Title

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ABSTRACT

This paper describes the results of stress measurements at Stripa, compares the results obtained by different techniques, and recommends a stress measurement program for a hard rock repository site. The state of stress at the Stripa Mine has been measured both in a 381 m deep hole drilled from the surface and in holes drilled from the drifts underground. Hydraulic fracturing and several overcoring methods have been used (Lulea triaxial gauge, CSIRO gauge, USBM gauge, Swedish State Power Board deep-hole Leeman triaxial gauge). The results of overcoring and hydraulic fracturing agree well, particularly for the magnitude and orientation of the greatest stress. A recommended program for stress measurement at a repository site would include hydraulic fracturing and deep-hole overcoring in a deep hole drilled from surface, and overcoring (Lulea gauge and USBM gauge) and hydraulic fracturing from holes drilled from underground openings when access is available. Propagation of the hydraulic fractures should be monitored acoustically to determine their location and orientation.

1. INTRODUCTION

Over the past several years stress measurements have been performed at the Stripa Mine in conjunction with the rock mechanics and hydrologic tests performed at the site. As a result of this work, there is now an extensive data base which is useful both for analyzing the results of the experiments that have been performed at the site and for developing stress measurement programs for other hard rock repository sites.

This paper serves three purposes. First, it summarizes the results of all the stress measurements that have been performed at the site. Second, it presents a comparison of the results by different methods and in different locations around the mine. Third, it makes suggestions as to how stress measurement programs can be designed for other hard rock repository sites. Due to limitations of space, detailed descriptions of the techniques used and the results are not included in this paper. This information is presented by Doe and others [1].

2. HISTORY OF STRESS MEASUREMENT ACTIVITIES

The first stress measurements were performed by Carlsson [2] in 1977 as part of the University of Luleå heater tests. The Leeman triaxial gauge was used for the measurements which were performed in a 20m hole drilled from the Luleå drift (Figure 1).

In 1980, an extensive stress measurement program was undertaken as part of the LBL-KBS Swedish-American Cooperative (SAC) project. The first phase of this program was to determine the stresses at a distance where the mine effects would be negligible. A 381 m vertical borehole, SBH-4, was drilled about 400 m north of the experimental area (Figure 1). The Swedish State Power Board performed stress measurements using their unique deep-hole Leeman gauge at hundred meter intervals over the length of the hole. After the drilling was complete, stress measurements were carried out by hydraulic fracturing. This effort represented the first time hydraulic fracturing and overcoring had been carried out in a common deep hole.

The second phase of the SAC program work was a series of stress measurements performed in the area between the Extensometer and Full Scale Heater test drifts underground (Figure 1 and 2). A vertical hole, BSP-1, was drilled in the floor of the Full Scale drift for measurements using hydraulic fracturing and the Swedish State Power Board Leeman gauge. Horizontal holes BSP-2 and BSP-3 were drilled from the Extensometer drift under the Full Scale drift for hydraulic fracturing and overcoring. BSP-1 and 2 were 76 mm in diameter; BSP-3 was 150 mm in diameter. The overcoring methods included the CSIRO triaxial gauge, the University of Luleå (LuH) triaxial gauge, and the USBM borehole deformation gauge.

The most recent stress measurements have been made in borehole V1 which is collared at the 360 meter level of the mine [3]. The Power Board has performed two sets of four measurements each at hole depths of 150 and 300 meters. These measurements are the deepest that have been made at the site.

3. FAR FIELD MEASUREMENTS

3.1 Stress Measurement Data

Measurement of the stresses in deep hole SBH-4 has been described elsewhere [4]. The Power Board triaxial gauge has been adapted from the Leeman triaxial gauge for use in deep holes by wireline emplacement. The gauge measures the complete state of stress through the response to overcoring of three strain gauge rosettes, each having three components. The rosettes are cemented to the wall of a 36 mm pilot hole which is then overcored with a conventional 76mm (NX) double tube core barrel. The data exhibit a large degree of scatter in the magnitudes [4]; however, there is consistency in the orientations of the principal stresses. The greatest principal stress is oriented horizontally, but the other principal stresses are generally skewed with respect to the vertical and horizontal. Hence the usual assumption in hydraulic fracture data analysis that the borehole is oriented in the direction of one of the principal stresses is not met.

