Nationale Genossenschaft für die Lagerung radioaktiver Abfälle
Société coopérative nationale pour l'entreposage de déchets radioactifs
Società cooperativa nazionale per l'immagazzinamento di scorie radioattive
NAGRA

TECHNISCHER BERICHT 81-05

Stripa Project

Summary of defined programs

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November 1980

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STRIPA PROJECT 81-01

Summary of defined programs

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November 1980

TECHNICAL REPORT

An OECD/NEA International project managed by:
SWEDISH NUCLEAR FUEL SUPPLY CO/DIVISION NUCLEAR FUEL SAFETY

STRIPA PROJECT

SKBF KBS

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

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

Seitens der Schweiz beteiligt sich die Nagra an diesen Untersuchungen.

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

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

Switzerland is represented in the Stripa Project by Nagra.

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

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

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

S T R I P A   P R O J E C T

SUMMARY OF DEFINED PROGRAMS

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November 1980

CONTENTS

PREFACE

During 1977-1980 a series of investigations in the field of radioactive waste storage were conducted in the abandoned Stripa mine, located in Central Sweden. The main part of the investigations were performed by Lawrence Berkeley Laboratory (LBL), University of California sponsored by the US Department of Energy (DOE) in cooperation with the Swedish Nuclear Fuel Supply Company (SKBF) through Division Nuclear Fuel Safety (KBS). The aim of these experiments was to develop techniques for determining regional rock mechanic, hydrologic and geophysic parameters at potential waste repository sites. In addition, the generated data increased the knowledge of the suitability of crystalline rock for terminal storage of radioactive material.

The LBL-KBS project aroused great interest in several countries. A new international cooperative project - the Stripa Project - again in the field of nuclear waste management, has therefore been established as an autonomous OECD/NEA project. The management of the Stripa project has been entrusted to KBS. Technical input and contribution of funds are so far given by the following countries:

Participant	Sponsored by
Canada	Atomic Energy of Canada Ltd (AECL)
Finland	Teollisuuden Voima Oy (TVO); Ministry of Trade and Industry; Imatra Power Company

Participant	Sponsored by
Japan	Power Reactor and Nuclear Fuel Development Corporation (PNC)
Sweden	Swedish Nuclear Fuel Supply Company (SKBF)
Switzerland	Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle (NAGRA)
United States	Department of Energy (DOE)

This is the first technical report in this series and it summarizes the programs for investigations funded at this stage.

HYDROGEOLOGICAL INVESTIGATIONS IN BOREHOLES

PRINCIPAL INVESTIGARORS: Leif Carlsson and Tommy Olsson
Geological Survey of Sweden (SGU)

1 Background

1.1 General

A proposal for an international cooperative hydrogeological investigation in the Stripa mine relating to the problems of underground disposal of nuclear waste was presented at a meeting arranged by OECD/NEA in Paris, June 1979. In revised form it was later discussed at Otaniemi in July, and in Stockholm in November 1979. It was then decided that a more comprehensive review of the proposed work should be prepared and sent to the delegates of the participating organisations, during December 1979. To fulfill this decision, an extended program was prepared by the Geological Survey of Sweden (SGU) on behalf of the Division of Nuclear Fuel Safety (KBS) within the Swedish Nuclear Fuel Supply Co (SKBF). Minor changes in this program were proposed in discussions during March 1980 within the Technical Subgroup for Hydrogeology (TSG) formed for the Stripa Project. These changes were presented in a supplement to the program dated in April 1980. The present paper presents the hydrogeological investigations which will be carried through as was decided upon at the TSG-meeting in May 1980.

1.2 Technical background

The final planning and layout of a deep underground repository for nuclear waste or spent fuel requires detailed information on the geological and hydrogeological conditions at repository depth. For many reasons it appears inpractical to aquire this information by investigations from the surface alone. Techniques of underground investigation to collect this information must therefore be developed and tested, and the validity of their results must be demonstrated.

Underground drilling of horizontal or subhorizontal drillholes seems to be a key element of such investigation prior to actual tunnelling. Such drillholes permit the accurate mapping of rocks, structures and hydrology of the penetrated sections, as well as the sampling and testing of the rocks and the local fluids and gases. In addition the rock-volumes surrounding the drillholes may be tested by a variety of geophysical and hydrological tools. These techniques and tools should be developed and tested at depth in order to reflect realistic working conditions and pressures. The present investigations will therefore take place in the Stripa mine where locations at depths of 350 - 400 m are available.

Actual mining at this former iron-mine in Stripa ended in 1976, and for the last two years the facilities have been used and extended in a Swedish-American cooperative program on radioactive waste storage in mined caverns in crystalline rock. A large amount of valuable background information has thus been accumulated. Efforts so far include:

- Compilation of available geological information
- Geological and tectonical mapping
- Rock stress measurements

- o Determination of mechanical and physical properties of the Stripa granite
- o Determination of hydraulic conductivity by means of water injection tests
- o Full-Scale heater experiment
- o Time-scaled heater experiment
- o Analysis of fractures and fracture hydrology assessment
- o Large-scale permeability experiment
- o Water analyses and groundwater dating

In order to carry out the above studies, various test arrangements were set up in the mine. Most of the experiments were performed at the 360 m level below the surface (c.f. Fig. 1). In addition, a 468 m deep vertical borehole was drilled at the 410 m level, as well as three approximately 350 m deep boreholes and seven 50 - 100 m deep boreholes from the surface. Geophysical, hydraulic and other tests were performed in these boreholes. The results of the completed measurements are presented in the report series Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns in Crystalline Rock, Technical Information.

1.3 The Stripa granite

The layout of the experiments suggested in the following text is to some extent determined by the local conditions. The target rock, the Stripa granite, is at the surface found north of the mine and in its extent limited towards the south by the orebearing series of metamorphic rock. The contact strikes approximately E-W, and, near the surface, is almost vertical. At depth it swings toward the south and at a depth of about 400 m, as exposed in the mine, it is nearly horizontal. The granite does not,however, swing upward to reach the surface again further

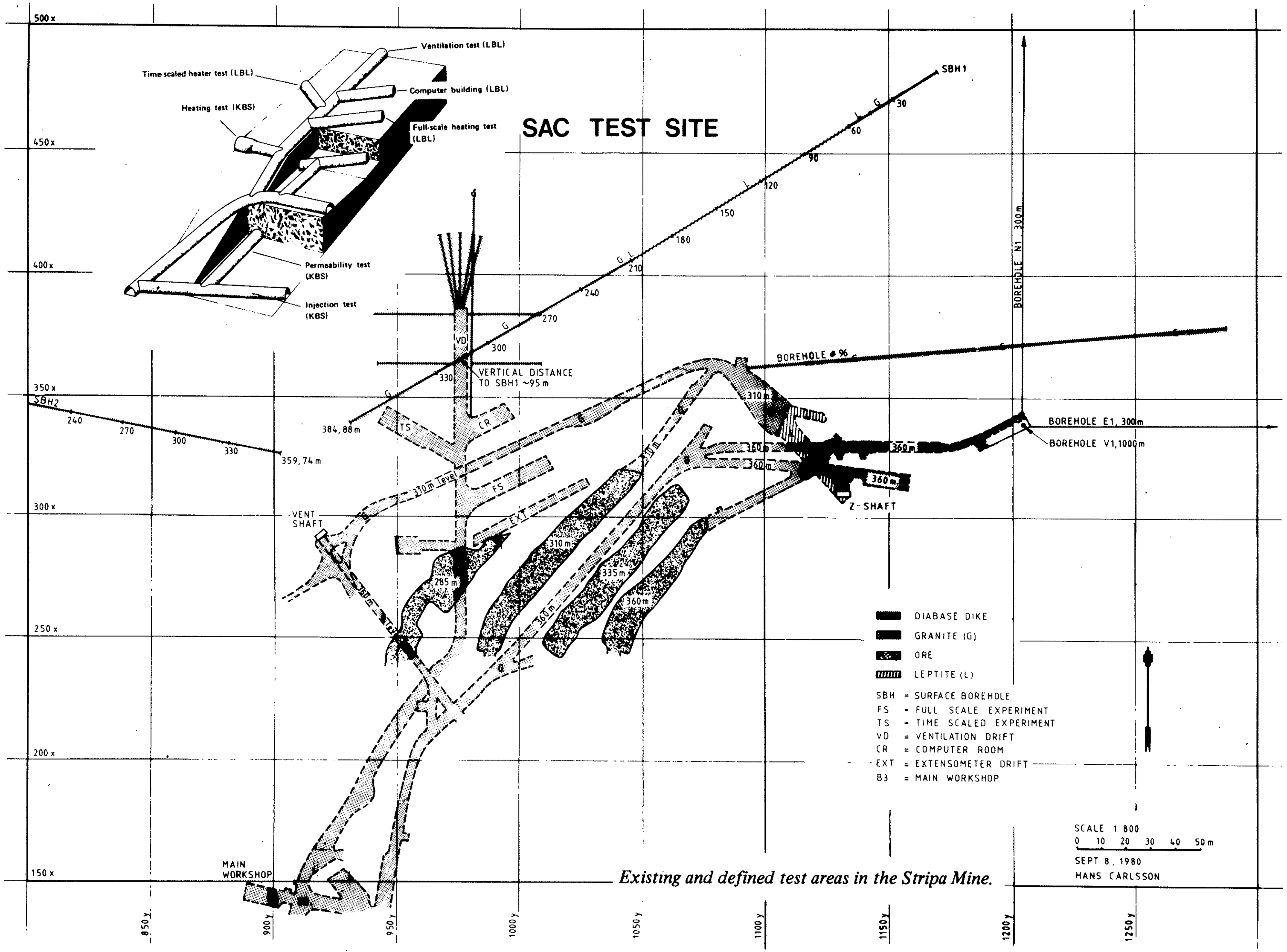

Figure 1. Map of the drifts at the 360 m level in the Stripa mine, with the extension of the ore body at different depths. The test sites used for former hydrogeological investigations are also shown. SAC = Swedish-American Cooperative Program.

south. The geology in the Stripa area is shown in Fig. 2 and 3 which represent the conditions at the surface and at the 360 m levels (Olkiewicz et. al. 1978).

The northern contact of the granite is hidden below a cover of till. The small iron ore of Hörningsbergsgruvan, about 800 m NE of Stripa, indicates, however, that the northern contact near the surface must be located about 400 m north of the southern one. The eastern and western boundaries of the granite body are not exposed. The general strike of the enclosing metamorphic rocks (leptites) suggests that the granite may be elongated in these directions. It may possibly represent the apex of a larger intrusion, which widens at depth, as indicated by the southern contact.

The granite is irregularily fractured with a great number of different orientations. It is, however, possible to distinguish some joint sets forming a fairly regular joint system.

The fractures predominantly strike NNE and WNW, most of them are within 30^{o} of the vertical. Similar orientations are shown by a number of diabase-dikes, which indicate a tensional phase with the main compressional stress directed SSW-NNE. The present stress-field which has been determined in a number of points out from the mine, shows that the largest principal stress is about 20.0 Mpa and directed parallel with the strike of the contact between the granite and the orebody, that is about NE-SW (Carlsson 1978). Many fractures are mineralized with chlorite, quartz epidote and calcite. Fracture-filling uraninite has been dated at around 1,560 mill years old. This is probably also the age of the diabase dikes.

