MINING METHODS USED IN THE UNDERGROUND TUNNELS AND TEST ROOMS AT STRIPA

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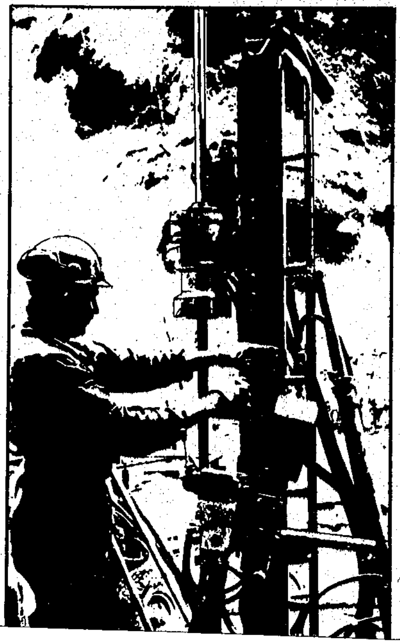

Technical Project Report No. 8

MINING METHODS USED IN THE UNDERGROUND TUNNELS AND TEST ROOMS AT STRIPA

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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 Håken 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)
5. *Borehole Drilling and Related Activities at the Stripa Mine* by P.J. Kurfurst, T. Hugo-Persson and G. Rudolph. (LBL-7080, SAC-05)
6. *A Pilot Heater Test in the Stripa Granite* by Hans Carlsson. (LBL-7086, SAC-06)
7. *An Analysis of Measured Values for the State of Stress in the Earth's Crust* by Dennis B. Jamison and Neville G.W. Cook. (LBL-7071, SAC-07)

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1. SHORT DESCRIPTION OF THE STRIPA MINE

The Stripa mine is situated in the middle of Sweden near the city of Örebro. Although it is not known exactly when mining started there, records indicate production before 1485. Maximum annual production was 450,000 tons per year, which gave some 250,000 tons of lumpy ore and fine concentrate. In total, 16 million tons of ore have been mined from Stripa. In the beginning of 1977 the ore was mined out.

The deposits consist of two different ore bodies, both very disrupted by faults and folds. The ore-bearing formation is a leptite, usually homogeneous but markedly banded in the footwall and close to the ore. The ore was a quartz-banded hematite, with around 50% iron and a low sulphur and phosphorus content. Both ore and leptite are intersected by a number of granite veins; in the deeper part of the mine is located a large granite mass.

2. THE TEST SITE

Using the Stripa mine as a test station, KBS, in a brief time, investigated many of the important problems pertaining to the terminal storage of radioactive waste in underground caverns, and developed basic information on how waste should be finally stored in crystalline rock (Witherspoon and Degerman, 1978).

The area chosen for investigation was located away from the excavated part of the mine, towards the center of the massive granite body. The starting point and direction were based on the surface outcrops, geological maps, and cross sections of the mine. In the Stripa mine, tunnelling in granite could start at the right depth, without expensive preparation.

The original plan was to drive an upper and a lower tunnel in the same vertical plane, with the bottom tunnel at the 360 m level, and to drill large repository holes between these two tunnels. The plan was later modified so experimental stations could conduct tests without disturbing excavation. The final configuration is shown in Fig. 1.