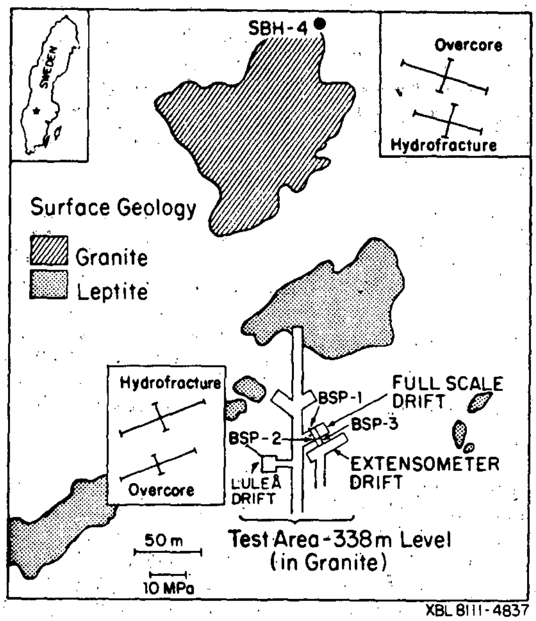


Figure 1. Map of Stripa Mine showing location of test areas and stress measurement holes.

The methods used to interpret the hydraulic fracturing records are described in detail in Doe and others [4]. Briefly. the methods use the first breakdown pressure and a tensile strength term determined in laboratory testing. This method is considered more reliable than second breakdown techniques [5,6] for sites where the ratio of the horizontal stresses exceeds two [4], as for such ratios the theoretical second breakdown pressure is less than the shut in pressure. The tensile strength term has been derived using methods of statistical fracture mechanics [7] which take into account the differences of size effect and sample geometry between laboratory tests and field fracturing tests. The orientations of the fractures were obtained using a wireline impression packer which contained a borehole survey compass for packer orientation.

2.2 Comparison of the Far-Field Hydraulic Fracturing and Overcoring Results

The results of the overcoring and hydraulic fracturing have been compared based on the orientation of the maximum horizontal stress, and the magnitudes of

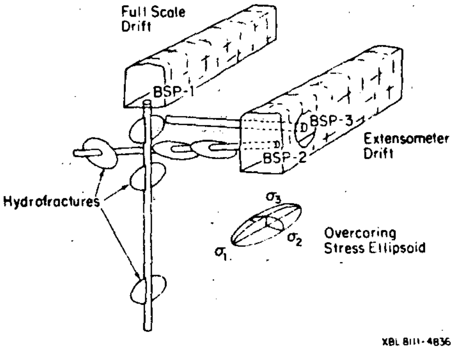


Figure 2. Cartoon of Full Scale drift area showing locations of stress measurement holes, orientations of hydraulic fractures, and approximate overcoring stress ellipsoid.

the maximum and minimum horizontal stresses at a depth of 320 m in the hole. This is the approximate depth of the test facility. The horizontal stresses are used for comparison because the hydraulic fracture test is generally thought to measure mainly the stress components normal to the borehole. The true stress magnitude at the test facility depth is estimated by interpolation of a linear regression of stress versus depth.

The orientation of the maximum horizontal stress depth is shown as a function of depth in Figure 3. The mean values of 9 hydraulic fractures and 11 overcores below 200 m stress direction agree within a one degree of N 83 W. The 95% confidence levels for the means are determined using the methods of Mardia [8] and are both about ± 20 degrees. Thus one can conclude that the correspondence between the overcoring and hydraulic fracturing is quite good. The confidence intervals could have been improved to about ± 15 degrees had over twenty measurements been made. Further improvement in the statistics with larger numbers of measurements would probably not be practical from the standpoint of cost and from the lack of suitable test zones.

The magnitudes of the secondary principal stresses for the overcoring and the hydraulic fracturing are shown as a function of depth in Figures 4 and 5. The data have been fitted to regression lines whose coefficients are given in the figures. The horizontal stress magnitude for the two methods interpolated to the depth of the test facility agree closely (Table 1). The hydraulic fracturing has somewhat better confidence intervals than the overcoring, particularly for the horizontal minimum stress, but both methods provide estimates for the mean stress values at the depth of the test facility within ± 20% or better.

The stress data by both methods is highly variable as shown by the values for standard errors of estimate for the regression and the confidence interval values for the slopes of the regression lines (Fig. 4 and 5). Despite these large values, the confidence intervals for the interpolations are srelatively small because a large number of measurements were made. One can conclude from these data that reliable predictions of the in situ stresses at depth cannot be made either on the basis of a few measurements or by extrapolating the results of a set of measurements taken at shallow depth.

