations. As a result, Lawrence Berkeley Laboratory have reinterpreted the geophysical and hydraulic data to better account for hydraulic features encountered in boreholes. Well tests in these zones will be interpreted using their inverse techniques and a fractal template for transmissivity variation in the zones. This will complement their idealised fracture-network template model.

3.5 CHANNELLING EXPERIMENT

3.5.1 General

Model calculations show that channelling may have a strong detrimental effect on radionuclide transport because fast channels may carry some of the mass of the nuclides considerably faster than the average flow would and may give this portion less time to decay. Channelling further aggravates the retardation of sorbing nuclides because less surface area for sorption is available in a channel within a fracture than if the whole fracture surface area is exposed to the flowing water.

The objectives of the experiment are:

- o To study channelling Properties within single fractures (single hole experiments).
- o To study interconnection and mixing between channels within a single fracture (double hole experiment).

Frequency of and distance between channels will be studied in the single hole experiments, where up to 10 holes in several fractures will be investigated. These experiments will give information along two lines in the fracture plane.

The interconnection and mixing between channels, fracture aperture and dispersion will be studied in one selected fracture, which previously has been investigated with a single hole test. A second measuring hole will be drilled at a 1 to 2 m distance. Pressure pulse tests as well as tracer injections will be utilized in the double hole experiment.

3.5.2 Equipment

The equipment for the channelling experiments can be divided into four major parts, namely:

- o Packer system in injection hole
- o Water injection system with flow meters
- o Data acquisition system
- o Bore hole camera

The packer system consists of an outer packer which seals off the injection hole from the drift and an inner packer which has 40 rubber cups, 20 on each side, which can be individually adjusted to fit over the fracture intersection, see Figure 3-24. It is also possible to seal off the innermost part of the hole which is not covered by the individual rubber cups. Each rubber cup has its own piston by which it is pressed against the wall of the borehole.

By moving the packer system and selecting which 20 cups to monitor individually, the injection flow rates over 5 cm sections along the intersection with the fracture plane can be monitored separately on the left and right side. The packer system has a total length of 2.5 m of which 2 m is used for the actual measurements. The weight is approximately 100 kg. To facilitate the individual positioning of the rubber cups, the borehole is scanned with a primitive borehole periscope with which it is possible to get the location of the fracture as a function of borehole depth.

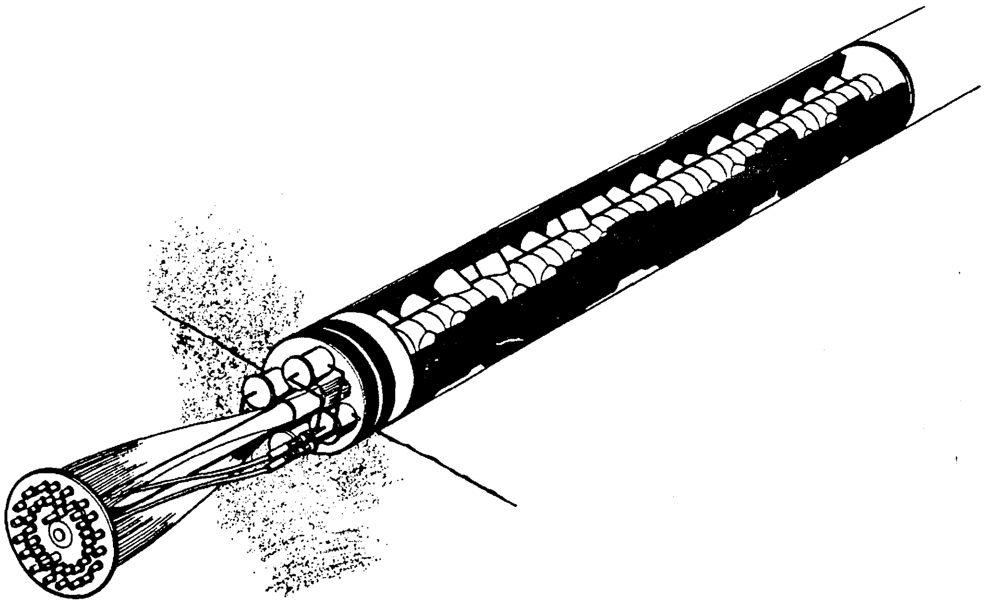


Figure 3-24. Packer system.

The water is injected with a constant over-pressure obtained from compressed nitrogen. Individual injection pressures can be set for 20 selected rubber cups. The injection flow rates were planned to be monitored in three groups, (1) the water flow which enters the uncovered part of the hole; (2) the sum of the water flow to 20 of the rubber cups; (3) the individual injection flow rate to the other 20 rubber cups.

Preliminary tests showed that it was difficult to distinguish between flow monitored by method (1) and (2) due to their interaction. For this reason separation of flow monitoring has been abolished. Injection flow rates of type (1) and (2) are now monitored together by a precision balance, see Figure 3-25.

To make sure that the monitored flow from the rubber cups actually enters the fracture of interest and not leaks past the rubber cup and into some uncovered part of the hole, a slightly lower (10 cm water head) injection pressure is applied when injecting water to the individually monitored rubber cups.

As the uncovered part of the fracture between two rubber cups will be subjected to a 10 cm higher water head there will be a pressure gradient within the fracture plane parallel to the axis of the hole. This pressure gradient may cause flow from uncovered to covered parts and thereby influence the injection flow rate from the rubber cups. To avoid this, the packer has been modified to cover the whole intersection of the fracture plane except for the 5 cm measuring sections.

The individual injection flow rates are monitored using a differential pressure transducer which registers the emptying of a vertical measuring tube. The measuring tubes are interchangeable so that tubes of different diameters can be used to accommodate a large range of flowrates, see Figure 3-26. The measuring tube is automatically refilled when a preset low level is reached. The monitoring

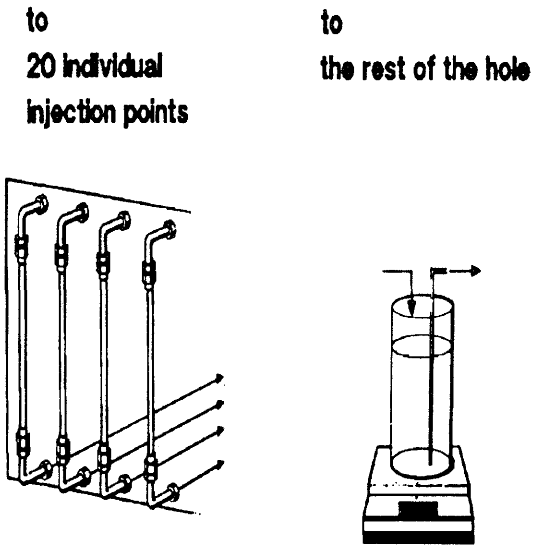


Figure 3-25. Injection flow monitoring.

system is equipped with 20 measuring tubes, i.e. 20 rubber cups at a time can be individually monitored. The injection system is designed for injection pressures up to 0.5 MPa. Injection flow rates down to a few hundredths of a milliliter per hour can be monitored.

All injection pressures are kept constant with time within a few cm of water head. As the injection pressure is the sum of the applied nitrogen pressure and

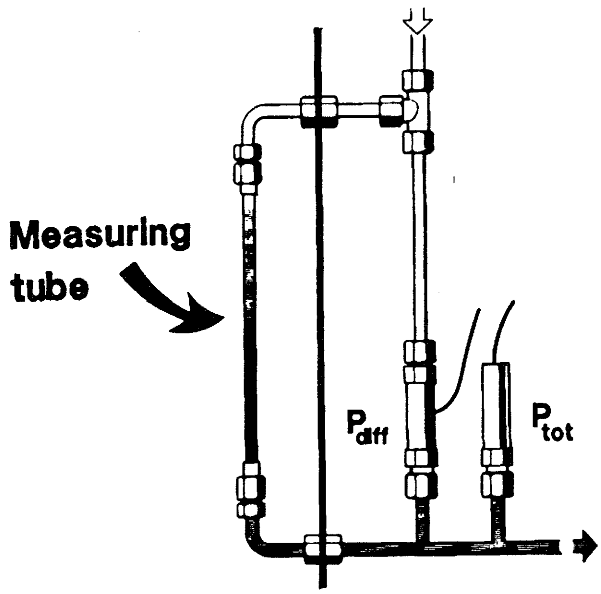


Figure 3-26. Individual flow monitoring.

the height of the water pillar in the measuring tube, the applied nitrogen pressure has to be individually adjusted with time. The computer code now includes this individual adjustment of applied nitrogen pressures. Speed and memory requirements have changed during this year. A HP 9816 is now used instead of the earlier HP 85 computer.

Time, total injection pressures as well as the changes in the differential pressures are registered and stored on magnetic disks. During start-up and ending of a test, settings of all the essential valves and diameters of the tubes as well as total water volume are automatically registered and stored. All data are stored in HP LIF format on magnetic disks and can easily be converted to IBMI PC format.

To facilitate the selection of suitable holes to be measured by the multi injection packer system, a coarse injection packer system has been designed with which a hole can be tested in 20 cm intervals during one workday. This monitoring system consists of just a few parts and is easily movable.

To be able to compare water injection flow rates into the fracture with fracture characteristics, a bore hole camera is used. It consists of a NIKON F501 with a flash unit CB 21 mounted on a specially designed sleigh. The hole is photographed in 7 cm sections. The photographs are of high quality and fracture openings down to a few tenths of a millimeter can be seen.

3.5.3 Activities during 1988

Five large diameter holes (Ø 200 mm) have been drilled during 1988 for single hole experiments. The first hole was used for testing equipment and injection methods. Based on these results the equipment has been modified as mentioned above. Four of the five holes have been measured with the coarse injection packer system. Two have been tested with the multi injection system.

All five holes have been photographed with the borehole camera.

The major efforts during this year have been modifications of equipment, transferring and refinements of computer codes.

3.5.4 Results and Discussion

The first fracture was tested with the multi injection system and it was not possible, with moderate injection pressures, to obtain flow rates higher than a few tenths of a milliliter per hour. This fracture can be considered as sealed and of no interest regarding water flow, however, channelling effects could be noticed.

The second hole was drilled in another fracture at the same site (single fracture migration site). This fracture showed pronounced channeling and had individual flowrates up to 15 milliliters per hour, see Figure 3-27.

These two fractures, looking similar from the drift, showed different flow behavior. This has implications on future measurements as one has to make certain that the movement of the multi injection monitoring system is worth the effort. To be able to select/reject future holes for multi injection measurements, an easily movable fast scanning device has been constructed. As soon as the hole has been drilled and photographed it will be scanned by monitoring flow rates in 20 cm intervals. These results will show if the hole has flowrates of interest.

The location of channels obtained with the scanning packer compare well with those obtained with the multi injection system.

All holes except the first one, being tight, has been tested with the scanning packer. The same effects as found in the first two holes monitored by the multi

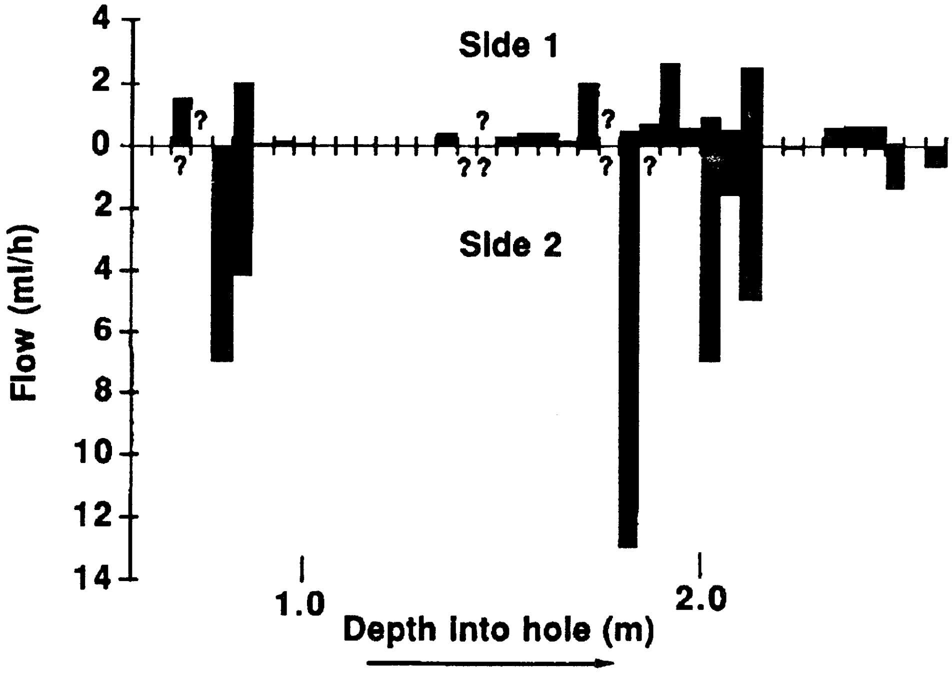


Figure 3-27. Injection flow rates in fracture 2 vs. depth.

injection system have also been found in those holes only monitored by the scanning packer, i.e. one was tight and the flow in the two other holes was only in a few sections within the holes.

Out of 5 tested prominent fractures, two were so tight that no or little water can be injected and the rest showed flow over minor parts along the fracture intersection.

Due to the initial problems with the equipment and measuring methods the project is delayed 3 months.

3.6 ESTIMATION OF FRACTURE LENGTH AND APERTURE FROM SINGLE FRACTURE WELL TESTS

3.6.1 General

The objectives of the experiment are to obtain information on the length and interconnection of fractures from single fracture well tests in the Phase III study area. The tests have been run using constant pressure methods while recording the transient flowrate. Two approaches are being used. One involves the detailed interpretation of constant-pressure well tests, the other is an analysis of the distribution of transmissivity values from well tests performed with fixed packer spacings.

The main activities of task were (1) completion of data acquisition in the W holes with BGS (2) estimation of the statistics of conductive fracture frequency and transmissivity from equally-spaced well tests in the N and W holes, and (3) analysis of the transient flow records from individual tests to determine evidence for boundaries and flow dimension.

3.6.2 Frequency and Transmissivity of Conductive Fractures

Two key parameters in the modelling of fracture flow are the distributions of the frequency and transmissivity of individual fractures. These parameters are not easily estimated directly from well test data, as test zones seldom intersect single fractures, and where multiple fractures are intersected, it may be difficult to determine which or how many are hydraulically conductive.

The methods of Snow (1971) for estimating spacing and transmissivity distributions of fractures from fixed-spaced tests have been expanded upon by Osnes in Doe and others (1988) and Osnes and others (1988) to provide less biased methods of estimating the parameters of the frequency and transmissivity distributions of individual fractures. These methods are used here to evaluate data from the N and W holes. The Osnes and others (1988) approach assumes a negative-exponential distribution of spacing and a gamma distribution of transmissivities. The gamma distribution was chosen for its similarity of form to the lognormal distribution and its mathematical tractability. Osnes and others (1988) then use a maximum-likelihood approach to determining the conductive fracture frequency and the scale and shape parameters of a gamma distribution of fracture transmissivities.

The results of analyzing the fixed-spaced tests for the W- and N-holes are presented in Table 3-2. The results indicate that conductive fractures are more frequent in the N-holes than the W-holes, however, the fractures in the W-holes are more conductive. The results vary depending on the packer spacing. The calculated spacing of conductive fractures increases with packer spacing. This variation may reflect a bias in the selection of the test zones. The calculations were made using only directly-measured test values and do not include transmissivities inferred from the reduction of the "focussed" tests. Thus there may be a bias in the 3-m and 1-m data, as these tests were only performed when a conductive zone was identified. The discrepancies between results at different packer spacings may also reflect leakage in the tests, either in the equipment or, more likely, in the rock itself back to the borehole.

Table 3-2. Fracture spacing and transmissivity statistics based on tests in W and N holes at Stripa: transmissivity limit is 10^{-11} m^2/s.

