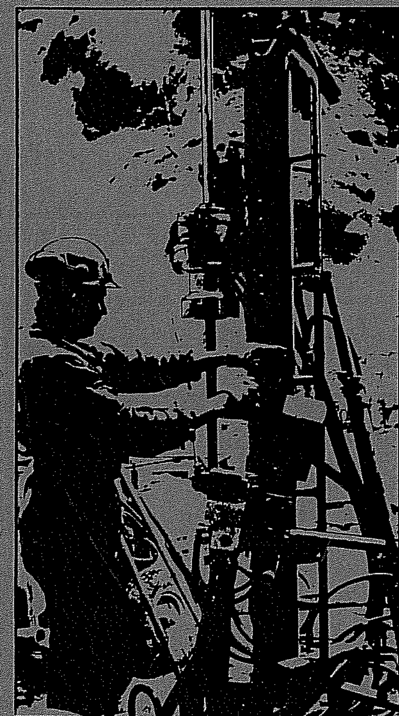
LBL-7080
SAC-05
UC-70

SWEDISH-AMERICAN COOPERATIVE PROGRAM ON RADIOACTIVE WASTE STORAGE IN MINED CAVERNS IN CRYSTALLINE ROCK



Technical Project Report No.5

BOREHOLE DRILLING AND RELATED ACTIVITIES AT THE STRIPA MINE

Pavel J. Kurfurst
Lawrence Berkeley Laboratory
University of California
Berkeley, California

T. Hugo-Persson
Hagby-Bruk AB
Nora, Sweden

G. Rudolph
VIAK AB
Falun, Sweden

August 1978

A Joint Project of

Swedish Nuclear Fuel Supply Co.
Fack 10240 Stockholm, Sweden

Operated for the Swedish
Nuclear Power Utility Industry

Lawrence Berkeley Laboratory
Earth Sciences Division
University of California
Berkeley, California 94720, USA

Operated for the U.S. Department of
Energy under Contract W-7405-ENG-48

KURFURST, Pavel J.

Office: Research Scientist
Geological Survey of Canada
401 Lebreton St.
Ottawa, Ont., Canada K1A 0E8
613-593-6103

Home: 22 Norice St.
Ottawa, Ont. Canada K2G 2X5
613-226-2319

ΔT = 3 Hours

FTS: 950-5111 (SYRACUSE)

give operator my FTS number plus my phone # for billing

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: $5.25 Printed Copy

LBL-7080
SAC-05

BOREHOLE DRILLING AND RELATED ACTIVITIES AT THE STRIPA MINE

Pavel J. Kurfurst
Lawrence Berkeley Laboratory
University of California
Berkeley, California

T. Hugo-Persson
Hagby-Bruk AB
Nora, Sweden

and

G. Rudolph
VIAK AB
Falun, Sweden

August 1978

PREFACE

This report is one of a series documenting the results of the Swedish-American cooperative research program in which the cooperating scientists explore the geological, geophysical, hydrological, geochemical, and structural effects anticipated from the use of a large crystalline rock mass as a geologic repository for nuclear waste. This program has been sponsored by the Swedish Nuclear Power Utilities through the Swedish Nuclear Fuel Supply Company (SKBF), and the U.S. Department of Energy (DOE) through the Lawrence Berkeley Laboratory (LBL).

The principal investigators are L.B. Nilsson and O. Degerman for SKBF, and N. G. W. Cook, P. A. Witherspoon, and J. E. Gale for LBL. Other participants will appear as authors of subsequent reports.

Previously published technical reports are listed below.

1. *Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns* by P. A. Witherspoon and O. Degerman.

   (LBL-7049, SAC-01)

2. *Large Scale Permeability Test of the Granite in the Stripa Mine and Thermal Conductivity Test* by Lars Lundström and Håkan Stille.

   (LBL-7052, SAC-02)

3. *The Mechanical Properties of the Stripa Granite* by Graham Swan

   (LBL-7074, SAC-03)

4. *Stress Measurements in the Stripa Granite* by Hans Carlsson

   (LBL-7078, SAC-04)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The drilling operations for the joint Swedish-U.S. program on radioactive waste storage in mined caverns commenced in early August, 1977 and continued until April, 1978. At the peak of drilling, six drills were active--one on the surface and five underground. Some 160 boreholes of various lengths were drilled, including over 700 meters of core drilling on the surface, and over 1800 meters underground. Boreholes ranged from 38 mm to 406 mm in diameter, the latter to accomodate the main heaters. Special techniques and drilling equipment were developed to drill and remove the large cores.

Instrumentation and heater installations required strict drilling specifications, including angular deviations of ±0.5 degree for the short underground boreholes and ±3 degrees for the long inclined boreholes on the surface. The required accuracy was achieved and even surpassed by the use of the best available drilling equipment and techniques, and by extensive surveying control before, during, and after the drilling.

Detailed descriptions of the fractures and other relevant rock properties required orientation of the core as well as special recovery techniques. To assure the best possible quality of the core, a triple-tube core barrel was used to drill all boreholes 76 mm diameter and larger. Complete core logs, kept for all boreholes, contained drilling information and characterization of the discontinuities in the core.

Very detailed planning and scheduling kept the project within the time constraints, and avoided any conflict between the drilling program and simultaneously conducted excavations of the underground test drifts, as well as a number of hydrological and geophysical activities.

1. INTRODUCTION

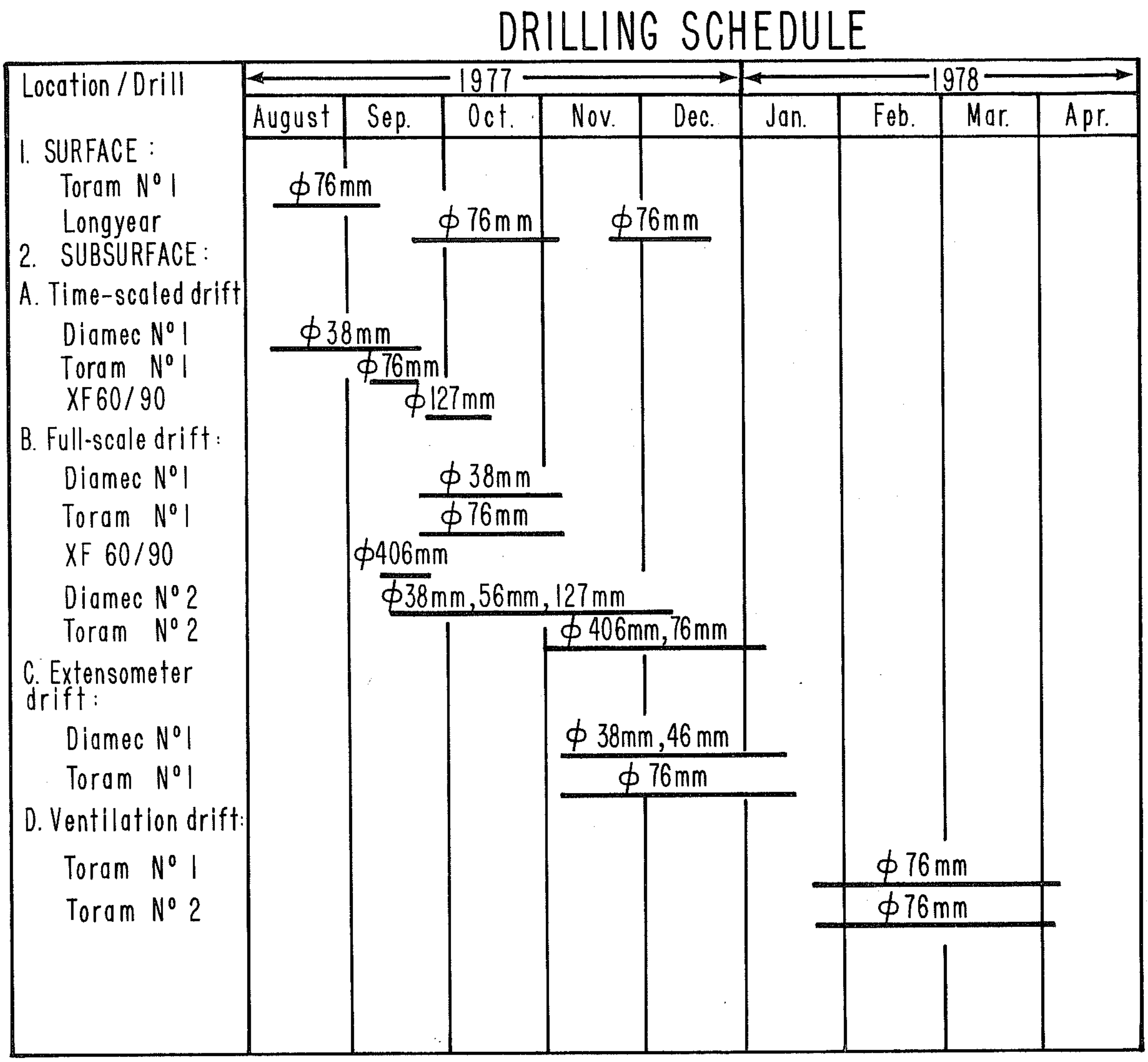
The Swedish-U.S. Cooperative Program to investigate radioactive waste storage in mined caverns was initiated in spring 1977. After the agreement between U.S. ERDA and Swedish SKBF (Nuclear Fuel Supply Company) was signed July 1, 1977, work started at the Stripa mine in Guldsmedshyttan. The Swedish part of the program was under the direction of KBS (Nuclear Fuel Safety Program), while the U.S. part was carried out by LBL.

The first stage of the program involved extensive mine excavations and drilling operations to provide working space and facilitate the large-scale experiments. A drilling company, Hagby Bruk AB, was contracted to drill some 3000 m of boreholes. Over 160 boreholes, ranging in size from ∅ 38 mm to ∅ 406 mm,[1] were drilled between August 8, 1977 and April 6, 1978 using several different drills. At the peak of drilling, six drills were active--five underground and one on the surface. The detailed drilling schedule and the deployment of the drills are shown in Fig. 1.

The Swedish engineering and surveying company VIAK AB conducted the required surveys and oversaw adherence to the strict drilling and specifications set up by KBS and LBL. The drilling pattern was complex, and instrumentation and heaters had to be emplaced with high accuracy. Drilling of unusually high precision was needed to ensure the straightness of the boreholes and the smallest possible deviation from their theoretical direction, and location of the collar and bottom.

---

1 ∅ = diameter



XBL 787-1981

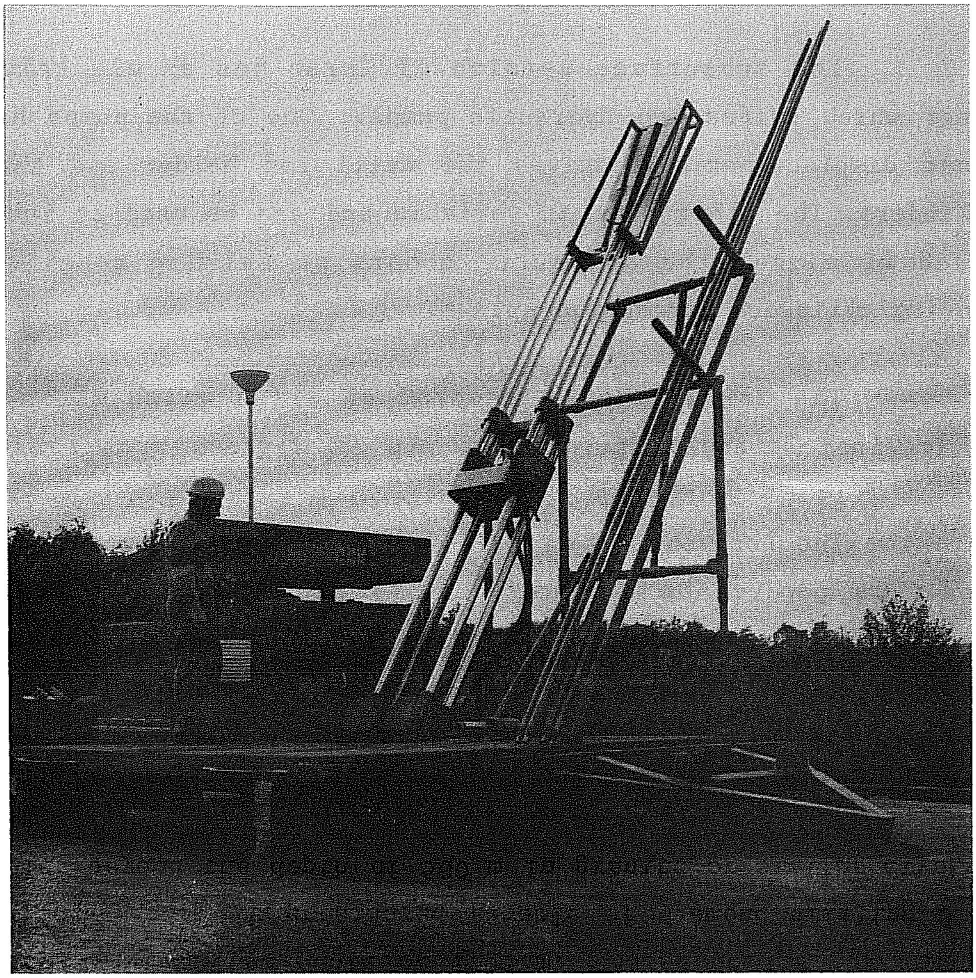
Fig. 1. Work schedule and deployment of drills.

2. DRILLING

2.1 Surface Drilling

Two Ø 76 mm boreholes, SBH 1 and SBH 2, were diamond drilled from the surface to depths of 385 m and 360 m, and with inclinations of 45 and 52 degrees, respectively. The drills used were a Toram 2x20 and a Longyear 44.

Toram 2x20 is a Hagby Bruk hydraulic core drilling machine which can be used either on the surface or underground (Fig. 2). For drilling boreholes ∅ 46 mm and ∅ 56 mm, the two most common dimensions used in diamond drilling in Sweden, this machine is capable of continuous coring to the depth of 1000 m. Based on its performance at Stripa, the Toram is considered capable of diamond drilling ∅ 76 mm boreholes beyond the depth of 500 m in granite or similar crystalline rock.



XBB 788-9284

Fig. 2. General view of Toram 2x20 drill.