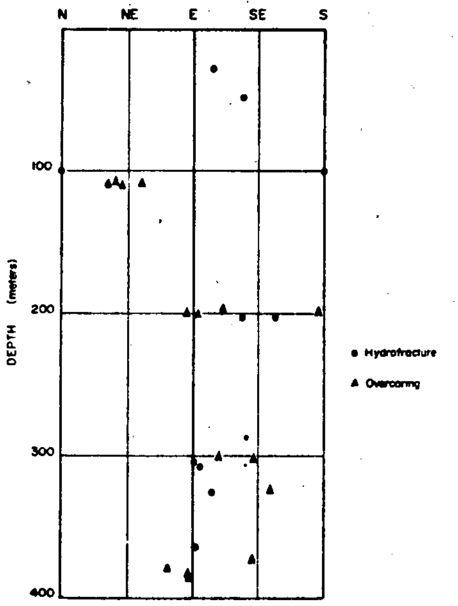
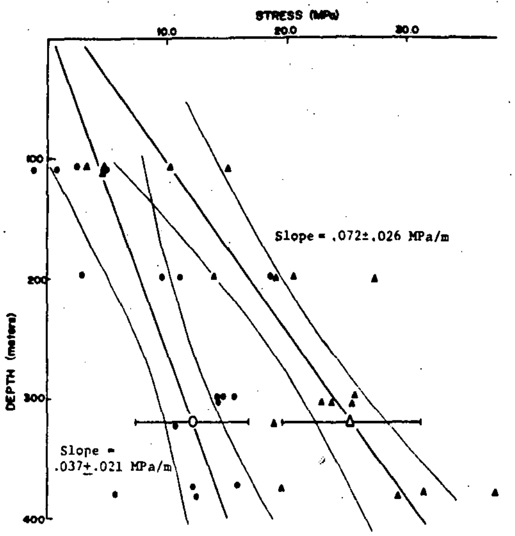


Figure 3. Measured orientations of maximum horizontal stress in SBH-4.



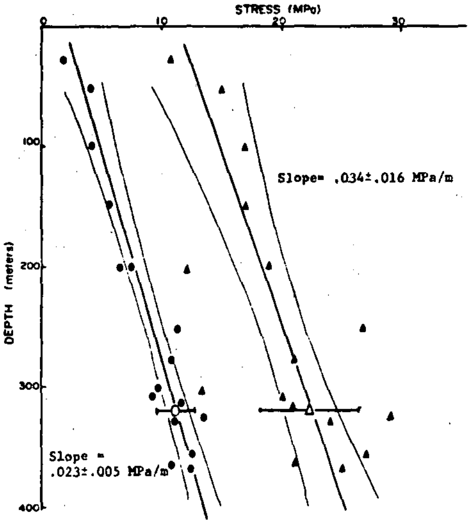


Figure 4. (left) Horizontal secondary stresses in SBH-4 as determined by overcoring. Curved lines are 90% confidence limits for regression line ordinate; bar at test facility depth (320 m) is standard error of estimate for regression.

Figure 5. (right) Horizontal secondary stresses in SBH-4 as determined by hydraulic fracturing; see Figure 4 for explanation.

4. NEAR-FIELD MEASUREMENTS

4.1 Measurements in the Luleå Drift

Carlsson [2] performed a series of 19 stress measurements in a borehole drilled off of the Luleå drift (Figure 1). The measurements were performed using the Leeman triaxial gauge. The overcored hole had an 87 mm diameter and the pilot holes were 38 mm in diameter.

The orientations of the individual points and the mean orientations of the principal stresses are shown in Figure 6. The mean values and orientations of the principal and secondary stresses are given in Table I. Contrary to the SBH-4 results, the maximum stress in the Luleå drift is oriented northeast with a plunge to the northwest.

4.2 Measurements in the Full Scale Drift Area

The second phase of the LBL stress measurement program was to measure the in situ stress in the immediate vicinity of the the full scale heater experiment (Figures 1 and 2). Three holes were drilled for the purposes of stress measurement. BSP-1 was drilled vertically downward from the center line of the full scale drift to a depth of 25 m. This hole was 76mm in diameter and was used for hydraulic fracturing and for overcoring by the Power Board method. Two holes were drilled from the extensometer drift, an opening excavated parallel to the full scale drift at a lower level to allow the installation of horizontal extensometers in the original heater experiment. Hole BSP-2 was drilled with a diameter of 76mm to a length of 20 m and was used exclusively for hydraulic fracturing. The hole was drilled at an angle three degrees downward from the horizontal to assure that the hole would remain full of water during the hydraulic fracturing tests. Hole BSP-3 had a diameter of 150 mm and was drilled to a length of 12 m for use in USBM, CSIRO, and LuH triaxial gauge measurements. It was drilled at a small angle upward from the horizontal to assure that water would drain from the hole and not affect the bonding of the triaxial strain gauges.

