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GEOLOGY AND FRACTURE SYSTEM
AT STRIPA

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February 1979

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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 the individual reports.

Previous technical reports in this series are listed below.


2. Large Scale Permeability Test of the Granite in the Stripa Mine and Thermal Conductivity Test by Lars Lundstrom and Haken Stille. (LBL-7052, SAC-02).


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ABSTRACT

The Stripa test site has been excavated in granitic rock between 338 m and 360 m below the ground surface, and is located under the north limb of an ENE-plunging synclinal structure. The granitic rocks, in the areas mapped, are of Archean age and are dominated by a reddish, medium-grained, massive monzogranite that shows varying degrees of deformation. The granitic rocks have been intruded by diabase (dolerite) and pegmatite dikes.

Surface and subsurface mapping shows that the Stripa granite is highly fractured and that there are at least four joint sets in the area of the test excavations. In addition to the joints, the rock mass contains fissures, fracture zones, and small-scale shear zones, representing the complete spectrum of the fracture family. Most of the fractures are lined with chlorite, occasionally with calcite. Many of the small-scale shear fractures are filled or coated with epidote. Offsets of pegmatite dikes formed by these fractures are usually limited to one to two meters. Water seepage is observed only as drops from fractures or moist fracture surfaces. It was found that reconstruction of the local three-dimensional fracture system in the heater-experiment sites was difficult, and in some cases subjective. Such reconstruction is a prerequisite to accurate interpretation of thermal and mechanical data from such sites.
1. INTRODUCTION

In February 1977, the Swedish Nuclear Fuel Supply Company (KBS) initiated an engineering- and hydrogeological-research program at the Stripa mine. This program was intended to help determine the feasibility of storing nuclear waste material in granitic rocks. As a first step in this program, the Swedish Geological Survey (SGU) carried out extensive geological documentation of the experimental site, both on the surface and underground. Early in July 1977, Lawrence Berkeley Laboratory (LBL) initiated the field activities of its cooperative program with KBS. The components of that program have been discussed by Witherspoon and Degerman (1978) and Witherspoon, Cook, and Gale (1978). The objectives of the program are: (1) to study the thermo-mechanical behavior of the granite by means of in-situ heater tests, and (2) to advance the state-of-the-art in evaluating the hydrology of a fractured rock mass. The preliminary geological aspects of the LBL program were designed to complement the work done by SGU. Hence, the purpose of this report is to summarize the basic data bases developed by both parties, prior to their synthesis of the data into a broad characterization of the rock mass surrounding the experimental sites. The primary aspects of the experimental program are described only briefly in this report. Actual interpretation and comparison of the large quantity of data are kept to a minimum, pending more complete reporting and interpretation.

Chapters 2, 3, and part of chapter 4 in this report cover work carried out by the Swedish Geological Survey during 1977 and include: (1) a summary of previous work; (2) geological and fracture mapping of the Stripa granite on the surface as well as in tunnels at the 338-m and 360-m levels; (3) descrip-
tion of three drill cores and; (4) television inspection of one of the sub-
surface boreholes, before and after excavation, to determine the change in
fracture frequency caused by excavation of a tunnel parallel to the borehole.

Part of chapter 4 and chapters 5, 6, and 7 cover work carried out by the
Lawrence Berkeley Laboratory and include: (1) description of the cores from
two surface boreholes; (2) mapping of all pegmatites and veins greater than 4
cm in width and fractures of greater than 1 m in length in a 22-m section of
drift designated as the ventilation drift, plus description of cores from
fifteen boreholes penetrating the rock mass in the first 20 m of this drift;
(3) detailed (1:20) mapping of the fracture system in the time-scale experi-
ment drift; (4) detailed (1:20) mapping of the fracture system in the full-
scale and extensometer drifts, and description of core from numerous heater-
experiment instrumentation boreholes. In the time-scale and full-scale
drifts, all pegmatites and veins greater than 1 cm in width and all fractures
greater than 30 cm in length were mapped.
1.1 Location

The Stripa mine, served by both rail and road networks, is located in central Sweden, about 47 km north of Orebro, which is about 200 km WNW of Stockholm (Fig. 1.1). At its peak the mine produced about 300,000 metric tons, annually, of low-phosphorous ore from quartz-banded iron ore formations —about 60 percent first-grade ore averaging 50 percent iron, and 40 percent second-grade ore averaging 42 percent iron. Over its operating lifetime of several hundred years the mine produced a total of about 60 million metric tons of ore.

Fig. 1.1 Location of the Stripa mine, Sweden.
The location of the underground test site, relative to the mine workings, is shown in Fig. 1.2. The heater and ventilation experiment drifts are shown in Figs. 1.3 and 1.4. The Y-axis of the mine-coordinate system is referred to as mine north, which is 10° west of true (geographic) north. Magnetic declination at the Stripa site is nearly zero. In the text, all directions are referenced to mine north, unless otherwise specified. In the figures, either mine north or true north, or both, are given.

Fig. 1.2 Underground test site relative to the mine workings (isometric view).
1.2 Bedrock Geology

This discussion, in part following that of Geijer and Magnussen (1943), has been updated and written in cooperation with Ingmar Lundstrom. For a more thorough description of the regional geology of the area, the reader is referred to Koark and Lundstrom (1980). A brief description and a simplified map of the bedrock geology is also given by Lundstrom in Magnusson (1978).

Figure 1.5 is a lithologic map of the region around Stripa. All of the formations are of late Precambrian age. The oldest formation is the leptite (see glossary) which consists of strongly regionally metamorphosed rhyolite lavas and tuffs that are high in $\text{SiO}_2$. The presence of ripple-like features
in Stripa suggests that at least some of the tuffs may have been deposited under water. Also, limestones and dolomites are interlayered with the volcanic sediments. Almost all of the ore deposits occur in the leptite formation, suggesting a chemical-sedimentary origin. In many areas a general leptite stratigraphy can be discerned: a lower sodium-rich leptite characterized by albite is followed by an upper potassium-rich leptite characterized by microcline.
At the top of the leptite formation occur epiclastic sediments, such as graywacke, slates, and conglomerates. A differentiated suite ranging from
gabbros to granites, commonly called the "urgranit" or "gnejsgranit" suite in the Swedish literature, intruded the leptite formation pre- or syntectonically in relation to the ensuing deformation. These intrusives, which most frequently have granodioritic compositions and are foliated, sometimes approach the nearby leptites in composition, leading to speculations about a common magmatic origin. The supracrustal and intrusive rocks were cut by numerous dykes of dolerite, which later were altered to amphibolite.

At least two main folding phases deformed the supracrustal and intrusive rocks. Stripa is situated within the NNE-trending Vikern syncline, which was formed by an E-W compression during the first main folding phase. This phase created folds along generally N-S-trending, horizontal fold-axes. These folds were mostly overturned to the west, so that eastward-dipping structures now predominate in the area. Later, a N-S compression cross-folded the older, largely N-S-trending structures (including the Vikern syncline), thereby generating eastward-dipping lineations and fold-axes. These two folding phases have been recognized by recent workers over the whole of eastern central Sweden.

During the waning stages of these deformations as well as in the post-tectonic time, the younger "serorogenic" granite, to which the Stripa granite belongs, intruded. It differs from the pre- or syntectonic intrusives in that it is not differentiated, very seldomly foliated, and is rich in pegmatites and aplites. It frequently cross-cuts the older rocks, while the older intrusives most commonly are concordant in relation to the supracrustals. The largely concordant nature of the Stripa granite is, however, not uncommon because these granites frequently intrude along pre-existing beddings and foliations.
1.3 Quarternary Geology

This discussion follows that of Lundstrom and Magnusson (1978), and is limited to an area with a radius of about 5 km, centered on the Stripa mine. The terrain is relatively hilly, with a relief of up to 200 m. The Stripa mine is located on the NW shore of Lake Rasvalen, which has an altitude of 60.5 m.

The highest paleo-shoreline is situated at about 170 m above sea level. Most of the area is covered with glacial sediments, but the bedrock is exposed at some places, especially on the tops of the hills south and north of the mine. The directions of the glacial striae vary gradually from the oldest, with trends of N40°W to N150°W, N100°W, and N-S, to the youngest which trends N15°-20°E. However, the direction N100°W dominates in the Stripa area.

As most of the area is situated below the highest coastline, the sandy till, which is the most common sediment, is often wavewashed--resulting in a surface layer that is coarser than the underlying nonwashed till. In some areas the washing process has been so effective that the till has been completely transformed into beach sediments: gravel, sand, and silt. Beach gravels are widely distributed, especially on exposed slopes of hills attaining levels near or above the highest shoreline. Deposits of sand are generally found at lower elevations near the gravel occurrences.

There are two eskers of importance in the area. Both are situated to the north of Stripa and enter into Lake Rasvalen; one trending NW, the other (more to the east) in a N-S direction.
Glacial clays, which are often distinctly varied, as well as other glacio-fluvial fine-grained sediments, are concentrated mainly in the Stora River Valley. Organic deposits are widespread, particularly to the west of Stripa.
2. GEOLOGY OF THE STRIPA MINE

2.1 Mine Geology

This brief description of the geology of the Stripa mine follows Olkiewicz et al. (1978), and is based on material available from the mine's archives. No additional mapping has been carried out. Because of the mine's long history of production, correlations between the various levels required some assumptions and generalizations.

A geologic map of the sub-till bedrock surface in the immediate mine area; horizontal sections of the 310-, 360-, and 410-m levels; and vertical profiles of the general test site area have been compiled (Figs. 2.1 through 2.7). Reference works used in the preparation of the vertical profiles and horizontal sections have been P. Geijer's monograph of Stripa (1938), A. Weslen's mapping of the mine area (1956), and S. Ljung's mapping of the mine workings (1966). Thorough checking of the original work has not been possible because of restricted access to parts of the mining area.

The Stripa deposit consists mainly of interbanded quartz and hematite with magnetite concentrations. The ore, which has a relatively high iron content and low phosphorous content, is stratiformly bound within the leptite series. The leptite series forms a folded and faulted synclinal structure with a gently plunging ENE axis (Fig. 2.1).

Parallel with the main ore, and stratigraphically below it, exists a smaller ore occurrence which is termed the "parallel ore." Above and within the 200-m level, the southern limb of the parallel ore is missing; below the 200-m level, both limbs are present.
The oldest rock type in the mine is a series of grey leptites forming a resistant, brownish horizon of layered leptite. Extending upwards to the parallel ore, grey leptite is clearly layered; immediately above the parallel ore, layering is absent. The same situation occurs with the main ore, where leptite just beneath is layered and the leptite above the ore is not layered. The ore itself, a brownish mass within this section of the leptite series, is the youngest component. There are a number of amphibolite dikes within the mine, which do not appear on the transverse profiles, but only on the mine-level maps. They are older than the grey to light-red, medium-grained, massive granite exposed north of the mine, where the actual test areas are located. Associated with the granite is a series of pegmatite and aplitic dikes which, because of their irregular occurrence, are only shown on the mine-level maps. The youngest dikes recognized are steeply dipping dolerite dikes which strike NNE.

