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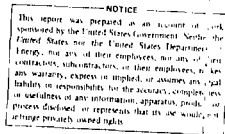
STRESS MEASUREMENTS IN THE STRIPA GRANITE

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PREFACE

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

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

Previously published technical reports are listed below.

1. *Swedish-American Cooperative Program on Radioactive Waste
   Storage in Mined Caverns* by P.A. Witherspoon and O. Degerman.
   (LBL-7049, SAC-01)

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

3. *The Mechanical Properties of Stripa Granite* by Graham Swan
   (LBL-7074, SAC-03)

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1.   SUMMARY

Rock stress measurements at the 348 m level of the Stripa Mine have been
carried out with the Leeman tri-axial equipment. The largest principal stress
is found to be 20.0 MPa and directed parallel with the strike of the contact
between the granite and the orebody. The intermediate principal stress is
11.4 MPa and directed almost horizontal and perpendicular to the contact.
The minor principal stress has a magnitude of 5.4 MPa. The deduced vertical
stress is approximately of the same value as can be theoretically calculated.

2.   INTRODUCTION

In order to solve the problems of nuclear waste storage the owners of
the nuclear plants in Sweden organized Nuclear Fuel Safety (KBS) in late
fall 1976.

Some of the reasearch that KBS performed took place in an abandoned iron
ore mine in Stripa, situated in the central part of Sweden. Adjacent to the
mine lies a massive body of granite where all experiments have been accom-
plished.

One of the investigations that took place in the Stripa granite was
stress measurements. These have been carried out by the Division of Rock
Mechanics, University of Luleå, Sweden.

3.   SHORT DESCRIPTION OF THE MEASURING METHOD

The method that was used for determination of the stress tensor was the
Leeman three-dimensional overcoring method. The method is based upon deter-
mination of strain in a borehole by using strain gauges. Twelve strain gauges
are divided into three rosettes spaced at an angle of 120° around the

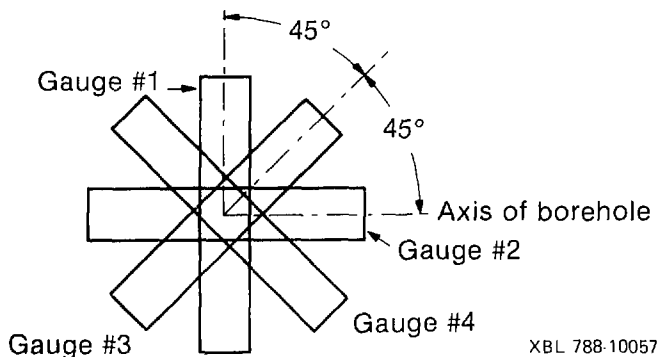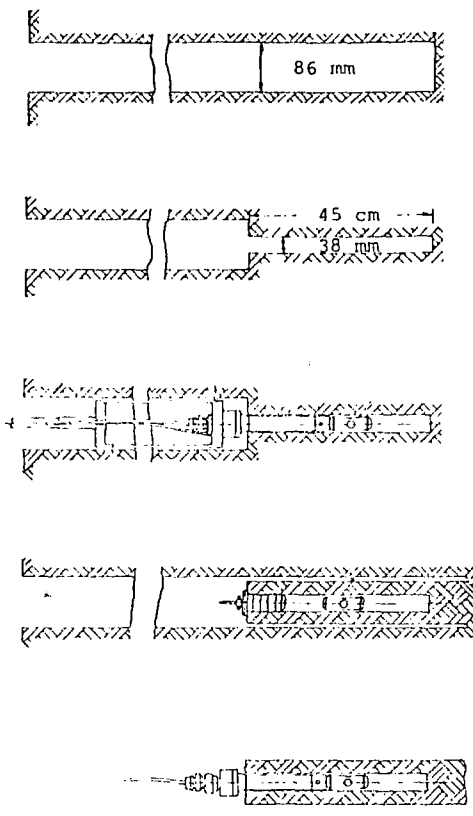perimeter of an EX drill hole. The layout of the rosette is shown in Fig. 1.

Fig. 1. The strain rosette of a triaxial cell.

In principle, the way of doing the measurements is shown in Fig. 2. An
86-mm borehole is drilled to the required depth. The bottom of the hole is
flattened with a full face diamond bit. Concentric with the 86-mm borehole
an EX hole (38 mm) is drilled for a distance of 45 cm. After the hole is
cleaned, a triaxial strain cell with three strain gauge rosettes is glued in
the EX portion of the hole. After the glue has hardened and stable readings
of the strain gauges have been recorded, the EX hole is plugged and a cylin-
der is overcored, as shown in Fig. 2d. The cylinder is then removed from the
borehole and the strain obtained is recorded by reading the 12 strain gauges.