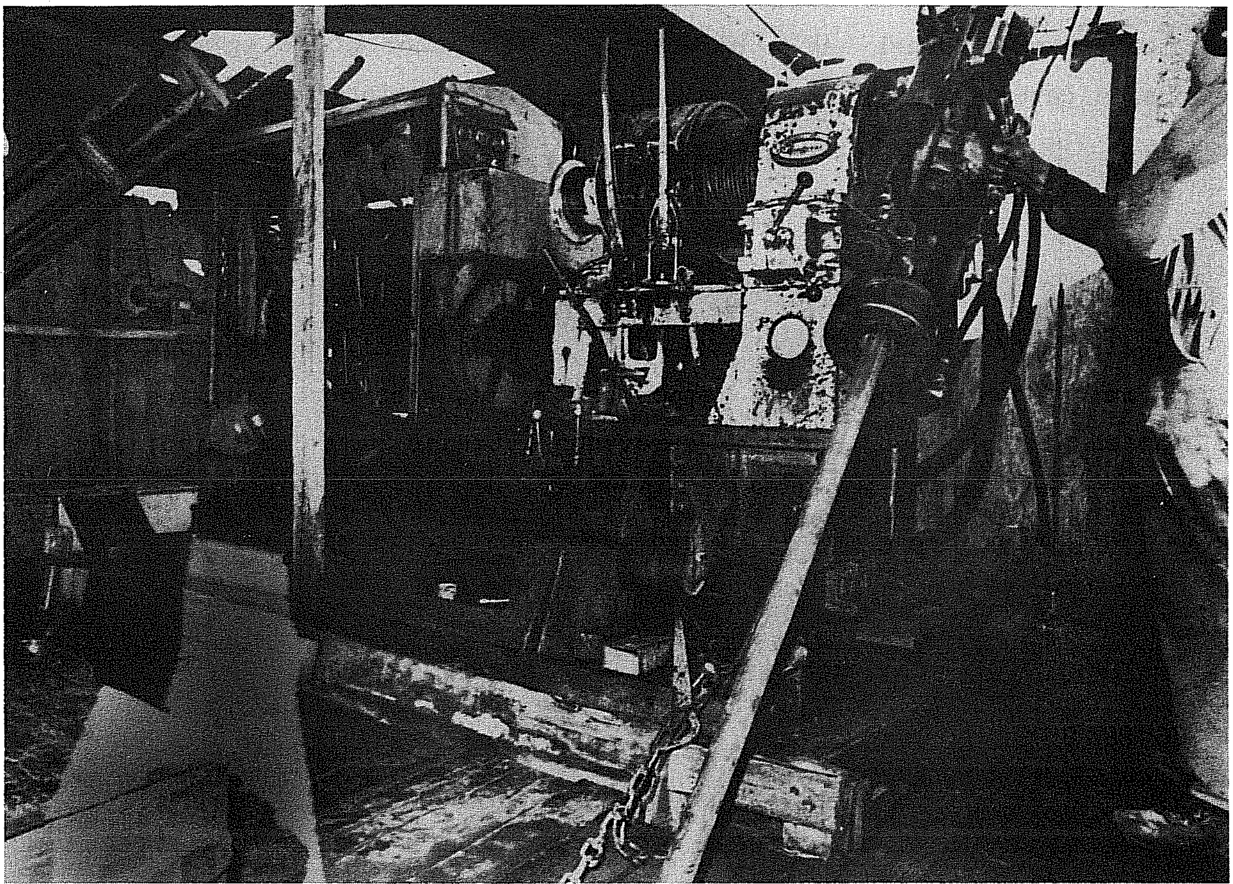
The drill has two engines which can be used either parallel or in series to provide two speed and torque ranges. Using transmission, the engines drive a hexagonal socket in which either a water swivel head with the drill rod connections, or a mechanical drill rod hoist can be placed. The motor assembly slides on four guide rods. The front two rods, placed in the hexagonal driver socket, are also used as a feeding cylinder. The power from the piston rods of the feeding cylinder is transferred by four pull rods which are connected to the piston rods. The drill rod holder with the hydraulic clamp is located in the lower part of the drill. The hydraulic clamp can handle drill rods varying in size from 33.5 mm to 101 mm.

The subsurface version of Toram has an electrical 45 kW motor which drives two hydraulic pumps. One of the pumps has a constant displacement and drives the drill rod holder and the feeding cylinders. The other pump is variable and can be used to increase the speed of either the hydraulic motors of spindle rotation or the feeding cylinders during the uptake.

The drill body is mounted on skids which allow drilling of inclined boreholes between 45 and 90 degrees from the vertical.

The Longyear 44 diamond drill (Fig. 3), mounted on a steel frame, is powered by a 90 Hp Perkins diesel engine. The power is transferred to the swivel head using a dry clutch and a 4-speed synchromesh transmission which provides four drilling and four hoisting speeds. The twin hydraulic swivel head has a hexagonal drive rod with a Ø 76 mm center hole. Hydraulic feeding cylinders of 100 mm with 600 mm stroke and the planetary gear hoist are used to hoist and lower the string of the drill rods.

A 6 m tower with a platform was used for handling the drill rods. A skid mounted pump unit provided drilling water from the nearby lake; the triplex pump used was driven either by a 2-cylinder 15.5 Hp diesel engine or by a 10 Hp electric engine.



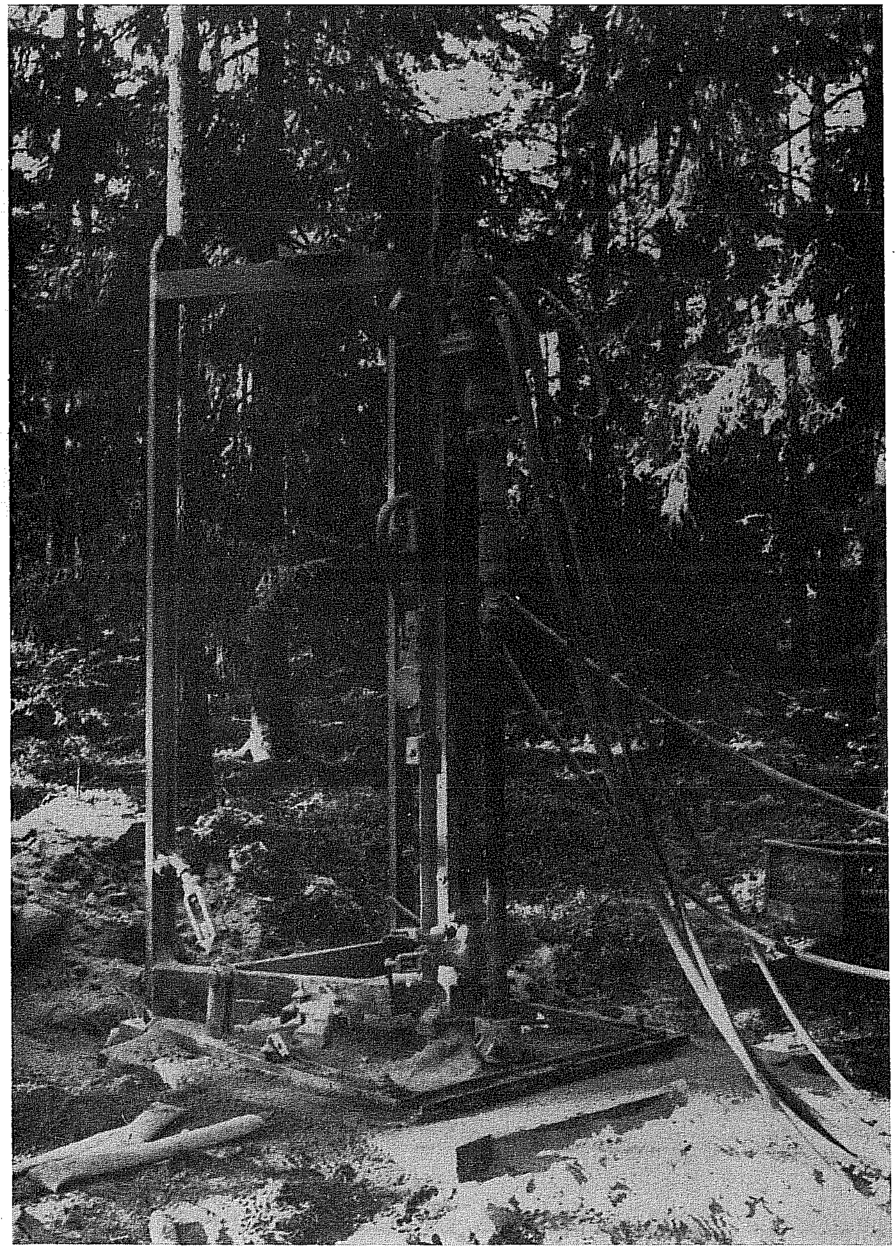
XBB 788-9286

Fig. 3. Longyear 44 drill in operation.

A NLMC triple tube core barrel (76 mm O.D., 48 mm I.D.) with a split inner steel tube made by Triefus of Australia, achieved strictly specified straight boreholes, and high quality core recovery. This triple tube core barrel was modified by Hagby Bruk to 52 mm I.D., to provide ∅ 52 mm I.D. A 76 mm reamer was used. The core barrel was emptied after each uptake by the water pressure from a water pump used during drilling.

Impregnated drill bits with the right combination of low diamond concentration and soft matrix ensured good penetration rates in the hard Stripa granite.

The flush-coupled drill rods (72 mm O.D., 61 mm I.D.) made of chromium steel had a minimum breaking point of 90 kg/mm^2. Tungsten carbide guides at the most heavily used points of the core barrel and the drill rod couplings were carefully maintained and frequently replaced.



XBB 788-9285

Fig. 4. General view of Cop 4 drill.

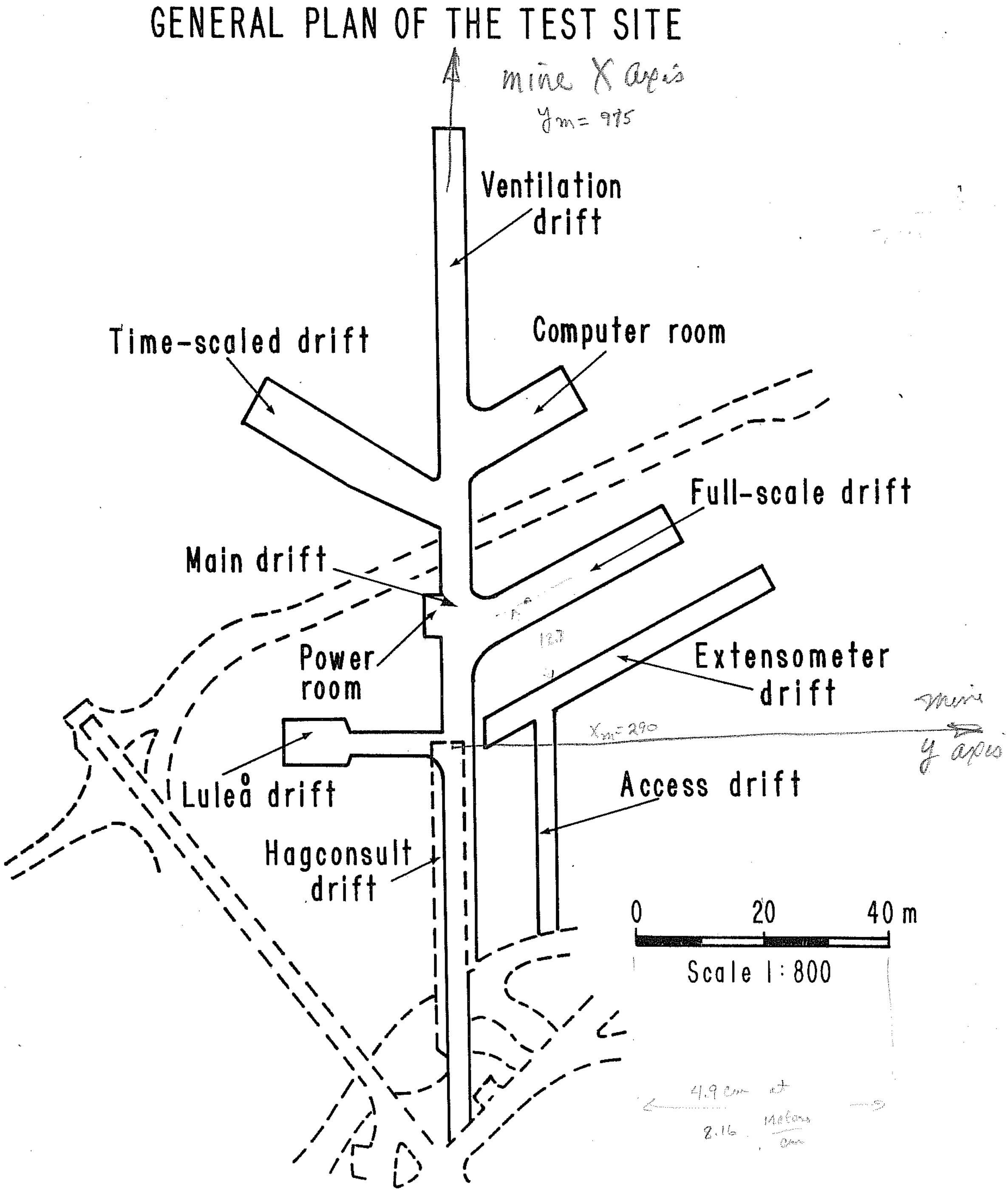
To achieve good core recovery, the bit pressure was kept very low and the drill rod string was carefully guided and kept stiff. All core was oriented: After every uptake a steel bar with a hard metal point was lowered by steel cable into the borehole. Sliding along the borehole wall, the bar hit the lowest point of the rock, making a visible indentation which was used as an orientation mark.

Seven water table boreholes were dry drilled on the surface to depths of 50 m to 100 m, using an Atlas Copco Cop 4 percussion drill with compressed air (Fig. 4). The top several meters of each borehole were cased with 125 mm O.D. steel casing. Drill bit diameter was changed gradually from 115 mm in the top part of the borehole to 105 mm in the bottom part. A two-man crew drilled from 4 m to 30 m in an 8 hour shift, depending on borehole depth and the quality of the encountered rock. Because the boreholes were percussion drilled, the walls were plugged with the drill fines to the depth of several mm, thus slowing down the process of groundwater table level recovery.

2.2 Subsurface Drilling

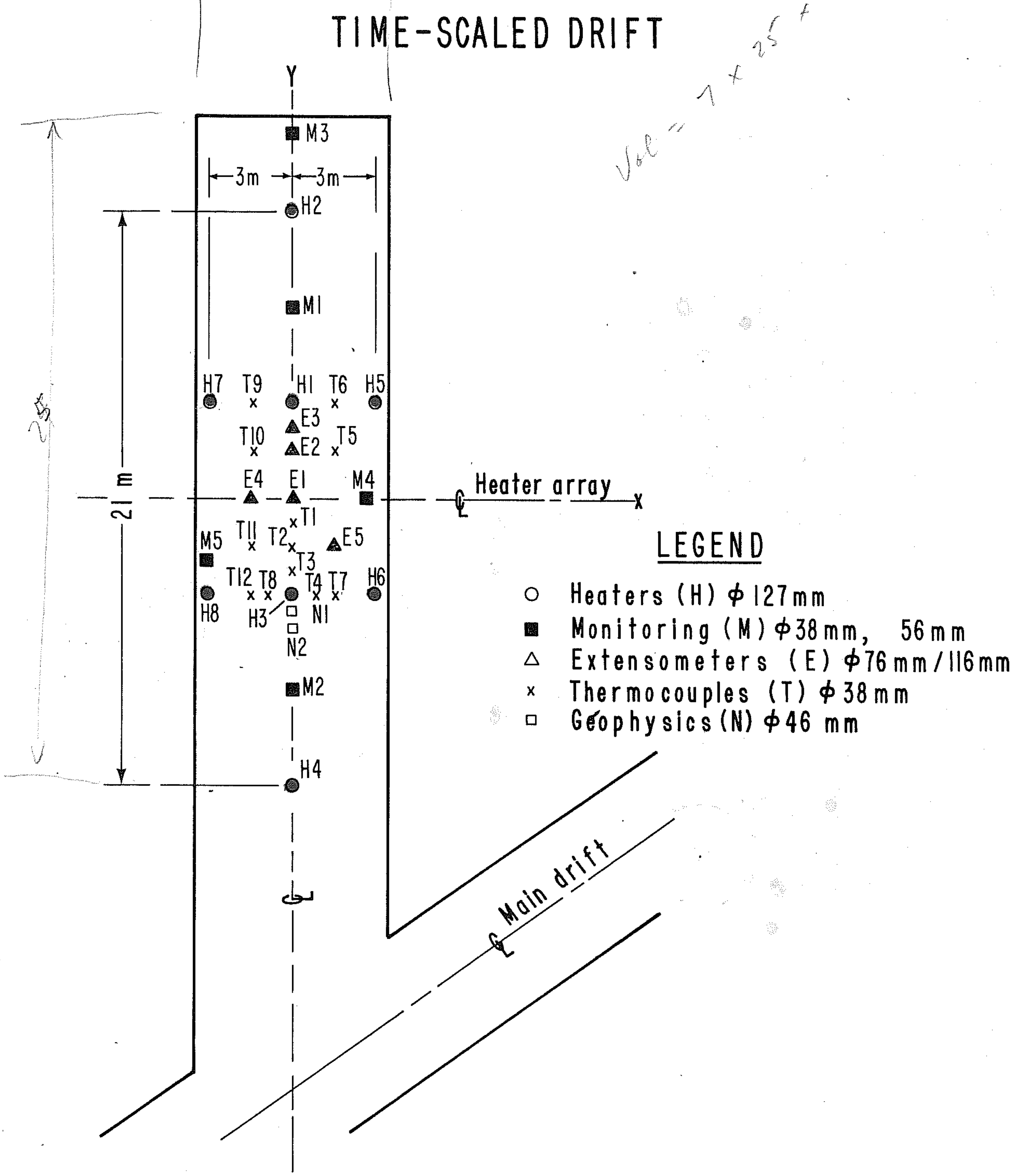
Subsurface drilling was carried out in the full-scale, time-scaled, extensometer, and ventilation drifts. Over 150 boreholes ranging in diameter from 38 mm to 406 mm and varying in depth from 4.5 m to 14.5 m were diamond drilled using Toram, Diamec, and XF 60/90 drill machines. All boreholes were cored, and all core from boreholes larger than ∅ 56 mm was oriented. The general plan of the drifts is shown in Fig. 5, and a detailed borehole layout in each drift in Figs. 6 to 10.