In his report on the geology of the Stripa mine, Ljung (1966) described the occurrence of an intrusive quartz porphyry. According to him, it should cut the parallel ore, and a xenolith of the porphyry should occur at the 260-m level. The quartz porphyry does not occur in the levels discussed here, but appears at the bedrock surface. In those outcrops where it is present, the quartz porphyry shows a schistosity which places it within the leptite series. Within other parts of Bergslagen (the region around Stripa), the leptite commonly incorporates quartz porphyry. The intrusive character of the quartz porphyry cannot be brought into this limited discussion, but as Ljung (1966) pointed out, quartz-porphyry dikes which cross-cut the iron ore occur in the
nearby Stallbergsfjalet (a small hill near the mine). The system of fractures in the mine has been studied by Geijer (1938) who differentiates between the steeply dipping younger fractures and the fractures associated with folding.

2.2 Surface Mapping

The granite which has been mapped within the mine outcrops on the surface about 200 m north of the ventilation shaft (Fig. 2.1). This outcrop rises somewhat over the surrounding landscape, and is relatively continuous over an area of about 4000 m². There are also scattered outcrops in nearby areas.

The surface granite is reddish, medium-grained, and massive. In the immediate area of the granite outcrop, twenty-six surface linears were mapped (Fig. 2.8). Twelve of these linears represent surface depressions; the remaining fourteen linears are fracture traces that were measured directly on the outcrops. Most of the fracture traces dip steeply to the north. About 75 percent of the linears have a definite NE trend; the remaining linears trend N45°W to N75°W.
Fig. 2.1 Stripa mine, sub-till geology in the immediate mine area. Original scale 1:4,000. (Compiled by G. Petersson, SGU, 1977).

(XBL 799-11293A)
Fig. 2.2  Stripa mine, 310-m level, plan view. For legend, see Fig. 2.1. Original scale 1:800. (Compiled by G. Petersson, SGU, 1977).
Fig. 2.3 Stripa mine, 360-m level, plan view. For legend, see Fig. 2.1. Original scale 1:800. (Compiled by G. Petersson, SGU, 1977).
Fig. 2.4 Stripa mine, 410-m level, plan view. For legend, see Fig. 2.1. Original scale 1:800. (Compiled by G. Petersson, SGU, 1977).
Fig. 2.5  Stripa mine, transverse profile 14. For legend and location of this section, refer to Fig. 2.1. Original scale 1:800. (Compiled by G. Petersson, SGU, 1977).
Fig. 2.6  Stripa mine, transverse profile 67. For legend and location of this section, refer to Fig. 2.1. Original scale 1:800. (Compiled by G. Petersson, SGU, 1977).
Fig. 2.7 Stripa mine, transverse profile 42. For legend and location of this section, refer to Fig. 2.1. Original scale 1:800. (Compiled by G. Petersson, SGU, 1977).
Fig. 2.8 Rose diagram showing joint orientation in the granite at the surface. Number of mapped joints = 26. (SGU-KBS project P23:02, 1977).
3. GENERAL GEOLOGY AND FRACTURE SYSTEM OF THE TEST EXCAVATIONS

3.1 Introduction

The geological investigation within the Strippa mine was concerned with bedrock and fractures in the ventilation tunnel; the lower test tunnel at the 360-m level; and the upper test-access drift with its connecting branch tunnels OV1, OV2, OH1, and OH2 at approximately the 338-m level (Fig. 1.3). Observations concerning geology and fractures have been measured in relation to fixed points within the mine. The cross-section of the ventilation tunnel is rectangular, therefore both the roof and walls have been mapped. Both the upper and lower tunnels are circular, therefore their respective fractures are projected to a horizontal plane in the center of the tunnels. Whenever applicable, minerals on fracture planes have been determined visually and the type of water leakage has been noted.

3.2 Mapping of the Ventilation Tunnel

3.2.1 Lithology

The dominant rock type is a reddish, medium-grained, massive granite with no obvious mineral foliation or lineation. The grain size can vary, but typically it is about 3 mm. In addition, a lens of monzonite several meters wide cuts across the tunnel, together with a few narrow, steeply inclined dikes of pegmatite and dolerite. The rock distribution in the tunnel is given in Fig. 3.1.

3.2.2 General Tectonics

Fracture orientation in the ventilation tunnel is illustrated in Figs. 3.1 and 3.2. Two-hundred-fourteen (214) measurements were taken on fractures...
Fig. 3.1  Rock-types and fracturing within the ventilation tunnel at the 360-m level.
Original scale :100. (SGU-KBS project P23:02, 1978).
Fig. 3.2 Stereographic projection of the poles to fracture planes in the ventilation tunnel. Schmidt net, lower hemisphere, 164 fractures. (SGU-KBS project P23:02, 1978).
in a 75-m length of tunnel. Fracture distribution and frequency are presented in Fig. 3.1 for each of the tunnel zones and also for the tunnel (see histogram in Fig. 3.1).

The northwestern parts of the tunnel are considerably more fractured than the southeastern parts (Fig. 3.1). In the former areas, the rock is quite crushed, and in zone 5 even brecciated. Zones 1, 2, 3, and 4 show a clear dominance of fractures with strike N80°W-S80°E. Approximately 85 percent of these fractures dip 60°-80° toward the NE. In zones 5, 6, 7, and 8 this strike orientation occurs less frequently. The fractures which strike N0°-40°E and N60°-90°E and dip NW are evenly distributed over the whole ventilation tunnel. Approximately 80 percent of the fractures with this strike dip 55°-80°NW. Only a few of the NW-dipping fractures strike in the N40°E to N60°E direction.

Thirty percent of the fractures dip toward the south, and are relatively evenly distributed within the tunnel exposure. Their strikes tend to be concentrated between N20°W and N30°E. The dip ranges evenly from 10°-80° with a somewhat larger concentration (approximately 35 percent) between 75° and 80°. Most of the fractures are closed, often infilled with chlorite, and occasionally with calcite. Open fractures are often lined with clay. Water leakage, often as dampness, but seldom as droplets, was observed in eight places.

3.3 Mapping of the Upper Tunnel

3.3.1 Lithology

For the rock distribution in the tunnel, see Fig. 3.3. A reddish (lighter variant than that in the lower tunnel and ventilation tunnel),
Fig. 3.3  Rock-types and fracturing in the upper tunnel at approximately the 330-m level. Every joint concentration is counted as one joint; approximate number of joints in joint concentration is given in the zone diagrams. Original scale 1:100. (SGU-KBS project 23:02, 1978).
### Table 3.1 Notes on rock specimens collected.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Description</th>
<th>Where Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.0</td>
<td>Reddish variant</td>
<td>Entrance of upper tunnel, east wall</td>
</tr>
<tr>
<td>S.1</td>
<td>Reddish, somewhat greyer version</td>
<td></td>
</tr>
<tr>
<td>S.2</td>
<td>Reddish, somewhat greyer, larger grained and with a greater content of dark minerals</td>
<td></td>
</tr>
<tr>
<td>S.3</td>
<td>Similar to S.1</td>
<td></td>
</tr>
<tr>
<td>S.4</td>
<td>Similar to S.1 although somewhat greyer</td>
<td></td>
</tr>
<tr>
<td>S.5</td>
<td>Grey version</td>
<td></td>
</tr>
<tr>
<td>S.6</td>
<td>Grey to reddish, larger grained with a greater content of dark minerals</td>
<td></td>
</tr>
<tr>
<td>S.12</td>
<td>Similar to S.6</td>
<td></td>
</tr>
<tr>
<td>S.28V</td>
<td>Reddish monzonite</td>
<td></td>
</tr>
<tr>
<td>S.00</td>
<td>Reddish (more red than S.0) version</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.2 Chemical Analyses of the Stripa granites.

<table>
<thead>
<tr>
<th>Sample</th>
<th>S.3</th>
<th>S.2</th>
<th>S.6</th>
<th>S.4</th>
<th>S.12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab number</td>
<td>S 3 1</td>
<td>S 2 2</td>
<td>S 6 3</td>
<td>S 4 4</td>
<td>S 12 5</td>
</tr>
<tr>
<td>SiO₂ %</td>
<td>75.3</td>
<td>74.8</td>
<td>74.0</td>
<td>74.3</td>
<td>74.9</td>
</tr>
<tr>
<td>TiO₂ %</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Al₂O₃ %</td>
<td>12.9</td>
<td>13.1</td>
<td>13.5</td>
<td>13.3</td>
<td>13.3</td>
</tr>
<tr>
<td>Fe₂O₃ %</td>
<td>1.8</td>
<td>1.7</td>
<td>1.6</td>
<td>1.0</td>
<td>1.7</td>
</tr>
<tr>
<td>FeO %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO %</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>CaO %</td>
<td>0.6</td>
<td>0.4</td>
<td>0.5</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>MgO %</td>
<td>0.22</td>
<td>0.22</td>
<td>0.18</td>
<td>0.20</td>
<td>0.18</td>
</tr>
<tr>
<td>K₂O %</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.1</td>
</tr>
<tr>
<td>K₂O %</td>
<td>4.5</td>
<td>4.6</td>
<td>4.8</td>
<td>4.6</td>
<td>4.5</td>
</tr>
<tr>
<td>H₂O&gt;105⁰C %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O&lt;105⁰C %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P₂O₅ %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaO %</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0/03</td>
<td>0.02</td>
</tr>
</tbody>
</table>

TOTAL | 99.43 | 98.92 | 98.68 | 99.15 | 99.48 |
Table 3.3  CIPW - norm of the Stripa granite.