	Spacing m	CFF m^{-1}	Mean T m^2/s	Var T m^4/s^2	Scale s/m^2	Shape m^{-1}
N-Holes						
1-m	0.56	1.8	6.8E-9	5.8E-16	1.2E+7	8.1E-2
3-m	1.09	0.92	1.9E-8	7.6E-15	2.5E+6	4.7E-2
7-m	1.85	0.54	1.4E-9	3.8E-17	3.8E+7	5.5E-2
W-Holes						
1-m	0.75	1.4	1.1E-8	1.2E-15	9.1E+6	1.0E-2
3-m	1.14	0.88	1.1E-8	1.6E-15	6.8E+6	7.2E-2
7-m	2.08	0.48	1.7E-8	4.3E-15	4.0E+6	7.0E-2

CFF = conductive fracture frequency
Shape and Scale = Parameters of Gamma distribution of T

3.6.3 Detailed Analysis of Well Test Data

The tests have been performed by several methods. High conductivity zones were tested using constant-pressure injection or withdrawal, where the constant pressure is controlled by the test system. For lower conductivity zones, the control system did not provide a sufficiently-constant test zone pressure. An alternate procedure was then used, which essentially was a slug test performed while monitoring the flow rate (slug-as-head test). This method was effective where the conductivity was sufficiently low that the head in the slug-test line did not change significantly during the test. In the conductivity range of about 10^{-10} to 10^{-9} m/s, the head changes during the test were appreciable (several percent) and the constant-pressure condition was not strictly maintained. The analysis of these tests requires use of multi-rate methods which are described below.

A major drawback to the use of constant-pressure or constant-rate tests underground is the problem of variable background pressures. The opening and closing of boreholes during testing can introduce transient-pressure conditions in the rock mass which violate the test analysis assumptions of a uniform pressure in the aquifer being tested. The transient effects associated with the background pressure variation especially influence the data from late in the testing period, where boundary effects and heterogeneous permeability conditions are most likely to appear. Unless background pressure variations are recognized, boundary-effect interpretations may be in error.

The problem of transient background pressures was recognized by John Black and was one of the motivations in developing sinusoidal methods. It also affected the selection of pulse and slug tests for testing underground. In using pressure decay methods, however, one loses much of the ability to recognize boundary effects and permeability variations.

One solution to this problem of interpreting constant-rate and constant-pressure tests is to use multi-rate analysis methods as described in Streltsova (1988) and Earlougher (1977). These methods treat test data where the production or injection pressure and the flowrate are both varying with time. In this case, production pressure would be the difference between the wellhead pressure and the extrapolated trend of the background pressure. The multi-rate approach divides the test into a number of sequential constant-rate steps. The pressure behavior in the well reflects the superposed effects of these steps. Recognizing the superposition of these steps allows correction of the data to an equivalent test conducted at a constant rate throughout. The corrected data may be analyzed using conventional constant-rate interpretation methods. Multi-rate methods also provide solutions to data from the "slug-as-head" tests run in W1 and W2 by BGS.

We have written a PC-program for making the multi-rate corrections and are using it to re-analyze those tests that were affected by variable head conditions. Multirate analysis approaches may prove very useful in analyzing tests performed in the presence of variable background pressures (such as in underground facilities) or where constant-rate or pressure conditions are difficult to maintain.

Closed boundary effects, that would indicate finite fractures, have not been noted in the tests analyzed from the W and N holes. There is, however, diversity in the dimension of flow from the constant-pressure tests. The results from tests in higher conductivity zones commonly show non-radial flow behavior. While such tests may reflect radial flow with conductivities increasing with distance, many appear to have spherical flow based on straight-line behavior on plots using the inverse square-root of time (Figure 3-28).

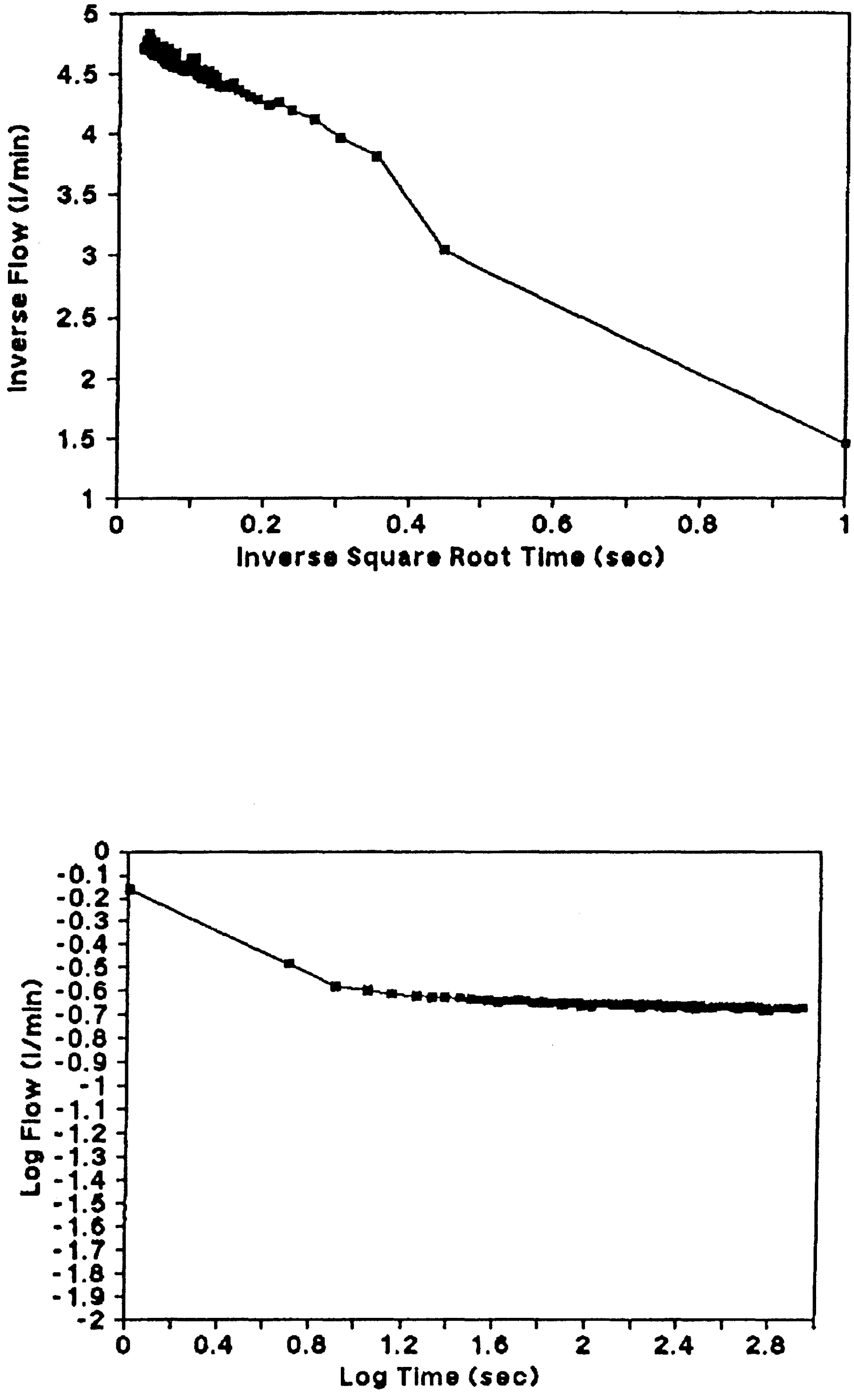


Figure 3-28. Example of spherical flow (as shown by inverse square-root time plot); (Note possible half-slope in very early-time data).

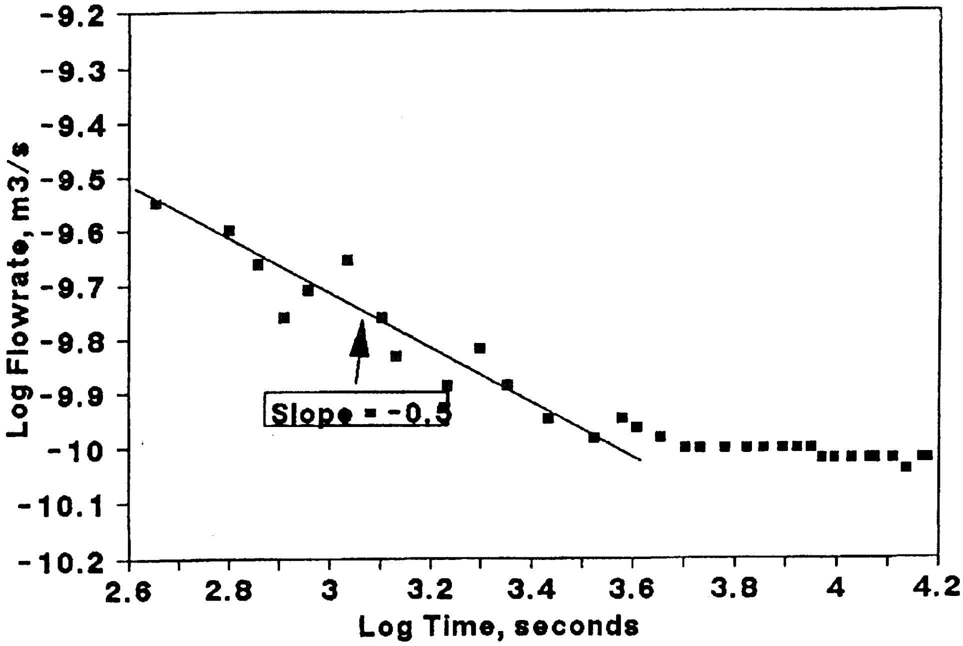


Figure 3-29. Example of linear flow (half-slope) with constant pressure boundary.

One criterion for selecting zones for detailed analysis was anomalously low storage values from slug and pulse tests. Such values may result from use of infinite-medium type curves for cases where there are constant-pressure boundaries. Constant-pressure tests from such zones, however, have not shown the steady flow that would result from a constant pressure boundary, but rather appear to exhibit spherical flow. The presence of spherical flow in well tests along with the absence of closed-boundary effects would strongly suggest a high degree of fracture interconnection in the Phase 3 block.

Linear (one-dimensional) flow has been noted from the characteristic half-slope behavior of log plots of flow versus time. Linear flow may be indicative of channel geometries. An example of linear flow with a constant pressure boundary has been noted from the preliminary data from the channel flow experiment (Figure 3-29). The analysis of the test depends on the following variables: conductivity, specific storage, channel width, and channel length. The test can be analyzed by relating the conductivity and specific storage to fracture aperture. This leaves three unknowns with three equations — the transient flow equation, the steady linear flow equation (which describes the steady, late-time, flow), and an equation describing the distance to the constant pressure boundary. For the example in Figure 3-29, the solution gives a channel width of about 1 meter, length of 9 meters, and aperture of 0.5 millimeters.

3.7 ROCK SEALING TEST

3.7.1 General

The general objective of the Rock Sealing Test is to identify suitable grouts and grouting techniques for sealing fine rock fractures in repositories. The grouts have to be sufficiently erosion-resistant and chemically stable to make them serve for long periods of time and part of the project is therefore focussed on the testing of candidate materials not only with respect to their initial sealing ability but also to their potential to survive in repository environment.

The requirement to seal fine fractures is met by use of "dynamic" injection technique, i.e. by applying vibrations of suitable amplitude and frequency to the grout in addition to the conventional static injection pressure. The project comprises development of a suitable field-adapted equipment for such grouting, and application of the technique in the mine for determination of the sealing effect and for evaluation of the validity of a grout flow theory.

3.7.2 Major Activities in 1988

The work in 1988 consisted of three major parts: 1) A large-scale pilot field test, 2) Preliminary conclusions from ongoing laboratory experiments concerning the longevity of primary candidate grouts, 3) Formulation of detailed field and lab test programs and initiation of these tests.

3.7.3 Pilot Field Test

A pilot field test was conducted in the Time Scale drift in January. Na bentonite clay gels and cement slurry were used for the grouting of four 1.5 m long and two 7 m long, as well as two 35 m long, core-drilled boreholes with 78 mm diameter. The fracture geometry and Lugeon testing gave a good hydraulic characterization of the rock and the theoretical grout flow model that had been worked out by Lennart Börgesson prior to the experiments could therefore be used for prediction of the inflow of the grouts into the identified fractures. The agreement between theory and practice was good (cf. Table 3-3), considering the approximations that were made in the development of the flow model and the generalizations that were required in the characterization of the fracture geometry (channel configuration).

Table 3-3. Comparison between predicted and measured grout penetration.

Borehole Code	length, m	Grout	Predicted inflow cm^3	Measured inflow cm^3
i1	1.5	Bentonite	0	5 – 25
i2	1.5	Bentonite/quartz	5 – 12	5 – 25
i3	1.5	Cement	13 – 54	40 – 70
i4	1.5	Cement	42 – 62 dm^3	>5 dm^3
i5	7.0	Cement	28 – 65 dm^3	>7 dm^3
i6	7.0	Bentonite/quartz	141 – 254	70 – 100
S1	35	Cement	100 – 540	50 – 200
S2	35	Bentonite/quartz	10 – 54	0

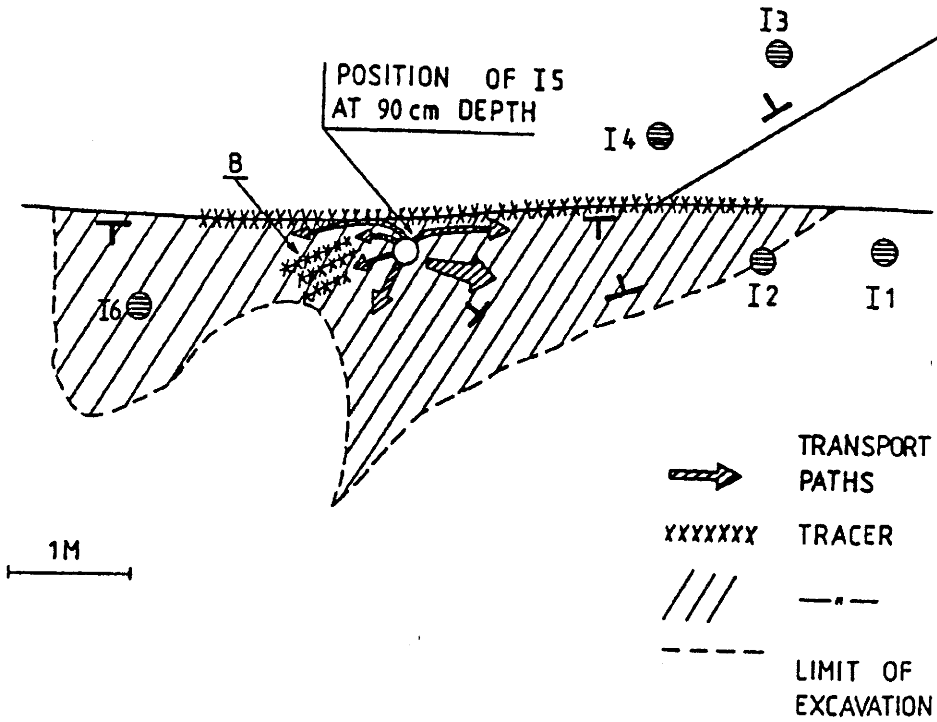


Figure 3-30. Grout migration paths at the injection of Hole i5.

A remarkable fact is that the recorded grout penetration took place in fractures which were as narrow as a few tens of microns and that the water content of the grouts could be kept low. Thus, the cement grout, for instance, had a w/c ratio of only about 0.4, while ordinary cement grouting is successful only when the fracture aperture exceeds 300 microns and the w/c ratio exceeds unity.

After the grouting, the holes were reopened by drilling and Lugeon-tested and the evaluated hydraulic conductivity was concluded to be less than 10^{-10} m/s regardless of the original value. The last operation was to excavate the grouted tunnel floor in order to identify the flow paths of the tracer-doped grouts. About 3 m^3 of rock were removed and it was found that the grout had followed channel-shaped passages in the groutable fractures to a distance of a few decimeters in the most narrow fractures to about 2 meters in the widest passages, which were formed by intersecting long-extending fractures (Figure 3-30).