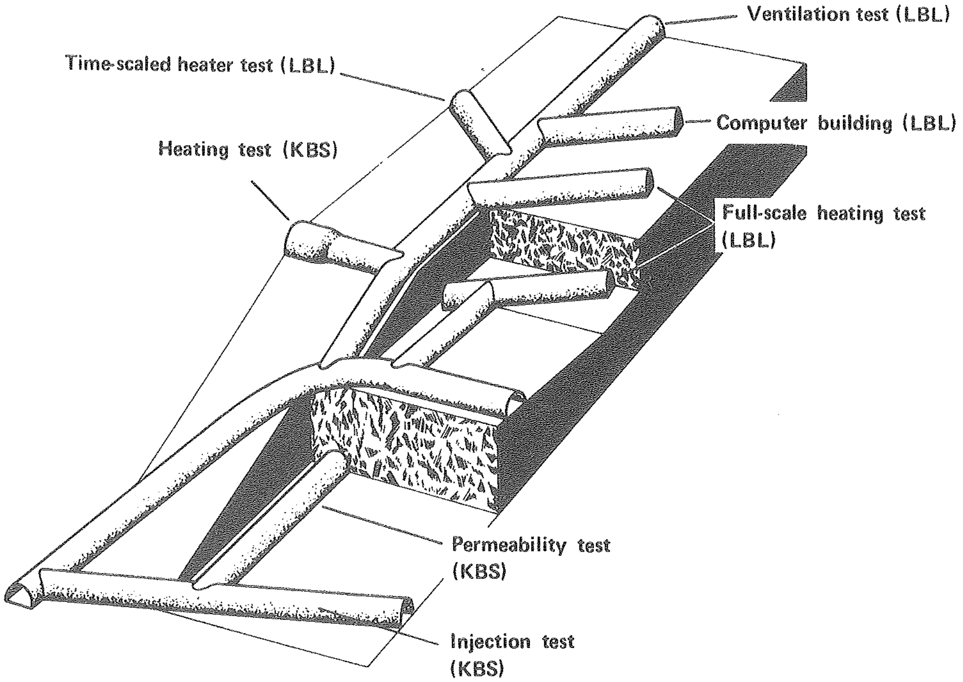

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Fig. 1: Perspective drawing of the experimental site in the granite at the Stripa mine.

After some preparatory work, tunnelling began in January 1977. First the bottom tunnel (ϕ 3 m)[1] was started, followed a few weeks later by the upper, main tunnel (ϕ 5 m) in the upper part of the old slant drift, 15 m above the bottom tunnel. These were usually two work shifts, with a crew in each tunnel. Total length of both tunnels is 400 m, and about 10,000 m^3 of solid rock were excavated.

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[1] ϕ = diameter

During the excavation, the United States Department of Energy, represented by the Lawrence Berkeley Laboratory (LBL) expressed interest in joining the project. In June 1977 the feasibility study between the Swedish Nuclear Fuel Supply Company, SKBF, and Lawrence Berkeley Laboratory, LBL, was drawn up. An agreement between ERDA and SKBF was signed July 1. Reponsible for the Swedish part of the work is the project organization "Kärnbränslesäkerhet", KBS, a division of SKBF.

The drilling program for the instrumentation and testing portion of the LBL project proceeded simultaneously with the final stages of excavation (Kurfurst et al. 1978).

The dimensions and location of the test rooms (Fig. 1) were arranged so that site excavation would meet both SKBF/KBS and LBL requirements. Figures 2 and 3 are photographs from the main tunnel.