An acoustic emission experiment was performed by Ernest Majer of Lawrence Berkeley Laboratory to detect the propagation of the hydraulic fractures and,

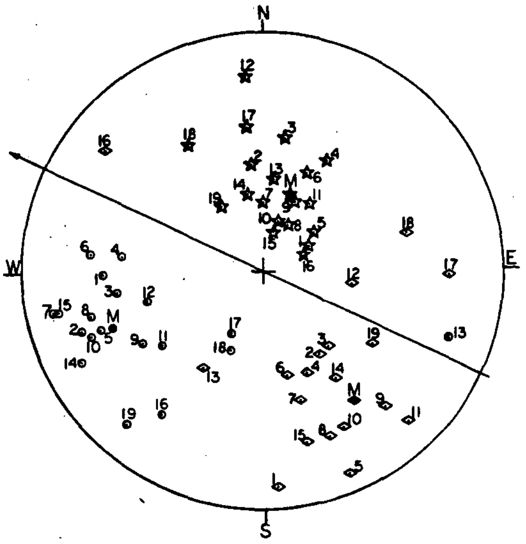


Figure 6. Principal stresses measured by overcoring off Luleå drift. Star-maximum stress, diamond- intermediate stress, circle- minimum stress. Mean values denoted by "M". Lower hemisphere stereographic projection.

hopefully, to map their locations. The layout and results of the acoustic experiment are discussed in Majer and McEvilly (1982).

In addition to the simple comparison of stress values from the various overcoring techniques, the underground experiment had several other objectives including:

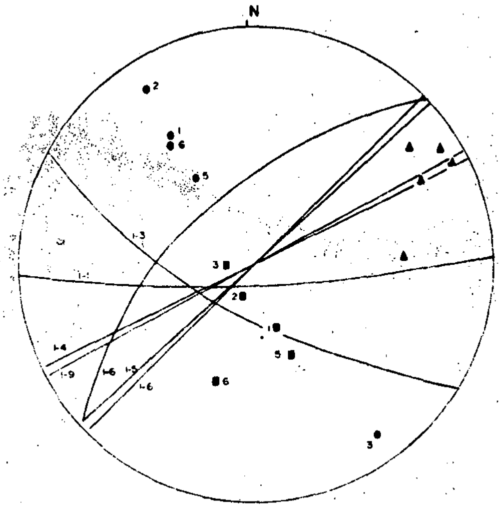
- investigating the effect of hole orientation on the hydraulic fracture results,
- measuring the influence of the extensometer drift and full scale drifts on the in situ stress orientations and magnitudes,
- investigating the correspondence of the acoustically mapped hydraulic fracture plane with the plane normal to the least principal stress determined by the overcoring.

4.3 Power Board Leeman Gauge Measurements (BSP-1)

A total of six measurements were made with the Power Board Leeman gauge in BSP-1. The measurements were made between 1.3 and 10.0 m below the floor of the full scale drift. The mean principal stress data are given in Table I and the orientation data are shown in Figure 7. The orientation of the maximum stress is very consistent among the measurements and is oriented northeast-southwest, parallel to the axes of the two drifts. The intermediate principal stresses are oriented off the vertical an average of about 30 degrees to the southeast. The minimum principal stresses are within about 30 degrees of the horizontal.

4.4 LuH Triaxial Gauge Measurements (BSP-3)

The University of Luleå triaxial gauge is an adaptation of the Leeman gauge used in the Luleå drift measurements. The major differences in equipment and procedures relate to the cleaning of the hole to assure good bonding of the strain gauges and use of four component strain gauge rosettes. Eight LuH triaxial gauge measurements were made at depths between 2.5 and 11.2 m in BSP-3. The magnitudes of the principal stresses are given in Table I and the orientations are shown in Figure 8. The maximum principal stress is consistently parallel to the axes of the drifts and coincides closely with the direction measured by the Power Board. The intermediate and minor principal stresses are nearly 45 degrees off the vertical



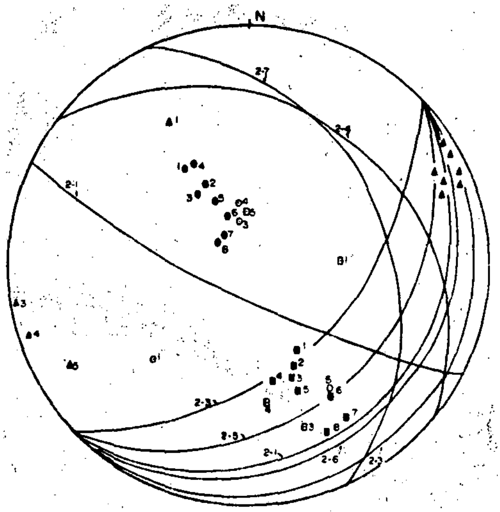


Figure 7. Principal stresses measured by Power Board overcoring and orientation of hydraulic fractures in BSP-1. Triangle- maximum stress, square- intermediate stress, circle- minimum stress. Lower hemisphere stereographic projection.