The subsurface drill was a modified version of the Toram 2x20 drill used on the surface (see section 2.1). A high torque version of the Toram was used for ∅ 406 mm coring to overcome the initial drilling problems.



XBL 787–1983

Fig. 5. General plan of test site.



XBL 787—1986

Fig. 6. Borehole layout in the time-scaled drift.

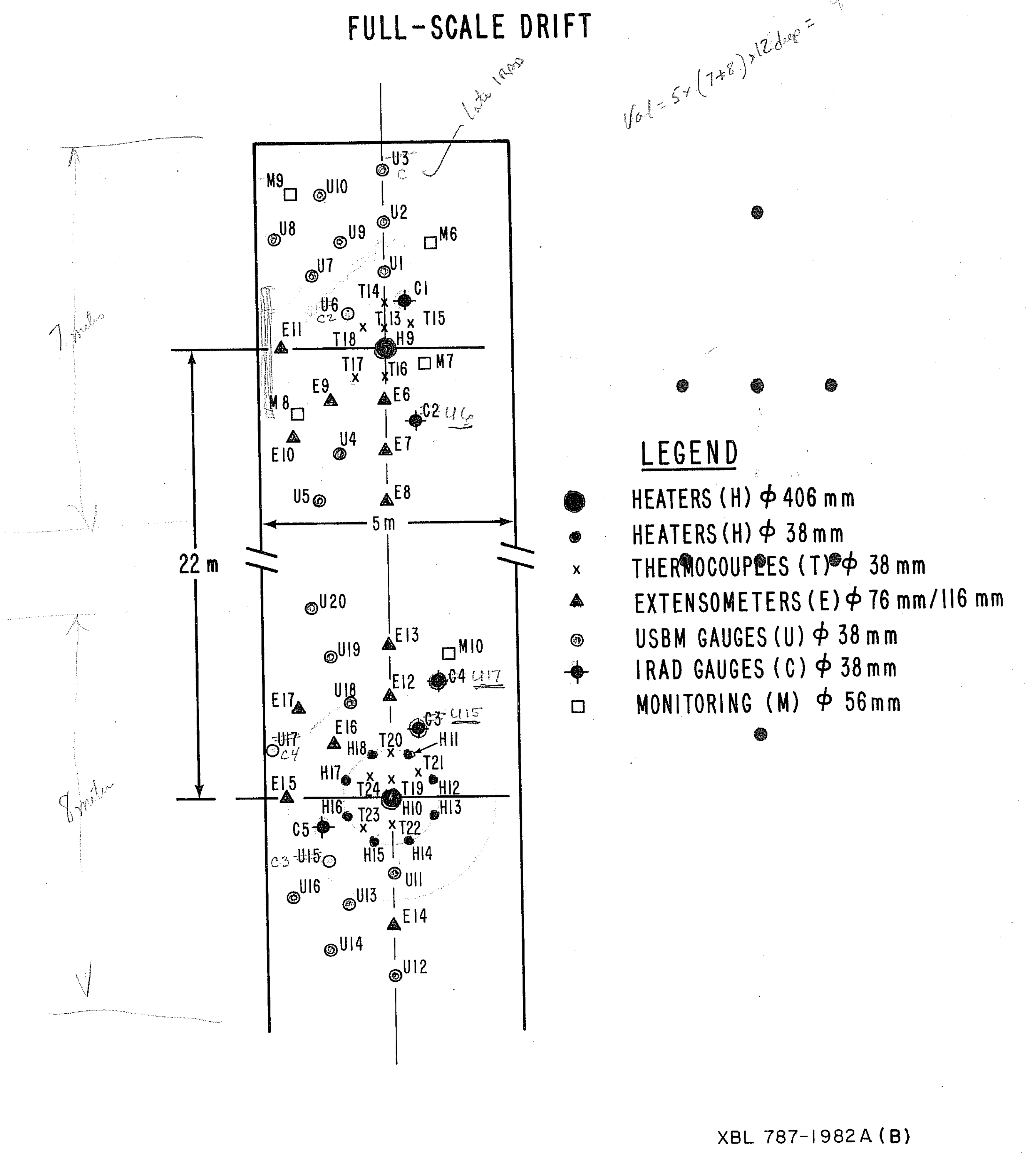


Fig. 7. Borehole layout in the full-scale drift.

deviation of the borehole, the pictures taken show the changes in the position of the reflector rings in relation to each other and to its center line. The pictures also show the position of the bubble that defines the vertical plane. The developed frames are projected onto a screen and the angular deflection of each ring is measured. A total of 6 values is measured from each frame. Three values, which refer to the position of the rings in relation to the vertical line defined by the bubble, give the deviation. The other three values, which represent the position of the lateral axis from the vertical, give the dip. These 6 values are compared with values of the displacement angles of the reflector rings obtained in the straight test borehole. The data are calculated and converted into actual borehole coordinates at desired intervals, using the computer program.

All calculations were based on measurements taken by VIAK AB at depths between 0 and 12 m. Two independent measurements ensured accuracy. The results were directly comparable for direction and dip values. The maximum difference between two measurements was:

SBH 1: Direction - 0.0222 grads; dip - 0.0557 grads.
SBH 2: Direction - 0.1055 grads; dip - 0.0448 grads;
elevation - 0.002 m; plan - 0.009 m;

The largest differences from the theoretical values were:

SBH 1: Direction - 0.8930 grads; dip - 0.6530 grads.
SBH 2: Direction - 0.3156 grads; dip - 0.0753 grads.

Tolerances stipulated in the initial specifications allowed a maximum directional deviation at the collar of borehole of ± 1.111 grads, and a total deviation at the bottom of borehole of ± 3.3333 grads.

The detailed surface borehole coordinates are available in LBL's index of data from experiments in Stripa.

3.2 Subsurface Surveying

The subsurface surveying was carried out in the full-scale, time-scaled, extensometer, and ventilation drifts and included positioning of the drills and surveying during and after the drilling operation.

Traverse network. All traverse network survey points in the full scale, time-scaled, extensometer, and ventilation drifts were measured and calculated using Kern DKM 2 AE and Kern DM 500 instruments and a calibrated measuring tape. The final errors in the traverse net were within the following tolerances:

Plan: $0.004 \sqrt{L}$ m, where L is the length of traverse in meters;

Elevation: 0.005 m.

The traverse points in the main drift, ventilation drift, and the adit to the extensometer drift were marked by roof markers of the conventional type. The traverse points in the full-scale, time-scaled, and extensometer drifts were marked using the fixed consoles attached to the rock walls with expander rock bolts. A horizontal panel with a center hole and an attached Kern instrument was located at the front of these consoles. The traverse points were defined as the center of the center hole and the center of the sighting axis of the theodolite, which was located 197 mm above the top surface of the panel. The traverse points in the individual drifts were determined by triangulation and by the net of triangulation compensation, which produced the following results:

Drift	Average error in length per 100 m	Average error in direction
Full-scale	0.0006 m	0.0006 grads
Time-scaled	0.0018 m	0.0024 grads
Extensometer	0.0032 m	0.0009 grads
Ventilation	0.0016 m	0.0017 grads

Two survey points defining the center line of the drifts were installed in the roof of each of the full-scale, time-scaled, extensometer, and ventilation drifts. In the extensometer drift these points were marked along the center line of the drift, perpendicular to the center line of the main heater boreholes H 9 and H 10.

Survey before and after drilling. In the full-scale and time-scaled drifts, where all boreholes were drilled vertically, the Kern DKM 2 AE theodolite was used. The location of the boreholes was calculated using all consoles, while at least two consoles were used to measure the angle of the drill. Vertically the drills were aligned using the theodolites to plumb the drill rods. A special grooved square set made by Hagby Bruk was used to align the drill rods in plan at the borehole collar directly along the center line of the drill rods. In addition special plates were made for each drill to mark the anchor bolt holes used to secure the drill to the rock.

A Kern DKM 1 theodolite with an auxiliary tube was used to survey the vertical boreholes after drilling was completed. The center point of this instrument, a tip of a special signal rod, was determined by intersection from at least two fixed consoles. The bottom of the boreholes was determined by measuring the horizontal and vertical angles and the distances to the reference point, which was lowered to the bottom of the borehole. The reference point was placed inside the drill rods and then illuminated from below. The diameter of the drill rod varied, depending on the diameter of the measured borehole.

In principle the measurements in the extensometer drift were taken in a similar way. Special pillars installed on the opposite wall from the boreholes simplified setting up the instrument by providing a base for a vertically and laterally adjustable console. A cross-slide, allowing horizontal movements, was fitted to the console. A micrometer allowing vertical movement and the Kern DKM 2 AE theodolite were mounted on the top of the cross-slide.

The drills were positioned by direct alignment of the center of each drill, and special reference points were placed on their front and back. A frame was made to bolt the drills to the rock wall. Because the drills could be only slightly adjusted, they were very precisely positioned by aligning a groove on a specially made "tongue." The "tongue," together with the drill frame, could be turned towards the theodolite placed in the extension of the borehole direction. Reference points of the same type employed for the vertical boreholes were used for the final borehole measurements. In addition, a sectional cylinder with a center point was used to check the collar of the boreholes and to allow parallel movement of the drills when required.

The theoretical borehole coordinates were first converted into the mine coordinate system, then the borehole location and distances were calculated using either the IBM 1130 computer or the HP 97 calculator.

The location of the boreholes in the full-scale and time-scaled drifts was determined by intersection from at least two fixed consoles. The angle of the drills was trued by directioning at the drill rods. Immediately after the start of the drilling and during the first meter of the drilling, the position, direction, and angle of the drill rods were continuously observed and checked from at least two consoles. In order to orient the core samples, scribed lines were marked on the rock surface and aligned parallel to the center line of each drift. With the drill in place, a well defined point on the drill was surveyed and a borehole depth at the end of drilling was calculated. The depth was then measured from the base of the drill frame.

In the extensometer drift, the theodolite was first placed on the adjustable console attached to the pillar. The location of the instrument in plan and elevation had been calculated in advance. The theodolite was then moved to its correct position using a three-dimensional intersection; and the direction, dip, and length of each borehole were measured directly. Initially the drilling frame was mounted on the rock wall. When the frame was aligned to an acceptable extent, the exact alignment and adjustment of the drill was made with the theodolite in the same position. The exact position was then checked during the first meter of drilling, or until the first core sample was recovered. As soon as any deviation became noticeable, drilling was stopped immediately and the drill adjusted.

To ensure proper orientation of the core samples, a vertical scribed line from the center of the borehole was marked on the rock wall before the start of drilling. After that, the core-orienting procedure used in the other drifts and on the surface was followed.

After completion of drilling, the top and bottom points of the reamed section were measured. In the full-scale and time-scaled drifts, the borehole collars were measured by intersection from the fixed consoles. The bottom of the borehole was measured both in plane and elevation by surveying the reference point lowered into the borehole. The position of the theodolite was then measured both in plan and elevation by a three-dimensional intersection from at least two fixed consoles.

In the extensometer drift, the theodolite was placed on the adjustable console on the pillar. The borehole collar, the reamed-out section, and the bottom of the borehole were then surveyed in relation to the known position of the theodolite. The final measurements were carried out twice and were entirely independent.

The following tolerances were stipulated in the initial specifications:

Location of the survey points (2 roof markers in each experiment drift):

Plan ± 50 mm,

Elevation ± 100 mm

Collar of boreholes:

Plan ± 20 mm (calculated perpendicular to the direction of borehole),

Direction ± 0.5556 grads

Bottom of borehole:

Direction ± 1.1111 grads

In general, the survey results were less than 1/10th of the required tolerances. The detailed survey results of all subsurface boreholes, showing the theoretical and real coordinates for the collar and bottom of the boreholes, are summarized in the Appendix.

Computations. After the borehole survey was completed, the following calculations were carried out: traverse network, partly by the IBM 1130 computer and partly manually; net of triangulation by the HP 9830 A calculator; theoretical borehole coordinates by the IBM 1130 computer and by the HP 97 calculator; measurements after completion of drilling by the HP 97 calculator.

Mainly existing programs were used for the calculations, although a special program for the HP 97 calculator was created to compute the final borehole measurements. The instrument centers (X, Y, Z coordinates) for the fixed consoles were stored on magnetic cards. A program for a three-dimensional intersection with subsequent indirect sequence three-dimensional polar measurements calculated the required points. The intersection part was programmed to check whether the measurements were within the required tolerances. Evaluation of the survey results showed that position, direction, or dip of any of the boreholes surveyed did not exceed the tolerances; values of the standard deviations are summarized in Table III.

Table III. Standard Deviations of Subsurface Borehole Surveys

	Radial distance at bottom of borehole (mm)	Angle at bottom of borehole (grads)	Number of boreholes
Time-scaled drift	4.7	0.2653	29
Full-scale "	3.8	0.2987	63
Extensometer "	2.6	0.2934	36
Ventilation "	7.3	0.1708	10
Boreholes ϕ 38 mm	3.9	0.3246	79
" ϕ 56 mm	5.6	0.2766	4
" ϕ 76 mm	4.4	0.2098	45
" ϕ 127 mm	3.9	0.2277	8
" ϕ 406 mm	1.4	0.1149	2

4. RELATED ACTIVITIES

Several associated activities were conducted concurrently with the drilling operation. In addition to excavations of the drifts, the most time consuming activities included construction of the computer and instrumentation houses, walkways, and safety gates, and installation of the power and instrumentation cables. The other activities were mainly part of or in support of the hydrological and geophysical programs. All activities were carried out either by LBL personnel directly or by subcontractors or other participating agencies [Stållbergsbolagen; the Swedish Geology Survey (SGU); the Tennessee Valley Authority (TVA); the University of Saskatchewan; the University of Waterloo; VIAK AB; Hagconsult AB; Undervattensfoto AB; the Atomic Energy of Canada Limited (AECL)].