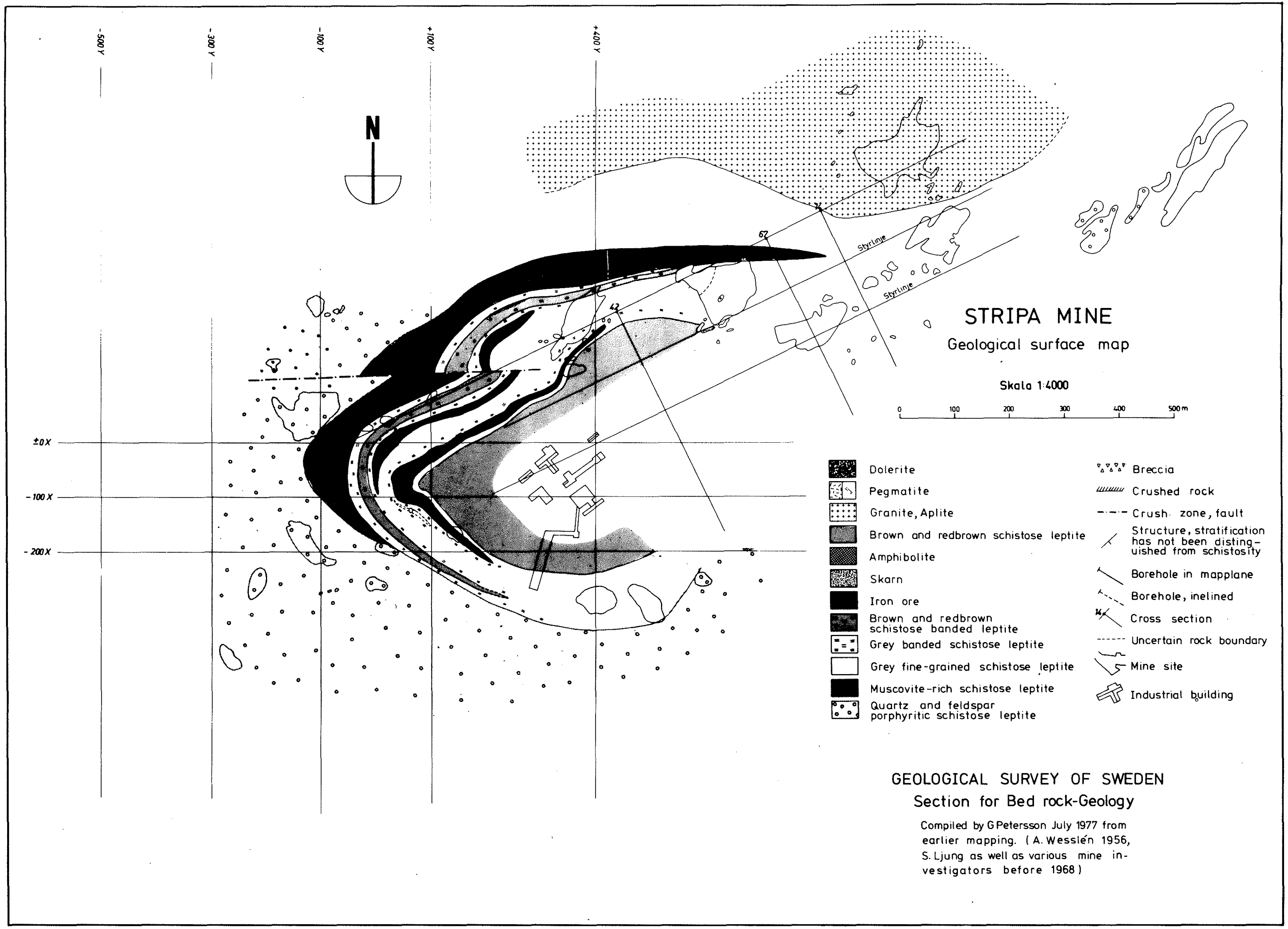

Figure 2. Geological map of the Stripa area. Extension of the ore at the surface level (Olkiewicz et al. 1978).

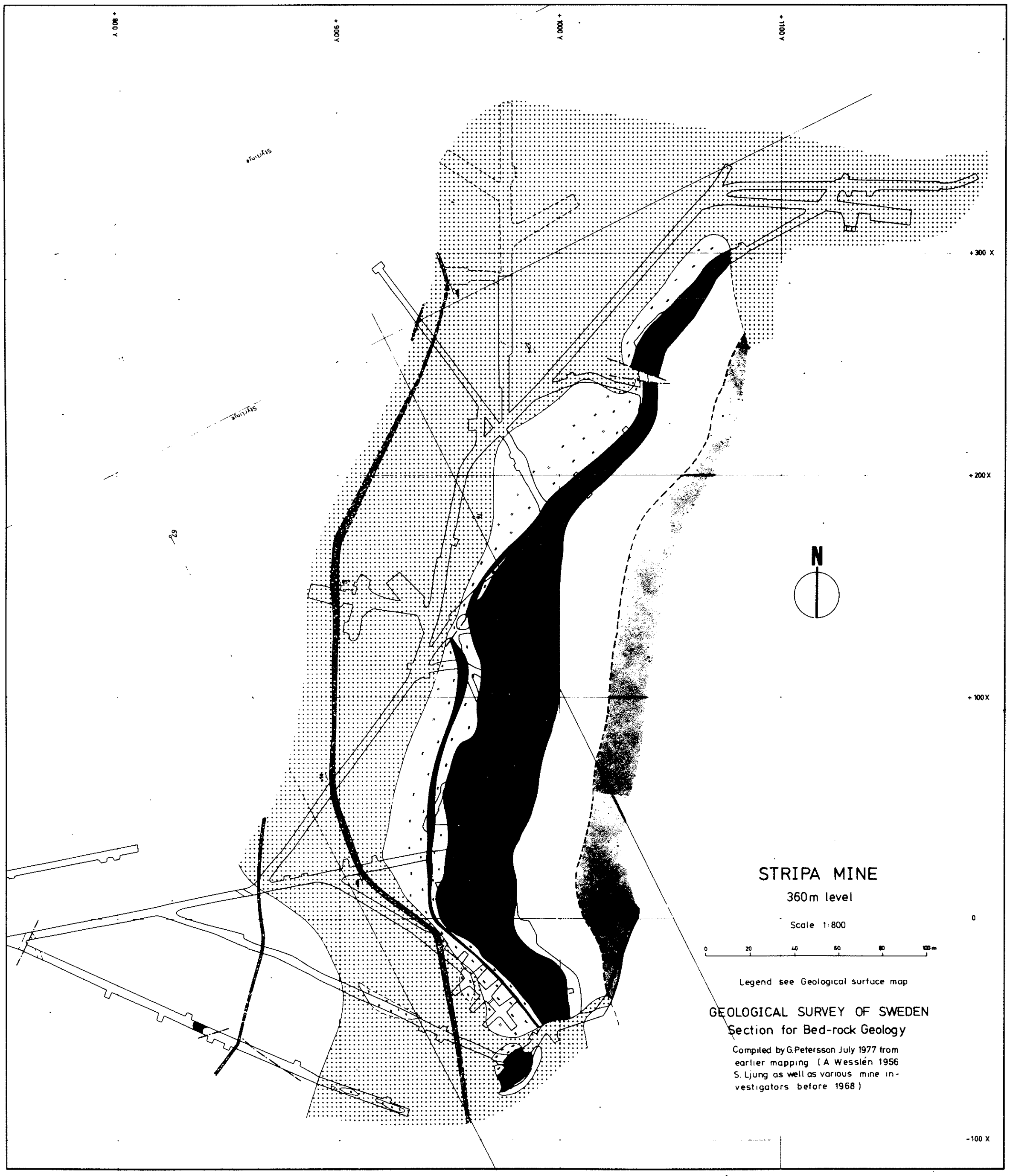

Figure 3. Geological map of the Stripa area. Extension of the ore at the 360 m level (Olkiewicz et al. 1978).

The mine workings are mainly set in the ore-bearing leptites, and reach from near the surface around local coordinates 0/0 to about 400 m N and 1,350 m E, at a depth of 410 m below zero level. Dewatering is achieved by pumping from the main shaft, at horizontal coordinates 70 m S, 350 m E, and from the Z-shaft at 290 N, 920 E. The total volume of water pumped from the mine is 0.5 m^3/min, this keeps the workings at the 410 m level accessible. The effects of the pumping on the local groundwater situation are incompletely known. The total area drained at the surface is extimated to be of the order of 2.5 km^2, and mainly confined within a distance of 500 - 700 m from the underground workings. Observations at the mine may suggest that the central depression of the groundwater table reaches a depth of about 150 m. Limited pressure-measurements indicate even greater depths. The complex geometry of the mine workings also suggest that the piezometric conditions above the mine may also be complex.

2 Objective

2.1 General

The purpose of the hydrogeological investigations included in the Stripa Project is mainly to design and test methods and instruments for geological, hydraulical, hydrogeochemical and geophysical studies in boreholes under conditions which may exist during the construction at a final repository. The aim of such studies is to determine hydraulic characteristics and interactions between fractures in the rock mass. The project also aims at gaining further knowledge on the chemical and physical conditions in the groundwater at great depth in crystalline bedrock.

To carry out these investigations three boreholes will be drilled at the 360 m level in the mine. The first of the boreholes is vertical and 1.000 m deep, in which priority is given to the hydrogeochemical investigations. Two 300 m long subhorizontal boreholes with an inclination of 10° to the horizontal will be drilled from the same test site and in these boreholes priority is given to hydraulic studies.

2.2 Investigation phases

The investigation will be carried out in two phases, each self-contained but based on the results and instrumentational development of the preceding phase. The present program deals mainly with the first phase, which so far is decided upon, while the second phase is only briefly outlined. Other phases may later be added. The preliminary contents of the phases are as follows:

Phase 1 Investigations in individual horizontal and vertical boreholes with associated problems.

a) Methods, techniques and instrumentation to measure hydraulic properties and conditions at depth in nearly horizontal boreholes in fractured granitic and similar rocks will be developed, tested and compared.

b) Basic quantitive information on the hydrogeologic conditions at depth in fractured granitic rock will be obtained. This is both of general interest to the field of waste management and valuable as background information for the evaluation of the current ant the planning of future investigations at Stripa.

c) The limited body of data on the geochemistry of groundwater in the deeper sections of fractured granitic rock will be expanded by sampling in the deep vertical borehole.

d) The analysis and interpretation of the forthcoming results will form the basis for the continued development of methods to characterize the near- and farfield conditions in fractured rock of low hydraulic conductivity at repository depths. The planning of such additional studies will be an important part of the project.

Phase 2 Investigations concerning the hydraulic inter-connection between different horizontal boreholes with associated problems.

- o Methods and instruments for establishing the hydraulic properties of existing fracture zones and the hydraulic inter-connection between boreholes
- o Migration of different substances between boreholes along existing fractures or fracture zones

The present investigation description deals only with plans for phase 1 and no decisions are taken concerning the second phase. It is proposed that plans for phase 2 be drawn up during the execution of phase 1.

3 Experimental Layout

3.1 Test site and drilling

The present study is to be carried out in a test site located at the 360 m level as shown in Fig. 4.

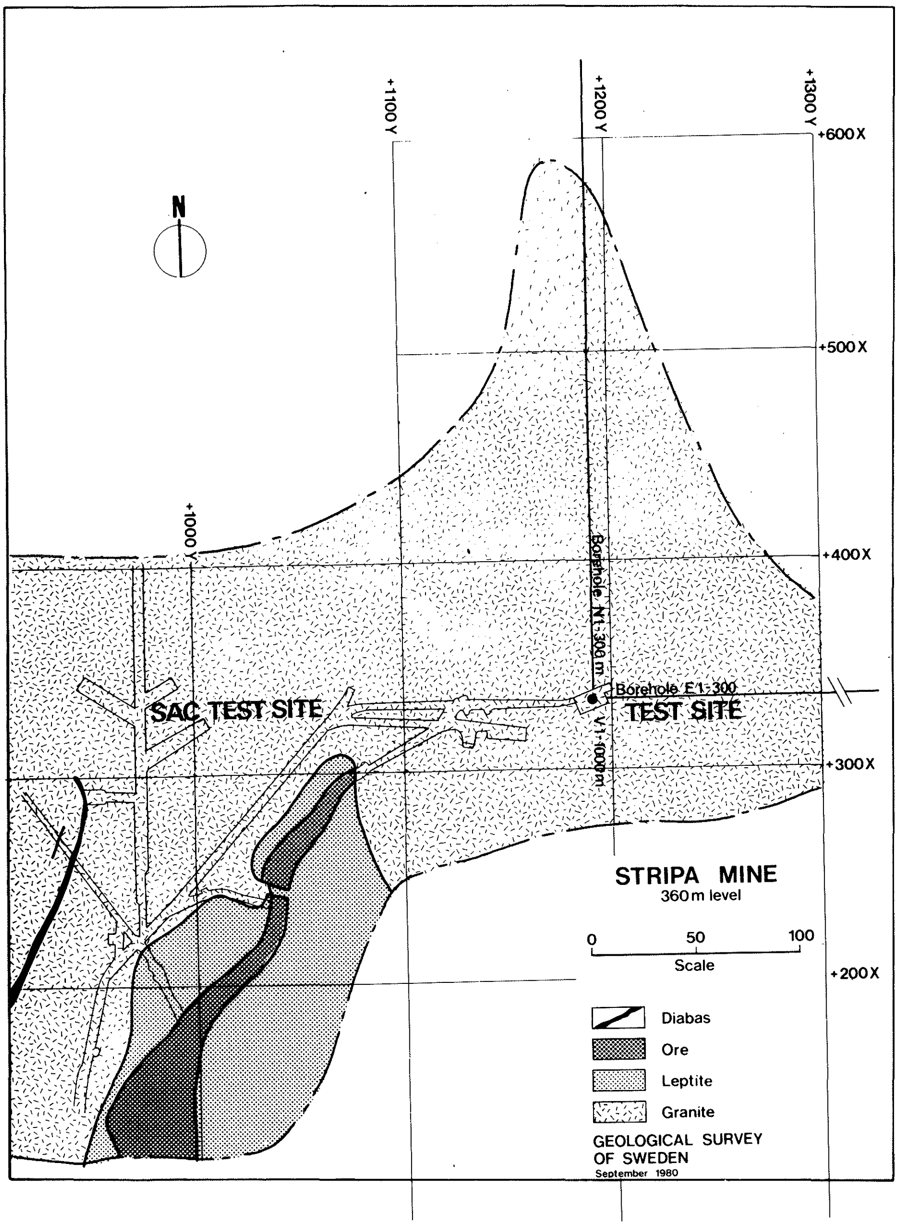

Figure 4. Location of the test site (cf Fig. 1)

This site is chosen in order to maintain a large distance to other sites and thus minimizing the hydrologic disturbances. Only minor completions of existing connections for water, air and electricity have to be done, which facilitate the work and reduce costs. In addition only minor rock work is necessary to prepare the site for drilling and investigation.