In each measuring location the stress tensor can be determined by know-
ing the Young's Modulus and Poisson's Ratio of the rock. These properties
are determined from the core associated with each measuring location in the
borehole.

In order to check the reliability of the gauge readings, the overcored
cylinder with the bounded triaxial cell is carefully tested in the laboratory.

a)   The borehole is drilled into
     the rock mass to the point
     where the stress in the rock
     is to be measured.

b)   A plot hole 45 cm ɩ ɔg is
     drilled into the eno of and
     concentric with the main
     borehole.

c)   After cleaning and drying of
     the pilot hole, the triaxial
     cell is inserted and the
     strain gauges are glued. When
     the glue has set, strain read-
     ings are taken.

d)   The pilot hole is plugged and
     the triaxial cell is overcored.

e)   The core is broken at the end
     of the borehole and stress re-
     lieved strain readings are taken.

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Fig. 2. The principles of rock stress measurements using the
overcoring technique. (From Instruction Manual for the use of
the C.S.I.R. rock stress measuring equipment.)

4. LOCATION OF BOREHOLE FOR THE MEASUREMENTS

The measurements were carried out in a borehole located in a drift at
348-m level. Determination of direction of the borehole was based upon the
strike and dip of visible fractures in the drift. Two dominating sets of
fractures were observed. The first set had a strike of N-S and a dip of 70° W.
The second set had a strike of N69-70° E and a dip of 65° W. Additional frac-
ture mapping in the main drift of the test site was carried out by SGU
(Swedish Geological Survey), as shown in Fig. 3.

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Fig. 3. Stereographic pro-
jection of joint surfaces
from the main drift of the
test site. Data from
Olkiewicz, 1977.
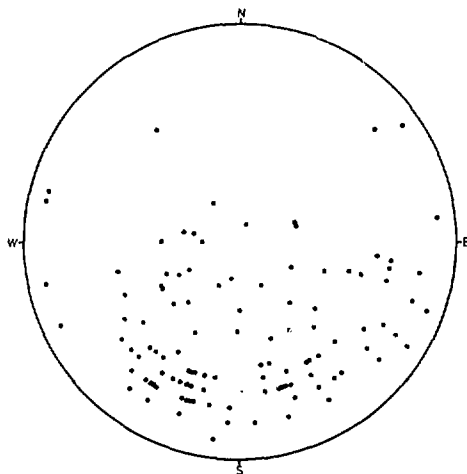
The effort was then made to orient the borehole so that no axial frac-
tures would appear in the core, since this would have affected the continuity
of the measurements. A diabase dike in the end of the drift also contributed

to determining the direction of the borehole. The same dike is observed else-
where in the mine, and has a width varying between 1.5-2.0 m. The decision
was made to drill through the dike and start the measurements at the location
in the borehole where the virgin stresses were not affected by the dike. The
test site and the direction of the borehole are shown in Fig. 4.
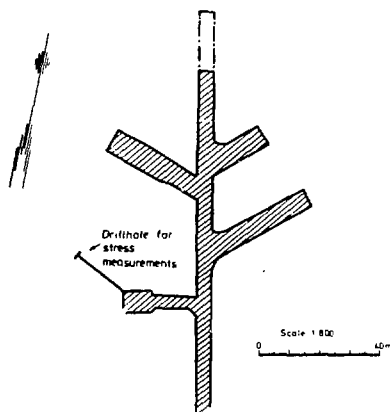
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Fig. 4. Location of rock stress
measurements at the 348 m level.

The results from the stress measurements were intended to be used for the
purpose of orienting the boreholes in a heater test to be accomplished in the
same drift. In order to get a satisfactory and reliable determination of the
stress tensor in the granite, the measurements were carried out at a great
number of locations in the borehole.

5. MECHANICAL PROPERTIES OF THE GRANITE

For the computation of the stress tensor, Young's Modulus and Poisson's
Ratio have to be known. These parameters have been determined from cores
sampled in association with the strain measurement locations in the borehole.
The cores have a diameter of 72 mm and a length of 180 mm, i.e., $1/d = 2.5$.
The determined parameters are tabled below. The values are secantvalues at
50% failure load.

Depth [m]	Young´s Modulus [GPa]	Poisson´s Ratio ν	Failure load [MPa]
6.03	59.97	0.19	151.39
7.68	56.46	0.17	140.40
8.53	59.94	0.19	152.50
10.10	61.68	0.22	141.40
11.44	59.06	0.19	154.70
$\overline{m}$	59.42	0.192	148.01

As shown in the table, the variation between Young's Modulus and Poisson's
Ratio is very small. The decision was made to use $E = 59.42$ GPa and $\nu = 0.192$
for all computations, since a minor change in these parameters has almost no
effect on the magnitudes and no effect on the directions of the stresses.