Although the subsurface drilling started in the first part of August 1977, excavation of the ventilation drift, the extensometer drift, and its access adit continued until early the next month. Since the drilling was done only in the full-scale and time-scaled drifts during the morning and afternoon shifts and the blasting for excavations was done mainly during the night shift, there was no interference and both operations proceeded without interruption.

Geophysical surveys were carried out both in the surface and subsurface boreholes by LBL, TVA, SGU, and University of Saskatchewan. The surveys included a set of conventional techniques (resistivity, SP, etc.), and special techniques (sonic waveform and in-hole and cross-hole ultrasonics.)

The following activities were part of the overall assessment of fracture hydrology: geological mapping, stereophotography, fracture mapping, TV logging, water inflow measurements, geochemical water sampling and testing of fracture fillings, and pressure and injection tests.

SGU did general geological mapping on the surface and detailed mapping of the underground drifts, including construction of the overall geological map of the rock types present and the detailed profiles pertinent to the LBL-KBS heater experiments. The detailed results have been issued as a separate KBS report by Olkiewicz, et al. (1978).

Detailed stereophotographs of the walls and floors in scale 1:20 were taken by the surveying firm VIAK AB in the time-scaled and extensometer drifts. In addition, LBL personnel took a set of photographs of the walls, floors, and ceilings in the full-scale, computer, and ventilation drifts. These photographs were later used to construct a detailed photomosaic needed for the fracture mapping and evaluation.

A very detailed fracture mapping of the walls and floors in the full-scale, time-scaled,and ventilation drifts was carried out by the LBL personnel. In addition to the maps, several profiles from the heater and instrumentation holes were constructed to supplement the base maps and help in determining the three-dimensional fracture system of the Stripa granite.

Immediately after completion of drilling in each drift, the consulting company (Hagconsult AB) TV logged all boreholes Ø 76 mm and larger. To compare different techniques and equipment used or to supplement the results already obtained, two other companies (Undervattensfoto, and the AECL) carried out additional logging both in the surface and subsurface boreholes.

Water inflow into the boreholes was measured repeatedly by the LBL personnel in all boreholes Ø 76 mm and larger. To obtain the representative values, measurements were taken either directly or with the upper highly fractured zones packed off.

Ongoing geochemical sampling, related directly to the drilling operation, included borehole water sampling and testing of the fracture fillings. The tests were performed either directly in situ by the LBL personnel or in the laboratory by the University of Waterloo or other subcontracted agencies.

Pressure and injection tests were carried out by LBL, University of Waterloo, or SGU personnel in the surface and subsurface boreholes. Since the majority of tests in the deep surface boreholes was done during drilling, it was impossible to avoid some slowdown of the drilling operation.

5. SUMMARY

The drilling operation and associated activities at the Stripa mine were a large undertaking completed in less than 8 months. The complexity of the drilling pattern, the accuracy and precision required of the drilling, and time constraints necessitated the highest possible quality of drilling and surveying. Due to the very large scope of the other ongoing activities and the time requirements, very detailed planning and scheduling was necessary to avoid any interference with the drilling program.

Several different drill types were used on the surface and underground to core drill more than 160 boreholes of various diameters and inclinations. The surveying results show that the accuracy and precision of drilling as required by the very strict specifications have been achieved and surpassed for all boreholes.

Several new methods have been developed and tested at Stripa. The smoothwall blasting technique was employed to excavate large drift openings with a relatively small degree of disturbance to the rock surfaces. Using the specially designed core barrels and a high torque version of the Toram drill, the Ø 406 mm core was drilled and recovered. The slot drilling technique was utilized to drill 1 m and larger-diameter cores.

All these techniques were developed, tested, and used with success and are recommended for future excavation and drilling operations for similar waste disposal programs in crystalline rock.

6. REFERENCES

Geological Society of London, "The Logging of Rock Cores for Engineering Purposes," Q. J. Engng. Geol., Vol. 3, 1970, pp. 1-24.

Goodman, R.L., METHODS OF GEOLOGICAL ENGINEERING IN DISCONTINUOUS ROCKS, West Publ. Co., N.Y., 1976.

Lau, J. S. O. and J. E. Gale, "The Determination of Attitudes of Planar Structures by Stereographic Projection and Spherical Trigonometry," Report of Activities, Part C, Geol. Surv. Can., Paper 7G-1C, 1976, pp. 175-177.

Olkiewicz, A., et. al., "Geological and Hydrogeological Documentation of the Stripa Test Station," KBS Technical Report No. 63, 1978.

except K?
all real values checked against Ramseys "Hole" print out of Viak survey (Viak final report previously checked against "Hole"). Note circled discrepancies below plus corrections. "Difference" values are not yet checked, A. DuBois 7/8/80
Errors greater than 1 cm are marked (x) in right margin

APPENDIX

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m)		Y (m)		Z (m)		
		Theoretical	Real	Theoretical	Real	Theoretical	Real	
TIME SCALED DRIFT								
H1	TOP	336.405	336.404	956.030	956.029		336.908	
	BOTTOM	336.405	336.406	956.030	956.036	348.061	348.077	
	DIFFERENCE	———	+0.002	———	+0.007		-11.169	
H2	T	339.791	339.788	949.903	949.903		336.563	
	B	339.791	339.778	949.903	949.908	348.061	348.336	
	D	———	-1.010	———	+0.005		-11.773	
H3	T	333.019	333.022	962.156	962 157		337.271	
	B	333.019	333.040	962.156	962.117	348.061	348.102	
	D	———	+0.018	———	-0.040		10.831	
H4	T	329.633	329.633	968.283	968.285		337.347	
	B	329.633	329.636	968.283	968.267	348.061	~~348.060~~ 347.897	X
	D	———	+0.003	———	-0.018		~~-10.713~~ 10.550	
H5	T	339.031	339.030	957.481	957.481		337.096	
	B	339.031	339.029	957.481	957.550	348.061	348.166	
	D	———	-0.001	———	+0.069		-11.070	
H6	T	335.645	335.641	963.608	963.610		337.224	
	B	335.645	335.644	963.608	963.640	348.061	348.024	
	D	———	+0.003	———	+0.030		-10.800	
H7	T	333.780	333.780	954.578	954.570		337.065 35	X
	B	337.780	333.778	954.578	954.566	348.061	348.210	
	D	———	-0.002	———	-0.004		-11.175	
H8	T	330.394	330.398	960.705	960.704		337.175	
	B	330.394	330.368	960.705	960.761	348.061	348.094	
	D	———	-0.030	———	+0.057		-10.919	
E1	T	334.713	334.715	959.093	959.091		337.227	
	B	334.713	334.701	959.093	959.092	351.061	351.217	
	D	———	-0.014	———	-0.001		-13.990	
E2	T	335.559	335.558	957.561	957.561		337.053	
	B	335.559	335.543	957.561	957.554	351.061	351.223	
	D	———	-0.016	———	-0.007		-14.170	
E3	T	335.980	335.982	956.800	956.800		336.928	
	B	335.980	335.972	956.800	956.812	351.061	351.568	
	D	———	-0.010	———	+0.012		-14.640	
E4	T	333.400	333.397	958.367	958.372		337.072	
	B	333.400	333.399	958.367	958.348	351.061	351.642	
	D	———	+0.002	———	-0.024		-14.570	
E5	T	335.179	335.182	961.350	961.348		337.224	
	B	335.179	335.146	961.350	961.337	351.061	351.224	
	D	———	-0.036	———	~~-0.011~~ .017		-14.000	
M1	T	338.098	338.100	952.966	952.968		336.678	
	B	338.098	338.116	952.966	953.013	351.061	351.147	
	D	———	+0.016	———	+0.045		-14.469	

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m)		Y (m)		Z (m)	
		Theoretical	Real	Theoretical	Real	Theoretical	Real
TIME SCALED DRIFT							
	T	331.326	331.326	965.220	964.220		336.678
M2	B	331.326	331.294	964.220	965.221	351.061	351.202
	D	———	-0.032	———	+0.001		-13.840
	T	334.292	334.288	959.855	959.866		337.139
T1	B	334.292	334.231	959.855	959.914	350.061	350.359
	D	———	-0.057	———	+0.048		-13.220
	T	333.866	333.863	960.625	960.629		337.255
T2	B	333.866	333.843	960.625	960.649	350.061	350.115
	D	———	-0.020	———	+0.020		-12.860
	T	333.445	333.447	961.386	961.392		337.314
T3	B	333.445	333.561	961.386	961.382	350.061	350.107
	D	———	+0.114	———	-0.010		-12.793
	T	333.781	333.780	962.577	962.577		337.313
T4	B	333.781	333.764	962.577	962.626	350.061	350.132
	D	———	-0.016	———	+0.049		-12.819
	T	336.872	336.868	958.287	958.291		337.244
T5	B	336.872	336.812	958.287	958.306	351.061	351.234
	D	———	-0.056	———	+0.015		-13.990
	T	337.718	337.714	956.755	956.764		336.945
T6	B	337.718	337.708	956.755	956.780	350.061	350.225
	D	———	-0.006	———	+0.016		-13.280
	T	334.332	334.333	962.882	962.883		337.326
T7	B	334.332	334.284	962.882	962.925	350.061	350.136
	D	———	-0.049	———	+0.042		-12.810
	T	332.258	332.254	961.736	961.739		337.329
T8	B	332.258	332.167	961.736	961.805	350.061	350.088
	D	———	-0.087	———	+0.066		-12.759
	T	335.093	335.093	955.304	955.303		337.080
T9	B	335.093	335.087	955.304	955.295	351.061	350.620
	D	———	-0.006	———	-0.008		-13.540
	T	334.246	334.245	956.836	956.840		337.021
T10	B	334.246	334.276	956.836	956.889	350.061	350.121
	D	———	+0.031	———	+0.049		-13.100
	T	332.553	332.547	959.899	959.904		337.240
T11	B	332.553	332.646	959.899	959.948	351.061	351.220
	D	———	+0.099	———	+0.044		-13.980
	T	331.707	331.707	961.431	961.431		337.230
T12	B	331.707	331.710	961.431	961.484	350.061	350.160
	D	———	+0.003	———	+0.053		-12.930
FULL SCALE DRIFT							
	T	323.422	323.420	1007.248	1007.248		338.777
H9	B	323.422	323.409	1007.248	1007.252	344.397	344.374
	D	———	-0.011	———	+0.004		-5.597
	T	312.713	312.713	988.030	988.030		338.953
H10	B	312.713	312.716	988.030	988.024	344.397	344.379
	D	———	+0.003	———	-0.006		-5.426

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m) Theoretical	X(m) Real	Y (m) Theoretical	Y (m) Real	Z (m) Theoretical	Z (m) Real
FULL SCALE DRIFT							
	T	312.817	312.815	988.924	988.925		338.801
H11	B	312.817	312.808	988.924	988.939	345.297	345.291
	D	———	-0.007	———	+0.014		-6.490
	T	312.154	312.153	988.736	988.737		338.762
H12	B	312.154	312.140	988.736	988.757	345.297	345.307
	D	———	-0.013	———	+0.020		-6.545
	T	311.819	311.815	988.134	988.138		338.905
H13	B	311.819	311.747	988.134	988.144	345.297	345.274
	D	———	-0.068	———	+0.006		-6.369
	T	312.007	312.006	987.471	987.470		338.871
H14	B	312.007	311.985	987.471	987.533	345.297	345.295
	D	———	-0.021	———	+0.063		-6.424
	T	312.609	312.611	987.136	987.137		338.882
H15	B	312.609	311.599	987.136	987.151	345.297	345.252
	D	———	-0.012	———	+0.014		-6.370
	T	313.271	313.274	987.324	987.321		339.094
H16	B	331.271	313.295	987.324	987.322	345.297	345.263
	D	———	+0.021	———	+0.001		-6.169
	T	313.607	313.608	987.926	987.925		338.946
H17	B	313.607	313.613	987.926	987.902	345.297	345.266
	D	———	+0.005	———	-0.023		-6.320
	T	313.418	313.424	988.589	988.589		338.912
H18	B	313.418	313.433	988.589	988.615	345.297	345.301
	D	———	+0.009	———	+0.026		-6.389
	T	323.617	323.618	1007.597	1007.594		338.735
T13	B	323.617	323.623	1007.597	1007.589	346 397	346.374
	D	———	+0.005	———	-0.005		-7.639
	T	323.860	323.858	1008.034	1008.037		338.698
T14	B	323.860	323.847	1008.034	1008.015	346.397	346.398
	D	———	-0.011	———	-0.022		-7.700
	T	323.231	323.232	1007.921	1007.920		338.755
T15	B	323.231	323.240	1007.921	1007.902	346.397	346.396
	D	———	+0.008	———	-0.018		-7.641
	T	323.179	323.182	1006.811	1006.810		338.848
T16	B	323.179	323.246	1006.811	1006.783	346.397	346.413
	D	———	+0.064	———	-0.027		-7.565
	T	323.641	323.641	1006.478	1006.475		338.767
T17	B	323.641	323.656	1006.478	1006.481	346.397	346.408
	D	———	+0.015	———	+0.006		-7.641
	T	323.999	324.000	1007.412	1007.411		338.678
T18	B	323.999	324.016	1007.412	1007.421	346.397	346.395
	D	———	+0.016	———	+0.010		-7.717
	T	312.907	312.907	988.380	988.372		338.903
T19	B	312.907	312.914	988.380	988.378	346.397	346.373
	D	———	+0.007	———	+0.006		-7.470

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m) Theoretical	X(m) Real	Y (m) Theoretical	Y (m) Real	Z (m) Theoretical	Z (m) Real
FULL SCALE DRIFT							
	T	313.151	313.153	988.816	988.814		338.781
T20	B	313.151	313.182	988.816	988.819	346.397	346.361
	D	———	+0.029	———	+0.005		-7.580
	T	312.521	312.529	988.703	988.700		388.788
T21	B	312.521	312.545	988.703	988.690	346.397	346.478
	D	———	+0.016	———	-0.010		-7.690
	T	312.469	312.474	987.593	987.589		338.967
T22	B	312.569	312.456	987.593...	987.606	346 397	346.366
	D	———	-0.018	———	+0.017		-7.399
	T	312.931	312.930	987.261	987.261		338.994
T23	B	312.931	312.912	987.261	987.275	346.397	346.370
	D	———	-0.018	———	+0.014		-7.376
	T	313.290	313.291	988.194	988.190		339.019
T24	B	313.290	313.320	988.194	988.208	346.397	346.394
	D	———	+0.029	———	+0.018		-7.375
	T	322.935	322.936	1006.374	1006.370		338.795
E6	B	322.935	322.941	1006.374	1006.368	351.397	351.742
	D	———	+0.005	———	-0.002		-12.947
	T	322.449	322.449	1005.500	1005.498		338.665
E7	B	322.449	322.444	1005.500	1005.489	351.397	351.350
	D	———	+0.005	———	-0.009		-12.685
	T	321.962	321.963	1004.627	1004.626		338.678
E8	B	321.962	321.962	1004.627	1004.625	351.397	351.345
	D	———	-0.001	———	-0.001		-12.667
	T	323.832	323.832	1005.805	1005.806		328.761
E9	B	323.832	323.820	1005.805	1005.810	351.397	351.342
	D	———	-0.012	———	+0.004		-12.581
	T	324.106	324.106	1004.843	1004.838		338.741
E10	B	324.106	324.095	1004.843	1004.829	351.397	351.373
	D	———	-0.009	———	-0.009		-12.632
	T	325.169	325.169	1006.274	1006.273		338.765
E11	B	325.169	325.165	1006.274	1006.278	351.397	351.302
	D	———	-0.004	———	+0.005		-12.537
	T	318.686	318.683	989.777	989.774		338.794
E12	B	318.686	318.665	987.777	989.741	351.397	351.870
	D	———	-0.018	———	-0.033		-12.576
	T	314.173	313.173	990.651	990.652		338.896
E13	B	314.173	313.173	990.651	990.647	351.397	351.192
	D	———	0.000	———	-0.005		-12.296
	T	311.496	311.499	985.846	985.851		338.824
E14	B	311.496	311.489	985.846	985.848	351.397	351.389
	D	———	-0.010	———	-0.003		-12.565
	T	314.460	314.460	987.057	987.060		338.980
E15	B	314.460	314.457	987.057	987.081	351.397	351.356
	D	———	-0.003	———	+01021		-12.376