Figure 8. Principal stress measured by LuH gauges (solid symbols) and CSIRO gauges (open symbols) in BSP-3 with orientation of hydraulic fracture planes in BSP-2. See Figure 7 for explanation of symbols.

and horizontal directions near the collar of the hole. As the hole proceeds toward the full scale drift, the intermediate stress rotates toward the horizontal and the least stress rotates toward the vertical. Near the drifts the minimum stresses will be normal to the drift walls, hence one would expect the minimum stress to rotate away from horizontal toward vertical along the length of the hole.

4.4 USBM Borehole Deformation Gauge Measurements (BSP-3)

The USBM borehole deformation gauge was used in the same hole as the LuH gauge and CSIRO gauge measurements. Unlike the triaxial strain gauges, the USBM gauge measures only the stress components normal to the hole axis. This disadvantage is balanced against the greater rapidity and reliability of the USBM gauge. Triaxial gauge and deformation gauge measurements complement one another when used in the same hole. The triaxial gauges provide the three dimensional information, and the deformation gauge provides the larger number of measurements necessary for confidence in the stress determination for a site.

Nine USBM measurements were made at hole depths ranging from 1.1 to 9.7 m. The results of the USBM measurements are plotted along with the secondary stress data for the LuH gauge measurements in Figure 9. The mean stress values are given in Table I. The agreement for both magnitude and orientation is excellent. The orientation of the maximum secondary stress is horizontal for both techniques.

4.5 CSIRO Triaxial Gauge Measurements (BSP-3)

The CSIRO triaxial gauge [9] is a hollow cylinder which is grouted into a 38 mm pilot hole and then overcored. The gauge is similar to the Leeman triaxial gauge in that it contains three strain gauge rosettes with three components each. The data reduction methods are the same as those for the Leeman gauge except for modifications to allow for the effect of the cylinder. The CSIRO gauge has several practical advantages over the Leeman gauge including protection of the electronic circuitry from the drilling fluids and capability for monitoring the strain gauge outputs during the overcoring. It has a disadvantage in that the cements require seventeen hours or more to cure to an acceptable hardness and the gauge is not as reliable in water filled holes.

Five CSIRO measurements were made in BSP-3. Despite using curing times in excess of seventeen hours, the first two measurements indicated inadequate bonding to the pilot borehole walls. Even after switching to a faster curing cement for the final three measurements, the gauge values showed an average drift rate of about five microstrains per minute before and after the overcoring. The mean orientation and magnitude data are calculated using strain data from which the linear drift has been subtracted and are presented in Table I. The data, shown in Figure 8, are consistent with the LuH results both in orientation and in magnitude.

4.6 Near Field Hydraulic Fracturing Measurements (BSP-1 and BSP-2)

Hydraulic fracturing stress measurement were carried out in the vertical borehole BSP-1 and the horizontal borehole BSP-2. Nine measurements were carried out in BSP-1 over 0.6 m test intervals ranging in depth from 2.3 m to 20.2 m. Eight measurements were performed in BSP-2 using the same test interval length at depths of between 3.8 m and 16.7 m.

The equipment and procedures used for conducting the tests and evaluating the results were essentially the same as those used for the far field stress measurement work in SBH-4. The results, given in Table I, are calculated using the first breakdown pressures and the tensile strength values determined by Ratigan [6]. It was assumed that the underground test area was drained of water, thus the pore pressure term was taken as zero.

The orientation of the hydraulic fractures was determined by an impression packer which was lowered into the hole on scribed tubing. Figure 7 shows the orientation of the hydraulic fracture planes at the borehole wall for the vertical hole, BSP-1, and Figure 8 shows the fracture orientations for the horizontal hole, BSP-2. Hydraulic fractures propagate from the borehole in the direction of the maximum secondary stress. The fracture orientations in BSP-1 are strongly aligned parallel to the axis of the full scale and extensometer drifts. Thus the maximum stress direction determined by the hydraulic fracturing in BSP-1 agrees closely with the maximum principal stress direction determined by the overcoring measurements in both BSP-1 and and BSP-3. The hydraulic fractures in BSP-2 were horizontal rather than vertical as in BSP-1. This direction nonetheless is consistent with the BSP-1 results and the overcoring as the maximum stress is also horizontal.