6. RESULTS FROM THE MEASUREMENTS

The stress tensor has been determined at 19 locations along a 20-m-long subhorizontal borehole at the 348 m level. As mentioned earlier, the borehole was drilled through a diabase intercept which ended after 0.87 m. In order to check the influence of the dike on the stresses in the granite, the first measuring location was placed at a depth of 1.55 m in the borehole. Unfortunately, the diabase again occurs at 2.05 m. At 2.87 m the diabase ends and the granite persists throughout the remainder of the borehole. Close to the dike the granite was highly fractured, which made it impossible to perform any measurements. As a result of this the second strain measurement was located at 4.41 m. The last strain measurement was located at a depth of 19.63 m.

Table I shows the measured strain for each gauge at each location in the borehole. Table II shows the calculated principal stresses for each location. In Fig. 5 the principal stresses are plotted as a function of depth of the borehole. The orientation of the principal stresses is shown in Fig. 6.

Table I. Strain measurements from each data point. A Young's Modulus of 59.42 GPa and Poisson's Ratio of 0.192 were used in the calculations.

| Depth (m)	Strain											
1.55	148	126	337	-50	47	102	185	-2	425	118	19	410
4.41	110	74	336	977	-220	100	182	323	426	190	100	426
6.03	210	124	253	1	-143	44	60	358	369	158	-6	502
6.53	203	75	401	-50	-140	179	139	-17	205	112	0	398
7.68	100	57	267	-113	75	155	202	7	639	178	61	686
8.53	253	243	405	109	-108	219	72	18	491	197	164	472
9.08	39	267	114	191	38	247	299	21	1911	392	497	870
9.60	96	188	335	-34	82	175	250	8	771	188	182	797
10.93	278	200	401	87	-7	220	155	39	1163	226	475	910
11.44	235	176	400	35	230	272	475	35	977	217	212	998
12.22	405	100	496	65	-44	95	121	-72	118	60	355	915
13.31	281	67	217	122	10	49	78	-32	255	59	31	298
13.87	248	181	136	236	54	241	235	88	443	234	293	388
14.37	165	236	169	199	222	114	272	69	636	99	233	480
15.43	43	144	183	16	141	188	233	41	488	158	110	512
16.54	164	48	185	29	538	60	328	239	1057	132	528	708
17.02	410	18	161	310	-84	82	80	-38	482	61	198	350
17.83	523	-43	148	340	-69	61	39	-42	843	9	457	376
19.63	-19	34	0	33	234	44	261	10	558	74	182	371
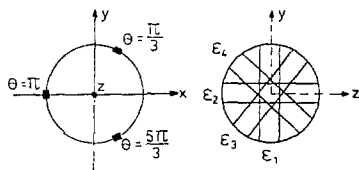
Table 11.   Calculated principal stresses.

Depth	Principal stresses			Vertical comp.	Secondary horiz. and principal stresses	
[m]	[MPa]			[MPa]	[MPa]	
					A	B
1.55	13.46	6.08	3.92	11.58	6.16	5.20
4.41	12.28	7.98	2.26	6.02	11.76	6.44
6.73	15.00	5.50	1.80	4.80	11.24	4.04
6.73	13.86	5.26	1.88	6.94	16.24	4.50
7.68	19.36	8.44	4.04	11.56	11.83	8.40
8.53	18.58	10.64	3.16	12.22	14.3	5.30
9.08	27.28	21.38	3.48	17.20	29.64	11.25
9.60	23.06	12.26	5.18	14.04	15.92	11.41
10.93	28.96	18.30	6.10	10.62	24.61	18.10
11.44	29.80	16.88	10.40	18.26	22.39	17.26
12.22	29.52	11.74	6.88	10.68	20.69	11.74
13.31	9.78	6.44	3.28	4.82	9.87	4.80
13.87	16.96	12.30	5.62	14.62	14.65	5.63
14.37	17.36	13.14	7.26	10.48	15.75	11.51
15.43	16.60	9.42	4.42	11.74	10.62	8.08
16.54	27.5	12.68	10.30	11.56	26.70	12.21
17.02	14.18	8.70	3.30	5.98	11.85	8.34
17.83	21.58	6.48	4.08	11.62	14.68	5.86
19.63	13.94	6.98	2.78	3.70	13.64	6.36
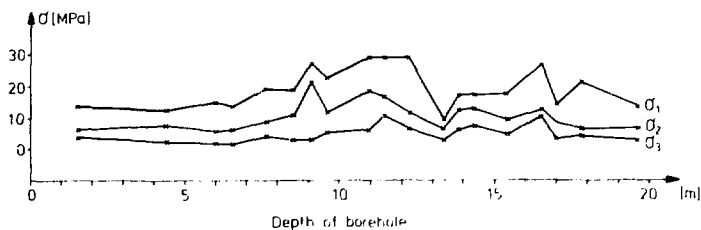
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Fig. 5. Variation of principal stresses in the borehole.
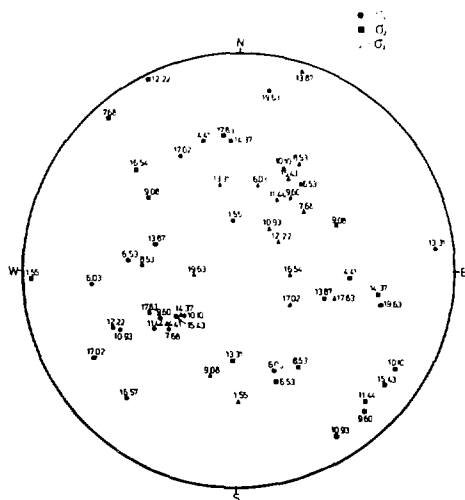
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Fig. 6. Direction of principal stresses at each measure point plotted. Depth of measurement in the borehole is indicated on Wulff's net lower hemisphere.