<table>
<thead>
<tr>
<th></th>
<th>S.0</th>
<th>S.1</th>
<th>S.2</th>
<th>S.28V</th>
<th>S.3</th>
<th>S.4</th>
<th>S.5</th>
<th>S.6</th>
<th>S.12</th>
<th>S.U0</th>
</tr>
</thead>
<tbody>
<tr>
<td>q</td>
<td>33.4</td>
<td>33.3</td>
<td>33.1</td>
<td>0.4</td>
<td>33.4</td>
<td>31.9</td>
<td>32.9</td>
<td>31.4</td>
<td>32.2</td>
<td>31.3</td>
</tr>
<tr>
<td>c</td>
<td>0.5</td>
<td>1.0</td>
<td>0.8</td>
<td>0.2</td>
<td>0.3</td>
<td>0.5</td>
<td>0.6</td>
<td>0.8</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>or</td>
<td>27.8</td>
<td>26.6</td>
<td>27.5</td>
<td>38.9</td>
<td>26.7</td>
<td>27.4</td>
<td>26.7</td>
<td>28.7</td>
<td>26.7</td>
<td>26.9</td>
</tr>
<tr>
<td>ab</td>
<td>33.0</td>
<td>34.1</td>
<td>34.2</td>
<td>54.0</td>
<td>34.0</td>
<td>34.1</td>
<td>34.0</td>
<td>34.3</td>
<td>34.9</td>
<td>35.9</td>
</tr>
<tr>
<td>an</td>
<td>3.0</td>
<td>2.6</td>
<td>2.1</td>
<td>3.1</td>
<td>3.0</td>
<td>3.6</td>
<td>3.5</td>
<td>2.6</td>
<td>3.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>
medium-grained, massive granite dominates the upper tunnel. Grey and red variants are also found. In addition to color variation, grain size—typically about 3 mm—varies between 1 and 5 mm. The transition to another color or grain size is diffuse.

Nine specimens of granite (several varieties) have been analyzed, eight taken from different parts of the upper tunnel and one from the lower tunnel (Table 3.1). The chemical analyses do not show significant differences in composition among the variants described above. The rock can be termed monzogranite (Tables 3.2, 3.3 and Fig. 3.4). Two thin sections of two granite varieties have been examined microscopically. Results indicate

![Fig. 3.4](image)

*Fig. 3.4* Normative (q:or:ab+an) composition (weight percent) of the Stripa granite. Four points (S0, S1, S5, and SU0) coincide with those already plotted. (SGU-KBS project 23:02, 1978).
variation in the proportion of the main minerals. But there is negligible difference in the chemical compositions and C.I.P.W. norms of the grey and red granites. A sample of the reddish granite, taken at the entrance of the tunnel, shows the following approximate mineral composition:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>44</td>
</tr>
<tr>
<td>Partly sericitised plagioclase</td>
<td>39</td>
</tr>
<tr>
<td>Microcline</td>
<td>12</td>
</tr>
<tr>
<td>Chlorite</td>
<td>3</td>
</tr>
<tr>
<td>Muscovite</td>
<td>2</td>
</tr>
<tr>
<td>Accessory minerals: Zircon; opaques</td>
<td></td>
</tr>
</tbody>
</table>

Samples of the grey-granite type taken 55 m along the tunnel show a marked increase of microcline in place of the plagioclase. In these samples the mineral composition is:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>35</td>
</tr>
<tr>
<td>Partly sericitised plagioclase</td>
<td>35</td>
</tr>
<tr>
<td>Microcline</td>
<td>24</td>
</tr>
<tr>
<td>Subordinate: Biotite, muscovite, chlorite, epidote</td>
<td></td>
</tr>
<tr>
<td>Accessory minerals: Zircon; opaques</td>
<td></td>
</tr>
</tbody>
</table>

A lens of quartz-monzonite several meters in width occurs in one of the walls in branch tunnel OV1 (for chemical analyses see Tables 3.1, 3.2, and
Microscopic studies have revealed the following mineral composition:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partly sericitised plagioclase</td>
<td>45</td>
</tr>
<tr>
<td>Microcline</td>
<td>33</td>
</tr>
<tr>
<td>Quartz</td>
<td>17</td>
</tr>
<tr>
<td>Subordinate: Chlorite; muscovite; epidote</td>
<td></td>
</tr>
<tr>
<td>Accessory minerals: Apatite; sphene; opaques</td>
<td></td>
</tr>
</tbody>
</table>

Several small pegmatite dikes have been noted in the upper tunnel and branch drifts. In addition, a dolerite dike is located at the end of the branch tunnel OV1.

### 3.3.2 General Tectonics

The fracture pattern in the upper tunnel is shown in Fig. 3.3. The distribution and frequency of the fractures within limited zones of the tunnel, and their occurrence along its whole length, are shown in the histogram in Fig. 3.3. The orientations of the fractures are shown in Fig. 3.3 (zones 1 to 9 and branch tunnels OV1 and OH1) and in Fig. 3.5. For the northern parts (the zones 9 to 12, and branch tunnels OV2 and OH2) see Fig. 3.6.

In comparison with the ventilation tunnel, the upper tunnel shows much less fracturing. The fractures are relatively evenly distributed within the tunnel, apart from several areas where there are concentrations of closely spaced, near-parallel fractures. Within one 10-m section in zone 4 and
Fig. 3.5 Upper tunnel. Stereographic projection of the poles to fractures in zones 1 to 8 and OV1 and OH2. Schmidt net, lower hemisphere, total 193 + (200 fractures. The numbers in brackets indicate the approximate accumulation of parallel fractures within a limited area. (SGU-KBS project 23:02, 1978).
Fig. 3.6 Upper tunnel. Stereographic projection of the poles to fractures in zones 9 to 12 and OV2 and OH2. Schmidt net, lower hemisphere, total 101 + (130) fractures. The numbers in brackets indicate the approximate accumulation of parallel fractures within a limited area. (SGU-KBS project 23:02, 1978).
partly in zone 5, there are up to 20 fractures per meter. Each such concentration of approximately parallel fractures has been plotted as one fracture in the summary histogram (Fig. 3.3), since 294 fractures were measured on a 234-m section of the tunnel. In the zone histograms (Fig. 3.3), however, all fractures have been taken into consideration, including every individual fracture in the fracture concentrations.

In the southern part of the tunnel, i.e., zones 1 to 8 as well as branch tunnels OVI and OH1, about 90 percent of the fractures dip north, 80 percent of which dip between 60° and 80°N. Within the northerly dipping fractures, one can see two fracture-direction groups. The strike of one group is concentrated between N60°W-N90°W and the strike of the other group between N0°E-N10°E. Other fractures have quite an even distribution from E to W. Southerly dipping fractures comprise only 10 percent of the total. They have a relatively even distribution within the tunnel; their strikes range from N30°W to N50°E. The fractures show two main dip inclinations; one group at about 30°S and the other at about 75°S.

Northward from zone 9, the northerly dipping fractures decrease in frequency while the southerly dipping variety increase in frequency. The northerly dipping fractures account for approximately 40 percent of the fractures in zone 12 and for approximately 30 percent of the fractures in OV2. However, the dip continues to be between 60° and 80°N. The dips of the southerly dipping fractures range from 25°S-85°S, with a large group having dips between 60°S and 70°S. The strike of these northerly and southerly dipping fractures is mainly from S80°W-60°W, and their spatial distribution is quite even.
Most of the fractures in this tunnel are closed and infilled with chlorite, or occasionally with calcite. Water leakage in the form of droplets or dampness has been observed in thirteen places, mostly in the northern parts of the tunnel.

3.4 Mapping of the Lower Tunnel

3.4.1 Lithology

The dominant rock type in this area is the reddish, medium-grained, massive granite. The grain size is variable, but typically is approximately 3 mm. The result of the chemical analysis of a specimen taken within the tunnel corresponds to the results of those specimens analyzed from the upper tunnel, as given by Tables 3.1, 3.2, and 3.3, and Fig. 3.4.

3.4.2 General Tectonics

Fracture distribution in the ventilation tunnel is shown in Fig. 3.7. The distribution and frequency of the fractures within limited zones within the tunnel, and their occurrence along its whole length, are shown in the histograms. For the orientations of the fractures, see the stereographic projection of the fracture planes (Fig. 3.7), and of the fracture poles (Fig. 3.8). The northern parts of the tunnel are considerably more fractured than the southern parts. Long sections of the northern part of the tunnel are quite crushed and in some cases brecciated. There are large groupings of the nearly parallel fractures, which in our overall analysis have each been considered as a single fracture zone. A total of 35 +[200] fractures have been measured on a 58-m section of the tunnel.*

*The figure within the brackets indicates the approximate sum of individual fractures from all the zones of closely spaced fractures within the tunnel.
Fig. 3.7  Rock-types and fracturing within the lower tunnel at approximately the 360-m level. Every joint concentration is counted as one joint; approximate number of joints in joint concentrations is given in zone diagrams. Original scale 1:100. (SGU-KBS project P23:02, 1978). (XBL 799-11918A)
Fig. 3.8 Lower tunnel. Stereographic projection of the poles to the fracture planes. Schmidt net, lower hemisphere, total 35 + (200) fractures. The numbers in brackets indicate the approximate accumulation of parallel fractures within a limited area. SGU-KBS project P23:02, 1978.)
About 75 percent of the fractures dip toward the north, of which 65 percent dip between 60°N and 80°N. Strikes of the northerly dipping fractures show two prominent concentrations; the largest between N50°W and N90°W and the other between N60°E and N70°E. The southerly dipping fractures are concentrated between N100°E and N40°E, and between N50°W and N60°W. Their dips range relatively evenly from 35°S-90°S.

Water leakage (in the form of droplets) was observed in only one place, at which the granite was brecciated.

3.5 Summary

The four mapped areas are dominated by a reddish, medium-grained, massive monzogranite that has been variably deformed. The granite in the experimental drifts is less deformed than the granite of the drift to the ventilation shaft and the granite of the northern part of the lower drift. In these places the granite is strongly fractured and sometimes brecciated.

When one compares orientations of the fractures, a high degree of conformity among all four areas is found. Steep, north-dipping fractures dominate, except in the northern parts of the upper tunnel where a large number of fractures dip to the south. Two strike directions recur in all four areas; one has a quite even distribution from N to E, and the other is concentrated in a smaller section from NW to W. The majority of fractures is closed, often infilled with chlorite, and occasionally with calcite. Water leakage in the surveyed tunnels consists only of damp surfaces or slow dripping.
4. GENERAL FRACTURE CONDITIONS DEFINED BY BOREHOLE DRILLING

4.1 Purpose and Scope of Drilling Program

In this chapter, the two groups of long boreholes that were drilled to determine the fracture distribution in the granite are discussed. The first group of boreholes drilled by SGU include Dbh-1 (45 m in length), Dbh-2 (100 m in length), and DbhV-1 (471 m in length). The three diamond-drilled boreholes Dbh-1, Dbh-2, and DbhV-1 are 56 mm in diameter and the cores are 46 mm in diameter. Dbh-1 and Dbh-2 were drilled parallel to the main drift of the test site (Fig. 1.3) prior to excavation. They are located approximately 2 m from the eastern wall of the main drift. The main purpose of the Dbh-2 borehole was to determine if the excavation work would increase the number of fractures intersecting the borehole or increase the apertures of the existing fractures. DbhV-1, which was drilled vertically from the 410-m mining level and extends to the 881-m depth (in the mine coordinate system), was drilled in order to determine fracture conditions at depth.