In order to prepare the site for the drilling, the existing drift has to be enlarged. The axis of this new drift heads in a north east direction and has a length of about 15 m. The cross-sectional area will be about 20 - 25 m^2. In this drift a housing to contain the test equipment will be constructed.

In the drift a 1,000 m deep vertical borehold (V1) and two 300 m long nearly horizontal boreholes (N1 and E1) will be drilled.

The geological information given earlier shows that horizontal drillings from the deeper parts of the mine should be directed towards the North and the East in order to escape the hydrogeological irregularities caused by the mine, to approach the area of undisturbed groundwater conditions, and to have maximum probability to stay in the body of granite. These directions also provide near maximum frequency of exposure to rock fractures. A slight (0 - 30°) anticlockwise rotation might reduce the frequency of fractures parallel to the drillhole, but this effect is probably marginal, due to the spread in fracture orientation. Thus, it is decided that the horizontal boreholes will be directed to the north and to the east.

Investigations in long horizontal boreholes have so far not been executed, but in the KBS work a horizontal drilling was made to a length of about 100 m (Olkiewicz et. al. 1978). Insertion of TV-equipment to this length has also been accomplished. The deviations from the horizontal of this hole stayed within $\pm 5^{\circ}$.

These variations, however, caused great difficulties in hydrological measurements and TV-inspection, due to the entrepment of air in the hole. This is the main reason for suggesting that the drilling proposed in the present program should be inclined to about 10°.

All boreholes will be core-drilled with a diameter of 76 mm and the deviation of the holes will be measured. In connection with the drilling operation, rock stress measurements, hydraulic tests and water sampling will be made.

3.2 Investigations

3.2.1 General

A number of investigations of a geophysical, geochemical and hydraulic nature will be carried out in the boreholes. In addition, the drill cores will be mapped and analysed. The following investigation programme is planned for phase 1:

Drill core investigations
Laboratory investigations of drill cores
TV-inspection of the boreholes
Geophysical borehole investigations
Hydraulic investigations
Water samplings, geochemical analyses and datings
Rock stress measurements

3.2.2 Investigations of drill cores

The drill cores will be analysed with respect to

- Type of rock
- Fractures
  - Frequency
  - Fracture filling and coating
  - Fracture orientation
- Discolouration
- Core loss

The results will be reported in the form of different drill core maps and statistical relationships.

These results will constitute the basis for planning the hydraulic investigations. The cores will be oriented as far as possible.

3.2.3 Laboratory investigations of drill cores

The following analyses will be carried out in the laboratory on selected parts of the drill cores:

- Density
- Porosity
- Compressive strength
- Modulus of elasticity
- Poisson's ratio
- Hydraulic conductivity of the rock
- Presence of microfissures

The analyses are intended to supplement and to some extent verify results that can be obtained from rock stress measurements, geophysical borehole investigations and hydraulic investigations.

3.2.4 TV-inspection of the boreholes

The boreholes will be inspected by means of TV-probes. Prior to the TV-inspection, the drill mud must be removed from the holes. This should be accomplished by the natural flow of water through the holes. All TV-logs will be stored on videotape.

3.2.5 Geophysical borehole investigations

After TV-logging of the boreholes, geophysical and certain chemical borehole logging will be carried out. The following measurements will be made:

- Resistivity
- Spontaneous potential
- Natural gamma
- Differential potential

- o Temperature
- o Eh
- o pH
- o Electrical conductivity of borehole liquid
- o Sonic logging

The hydraulic investigations will be based in part on the results of the geophysical measurements.

3.2.6 Hydraulic testing

The hydraulic measurements will be two-fold in purpose.

- o Determination of hydraulic conductivity within different sections of the boreholes.
- o Measurement of hydraulic pressure within different sections of the boreholes and, if possible, recording of the natural fluctuations of this pressure.

The two parts will be carried out simultaneously, which means that the build-up of the naturally prevailing hydrostatic pressure will be recorded. From these measurements, the hydraulic conductivity can be calculated.

Stand-by equipment should be available for the hydraulic investigations.

Owing to the high hydrostatic pressures that can occur at the depths in question, the measurements will be carried out chiefly in the form of pressure build-up tests. The measuring equipment must be designed for horizontal holes. The proposals for equipment design and measurement procedure presented below are preliminary and should be discussed and further improved.

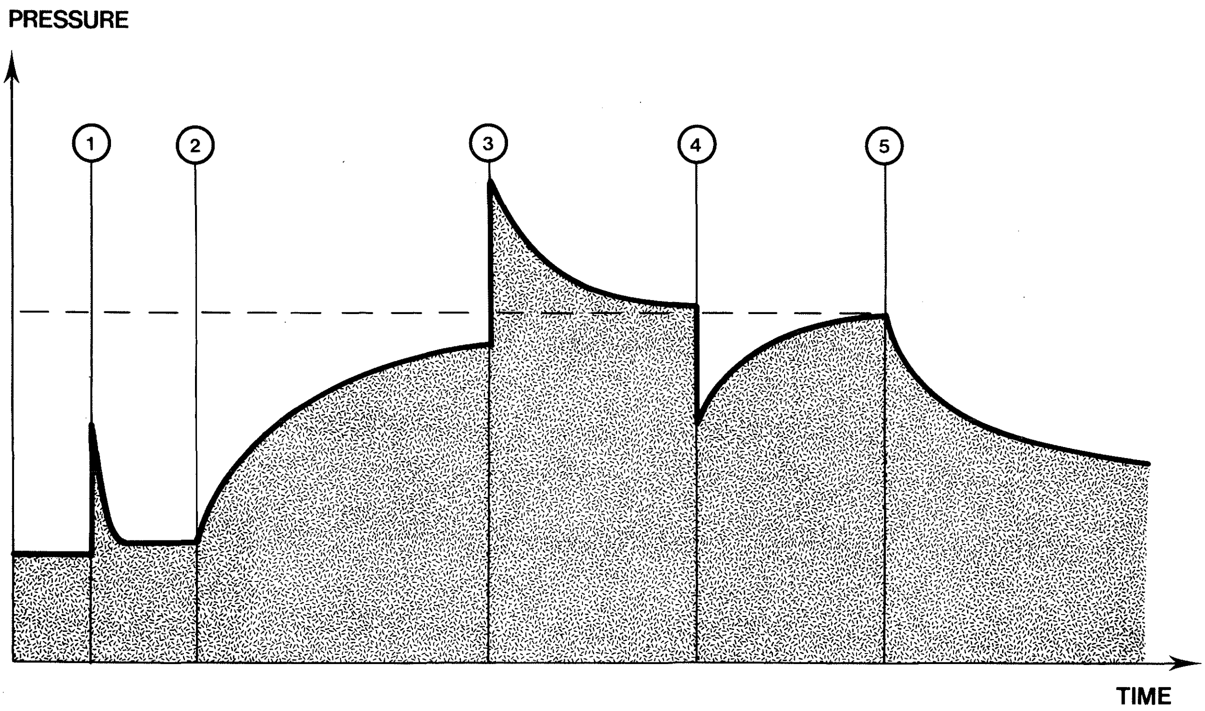

Figure 5.

Following detailed planning, phase 1 will begin with the drilling of the vertical 1,000 m borehole V1. During the drilling, stops will be made at 150, 300, 450, 600, 750 and 900 m in order to execute rock mechanical and hydrogeological studies.

In the next stage, the subhorizontal hole E1 will be drilled and at last borehole N1. During drilling of these boreholes, stops will be made each 50 m for the same purpose as for V1. The hydraulic tests during the drilling will be performed as flow measurements and as shut-in tests.

After completion of holes E1 and N1, the main hydraulic testing will start which will be carried out in two gauge sections in different stages as follows (c.f. Fig. 5).

1 Packer inflation

2 Shut-in, pressure build-up

3 Pulse-tests, positive and/or negative

5 Recovery and flow measurement

The pressure build-up (Stage 2) is a process that takes a long time, especially in formations with low hydraulic conductivity. For this reason, only a selection of gauge sections should be considered for measurement. These should be selected on the basis of fracture mapping and geophysical measurements. To supplement these measurements, transient water pressure tests should be considered.

3.2.7 Water samplings, geochemical analyses and datings

In connection with the hydraulic investigations, water samples will be taken from different borehole levels. The samples will be taken and stored in such a manner that analyses of both their chemistry, isotope relation and gas content are possible. In addition, the water will be dated by means of the carbon-14 method, tritium and other methods as well. The results of both the chemical analyses and the datings will provide a basis for estimating the residence times of the groundwater. Equipment for water sampling should be inventoried and developed in this connection.

The program for the hydrogeochemical sampling will be worked out by a group of experts in the field under the chairmanship of P Fritz, Canada, but has not yet been completed. However, the following preliminary program will be carried out (SGU 1980).

As the drilling operation will create a disturbance in the existing steady-state situation in the ground flow, it is necessary to start the hydrogeochemical investigations as the drilling begins. For this reason breaks with a duration of about 8 days will be made each 150 m in the vertical borehole and each

50 m in the horizontal holes. During these breaks a simple hydraulic test and sampling for chemical analyses may be carried out. After the completion of the vertical borehole, it will be demarcated into a number of separate sections by inflatible packers and the groundwater from the different sections will be sampled at certain intervals.

As pointed out above priority has been given to the hydrogeochemical investigations in the vertical borehole while only minor such studies will be made in the subhorizontal ones. But also these latter holes will be sampled both during breaks in the drilling and at certain intervals after the completion of the holes.

These conditions indicate that the program for the sampling procedure contain four different parts:

1 Sampling in the vertical borehole during drilling
2 Sampling in the vertical borehole after borehole completion
3 Sampling in the horizontal boreholes during drilling
4 Sampling in the horizontal boreholes after borehole completion

Vertical borehole

During drilling of the vertical hole stops will be made every 150 meter for water-sampling. This sampling will be carried out in connection with measurement of water flow, hydraulic head and head transience. Water coming in to the lowest 50 m of the drilled 100 m will be sampled. Sampling will be made at the 360 m:s level as the water will flow up in the hole due to the hydraulic situation. It should be remembered that the conductivity will be low, so analyses requiring large volumes of water should be avoided at this stage.

It is also important that the drilling arrests are long enough to ensure that all drilling fluids are adequately flushed from the packer system. Andrews (1980-08-13) has suggested a stop of at least 1 - 3 days. As also some simple hydraulic tests are to be made the breaks in the drilling operation will be 8 days at maximum. However, as the hydraulic tests will be head measurements and flow measurements and not water injections it is proposed that the sampling for the chemical analyses is carried out at the end of the breaks.

In total, samples from six different levels in the hole will be taken together with samples from the entire length. The drilling fluid will be marked with a dye in order to be recognized.

After drilling, the borehole is geophysically logged and then monitored by a multiple-packer system. It is proposed that 6 packers are to be installed at 5 m, 150 m, 300 m, 450 m, 600 m and 800 m which give 6 separate sections. Each section is connected with a plastic tubing for the water flow and samples of outflowing water from the packed off sections will be taken at the drift level. Sampling has to be carried out according to a chosen time-schedule in order to be able to monitor any possible disturbances from the encountered new pressure and flow situation.