The pressure-time records for the hydraulic fracturing showed distinctly different shut in pressures for the early and late pumping cycles. This difference

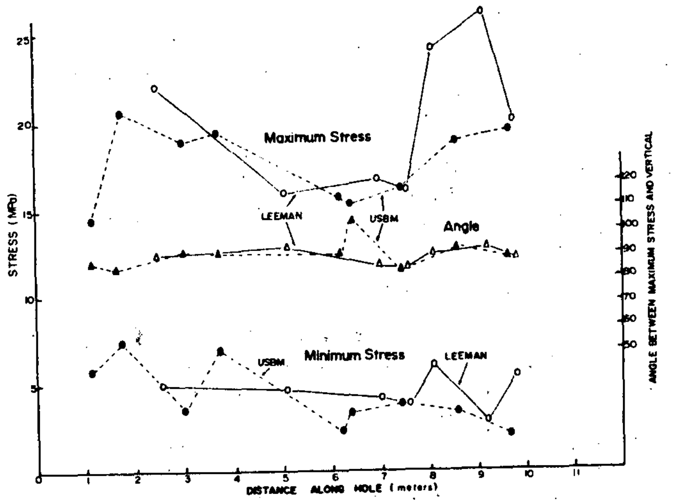


Figure 9. Secondary stresses along BSP-3 measured by LuH and USBM gauge overcoring.

was observed in both BSP-1 and BSP-2. The interpretation generally assigned to this phenomenon is that the borehole does not lie in the plane of the minimum stress, thus the fracture rotates as it propagates from the hole. The early shut in pressure would therefore represent the minimum stress normal to the hole and the later shut in pressure would be the minimum principal stress [4,5]. Following this interpretation, one would deduce that neither BSP-1 nor BSP-2 follows a principal stress direction. Were this the case one of the two boreholes would have to lie in the plane of the minimum stress and only one shut in pressure would be observed for that hole. The fact that two shut in pressures were observed in both holes, and the corresponding shut in pressures have the same value in each hole, suggests that the plane normal to the least principal stress lies 45 degrees between the two holes. This conclusion is in accord with the overcoring results, but the fact that the first shut in pressures are higher than the corresponding secondary stress values from the overcoring, and the second shut in pressures are higher than the overcoring's minimum stress values, casts some doubt on the hydraulic fracture interpretations.

The propagation of the hydraulic fractures from BSP-1 and BSP-2 was monitored with an array of acoustic sensors placed on the floor of the Full Scale drift and in the heater test instrument boreholes. Due to damage to the recording equipment in shipment, only one test from BSP-1 yielded results. Analysis of the acoustic records showed that the fracture propagated assymetrically from the borehole in a direction rotated about 20 degrees from the axis of the Full Scale drift. The most distant emissions from the fracturing were located about 2 m from the borehole. As only three stations recorded the emissions, the data was insufficient to accurately define the fracture plane, thus it is not possible to use the acoustic data to validate the stress measurement results. The fact that the emissions did appear as discrete, locatable events indicates that the method has great promise for further application.

4.7 Power Board Leeman Gauge Measurements (V1)

Measurements were performed with the Power Board's deep hole Leeman gauge at hole depths of 150 and 300 m (510 and 660 m below surface). The tests were run in sets of four. The average values of the magnitude and orientation are given in Table I. Although there is some scatter in the results, the overall magnitudes and orientations are similar to those measured in the Full Scale and Lulea drift areas. Again the maximum stress direction appears to be oriented to the northeast (Figure 10).

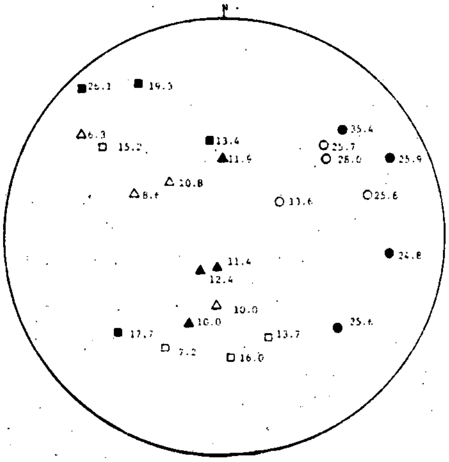


Figure 10. Orientations and magnitudes of principal stresses measured in V1 by Power Board overcoring. Circle- maximum stress, square- intermediate stress, triangle- minimum stress. Solid symbols- 150 m depth; open symbols- 300 m depth. Lower hemisphere stereographic projection.

4.8 Comparison of Near Field Results

The agreement between the results of the overcoring and the hydraulic fracturing for the Full Scale drift area measurements is excellent in the magnitude and orientation of the maximum principal stress. All the techniques are in agreement that that the direction of the maximum stress is horizontal and parallel to the axes of the full scale and extensometer drifts. The magnitudes for the stresses cover a range within about ± 15% of 22 MPa.