The second group of boreholes includes SBH-1 and SBH-2 (Fig. 4.1), both of which were drilled from the surface and directed toward the excavation. Both holes are diamond cored, 76-mm-diameter boreholes which yielded core of 52-mm diameter. SBH-1, 385 m in length, is inclined at 45° from the horizontal in a WSW direction, passes over the end of the test excavation, and terminates at the 290-m level. SBH-2, 365 m in length, was drilled from the west toward the test excavations, is inclined 52° from the horizontal, and terminates at approximately the 290-m level.
Fig. 4.1  Location of surface boreholes, SBH-1, SBH-2, and the water table wells (WT).

4.2 Drilling Methods and Core Logging Procedures

Dbh-1, Dbh-2, and DbhV-1 were drilled using standard double-tube core barrels. Some core material was lost, especially in the more fractured zones. In an attempt to minimize core loss and to permit reconstruction and orientation of the core, SBH-1 and SBH-2 were drilled using triple-tube core barrels. Hence, slightly different core-description procedures were used for the two groups of boreholes.
In describing the cores from Dbh-1, Dbh-2, and DbhV-1, the main purpose, in addition to describing rock distribution, was to describe the distribution and characteristics of fractures intersecting the core. The fractures were divided into two types. The first type are fractures with smooth, coated faces (natural fractures). The second type are fractures with clean, uneven, surfaces that possibly were induced by the drilling process. The angle between the drill-axis and the fracture plane was measured and the infilling material and any visible shearing noted. Infilling material was described according to nomenclature which follows, as far as possible, recommendations from Swedish Geotechnical Institute's (SGI) report, Part I: "Nomenclature System for Geological Investigations 1977." An explanation of the nomenclature is given in Appendix A, Fig. A.1.

Core-description procedures for SBH-1 and SBH-2 were somewhat more detailed, since core description provides part of the data needed to calculate directional permeabilities of the rock mass. Although distinctive changes in rock type, color, or grain size were noted, along with their exact locations, the main emphasis was placed on description of fractures in the core. An attempt was made, using the above criteria, to distinguish between naturally occurring and induced fractures. Natural fractures were described as open or closed in situ; and planar, curved, or irregular in terms of surface qualities. Roughness of the surface was estimated in millimeters by visual comparison of the surface relief with a millimeter scale. Weathering (the condition of joint coatings) and mineralization on the fracture surface, along with any indications of shear movement, were identified and described.
Triple-tube core barrels were used in drilling SBH-1 and SBH-2 to improve core recovery and to minimize core disturbance during drilling and extraction, so that an attempt could be made to orient fractures in the core. A wire-line indentor, which marks the lowest point on the core that is to be drilled, was used to provide a reference point from which a reference line could be drawn on the core. Then, following the method outlined by Goodman (1976), relative orientations of the fractures, the apparent dip and the apparent-dip direction of the fracture, can be mapped. From these two measurements and the bearing and plunge of the borehole, it should be possible to calculate the true strike and dip of the fracture (Lau and Gale 1976). In addition to relative orientation and descriptive data, the core was described, following Knill and Jones (1965), in terms of percent core recovery, percent sample recovery, and mean core length.

Provision was made for calculating RQD (Rock Quality Designation) values in both core description procedures. RQD values (Deere et al. 1964) are determined by summing the lengths of core sections that are 10 cm or greater in length, and dividing by the total measured length. The results vary from 1.0 to 0.0 (or 100 percent to 0 percent), where 1.0 originally represented good rock conditions and 0.0 represented bad rock conditions. In this report 1.0 refers to low fracture density, and values less than 1.0 represent higher fracture densities.

RQD values were calculated over 2-m intervals for all boreholes. This interval was chosen since it corresponded to the water-pressure test interval; hence, any gross correlation between water flow and fracturing would be
more obvious. For every 2-m interval, two ROD calculations were made. In one calculation, fractures with smooth or coated surfaces (natural fractures) were included. In the other calculation all fractures, even those with clean, irregular faces (induced fractures) were included.

4.3 Description of Dbh-1, Dbh-2, and DbhV-1 Drill Core

All three boreholes are dominated by a reddish, medium-grained granite. Some grey and lighter red varieties of this granite also occur. The grain size of the granite is generally about 3 mm, but can vary between 1 and 5 mm. Both the color and grain-size gradation are diffuse. The distribution of rock units for each borehole is given in Appendix A (Figs. A.2, A.3, and A.4).

The simplified log-RQD diagram in Fig. A.5, and the more detailed fracture log in Fig. A.6 for Dbh-1, show that the frequency of the fractures and the fracture zones is relatively high and evenly distributed. The most common coating on the fracture planes is chlorite and, occasionally, calcite. In the section from 23 m to 30 m, fractures in the core show movement indicated by slickensides. Fractures in the core show some similarity to those in the east wall of the upper tunnel, to which Dbh-1 was drilled parallel. Fracture zones described in the core tend to occur in approximately the same area where there are larger groupings of fractures in the tunnel.

Dbh-2, 10 m in length, was also drilled parallel to the east wall of the upper tunnel. The detailed fracture log (Fig. A.7) and the simplified fracture log-RQD diagram (Fig. A.8) for Dbh-2 are similar to those for Dbh-1, and show a high frequency of fracturing and a relatively even distribution of fractures and fracture zones. As in Dbh-1, the most common coating
on fracture planes is chlorite and, occasionally, calcite. In sections 76 m to 79 m and 90 m to 95 m, fractures in core contain abundant slickensides.

DbhV-1 was drilled vertically downwards from the 410-m level for a distance of 471 m (i.e., to 881 m beneath the surface). The detailed fracture log (Fig. A.9) and the simplified fracture log-RQD diagram (Fig. A.10) show that, in contrast to Dbh-1 and Dbh-2, the fracture frequency and fracture zones are unevenly distributed. There are three sections of the core (about 50 percent of the total borehole) which show a high fracture frequency. These sections are situated at depths of 8 m to 35 m (27 m in length), 146 m to 174 m (28 m in length), and 274 m to 440 m (166 m in length). The most common fracture coating is chlorite and, occasionally, calcite; although two zones, 198 m to 250 m and 280 m to 290 m, are dominated by calcite and pyrite, respectively. In sections 70 m to 87 m and 370 m to 377 m, the fractures in the core show an increase in the frequency of slickensides over those observed in the other fractured intervals.

4.4 Description of SBH-1 and SBH-2 Drill Core

Both SBH-1 and SBH-2 were drilled from the surface (Fig. 4.1) toward the underground test excavations. Both boreholes trend subparallel to the contact between the leptite and the granite. SBH-1 was started in loose overburden material that consisted primarily of reddish granite. Coring started at approximately 10.6 m. The borehole intersected granite from 10.6 m to 52.2 m, leptite from 52.2 m to 208.2 m, and granite from 208.2 m to 384.8 m. Greenstone was intersected from 245.5 m to 246.2 m. Granitic pegmatites and quartz veins, measuring a few centimeters in width, are found
in both the granite and the leptite sections. Generalized geology of the SBH-1 core, major fracture zones, and RQD values (based on a 4-m interval) for all fractures in the core are shown in Fig. 4.2. The detailed fracture logs are given in Fig. A.11. Figure A.12 shows the detailed fracture log symbols and the RQD values based on the 2-m interval. Figures A.11 and A.12 show that fracture zones and fracture frequencies are unevenly distributed. Figure A.11 also shows the locations of pegmatites and quartz veins intersected by the borehole, as well as the type of material filling, or coating, fractures. In general the most common coating materials were calcite and chlorite.

Generalized geology, major fracture zones, and RQD values for SBH-2 are shown in Fig. 4.3. The borehole intersected what appears to be amphibolite or diorite near the surface, grading into leptite in the upper 30 m. Leptite extends to 81.25 m and granite from 81.25 m to the bottom of the hole, at 360 m. Both the leptite and granite are cut by pegmatites and quartz veins, as indicated on the detailed fracture log (Fig. A.13). Figure A.14, the simplified fracture log-RQD values, shows the uneven distribution of fracture zones and RQD values.

4.5 Examination of Dbh-2 Before and After Blasting of the Tunnel

The purpose of this survey was to study the possible effect of blasting on fractures within the granite. The data are difficult to interpret because of several sources of sizeable error, explained below.

The 50-m length of borehole parallel to the tunnel was inspected, using a television camera, before and after the tunnel was blasted, and these
observations were compared to the core log. Although the fractures showed a relatively good correlation before and after blasting, such information cannot indicate the effects of blasting and fracture frequency. This is because (a) the core can fracture and even become crushed during drilling and handling, and (b) some fractures registered during television examination could have been annealed, or partly annealed, and therefore may not have been identified during core description. Additional problems include (a) the difficulty of obtaining a sharp picture because the drill hole was filled half with water and half with air, which have different refractive coefficients, and (b) further deterioration of the television picture because the light used for photography was reflected from the water surface.
Fig. 4.2 General geology, major fracture zones (based on 4-m interval), and RQD values for SBH-1.
Fig. 4.3 General geology, major fracture zones (based on 4-m interval), and RQD values for SBH-2.
5. FRACTURE SYSTEM IN THE VENTILATION DRIFT

5.1 Introduction

A clear distinction should be made between the ventilation drift discussed in this chapter and the ventilation tunnel discussed in chapter 3. The ventilation tunnel (Fig. 1.3) connects the vertical ventilation shaft with the 360-m mining levels. The ventilation drift is a 40-m section of drift located at the north end of the main test excavations, at the 338-m level (Fig. 1.2).

5.2 Purpose of Ventilation-Drift Experiment

It has been proposed (Raven and Gale 1977) that the surfaces of underground openings in "dry mines" appear to be dry because the permeability of the rock mass is so low that the mine ventilation system can evaporate water that is slowly seeping into the underground openings. If one could determine the volume of water being removed by the ventilation system, one would have a direct measure of the volume of water seeping into that section of the mine. Furthermore, if the ground water pressure gradients near the mine opening were known, it should be possible to determine the rock-mass permeability.