Horizontal boreholes

During drilling of the horizontal boreholes water-samples will be taken after each 50 meters. The samples will represent water from the innermost 20 meters of the holes at each sampling occasion. Samples will be taken in the same way and using the same kind of equipment as in the vertical borehole during drilling. In total, samples will be taken from 6 different locations in each hole together with samples from the entire length.

After drilling and geophysical logging, hydraulic testing will be carried out, involving measurement of water flow, head and head transcience. In connection with these tests water samples will be taken. No special equipment for water sampling will be installed in the horizontal boreholes.

The proposed sampling and analysing of the waters from the vertical and horizontal boreholes are according to the proposal of J Andrews (1980-08-13) with some minor changes, mainly due to changes in the drilling program. The analyses are suggested to include the following constituents.

1 Inert gas and $^{40}Ar/^{36}Ar$-ratio 1 ml sample
2 ^{222}Ra analysis 500 ml sample
3 $^{226}/Ra$ analysis 5 l sample. Omitted if flow not adequate
4 $^{234}/U^{238}U$ analysis 1 - 5 l sample
5 U, Th, K-analysis on rock cores
6 Major element chemistry 1 l. sample
7 Oxygen and hydrogen isotopes
8 Tritium analysis
9 ^{13}C, ^{14}C - analysis
10 Physical properties

The sampling intervals suggested to be as follows.

A During drilling
 1 Vertical borehole. Each 150 m in all 7 sampling occasions including the final drillstop. Total analyses of all parameters 1 - 9.
 2 Horizontal boreholes. Each 50 m, in all 6 sampling occasions in each borehole, including the final drillstop. 12 samples. Total analyse.

B Monitoring phase

1 Vertical borehole. Sampling at 6 sections with the following intervals.
Constituents 1 - 4, 7 and 9. Every second month during three years. Total 18 occasions.
Constituent 5. 5 analyses from each section.

2 Horizontal boreholes. Sampling every second month during three years. Total 18 occasions. Total analyse of all parameters.

This part of the program is, however, not yet fixed in detail, and changes may be necessary as the working group for hydrogeochemistry present their program.

3.3 Instrumentation

For the hydraulic tests and for the hydrogeochemical sampling in V1 equipment has to be developed and designed.

The hydraulic tests will be carried out using two packers that enclose a gauge section with a length of 2 meters. Pressure sensors will be emplaced in the actual gauge section and in the section between the bottom of the borehole and the innermost packer. Fig. 6 shows the down-hole equipment with the packers system and the probe for the pressure transducers and temperature gauge.

The signals from the transducers and temperature gauge are measured at certain intervals by a data-logger, placed in a housing at the site. Handling, storage and control of the measured data are made by

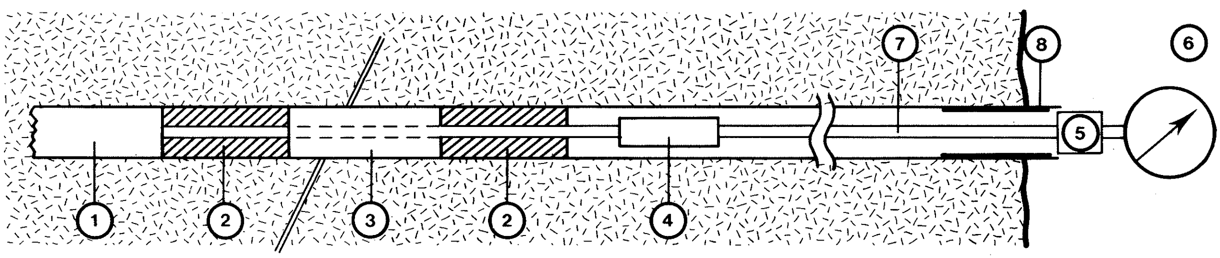

Figure 6. Schematical layout of the testing equipment. 1. Inner test section - variable length. 2. Inflatable packer. 3. Test section - length 2 m. 4. Probe containing pressure transducers, termocouple, valve for shut-in of test section. 5. Valve for shut-in of test section. 6. Registration of water flow, pressure and temperature. 7. Steel tubing. 8. Borehole casing.

a computer,placed at the drift. The final processing of the tests will,however, be made at the computer center at the Geological Survey. The set up of the datalogger and the computer for use in the site are shown in Fig. 7.

3.4 Outline phase 2

In the second phase of the hydrogeological investigations in boreholes, tests will be performed to study and characterize the rock mass and fractures in between boreholes. The test site with three perpendicular boreholes offers good opportunities for testing of methods and instruments in cross-borehole investigations. Additional subhorizontal boreholes parallel to those made during phase 1 but from 410 m:s level will provide further possibilities for studies of hydraulic characteristics between

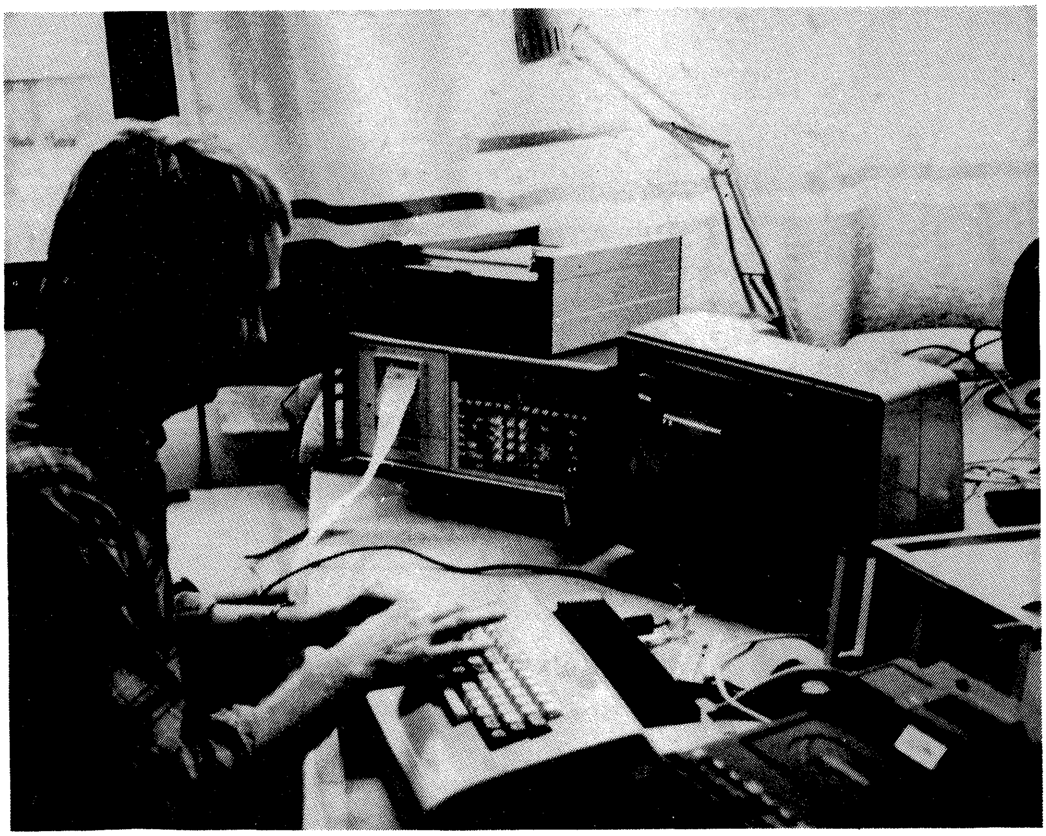

Figure 7.

boreholes. Preliminary the following activities might be considered:

- o Drilling of subhorizontal boreholes oriented parallel to those made during phase 1.
- o Cross-borehole geophysics (a first outline is under preparation).
- o Testing of fracture hydraulic conductivity intersected by the boreholes.
- o Tracer tests in fractures between different boreholes.

The activities included in this phase are only tentatively outlined and will be revised as a consequence of the results obtained in phase 1.

4 Time Schedule

The hydraulic investigations will take the longest time. In view of the low hydraulic conductivity values which are expected to occur, a pressure build-up may take more than one year. By choosing (on the basis of the geophysical measurements, among other things) primarily sections where the hydraulic conductivity is judged to be "high" with reference to fracture frequency, the times required for pressure build-up can be reduced. But it is of interest to determine the hydraulic conductivity within one or several fracture-free sections as well. The drilling work is expected to take about twelve months. The drill core investigations including stress-measurements and primarily hydraulic tests will be carried out simultaneously. TV-inspection and geophysical borehole investigation will be carried out after borehole completion and are expected to take about three months. The main hydraulic testing is tentatively expected to take about 1.5 years, and will be conducted at the same time as water sampling, chemical analysis and datings.

Quarterly reports will be submitted during the course of the work. In addition, a report will be submitted on each stage of the investigations. The final evaluation and reporting of results is expected to take about six months. It should be possible to start this while the hydraulic investigations are still in progress. A rough timetable for the investigations, including its various stages, is presented in Figure 8.

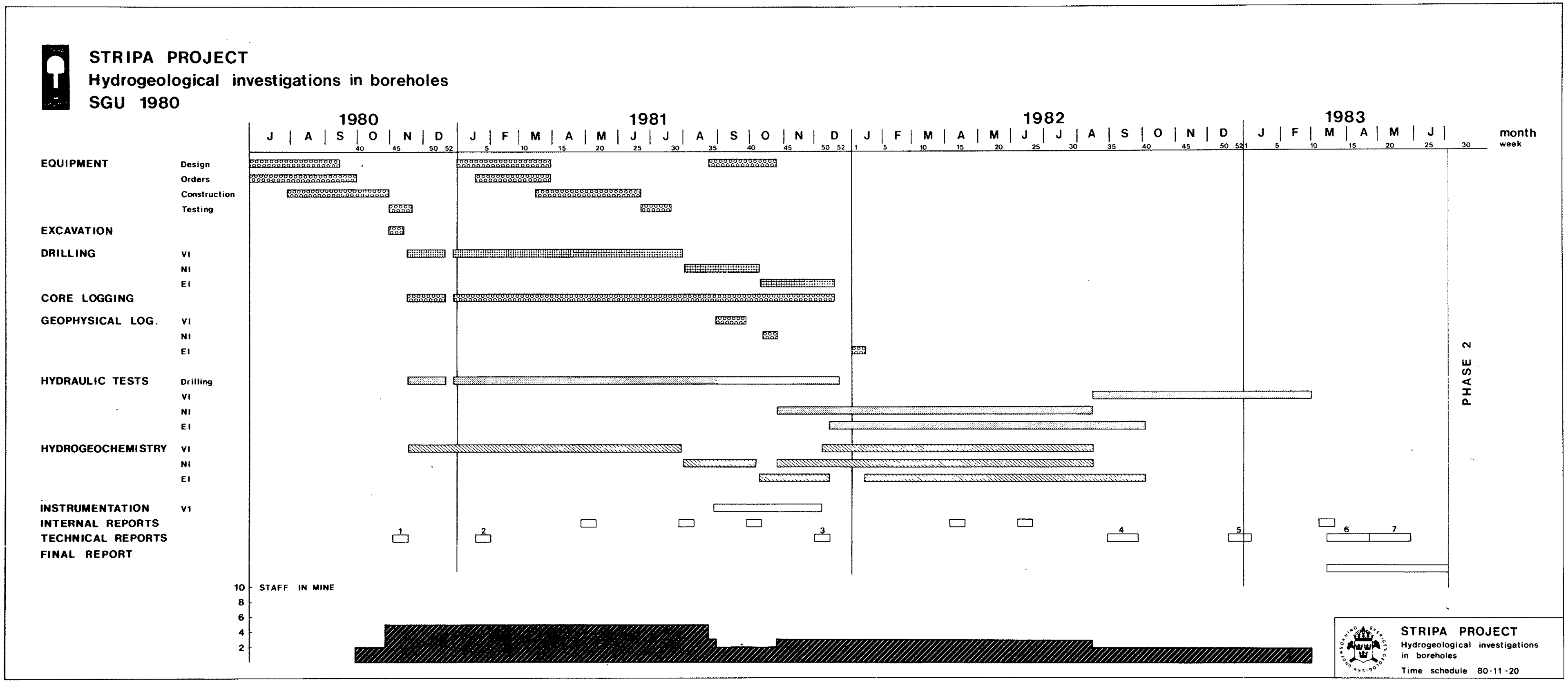

Figure 8. Time schedule for the hydrogeological investigations included in the Stripa Project.