3.7.4 Longevity

Smectitic Clays

Hydrothermal tests and analysis of the Busachi bentonite profile in Sardinia have added valuable information of the longevity of smectite clays. A basic, well founded idea is that heating is the major threat to the long-term performance of bentonite clay gels. Hydrothermal tests have shown that heating to more than about 60°C produces permanent microstructural changes of insignificant to moderate importance as to the influence on the hydraulic conductivity and swelling ability. Higher temperatures than 130 to 150°C cause permanent crystal lattice changes and partial solution, resulting in conversion to mixed layer minerals and neoformation of illite (hydrous mica).

The Busachi profile, which was inspected by the Task Force at the Sardinian excursion in 1987, is of great interest because it offers geological evidence of the effect of a heat pulse that raised the temperature to between 100 and 700°C in a several meter thick clay sequence. Ongoing analyses tend to validate the physical model of heat influence that has been developed on the basis of thermodynamics and hydrothermal laboratory tests. A preliminary estimate is that Na bentonite clay gels are very moderately influenced by temperatures below about 100°C, while a stronger impact on their sealing ability is caused by heating beyond this level. The temperature effect on a mixture of quartz and bentonite, which appears to represent an optimum grout blend, is not yet known.

The addition of quartz gives the bentonite gel a much improved resistance to piping and erosion although its expanding and self-healing abilities are somewhat reduced. This can be effectively counteracted by adding NaCl to the gel since this decreases the water content that is required to give the mixture the required fluidity. Thus, if the salt content in the groundwater is lower than that of the grout, salt will diffuse into the rock and leave a more expandable residue in the fractures. A preliminary conclusion is that a NaCl content of 1 % is at optimum.

A "cone-in-cone" test equipment has been used for systematic testing of the sealing properties of clay-based grouts in fractures with variable aperture. The grout is applied in a conical narrow slot and exposed to a hydraulic gradient for determination of the hydraulic conductivity. After development of steady state flow conditions the aperture can be increased and then reduced back to the original value with a temperature cycle superimposed. Such tests simulate the thermo-mechanical scenario in grouted rock and the results obtained so far show that the major clay grout candidates have their sealing ability largely preserved after such treatment (Figure 3-31).

Cement

The chemical stability of cement grouts is of fundamental importance for the their use in repositories. While it was obvious at an early stage that low w/c cement grouts of the type that were used in the field pilot test are extremely low-permeable, it was concluded that their chemical composition could be altered by higher temperatures. Since cement is considered to be very suitable for grouting of permeable zones which are exposed to high hydraulic gradients and eroding groundwater soon after the grouting, its usefulness needed to be investigated in detail. No deep insight in this matter has been reached in earlier investigations and a new program was worked out, requiring both a theoretical approach based on thermodynamics, and experimental research. Malcolm Gray at the AECL and Bill Coons at the IT corporation (now at the RE/SPEC Inc.) were appointed for carrying out this work and they concluded at mid 1988 that the question of cement longevity can most certainly be solved with sufficient accuracy in a three year period if sufficient resources are offered. Their preliminary estimate was that cement with silica fume and superplasticizer in suitable proportions, will survive for thousands of years in repository environment. They gave the following explicite statements:

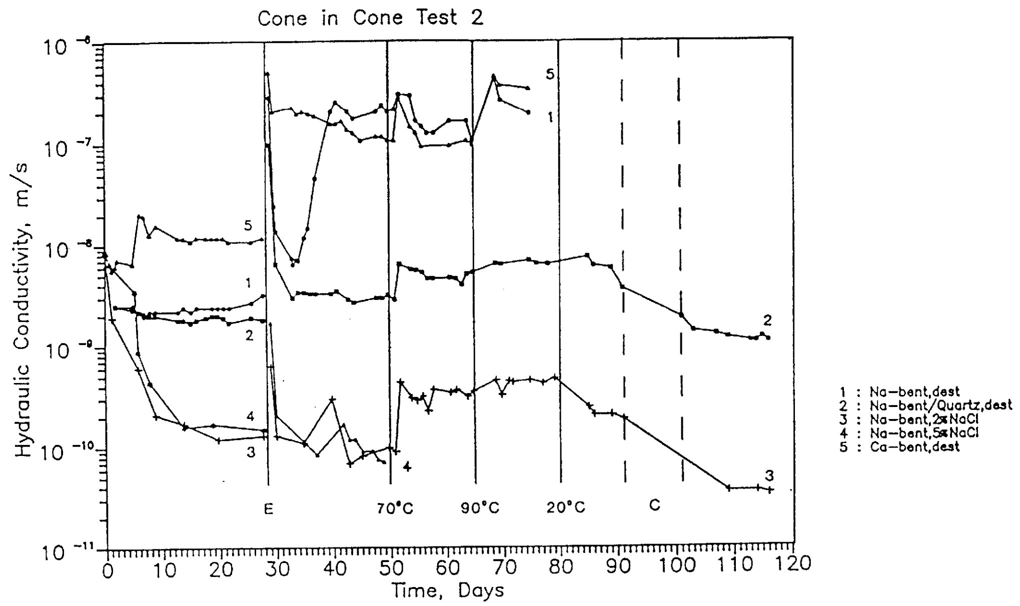


Figure 3-31. Hydraulic conductivity of clay grouts as influenced by 30% slot expansion (E), heating to 70 and 90°C, and finally to 30% sloy contraction (C). This cycle represents the different stages that a clay grout in a fracture may undergo in the "near field".

Bill Coons:

"Investigations of-cement performance longevity have utilized both experimental and theoretical approaches. The program involves iteration and coordination between them. Current results show the potential for acceptable performance over the long term (hundreds of thousands to millions of years). This preliminary result enhances confidence in the application of cement formulations for repository sealing. Confidence is bolstered by the findings that: 1) Superplasticisers do not bleed from cement during curing, and only a small portion is readily leachable thereafter. This result indicates that superplasticisers will not introduce an unacceptable amount of organic material into the repository system, thereby enhancing solubility of radionuclides beyond that which otherwise would occur; 2) Cements can be engineered with w/c ratios that are low enough to yield low permeability, self-healing materials. This newly engineered dimension implies that cements grout may continue to perform acceptably even if the system is mechanically disturbed by minor ground motions or thermal expansions. However, at the very low w/c ratios, required some long-term performance may be sacrificed; 3) The degradation of cement performance caused by inversion of thermodynamically metastable to stable phases is considerable. While kinetically hindered for times in excess of thousands of years, the inversion could result in a five to six order of magnitude increase in permeability. However, because of the very low initial permeability of the cement, this very long range performance is still on the same order as that for degraded bentonite seals. Moreover, for grouted fractures, the average permeability is acceptably low from system permeability considerations; 4) The degradation of cement performance by dissolution appears to be acceptably low for periods on the order of hundreds of thousands to millions of years. Performance is determined by low ini-

tial permeability and the prevailing site conditions. Both theoretical and experimental studies also indicate that cement dissolution will be accompanied by precipitation of sulfate, carbonate and calc-silicate hydrate phases, so long as site conditions permit an approach to steady state. These consistencies between experimental and theoretical studies imply that the long range predictions are reasonable with!n the limits of the porosity/permeability assumptions. Further work will test the extension of the current model and provide data necessary to investigate kinetic controls on cement performance."

Malcolm Gray/Maria Onofrei:
"The Joint Technical Committee met in June and endorsed the recommendation of the Task Force on Sealing supporting further laboratory based research on the longevity of cement-based grouts. The research program proposed by AECL — Whiteshell Nuclear Research Establishment has been approved and initiated. Through the work an improved understanding of the fundamental aspects of potentiaI degradation modes of grouts (e.g. leaching, metastable components transformations, corrosive ions attack) will be developed. The connection between the theoretical modelling and laboratory studies will be enhanced. The program is divided into four major activities:

1. *investigation of superplasticizer*
2. *general grout leaching studies*
3. *investigation of diffusion of corrosive ions*
4. *pure cement compounds studies*

Microstructural investigations using ^{35}S labelled superplasticizer has included a wide range of materials and preliminary data indicate that the superplasticizer is directly incorporated into the calcium-rich phases of C-S-H through association with the hydration-water and in C-A-H phases due to the reaction with SO_3^- in the superplasticizer.

A general analysis has been designed to investigate the effects of temperature, groundwater composition and cation exchange capacity of clay on leaching properties of low and high water content grouts. The data indicate that by influencing the degree of homogeneity of the grout, the w/c ratio influences the leaching behavior of the cement grout. The most durable grout may not necessarily have the lowest possible water content.

The pure compounds selected for use in the tests designed to provide basic data to qualify the theoretical models have been acquired."

Test Program

Much effort has been put in the formulation of detailed testing programs for both the clay and cement grouts. They highlight important milestones over the next three years and are expected to yield sufficiently complete information on the longevity to allow for practical use of the suggested candidate grouts in actual repositories.

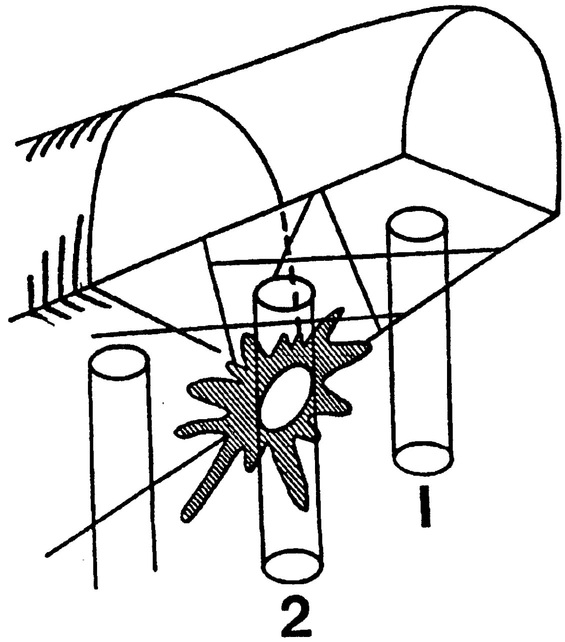


Figure 3-32. Schematic view of "in.hole" grouting of heater hole in the BMT area.

3.7.5 Main Field Tests

A program for carrying out four large-scale field tests has been worked out. They will give information of how effectively rock sealing can be made in order to virtually stop water flow in the vicinity of canister deposition holes, and to shunt off water flow in major flow paths in the rock mass from deposition tunnels. The general philosophy is to develop practical tools for retarding water flow within as well as to and from a repository.

In principle, the tests can be described as follows:

1. Sealing of discrete natural fractures intersecting deposition holes. A technique for grouting large diameter holes from the inside will be tested (Figure 3-32). After grouting, the sealing power will be checked by Lugeon testing, which will be repeated after an about 8 months long heating period which brings the temperature up to around 90°C. Finally, the tunnel floor will be excavated for identification of the grout flow paths in order to validate the grout flow theory. The design and construction of the large-sized injector and packers were made in 1988.

2. Quantification of the increase in hydraulic conductivity along blasted tunnels and shafts, and reduction of it by use of "hedgehog" and "screen" grouting. It is generally believed that blasting creates a narrow zone of fractured rock with isotropically increased hydraulic conductivity, while stress release causes anisotropic changes in conductivity. In the axial direction these effects combine to yield a high-conductivity zone close to the opening and an outer permeable zone extending a few meters outside the inner one.

   The relative importance of the zones, which together are thought to cause a "superconductor" of vital importance for the transport of corrodants and radionuclides, will be determined by forcing water to flow along a sealed drift

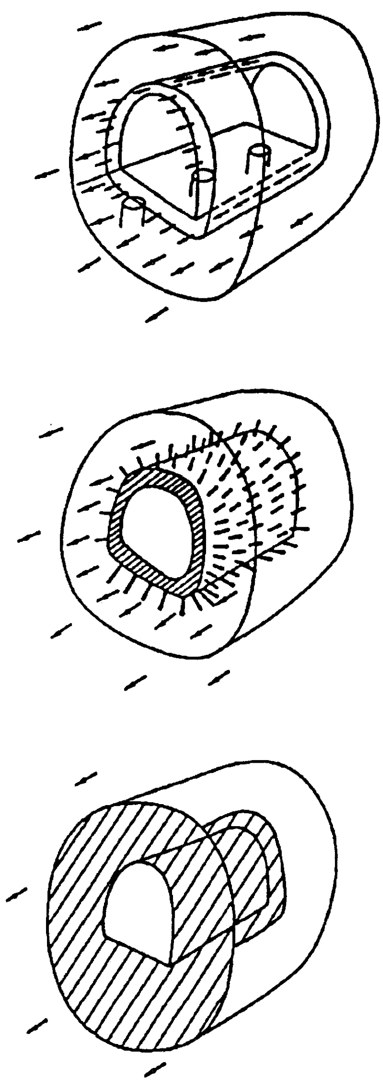


Figure 3-33. The three stages for determining the relative importance of rock disturbance. Upper: Flow is produced through the inner, blasting-affected zone and the outer zone influenced by stress release. Center: After "hedgehog"-grouting of the inner zone, water is expected to flow through the outer zone. Lower: After screen-grouting at the outer end of the drift water will flow only through the surronding, virgin rock.

(BMT) before and after grouting the rock close to the drift, and, in a second stage of the test, before and after grouting the rock to a larger distance. The different stages are schematically illustrated in Figure 3-33. The study includes extensive characterization of the rock with respect to fracture distribution and conductivity, and computation of stress-related changes in water flow by applying advanced codes.The field work was initiated in late 1988.

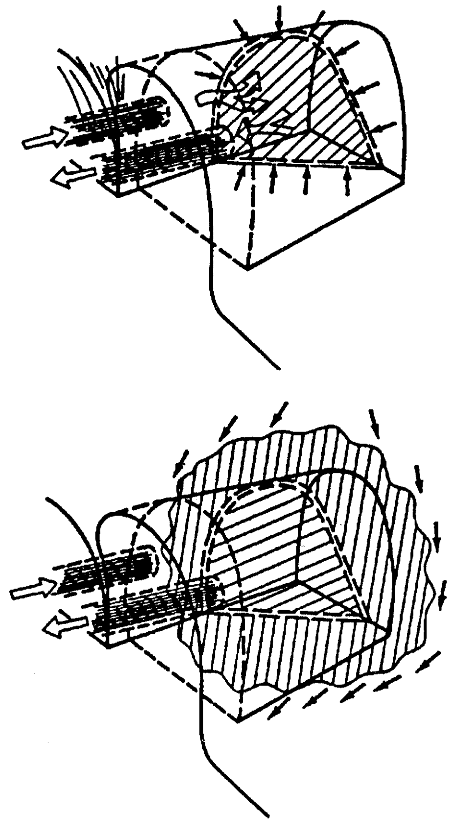


Figure 3-34. The two stages in the experiment with sealing of a natural fracture zone. Upper: Water flows into the drift from the fracture zone, the flux being determined by a "ventilation test". Lower: After sealing, water is redirected with an associated raise in pressure.

3. Sealing of a natural, narrow fracture zone that intersects a drift (3D area). The general purpose is to find out how effectively a moderately water-bearing fracture zone of rather complex nature can be sealed, and to record how water will be redirected in the rock and how the piezometric conditions are altered around the drift as a consequence of the sealing.
   The sealing effect will be determined by a low-temperature "ventilation drift" experiment combined with detailed measurement of the water given off from the sealed fractured by moisture sensor technique.

   This field test, which is schematically shown in Figure 3-34, was initiated in late 1988.

3.8 ECONOMY

The total cost of the Stripa Project Phase 3 as of December 31, 1988 is given in the Table 3-4 below.

Table 3-4. Stripa Project Phase 3 — Summary of costs as per December 31, 1988. All figures in SEK.