In the ventilation drift at Stripa, a ventilation experiment is planned (Gale and Witherspoon 1978) with the objective of measuring the total amount of water that is seeping into a 30-m section of drift at the end of the main drift (Fig. 1.2). This section will be sealed off with airtight and watertight bulkheads. A controlled amount of heated air will be pumped into and out of the sealed room, and the change in the water content of the air will be measured. After steady-state conditions are reached, the change in water content will give the rate of in-situ seepage.
In order to measure fluid pressure gradients in the rock mass adjacent to the ventilation drift, two groups of 76-mm-diameter boreholes have been drilled. Ten boreholes approximately 30 m in length have been drilled in two radial patterns (radial boreholes or R-holes), as shown in Fig. 5.1A. Five boreholes, 30 m in length, have been drilled in a diverging pattern from the end of the ventilation drift (hydrological and geophysical boreholes or H-G holes), as shown in Fig. 5.1B.

Fig. 5.1 Location of A. radial (R) boreholes, and B. hydrological-geophysical (H-G) boreholes in the north end of the ventilation drift.
5.3 Detailed Mapping of Ventilation Drift

Figure 5.2 is a map of the last 22 m of the floor and east wall of the ventilation drift. This mapped area coincides with the area in which the R and H-G holes have been drilled. Mapping is referenced to a 1-m grid painted on the floor and the walls of the drift. All pegmatites and veins greater than 4 cm in width and fractures greater than 1 m in length were located with respect to the grid and then transferred to the base map. The floor and walls were also photographed. The photographs are also referenced to the grid. Directions on this map (Fig. 5.2) are references to north in the mine-coordinate system which is 100°W of true north.

The ventilation drift was mapped to provide data that would help in understanding the fracture hydrology of this part of the granite. As indicated above, only the more prominent fractures in the floor and walls were mapped. Many small fissures and welded fractures are not shown on Fig. 5.2.

Thus, while much more detail is given for this part of the ventilation drift than is given in chapter 3 from the general mapping of the test excavations, the detail is still less than that given for the time-scale and full-scale heater sites in the following chapters.

The main feature that dominates this part of the ventilation drift is a zone of closely spaced (2 cm to 5 cm), subparallel fractures, that trends approximately N150E and dips about 70° to the west. Two strong fracture directions are evident: (1) a W-NW direction with fractures dipping steeply to the north or to the south, and (2) a N-NE direction with fractures that
Fig. 5.2 Detailed fracture map of the east wall and floor of the ventilation drift (last 22 m).
generally dip 50° to 60° to the west. The fractures generally show evidence of groundwater seepage, in the form of either drops or moist fracture planes. The first fracture set (the W-NW-trending set that dips to the south) has fracture planes that are generally planar to slightly curved, and continuous for at least 2 m. Fracture planes in this set generally have a pale-green coating that gives the fracture plane a smooth appearance. Occasionally, fractures in this set have a thick, black, chloritic coating that imparts a roughness of 1 mm to 2 mm to the fracture surface.

Fractures with a WNW trend that dip to the north form a second set. Fractures in this set are continuous over distances of at least 4 m and their fracture planes generally have a thick, black, chloritic coating. Fractures in this set frequently show evidence of movement and, in some cases, represent 1- to 2-cm-wide slip planes that are sometimes filled with quartz. Fractures in the NNE trending set are generally curved and continuous for 3 to 4 m. The fracture planes usually have a black, chloritic coating that shows evidence of shear movements.

Offset of the fracture zone in the floor of the drift indicates apparent left-lateral displacement. Right-lateral displacements are indicated by offset of small pegmatites that cut the rock mass and fracture offsets. The fracture system in the ventilation drift will be analyzed in more detail as the hydrology work proceeds. The approximate locations of R4 and R9 boreholes are shown on Fig. 5.2.
5.4 Fractures Intersected by Radial and Hydrology-Geophysical Boreholes

The radial (R) and hydrology-geophysical (H-G) boreholes were drilled using standard double-tube core barrels. Detailed fracture logs, drawn following the procedures discussed in chapter 4, are presented in Appendix B, along with simplified fracture logs and RQD values for each of the boreholes.

The main rock type encountered is a grey to pinkish granite. The rock is cut by scattered quartz veins and pegmatites (see Fig. 5.2) that are usually less than 5 cm in width. Fracture frequency and fracture zones are unevenly distributed, but this is in part a function of borehole orientation. Note for example the general similarity of the fracture logs (Fig. 5.3) and RQD plots (Fig. 5.4) for R9 and R10. The main fracture coatings are calcite, chlorite, and epidote.
Fig. 5.3 Fracture logs for R9 and R10. (XBL 798-11063)
Fig. 5.4 RQD values for R9 and R10. (XBL 798-11064)
6. CHARACTERIZATION OF THE FRACTURE SYSTEM IN THE TIME-SCALE EXPERIMENT DRIFT

6.1 Introduction

The time-scale experiment is designed to model the thermo-mechanical behavior of rock surrounding an array of hot, radioactive waste canisters. The objectives and rationale of the test are discussed by Witherspoon, Cook, and Gale (1978). The experiment consists of eight 1-kW electrical heaters arranged in an elliptical pattern at a depth of 10 m below the floor of the drift (approximately 347 m below the surface). The rough layout is shown in Fig. 1.2. The laws of similitude applied to heat conduction dictate that reducing of the length dimensions and power output by a factor of $1/3.54$ produces a time-scaling factor of about $1/12.5$ (i.e., $1/3.54^2$); hence the experiment, if operated for 2 years as planned, will simulate 25 years of thermal output from the heater array. The power output of the heaters will be gradually decreased to simulate the thermal decay of waste over a 25-year period after emplacement.

During the experiment, the principal factor controlling the non-elastic response of the rock mass to the thermal loads will be its natural discontinuities. In order to predict or assess the influence of discontinuities, it is necessary to determine their spatial orientations, frequencies, sizes, and mechanical properties. Therefore, considerable effort has been directed toward defining the local discontinuity system in the granite surrounding the heaters. We expect that our results will facilitate the interpretation of thermo-mechanical data now being collected and, furthermore, provide insight into the degree to which one can realistically define a highly fractured
granitic rock mass over a limited area. The work described in this chapter focuses only on the time-scale heater drift, but it is relevant to compare these data with the broadly based information presented in the previous chapters.

The problems of characterizing this local fracture system have been attacked in two ways. First, we have correlated major features mapped on the surface of the drift with their borehole interceptions, as determined by the detailed core logs described earlier. Results of this analysis show that four major parallel discontinuities, or fracture zones, extend downward through the array of eight heaters. At least one of these may be considered a shear fracture since it apparently offsets a nearly vertical pegmatite dike in the central portion of the array. The second approach is statistical, and endeavors to define the numerous discontinuous fractures for which the first approach was impracticable. From a stereographic evaluation of 826 fractures logged in the core sample from 17 vertical boreholes, 4 distinct joint sets have been identified. The size and distribution of fractures within these sets are being interpreted so that approximate three-dimensional blocks of intact rock can be defined. These statistical blocks, along with the discrete continuous fractures, should constitute a model by which the rock-deformation data can be interpreted.

It is important to note that our analysis of the fracture system is being complemented by geophysical and mechanical borehole-logging techniques (Nelson et al. 1979). Also, extensive work at Stripa (Gale and Witherspoon 1978) is involved with characterizing fracture-flow properties over broad
6.2 Methodology and Results

The primary source of information is a 1:20 map of the floor surface, showing natural fractures, faults, and dikes ranging in length from about 0.3 m to the dimensions of the drift. Mapping was referenced to a 1x1-m coordinate system painted on the rock. The resulting floor map (Fig. 6.1A) yielded considerable detail, from which the major features shown in Fig. 6.1B were delineated. These major features are typically 1 cm to 5 cm in width, with wall coatings of chlorite, calcite, and/or epidote. Field inspection showed that the fractures striking roughly perpendicular to the drift centerline (labeled 1 to 4 in the figure) are continuous throughout the walls and roof of the drift. They also tend to have thicker infillings (2 cm to 15 cm) which frequently display slickensides.

Since an important aspect of this report is to contrast the different fracture-system data bases, Fig. 6.1B may be compared with the large-scale fracture diagram for the time-scale drift shown in Fig. 3.3 (OV2 drift). Because fractures in Fig. 3.3 were sampled on the bases of significant wall expressions, then extrapolated to the drift centerline, the resulting diagram does not coincide precisely with that from the detailed floor mapping (Fig. 6.1B). Most notably, fractures striking parallel to the drift are weakly represented by the large-scale data. However, the non-parallel features are well documented in relation to the detailed data base. There-
fore, it appears that the sampling techniques described in chapter 3 are an efficient and reliable means of mapping the fracture system over a broad scale, provided that a diversity of drift orientations is used.

In addition to mapping techniques, the core description methods described in chapter 4 varied between the two research programs. Because of the different objectives of each program, the fracture analysis work for the heater studies required that the nature and orientation of fractures in the drill core be described in considerable detail. Summary fracture-log profiles from the time-scale experiment drilling program are included in Appendix C, so that comparison of the two logging techniques can be made.

Because of their prominence, several of the major features in Fig. 6.1B could be projected downward from the surface-mapped locations and correlated to features identified in the core samples. Planar projections were computed analytically, and the resulting subsurface correlations were checked visually on a three-dimensional physical model of the local rock mass. Other factors considered, besides borehole position, include similarity of orientation (±15 degrees normal deviation) and infilling characteristics (thickness, weathering, and type of mineralization). Figure 6.2 shows four major features in profile along the vertical centerline plane of the time-scale experiment. For purposes of computer storage and display, these surfaces are represented in three dimensions as a series of contiguous triangles, the vertices of which are the correlated locations in the various boreholes. In addition to the four major fractures, a pegmatite dike with a width of 20 cm has been mapped in the central part of the heater array. From its discontinuous expression in the core samples, an offset of about 1.5 m has been
inferred, as shown in the profile. The shear fracture associated with this displacement is the most prominent feature of the drift, and in most cases it is clearly visible in the core samples. Subsurface delineation of the three other major fractures was somewhat more difficult, mainly due to their less frequent interception by boreholes. Nonetheless, Fig. 6.2 gives a realistic view of the dominant discontinuities affecting the time-scale experiment. It is important to note that in several core samples, the major shear fractures were observed to be sealed, as shown by the dashed lines in the borehole profiles. This finding implies that these surfaces have healed contact zones; however, the strength of such cohesion is not known.