7. COMMENTS ON THE RESULTS

In spite of the fact that there is a fairly wide scattering of the orientation of the principal stresses, there is a maximum of σ_1 with a dip of approximately $40°$ in the direction of S60°W. The corresponding maximum for σ_3 is a dip of approximately $50°$ in the direction of N40°E. The medium principal stress is more or less horizontal. The location of these measurements is in the interval 6.03-16.53, i.e., well spread along the borehole.

The mean value of the magnitude and orientation of the principal stresses has been calculated within the interval 6.03-16.53 m. The computed principal stresses have been calculated from the mean value of gauges 1, 2, 3 ..... 12 along the borehole. The result, which is plotted in Fig. 7, shows that the maximum principal stress σ_1 has the magnitude 20 MPa and is oriented with a dip of $31°$ in the direction S68°W.
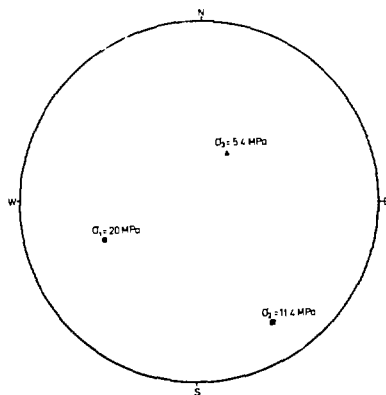

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Fig. 7. Principal stresses and their directions for the test site, Stripa mine, 348 m level.

The medium principal stress $_2$ has been computed to 11.4 MPa and with a dip of 13' in the direction of S32 E. The minimum principal stress $_3$ has the magnitude 5.4 MPa and a dip of 56 in the direction of N29 E.

The measured vertical stress is 9.8 MPa. An overburden of 348 m and a density of 2.7 give a theoretical value of 9.40 MPa, i.e., the deduced vertical component is within 5 of the theoretically derived value.

The biaxial horizontal components, $_A$ and $_B$, of the principal stresses have also been computed. These are called "secondary horizontal principal stresses" and are listed in Table II. The mean value for $_A$ is 15.58 MPa; and for $_B$, 8.64 MPa.

B. CORRELATION WITH GEOLOGICAL STRUCTURES

Unfortunately very little has been published about the geology and especially the tectonic features of the rocks in the Stripa area.

The regional and mine maps show that the rocks are striking in a NE direction and are steeply dipping towards SE. The ore that was mined at Stripa was a quartz-banded iron ore. The main ore had the appearance of a folded disc and the strike was approximately NE. Close to the surface the ore was steeply dipping towards SE, but in deeper regions the dip was very shallow. Bordering the ore was a leptite and a serorogenic granite in which the stress measurements took place. The shallow dip of the ore at deeper regions is believed to be caused by the intrusion of the granite.

The contacts between the rocks undulate both within and between different levels in the mine. At the 348-m level where the measurements were carried out, a strike of N45°E can be observed; and the distance to the contact between the granite and the ore is approximately 100 m.

The main principal stress σ_1 is measured to be 20 MPa, and the orientation is more or less parallel to the strike of the granite. The medium principal stress, σ_2, which has been measured to be 11.4 MPa, has a subhorizontal orientation and the direction is almost perpendicular to the contact of the granite.

It is not certain that the calculated stress tensor is the same for the granite intrusion as a whole. Faults and folds which have a general appearance in the Stripa granite disturb the stress field. The only way to get a more detailed picture of the stress tensor in the Stripa granite is to do more measurements at suitable locations in the area.

9.   REFERENCES

Denkhaus, H. G., Instruction Manual for the Use of the C.S.I.R. Triaxial Rock Stress Measuring Equipment. C.S.I.R. - Report MWF 4401, Pretoria 1973.

Olkiewicz, A., Personal communication. Swedish Geological Survey, 1977.