5 References

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MIGRATION IN A SINGLE FISSURE - EXPERIMENTS IN STRIPA

PRINCIPAL INVESTIGATOR: Ivars Neretnieks
Royal Institute of Technology (KTH)

1 Summary

The bedrock is one of the most important barriers of a final repository. The radionuclides will migrate with the water flowing in the fissures in the bedrock. Their movement will be retarded by sorption on the fissure surfaces and possibly by migration into the microfissures in the rock matrix.

One experiment is proposed where various tracers representing all important types of radionuclides are introduced in the naturally flowing water in a single fissure in granite. Suitable fissures can be found in Stripa. The migration distance is about 5 m. The natural flow system in Stripa is well suited for this type of experiment as the hydraulic gradient and flow-rate is many orders of magnitude larger than in a natural system and a time scaling of 2 to 3 orders of magnitude is automatically achieved. The fissure is excavated after completion of the runs with the sorbing tracers. The concentration of tracers on the surface is analysed.

The experiment will show how well sorption data from the laboratory can be used to predict radionuclide migration in the field with real surfaces and waters. It will also give data on longitudinal and transverse dispersion in a single fissure.

Radioactive tracers will not be used in the first part of the investigation as practically all necessary information can be derived using stable nuclides of the same or very similar species. In a subsequent investigation radio tracers may be used for ultimate confirmation.

The investigation is divided into a preliminary part, to test the techniques, and a main investigation to do the actual tracer experiments.

The first part of the investigation covering the time May 1980 to February 1981, is under way. This part is funded by the Stripa project. Injection and sampling holes have been bored to a fissure. Water is being collected, and injection and sampling equipment is being manufactured. Water samples and rock samples have been sent for analysis to determine major and minor constituents. The injection hole and 4 of the 6 sampling holes are water bearing. Some large molecular weight tracers are being tested for their stability.

The main investigation will start March 1981, provided it is funded.

The supporting investigations "Flow in a single fissure" in the laboratory, "Migration in the rock matrix", and Mathematical modelling are in their second year. These investigations are funded by Prav and KBS. Preliminary results indicate that there is stratified flow within a single fissure and that tracers diffuce into the rock matrix.

2 Background

The bedrock is one of the most important barriers of a final repository for radioactive waste. It limits the amount of water which can contact and leach the waste. If and when any radionuclides are leached from the waste, the majority of the important radionuclides will interact chemically or physically with the bedrock and will be considerably retarded. The interaction and the retardation depend on the velocity of the water, the sorption rates and equilibria of the reactions as well as the surface area of the rock in contact with the moving water.

Practically all studies on radionuclide migration in the bedrock are based upon the assumption that the flow can be described as porous media flow. This might be true for very large distances where the flow would encounter a multitude of channels and some averaging may be conceivable on the scale considered. However, no large scale tracer tests have been performed in fissured crystalline rock with known flow paths. Transport over short distances, i.e. in the near field of a canister, most probably occurs in individual fissures. On an intermediate scale where more than a few fissures conduct the flow, well type tracer tests alone cannot give the detailed information needed to understand dispersion and sorption phenomena in fissured rock.

It is therefore proposed to investigate flow and sorption in readily identifiable fissures which can be excavated for a detailed examination of flow paths and sorption sites.

3 Purpose

The proposed study has the following main objectives:

- To observe the movement of nonsorbing and sorbing tracers under controlled and well defined conditions in a real environment.

- To interpret the movement of the tracers in such a way that the results become useful for the prediction of radionuclide migration.

- To obtain a basis for comparing laboratory data on sorption with observations in a real environment.

- To develop good techniques for small volume sampling of water and techniques for investigating fissure surfaces with sorbed tracers.

- To gather experience with stable tracers before using radioactive tracers.

4 Proposed Investigation

The Stripa mine is excellently suited for performing tracer test in single fissures as well as in a network of interconnected fissures. The water constantly flows into the tunnels, and this natural movement can be utilized in the tracer tests. The water found in the Stripa bedrock is old and has a water chemistry which is in all major respects (pH, Eh, major ions) similar to the groundwaters to be expected in the Swedish bedrock.

Old water bearing fissures have been found in and near the tunnels now in use. As the tunnels are well below the water table, the fissures have been conducting water for a very long time and thus are as well "equilibrated" as we can reasonably achieve in a sorption experiment.

The experimental study in this proposal is performed in a single fissure. Fig. 1 shows how a well defined, easily identifiable major fissure is injected with a tracer.

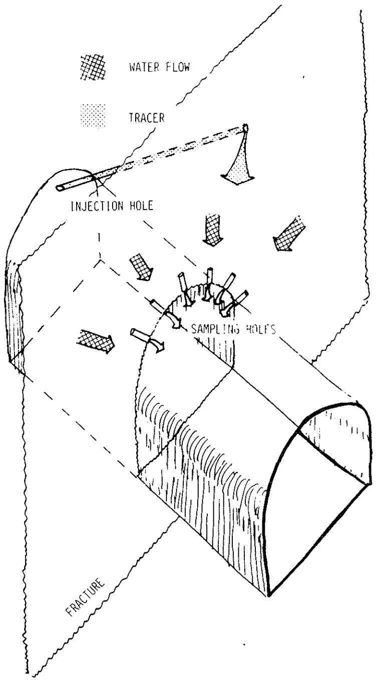


Figure 1

The injection point is about 5 m from the series of sampling holes, 0.7 m deep.

By having a series of sampling holes, the transverse dispersion of the tracer can be observed in addition to the axial dispersion.

Tracers to be used

Stable tracers will be used throughout in the field experiments. Except for very few nuclides, notably Np, Pu, and Tc, all the objectives stated can be achieved with less effort. "Hot" experiments are run parallel in the laboratories in a supporting investigation. These latter experiments are funded by KBS.

Four classes of tracers are used:

o	Particles:	Plastic pellets ∿ 0.4 µm are used to simulate the movement of particulate matter
o	High molecular weight solutes:	Blue Dextran M = 2,000,000 or Albumine is used to simulate the movement of high molecular weight organic nonsorbing matter
o	Nonsorbing tracers:	Various Rhodamines, Uranine, Br^- (I^-)
o	Sorbing tracers:	Cs I Sr (Ba) II Eu (Nd) III Th IV ? V U IV and VII

The nonsorbing and sorbing tracers by themselves or by similarity cover (valency and chemistry) all major radionuclides of interest except Np, Pu and Tc.

Injection and sampling techniques

The injection is performed at the natural pressure of the system by sealing the bottom of the injection hole with a packer and circulating the tracer at the natural pressure in the sealed off part of the hole. Samples will be withdrawn by collecting the water in holes bored from the tunnel into the rock along the fissure. Injection and sampling is done under anoxic conditions by constantly purging the system with nitrogen.

Analysis of tracers

Particles are counted using a microscope. Other methods include visible light and ultraviolet spectrophotometry and fluorescence, ion selective electrodes, atomic absorption, neutron activation analysis, and, if cooperation can be arranged with Los Alamos Scientific Laboratories, also mass spectrometry. The latter method would be very useful in the investigation of how deep and where in the rock matrix the sorption has taken place.

Analysis of water and rock

The water composition, pH and Eh will be measured with frequent intervals. All minor constituents of interest in water and rock will be measured by neutron activation analysis. The rock will be characterized mineralogically, and the fissure filling material will also be characterized.

Excavation of the fissure

The experiments with the sorbing tracers will be designed so as to retain many of them along the fissure. The strongly sorbing tracers probably cannot be made to migrate very far away during the time available. The fissure will be excavated by coring it out. Se Fig. 2. The concentrations on the surface will be measured, and, at some points at least, also the penetration in depth will be analyzed using either neutron activation analysis - or, if forthcoming, mass spectrometry.

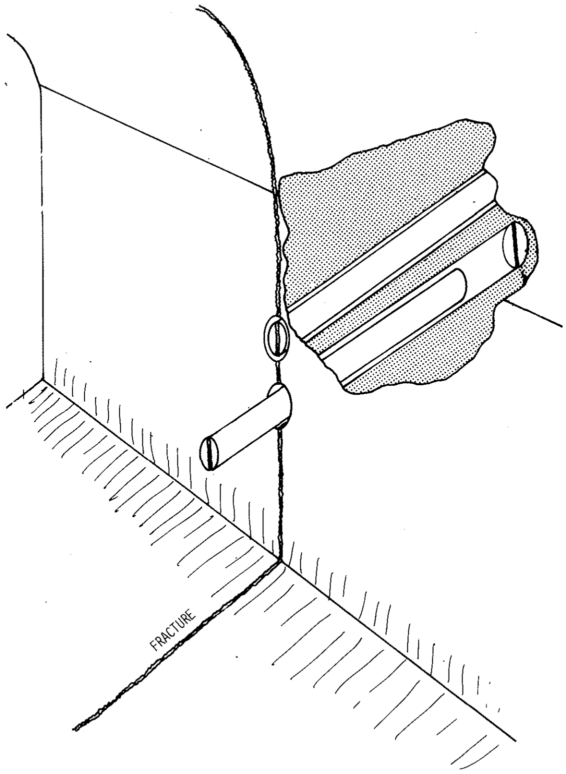


Figure 2.

5 Preliminary Investigation

This part of the investigation is funded by the Stripa project and covers the time period May 1980 to February 1981. The objectives are to find a suitable fissure, to develop equipment for injection and sampling, and to perform preliminary tracer runs.

Eight large visual fissures have been sealed off by plastic sheets. The water which seeps from the fissures, has been collected. One of the fissures with "high" water seepage has been selected for the preliminary test. An injection and 6 sampling holes have been drilled. Water has been collected for more than a month under anoxic conditions. The seepage rate in the injection hole is about 100 ml/h. The sampling holes give less water, with large variations between holes.

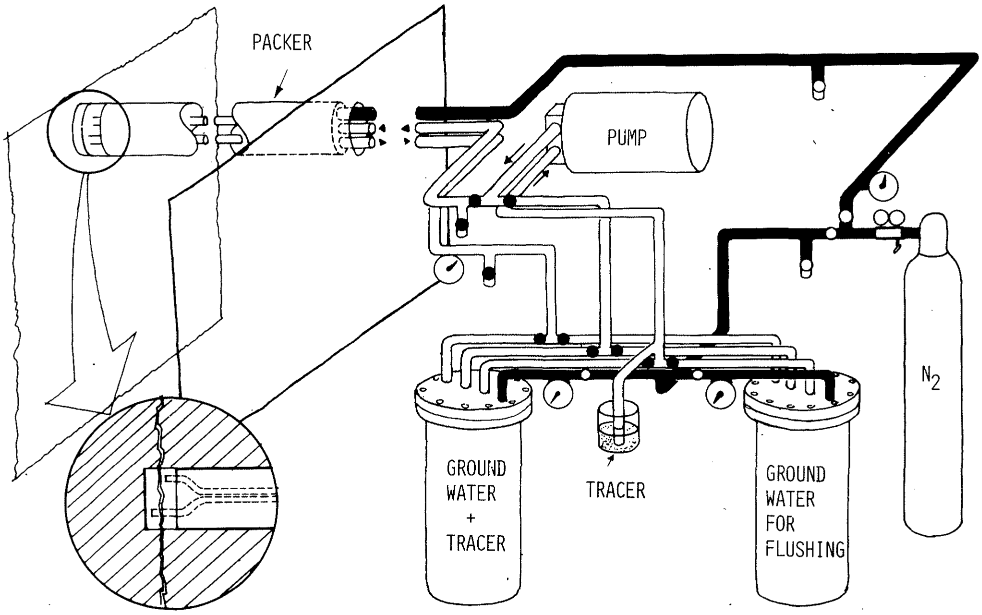


Figure 3.

Injection and sampling equipment has been manufactured and is being tested and installed.

Figure 3 shows the injection equipment.

The equipment consists of a packer which seals off the bottom of the injection hole. Natural pressure is allowed to build up at the bottom of the hole. Anoxic conditions are ensured by purging the system with nitrogen. The natural groundwater is collected in two pressure vessels. Tracer is added to one of these, and the tracer solution is circulated to the injection hole during a predetermined injection time. After this time the injection hole is flushed with groundwater from the other pressure vessel. The pressure is maintained at the natural pressure of the injection hole.