		Total program	
Program	**Original budget excl annual index esc. Jan 1988**	**Accumulated**	**Estimated Remaining**
Project management	6 800 000	1 403 794	5 396 206
Stripa Generally	23 500 000	7 252 820	16 247 180
Site Char. and Validation	41 100 000	16 979 054	24 120 946
Dev. of Radar	5 200 000	4 092 129	1 107 871
Improv. of Bore-hole Seismics	3 400 000	1 520 467	1 879 533
Network Modelling	6 800 000	1 658 760	5 141 240
Channeling Experim.	7 000 000	4 205 515	2 794 485
Frac. length and Apert. f. Single	900 000	776 283	123 717
Sealing of Frac-tured Rock	7 500 000	7 500 000	0
Other Investi-gations	22 800 000	2 490 440	20 309 560
Total	**125 000 000**	**47 879 262**	**77 120 738**

Appendix

Stripa Project — Previously Published Reports, 1980–1988

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

SUMMARY

A method of tracer injection and of water collection to be used in the main investigation of "Migration in a single fissure" has been tested and found to function well. With this injection equipment it is possible to introduce tracers into the fissure as a step or a pulse. The injection can be done either under natural pressure or with over pressure.

The collection of water sampled can be done under anoxic atmosphere. Injection of Rhodamine-WT and Na-Fluorescein with over pressure has been performed.

It has been found that Rhodamine-WT is influenced in some way along the flow path. Rhodamine-WT thus cannot be used to characterize the water residence time without a knowledge of the interaction mechanisms.

Based on the experiences from this investigation the equipment and operation will be somewhat modified for use in the main investigation.

1981 **IR 81 – 04**

"EQUIPMENT FOR HYDRAULIC TESTING"

Lars Jacobsson, Henrik Norlander
Ställbergs Grufve AB, Stripa

Sweden, July 1981

ABSTRACT
Hydraulic testing in boreholes is one major task of the hydrogeological program in the Stripa Project. A new testing equipment for this purpose was constructed. It consists of a downhole part and a surface part. The downhole part consists of two packers enclosing two test sections when inflated; one between the packers and one between the bottom packer and the bottom of the borehole. A probe for downhole electronics is also included in the downhole equipment together with electrical cable and nylon tubing. In order to perform shut-in and pulse tests with high accuracy a surface controlled downhole valve was constructed.

The surface equipment consists of the data acquisition system, transducer amplifier and surface gauges. In the report detailed descriptions of each component in the whole testing equipment are given.

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

ABSTRACT
In the hydrogeological program of the Stripa project the vertical borehole V1 has been drilled 505.5 m. The drillcore has been logged with regard to rock characteristic, fracture frequency, dipping and filling. The results presented as cumulative fracture diagram have formed the base for subdivision of the borehole according to fracture frequency. The variation in the fracture dipping was also taken into account. Chlorite is the most common of the infilling material in the fractures. For the borehole 0 466 m the average fracture frequency is 1.46 fractures/m. Below 466 m the core is highly fractured and crushed indicating that the borehole has entered a crushed zone. Because of this the drilling is temporarily stopped.

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

SUMMARY
This report describes data aquisition and data processing systems used for the Buffer Mass Test at Stripa. A data aquisition system, designed mainly to provide high reliability, in Stripa produces raw-data log tapes. Copies of these tapes are mailed to the computer center at the University of Luleå for processing of raw-data. The computer systems in Luleå offer a wide range of processing facilities: large mass storage units, several plotting facilities, programs for processing and monitoring of vast amounts of data, etc..

IR 82 – 03

"BUFFER MASS TEST – SOFTWARE FOR THE DATA ACQUISITION SYSTEM"

B Hagvall
University of Luleå

Sweden, August 1982

SUMMARY
This report describes the data aquisition software for the buffer mass test at Stripa. The software system handles input of information concerning the experiment design as well as measuring and storing of transducer signal values. It also provides a lot of service functions like measuring and printing of transducer signal values, printing of data stored on floppy disks, reporting transducers exceeding their alarm limits, etc.. The system also continuously checks the status of voltmeters, scanners, printers, etc. and reports failing devices. The software is written for a Hewlett Packard 9835A desktop computer.

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

ABSTRACT
The subhorizontal boreholes N1 and E1 were drilled in the monzogranite of the Stripa pluton for purposes of the hydrogeological investigations. This report presents the results of the megascopic petrographic investigation of the cores and fracture measurements compiled as fracture-logs, RQD-diagrams, cumulative fracture diagram and contour diagrams of oriented fracture measurements. It also describes geologic structures connected with the Stripa pluton.

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

ABSTRACT
In the hydrogeological programme of the Stripa Project, borehole V2 (previously termed Dbh V1) was prolonged to a final depth of 822 m. The previous core from 0—471.4 m was relogged, but the old log was partly used as seven core boxes have been sent to LBL. The drill core was logged with regard to rock characteristics, fracture frequency, dipping and filling. The results are presented as core-logs and fracture diagrams. Borehole V2 shows similar characteristics as found in other drillings in the Stripa Mine. It penetrates Stripa granite to its full depth. Recorded fractures show a clear predominance of medium-steep fractures, while flat-lying fractures are more sparsely occurring, a fact which is even more pronounced below 400 m depth. Due to the vertical direction of the borehole, steeply dipping fractures are underestimated in the core. The mean fracture frequency, related to the total length of the core, is 2.1 fractures/m. Chlorite, calcite and epidote are the dominating coating minerals in the fractures, each making up about 25—30 percent of all coated fractures.

"BUFFER MASS TEST – BUFFER MATERIALS"

R Pusch, L Börgesson
University of Luleå

J Nilsson
AB Jacobson & Widmark, Luleå

Sweden, August 1982

SUMMARY
Commercial Na bentonite (MX-80) is the clay component of the buffer material in the heater holes as well of the tunnel backfill. Important characteristics are the clay content, liquid limit, X-ray diffraction pattern, water content, and degree of granulation. The ballast material consists of quartz-rich sand and feldspar-rich filler.

The preparation of highly compacted bentonite for the near-field isolation of the canisters was made by using isolatatic compaction technique. The resulting dense bentonite core was cut into regularly shaped blocks which were arranged around each heater and lowered as one unit — heavily instrumented — in the respective deposition holes. For three of the six holes a narrow slot was left open between the bentonite stack and the rock; for the remaining ones a wider slot was chosen with a fill of soft bentonite powder. Both arrangements are expected to yield an ultimate bulk density which is sufficiently high to fulfill the requirement of a negligible permeability and a sufficient swelling pressure as well as heat conductivity, which are the essential parameters.

The tunnel backfill, which consists of a mixture of suitably graded ballast material and MX-80 powder, has a considerably lower swelling pressure and heat conductivity, and a higher permeability, all these parameters still within the requirements of the KBS-2 concept. The various zones with different bentonite/sand ratios and the technique to apply them are described in the final part of the report.

"BUFFER MASS TEST – ROCK DRILLING AND CIVIL ENGINEERING"

R Pusch
University of Luleå

J Nilsson
AB Jacobson & Widmark, Luleå

Sweden, September 1982

SUMMARY

The Buffer Mass Test (BMT) is being run in the former "ventilation drift" in which a number of rock investigations were previously conducted by the Lawrence Berkeley Laboratory (LBL). They have yielded valuable information on the rock properties, particularly the water pressure situation and the gross permeability, and a number of pressure gauges were still in operation when the BMT was prepared. A light wooden wall, anchored to the rock in a shallow slot, formed an outer boundary of the LBL test and the removal of this wall was the first step in the preparation of the BMT test. Next, a number of vertical pilot holes were drilled from the tunnel floor to get information of the water inflow in possible heater hole positions. The final decision of the location of the heater holes was then made, the main principle being that much water should be available in each hole with the possible exception of one of the holes. Thereafter, the Ø 0.76 m heater holes were drilled to a depth of 3—3.3 m. Additional holes were then drilled for rock anchoring of the lids of the four outer heater holes, for the rock mechanical investigation, as well as for a number of water pressure gauges. The complete drilling program will be specified in the text.

The inner, about 12 m long part of the tunnel, was separated from the outer by a bulwark. The purpose of this construction was to confine a backfill, the requirements of the bulwark being to withstand the swelling pressure as well as the water pressure. The design and performance of the construction is described in some detail.

Outside the bulwark an approximately 1.5—1.7 m thick concrete slab was cast on the tunnel floor, extending about 24.7 m from the bulwark. Boxing-outs with the same height as the slab and with the horizontal dimensions 1.8 x 1.8 m, were made and rock-anchored concrete lids were cast on top of them after backfilling, Fig. 1. This figure illustrates that a cross section through the boxing-outs and the heater holes represents an almost exact half-scale equivalent of a section through a true tunnel with a deposition hole as specified by the KBS 2 concept. The slab which thus represents "rock", also forms a basal support of the bulwark. The lids permit access to the backfill as well as to the underlying, highly compacted bentonite for rapid direct determination of the water distribution at the intended successive test stops. The construction of the slab and lids will be described in this report.

"BUFFER MASS TEST – PREDICTIONS OF THE BEHAVIOUR OF THE BENTONITE-BASED BUFFER MATERIALS"

L Börgesson
University of Luleå

Sweden, August 1982

SUMMARY

The predictions are based on laboratory-derived material parameters and assumed test conditions as they were at the start of the test.

The predictions show that the temperature of the bentonite will only slightly exceed 70° C if no drying takes place. The dried-out material may be as hot as 120° C.

The rate of the water uptake is highly dependent on the availability of water along the rock surface but not very much on the difference in the amount of water available in the six holes. The predicted time for water saturation (Sr95%) is about 2 years in the deposition holes and about 5 years in the tunnel if water is available from the entire rock surface. If water is available from only one or two fractures or narrow zones the highly compacted bentonite and the tunnel backfill will not be water saturated until after more than 100 years.

The ultimate heaving of the interface between the highly compacted bentonite and the tunnel backfill is estimated to be 6—12 cm, the maximum swelling pressure is 10—20 MPa.

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

ABSTRACT
This progress report contains the recent results of the hydrogeochemical program, a part of the hydrogeological investigations at the Stripa test site. A considerable number of groundwater samples have been collected and analyzed for major dissolved cations, anions, trace elements, stable isotopes, radioisotopes and dissolved gases to depths approaching 900 m. This report presents (1) the background geology and hydrogeology (2) major and trace element characteristics of the deep groundwaters (3) major radioelement characteristics and inert gases (4) stable isotopes of water and dissolved sulfate and (5) preliminary interpretations of the groundwater chemistry trends. As the studies at Stripa are still in progress, all interpretations are considered tentative and preliminary. Any conclusions drawn may be modified as a consequence of continued sampling and analysis.

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

INTRODUCTION
The successive emptying of the heater holes in the running BMT in the Stripa mine, offers an opportunity of testing the properties of the highly compacted bentonite at higher temperatures than in the presently running tests. In the current study the temperatures in the bentonite do not exceed about 80° C, which is estimated to be a safe temperature with respect to chemical stability of the smectite. This temperature level is reached by a heater effect of 600 W. If this is increased to 1200 W the temperature at the surface of the heater is expected to yield a level of about 150°C. Thereby the water uptake and water redistribution will be largely influenced as well as the temperatures around the heater.

This report deals with some basic predictions of the temperature distribution in the vicinity of a heater producing an effect of 1200 W.

1983 IR 83 – 04

"BUFFER MASS TEST – SITE DOCUMENTATION"

Roland Pusch
University of Luleå and Swedish State Power Board

Jan Nilsson
AB Jacobsson & Widmark, Luleå

Sweden, October 1983

SUMMARY

The purpose of this report is to compile test site data that are assumed to be of importance for the interpretation of the Buffer Mass Test. Since this test mainly concerns water uptake and migration processes in the integrated rock/backfill system and the development of temperature fields in this system, the work has been focused on the constitution and hydrology of the rock.

The major constitutional rock feature of interest for the BMT is the frequency and distribution of joints and fractures. Earlier investigations by Lawrence Berkeley Laboratory offer comprehensive fracture data which are sufficiently detailed for BMT purposes with respect to the interaction between the rock and the tunnel backfill. However, the development of models for water uptake into the highly compacted bentonite in the heater holes requires a very detailed fracture survey. The present investigation shows that two of the holes (no. 1 and 2) are located in richly fractured rock, while the others are located in fracture-poor to moderately fractured rock.

The hydrologic conditions of the rock in the BMT area are characterized by water pressures of as much as 100 m water head at a few meters distance from the test site. The average hydraulic conductivity of the rock that confines the BMT tunnel has been estimated at about 10 m/s by Lawrence Berkeley Laboratory. The actual distribution of the water that enters the tunnel has been estimated by observing the successive moistening after having switched off the ventilation, and this has offered a basis of predicting the rate and uniformity of the water uptake in the tunnel backfill. As to the water inflow into the heater holes the detailed fracture patterns and various inflow measurements have yielded a similar basis.

The report also gives major data on the rock temperature, gas conditions, mineralogy, rock mechanics, and groundwater chemistry for BMT purposes.

"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

SUMMARY
In October 1983 the first heaters have been running for about two years and a number of observations show that the original physical model of the water uptake must be changed somewhat. The same goes for the tunnel backfill.

As to the highly compacted bentonite in the heater holes, the formulation of an improved model needs considering the following observations:

* Single water-bearing joints and fractures with apertures exceeding about 0.1 mm become sealed relatively soon by penetrating bentonite and do not serve as an effective water source.
* Fractured rock with a network of narrow joints and fractures serves as an effective water source.
* Rock with no visible joints or fractures serves as a stingy water source which, however, determines the water inflow into the larger part of the heater holes.
* Temperature gradients and absolute temperatures of the present magnitude drive water from the hot interior towards the periphery, where it accumulates. This is a rapid process with a rather well defined relationship between water content and temperature.
* The ultimate stage of water uptake is one characterized by slow flow driven by the hydraulic gradients in the rock.

The improved model for the water uptake in the tunnel is based on the well-founded assumption that the fairly small inflow in the tunnel that was observed before the backfilling has not changed. It is highly probable that the inflowing water is uniformly distributed over the tunnel periphery from where it is sucked by the backfill and transported towards the interior through a diffusion like process. This yields a fairly rapid moistening of the central parts of the backfill, and late saturation of the periphery, which is in good agreement with moisture sensor reactions and low water pressure recordings at the rock/backfill interface.

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

ABSTRACT
A borehole radar system has been developed by Boliden Mineral AB in Sweden. The system consists of a control unit and separate units for transmitter and receiver antennas. Thus the system may be used both for single hole and cross hole measurements. The communication of data and control signals between the control unit and transmitter and receiver is made on optical fibers. The system transmits energy in the frequency range 10—50 MHz.

Measurements have mainly been performed in the form of single hole measurements with a transmitter-receiver spacing of 13 m. Attenuation and delay of the direct wave between transmitter and receiver has been observed in connection with fracture zones which penetrate the borehole. Fracture zones also cause reflections which give information on the orientation of the fracture zone relative to the borehole. Reflections have also been observed from an air filled drift 30 m from the borehole. Reflections from a fracture zone has been observed for a two way travel distance of 88 m. The distance from the borehole to the drift and the orientation of the fracture zones relative the borehole has been found to agree well with other data available on the site.

In the present system resolution is limited by ringing on the antenna, however significant enhancement has been obtained of the radar data by deconvolution filtering.

The main part of this project has been funded by the Swedish Nuclear Fuel Supply Co. (SKBF/KBS) while some of the final evaluations have been performed within the OECD/NEA International Stripa Project.

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

June 1984

The nuclear waste is assumed to be contained in cylindrical metal canisters which will be inserted in deposition holes. Heat is generated as a result of the continuing decay of the radioactive waste and in the Buffer Mass Test (BMT) the heat flux expected from such canisters was simulated by the use of six electric heaters. The heaters were constructed partly of aluminium and partly of stainless steel. They are 1520 mm in length and 380 mm in diameter, and give a maximum power output of 3000 W. The heater power can be monitored by panel meters coupled to a computer-based data acquisition system. Both the heater and the control system were manufactured with a high degree of redundancy in case of component failure. This report describes the design, construction, testing, installation and necessary tools for heater installation and dismantling operation.

1984 **IR 84 – 03**

"HYDROGEOLOGICAL AND HYDROGEOCHEMICAL INVESTIGATIONS – GEOPHYSICAL BOREHOLE MEASUREMENTS"

Olle Olsson, Ante Jämtlid
Swedish Geological Co.