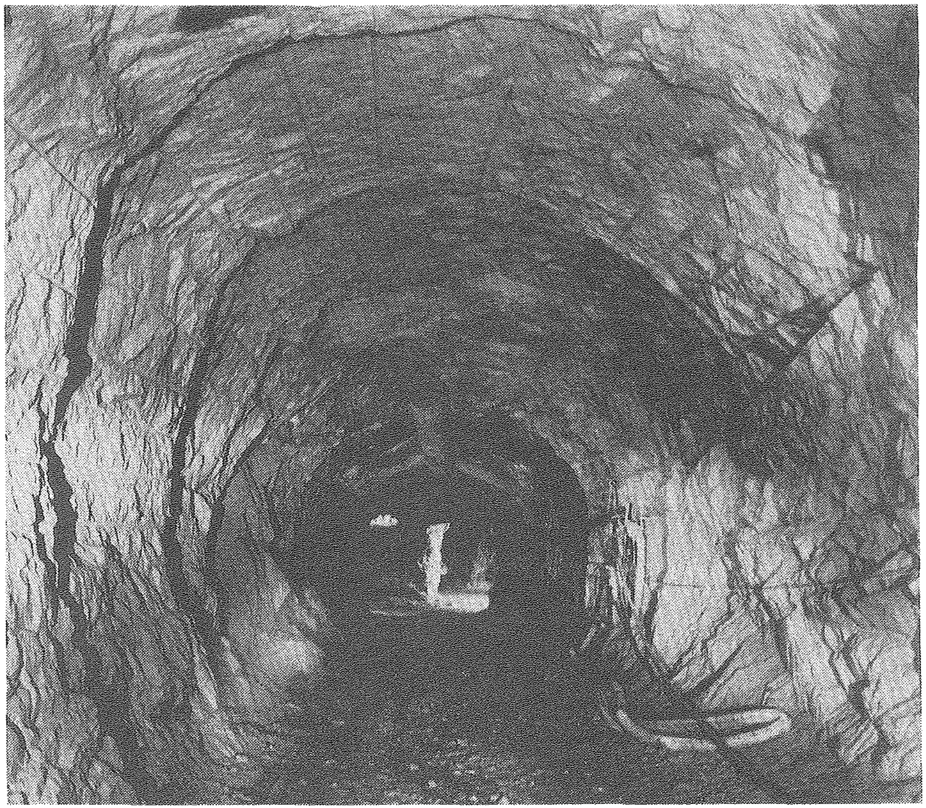

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Fig. 2: The main tunnel viewed from the upper end of the ramp.

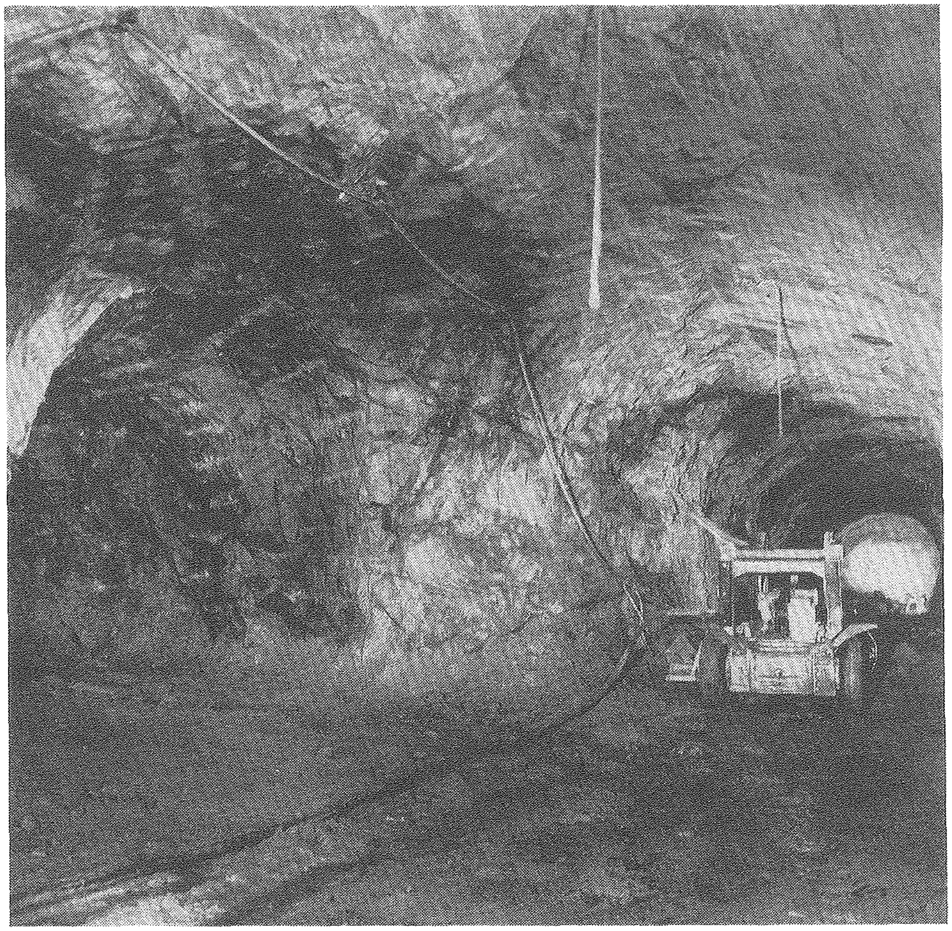

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Fig. 3: The main tunnel viewed from the lower end of the ramp. The KBS heater test room is at the left.