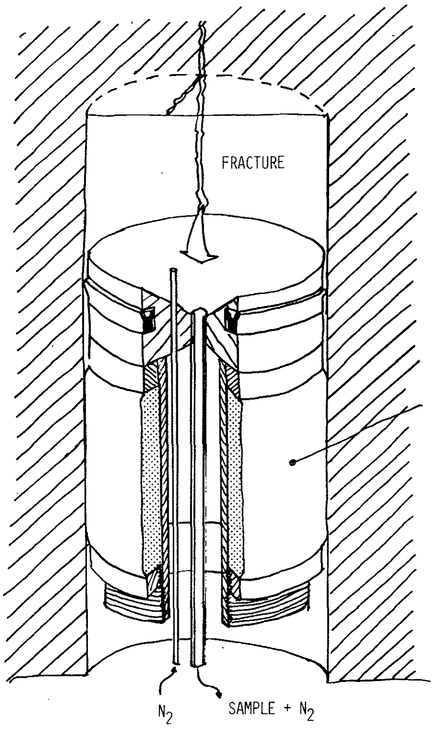


Figure 4.

The sampling holes are sealed off by mechanical packers with outlet holes arranged in a way which allows all the water seeping into these holes to be withdrawn and collected immediately. See Fig. 4.

6 Supporting Investigations

The following investigations are funded by Prav and KBS. They are necessary to perform for the understanding of the fissure experiment in Stripa.

Flow in a single fissure is being studied in a project run jointly by the department of Nuclear Chemistry, KTH, and the department of Chemical Engineering, KTH. Cores have been taken from Stripa with natural longitudinal fissures. Br^-, SCN^-, ^3H, Na-lignosulphonate and Cs and Sr have been run in some cores of 20 cm diameter and up to 30 cm length. The techniques for injection, sampling and measurement have now been developed, and a series of runs are underway. These laboratory runs are done with radioactive tracers.

Migration into the rock matrix is being studied at the department of Chemical Engineering, KTH. Crushed rock samples as well as tablets from cores are used. Experimental techniques include in-stationary measurements of bath concentration depletion using Cs and Sr as well as stationary diffusion measurements using tritiated water, and will also include resistivity measurements to determine the accessibility of the micropores.

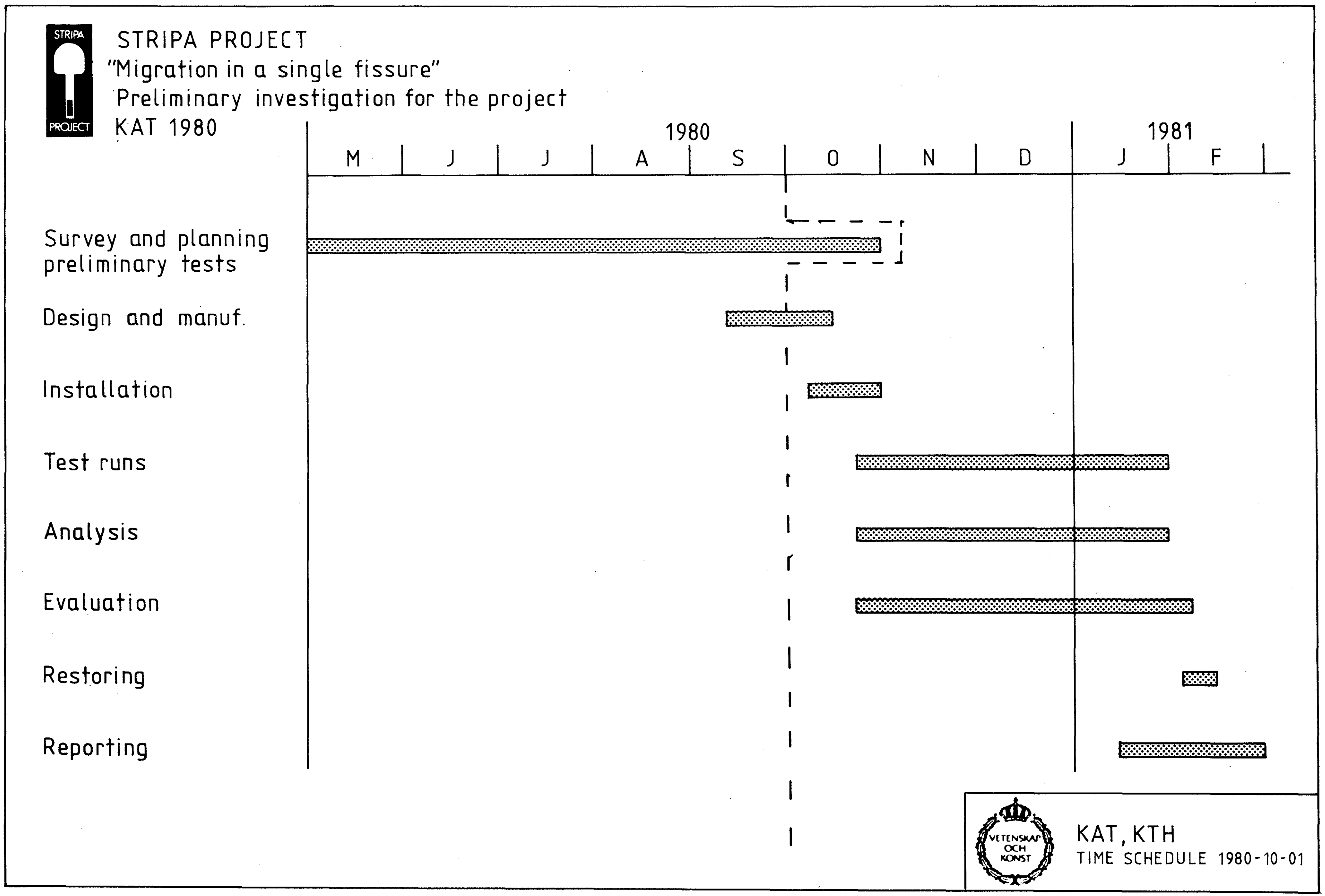
Mathematical modelling of flow in a single fissure including various interaction effects such as surface sorption, diffusion into the rock matrix and sorption in the microfissures, as well as slow first order chemical reaction, has been completed. The classic formulation of longitudinal dispersion is also included in the available models. The modelling will also include transverse dispersion in the fissure in future work in order to evaluate the experimental results. This work is also done at the department of Chemical Engineering, KTH.

In addition to these projects, the sorption data and water chemistry work at the department of Nuclear Chemistry at Chalmers Institute of Technology will be directly utilized in the project.

In the analysis of the excavated fissure much valuable information could be gained if an in-depth analysis of the sorbed species could be performed. Discussions with our American colleagues at Los Alamos indicate that they have the technical facilities and the experience (OKLO samples) to do this work by using mass spectrometry. We would welcome their cooperation.

7 Time Schedule

The time schedule is shown in Fig. 5 for the preliminary investigation which is underway, and in Fig. 6 for the main investigation. The total time of the project is 3 years and 2 months for the preliminary and the main investigation.



STRIPA PROJECT
"Migration in a single fissure"
Preliminary investigation for the project
KAT 1980
1980
1981
M
J
J
A
S
O
N
D
J
F
Survey and planning preliminary tests
Design and manuf.
Installation
Test runs
Analysis
Evaluation
Restoring
Reporting
KAT, KTH
TIME SCHEDULE 1980-10-01

Figure 5.

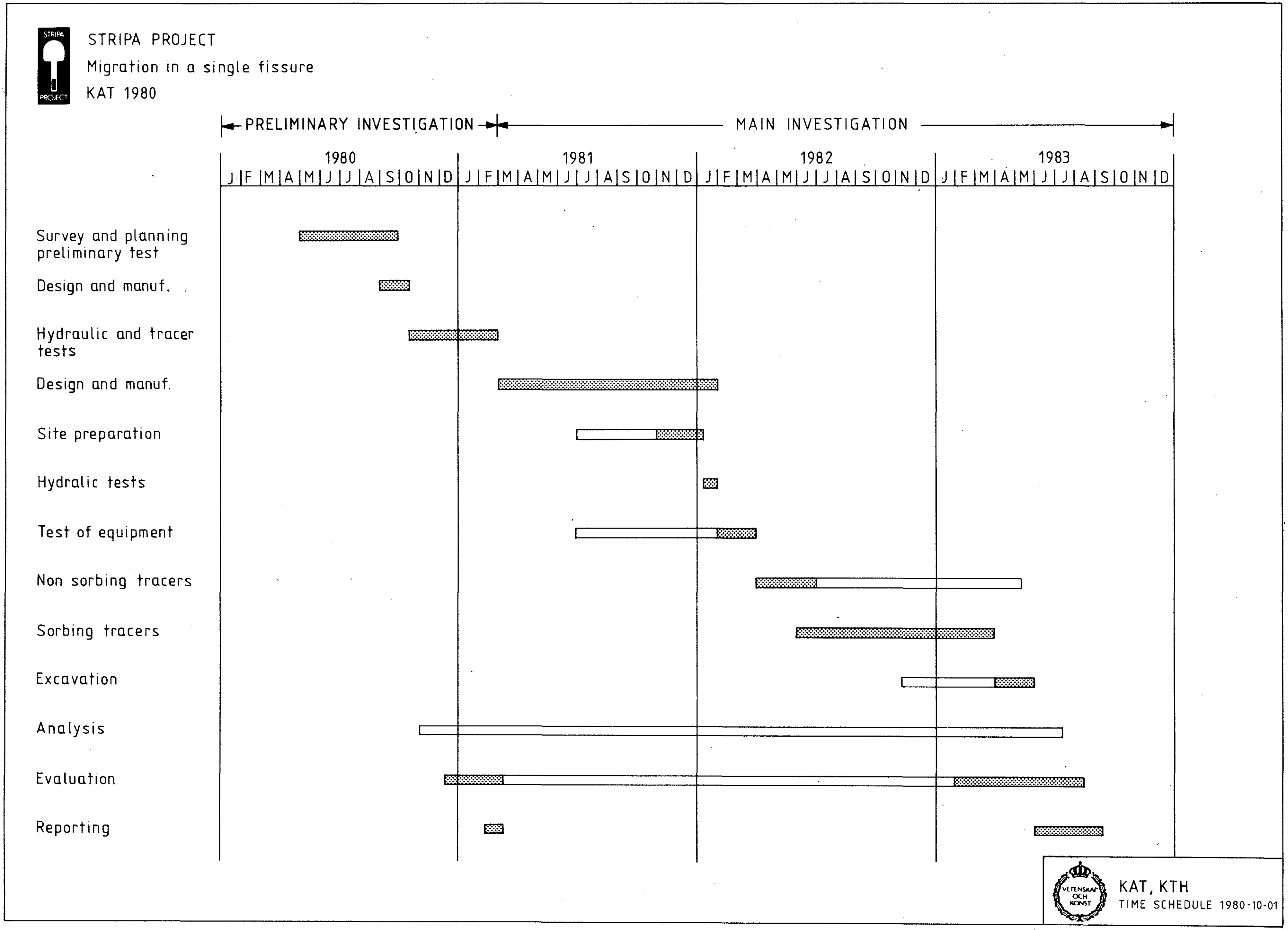

STRIPA PROJECT
Migration in a single fissure
KAT 1980
PRELIMINARY INVESTIGATION
MAIN INVESTIGATION
1980
1981
1982
1983
J F M A M J J A S O N D
Survey and planning preliminary test
Design and manuf.
Hydraulic and tracer tests
Design and manuf.
Site preparation
Hydralic tests
Test of equipment
Non sorbing tracers
Sorbing tracers
Excavation
Analysis
Evaluation
Reporting
KAT, KTH
TIME SCHEDULE 1980-10-01

Figure 6.

BUFFER MASS TEST

PRINCIPAL INVESTIGATOR: Roland Pusch
University of Luleå

1 Scope

1.1 Object

Highly compacted bentonite and mixtures of bentonite and quartzsand are proposed as buffer materials in final repositories for HLW according to the KBS 2 concept. The object of the tests described in this program is to verify the suitability of the suggested buffer materials at real conditions on site.

1.2 Test site

The Stripa mine provides excellent conditions for the testing of the buffer materials in crystalline rock. At a depth of about 350 meters a drift of 30-40 meter length, the so-called "Ventilation Drift" will be disposed for the testing.

1.3 Effects to be studied

Although theoretical considerations and various previous and current laboratory tests seem to yield similar results with respect to the expected properties of the buffer materials in situ, it is still required to test the behaviour of the integrated system of heat-producing objects, buffer materials, rock, and groundwater in a representative crystalline rock mass.

The rate and uniformity of the water uptake in the tunnel fill and the bentonite in the deposition holes are essential for the functions of the buffer substances, and their determination under realistic conditions in nature is therefore the primary object of the Stripa field test. Also, the associated effects, such as the development of pore water pressures, swelling pressures, temperatures and temperature gradients are of interest and will be investigated in great detail.