Reasonable as Fig. 6.2 may be, it remains a gross simplification of the highly fractured rock mass beneath the drift floor. With this in mind, exhaustive attempts were made to correlate the other fractures of Fig. 6.1B with subsurface features logged in the core. While this was somewhat productive near the surface of the drift, no reliable correlations were possible beyond a depth of about 5 m. Since the heating experiment takes place in the region below this level, definition of such shallow fractures would be superfluous. Cross-hole correlation of other fractures at relevant depths proved equally futile; so it seems likely that features other than those shown in Fig. 6.2 are discontinuous. Based on the available data, we believe that delineation of such discontinuities in a deterministic sense would be speculative and tenuous at best. Hence, in order to more fully characterize the local rock mass, the statistical distribution of fractures in the core samples is being studied.
Fig. 6.1  A. Detailed fracture map of time-scale experiment floor, and B. generalized major-fracture map.
Fig. 6.2 Centerline profile through time-scale experiment, showing major subsurface features. (Borehole widths not to scale).
While interpretative results are not yet available, basic data are presented here. A Schmidt contour plot of the downward normals, or poles, of fractures logged in the time-scale boreholes is given in Fig. 6.3. Contouring was accomplished with a \(10^\circ\) counting radius on the lower hemisphere, with the results plotted on an equal-area projection. Intervals represent the percentage of poles, based on 826 observations, per 1.5 percent area. Three sets of fractures are clearly displayed, but a fourth set (set 1) is less defined. Set 1 may be significant, however, because it roughly corresponds to the orientation of the major fractures shown in Figs. 6.1B and

![Schmidt contour plot](XBL_799-11320A)

Fig. 6.3 Schmidt contour plot of poles from logged fractures in time-scale experiment boreholes. Contour intervals represent percentage of points per 1.5 percent area (\(10^\circ\) counting circle radius). Lower hemisphere projection, 827 points. Boxed numbers are orientations of mean poles to joint sets.
6.2. Set 2 likewise correlates with surficial features in 6.1B; however, set 3 is not expressed in the form of major mapped fractures. This suggests that the dimensions of fractures of set 3 are less than 0.5 m in the drift and thus not mapped. The nearly horizontal fractures of set 4, although not documented here, are visible in the walls of the drift. Set 2 is orthogonal to each of sets 1 and 3, but the angle between sets 1 and 3 is about 128°. A weak clustering of poles is evident southeast of set 2, but it may be considered a non-uniform dispersion about the mean.

Except for set 2, the distributions of poles about the mean orientations are approximately spherical normal according to the graphical test described by Goodman (1976). Because of this fairly uniform scattering, the limits of each cluster can be approximated by a circular area centered at the mean and roughly corresponding to the 1.5 percent contour. This minimum contour represents a "significance threshold" similar to that described by Mahtab et al. (1972), and equals the average (random) density of the diagram. The cluster radius for sets 1 and 2 is taken as about 20°, while cluster radii defined for sets 3 and 4 are 25° and 15°, respectively. For present simplicity, the significant clustering about the mean of set 2 is considered spherical normal.

Having chosen this expected deviation of fractures from a given mean set orientation, it is possible to identify the sets in the borehole profiles, as shown in Fig. 6.2. It is evident from the figure that fracture spacings within a set are quite variable; hence, a mean spacing is difficult to quantify. An effort is being made to characterize the distribution of joint
spacings. In addition, an interpretation of fracture trace lengths in Fig. 6.1a is being made to quantify length distributions. These results are reported by Thorpe (1979).

6.3 Conclusions

The geological study of the time-scale drift is considerably more detailed than the mapping done by SGU throughout the test site. However, the major features described in this chapter are similar to those reported in chapter 3 in terms of statistical representation. The SGU reconnaissance survey, therefore, appears adequate for characterizing the major fracture system on a scale of tens of meters, while more detailed mapping, such as that performed in the time-scale drift, is necessary for scales on the order of meters.

Detailed mapping and interpretation of subsurface data show that four continuous fractures or faults, plus a pegmatite dike, pass through the time-scale experiment rock mass. Because of their continuity and orientation, these features should be of primary importance to the mechanical behavior of the rock mass, particularly in the case of shear deformation. Statistical analysis of core fractures indicates the existence of three other fracture sets, all believed to be discontinuous with respect to the main features.
7. CHARACTERIZATION OF THE FRACTURE SYSTEM IN THE FULL-SCALE AND EXTENSOMETER DRIFTS

7.1 Introduction

The objective of the full-scale experiment is to study the thermo-mechanical behavior of granite immediately surrounding simulated radioactive waste canisters. The experiment consists of two electrical heaters, H9 and H10, emplaced within the granite approximately 22 m apart. A separate tunnel parallel to the full-scale drift allows for two arrays of horizontal extensometers to be directed radially toward the heaters, as shown in Fig. 7.1a-c. Figure 7.2 is a cross-section of the two drifts.

There are two principal differences between the H9 and H10 heater tests. First, the H9 heater is designed to deliver 3.6-kW power; whereas, the H10 is to have 5.0-kW output. It is intended that these power levels simulate different grades of nuclear waste; or alternatively, different levels of decay prior to emplacement in an underground repository. The second difference is that the H10 heater has a set of eight low-power peripheral heaters which simulate the heating effects of neighboring waste canisters in a repository. In general, the instrumentation for monitoring temperatures and displacements in the experiments is very similar.

As noted in the previous chapter, the principal factor contributing to non-linear, thermo-mechanical response of the local rock mass is the system of geologic discontinuities. Fracturing around the full-scale heaters is intense, just as it is in the nearby time-scale drift. A three-dimensional characterization of the complex local system is essential to interpreting temperature and displacement data, as well as changes in the rock
FULL-SCALE DRIFT

LEGEND
- HEATERS (H) $\phi$ 406 mm
- HEATERS (H) $\phi$ 38 mm
- THERMOCOUPLES (T) $\phi$ 38 mm
- EXTENSOMETERS (E) $\phi$ 76 mm/116 mm
- USBM GAUGES (U) $\phi$ 38 mm
- IRAD GAUGES (C) $\phi$ 38 mm
- MONITORING (M) $\phi$ 56 mm

Fig. 7.1a Vertical borehole layout in the full-scale drift.
Fig. 7.1b  Borehole layout in the extensometer drift--H9 heater area.
Fig. 7.1c  Borehole layout in the extensometer drift--H10 heater area.
properties caused by elevated temperatures. In relation to the evaluation of the time-scale rock mass, the degree to which fracturing can be detailed in the full-scale drift is enhanced by (1) the proximity of the H9 and H10 heaters to the surface, and (2) the greater density of core data, as evident from Fig 7.1. Due to the complexity being sought in each of the full-scale fracture representations, the results presented here are only preliminary and apply primarily to the area around the H9 heater.

7.2 Sources of Data

The data base used to evaluate and describe the fracture patterns in the full-scale drift is similar to that discussed earlier for the time-scale
work. A detailed map of features in the floor of the drift was prepared at a scale of 1:20, and is shown in Fig. 7.3. The walls of the full-scale and extensometer drifts were also mapped; however, only fractures over 1.0-m long were included (versus 0.2 m for the floor map). Wall fracture maps for the extensometer drift are given in Fig. 7.4. Wall fracture maps of the full-scale drift are included with the subsurface fracture profiles discussed later in the chapter. In order to facilitate all mapping, photomosaics were prepared to display the major geologic features in the floor and walls.

The subsurface fracture data consist of core data from the 102 boreholes associated with the two heater tests (Fig. 7.1). Most of the core was not oriented, since it came from 38-mm or 44-mm holes. Thirty-six boreholes, including those with 406-, 76-, and 56-mm diameters, provided reconstructable and oriented core. The initial core logs prepared at the time of drilling typically described only those fractures which were open in the core sample. Later, the numerous sealed fractures or veins were documented by re-logging. Summary logs for the vertical boreholes, showing both open and sealed fractures, are provided in Appendix D. Apparent fracture dips are shown in these borehole logs, depending on the particular cross-section direction.

7.3 Synthesis of Data

The methodology being used to geometrically reconstruct the fracture system near the full-scale heaters is basically the same as that described for the time-scale analysis. Major features in the surface maps were first delineated in the generalized manner shown in Fig. 7.3. These fractures or dikes were then extrapolated into the subsurface and correlated to either
sealed or open features in the core logs of Appendix D. Since the fractures were logged as to infilling type and thickness, as well as orientation, all three of these descriptions were used in the correlation process. In order to visualize and extrapolate discrete features in three dimensions, a physical model (1:20 scale) of the drifts and borehole arrays was fabricated. In the model, transparent vertical cross-sections were oriented radially outward from the main heaters and through various borehole areas. Logged fractures in the borehole profiles were displayed according to their apparent orientations in each particular cross-section, which facilitated their cross-correlation.

7.4 Results

7.4.1 Three-Dimensional Fracture Pattern

A number of cross-sections through the H9 and H10 heater sites shown in Fig. 7.3, are being developed (Paulsson and Kurfurst et al. 1979) which together will display the significant discontinuities in three dimensions. The most illustrative profiles are those oriented vertically along the centerline of the drift and through the main heaters (N51°E). The major features mapped on the walls of the full-scale drift have been projected to the centerline profiles, and these surficial features can then be viewed in relation to their extensions into the subsurface.

Preliminary results of the subsurface reconstructions from the surficially mapped features are shown in Figs. 7.5a and 7.5b, which represent the rock around the H9 and H10 heaters, respectively. In the H9 area, much of the fracturing consists of parallel epidote-filled shear fractures, which in many instances appear sealed in the core samples. These features strike
Fig. 7.3 Detailed and generalized fracture maps of the full-scale drift floor in the vicinity of (a) H9 heater, and (b) H10 heater. Bold letters indicate various profiles through the experiment area. Large arrows represent cross-hole geophysical studies. (XBL 793-659)
Fig. 7.4  Extensometer wall fracture maps for H10 and H9 heater experiments.
roughly perpendicular to the drift centerline (N20°-10°E) and dip 45° to 65° west. Shear displacements up to about 2 m have been inferred on the basis of apparent offsets of a pegmatite dike, shown in Fig. 7.5a. This dike strikes N20°W and dips 57°E, which is similar in orientation to dikes identified in other drifts in the granite. Thinner pegmatite veins (1 cm to 2 cm) pass through the H9 area, and these also are offset by the major shear fractures. A second fracture set can be identified in the area, oriented approximately orthogonal to the shear fractures and parallel to the major pegmatite dike.

Very preliminary results of the subsurface investigation around H10 are shown in the centerline profile of Fig. 7.5b. In general, the fractures in this area are less continuous than those around H9, and therefore are more difficult to extrapolate and cross-correlate with confidence. The area is marked by a minor pegmatite dike oriented N67°W/53°N. This dike is offset approximately 1.75 m by a prominent epidote-filled shear fracture (Fig. 7.5b) which strikes roughly N-S and dips 60°W; however, the trace of this fault has not yet been identified in the subsurface.