3. PRELIMINARY SITE EXPLORATION

Intermittently during excavation, SGU (Swedish Geological Survey) mapped the fractures in the drifts. Every second or third round, the Swedish company Ställbergsbolagen helped SGU map the end wall, which clearly showed locations and directions of the large continuous, and the small discontinuous fractures. In addition, SGU carried out water injection and hydrostatic pressure tests before and after the excavation of the ventilation drift (Olkiewicz, et al. 1978).

The ϕ 76 mm borehole Dbh-2, drilled horizontally 1.5 m from the side of the planned ventilation drift, was started in the area of the computer room before excavation of the ventilation drift. The 100 m long borehole, which exceeded the length of the ventilation drift by 50 m, proved the extent of the massive homogeneous granite.

4. DESIGN OF THE OPENING AND THE DRILLING AND CHARGING PATTERN

The shape of an opening, the quality of the drilling, and the fundamentals of smooth blasting determine the strength and stability of an underground cavern. A stable cavern cannot be produced with a large random scatter in hole position and direction. This is, of course, most important for the contour holes and the round next to these holes. Hole deviations and positioning errors which increase the overburden can make the charge produce more damage to the remaining rock than it would have done otherwise. Figure 4 illustrates the crack distributions produced by various drilling patterns.

In smooth blasting the charge density in the contour holes is very low compared with that in ordinary blast holes. Minor cracks run from hole to hole, but the damage to the remaining rock is limited to a narrow zone. The diameter of the main tunnel and the drilling and charging pattern are shown in Fig. 5.

The symmetric hole pattern used in the round has two major benefits: (1) it is simple; and (2) it assures an even distribution of the charge. Providing the charge has been properly selected, damage to the roof and walls is uniform and minimal.

The two large holes are drilled slightly longer than the round holes. This extra length is not loaded, hence these ends remain to guide the large holes for the following round. A special technique involving a paint brush