Realistic conditions with respect to the heat production of the canisters are provided by using electric heaters. A certain minimum access to groundwater is necessary to yield measurable changes in water content in the buffer materials especially in the highly compacted bentonite. This is very probably offered by the chosen drift into which the seepage rate has been determined to be 50 ml/min according to a LBL field study. If the final evaluation of the groundwater inflow into the drift still turns out to be insufficient, irrigation will be applied.

2 Civil works

2.1 General outline

The general outline of the test tunnel is shown in Drws 131-132. The diameter of the six deposition holes is chosen as 0.75 m since this is the largest suitable diameter if diamond coring is applied. The scale factor is thus 1:2 compared to the KBS 2 concept in which the diameter is 1.5 m. This scale governs the geometrical pattern of most of the test arrangements.

In order to obtain a scaled tunnel section a concrete slab is cast on the tunnel floor. Four boxing-outs are taken in the slab around four deposition holes. The dimensions of the boxing-outs are taken as 1.8 m and the height as 1.5 m as an average. A removable concrete lid is used to cover each boxing-out. The concrete slab and lids thus form an artificial tunnel scaled 1:2 with reference to the KBS 2 concept.

In the innermost part of the tunnel with two deposition holes, the whole tunnel section is filled with bentonite/sand. This is not in accordance with the 1:2 scale but it provides an opportunity to test, on a full scale, the technique for application of the tunnel backfill and its behaviour during water uptake.

The deposition holes are equipped with heaters to simulate the canisters. The buffer mass in the holes consists of highly compacted bentonite.

2.2 Deposition holes

The depth and diameter of the holes is approximately 3 m and 0.75 m, respectively. The spacing of the holes is 6 m.

The rock surrounding holes No. 3 and 4 is fractured by means of controlled blasting or by a heating/cooling procedure, so that water access to the compacted bentonite will be axi-symmetrical along the holes. At the remaining holes, No. 1, 2, 5 and 6, natural conditions prevail.

The deposition holes are filled with blocks of compacted bentonite which are trimmed to fit the holes and heaters with the exception of an outer slot. The slot, which will be approximately 10 mm wide, is filled with coarse bentonite powder.

2.3 Concrete slab

The slab is designed for a vertical water pressure of the order of 0.05 MPa. In order to prevent higher water pressures, drainage pipes are cast into the structure. During the test the water level in the pipes can be recorded.

The boxing-outs are filled with bentonite/sand.

2.4 Concrete lids

The removable lids are designed for the expected vertical swelling pressure (10 MPa). The lifting force is counteracted by prestressed rock anchors through the concrete slab at the periphery of the lids.

2.5 Isolation of inner tunnel part, tunnel backfill

The inner tunnel part is separated from the rest of the tunnel by a concrete wall. The wall is anchored by recesses in the bedrock. It is cast in sections in fours of the application of the backfill. This fill, which consists of bentonite/sand (10%/90%), is compacted in layers of about 0.20 m thickness by applying ordinary contractor's technique to about 2/3 of the tunnel height. The upper 1/3 is filled by spraying a bentonite/sand mixture (20%/80%).

2.6 Site investigations

A Ø 76 mm pilot core bore hole is made at each deposition hole site and these holes are used for a preliminary determination of the joint pattern and hydraulic conductivity of the rock.

A more detailed investigation of these properties is made after the widening of the holes to approximately 0.75 m diameter.

3 Heater arrangement

Electric heaters with a power of about 600 W are used to simulate the canisters. With this power this will yield a temperature at the heater/bentonite interface which will probably be in the interval 60-80°C. The average temperature gradient in the bentonite will be of the order of 1.5-3°C/cm.

4 Instrumentation and recording

4.1 The field test comprises the determination of:

1 Rate and distribution of water uptake in the tunnel and the bentonite in the deposition holes (4.2)

2 Swelling pressures in the bentonite in the deposition holes and in the tunnel backfill (4.3)

3 Temperature changes in the tunnel backfill and in the bentonite in the deposition holes (4.4), as well as in the rock around one of the deposition holes.

4.2 The detailed water uptake pattern is determined by excavating and investigating the buffer mass in the deposition holes and in the tunnel backfill. This requires sampling and analysing of a large number of specimens with respect to the water content and degree of water saturation. Suitable time intervals for the opening and sampling are indicated by moisture sensors embedded in the buffer mass. These sensors are distributed in the mass so as to reflect the average rate and uniformity of the water uptake. They record the electric resistivity (AC-technique) which is a function of the water content. Prototype gauges have been developed and are found to operate satisfactorily in current laboratory tests which have been going on for more than 8 months.

4.3 In two of the deposition holes (fractured rock) the swelling pressure will probably approach a state of equilibrium with a rather high value (10 MPa).

This offers a possibility of observing the expected displacement of the interface between expanding compacted bentonite in the deposition holes and the overlying bentonite/sand fill. Also, variations of the swelling pressure are expected to be detectable.

The swelling pressure will be measured horizontally as well as vertically by applying Gloetzl-technique. This is a very reliable way of determining soil pressure during longer periods of time.

4.4 The temperature will be measured by means of a large number of gauges. It has been decided that one type of gauges is sufficient, provided that a smaller number of very long-lasting gauges are installed for calibration purposes. Thermocouples will be used since they have been found to operate well in laboratory tests. Teflon coating of the gauges will probably be necessary.

4.5 While the external water pressure does hardly influence the rate of water uptake in the highly compacted bentonite, it will govern this rate for the bentonite/ sand tunnel fill. A meaningful field test therefore requires that the water head at the rock/tunnel backfill interface is determined. The existence of a fairly permeable shallow zone around the tunnel periphery means that it will be sufficient to measure the water pressure by a fairly small number of devices coated on the rock close to this interface and at the bottom of the deposition holes. Two independent systems will be used: direct, continuous recording by means of strain gauges as well as intermittent recording with transducers. Both systems are known to be very reliable provided that the tips are made of non-corrosive material.

A number of gauges installed by LBL for water pressure recording will also be in operation. Manometers will be used for the readings as previously.

4.6 Possible displacements and changes in the width of joints in the rock surrounding one heater hole will be determined by using sealed strain gauge systems. The tension forces in the bars which anchor the lids of the boxing-outs, will be measured. This yields information of the development of swelling pressures.

4.7 The application of the various gauges and cable connections etc will be made so that the physical processes are not affected. The recording of signals from moisture and temperature sensors will be made already during the application of the buffer material.

4.8 All the signals from the large number of gauges (1800-1900) will be collected by data logging systems and recorded on magnetic tape. Interpretation, plotting and presentation will be made at the University of Luleå but the results, prognoses etc will be currently available also at the Stripa field station.

5 Predictions

Thermal calculations, covering also the three-dimensional, assymetrical case represented by the heater holes with overlapping temperature fields, are planned. This will yield a detailed picture of the temperature distribution in the buffer masses in heater holes and tunnel backfill, as well as in the confining rock. Also, detailed moisture uptake distributions will be deduced on the basis of computer simulations. The latter prognosis will be adapted to the actual joint patterns when these can be observed in the heater holes.

6 Current supporting investigations

(performed within the Swedish KBS program)

6.1 Swelling pressure and permeability in bentonite

The swelling pressure and permeability are being determined for certain representative bentonites as a function of density and electrolyte contents and compositions in oedometers during 1979-1980. This work has led to a largely improved understanding on the involved mechanisms and seems to confirm the assumptions concerning the expected behaviour of the buffer materials. Final reports in September 1980.

6.2 Water uptake in bentonite

The temperature and rate of water uptake are measured in highly compacted bentonite as well as in bentonite/ sand mixtures compacted in steel cylinders with 0.3 m diameter and 1.3 m length, supplied with heaters. Final report in October 1980.

6.3 Borehole sealing

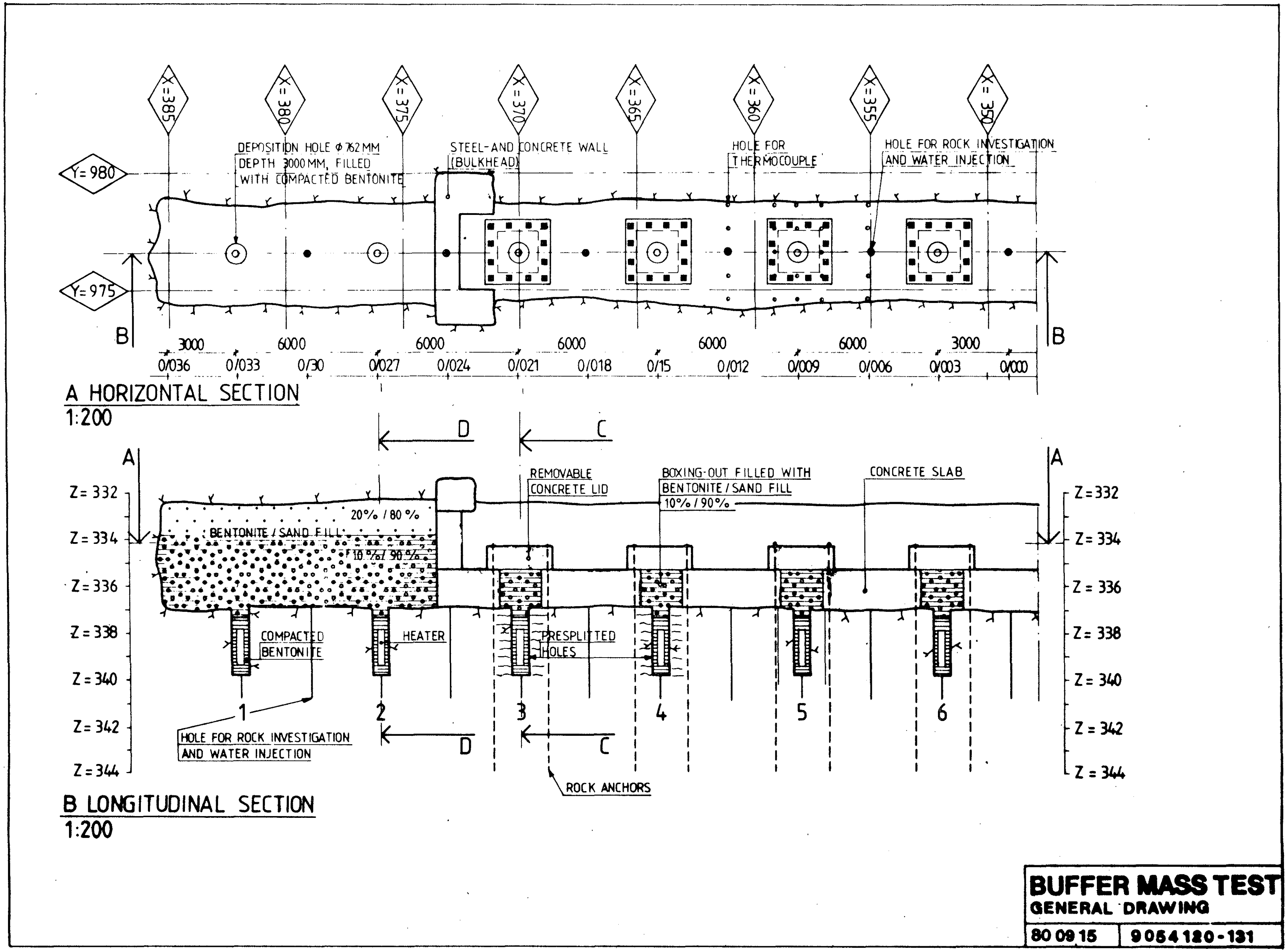
Borehole and shaft sealing by means of highly compacted bentonite on a laboratory scale. Preliminary results are expected in early 1981.

7 Time schedule for the field study

The testing period is estimated to three years. The time required for the civil works and for the installation of instruments and other activities are shown in Drw. 127.

8 Staff

The organization plan is shown in Drw. 128.