August 1984

ABSTRACT
A standard geophysical logging program was performed in the boreholes N1, E1, V1 and V2 in the Stripa Mine. Several minor fracture zones were identified in the boreholes particularly with the aid of the resistivity logs. Information on the hydraulic properties of the fracture zones were mainly obtained from the temperature and the salinity logs. The borehole fluid in the boreholes V1 and V2 were found to be saline. The Stripa granite has a relatively high background radiation level of 70 R/h. Higher radiation levels, which were commonly observed, are mainly due to radon transported by groundwater from fractures into the boreholes.

The large fracture zone encountered at the bottom of V1 (466—505 m) gave a large resistivity anomaly, but no anomaly of comparable magnitude was found 1984 in any of the other holes. The single hole data from V2 indicated a fracture zone at 404—440 m, which to some extent had the same geophysical character as the zone in V1.

Mise a la masse or cross-hole electrical measurements were performed to find the orientation of the fracture zone in V1. The data were interpreted with a theoretical model where a trial and error procedure was used to find the best fit to the measured data. The fracture zone was interpreted to have the dip 60° SE and the strike N60° E. This zone intersects V2 at 409 m and N1 at 270 m. In the final interpretation consideration was also taken to the single hole data.

"CROSSHOLE INVESTIGATIONS – PRELIMINARY DESIGN OF A NEW BOREHOLE RADAR SYSTEM"

O Olsson, E Sandberg
Swedish Geological Co.

August 1984

ABSTRACT

If the resistivity of the bedrock is large enough electromagnetic waves will propagate through the bedrock for considerable distances. It is estimated that penetration ranges of several hundred meters are attainable in granitic rock for electromagnetic waves in the frequency range 20—200 MHz. The corresponding wavelengths will be in the range 0.5 m to 10 m. A resolution of objects with dimensions larger than a few parts of the wavelength is expected.

The new radar system designed as a part of the cross-hole program of the Stripa Project will be applicable both to cross-hole and single-hole measurements. The system will be a short pulse radar system to obtain a good resolution in the distance to reflectors. The radar system will consist of three units; a control unit, a borehole transmitter and a borehole receiver. All communication between these units will be made on optical fibers.

The control unit will be used to transmit trig-pulses to the transmitter and the receiver. The trig-pulses will determine when a radar pulse is transmitted and when a sample is taken of the received waveform. In principle the system will work as a sampling oscilloscope in recovering the high frequency pulses. The control unit will collect digital data from the borehole receiver. Stacking may also be done by the control unit. Sampling frequency, number of stacks, and sampling window position and length will be under software control. Data storage and display will be made on a micro-computer system with floppy discs.

The transmitter will generate a current pulse that is fed to the antenna. The pulse will be generated by a discharge of a transmission line, which will be controlled by an avalanche transistor. The transmission line will be charged by a DC voltage of 500 V. The pulse repetition frequency will be 40 kHz.

The receiver will consist of a high frequency amplifier, a sampler and an A/D converter. The A/D converter will have a resolution of 16 bits.

To obtain well defined radar pulses broadband antennas will be used. For borehole applications it is possible to construct broadband dipole antennas by increasing the characteristic impedance along the length of the antenna. Different antennas will be tested where the impedance increase is made either resistive, capacitive or inductive.

"CROSSHOLE INVESTIGATIONS – EQUIPMENT DESIGN CONSIDERATIONS FOR SINUSOIDAL PRESSURE TESTS"

David C. Holmes
British Geological Survey

September 1984

SUMMARY
This report is one of a series which describes work being undertaken by the British Geological Survey for the Stripa Project. The work forms part of the Crosshole Programme, which is a multidisciplinary approach to rock mass assessment around a potential repository, using radar, seismic and hydrogeological techniques.

Hydrogeological characterization will be attempted using the sinusoidal pressure test method, in addition to more standard methods, in six boreholes drilled from the 360 m level in the mine. Equipment has been designed to generate a hydraulic signal (source borehole) and monitor its progress through the rock mass (receiver borehole). Packers are used to isolate sections of rock.

The equipment design has been influenced by hydraulic conditions likely to be encountered in the local rock environment. Of major importance is the hydraulic pressure field caused by groundwater movement into mine cavities. This field varies considerably and has necessitated the design of a testing system which is extremely adaptable in generating and receiving hydraulic signals.

1984 **IR 84 – 06**

"BUFFER MASS TEST – INSTRUMENTATION"

Roland Pusch, Thomas Forsberg
University of Luleå, Sweden

Jan Nilsson
Swedish Geological, Luleå

Gunnar Ramqvist, Sven-Erik Tegelmark
Stripa Mine Service, Storå

September 1984

SUMMARY
The major objective of the Buffer Mass Test is to record the development of temperature fields, water uptake, and swelling and water pressures in the highly compacted bentonite in the heater holes, as well as in the tunnel backfill. In addition, internal displacements in the clay materials and change of rock joint apertures will be determined.

The temperature recording is made by use of more than 1200 copper-constant and thermal elements for detailed information of the temperatures, especially in the vicinity of the heaters. Swelling, or rather total pressures, are primarily measured by means of about 130 Gloetzl pressure cells, and this system is also applied for recording water pressures in heater holes, backfill and rock (28 gauges). 25 BAT-piezometers are used as a back-up of the Gloetzl system and for the recording of low water pressures.

Moistening of the clay materials is evaluated from moisture sensor signals which reflect the electric resistivity, or rather the capacitance, of these materials. The lack of suitable commercial gauges made it necessary to develop new equipment (560 gauges), which is useful for a rough estimation of moisture content changes, but less accurate for quantitative determination of the moisture content, particularly of the bentonite/sand backfill materials.

The water uptake and swelling of the highly compacted bentonite in the heater holes is expected to produce displacement of the interface between this bentonite and the overlying bentonite/sand backfill. This displacement, which is probably non-uniform, will be measured at the excavation of the heater holes by determining the z-coordinate of 40 copper "coins" located at the interface. Their original positions, expressed in terms of z=coordinates, were carefully determined at the application. Possible internal displacements in the overlying backfill are identified by measuring z-coordinate changes of long plastic tape stripes which were applied in connection with the backfilling operation.

The expansion of the highly compacted bentonite is also expected to affect the aperture of rock joints which intersect the heater holes. The possible changes in aperture will be determined by measuring axial displacements in four vertical boreholes. Kovari's technique is used for this purpose.

"HYDROGEOLOGICAL AND HYDROGEOCHEMICAL" INVESTIGATIONS IN BOREHOLES – FLUID INCLUSION STUDIES IN THE STRIPA GRANITE

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October 1984

ABSTRACT

Abundant fluid inclusions have been found in quartz in the Stripa granite. Inclusion occurrence reaches 1.74×10^8 inclusions per cm^3 with a mean size of 6 m in diameter.

These inclusions mainly contain an aqueous solution. Fractured rock sections contain inclusions with lower salinity than unfractured rock sections, 1.7 and 4 eq. wt% NaCl respectively. Comparison with measured salinities in the Stripa groundwater shows that only about 5—10% of the available fluid inclusions have to be leached in order to explain ground-water salinities.

Homogenization temperatures from the same inclusions indicate formation at over 130° C for the inclusions in unfractured rock sections. A later rehealing event at over 190° C is represented by inclusions in fractured rock sections. This later fluid has a lower salinity and indicates that the granite may have been flushed by deep circulating meteoric waters at a possible late date.

The aqueous inclusions are secondary but rare primary CO_2 inclusions occur which may indicate conditions of granite emplacement.

1984 **IR 84 – 08**

"CROSSHOLE INVESTIGATIONS – TOMOGRAPHY AND ITS APPLICATION TO CROSSHOLE SEISMIC MEASUREMENTS"

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November 1984

ABSTRACT
The problem of seismic velocity estimation from first-arrival travel-times is discussed. mainly in a two dimensional crosshole geometry. Use is made of previously developed geophysical inverse theory and modern methods of computerized tomography. An overview of these foundations is included.

For typical crosshole cases the ray-path coverage will unfortunately be much less complete than what is generally achieved in medical applications of tomography. The implied uniqueness problems are discussed using the Radon transform.

Different ways of performing the tomographic inversion are tested on a number of synthetic examples. In general, the criterion of damped least-squares is used and solutions are computed by (for example) Gaussian elimination. SIRT-methods and the conjugate gradients (CG)method. The CG-method is found to converge very rapidly.

Because the risk of getting a distorted image will always be present, it is concluded that comparison with results from synthetic examples (forward modelling) is a valuable tool in the interpretation process.

Methods to include estimation of anisotropy and iterative procedures to take account of ray-bending are also discussed.

1985 IR 85 – 01

"BOREHOLE AND SHAFT SEALING – SITE DOCUMENTATION"

Roland Pusch, Jan Nilsson
Swedish Geological Co.

Gunnar Ramqvist
El-tekno AB

Sweden, February 1985

ABSTRACT
Highly compacted bentonite as sealing substance is being tested in Stripa. The experiments comprise of borehole, shaft, and tunnel plugging tests which serve to illustrate clay application techniques, maturation rate of the clay plugs and sealing ability of such plugs. The latter is due to the very low hydraulic conductivity of dense smectite-rich clay, and of the swelling pressure, which it exerts on the confining rock. The swelling creates a tight contact with the rock and a tendency of closing joints and fractures in the rock adjacent to the clay plugs.

The sealing properties of bentonite plugs are known to be related to the structure and water bearing properties of the rock, which are the subjects of the present report.

IR 85 – 02

"MIGRATION IN A SINGLE FRACTURE – INSTRUMENTATION AND SITE DESCRIPTION"

Harald Abelin, Jard Gidlund
Royal Institute of Technology, Stockholm

Sweden, February 1985

ABSTRACT
The physical and chemical interaction between the bedrock and eventually leached radionuclides is considered to be one of the major retarding mechanisms in radionuclide migration. To test if it is possible to extend results obtained in the laboratory to a larger scale under real conditions an in situ migration experiment has been performed. A single fracture, in granitic rock, at the 360 m level in the Stripa mine, has been utilized. Both conservative (nonsorbing) and sorbing tracers have been injected. Equipment for automatic pressure pulse tests and tracer injection (pulse of step) have been developed. The injection equipment also allows small volume water sampling at the injection point. At the end of the injections part of the fracture has been excavated and the concentration of the injected sorbing tracers on the fracture surface as well as in the rock matrix have been determined. The rock samples have been prepared in an automatic grinding machine that uses a diamond-coated metal sheet as abrasive material.

1985 **TR 85 – 03**

"FINAL REPORT OF THE MIGRATION IN A SINGLE FRACTURE – EXPERIMENTAL RESULTS AND EVALUATION"

H Abelin, I Neretnieks, S Tunbrant, L Moreno
Royal Institute of Technology, Stockholm

Sweden, May 1985

ABSTRACT
Three fractures in granitic rock have been investigated by hydraulic testing and by migration tests with nonsorbing as well as with sorbing tracers. The sorbing tracers were Cs, Sr, Eu, Nd, Th and U.

The fractures are located in drifts at 360 m depth in the Stripa mine in mid Sweden. The fractures are clearly visible in the drifts. There is natural water flow in the fractures. Injection took place at 5—10 m distance from the roof of the drifts. The water was collected at 10—15 locations on every fracture as it intersects the drift. Injection and collection of water was done during more than 7 months in one of the fractures. The fracture where the sorbing tracers were injected was excavated after the test and the surface of the fracture was analysed for the tracers. The tracers were also analysed for, to a depth of up to 5 mm in the rock matrix.

The results show that there is distinct channelling in the plane of the fractures. The channels make up 5—20% of fracture. The fissure (or channel) widths are much (order(s) of magnitude) larger than what can be deduced from hydraulic testing assuming laminar flow in a smooth slit.

None of the sorbing tracers arrived at the collection points with the water. The sorbing tracer Sr migrated less than was originally expected. Cs, Eu, and U were found in highest concentrations very near the injection point. Nd and Th could not be found on the fracture surface because of the high natural background.

"HYDROGEOLOGICAL AND HYDROGEOCHEMICAL INVESTIGATIONS IN BOREHOLES – COMPILATION OF GEOLOGICAL DATA"

Seje Carlsten
Swedish Geological Co., Uppsala

Sweden, June 1985

ABSTRACT
Several reports on performed geological investigations in the Stripa granite have been published since 1977. The current one is in summary a compilation of these reports updated with additional data collected during the Stripa project, phase 1. The Stripa granite is a grey to reddish middle-grained granite with a rather high fracture frequency and it is considered to be about 1800 Ma, formed during the serorogenic phase of the Svecokarelian orogeny. The granite is composed of quartz, plagioclase, microcline, muscovite and chlorite. It also has a high uranium and thorium content. Breccias are a common feature in the granite. Associated to those are cavities containing idiomorphic crystals. Porous sections with up to 9% porosity occur in the granite, probably caused by dissolution of quartz. The granite is surrounded by leptite in which it has intruded. The contacts between leptite and granite is concordant with structures in the leptite. The ironore is located in the leptite. Numerous thermal and tectonic events since the original emplacement of the granite is indicated by fluid inclusions. The chloride content in the fluid inclusions is sufficiently enough to account for the salinity of the groundwater. Fracture orientation is mainly directed in NE—NNE with a secondary maximum in N 30 E, both with a steep dip. Microfractures occur both in association with tectonic zones and in the rock mass. Chlorite, sericite, quartz, epidote, calcite and fluorite are the most common fracture filling minerals in the granite.

1985 IR 85 – 05

"CROSSHOLE INVESTIGATIONS – DESCRIPTION OF THE SMALL SCALE SITE"

Seje Carlsten, Kurt-Åke Magnusson, Olle Olsson
Swedish Geological Co., Uppsala

Sweden, June 1985

ABSTRACT
At the Crosshole-site, located at the 360 m level in the Stripa mine, six boreholes have been drilled in a fanlike fashion. This borehole configuration was choosen in order to penetrate fracture zones in the test area with several boreholes.

To achieve a comprehensive knowledge of the geological and physical conditions, core mapping and a comprehensive program of geophysical borehole measurements has been carried out.

The specific geological and physical character of the major fractured zones distinguished in the boreholes can be recognized and correlated between several boreholes. The extension of six major zones and one minor zone have thus been correlated between the boreholes. The fractures within the zones and the rock mass have a dominating direction more or less subparallel with the zones. Parameter measurements on core samples show that the major zones have considerably higher porosity (up to 2%) than the rock mass (about 0.2%). The major zones are altered and tectonized and contain several deformed zones such as breccia, mylonites etc. Cavities partly filled with idiomorphic crystals, often occur in association with the deformed zones.

Key words: Granite, core logging, geophysical logging, fracture zones, tectonization, cross-hole.

1985 **TR 85–06**

"HYDROGEOLOGICAL AND HYDROGEOCHEMICAL INVESTIGATIONS IN BOREHOLES – FINAL REPORT OF THE PHASE I GEOCHEMICAL INVESTIGATIONS OF THE STRIPA GROUNDWATERS"

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July 1985

ABSTRACT
The hydrogeochemical investigations of Phase I of the Stripa Project (1980—84) have been completed, and the results are presented in this final report. All chemical and isotopic data on the groundwaters from the beginning of the Stripa Project to the present (1977—84) are tabulated and used in the final interpretations. The background geology and hydrology is summarized and updated along with new analyses of the Stripa granite. Water-rock interactions form a basic framework for the changes in major-element chemistry with depth, including carbonate geochemistry, the fluid-inclusion hypothesis, redox processes, and mineral precipitation. The irregular distribution of chloride suggests channelling is occurring and the effect of thermomechanical perturbations on the groundwater chemistry is documented. Stable and radioactive isotopes provide information on the origin and evolution of the groundwater itself and of several elements within the groundwater. Subsurface production of radionuclides is documented in these investigations, and a general picture of uranium transformations during weathering is presented. One of the primary conclusions reached in these studies is that different dissolved constituents will provide different residence times because they have different origins and different evolutionary histories that may or may not be related to the overall evolution of the groundwater itself.