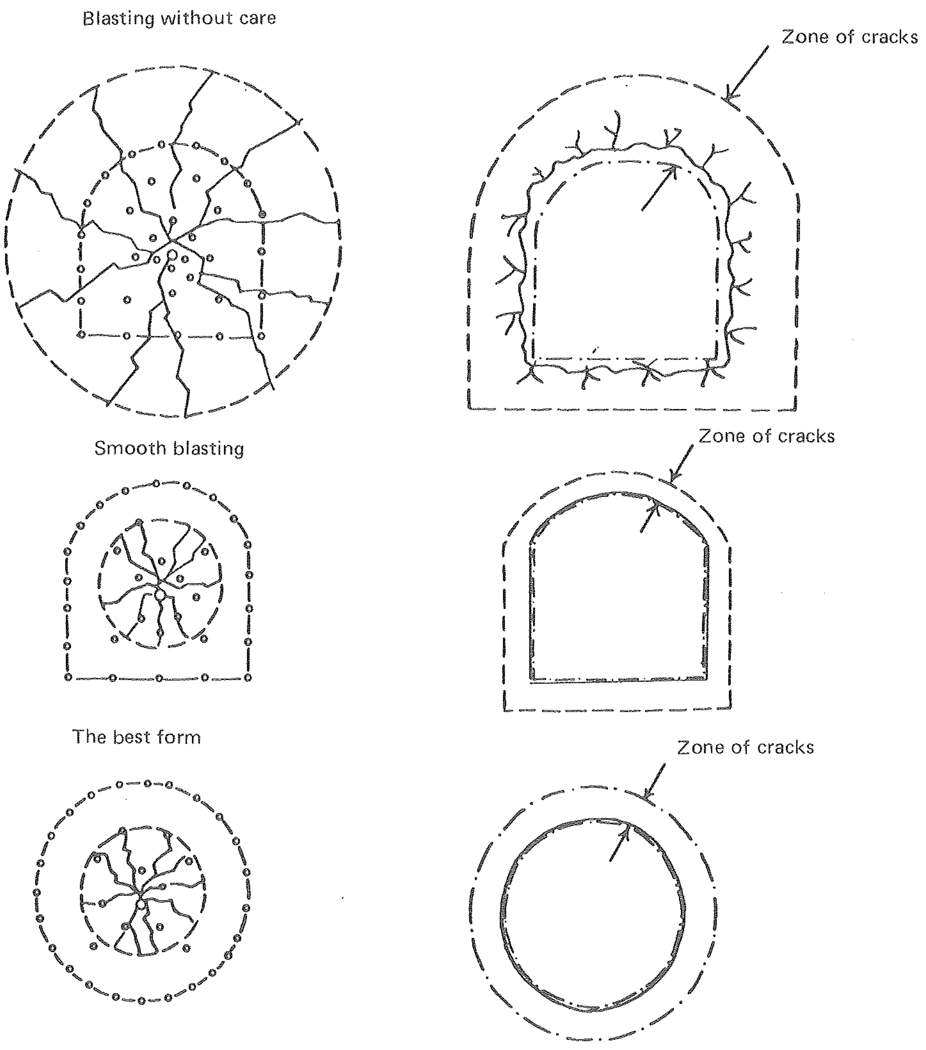

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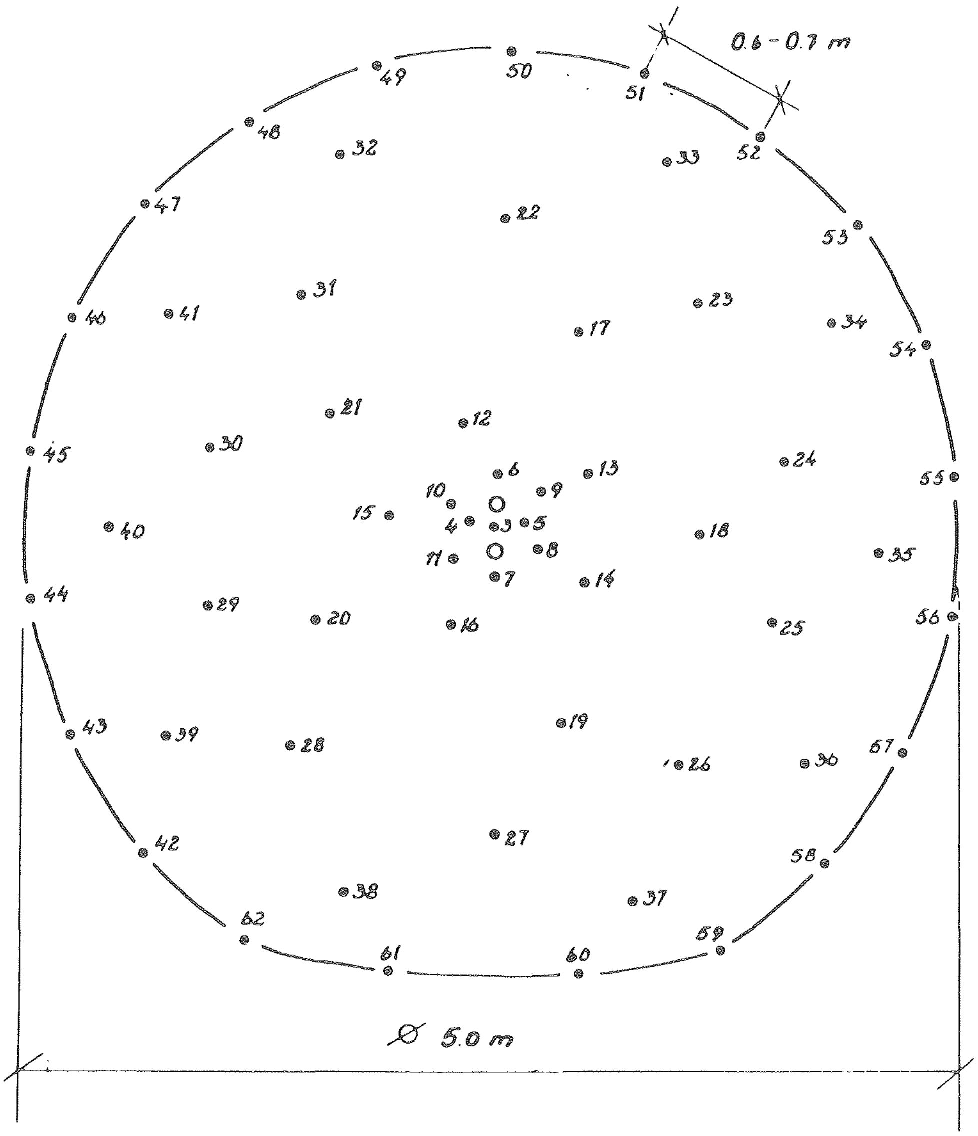
Fig. 4: Schematic drawing of the various hole geometries and densities and the nature of the consequent cracking patterns.