The values for the magnitudes of the intermediate and least stresses are in general agreement; however, a number of inconsistencies exist in the orientation results. These have been discussed above, and can be summarized as (1) the inconsistency in the secondary shut in pressures between the tests run in the two orthogonal holes, and (2) the divergence in orientation between the LuH and the Power Board methods for the measurements made underneath the Full Scale drift.

The results of stress measurements from the Lulea drift and V1 also show that the maximum principal stress trends to the northeast. The overcoring results in both areas are somewhat scattered with respect to both magnitude and orientation, nonetheless the mean values are consistent with those obtained in the Full Scale drift area.

5. COMPARISON OF NEAR FIELD AND FAR FIELD RESULTS

One of the striking aspects of the comparison of the near field and far field stress data is the change in orientation of the maximum principal stress from northwest in SBH-4 to northeast in the Full Scale drift area (Figure 1). The cause of this rotation is not clear. However, as the structure of the orebody and the mine have a northeast trend, it is likely that the rotation is related to either the mine openings or the contrast in mechanical properties of the leptite and the granite. The fact that the far-field measurements are consistent with one another, as are the near-field, suggests strongly that the rotation of the stresses is real and not an instrumentation induced error. Solving the cause of the stress distribution would require stress calculations for the mine in three dimensions -- a very complicated undertaking. Chan and others [10] have prepared a two dimensional model to look the influence of the mine on the measurements at SBH-4. The model was two dimensional and completely removed the orebody as a single slab. The results showed that even with these extreme geometries the mine only influenced the stresses in the upper portions of the hole. As with most underground openings, the stress effects shown by the model die out rapidly with distance.

6. CONCLUSIONS FOR DESIGN OF STRESS MEASUREMENT PROGRAMS

The experience that has been obtained in stress measurement at the Stripa site can be used to develop recommendations for stress measurement in other hard rock locations. The site characterization program for a repository site should consider in situ stress as one criterion for acceptance of a site. Also, stress measurement data should be used to design the initial shaft and underground workings. Designers have sometimes used, in the absence of data, calculations of the the in situ stress stresses based on gravitational loading alone. This approach clearly would be in error at Stripa as the horizontal stresses are about three times the stress of the vertical load. The initial stress measurements for a repository should be made in a vertical hole similar to SBH-4. Stress should be measured at least as deep as the zone of interest, and preferably a hundred meters deeper. Measurements should be made during drilling using overcoring method like that of the Power Board. Hydraulic fracturing should be carried out after the hole is completed. Concern has been expressed that the hydraulic fractures might unduly increase the permeability of the rock, however this concern is unfounded. The acousitc results suggest that hydraulic fractures for stress measurement are limited to a few meters in size, and the permeabilities of the fracture, as shown from the shut in pressure records, are small compared to natural fractures which will be present at the site. The hydraulic fracturing complements the overcoring in that the stress measurements show less scatter and provide a larger scale, more representative value of the minimum stress magnitude (shut in pressure) and the maximum stress orientation. The overcoring complements the hydraulic fracturing in that it gives the complete state of stress and indicates if the principal stresses

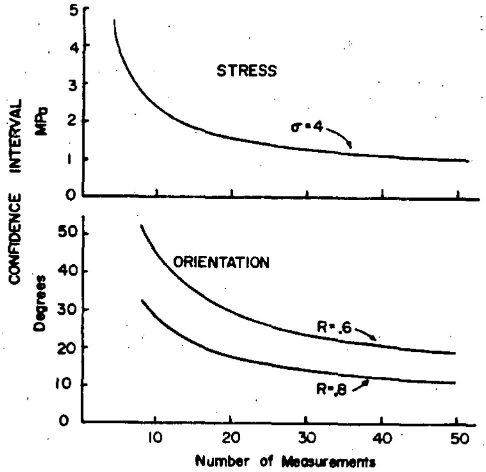


Figure 11. Improvement in confidence interval with number of measurements. Top- 90% confidence interval of stress magnitude for standard deviation of 4 MPa. Bottom- 95% confidence interval of maximum secondary stress orientation for vector length of 0.6 and 0.8.

are strongly skewed with respect to the borehole axis. Figure 11 shows the improvement in confidence interval for stress magnitude and orientation for the variance values obtained in SBH-4. The results suggest that at least 20 measurements by each technique should be made to obtain reasonably tight confidence intervals for the stress values. If a stress value at a particular depth is desired, then the measurements should either be clustered at that depth, or the measurement points should be spread over a range well above and below the depth of interest to obtain the best confidence intervals.