### 7.4.2 Statistical Analysis of Core Data

Stereographic plots of sealed and open fractures logged in the H9 and H10 borehole arrays are shown in Figs. 7.6a-c. The general clustering of poles tends to be in the SE quadrant of the diagrams, regardless of whether the fractures are open or sealed. This orientation is approximately that of the major shear fractures described above, which indicates that the fracturing is generally associated with fault zones. The lack of several
Fig. 7.5 Centerline profile of projected wall and sub-floor discontinuities (a) H9 area, and (b) H10 area. "A" profiles are from Fig. 7.3. (XBL 791-253A)
Fig. 7.5  (continued)  (XBL 799-11541)
distinct joint sets, as identified from the larger sampling base in the
time-scale drift, suggests that the overall fracture pattern in the granite
is, at least statistically, represented poorly by the localized sampling
around the H9 and H10 experiments.

In order to study the effect of logging only open fractures in the
core samples, rock quality designation (RQD) values were computed for the
first (open fracture) logging and then re-computed on the basis of all
fractures, assuming that all sealed fractures could be opened by poor-
quality drilling. Core logs showing the open versus sealed RQD values for
vertical boreholes are given in Appendix C. Boreholes in the H10 area
(E-holes) were drilled with double-tube core barrels, whereas the E-holes
near H9 employed the more complicated triple-tube equipment. Although the
total fracture frequency is less in the H10 area than around H9, the former
generally show lower open-fracture RQD values. This indicates that the
significance placed on open fractures in the core can be biased by the
drilling and core recovery technique.
Fig. 7.6 Stereographic plots of poles to fractures from full-scale experiment core logs (Wulff net, lower hemisphere projections): (a) open fractures from E and M holes in the H9 area, (b) sealed fractures from E and M holes in the H9 area, and (c) open fractures from E holes in the H10 area.
Fig. 7.6 (continued)

[XBL 7910-4455]
Fig. 7.6 (continued)
8. SUMMARY

This report presents the results of four different investigations of the Stripa site. Each investigation had different objectives, different sources and types of data. Time constraints as well as resources available to each of the investigators also differed. Thus we wish to re-emphasize that this is not meant to be a final interpretive report on the geology and fracture system at Stripa. Rather, this report is meant to be a compilation of the data accumulated from previous surface and subsurface mapping, mapping associated with this project, and the cores from approximately 3 km of boreholes. Each of the four investigations, whose preliminary results are summarized in this report, are ongoing and will be the subject of future reports. Also, additional interpretative work and fracture analysis will be completed as part of the fracture hydrology and geochemical studies.

The Stripa test site is excavated in granite under the north limb of an ENF, gently dipping, synclinal structure. The site is characterized by a reddish, medium-grained, massive monzogranite that shows varying degrees of deformation. The granite on the surface, in the ventilation tunnel, and in the northern part of the lower tunnel (360-m level) is, in contrast to the upper tunnel (338-m level), in places strongly crushed and sometimes brecciated. The orientation of the joints in general is similar in all of the mapped areas.

There is an absolute dominance of near-vertical, north-dipping fractures. However, the northern part of the upper tunnel is an exception as south-dipping fractures are more numerous than the north-dipping ones. Two strike directions dominate: one with a rather even distribution from N to E
and the second concentrated in a smaller sector from NW to W. Most of the joints are closed and lined with chlorite or occasionally with calcite. Visible water leakage throughout the test area consists of drops and moist fracture surfaces. More sustained seepage is provided by the subsurface boreholes penetrating the rock mass. Mapping of the drill cores showed that the frequency of joints and joint sets is relatively high, and the joints are unevenly distributed along the borehole length.

The results of the fracture mapping show that the Stripa granite is highly deformed and that approximately four joint sets exist in the area of the test excavations. In addition to the joints, the rock mass also contains fissures, fracture zones, and small-scale shear zones so that the complete fracture family is represented. The rock mass is cut by a number of small (10-cm to 15-cm wide) pegmatite dikes and narrow quartz veins. The pegmatites and quartz veins are commonly offset by small-scale faults. The fault zones or traces are usually filled or coated with epidote.

Results of the detailed fracture mapping in the ventilation, time-scale, full-scale, and extensometer drifts are in general agreement with the large-scale fracture mapping of the entire test site area. The detailed mapping provided considerable data on the fracture system and suggests that fractures in three of the sets are discontinuous. The detailed work has shown that the three-dimensional reconstruction of a local fracture system is difficult, and in some cases subjective. Reconstruction work is aided by good quality floor photography, careful core logging, core reconstruction, core orientation, and by the use of physical models.
9. ACKNOWLEDGEMENTS

Work described in the Swedish Geological Survey (SGU) part of this report was done in collaboration with geologists T. Grahn and M. Hammargren, who assisted with the field work. Part 1.2 of chapter 1 was written by State Geologist I. Lundstrom, and part 2.1 of chapter 2 was written by State Geologist G. Peterson and Geologist P. Hammargren.

Participants in the geological mapping for the LRL portion of the report included S. Abrahamson, K.-E. Almen, L. Andersson, T. Daugaard, L. Jacobsson, and U. Jacobsson. D. McCarthy and W. Klauber provided assistance in interpretation of the fracture system in the time-scale drift, and T. Daugaard played a major role in preparing the fracture profiles for the full-scale work. S. Prior, G. Jones, and B. Bearinger assisted with tabulation of fracture data for the ventilation drift and the surface boreholes. The contributions of all these individuals are gratefully acknowledged.

We are grateful to P.A. Halen and the Stallbergsbolagen mining crew of Stripa for providing access and continued logistic support.

We also thank M. Harding and T. Pfeiffer (LBL) for their fine illustration work and S. Berlowitz and L. Egenberger (LBL) for their editorial help.
10. REFERENCES


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11. GLOSSARY

**Joint**
A break of geologic origin in the continuity of a body of rock occurring either singly, or more frequently in a set or system, but not attended by a visible movement parallel to the surface of discontinuity.

**Fissure**
A gapped fracture.

**Fracture**
The general term for any mechanical discontinuity in the rock; it therefore is the collective term for joints, faults, cracks, etc.

**Fracture zone**
Dense zone of sub-parallel fractures.

**Fault**
A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture.

**Dike**
A tabular body of igneous rock that cuts across the structure of adjacent rocks or cuts massive rocks.

**Granite**
A term referring loosely in this report to any light-colored, coarse-grained igneous rock. The Stripa "granite" is more properly classed as "quartz monzonite."

**Leptite**
European term referring to a broad classification of metasedimentary rock.

**Ventilation Experiment**
Experiment at Stripa in which the minute amounts of water seeping into a cavern are being measured via the humidity of the ventilation air.

**Ventilation Tunnel**
Horizontal tunnel connecting the ventilation shaft with the mine workings.

**Ventilation Drift**
A tunnel in the underground experiment area being used for the ventilation experiment.

**Shear Zone**
Synonymous with fault.

**RQD**
(Rock Quality Designation) percent modified core recovery, calculated from drilling logs by deleting from the "recovered" category all pieces of core less than 10 cm long.
12. APPENDICES

APPENDIX A. Fracture Logs for Stripa Dbh-1, Dbh-2, SBH-1, and SBH-2.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
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<tr>
<td>Fig. A.1</td>
<td>Key to fracture logs</td>
<td>94</td>
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<td>Rock-distribution of Dbh-1</td>
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<td>Fig. A.3</td>
<td>Rock-distribution of Dbh-2</td>
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<td>Fig. A.7</td>
<td>Detailed fracture log for Dbh-2</td>
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<td>Fig. A.8</td>
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<td>Fig. A.9</td>
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<td>Fig. A.10</td>
<td>RQD values for DbhV-1</td>
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<td>Fig. A.11</td>
<td>Detailed fracture logs for SBH-1</td>
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<td>Fig. A.12</td>
<td>RQD values for SBH-1</td>
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<td>Fig. A.13</td>
<td>Detailed fracture log for SBH-2</td>
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</tr>
<tr>
<td>Fig. A.14</td>
<td>RQD values for SBH-2</td>
<td>123</td>
</tr>
</tbody>
</table>
Coated fractures, 0° to 30° angle to the drill-core axis.
Coated fractures, 31° to 60° angle to the drill-core axis.
Coated fractures, 61° to 90° angle to the drill-core axis.
Fractures with clean irregular faces.

Disturbed zones
Crushed zone
Fracture zone with mainly coated fracture surfaces
Fracture zone with clean, irregular fracture surfaces
Shear zone
Slickenside (striated surface)

Infilling material in fractures; list of abbreviations
Bi Biotite
L Clay
C Calcite
K Chlorite
Cu Chalcopyrite
E Epidote
F Fluorspar
Fe Iron oxides, rust
Fs Feldspar
H Hornblende
Mo Molybdenum
Mu Muscovite
Pb Galena
P Pyrite
Q Quartz
Se Sericite
T Talc
Zn Zinc blende
Pc Pegmatite
S Sulfide
M Mica

ROD-Factor
RQD with respect to smooth, often coated, fracture surfaces
RQD with respect to the total number of fractures

Fig. A.1 Key to fracture logs.
0.00 to 45.00  Reddish, medium grained massive granite; some short 10 to 20-cm darker sections (biotite-richer) from 30 m, some greyer granite.

45.00    End.

Fig. A.2  Rock distribution of Dbh-1.

0.00 to 100.80  Reddish, grey, seldom red, medium-grained massive granite. Little variation in coloration; no notable transitions.

23.00 to 23.70  Grey, biotite-poor granite.

34.20 to 36.50  Several annealed fractures: small sections of brecciated rock.

75.30 to 75.70  White pegmatite.

91.00 to 93.00  High content of dark minerals.

93.50 to 99.00  Many chlorite-infilled fractures.