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m)		Y (m)		Z (m)	
		Theoretical	Real	Theoretical	Real	Theoretical	Real
FULL SCALE DRIFT							
	T	314.156	314.153	988.440	988.441		388.922
E16	B	314.156	314.165	988.440	988.455	351.397	351.387
	D	———	+0.012	———	+0.014		-12.465
	T	314.117	315.117	988.714	988.717		338.854
E17	B	315.117	315.116	988.714	988.744	351.397	351.400
	D	———	-0.001	———	+0.027		-12.546
	T	323.538	323.539	1008.241	1008.239		338.732
C1	B	323.538	323.526	1008.241	1008.230	345.897	345.852
	D	———	-0.013	———	-0.009		-7.120
	T	322.246	322.246	1006.316	1006.315		338.723
C2	B	322.246	322.253	1006.316	1006.336	345.897	345.871
	D	———	+0.007	———	+0.021		-7.148
	T	312.886	312.888	989.520	989.529		338.804
C3	B	312.886	312.939	989.520	989.635	345.897	345.890
	D	———	+0.051	———	+0.106		-7.086
	T	313.001	313.004	990.513	990.511		338.684
C4	B	313.001	312.996	990.513	990.509	345.897	345.884
	D	———	-0.008	———	-0.002		-7.200
	T	313.644	313.646	986.854	986.851		339.054
C5	B	313.644	313.670	986.854	986.850	345.897	345.854
	D	———	+0.024	———	-0.001		-6.800
	T	324.152	324.154	1008.558	1008.558		338.646
U1	B	324.152	324.168	1008.558	1008.558	345.897	346.094
	D	———	+0.014	———	0.000		-7.448
	T	324.639	324.639	1009.431	1009.429		338.619
U2	B	324.639	324.633	1009.431	1009.411	345.897	346.385
	D	———	-0.006	———	-0.081		-7.776
	T	325.126	325.129	1010.305	1010.306		338.608
U3	B	325.126	325.115	1010.305	1010.289	345.897	346.006
	D	———	-0.014	———	-0.017		-7.458
	T	323.162	323.161	1005.014	1005.014		338.830
U4	B	323.162	323.146	1005.013	1005.016	345.897	345.874
	D	———	-0.015	———	+0.002		-7.044
	T	323.047	323.049	1004.019	1004.019		338.661
U5	B	323.047	323.050	1004.019	1003.999	345.897	345.876
	D	———	+0.001	———	-0.020		-7.215
	T	324.384	324.384	1007.521	1007.521		338.688
U6	B	324.384	324.382	1007.521	1007.526	345.897	346.108
	D	———	-0.002	———	+0.005		-7.420
	T	325.346	325.343	1007.794	1007.787		338.747
U7	B	325.346	325.334	1007.796	1007.784	345.897	346.086
	D	———	-0.009	———	-0.003		-7.337
	T	326.308	326.308	1008.068	1008.068		338.754
U8	B	326.308	326.319	1008.068	1008.054	345.897	345.890
	D	———	+0.011	———	-0.014		-7.136

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m) Theoretical	X(m) Real	Y (m) Theoretical	Y (m) Real	Z (m) Theoretical	Z (m) Real
FULL SCALE DRIFT							
U9	T	325.186	325.187	1008.644	1008.645		338.736
	B	325.186	325.230	1008.644	1008.666	345.897	345.873
	D	———	+0.043	———	+0.021		-7.137
U10	T	325.970	325.971	1009.265	1009.266		388.733
	B	325.970	325.965	1009.265	1009.245	345.897	345.920
	D	———	-0.006	———	-0.021		-7.187
U11	T	311.983	311.982	986.720	986.722		338.954
	B	311.983	311.988	986.720	986.692	345.897	345.829
	D	———	+0.006	———	-0 030		-6.875
U12	T	311.009	311.011	984.973	984.974		338.940
	B	311.009	311.038	984.973	984.985	345.897	345.894
	D	———	+0.027	———	+0.011		-6.954
U13	T	312.453	312.452	985.795	985.793		338.941
	B	312.453	312.426	985.795	985.777	345.897	345.889
	D	———	-0.026	———	-0.016		-6.948
U14	T	312.337	312.338	984.802	984.803		338.778
	B	312.337	312.308	984.802	984.847	345.897	345.893
	D	———	-0.030	———	+0.044		-7.115
U15	T	313.191	313.191	986.347	986.350		338.917
	B	313.191	313.205	986.347	986.395	345.897	345.837
	D	———	+0.014	———	+0.045		-6.920
U16	T	313.464	313.465	985.385	985.384		338.889
	B	313.465	313.463	985.385	985.324	345.897	345.896
	D	———	-0.002	———	-0.060		-7.007
U17	T	315.196	315.193	987.741	987.741		338.760
	B	315.196	315.143	987.741	987.752	345.897	345.888
	D	———	-0.050	———	+0.009		-7.128
U18	T	314.281	318.283	989.272	989.266		338.837
	B	314.281	318.250	989.272	989.282	345.897	345.897
	D	———	-0.033	———	+0.016		-7.060
U19	T	315.065	315.060	989.892	989.896		338.859
	B	315.065	315.062	989.892	989.903	345.897	345.899
	D	———	+0.002	———	+0.007		-7.040
U20	T	315.849	315.845	990.513	990.511		338.853
	B	315.849	315.823	990.513	990.576	345.897	345.889
	D	———	-0.022	———	+0.065		-7.036
EXTENSOMETER DRIFT							
C6	T	319.554	319.553	1020.849	1020.849	342.397	342.397
	B	323.149	323.030	1008.210	1008.133	342.304	342.339
	D	+3.595	+3.477	-12.639	-12.716	-0.093	-0.058
C7	T	314.609	314.610	1012.159	1012.161	342.398	342.397
	B	322.548	322.545	1007.735	1007.728	342.307	342.334
	D	+7.939	+7.935	-4.424	-4.433	-0.091	-0.063
C8	T	309.748	309.748	1003.363	1003.363	342.397	342.395
	B	322.460	322.399	1006.975	1006.978	342.304	342.288
	D	+12.712	+12.651	+3.612	+3.615	-0.093	-0.107

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m)		Y (m)		Z (m)	
		Theoretical	Real	Theoretical	Real	Theoretical	Real
EXTENSOMETER DRIFT							
	T	302.203	302.203	989.251	989.252	342.395	342.392
C10	B	311.720	311.718	988.145	988.135	342.306	342.306
	D	+9.517	+9.515	-1.106	-1.117	-0.089	-0.086
	T	316.906	316.904	1015.477	1015.475	343.894	343.895
C11	B	322.801	322.769	1008.032	1008.017	343.806	343.833
	D	+5.895	+5.865	-7.445	-7.458	-0.088	-0.062
	T	312.473	312.474	1008.520	1008.523	343.899	343.898
C12	B	320.442	320.434	1007.594	1007.586	343.824	343.864
	D	+7.969	+7.960	-0.926	-0.937	-0.075	-0.034
	T	304.316	304.315	992.710	992.707	343.893	343.892
C14	B	311.839	311.802	988.517	988.506	343.807	343.814
	D	+7.523	+7.487	-4.193	-4.201	-0.086	-0.078
	T	299.250	299.251	984.202	984.201	343.896	343.894
C15	B	311.751	311.746	987.757	987.734	343.804	343.800
	D	+12.501	+12.495	+3.555	+3.533	-0.092	-0.094
	T	316.744	316.744	1015.682	1015.682	342.397	342.402
U21	B	322.801	322.777	1008.032	1008.017	342.306	342.374
	D	+6.057	+6.033	-7.650	-7.665	-0.091	-0.028
	T	312.417	312.417	1008.526	1008.529	342.399	342.398
U22	B	320.442	320.438	1007.594	1007.582	342.324	342.316
	D	+8.025	+8.021	-0.932	-0.947	-0.075	-0.082
	T	308.845	308.846	1001.633	1001.633	342.397	342.396
U23	B	312.440	312.356	988.992	988.991	342.304	342.330
	D	+3.595	+3.510	-12.641	-12.642	-0.093	-0.066
	T	303.981	303.981	992.896	992.896	342.397	342.397
U24	B	311.839	311.775	988.517	988.532	342.307	342.334
	D	+7.858	+7.794	-4.379	-4.364	-0.090	-0.063
	T	398.959	398.958	984.119	984.123	342.398	342.399
U25	B	311.751	311.735	987.757	987.779	342.304	342.374
	D	+12.792	+12.777	+3.638	+3.656	-0.094	-0.025
	T	319.604	319.604	1020.675	1020.675	343.896	343.896
U26	B	323.149	323.068	1008.210	1008.237	343.804	343.810
	D	+3.545	+3.464	-12.465	-12.438	-0.092	-0.086
	T	314.810	314.810	1012.047	1012.048	343.898	343.897
U27	B	322.548	322.503	1007.735	1007.719	343.807	343.818
	D	+7.738	+7.693	-4.312	-4.329	-0.091	-0.079
	T	309.700	309.699	1003.346	1003.347	343.898	343.899
U28	B	322.460	322.439	1006.975	1006.954	343.804	343.830
	D	+12.760	+12.760	+3.629	+3.607	-0.094	-0.069
	T	305.973	305.972	996.543	996.542	343.897	343.897
U29	B	312.092	312.070	988.814	988.815	343.806	343.831
	D	+6.119	+6.098	-7.729	-7.727	-0.091	-0.066
	T	302.343	302.344	989.235	989.236	343.893	343.894
U30	B	311.720	311.646	988.145	988.153	232.806	343.818
	D	+9.377	+9.302	-1.090	-1.083	-0.087	-0.076

THEORETICAL AND REAL BOREHOLE COORDINATES

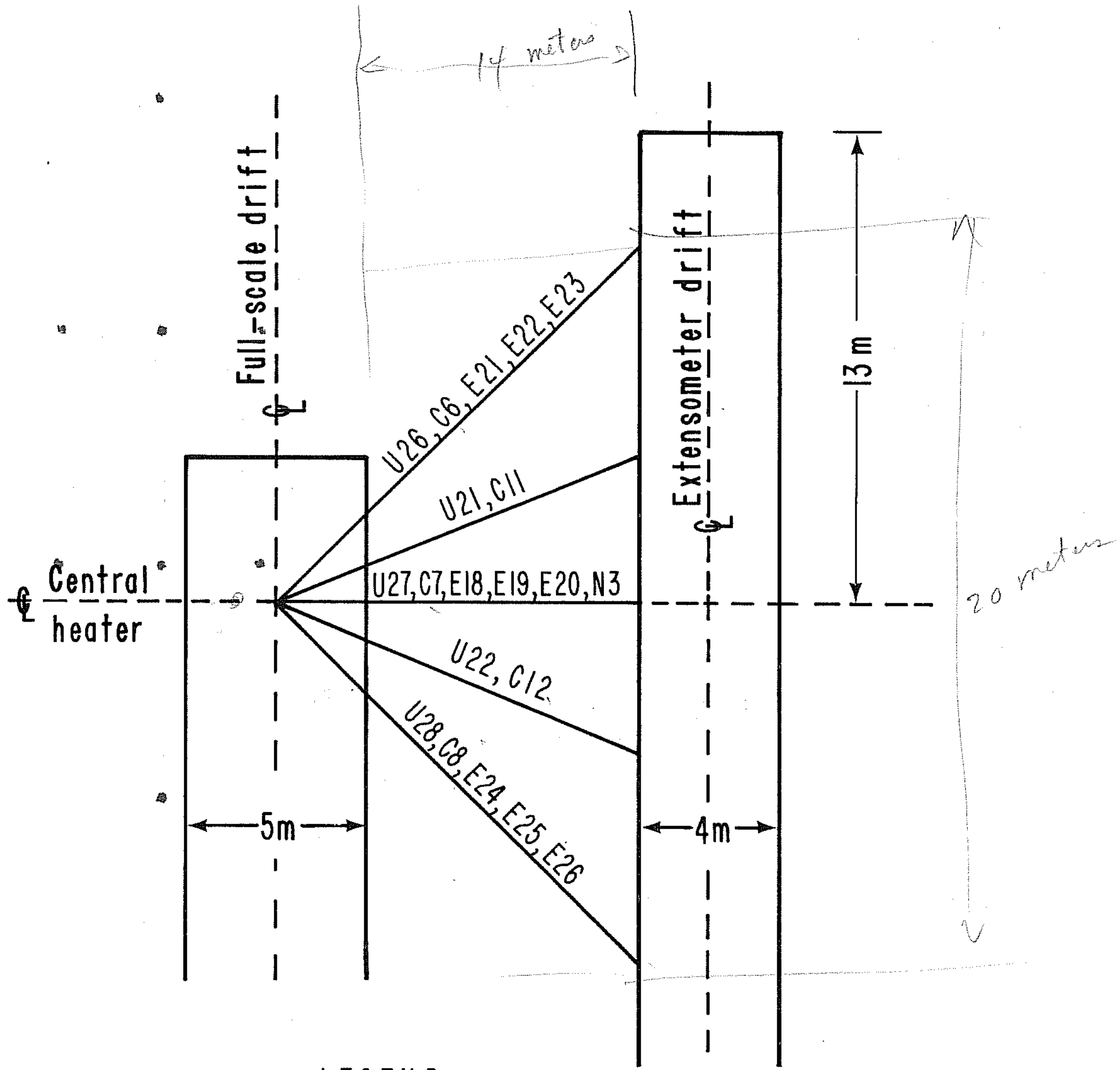
Borehole		X(m)		Y (m)		Z (m)		
		Theoretical	Real	Theoretical	Real	Theoretical	Real	
EXTENSOMETER DRIFT								
	T	314.639	314.638	1012.143	1012.141	341.903	341.903	
E18	B	322.548	322.493	1007.735	1007.775	340.997	340.986	
	D	+7.909	+7.855	-4.408	-4.366	-0.906	-0.917	
	T	314.759	314.759	1012.076	1012.074	343.393	343.393	
E19	B	322.548	322.526	1007.735	1007.757	342.947	342.937	
	D	+7.789	+7.767	-4.341	-4.317	-0.446	-0.456	
	T	314.950	314.950	1011.969	1011.969	345.140	345.142	
E20	B	324.732.	324.674	1006.518	1006.576	344.859	344.830	
	D	+9.782	+9.724	-5.451	-5.393	-0.281	-0.312	
	T	319.529	319.529	1020.940	1020.940	341.906	341.905	
E21	B	322.149	323.161	1008.210	1008.202	340.968	340.932	
	D	+3.620	+3.632	-12.730	-12.738	-0.938	-0.973	
	T	319.588	319.588	1020.730	1020.730	343.393	343.397	
E22	B	323.149	323.157	1008.210	1008.230	342.932	342.909	
	D	+3.561	+3.569	-12.520	-12.500	-0.461	-0.488	
	T	319.624	319.625	1020.604	1020.604	345.143	345.145	
E23	B	323.149	323.146	1008.210	1008.247	344.915	344.880	
	D	+3.525	+3.521	-12.394	-12.357	-0.198	-0.265	
	T	309.745	309.745	1003.359	1003.360	341.902	341.906	
E24	B	322.460	322.441	1006.975	1007.026	340.968	340.925	
	D	+12.715	+12.696	+3.616	+3.666	-0.934	-0.981	
	T	309.584	309.585	1003.313	1003.313	343.406	343.407	
E25	B	322.460	322.423	1006.975	1007.026	342.932	342.892	
	D	+12.876	+12.838	+3.662	+3.713	-0.474	-0.515	
	T	309.857	309.857	1003.391	1003.389	345.146	345.149	
E26	B	322.460	322.419	1006.975	1007.021	344.915	344.870	
	D	+12.603	+12.562	+3.584	+3.632	-0.231	-0.279	
	T	303.926	303.925	992.927	992.926	341.903	341.903	
E27	B	311.839	311.824	988.517	988.541	340.997	340.993	9.080 dip
	D	+7.913	+7.899	-4.410	-4.385	-0.906	-0.910	
	T	304.289	304.288	992.725	992.723	343.379	343.382	
E28	B	311.839	311.822	988.517	988.549	342.947	342.930	8.625 dip
	D	+7.550	+7.534	-4.208	-4.174	-0.432	-0.452	
	T	304.307	304.308	992.714	992.715	345.138	345,138	
E29	B	314.023	313.946	987.300	987.376	344.859	344.844	11.622 dip
	D	+9.716	+9.638	-5.414	-5.339	-0.279	-0.294	
	T	308.813	308.811	1001.746	1001.746	341.905	341.906	13.726 dip
E30	B	312.440	312.401	988.992	989.054	340.968	340.927	
	D	+3.627	+3.590	-12.754	-12.692	-0.937	-0.979	
	T	308.835	308.832	1001.669	1001.668	343.398	343.400	
E31	B	312.440	312.416	988.992	989.044	342.932	342.882	13.833 dip
	D	+3.605	+3.584	-12.677	-12.624	-0.466	-0.518	
	T	308.855	308.854	1001.598	1001.598	345.146	345.149	
E32	B	312.440	312.454	988.992	998.996	344.915	344.868	X
	D	+3.585	+3.600	-12.606	-12.602 988.996	-0.231	-0.281	13.109 dip