1985 **TR 85–07**

"ANNUAL REPORT 1984"

Swedish Nuclear Fuel and Waste Management Co., Stockholm

July 1985

IR 85–08

"HYDROGEOLOGICAL AND HYDROGEOCHEMICAL INVESTIGATIONS IN BOREHOLES – SHUT-IN TESTS"

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July 1985

ABSTRACT
This report present the results from the shut-in tests carried out within the program on hydrogeological investigations in boreholes. The groundwater system at the mine has successively been affected by the mining activities, and the mine acts as a sink, which gives a hydraulic system well suited for hydrogeological studies underground. The current shut-in tests utilize this condition, i.e. to use the natural drainage and to measure the build-up after shut-in. By this technique no foreign water is introduced in the water system which may disturb studies of the groundwater chemistry. In addition, the technique only causes a minor disturbance on the head around the mine which in turn gives only a minor interference to other activities in the project.

The report on the shut-in tests describes the testing techniques and illustrates different evaluation approaches to be used in order to obtain as much information as possible on the hydrogeological conditions of the target rock. Thus, evaluation was made with consideration to different flow regimes and to wellbore storage and skin; the latter effects were of great significance in the very low conductive rock mass found at the test site. In general the hydraulic conductivity is below 10^{-11} m/s, although some minor zones were found with a conductivity of about 10^{-8} m/s at the most. All of the tested zones were selected zones of expected higher conductivity and the remaining rock mass is therefore of even lower conductivity than the results reported.

The evaluation showed that the required testing time in order to overcome the secondary effects of wellbore storage and skin will be large in this kind of test, normally at least some days, which make an accurate testing in a low conductive formation very time consuming. Other techniques are also used and presented in a separate report.

1985 **IR 85–09**

"HYDROGEOLOGICAL AND HYDROGEOCHEMICAL INVESTIGATONS IN BOREHOLES – INJECTION-RECOVERY TESTS AND INTERFERENCE TESTS"

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July 1985

ABSTRACT
The current report presents the results from hydraulic tests performed as water injection tests and interference tests. The water injection tests were conducted in 10 m sections in the three boreholes at the SGU-site in the Stripa mine. A major problem with these test was the significant formation pressure build-up which took place during testing. In several sections the injection stage was converted into a build-up stage, i.e. the formation pressure exceeded the applied injection pressure. The testing technique is fast and less time consuming than shut-in tests, and should therefore be considered for certain testing purposes. However, it is recommended to perform the tests when the natural formation pressure is in steady-state and to use specially designed equipment for this purpose.

The result of the water injection test gives results in the same orders of magnitude as other techniques used. As regards the different evaluation techniques, it is seen that no considerable difference exist between different techniques. However, the spreading is become more significant in the low conductive rock mass, i.e. below 10^{-11} m/s.

The interference tests were carried out by using the natural build-up or fall-off in the groundwater system around the mine. Thus, the natural drainage to the potential sink made up by the mine creates the disturbances. The disturbance was introduced in a specific section in one borehole and the resulting effect was recorded in other boreholes. The results from these tests give the hydraulic properties of the rock mass between the source and receiver holes. By this technique a hydraulic conductivity of the more fractured parts of the rock mass in the range 10^{-8} was obtained. A corresponding specific storage coefficient was also determined.

"HYDROGEOLOGICAL AND HYDROGEOCHEMICAL INVESTIGATIONS IN BOREHOLES – FINAL REPORT"

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July 1985

ABSTRACT
Underground investigations in boreholes are presumed to be an important investigation technique for the detailed design of a final repository for nuclear waste. The siting of the repository will be based on surface investigations, but for detailed investigations when the access shafts are sunk, investigations in underground boreholes from the initial shafts and tunnels will be of importance. The hydrogeological investigations in boreholes aimed at testing and developing of hydrogeological techniques and instruments for use in an underground environment in order to reflect actual working and testing conditions.

This report is the final report from the hydrogeological investigations in boreholes, and it summarizes the different activities carried out during the course of the program. Most of the included activities are reported in separate internal reports, and therefore only the most important results are included, together with the experiences and conclusions gained during the investigations.

The hydrogeochemical part of the program is in a separate final report, consequently no hydrogeochemical information is in the current report.

"FINAL REPORT OF THE BUFFER MASS TEST – Volume I: scope, preparative field work, and test arrangement"

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July 1985

ABSTRACT
The Buffer Mass Test was conducted in a 30 m long drift at 340 m depth in the Stripa mine, the main objective being to check the predicted functions of certain bentonite-based buffer materials in rock environment. These materials were blocks of highly compacted sodium bentonite placed in large boreholes simulating deposition holes for canisters, and on-site compacted sand/bentonite mixtures used as tunnel backfill. The blocks of bentonite embedded electrical heaters which served to produce heat so as to create conditions similar to those in a repository. The temperature in the initially non-saturated buffer materials was expected to be a function of the water uptake from the rock, which was also assumed to lead to rather high swelling pressures. The recording of these processes and of the moistening of the buffer materials, as well as of the associated build-up of piezometric heads at rock/buffer interfaces, was the major item of the field test. For this purpose the buffer materials and the rock were equipped with a large number of thermal elements, pressure and piezometric cells as well as moisture sensors. The choice of positions and properties of these gauges, which were connected to an effective data acquisition system, was based on predictions that required a careful site documentation with respect to the fracture characteristics and hydrological properties of the surrounding rock.

1985 **TR 85–12**

"FINAL REPORT OF THE BUFFER MASS TEST – Volume II: test results"

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August 1985

ABSTRACT

The evaluation of the Buffer Mass Test mainly concerned the heating of the bentonite/rock system that simulated hot canisters in deposition holes, the swelling and swelling pressures of the expanding bentonite in the heater holes, and the water uptake of the bentonite in the holes as well as in the tunnel backfill. These processes had been predicted on the basis of laboratory-derived data and FEM calculations with due consideration of the actual geometry.

The recorded temperatures of the bentonite and surrounding rock were found to be below the maximum temperature that had been set, but higher than the expected values in the initial period of testing. The heater surface temperatures dropped in the course of the tests due to the uptake of water from the rock even in the "driest" hole which was located in almost fracture-free rock.

The water uptake in the highly compacted bentonite in the heater holes was manifested by a successively increased swelling pressure at the bentonite/rock interface. It was rather uniformly distributed over this interface and reached a maximum value of about 10 MPa.

The water content determination confirmed that water had been absorbed by the bentonite from the rock even in the driest holes where the counteracting thermal gradient was rather high. In the wettest holes the saturation became almost complete and a high degree of saturation was also observed in the tunnel backfill. Both in the heater holes and the tunnel, the moistening was found to be very uniform along the periphery, which is at least partly explained by the self-sealing ability of bentonitic buffer materials.

A general conclusion is that the involved physical processes are well understood and that the ultimate physical state of the buffer materials under repository conditions can be safely predicted.

1985 **IR 85–13**

"CROSSHOLE INVESTIGATIONS – COMPILATION OF CORE LOG DATA FROM F1 – F6"

S Carlsten, A Stråhle
Swedish Geological Co., Sweden

September 1985

TR 85–14

"FINAL REPORT OF THE BUFFER MASS TEST — Volume III: Chemical and physical stability of the buffer materials"

Roland Pusch
Swedish Geological Co., Sweden

November 1985

ABSTRACT
The Buffer Mass Test offered a possibility to investigate whether changes took place in the smectite component at heating to about one year. The alterations that could possibly take were a slight charge change in the crystal lattice with an associated precipitation of silica compounds, and a tendency of illite formation. The analysis showed that there were indications of both but to such a slight extent that the processes could not have affected the physical properties, which was also demonstrated by determining the swelling pressure and the hydraulic conductivity.

The BMT also showed that the erodibility of bentonite-based buffer materials is less than or about equal to what can be expected on theoretical grounds.

1986 **IR 86–01**

"CROSSHOLE INVESTIGATIONS – DESCRIPTION OF THE LARGE SCALE SITE"

Göran Nilsson, Olle Olsson
Swedish Geological Co., Sweden

February 1986

ABSTRACT
The Gideå site in Northern Sweden was selected as an experimental site for the large scale crosshole seismic field tests. The investigations made to characterize the site prior to the seismic tests cover an area of approximately 6 km^2 and extends to a depth of about 600 m. The Gideå site has a flat topography, insignificant soil depth and a high percentage of outcrops. The dominating rock type is veined gneiss of North-Easterly structural strike and small dip. In conformity with the structure of the gneiss there are strata of granite gneiss. The proportion of the granite gneiss in the boreholes is 6%.

Outside the Gideå site there are regional fracture zones towards the West-North-West and the North-West. Eleven local fracture zones have been identified within the site. The borehole investigations indicate that the fracture zones have an average width of 11 m and contain small portions of crushed and clay-altered rock. The fracture zones are steeply dipping with the exception of two subhorizontal zones in the northern and eastern parts of the site.

Existing strata of granite gneiss have a higher hydraulic conductivity compared to the surrounding veined gneiss. At a depth of 500 m the average hydraulic conductivity of the granite gneiss is 1.5×10^{-10} m/s and that of the veined gneiss 2×10^{-11} m/s. This implies anisotropic hydraulic properties in the rock mass with a higher hydraulic conductivity in the horizontal direction.

"HYDROGEOLOGICAL CHARACTERIZATION OF THE VENTILATION DRIFT (Buffer Mass Test) AREA, STRIPA, SWEDEN"

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February 1986

ABSTRACT
Fracture and hydrology data collected during the original KBS-LBL research program at Stripa, Sweden, have been reviewed, processed and analyzed in order to (1) describe the variation of permeability frequency and permeability with depth, (2) determine the relationship between fracture frequency and permeability, (3) calculate the parameters of the permeability and fracture aperture distributions, and (4) use the field data in a numerical simulation of the flow through the fracture network in the ventilation drift (Buffer Mars test) area at the Stripa site. These data include 766 injection and withdrawal tests that were completed in 3 surface and 15 subsurface boreholes. Detailed analysis of the hydrology and fracture data showed a general pattern of decreasing permeability with depth and no significant change in fracture frequency with depth in the surface boreholes. A weak correlation was found between fracture frequency and permeability in the subsurface boreholes. The large number of intervals with flowrates below the measurement limit of the packer test equipment produced truncation errors in the permeability and aperture data that were empirically corrected using cumulative probability plots.

The distribution parameters for fracture orientation, trace lengths, spacings and apertures for each of the four fracture sets, at the Stripa site, have been used as input for the generation of fracture networks for the ventilation drift (Buffer Mass Test) area. The total flowrates computed for these fracture networks, based on field defined hydraulic boundary conditions, agreed very closely with the flowrates measured during the macropermeability experiment 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.

"CROSSHOLE INVESTIGATIONS – THE METHOD, THEORY AND ANALYSIS OF CROSSHOLE SINUSOIDAL PRESSURE TESTS IN FISSURED ROCK"

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June 1986

ABSTRACT
This report describes the cross-hole hydrogeological testing technique known as sinusoidal pressure testing. The terms amplitude attenuation and phase lag which characterize a sinusoidal pressure test are defined and their measurement in the "Crosshole Programme" of the Stripa Project is described. The equipment to produce a sinusoidal variation is described in detail elsewhere but the computerized method of deriving the characteristic parameters, attenuation and phase lag, from the raw data is detailed. The small computer programme "SINEFIT" which performs this function is described in Appendix I.

Concepts of flow geometry are introduced in relation to sinusoidal tests and relationships between hydrogeological properties and measured characteristic parameters are derived. Mathematical solutions for a point source in a homogeneous porous medium, an isotropic fissured porous medium, an anisotropically fissured porous medium and a single fissure are given. The line source case in these configurations is introduced briefly as Appendix II. Additionally, for the fissured porous medium cases, the effect of differing shapes of matrix block is evaluated and a generalized solution applicable to fissured crystalline rock suggested. The possible option of mixing frequencies in a single test is considered unsuitable given the amount of background pressure fluctuation and the processing of the received signal. The inclusion of anisotropy produces large numbers of unknowns so a least squares interpretation procedure is introduced. This has been evaluated with a synthetic data set where it was found that fissure specific storage was effectively undefined. The accurate measurement of phase lag is crucial to test interpretation.

1986 **TR 86 – 04**

"EXECUTIVE SUMMARY OF PHASE 1"

Swedish Nuclear Fuel and Waste Management Co., Stockholm

July 1986

SUMMARY OF CONCLUSIONS

The first phase of the Stripa Project concerned the development of methods and techniques for repository site investigations as well as verification of previously obtained laboratory results by in situ experiments.

The hydrogeological and hydrogeochemical investigations resulted in a recommendation on hydraulic testing at repository depth and the conclusion that detailed hydrogeochemical processes cannot be understood without the integrated use of several investigation techniques.

Increased knowledge on the detailed flow of water and migration of nuclides in single fractures have strengthened our confidence in predicted retardation. The diffusion of the radionuclides into the rock matrix and sorption onto fracture surfaces have proven to be active in situ processes.

The major conclusion from the investigation of bentonite as a buffer and backfilling material is that the main physical processes are understood and can be predicted for various repository geometries. The major process is water uptake from the rock since it governs the build-up of temperatures and swelling pressures. This uptake is primarily related to the water-bearing capacity of the surrounding rock and yields a fast maturation of the clay if the deposition holes are intersected by hydraulically active fractures. It was also concluded from the experiment that the techniques required for preparation and application of bentonite-based buffer materials are available.

TR 86 – 05

"ANNUAL REPORT 1985"

Swedish Nuclear Fuel and Waste Management Co., Stockholm

August 1986

1987 **TR 87–01**

"FINAL REPORT OF THE BOREHOLE, SHAFT, AND TUNNEL SEALING TEST – Volume I: Borehole plugging"

R Pusch, L Börgesson
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January 1987

ABSTRACT
The Borehole Plugging Experiment comprised field tests of the sealing function and the practicality in handling and application of plugs consisting of segments of perforated metal casings filled with cylindrical blocks of highly compacted sodium bentonite. Preparative tests had shown that the clay swells out through the perforation and embeds the casings. The field tests demonstrated that even very long holes can be effectively sealed by such plugs and that the clay becomes very homogeneous and forms a tight contact with the rock in a relatively short time. By that the plugs become practically impervious and the flow along the clay/rock contact will be insignificant. The longevity of such plugs extends over several thousand years under the conditions that usually prevail in crystalline rock.

TR 87–02

"FINAL REPORT OF THE BOREHOLE, SHAFT, AND TUNNEL SEALING TEST – Volume II: Shaft plugging"

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G Ramqvist
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January 1987

ABSTRACT
Shaft sealing by use of highly compacted bentonite was investigated in a 14 m long shaft in which two plugs were constructed with a central sand-filled central space for injecting water. A first reference test with concrete plugs was followed by a main test in which the plug material consisted of blocks of highly compacted sodium bentonite powder. In the latter test, the outflow from the injection chamber was only a few percent of that with the concrete plugs, which demonstrates the excellent sealing properties of the clay. The main effect was that practically no water flow took place along the rock/clay interface. The longevity of smectite clay in crystalline rock is sufficient to make bentonite plugs operative for several thousand years.

1987 TR 87 – 03

"FINAL REPORT OF THE BOREHOLE, SHAFT, AND TUNNEL SEALING TEST – Volume III: Tunnel plugging"

R Pusch, L Börgesson
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G Ramqvist
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February 1987

ABSTRACT
Like the Borehole and Shaft plugging tests, the Tunnel test gave evidence of the very effective sealing power of Na bentonite. The test arrangement consisted of a 9 m long 1.5 m diameter steel tube surrounded by sand and cast in concrete plugs at each end. These plugs contained bentonite forming "O-ring" sealings at the concrete/rock interface. The test had the form of injecting water into the sand and measuring the leakage that took place through the adjacent rock and along the plug. It was concluded that the drop in leakage from more than 200 l/hour at 100 kPa water pressure early in the test to 75 l/hour at 3 MPa pressure at the end was due partly to the swelling pressure exerted by the bentonite on the rock and by penetration of bentonite into water-bearing rock fractures. The major sealing process appears to be the establishment of a very tight bentonite/rock interface.