100.80    End

Fig. A.3  Rock distribution of Dbh-2.
<table>
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<tr>
<th>Range</th>
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<tr>
<td>0.00 to 8.10</td>
<td>White to grey granite.</td>
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<tr>
<td>8.10 to 12.40</td>
<td>Reddish granite; sporadically brecciated.</td>
</tr>
<tr>
<td>12.40 to 31.00</td>
<td>Reddish granite.</td>
</tr>
<tr>
<td>31.00 to 48.60</td>
<td>Grey granite.</td>
</tr>
<tr>
<td>48.60 to 50.60</td>
<td>Grey granite; sporadically dark grey and probably earlier a dolerite; pyrite impregnated.</td>
</tr>
<tr>
<td>50.60 to 72.20</td>
<td>Reddish granite.</td>
</tr>
<tr>
<td>65.00 to 67.70</td>
<td>Epidote-filled fractures (epidote veins)</td>
</tr>
<tr>
<td>72.20 to 75.00</td>
<td>Grey granite.</td>
</tr>
<tr>
<td>75.00 to 87.50</td>
<td>Reddish granite.</td>
</tr>
<tr>
<td>77.00 to 79.00</td>
<td>Redder variant of granite.</td>
</tr>
<tr>
<td>87.00 to 87.50</td>
<td>Crushed zone; many small infilled fractures; high content of dark minerals.</td>
</tr>
<tr>
<td>87.50 to 90.00</td>
<td>Reddish granite; less quantity of dark minerals than in the test of the granite.</td>
</tr>
<tr>
<td>90.00 to 103.00</td>
<td>Reddish granite</td>
</tr>
<tr>
<td>103.00 to 138.00</td>
<td>Grey to reddish granite.</td>
</tr>
<tr>
<td>138.00 to 158.00</td>
<td>Reddish granite.</td>
</tr>
<tr>
<td>158.00 to 196.00</td>
<td>Grey granite.</td>
</tr>
<tr>
<td>196.00 to 203.00</td>
<td>Reddish granite.</td>
</tr>
<tr>
<td>203.00 to 262.00</td>
<td>Grey granite; number of dark minerals are variable.</td>
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<tr>
<td>262.00 to 273.00</td>
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<tr>
<td>296.00 to 300.20</td>
<td>One zone with many chlorite infilled fractures at 45°.</td>
</tr>
<tr>
<td>298.00 to 300.20</td>
<td>Reddish granite with intruded pegmatites; broad quartz and chlorite-filled fractures.</td>
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<tr>
<td>300.20 to 358.50</td>
<td>Red, medium- to fine-grained massive granite.</td>
</tr>
<tr>
<td>319.50 to 325.00</td>
<td>Reddish granite</td>
</tr>
<tr>
<td>325.00 to 331.00</td>
<td>Red granite</td>
</tr>
<tr>
<td>331.00 to 332.00</td>
<td>Fine-grained dolerite.</td>
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<tr>
<td>332.00 to 358.50</td>
<td>Red, medium- to fine-grained massive granite.</td>
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<tr>
<td>356.70 to 357.20</td>
<td>Pegmatite.</td>
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<td>366.50 to 404.40</td>
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<td>372.00 to 373.50</td>
<td>Granitised dolerite.</td>
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<tr>
<td>375.00 to 376.00</td>
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<td>392.50 to 392.70</td>
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<td>404.40 to 407.00</td>
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<td>407.00 to 418.30</td>
<td>Red to reddish granite; brecciated zone.</td>
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<td>419.30 to 464.00</td>
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<td>429.00 to 430.50</td>
<td>Granitised dolerite</td>
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<tr>
<td>464.00 to 471.40</td>
<td>Reddish granite.</td>
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<td>471.40</td>
<td>End.</td>
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</table>

Fig. A.4 Rock distribution of DbhV-1. Unless stated to the contrary, the granite is medium grained and massive.
RQD with respect to smooth often coated fracture surfaces
RQD with respect to the total number of fractures

Total depth 45 m

(XBL 799-11963)

Fig. A.5 RQD values for Dbh-1. (SGH-KBS project P23:02, 1977).
Fig. A.6 Detailed fracture log for Dbh-1. (SGU-KBS project P23:02, 1977).
Fig. A.7  Detailed fracture log for Dbh-2. (SGU-KBS project P23:02, 1977).
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(XBL 799-11967)

**Fig. A.9** Detailed fracture log for DbhV-1. (SGU-KBS project P23:02, 1977.)
Fig. A.9 (continued)
Fig. A.9 (continued)
Fig. A.9 (continued)
Fig. A.9 (continued)
Fig. A.10  RQD values for DbhV-1. (SGU-KBS project P23:02, 1977).
RQD with respect to smooth, often coated fracture surfaces

RQD with respect to the total number of fractures

Fig. A.10 (continued)
RQD with respect to smooth, often coated fracture surfaces

RQD with respect to the total number of fractures

Fig. A.10 (continued)
Fig. A.10 (continued)
RQD with respect to smooth, often coated fracture faces

RQD with respect to the total number of fractures

Total depth 471.40 m

Fig. A.10 (continued)
Fig. A.11 Detailed fracture log for SBH-1. (XBL 799-11930)
Fig. A.11 (continued)
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**LENGTH (m)**

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**Fig. A.11 (continued) (XBL 799-11933)**
Fig. A.12 RQD values for SBH-1.

(XBL 799-11934)
Fig. A.12 (continued)
Fig. A.12 (continued)
Fig. A.13 Detailed fracture log for SBH-2.
Fig. A.13 (continued)
Fig. A.13 (continued)
Fig. A.14 RQD values for SBH-2.
Fig. A.14 (continued)
Fig. A.14 (continued)
APPENDIX B. Fracture and RQD Logs for R and H-G Boreholes.

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(XBL 799-11950)
LENGTH (M) | R4 | R5 | R6
---|---|---|---
- 0 | | | |
- 5 | | | |
- 10 | | | |
- 15 | | | |
- 20 | | | |
- 25 | | | |
- 30 | | | |
- 35 | | | |
- 40 | (XBL 799-11953) | | |
LENGTH (M)  | R7          | R8          | R9          
---         | ---         | ---         | ---         
0           |             |             |             
5           |             |             |             
10          |             |             |             
15          |             |             |             
20          |             |             |             
25          |             |             |             
30          |             |             |             

(XBL 799-11954)
APPENDIX C. Fracture and RQD Logs for Boreholes in the Time-Scale Experiment Site

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<tr>
<td>RQD logs</td>
<td>147</td>
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</table>
TIME-SCALED EXPERIMENT
Fracture Logs

E1

Depth (meters)

E2

70 K, C
65 K, C
55 K, C
45 K, C
35 K, C
25 K, C
15 K, C
5 K, C
0 K, C

E3

70 K, C
65 K, C
60 K, C
55 K, C
50 K, C
45 K, C
40 K, C
35 K, C
30 K, C
25 K, C
20 K, C
15 K, C
10 K, C
5 K, C
0 K, C

(XBL 791-88)
TIME-SCALED EXPERIMENT
Fracture Logs

E4  E5  H1

Depth (meters)

142
### TIME-SCALED EXPERIMENT

**Fracture Logs**

**H5**

- Depth (meters)
  - 0: K, C
  - 1: K, C
  - 2: K, C
  - 3: K, C
  - 4: K, C
  - 5: K, C
  - 6: K, C
  - 7: K, C
  - 8: K, C
  - 9: K, C
  - 10: K, C
  - 11: K

**H6**

- Depth (meters)
  - 0: K, C
  - 1: K, C
  - 2: K, C
  - 3: K, C
  - 4: K, C
  - 5: K, C
  - 6: K, C
  - 7: K, C
  - 8: K, C
  - 9: K, C
  - 10: K

**H7**

- Depth (meters)
  - 0: K
  - 1: K
  - 2: K
  - 3: K
  - 4: K
  - 5: K
  - 6: K
  - 7: K
  - 8: K
  - 9: K
  - 10: K

(XBL 791-87)
TIME-SCALED EXPERIMENT
Fracture Logs

H 8

M 1

M 2

Depth (meters)
(XBL 799-11925)

(XBL 799-11926)

(XBL 799-11927)

(XBL 799-11928)
APPENDIX D. Fracture Logs and RQD Diagrams, and Pole Plots for Full-Scale Heater Boreholes M 6 to 9 and E 6 to 11 (H-9 Area)*, Plus a Plot of All Open Fractures in Boreholes E 12 to E 17 (H-10 Area)

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Page</th>
</tr>
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<tbody>
<tr>
<td>M6</td>
<td>153</td>
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<tr>
<td>M7</td>
<td>154</td>
</tr>
<tr>
<td>M8</td>
<td>155</td>
</tr>
<tr>
<td>M9</td>
<td>156</td>
</tr>
<tr>
<td>E6</td>
<td>157</td>
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<tr>
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<td>E10</td>
<td>161</td>
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<tr>
<td>E11</td>
<td>162</td>
</tr>
<tr>
<td>E12 to 14</td>
<td>163</td>
</tr>
<tr>
<td>E15 to 17</td>
<td>164</td>
</tr>
</tbody>
</table>

*Fractures in the left column are shown with their apparent dips in a cross section striking N51°E, except for E9, which strikes N89°E.
M-7 Pole plot

Open fractures

Sealed fractures

Wulff net lower hemisphere projection

H9 AREA

(XBL 7910-13069)
Length (m) | M-8
---|---
Open and sealed | Open

M-8 Pole plot

Open fractures:
- cl, col
- ep
- op
- opq

Sealed fractures:
- cl,.col
- ep
- op
- opq

Wulff net lower hemisphere projection

H9 AREA

(XBL 7910-13074)
M9 Pole plot

Open fractures:
- ecl, cal
- ep
- apeg

Sealed fractures:
- ecl, cal
- ep
- apeg

Wulff net lower hemisphere projection

H9 AREA

(XBL 7910-13070)
Sealed fractures
cl, cal, ep, cpeg

Open fractures
cl, cal, ep, cpeg

1. Open and sealed fractures
2. RQD
3. Pole plot
4. Wulff net lower hemisphere projection
5. E-6 Pole plot
6. Open fractures
7. Sealed fractures
8. E-6 Pole plot
9. H9 AREA

(XBL 7910-13073)
E-9 Pole plot

Open fractures Sealed fractures
\( \text{vcl, cal} \) \( \text{vcl, cal} \)
\( \text{ep} \) \( \text{ep} \)
\( \text{ap eg} \) \( \text{ap eg} \)

E9 Length (m)

Open and sealed

1 several ep & cl 10 ep (1) 19 cl (2)
fractures cl (2) 20 ep (3)
2 ep zone cl (1/1) 21 ep (3)
3 cl zone 12 ep (1) cl (2)
4 cl (1/1) 13 cl (2) 22 cl (2)
5 cl (1) 14 ep (1) 23 ep (2)
6 ep (1) cl (1) 24 ep (2)
7 ep (2) cl (2) cl (1)
8 cl (4) 17 cl (2) Wulff net lower hemisphere projection
9 ep (2) 18 ep (1)
10 cl (3) cl (1)

H9 AREA

(XBL 7910-13066)
Open fractures
vel
N
Sea led fractures
vel
N51°E
(XBL 7910-13067)

Wulff net lower hemisphere projection

E-10 Pole plot

Open fractures
vel, cal
ep
apeg
H9 AREA

Sealed fractures
vel, cal
ep
peg

(XBL 7910-13067)
Open and sealed fractures

Sealed fractures

Open fractures

Wulff net lower hemisphere projection

E-11 Pole plot

H9 AREA
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