THEORETICAL AND REAL BOREHOLE COORDINATES

Borehole		X(m) Theoretical	X(m) Real	Y (m) Theoretical	Y (m) Real	Z (m) Theoretical	Z (m) Real
EXTENSOMETER DRIFT							
E33	T	298.917	298.916	984.107	984.111	341.911	341.913
	B	311.751	311.706	987.757	987.846	340.968	340.928
	D	+12.834	+12.790	+3.650	+3.735	-0.943	-0.985
E34	T	399.197	299.197	984.187	984.188	343.394	343.394
	B	311.751	311.691	987.757	987.809	342.932	342.891
	D	+12.554	+12.494	+3.570	+3.621	-0.462	-0.503
E35	T	299.520	299.519	984.279	984.281	345.139	345.138
	B	311.751	311.711	987.757	987.820	344.915	344.867
	D	+12.231	+12.192	+3.478	+3.539	-0.224	-0.271
VENTILATION DRIFT							
R1	T	384.122	384.122	974.863	974.863	333.137	333.134
	B	384.331	384.345	948.947	948.946	302.465	302.438
	D	+0.209	+0.223	-25.916	-25.917	-30.672	-30.696
R2	T	384.091	384.098	978.538	978.538	333.148	333.148
	B	383.938	383.881	997.396	997.396	310.672	310.654
	D	-0.153	-0.217	+18.858	+18.858	-22.476	-22.494
R3	T	384.089	384.087	978.981	987.981	336.378	336.378
	B	383.860	383.809	1007.216	1007.215	346.654	346.620
	D	-0.229	-0.278	+28.235	+28.234	-10.276	-10.242
R4	T	384.107	384.097	976.577	976.577	336.496	336.496
	B	384.107	384.072	976.577	976.654	366.496	366.605
	D	———	-0.025	———	+0.077	+30.000	+30.109
R5	T	384.125	384.125	974.363	974.363	336.362	336.368
	B	384.354	384.353	946.110	946.110	346.646	346.666
	D	+0.229	+0.228	-28.253	-28.253	+10.284	+10.298
R6	T	364.122	364.116	974.583	948.893	333.091	333.089
	B	364.330	364.479	974.583	948.895	302.474	302.447
	D	+0.208	+0.363	0.000	+0.002	-30.617	-30.642
R7	T	364.093	364.099	978.192	978.192	333.155	333.135
	B	363.938	363.933	997.282	997.282	310.403	310.267
	D	-0.155	-0.166	+19.090	-19.090	-22.752	-22.868
R8	T	364.088	364.089	978.732	978.732	336.404	336.405
	B	363.859	363.780	1007.007	1007.006	346.696	346.553
	D	-0.229	-0.309	+28.275	+28.274	+10.292	+10.148
R9	T	364.107	364.106	976.415	976.421	336.688	336.688
	B	364.107	364.078	976.415	976.379	366.688	366.722
	D	———	-0.028	———	-0.042	+30.000	+30.034
R10	T	364.125	364.119	974.257	974.256	336.407	336.402
	B	364.354	364.423	946.005	946.006	346.690	346.614
	D	+0.229	+0.304	-28.252	-28.251	+10.283	+10.212
S1	T	330.885	330.885	974.287	974.287	336.967	336.970
	B	346.808	347.060	945.481	945.578	359.985	359.839
	D	+15.923	+16.175	-28.806	-28.709	+23.018	+22.869
S2	T	332.796	332.799	974.966	974.968	337.197	337.196
	B	348.689	348.699	946.212	946.217	360.174	359.977
	D	+15.893	+15.900	-28.754	-28.751	+22.977	+22.781

EXTENSOMETER DRIFT-H9 AREA

Vol 14 x 20 x 7dp x 2 pls = 3900 m³

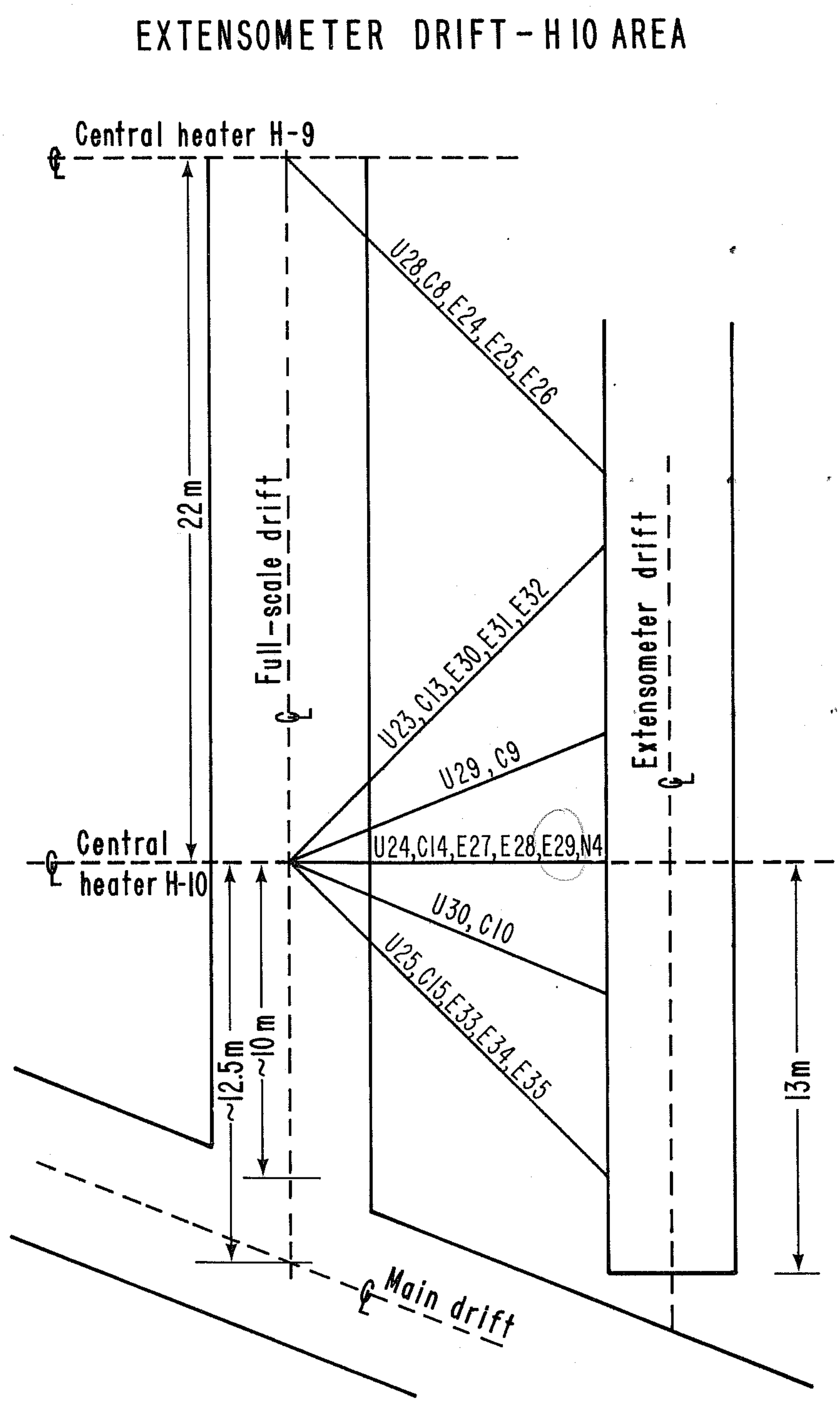


LEGEND

(E) Extensometers ϕ76mm/116mm
(U) USBM gauges ϕ38 mm
(C) IRAD gauges ϕ38 mm
(N) Geophysics ϕ46 mm

XBL 787—1985

Fig. 8. Borehole layout in the extensometer drift - heater H 9 area.



XBL 787-1984

Fig. 9. Borehole layout in the extensometer drift - heater H 10 area.

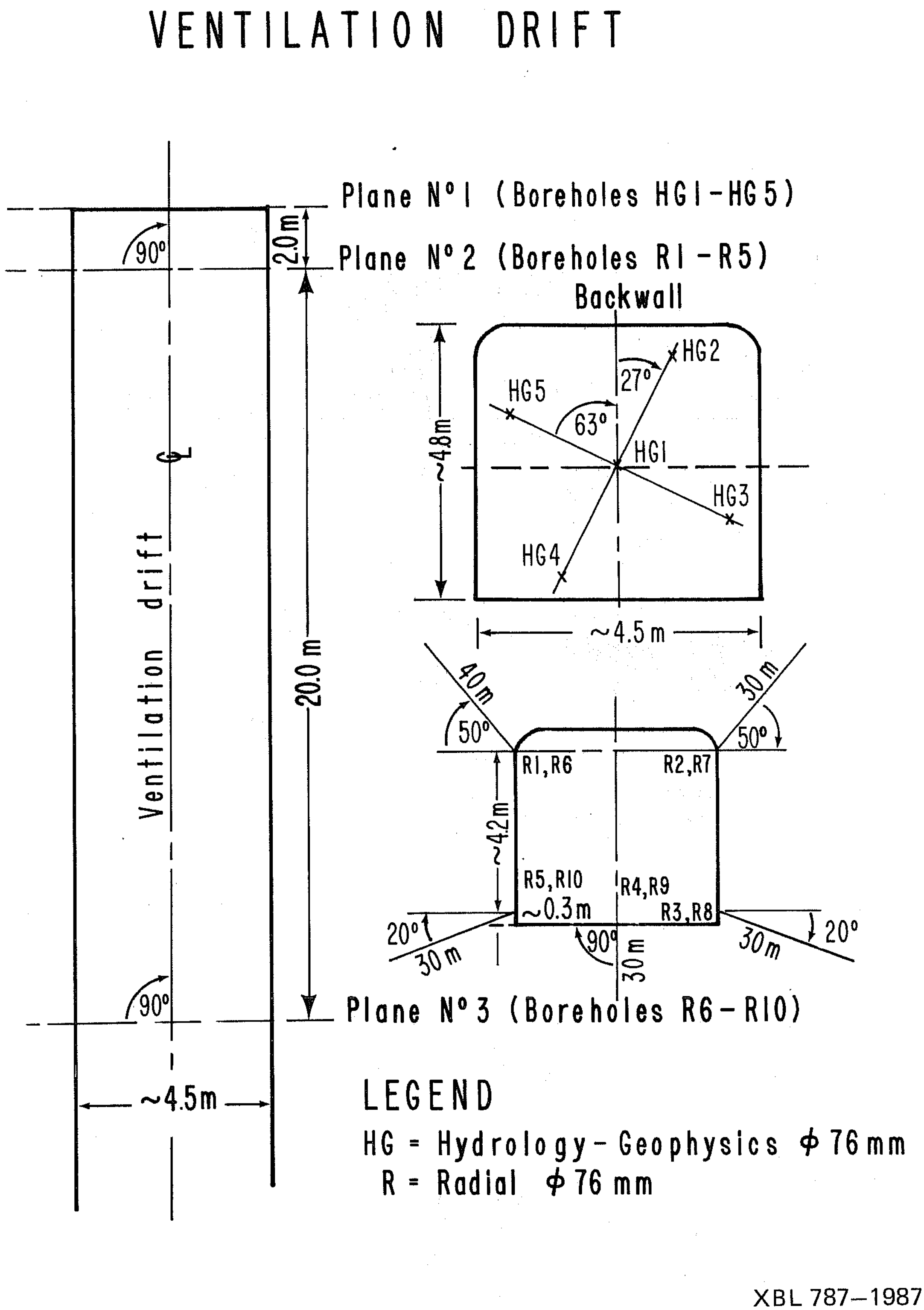
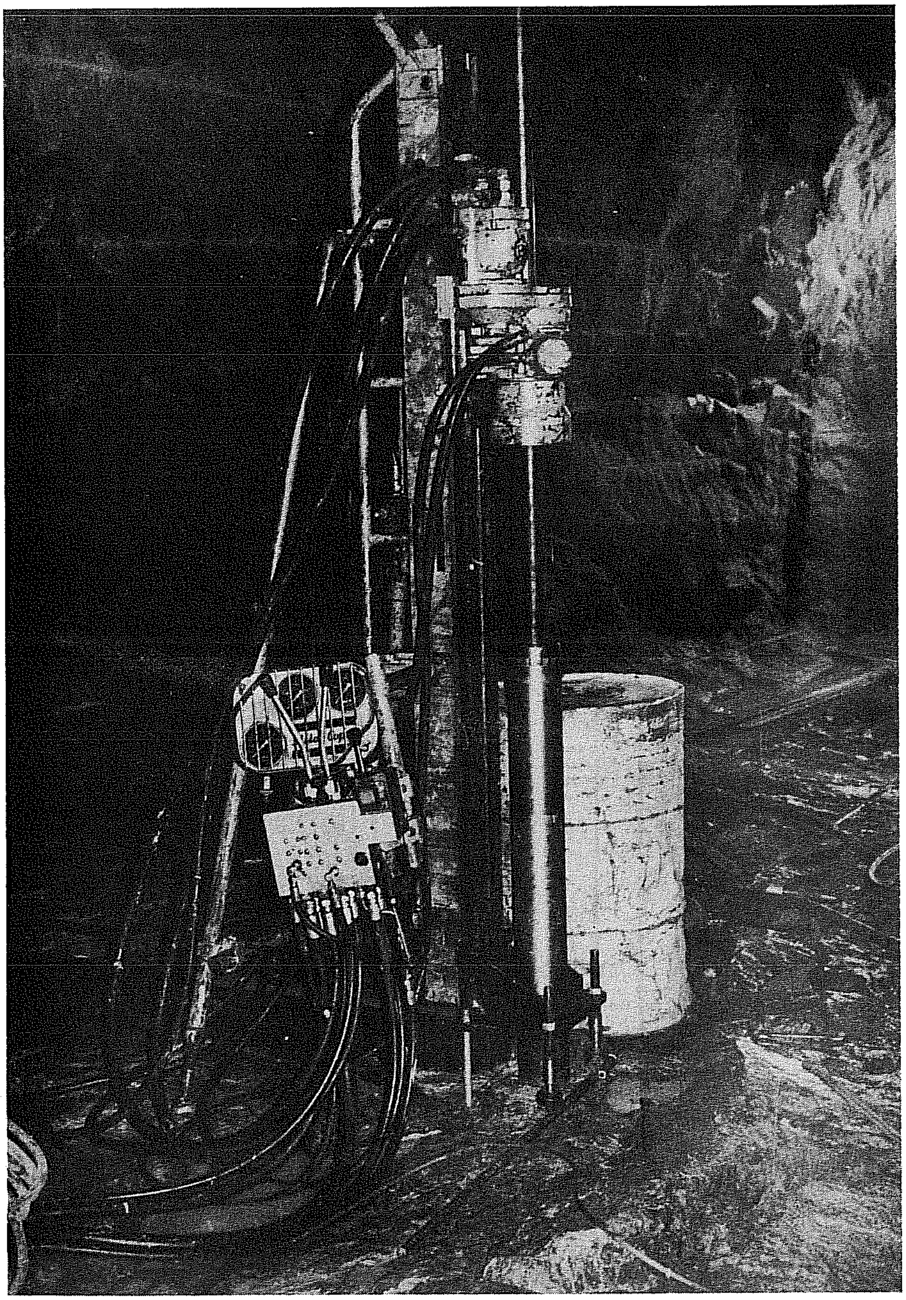