Once the initial underground workings have been excavated, the stress measurements should be repeated. There are two reasons for this. First, the comparison of the Full Scale drift and the SBH-4 results show that stress orientations can change significantly over distances of hundreds of meters, and second, the underground measurements have less scatter. At Stripa the most successful underground overcoring measurements were made with the USBM gauge and the LuH gauge. These can be run in the same hole and the results complement one another well. The USBM gauge is rapid to run, allowing a statistically significant sample to be taken, but it does not give the complete stress field from a single hole. The LuH gauge required more effort in bonding the gauges, but gives the complete stress field. Ten measurements by each technique should be sufficient to define the stress field within acceptable bounds. Again, the hydraulic fracturing can be used to complement the overcoring to provide a larger scale measurement. The Stripa results showed that acoustic methods have considerable potential to confirmation of the overcoring results on a large scale.

As the repository is developed additional stress measurements should be performed, particularly if anomalous structures or lithologies that might affect the stress field are encountered.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. Doe, T.W., ed.: "Determination of the State of Stress at the Stripa Mine, Sweden", Lawrence Berkeley Laboratory Report, in preparation.

2. Carlsson, H.: "Stress Measurements in Stripa Granite", Lawrence Berkeley Laboratory Report, LBL-7080/SAC-04, 13p., 1978.

3. Strindell. L. and M. Andersson: "Measurement of Triaxial Stresses in Borehole V1", SKBF/KBS Stripa Project Internal Report 81-05, 12p., 1981.

4. Doe, T., K. Ingevald, L. Strindell, B. Haimson, and H. Carlsson: Hydraulic Fracturing and Overcoring Stress Measurements In a Deep Borehole at the Stripa Test Mine, Sweden", Proc. 22d U.S. Symposium on Rock Mechanics, Massachusetts Inst. of Tech., p. 373-378., 1981.

5. Zoback, M. and D. Pollard: "Hydraulic Fracture Propagation and the Interpretation of In Situ Stress Measurements", Proceedings 19 U.S. Rock Mechanics Symposium, University of Nevada--Reno., 1978.

6. Haimson, B.: "The Hydraulic Fracturing Stress Measurement Method and Recent Results", International Journal of Rock Mechanics, v. 15, p. 167-178., 1978.

7. Ratigan, J. :" A Statistical Fracture Mechanics Approach to the Strength of Brittle Rock", Ph.D. thesis, University of California-Berkeley, 92p., 1981.

8. Mardia, K. : "Statistics of Orientation Data", Academic Press, London, 357 p., 1972.

9. Worotnicki, G. and R. Walton: "Triaxial `Hollow-Inclusion´ Gauges for Determination of Stresses In Situ.", Proc. Int. Soc. Rock Mech. Symposium -- Investigation of Stress in Rock, Inst. of Engineers, Australia, National Conf. Pub. No. 76/4., 1976

10. Chan, T., Guvanasen, V., and Littlestone, N.: "Numerical Modelling to Assess Possible Influence of Mine Openings on Far-Field In Situ Stress Measurements", Lawrence Berkeley Laboratory Report, in press.

Table 1. Average values of principal and secondary stresses measured at Stripa. Values given with 90% confidence interval.

	Principal Stresses (MPa)			Secondary Stresses* (MPa)		
	σ_1	σ_2	σ_3	σ_{Max}	σ_{Min}	σ_{Ax}
SBH-4** Hydrofrac	-	-	-	22.1±2.1	11.1±0.8	-
SBH-4** Power Board	-	-	-	25.4±2.9	12.1±2.4	-
BSP-1 Hydrofrac	-	-	-	24.0±2.9	7.6±1.0	5.1±0.8
BSP-1 Power Board	24.2±5.0	10.0±1.9	1.9±1.6	23.0±4.5	4.8±1.1	9.5±0.8
BSP-2 Hydrofrac	-	-	-	22.3±1.9	7.6±0.5	5.7±0.7
BSP-3 LuH	20.8±3.1	9.2±1.1	1.9±1.6	20.2±3.2	4.3±0.7	-
BSP-3 CSIRO	18.7±5.5	8.0±3.4	2.6±1.2	18.3±6.0	5.1±3.2	-
BSP-3 USBM	-	-	-	18.3±1.7	4.4±1.2	-
Lulea Drift Leeman Cell	19.5±2.9	8.0±3.2	4.8±1.2	15.6±2.8	8.7±1.9	10.4±1.9
V1-150m Power Board	27.9±5.0	19.1±5.3	11.4±1.0	26.0±5.1	18.3±5.9	13.4±1.4
V1-300m Power Board	22.7±6.3	13.0±4.0	9.2±2.4	19.7±7.1	11.7±3.3	13.6±1.4

* Max and Min are the stresses normal to the borehole, Ax is the stress along the borehole axis. Ax is vertical except for BSP-2, BSP-3, and Lulea Drift.

** Interpolated values at depth of test facility (338 m level).

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