1987 **TR 87 – 04**

"CROSSHOLE INVESTIGATIONS – DETAILS OF THE CONSTRUCTION AND OPERATION OF THE HYDRAULIC TESTING SYSTEM"

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May 1986

ABSTRACT
The Crosshole Programme, part of the international Stripa Project is designed to evaluate the effectiveness of various remote-sensing techniques in characterising a rock mass around a repository. A multidisciplinary approach has been adopted in which various geophysical, mapping and hydrogeological methods are used to determine the location and characteristics of significant features in the rock. The Programme utilises six boreholes drilled in a fan array from the 360 metre level in the Stripa Mine, Sweden.

The hydrogeological component of the work uses single and crosshole testing methods, including sinusoidal pressure testing, to locate fractures and characterise groundwater movement within them. Crosshole methods use packers to isolate portions of two boreholes which both intersect a significant feature in the rock mass. Hydraulic signals are generated in one isolated section and received in the other borehole. This report describes the design and operation of the computer-controlled system which automatically performs the hydrogeological tests.

Key words: Hydrogeological testing, equipment, mines, single hole testing, crosshole testing, sinusoidal testing.

"WORKSHOP ON SEALING TECHNIQUES, TESTED IN THE STRIPA PROJECT AND BEING OF GENERAL POTENTIAL USE FOR ROCK SEALING"

R Pusch
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February 1987

1 INTRODUCTION

While conventional rock sealing is normally made by use of cement grouts, clay has been applied in the very comprehensive rock sealing study that is part of the Stripa Project. This enterprise is an autonomous OECD project, financed and supervised by USA, Switzerland, Japan, Canada, Finland, Great Britain, France, Spain and Sweden. The major item has been to investigate the sealing power of sodium bentonite for the following purposes:

- To create a low-permeable envelope of metal canister with highly radioactive wastes.
- To plug boreholes and shafts so that the opening gets backfilled with a medium of lower hydraulic conductivity than the excavated rock.
- To seal off strongly water-bearing rock zones from intersecting tunnels while leaving a sufficiently large part of the plug open for vehicles etc.

The first-mentioned item was covered in the Buffer Mass Test (BMT), in which a setup was investigated that can be considered as an almost full-scaled version of the Swedish KBS 3 concept, while the other two served to investigate how the near-field isolation effect could be improved by sealing certain important structures which may indirectly affect the canister isolation. While the BMT involved application of thermal gradients to the clay, which largely affected the water uptake, the other tests were conducted at normal rock temperature, i.e. around 10°C.

The common feature of all the tests was that the sealing effect was obtained by the ability of Na bentonite to take up water and expand to fill up the space which was supposed to be sealed.

1987 TR 87–06

"CROSSHOLE INVESTIGATIONS – RESULTS FROM SEISMIC BOREHOLE TOMOGRAPHY"

J Pihl, M Hammarström, S Ivansson, P Morén
National Defence Research Institute, Sweden

December 1986

ABSTRACT

A system for seismic crosshole measurements has been designed, built and tested. The system can be used both for small-scale (ie 10 — 200 m) and large-scale (ie 200 — 1000 m) operations.

The design includes both borehole receivers, amplifiers and recording system. The receivers can be used down to 700 m depth in slim boreholes.

Much work has gone into the development of analysis methods. Tomographic algorithms have been developed for the analysis of seismic data. The development includes basic theory as well as numerical methods.

Special care has been taken to minimize systematic errors. Many data quality checks have been made.

Field tests have been carried out at the large-scale test site at Gideå and at the small-scale test site at Stripa.

In the large-scale test some zones of fractured rock were found. In addition, there appears to be a relatively large area of rock without any major anomalous features.

It appears that problems asscociated with large-scale crosshole seismics are still substantial. Further work is needed to solve the problems with ray-bending and anisotropy.

In the small-scale test the measurements could be carried out with high precision. Several zones with different properties are visible in the tomograms.

It is our opinion that the technique for small-scale crosshole seismics is now developed to a level where it can be utilized as a useful tool for rock-quality assessment.

1987 TR 87 – 07

"REFLECTION AND TUBEWAVE ANALYSIS OF THE SEISMIC DATA FROM THE STRIPA CROSSHOLE SITE"

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Vibrometric OY, Finland

S Bähler, M Hammarström, J Pihl
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December 1986

ABSTRACT
Reflection and tubewave analysis has been made using existing seismic crosshole data. The purpose of the work was to test if crosshole data are suitable for analysis by reflection and tubewave analysis methods.

The data from the crosshole research program (radar, seismics and hydraulics) in the Stripa Phase II Project resulted in the construction of a model. The results from the present study were compared to this model.

It was found that the existing data set used for tomographic analysis could only be used to a limited extent, as reflection analysis requires a more dense detector coverage. Nevertheless two reflectors were detected. The positions of the 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 the results with previous hydraulic tests, it was found that tubewave sources and hydraulically conductive zones are in concordance. All previously defined zones but one could be detected.

1987 **TR 87 – 08**

"CROSSHOLE INVESTIGATIONS – SHORT AND MEDIUM RANGE SEISMIC TOMOGRAPHY"

C Cosma
Vibrometric OY, Finland

February 1987

ABSTRACT
Seismic tomographic tests were conducted as a part of the Crosshole Investigations program of the Stripa Project. The aim has been to study if it is possible to detect by seismic tomography major fracture zones and determine their dimensions and orientation. The analysis was based on both compressional (P) and transversal (S) waves. The Young's modulus has been also calculated for a subset of measurements as a cross check for the P and S wave velocities.

The experimental data was collected at the crosshole site in the Stripa mine during 1984—1985. A down-thehole impact source was used together with triaxial detectors and a digital seismograph. Five tomographic sections were obtained. The number of records per section was appr. 250. Measurements were done down to 200 m depth in all boreholes.

The main conclusion of this report is that it is possible to detect major fracture zones by seismic tomography. Their position and orientation can also be estimated.

TR 87 – 09

"PROGRAM FOR THE STRIPA PROJECT PHASE 3, 1986 – 1991"

Swedish Nuclear Fuel and Waste Management Co., Stockholm

May 1987

"CROSSHOLE INVESTIGATIONS – PHYSICAL PROPERTIES OF CORE SAMPLES FROM BOREHOLES F1 AND F2"

K-Å Magnusson, S Carlsten, O Olsson
Swedish Geological Co., Sweden

June 1987

ABSTRACT
The geology and physical properties has been studied of roughly 100 core samples from the boreholes F1 and F2 drilled at the Crosshole site, located at the 360 m level in the Stripa mine. The granitic rock has been divided into two classes: fracture zones (also called major units) and a rock mass which is relatively undeformed. Samples from the major units have lower resistivity, higher porosity and dielectric constant than the samples from the less deformed rock mass.

The electrical properties of the core samples have been measured over a frequency interval ranging from 1 Hz to 70 MHz. The conductivity of the samples increases with frequency, approximately with the frequency raised to the power 0.38. The dielectric constant decreases with frequency but is essentially constant above 3 MHz. These results show that the Hanai-Bruggeman equation can be used to describe the electrical bulk properties of the Stripa granite.

The electrical conductivity of the samples is well correlated to the water content of the samples. The granite has a small contents of electrically conductive minerals which could influence the electrical bulk properties.

"CROSSHOLE INVESTIGATIONS – RESULTS FROM BOREHOLE RADAR INVESTIGATIONS"

O Olsson, L Falk, O Forslund, L Lundmark, E Sandberg
Swedish Geological Co., Sweden

May 1987

ABSTRACT
The borehole radar method has been developed and applied to the localization and characterization of fracture zones in crystalline rock. In a geological medium such as crystalline rock there is a significant attenuation of the radar waves, increasing with frequency. There is, however, a frequency window from a few MHz to a few hundred MHz where the wave aspect of the radar dominates and acceptable ranges can be achieved.

A new borehole radar system has been designed, built and tested. The system consists of borehole transmitter and receiver probes, a signal control unit for communication with the borehole probes, and a computer unit for storage and display of data. The system can be used both in singlehole and crosshole modes and probing ranges of 115 m and 300 m, respectively, have been obtained at Stripa. The borehole radar is a short pulse system which uses center frequencies in the range 20 to 60 MHz, corresponding to wavelengths of a few meters in the rock.

Single hole reflection measurements have been used to identify fracture zones and to determine their position and orientation. The zones often cause strong and well defined reflections originating from the resistivity change at the edges of the zones. The exact orientation of the zones can be determined by combining data from several boreholes.

Reflections are also observed in crosshole measurements. A new technique has been developed for the analysis of crosshole reflection data which in principle allows the orientation to be uniquely determined if the boreholes are not in the same plane.

The travel time and amplitude of the first arrival measured in a crosshole experiment can be used as input data in a tomographic analysis. Tomographic inversion has given detailed information about the extent of fracture zones in the plane spanned by the boreholes as well as a quantitative estimate of their electrical properties.

The radar method has been intensively tested at Stripa and has been shown to be an efficient instrument for locating and characterizing fracture zones. It is a unique instrument combining a resolution on the order of meters with probing ranges of about a hundred meters.

Keywords: Borehole radar, reflection, crosshole tomography, fracture zones, site investigations.

1987 **TR 87 – 12**

"STATE-OF-THE-ART REPORT ON POTENTIALLY USEFUL MATERIALS FOR SEALING NUCLEAR WASTE REPOSITORIES"

Swedish Nuclear Fuel and Waste Management Co., Stockholm

June 1987

IR 87 – 13

"ROCK STRESS MEASUREMENTS IN BOREHOLE V3"

B Bjarnason, G Raillard
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July 1987

ABSTRACT
Hydrofracturing rock stress measurements have been conducted in a 50 m deep, vertical borehole at the end of the 3-D migration test drift in the Stripa Mine to determine the horizontal stress field in the test block of Phase 3 of the Stripa Project. The orientation of the maximum horizontal stress is found to be N71° W. The magnitude of the minimum horizontal stress is 11.1 MPa and the maximum stress is approximately twice as large. The vertical stress is found to be equal to the lithostatic stress from the weight of the overburden. The results are in excellent agreement with previous measurements in a deep surface borehole some 200 m to the NW of the test block but disagree to the stress data from the buffer mass test area located at similar distance but to the SW of the block. An attempt to measure the three-dimensional state of stress in the rock by injection tests on preexisting fractures in the borehole was not successful as the data set collected by the method was incomplete.

TR 87 – 14

"ANNUAL REPORT 1986"

Swedish Nuclear Fuel and Waste Management Co., Stockholm

August 1987

1987 **TR 87–15**

"HYDROGEOLOGICAL CHARACTERIZATION OF THE STRIPA SITE"

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June 1987

ABSTRACT
This study was initiated in January, 1986, to determine a) if the permeability of the rock mass in the immediate mine area was anisotropic, b) the effective and total fracture porosity distributions based on field and laboratory data and c) the three dimensional configuration of the groundwater flow system at Stripa in order to properly interpret the hydrogeological, geochemical and isotopic data. The borehole packer test data show that on average SBH1 and SBH2 have lower permeabilities than SBH3. This is consistent with the pattern that one would expect for the orientation of the boreholes with respect to in-situ stresses. Laboratory studies showed a strong decrease in fracture permeability with increase in normal stress in core samples containing natural fractures suggesting that anisotropy to flow in the vertical direction must exist, since in-situ stresses increase with depth. The contribution of fracture geometry to the rock mass flow anisotropy was analyzed using a fracture network generator to simulate fracture networks in three orthogonal planes. In the horizontal plane the relative flowrates indicate an anisotropy factor of 1.5 with the principal direction oriented North-Northwest. Similar degrees on anisotropy were determined for the two vertical planes.

The total and flow porosities of single fractures from Stripa were determined in the laboratory using a resin impregnation technique. The equivalent uniform apertures for two samples, computed using the measured variation in fracture aperture and resin thickness, were consistent with apertures computed from the hydraulic data. The mean effective porosity contributed by the fractures in the rock mass calculated by combining the aperture data from the field packer tests with the fracture statistics for trace length and spacing was about an order of magnitude less than the porosity computed using the hydraulic data from the laboratory tests on single fractures in the core samples. More important, the porosity calculated using resin thickness data was almost a factor of 100 greater than that computed using the field data.

The three-dimensional numerical model gave mine inflows that were consistent with the measured mine inflows with perturbations extending to at least 3.000 m of depth. Transit times predicted from the flow tube calculations were much shorter than those predicted from the existing geochemical and isotopic data for porosities developed from field data. Corrections for the higher porosities determined from laboratory studies gave transit times that were more consistent with those inferred from isotope studies.

1987 TR 87–16

"CROSSHOLE INVESTIGATIONS – FINAL REPORT"

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J Black
British Geological Survey, United Kingdom

C Cosma
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J Phil
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September 1987

The Crosshole programme has comprised the development of borehole radar, borehole seismic, and hydraulic testing methods. These methods provide data on the electric, elastic, and hydraulic properties of the rock. For each of these methods new equipment has been development, field tests have been performed, interpretation techniques developed and tested on the obtained data. Finally, a comparison of the results obtained with the different methods has been made.

During the course of the Crosshole project the radar and seismic methods have been taken from the prototype stage into being practical site characterization tools.

The analysis of the radar and seismic data has given a consistent description of the fracture zones at the Crosshole site in agreement with geological and other geophysical observations made in the boreholes. The geophysical methods have achieved a resolution of a few metres combined with a probing ranges of a few hundred metres.

The hydraulic investigations within the Crosshole project have yielded substantial progress in assessing the hydrogeology of fractured granitic rocks. The crosshole hydraulic testing concentrated on measuring the distribution of hydraulic properties within the extensive fractured zones identified by geophysics. An approach was adopted based on a sinusoidally varying pressure and flow rate to minimize testing time and to allow the signal to be observed against a changing background.

A new analysis involving the "dimension" of the flow test has been developed to analyse the results of the crosshole sinusoidal testing. This is a versatile analysis well-suited to the sort of flow geometries likely to be found in crystalline rocks.

The combined analysis of the geophysical and the hydraulic data set has shown that groundwater flow is concentrated within a few major features which have been identified by the geophysical methods. The main features are considered to be broadly planar, containing patches of high and low hydraulic conductivity. The fracture zones are likely to be channelled, where the flow paths constitute a branching interconnecting network.

1987 **IR 87–17**

"SITE CHARACTERIZATION AND VALIDATION – GEOPHYSICAL SINGLE HOLE LOGGING"

B Fridh
Swedish Geological Co., Sweden

December 1987

ABSTRACT
Five "boundary boreholes" have been drilled for preliminary characterization of a previously unexplored site at the 360 m level in the Stripa mine. Three of these boreholes are directed towards the North in the mine coordinate system, while two are directed towards the West. Furthermore, a vertical hole has been drilled at the end of the 3D-migration drift.

To adequately describe the rock mass in the vicinity of these boreholes, a comprehensive program utilizing a large number of geophysical borehole methods has been carried out.

The specific geophysical character of the rock mass and the major deformed units distinguished in the boreholes are recognized, and in certain cases also correlated between the boreholes.

Key words: Granite, geophysical borehole logging, fracture zones.

1987 **TR 87–18**

"CROSSHOLE INVESTIGATIONS – HYDROGEOLOGICAL RESULTS AND INTERPRETATIONS"

J Black, D Holmes, M Brightman
British Geological Survey, United Kingdom

December 1987

ABSTRACT
The Crosshole Programme was an integrated geophysical and hydrogeophysical study of limited volume of rock (known as the Crosshole Site) within the Stripa Mine. Borehole radar, borehole seismic and hydraulic methods were developed for specific application to fractured crystalline rock.

The hydrogeological investigations contained both single borehole and crosshole test techniques. A novel technique, using a sinusoidal variation of pressure, formed the main method of crosshole testing and was assessed during the programme. The strategy of crosshole testing was strongly influenced by the results from the geophysical measurements.