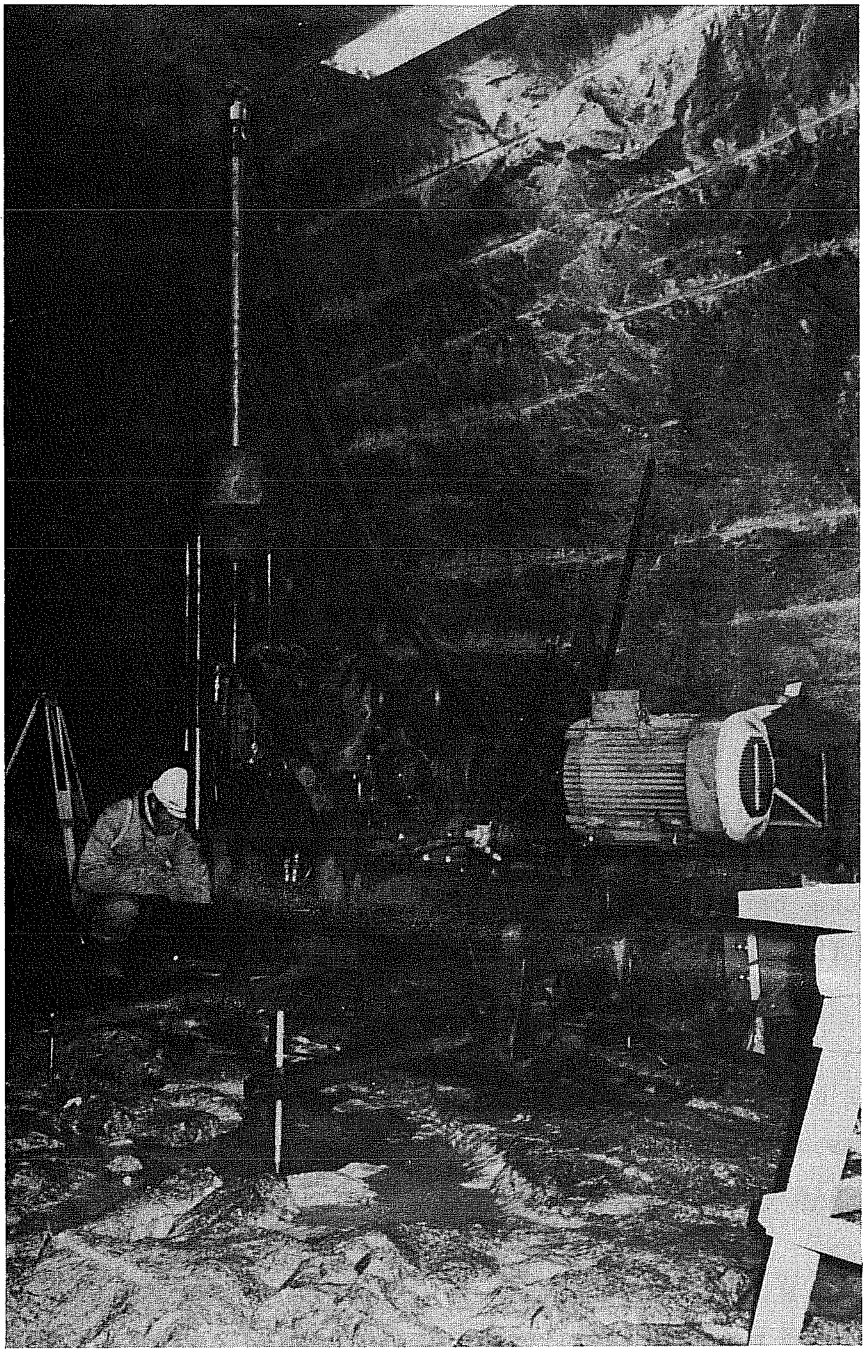
Fig. 10. Borehole layout in the ventilation drift.

The Diamec 250 (Fig. 11) is an Atlas Copco drill machine developed mainly for core drilling Ø 38 mm and Ø 46 mm boreholes to depths of approximately 250 m. At Stripa, this machine was used to



XBB 788-9282

Fig. 11. General view of Diamec 250 drill.



XBB 788-9287

Fig. 12. General view of XF 60/90 H drill.

drill ∅ 38 mm, ∅ 46 mm, ∅ 56 mm, and ∅ 127 mm boreholes. The drill consists of three main parts: feeding frame with a rotation unit and a drill rod holder, control panel with a detached power unit (25 Hp electric motor), and a hydraulic tank with a pump unit. The rotation unit and the drill rod holder are used to handle the drill rods.

The XF 60/90 H drill (Fig. 12) is an Atlas Copco conventional mechanical drill which was used to core Ø 127 mm and Ø 406 mm boreholes. The skid-mounted drill frame and the guiding rods have an electric motor with an LB-coupling attached. The drill has a 3-speed gear box, with power transmitted from the LB-couplings to the drill head; it is equipped with a hydraulic chuck for handling the drill rods.

Ø 38 mm boreholes. A total of seventy-six Ø 38 mm instrumentation and heater boreholes was drilled with the Diamec 250 drill in the full-scale, time-scaled, and extensometer drifts to depths ranging from 6 m to 14 m. The boreholes drilled were either vertical (in the full-scale and time-scaled drifts) or horizontal (in the extensometer drift). To drill the horizontal boreholes, the drill was bolted to the rock wall and the drillers operated from the scaffolding. The standard T 36 core barrels, type 1500/2 mm with core bits (38 mm O.D.) and reamers (38.2 mm O.D.), were used.

Ø 46 mm boreholes. Four Ø 46 mm boreholes for the geophysical survey were drilled in the time-scaled and extensometer drifts to depths of 11 m to 13 m, with the Diamec 250 drill using the standard T 46 double tube core barrel.

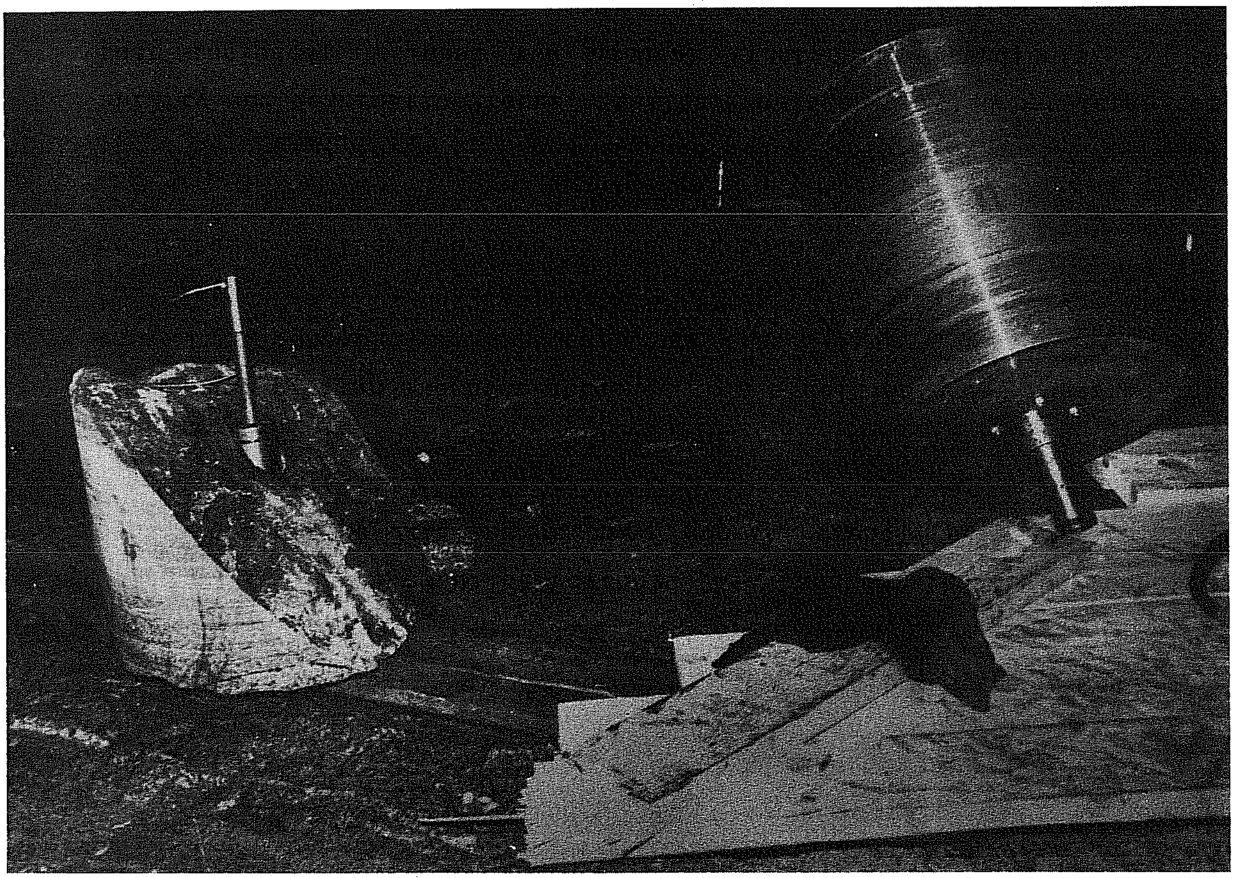
Ø 56 mm boreholes. Two Ø 56 mm boreholes were drilled to a depth of 5.5 m in the full-scale drift with the Diamec 250 and XF 60/90 drills. The boreholes were used as pilot holes for the Ø 406 mm main heater boreholes. Standard T 56 core bits, core barrels, and reamers were used. Six additional Ø 56 mm boreholes ranging from 10 m to 14 m in depth were drilled in the full-scale and time-scaled drifts for the geophysical survey, using the same drilling equipment.

<u>ϕ 76 mm boreholes</u>. A total of fifty-five ϕ 76 mm instrumentation and hydrological boreholes was drilled in the full-scale, time-scaled, extensometer, and ventilation drifts. The boreholes were drilled vertically, horizontally, and at various angles from the horizontal plane to depths of 5 m to 40 m, with a Toram 2x20 drill. To accomodate installation of the instruments, 35 of these boreholes were reamed to a ϕ 116 mm to a depth of 1 m below surface. The triple tube core barrel and the standard T 76 double core barrel, both with split inner tubes, were used--the former produced core of higher quality.

To drill the horizontal or inclined boreholes, the drill was bolted to the rock wall and the drillers operated from the scaffolding.

<u>ϕ 127 mm boreholes</u>. Eight ϕ 127 mm heater boreholes were drilled in the time-scaled drift with the Diamec 250 and XF 60/90 drills to depths of 11 m. Only one heater borehole was drilled with the Diamec using the thin wall core barrel. Core was of poor quality and difficult to recover due to frequent breakage of the core catcher. Even after using the XF 60/90 drill and the single tube core barrel with a B-type core bit (127 mm O.D., 116 mm I.D.) to drill the remaining heater boreholes, drilling proceeded at a slow rate. Drilling boreholes of this diameter would be improved by using the high torque version of the Toram drill with the standard B-type drill bits, core barrels, and the heavy drill rods.

<u>ϕ 406 mm boreholes</u>. Two ϕ 406 mm heater boreholes were drilled in the full-scale drift to a depth of 5.5 m. In the first, there were problems with the XF 60/90 drill, and with core recovery, mainly due to changes in the borehole dimensions. For the second, a high torque Toram drill was used, along with a specially built core barrel (Fig. 13), with 408 mm O.D., 399 mm I.D. and several supports and steerings. No further problems were encountered; the second borehole was successfully completed in three 8-hour shifts.