attached to the end of a piece of lath is used to mark the remaining holes on the drift centerline, the lath can simply be held at the appropriate length, and the brush rotated around the centerline at the correct angle. The hole position is marked by touching the brush to the rock face. The process is then repeated for other holes in the ring and at other radii. With a little practice, the whole round can be marked very quickly.

DRILLING and CHARGING PATTERN



Hole nr	Charge	kg/m
3 – 31	ANFO	0,8
32 – 41	–"–	0,8 detonating cord
42 – 62	Gurit	0,3

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Fig. 5: The drilling and charging pattern adopted for the tunnelling at Stripa.

Hole #	Fracture Length (cm)			Distance from Primer
1	20	Fresh opening		220
9	20	Fresh opening		30
3	1	Fresh opening		0
5	15	Fresh opening	24 cm from transverse fracture	280
4	30	Fresh opening	Stopped at old fracture	40
8	15	Fresh opening	Stopped at old fracture	80
10	20	Fresh opening	Stopped at old fracture	50
7	20	Weak zone (mica)		0
2	--	Opening of old fracture		0
6	--	Opening of old fracture		40

6. THE SLOT DRILLING METHOD FOR LARGE CORE RETRIEVAL

In Stripa we have also tested a new drilling technique called slot drilling. With this technique it is possible to drill big holes for canisters in the bottom of a tunnel. Figures 7 and 8 show a large core which has been drilled for LBL using this technique.

One large core, 100 cm diameter and 180 cm long, weighing approximately 3500 kg, was drilled by Ställbergsbolagen at the 360 m level in the Hagconsult drift for the laboratory triaxial fracture permeability and deformation tests. To conform with the test specifications, the location was chosen where the core would include at least two natural fractures perpendicular to the longitudinal axis.

A pilot center hole, ϕ 64 mm, was percussion drilled to the depth of 25 cm. The hole was extended to 160 cm depth using a 35 mm diameter drill