The single borehole testing comprised roughly equal amounts of constant head and slug/pulse testing. Transmissivities varied between values around $1x10^{-12}$ $m^2 sec^{-1}$ and $5x10^{-7}$ $m^2 sec^{-1}$. For the most part high transmissivities were associated with geophysically identifiable fracture zones. Test zone lengths varied between 2 and 13 m and few tests were interpretable as single fissure responses.

The crosshole sinusoidal testing was carried out using computer-controlled test equipment to generate the sinusoidally varying head in a single zoner (the "source") isolated by packers. A second ("receiver") borehole contained a number of straddle intervals and was used to observe the propagation of the sinusoidal signal. The number of positive responses was limited and flow appeared to be concentrated within a few "channels". Analysis was attempted using single fissure, regularly fissured and porous medium models. None gave satisfactory fits to the measured data. A new analysis involving the "dimension" of the flow test has been developed to analyse the results of the crosshole sinusoidal testing. This yields results involving "fractional dimensions" where flow may be assumed to occur within regions which do not fit within the existing 1, 2 and 3 dimensional models. This is a versatile analysis, well-suited to the sort of flow geometries likely to be found in crystalline rocks.

The long term, larger scale hydrogeological response of the region was assessed by examining the variation of heads over the region. These were responding to the presence of an old drift. A method of overall assessment involving minimising the divergence from a homogeneous response yielded credible values of hydraulic conductivity for the rock as a whole.

1987 **TR 87–19**

"3-D MIGRATION EXPERIMENT – REPORT 1 SITE PREPARATION AND DOCUMENTATION"

H Abelin, L Birgersson
Royal Institute of Technology, Sweden

November 1987

ABSTRACT
This report is one of the four reports describing the Stripa 3D experiment where water and tracer flow has been monitored in a specially excavated drift in the Stripa mine. The experiment was performed in a specially excavated drift at the 360 m level in granite. The whole ceiling and upper part of the walls were covered with more than 350 individual plastic sheets where the water flow into the drift could be collected. 11 different tracers were injected at distances between 11 and 50 m from the ceiling of the drift. The flowrate and tracer monitoring was kept up for more than two years. The tracer breakthrough curves and flowrate distributions were used to study the flow paths, velocities, hydraulic conductivities, dispersivities and channeling effects in the rock.

The present report describes how the site was prepared and what documentation is available.

TR 87–20

"3-D MIGRATION EXPERIMENT – REPORT 2 INSTRUMENTATION AND TRACERS"

H Abelin, L Birgersson, J Gidlund
Royal Institute of Technology, Sweden

November 1987

ABSTRACT
This report is one of the four reports describing the Stripa 3D experiment where water and tracer flow has been monitored in a specially excavated drift in the Stripa mine. The experiment was performed in a specially excavated drift at the 360 m level in granite. The whole ceiling and upper part of the walls were covered with more than 350 individual plastic sheets where the water flow into the drift could be collected. 11 different tracers were injected at distances between 11 and 50 m from the ceiling of the drift. The flowrate and tracer monitoring was kept up for more than two years. The tracer breakthrough curves and flowrate distributions were used to study the flow paths, velocities, hydraulic conductivities, dispersivities and channeling effects in the rock.

The present report describes the instrumentation developed and used as well as the tracers that were tested and used in the experiment.

1987 **TR 87–21**

Part I "3-D MIGRATION EXPERIMENT – REPORT 3 PERFORMED EXPERIMENTS, RESULTS AND EVALUATION"

H Abelin, L Birgersson, J Gidlund, L Moreno, I Neretnieks, H Widén, T Ågren
Royal Institute of Technology, Sweden

November 1987

Part II "3-D MIGRATION EXPERIMENT – REPORT 3 PERFORMED EXPERIMENTS, RESULTS AND EVALUATIONS, APPENDICES 15, 16 AND 17"

H Abelin, L Birgersson, J Gidlund, L Moreno, I Neretnieks, H Widén, T Ågren
Royal Institute of Technology, Sweden

November 1987

ABSTRACT
This report is one of the four reports describing the Stripa 3D experiment where water and tracer flow has been monitored in a specially excavated drift in the Stripa mine. The experiment was performed in a specially excavated drift at the 360 m level in granite. The whole ceiling and upper part of the walls were covered with more than 350 individual plastic sheets where the water flow into the drift could be collected. 11 different tracers were injected at distances between 11 and 50 m from the ceiling of the drift. The flowrate and tracer monitoring was kept up for more than two years. The tracer breakthrough curves and flowrate distributions were used to study the flow paths, velocities, hydraulic conductivities, dispersivities and channeling effects in the rock.

The present report describes the structure of the observations, fracture mapping the flowrate measurements and how these were used to estimate the hydraulic conductivities. The main part of this report addresses the interpretation of the tracer movement in the rock outside the drift. The tracer movement as measured by the more than 160 individual tracer curves has been analyzed with the traditional advection-dispersion model, but also with more recent models which include the effects of channeling and the diffusion of tracers into stagnant waters in the rock matrix and in stagnant waters in the fractures themselves. The tracer experiments have permitted the flow porosity and dispersion to be studied.

1987 **TR 87–22**

"3-D MIGRATION EXPERIMENT – REPORT 4 FRACTURE NETWORK MODELLING OF THE STRIPA 3-D SITE"

J Andersson, B Dverstorp
Royal Institute of Technology, Sweden

November 1987

ABSTRACT
This report is one of the four reports describing the Stripa 3D experiment where water and tracer flow has been monitored in a specially excavated drift in the Stripa mine. The experiment was performed in a specially excavated drift at the 360 m level in granite. The whole ceiling and upper part of the walls were covered with more than 350 individual plastic sheets where the water flow into the drift could be collected. 11 different tracers were injected at distances between 11 and 50 m from the ceiling of the drift. The flowrate and tracer monitoring was kept up for more than two years. The tracer breakthrough curves and flowrate distributions were used to study the flow paths, velocities, hydraulic conductivities, dispersivities and channeling effects in the rock.

The present report describes how fracture statistics and a fracture network model have been used to interpret the flow pattern in the 3D-drift.

"CROSSHOLE INVESTIGATIONS – IMPLEMENTATION AND FRACTIONAL DIMENSION INTERPRETATION OF SINUSOIDAL TESTS"

D Noy, J Barker, J Black, D Holmes
British Geological Survey, United Kingdom

February 1988

ABSTRACT
The Crosshole Programme was an integrated geophysical and hydrogeological study of a limited volume of rock (known as the Crosshole Site) within the Stripa Mine. Borehole radar, borehole seismic and hydraulic methods were developed for specific application to fractured crystalline rock.

The hydrogeological investigations contained both single borehole and crosshole test techniques. A novel technique, using a sinusoidal variation of pressure, formed the main method of crosshole testing and was assessed during the programme. The strategy of crosshole testing was strongly influenced by the results from the geophysical measurements.

The crosshole sinusoidal testing was carried out using computer-controlled test equipment to generate the sinusoidally varying head in a single zone (the "source") isolated by packers. A second ("receiver") borehole contained a number of straddle intervals and was used to observe the propagation of the sinusoidal signal. The number of positive responses was limited and flow appeared to be concentrated within a few "channels". Analysis was attempted using single fissure, regularly fissured and porous medium models. None gave satisfactory fits to the measured data. A new analysis involving the "dimension" of the flow test has been developed to analyse the results of the crosshole sinusoidal testing. This analysis allows the dimension of the flow to assume non-integer values whereas conventionally the dimension is taken as either one, two or three, for example, radial flow in a uniform planar fissure would be two dimensional.

The new model is found to give a more consistent description of the test data than the conventional models and suggests a complex pattern of fracture properties within each fracture zone. However, the results presented must be considered as being preliminary since we still have much to learn about how to best apply this model and present the results. Also, it is not yet clear how the derived value of "dimension" can be related to the transport properties of the rock.

1988 **IR 88–02**

“SITE CHARACTERIZATION AND VALIDATION – MONITORING OF HEAD IN THE STRIPA MINE DURING 1987”

S Carlsten, O Olsson, O Persson, M Sehlstedt
Swedish Geological Co.

Sweden, April 1988

ABSTRACT
The groundwater head has been monitored in 26 borehole sections surrounding the site which is investigated as a part of the Site Characterization and Validation Project. This report contains basic data on the head monitoring system and graphical presentation of the results obtained during 1987.

Keywords: Piezometric head, monitoring system, crystalline rock.

TR 88–03

“SITE CHARACTERIZATION AND VALIDATION – BOREHOLE RADAR INVESTIGATIONS, STAGE I”

O Olsson, J Eriksson, L Falk, E Sandberg
Swedish Geological Co.

Sweden, April 1988

ABSTRACT
The borehole radar investigation program of the SCV site has comprised single hole reflection measurements with centre frequencies of 22, 45, and 60 MHz. Crosshole tomographic measurements have been made between the boreholes W1—W2, N2—N3, N3—N4, and N2—N4. Crosshole reflection measurements have also been made between the same boreholes. The radar range obtained in the single hole reflection measurements was approximately 100 m for the lower frequency (22 MHz) and about 60 m for the centre frequency 45 MHz. In the crosshole measurements transmitter-receiver separations from 60 to 200 m have been used.

The radar investigations have given a three dimensional description of the structure at the SCV site. A generalized model of the site has been produced which includes three major zones (RA, RB, and RH), four minor zones (RC, RD, RK, and RL), and a circular feature (RQ). These features are considered to be the most significant at the site. Smaller features than the ones included in the generalized model certainly exist but no additional features comparable to the three major zones are thought to exist. The results indicate that the zones are not homogeneous but rather that they are highly irregular containing parts of considerably increased fracturing and parts where their contrast to the background rock is quite small. The zones appear to be approximately planar at least at the scale of the site. At a smaller scale the zones can appear quite irregular.

Keywords: Borehole radar, fracture zones, granite

"ROCK SEALING – LARGE SCALE FIELD TEST AND ACCESSORY INVESTIGATIONS"

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March 1988

SUMMARY
The experience from the pilot field test and the basic knowledge extracted from the lab experiments have formed the basis of the planning of a Large Scale Field Test. The intention is to find out how the "instrument of rock sealing" can be applied to a number of practical cases, where cutting-off and redirection of groundwater flow in repositories are called for. Five field subtests, which are integrated mutually or with other Stripa projects (3D), are proposed. One of them concerns "near-field" sealing, i e sealing of tunnel floors hosting deposition holes, while two involve sealing of "disturbed" rock around tunnels. The fourth concerns sealing of a natural fracture zone in the 3D area, and this latter test has the expected spin-off effect of obtaining additional information on the general flow pattern around the norhteastern wing of the 3D cross. The fifth test in an option of sealing structures in the Validation Drift. The longevity of major grout types is focussed on as the most important part of the "Accessory Investigations", and detailed plans have been worked out for that purpose.

It is foreseen that the continuation of the project, as outlined in this report, will yield suitable methods and grouts for effective and long-lasting sealing of rock for use at strategic points in repositories.

1988 **TR 88 – 05**

"HYDROGEOCHEMICAL ASSESSMENT OF CRYSTALLINE ROCK FOR RADIOACTIVE WASTE DISPOSAL THE STRIPA EXPERIENCE"

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Université Paris-Sud, France

P Fritz
University of Waterloo, Canada

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US Geological Survey, USA

August 1988

ABSTRACT
This report presents a programme for the hydro-geochemical assessment of a crystalline rock site for radioactive waste disposal. It is based upon experience gained during the international programme of hydrochemical work at the Stripa mine. The important results of this work are summarised in this report and fuller details may be found in the separate final reports of the Phase 1 and Phase 2 geochemical investigations of the Stripa groundwaters.

The present report summarises the general sampling requirements for a successful hydrochemical investigation; the isotopic and chemical parameters which should be determined and the geochemical characterization of the rock matrix necessary for the interpretation of hydrochemistry. A general strategy for site evaluation by geochemical methods is presented.

TR 88 – 06

"ANNUAL REPORT 1987"

Swedish Nuclear Fuel and Waste Management Co., Stockholm

June 1988

"SITE CHARACTERIZATION AND VALIDATION – RESULTS FROM SEISMIC CROSSHOLE AND REFLECTION MEASUREMENTS, STAGE 1"

Calin Cosma, Reijo Korhonen
Vibrometric OY, Finland

Monica Hammarström, Per Norén, Jörgen Pihl
National Defence Research Institute, Sweden

September 1988

ABSTRACT

The SCV site has been surveyed by seismic crosshole and reflection methods. The analysis shows a rather patchy structure, with features of three main orientations.

Three crosshole sections were measured. Tomographic analyses were made using both Direct Inversion and Conjugate Gradient methods. Six major features were found. Most of these seem to have a rather uneven structure.

Reflection measurements were made using a VSP geometry. Two zero offset and one 70 m offset sections were recorded. By means of an elaborate signal analysis many structures become visible. The correlation with the tomographic analysis is good. In addition to the major features several other ones can be found following one of the three main directions.

The borehole geometry of the SCV site is not the optimum for a survey of this type. A larger angle between the planes of the W and N sections would have made it possible to determine the dips of the features with higher accuracy.

1988 **IR 88 – 08**

"STAGE 1 JOINT CHARACTERIZATION AND STAGE 2 PRELIMINARY PREDICTION USING SMALL CORE SAMPLES"

Gunnar Vik, Nick Barton
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August 1988

ABSTRACT
This report describes the preliminary results from an investigation of joint surfaces from small diameter core samples from sections of the boreholes W1, N3 and W2. Fracture surface features such as roughness and compression strength have been measured for each individual joint, and the data has been grouped in the two major joint sets as described by John Gale (6).

The data are presented as histograms and frequency diagrams to define natural variation and mean values for each parameter.

Finally, the report gives a prediction of shear strength, vs shear deformation and change of joint aperture vs normal loading and conductivity change as result of this loading.

IR 88 – 09

"SITE CHARACTERIZATION AND VALIDATION – HYDROCHEMICAL INVESTIGATIONS IN STAGE 1"

P Wikberg, M Laaksoharju, J Bruno, A Sandino
Royal Institute of Technology, Sweden

September 1988

ABSTRACT
The chemical composition of the groundwater in the SCV site has been determined. The samples have been taken from the boreholes N2, N3, N4, W1 and W2. A groundwater flow pattern has been established on the basis of the results. The redox conditions in the groundwater/rock system have been evaluated by analyses of the redox sensitive groundwater components iron, sulphide and uranium.

1988 IR 88–10

"SITE CHARACTERIZATION AND VALIDATION – DRIFT AND BOREHOLE FRACTURE DATA, STAGE I"

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September 1988

ABSTRACT

This report describes the procedures used in mapping fractures intersecting seven scanlines along the southern and eastern boundaries of the Site Characterization and Validation (SCV) site and the procedures used in logging and orienting the fractures intersecting the core from six "boundary boreholes" that were drilled as part of the site characterization program for the SCV site at the 360 m level in the Stripa mine. Scanline mapping along the mine drifts provided a detailed description of the fracture geometry on the boundaries of the SCV site. The cores from the boundary boreholes have been logged, reconstructed and oriented using a borehole Televiewer and a borehole TV camera and the true fracture orientations calculated. This has provide additional data on the fracture geometry within the SCV site.

The fracture data from both the scanlines and the core logging are presented in the Appendices. In addition, an initial analysis has been completed of the fracture orientations, trace lengths and spacings. Based on the variation in fracture orientations over the SCV site, there are two strong sub-vertical fracture sets or clusters and a poorly represented sub-horizontal fracture set. An empirical approach, based on the "blind zone" concept has been used to correct for orientation bias and to predict the orientations of the fracture system that will be intersected by the C and D boreholes in Stage III.

1988 **TR 88 – 11**

"ROCK SEALING – INTERIM REPORT ON THE ROCK SEALING PROJECT (STAGE I)"

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September 1988

ABSTRACT
The objective of the Sealing Project is to find ways of sealing finely fractured rock by grouting. This requires development of new injection technique as well as to identify materials which are sufficiently fluid to be groutable and acceptably low-pervious and physically and chemically stable. The present report describes the results of the first two years of investigation (Stage 1), which gave very positive results as concluded from a large field-scale test.

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