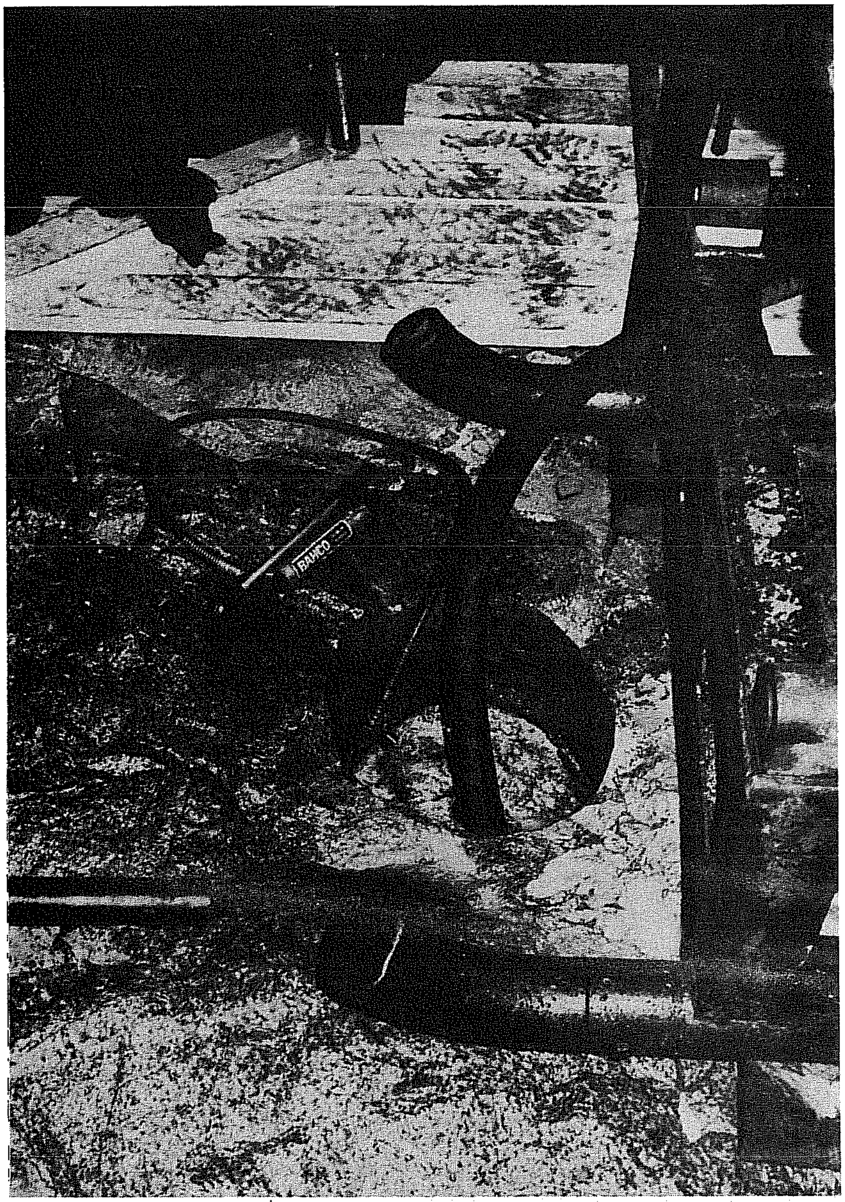


XBB 788-9283

Fig. 13. Detailed view of the ϕ 406 mm core barrel and the expander.

The ϕ 56 mm pilot boreholes had been drilled to the required depths before the drilling of the ϕ 406 mm borehole started. To break the ϕ 406 core at 50 - 75 cm, a hydraulic wedge was inserted in the space between the borehole wall and the core (Fig. 14). After the core was broken off, an expander attached to a steel cable was inserted into the pilot borehole and the core was lifted with a winch (Fig. 15). This method of core recovery proved to be very efficient and fast, with no damage to either the core or the borehole wall.

<u>Large core</u>. For the laboratory triaxial fracture permeability and deformation tests, Ställbergsbolagen drilled one large core that included at least two natural fractures perpendicular to the

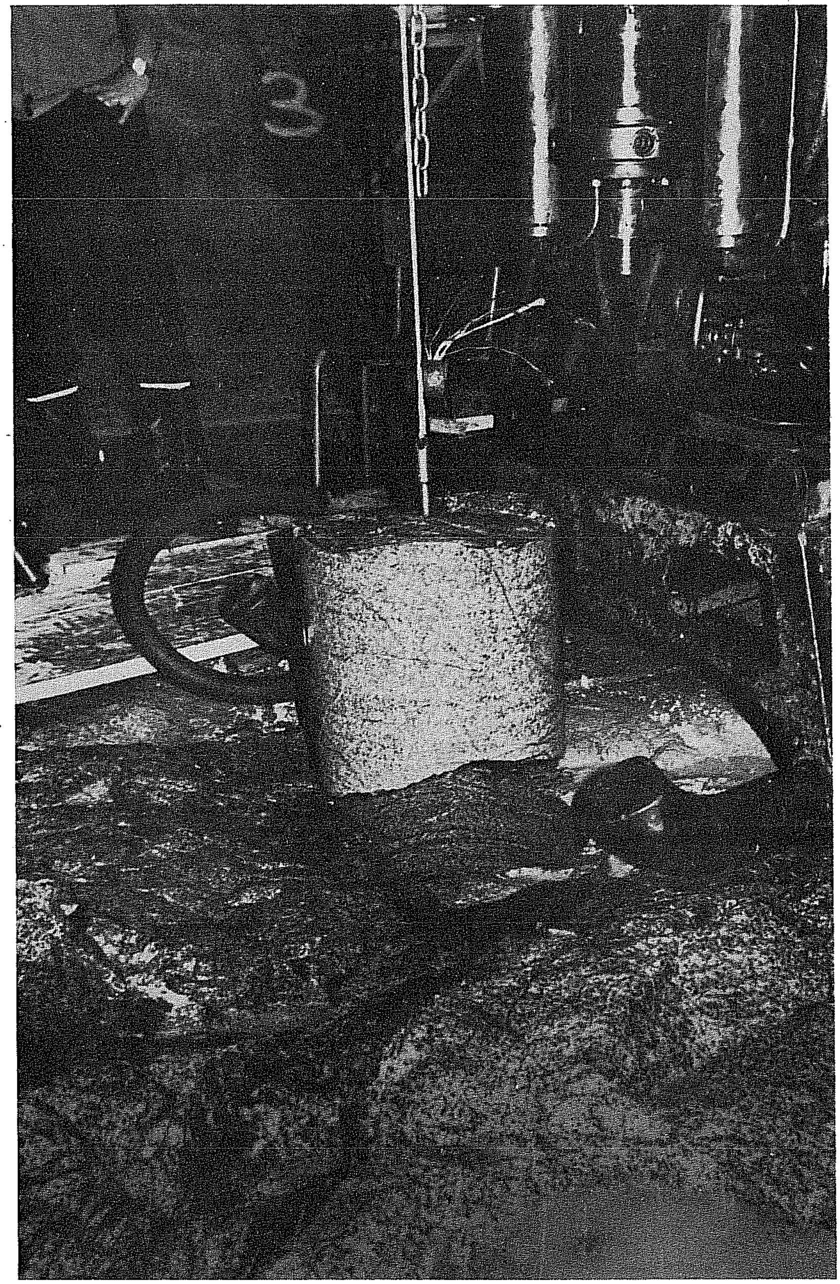


XBB 779-9509

Fig. 14. Detailed view of the hydraulic wedge.

longitudinal axis. This core, drilled at the 360 m level in the Hagconsult drift, was 100 cm in diameter and 180 cm long, and weighed approximately 3500 kg.

A pilot center borehole of Ø 64 mm was percussion drilled to the depth of 25 cm. The borehole was extended to a 160 cm depth using



XBB 779-9505

Fig. 15. Ø 406 mm core being winched out, using the expander.

a Ø 35 mm drill bit. An anchor bolt was then inserted and pretensioned to 100 kg.

An Atlas Copco F-120 percussion drill was used to drill both the center pilot borehole and the peripheral holes. For the core, the slot drilling technique developed by Ställbergsbolagen was used. After the anchor bolt was in place, a 15 cm-long center pin of the drill rig was placed into the pilot borehole. Using a Ø 51 mm drill rod, 52 peripheral holes were drilled along the perimeter of the core. The first peripheral hole was drilled conventionally; the others were drilled using a specially built guide attached to the drill rod and inserted into the previously drilled hole. After the last peripheral hole was completed, the core broke along the predetermined fracture plane, and was lifted out of the borehole with a winch.

A 2-man drilling crew completed drilling operation, including the drill set-up, in four 8-hour shifts.

2.3 Drilling Costs and Rates

Costs of drilling varied widely, depending on diameter, location, and depth of the boreholes; types of drills and core barrels used; and driller's time. The breakdown of costs and the average costs per meter are summarized in Table I.

Drilling rates varied considerably from 1.6 m/8 hr. shift for the Ø 127 boreholes to 10.7 m/8 hr. shift for the Ø 46 mm boreholes. The rate of drilling depended on size of the borehole, type of core barrel used (single, double, or triple tube), location of the drill (mounted on the floor or on the walls), orientation of the borehole (vertical, horizontal, or inclined), and other associated factors.

The average rates of drilling for various borehole sizes for both surface and subsurface drilling are given in Table II. In addition to actual drilling time, these rates include time required for positioning, depositioning, and moving the drills; repairs; surveying; and Fotobor survey.

Table I. Costs Of Core Drilling Per Meter (Sw. kr./m)

Borehole ∅ (in mm)	Drill rental	Tools	Labor	Core boxes	Surveying: VIAK	Surveying: Fotobor	Admin. costs (20%)	Subcontractors (5%)	TOTAL
127	336:-	290:-	730:-	45:-	200:-		1569:-	210:-	1779:-
76*	145:-	190:-	313:-	20:-	200:-		748:-	210:-	958:-
76**	60:-	205:-	122:-	20:-	200:-		456:-	210:-	666:-
76***	160:-	245:-	238:-	20:-	200:-	100:-	743:-	315:-	1058:-
38	65:-	105:-	219:-	5:-	200:-	-	441:-	210:-	651:-

Note: Due to the small number of boreholes drilled, no average cost is available for 0.46 mm, 56 mm, 406 mm boreholes.

* short
** medium
*** long

2.4 Borehole Core Logging

Two borehole core logs were kept: one contained relevant drilling information, the other characterized the geological discontinuities in the core sample. In general, the recommendations set forth by the Geological Society of London (1970), with some modifications to suit our program, were followed.

The logger communicated with each shift of the drill crew to record certain information during the drilling. Information included drill site, borehole numbers, date, names of the drill crew and logger, and, of primary importance, drilling times and penetration rates. Drill and water pressures were recorded at thirty minute intervals, or as often as necessary to describe unusual drilling conditions. Information on diamond bits was also noted to help in this regard as well as in cost projection. Water depth measurements in the surface boreholes were made at the beginning and end of each shift. Water depths were not recorded in the subsurface boreholes since most

Table II. Average Rates of Drilling

Surface Drilling:

Borehole ∅ (mm)	Depth (m)	Time (hours)	Meters/8 hr. shift
76	0-100	212	7.55
	100-200	257	6.22
	200-300	375	4.27
	>300	280	5.71
	TOTAL:	1124	AVERAGE: 5.30

Subsurface Drilling:

Borehole ∅ (mm)	TOTAL LENGTH (m)	Time (hours)	Meters/8 hr. shift
38	693	672	8.25
46	48	36	10.66
56	74	100	5.92
76	1011	1012	8.00
127	88	440	1.61
406	5.5	27	1.63

of them were either under drilling water or flowing. All activities at the site that could affect the condition of the borehole or rock core were recorded: drilling technique, contamination of drill water by oil or fuel, incomplete core recovery, equipment breakdowns.

The form used for recording all rock core samples was basically a log of geological discontinuities, although distinctive changes in rock type, color, or grain size were also noted along with their exact locations. Discontinuities or fractures were described as naturally occuring or induced by drilling or handling. When this distinction was difficult, uncertainty was noted in the log. Natural fractures were described as open or closed in-situ, and planar, curved, or irregular in terms of surface qualities. Toughness of the surface was estimated in millimeters. Weathering referred to the condition of the joint coatings, described as non-weathered, slightly weathered, moderately weathered, or highly weathered. Any mineralization on the fracture surface was identified and described, and signs of shear movement noted.

The orientation of each fracture was of particular interest. Following the method described by Goodman (1976), and Lau and Gale (1976), the angular relationship of the fracture to the core axis (apparent dip direction "α") was determined to within 5 degrees. For core that was marked with a reference line, the direction of the apparent dip "β" was found to the nearest 5 degrees. All of the core from the ∅ 76 mm surface boreholes was so oriented, using a wireline indentor which marked the lowest point on the new core uptake. The vertical subsurface core samples were oriented in a similar manner, using an eccentric cylindrical guide apparatus to position the indenting rod with respect to a surveyed line at the top of each borehole. Due to the large number of fractures induced by drilling and the amount of time involved, it was impractical to reconstruct the small diameter core. Only ∅ 56 mm and larger core were oriented.

The following data indicated degree of fracturing for a given core uptake:

- Core sample length, as measured; and drilled interval, as measured by bit penetration

- Number of core sections, defined as core pieces with a complete circular cross section

- Percent sample recovery, defined as percent ratio of length of total sample to length of drilled interval

- Percent core recovery, defined as percent ratio of total length of complete core sections to length of the drilled interval

- Mean core length, defined as total length of complete core sections divided by the number of core sections

Exact borehole depths were determined for each core uptake in the subsurface drilling. This permitted an accurate measurement of fracture locations on the core relative to the top of the borehole, since the bottom of a core interval rarely coincided with its drilled depth. While it was impractical to measure exact borehole depths with each core uptake for the surface drilling, subsequent borehole TV logging provided a more accurate correlation of core sample with true depth.

For the surface boreholes, Polaroid photographs of the core were taken immediately upon recovery, before core was logged or removed from the split inner barrel. Metric scales were included in the pictures, and drill intervals were clearly labelled at each end of the sample. Four frames were usually necessary to cover an entire 2.5 to 3.0 m uptake. These photographs were later spliced together and filed in the data repository. Photographs of dry core samples produced a clearer view of the fractures. After the Polaroid photography, the core sample was transferred to a plastic split tube and set into its core box, thereby minimizing handling disturbance prior to marking the reference line. After a complete core box (about 5 to 6 m of core) was logged, 35 mm black and white prints were taken of the rock in a dry condition. The reference lines, scale, and fracture labellings were always visible in the photographs. Again, the photographs of each box were spliced together and filed in the data repository.

For subsurface drilling, Polaroid photographs of the core were taken after an entire box had been logged, instead of immediately after an uptake. After the boxes were transported to the surface, 35 mm black and white photographs were taken in the manner described above. All photographs were catalogued and placed in the data files.

Core boxes were permanently stored in a separate building equipped with storage racks. Boxes were stacked individually, in a clear pattern which was posted on a location chart in the building. To check out core samples, permission was obtained from KBS and the LBL site manager, and the checkout form filled out. A wooden dowel, cut to the same length as the removed section, was labelled as on the checkout form and placed in the vacant interval of the box.

3. SURVEYING

3.1 Surface Surveying

Surveying on the surface included positioning the drills and detailed measurements of two inclined boreholes, SBH 1 and SBH 2 (385 m and 360 m deep, respectively). Drill position was based on a traverse network set up by VIAK AB in June 1977; this network was calculated both in plane and elevation using the mine survey system. Exact positions were measured directly on the drill rods using the theodolite, Kern DKM 2 AE; an electrooptical distance measuring instrument, Kern DM 500; and a calibrated measuring tape. The location, direction, and inclination of the boreholes were stipulated by the mine engineer, P-A. Halen.

Hagby Bruk AB subcontracted an independent consultant, M. Haglund, to supervise measurement of the actual position, dip, and deviation of each borehole during drilling with the Reflex-Fotobor dip and direction instrument. He was also responsible for all calculations and evaluations.

The Reflex-Fotobor probe consists of the power pack, camera, optics, and four 3-m rod sections. Each section includes a reflector ring placed 3, 6, 9 and 12 m from the camera. The whole assembly is attached to conventional drill rods and lowered into the borehole. After the camera is switched on, it functions automatically, taking one frame every 1 or 2 minutes. The reflector rings are illuminated during the camera exposure time by small lamps placed in front of the lens. As the probe bends due to changes in the dip and direction

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720