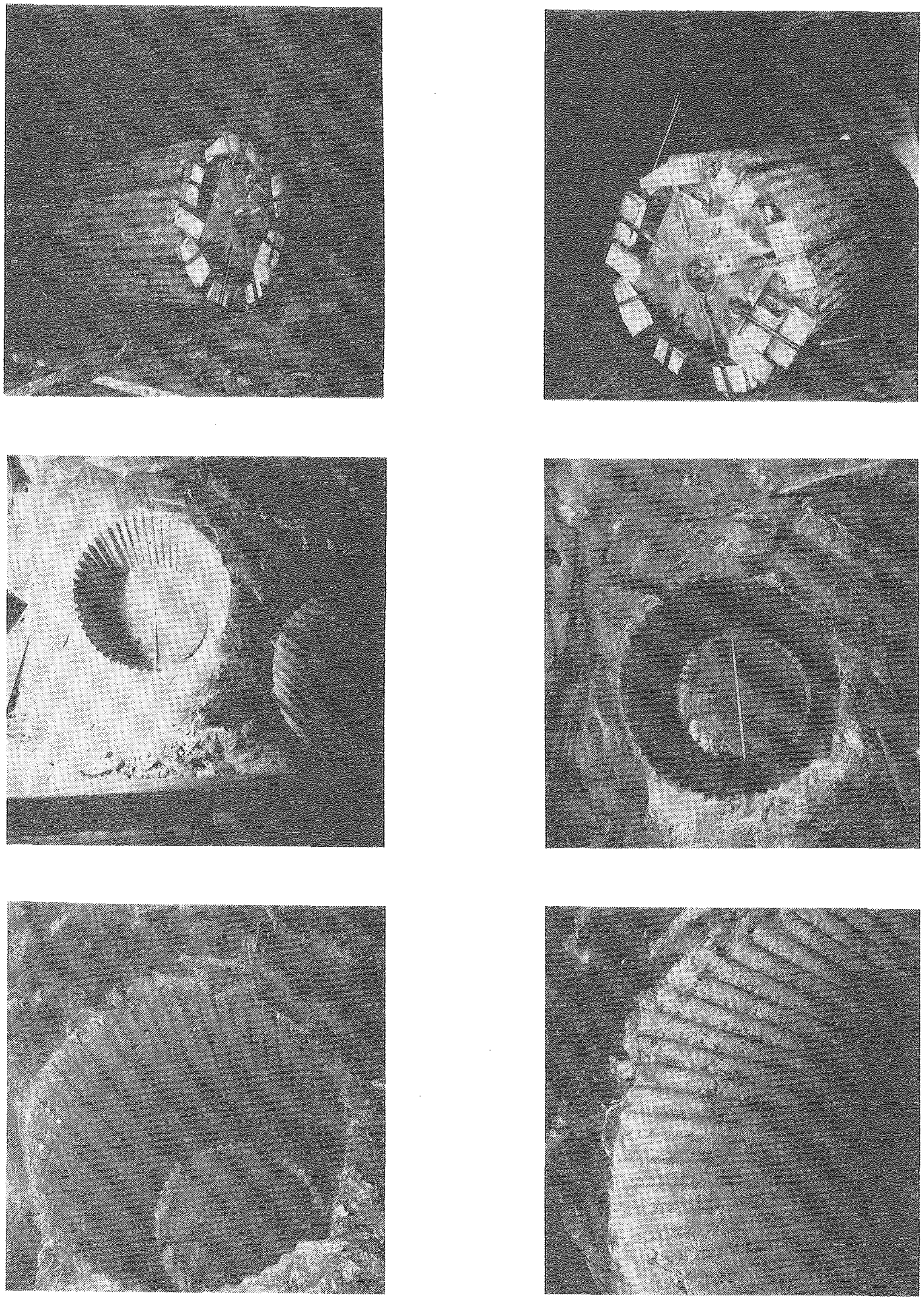

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Fig. 7: The large core and its excavation made with the slot drilling method.

SLOT DRILLING TECHNIQUE

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Fig. 8: The slot drilling method in progress.

bit. An anchor bolt was then inserted and pretensioned to 100 kgm. An Atlas Copco F-120 percussion drill was used to drill both the center pilot hole and the peripheral holes.

To drill the large core, the slot drilling technique was used. After the anchor bolt was in place, a 15-cm-long center pin of the drill rig was placed into the pilot hole. Using 51 mm drill rod, a total of 52 peripheral holes were drilled along the perimeter of the core. The first peripheral hole was drilled conventionally, while the others were drilled using a specially built guide attached to the drill rod and inserted in the previously drilled hole. After the last peripheral hole was completed, the core broke along the predetermined fracture plane and was then winched out of the borehole.

The complete drilling operation, including the drill set-up, required four 8-hour shifts of a two-man drilling crew.

7. SUMMARY

Two new methods, smooth blasting and slot drilling, were tested and used at Stripa.

The smooth blasting technique uses the symmetric pattern of the contour holes and a low charge density in each round, which results in a uniform and minimal damage to the roof and walls of the excavated cavern and limits the number of newly opened fractures. The length of freshly opened fractures in meters is equal to the charge in kilograms per meter. The slot drilling technique uses an array of small-diameter peripheral percussion-drilled holes to drill ultra-large cores 1 meter in diameter and larger.

Both techniques described have been successfully tested and their further use in future excavations of large storage caverns is recommended.

8. REFERENCES

Kurfurst, P. J., T. Hugo-Persson and G. Rudolph, Borehole Drilling and Related Activities at the Stripa Mine. (LBL-7080, SAC-05)

Olkiewicz, A., K. Hansson, K. Almen, and G. Gudkybdm, Geologisk och hydrogeologisk grunddokumentation av Stripa forsoksstation, KBS Teknisk Rapport 63, February 1978.

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