X = 385
X = 380
X = 375
X = 370
X = 365
X = 360
X = 355
X = 350
Y= 980
Y= 975
DEPOSITION HOLE ϕ 762 MM
DEPTH 3000 MM, FILLED
WITH COMPACTED BENTONITE
STEEL-AND CONCRETE WALL
(BULKHEAD)
HOLE FOR
THERMOCOUPLE
HOLE FOR ROCK INVESTIGATION
AND WATER INJECTION
B
3000
6000
6000
6000
6000
6000
3000
0/036
0/033
0/30
0/027
0/024
0/021
0/018
0/15
0/012
0/009
0/006
0/003
0/000
A HORIZONTAL SECTION
1:200
D
C
A
REMOVABLE
CONCRETE LID
BOXING-OUT FILLED WITH
BENTONITE / SAND FILL
10% / 90%
CONCRETE SLAB
Z = 332
Z = 334
Z = 336
Z = 338
Z = 340
Z = 342
Z = 344
20% / 80 %
BENTONITE / SAND FILL
10 % / 90 %
COMPACTED
BENTONITE
HEATER
PRESPLITTED
HOLES
1
2
3
4
5
6
HOLE FOR ROCK INVESTIGATION
AND WATER INJECTION
ROCK ANCHORS
B LONGITUDINAL SECTION
1:200
BUFFER MASS TEST
GENERAL DRAWING
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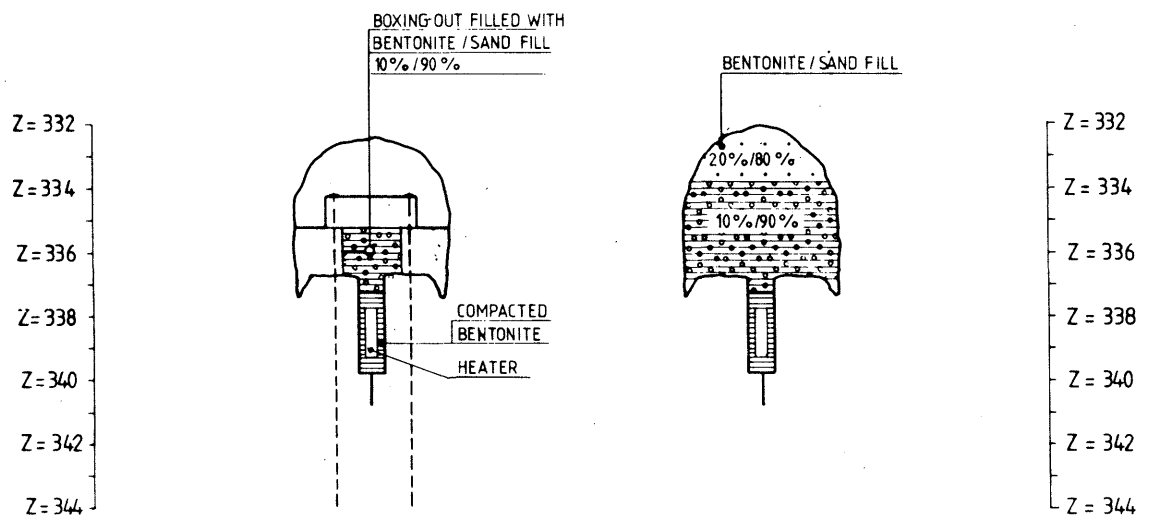
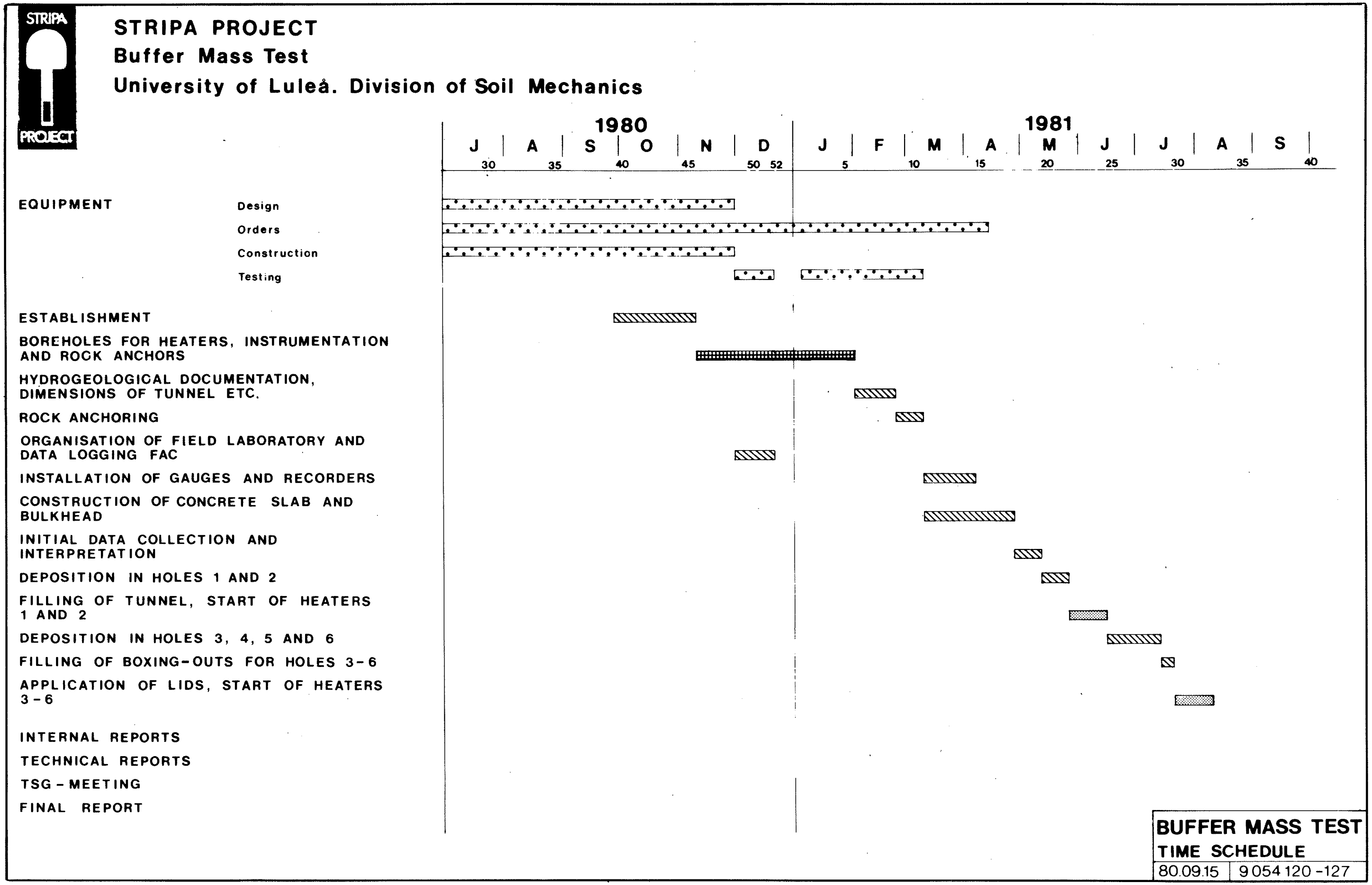


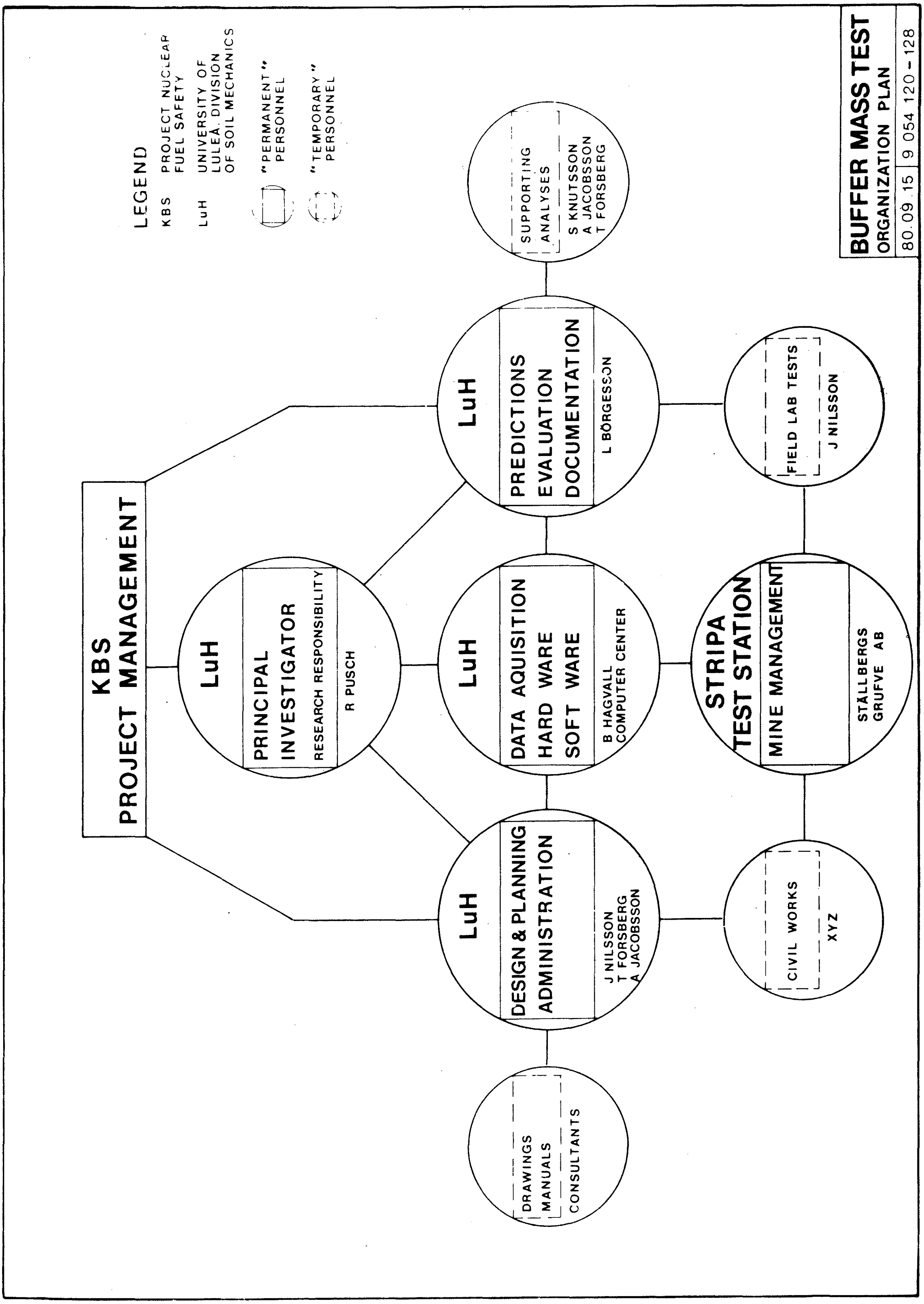
C CROSS SECTION
1:200

D CROSS SECTION
1:200

BUFFER MASS TEST
GENERAL DRAWING

80 09 15	9 054 120-132


STRIPA PROJECT
Buffer Mass Test
University of Luleå. Division of Soil Mechanics
1980
1981
J A S O N D J F M A M J J A S
30 35 40 45 50 52 5 10 15 20 25 30 35 40
EQUIPMENT
Design
Orders
Construction
Testing
ESTABLISHMENT
BOREHOLES FOR HEATERS, INSTRUMENTATION AND ROCK ANCHORS
HYDROGEOLOGICAL DOCUMENTATION, DIMENSIONS OF TUNNEL ETC.
ROCK ANCHORING
ORGANISATION OF FIELD LABORATORY AND DATA LOGGING FAC
INSTALLATION OF GAUGES AND RECORDERS
CONSTRUCTION OF CONCRETE SLAB AND BULKHEAD
INITIAL DATA COLLECTION AND INTERPRETATION
DEPOSITION IN HOLES 1 AND 2
FILLING OF TUNNEL, START OF HEATERS 1 AND 2
DEPOSITION IN HOLES 3, 4, 5 AND 6
FILLING OF BOXING-OUTS FOR HOLES 3-6
APPLICATION OF LIDS, START OF HEATERS 3-6
INTERNAL REPORTS
TECHNICAL REPORTS
TSG-MEETING
FINAL REPORT
BUFFER MASS TEST
TIME SCHEDULE
80.09.15
9 054 120-127


KBS
PROJECT MANAGEMENT
LuH
PRINCIPAL INVESTIGATOR
RESEARCH RESPONSIBILITY
R PUSCH
LuH
DESIGN & PLANNING
ADMINISTRATION
J NILSSON
T FORSBERG
A JACOBSSON
LuH
DATA AQUISITION
HARD WARE
SOFT WARE
B HAGVALL
COMPUTER CENTER
LuH
PREDICTIONS
EVALUATION
DOCUMENTATION
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KBS PROJECT NUCLEAR FUEL SAFETY
LuH UNIVERSITY OF LULEÅ, DIVISION OF SOIL MECHANICS
"PERMANENT" PERSONNEL
"TEMPORARY" PERSONNEL
BUFFER MASS TEST
ORGANIZATION PLAN
80.09.15
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