

APPENDIX 6

DESCRIPTION OF THE TESTS AND DATA USED IN THE CALIBRATION OF THE RMi

"Engineers constantly need to simplify the problems that they encounter; this fact was widely accepted until the days of the computer and its numerical techniques introduced a dangerous proclivity for complexity."

A. M. Muir Wood, 1979

The problems and costs in performing in situ strength tests on rock masses cause that very few such test results exist. Only results from 7 sets of such data have been found during this work. This appendix briefly describes the composition of the material and the results from:

- large samples tested in laboratory;
- in situ tests on pillars in a mine (one 'sample'); and
- tests combined with back analysis from a slide in a mine.

The values found for the block volume (V_b), the joint condition factor (jC) and the jointing parameter (JP) for the samples have been plotted in Fig. 4-3 in Chapter 4 to develop a relation between the three parameters.

1 Sample 1. Results from triaxial laboratory tests on Panguna andesite

One of the most complete sets of triaxial test data available is that on the Panguna andesite which comprises the host rock for a large copper deposit on the island of Bougainville in Papua New Guinea. Jaeger (1969) has given a description of the samples tested. Essentially, the rock mass consists of an aggregate of small interlocking blocks. Major joint systems and probably many minor planes of weakness cause the blocks in the quarry to be of almost random shape. The material of the test samples is divided up by a network of open joints and veins with a rather weak filling, the spacings of these being so close *"that a cross section of the core would usually contain 50 - 100 individual areas separated by planes of weakness."* It was difficult to obtain sufficient small 25 x 50 mm cylinders of rock containing no planes of weakness for triaxial test on intact rock.

The test samples for triaxial tests were taken by very careful drilling, using 150 mm diameter triple tube drilling equipment. A triaxial pot to take specimens 150 mm diameter by 300 mm long was developed and used to produce a number of undisturbed core samples of jointed Panguna andesite. These samples were prepared and tested triaxially by Jaeger (1969). The measured unconfined compressive strength of intact rock was 269 MPa. From the triaxial tests at low confining stress carried out on 150 mm cores an unconfined compressive strength of 3.7 MPa was evaluated by Jaeger, who noticed that an important effect during testing was the interlocking of adjacent blocks.

As very little has been published on large triaxial tests on rock mass, Hoek and Brown (1980) concluded from studies of test results of the Panguna andesite that these may be taken as a reasonable model for the in situ strength of a heavily jointed hard rock mass.

Hoek and Brown (1980) used the following characteristics of the Panguna andesite in their work on the original Hoek-Brown failure criterion, see Fig. A6-1:

- rock intact compressive strength $\sigma_c = 265$ MPa
- joint roughness number ¹: $J_r = 3$
- slightly rough surfaces, with separation < 1 mm
- joint alteration number ¹: $J_a = 2$
- 3 joint sets, with joint spacing < 60 mm

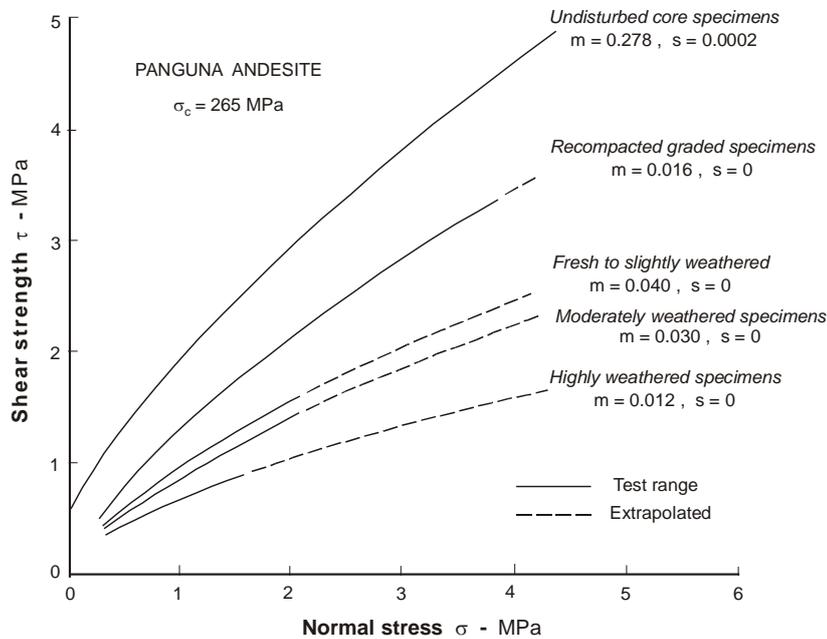


Fig. A6-1 Triaxial test results and Hoek and Brown's estimated values of s and m (from Hoek and Brown, 1980)

The following values have been applied in the calibration of RM_i :

- Jointing characteristics: Most joints are small, undulating/interlocking and partly discontinuous with:
 - rough joint surfaces, i.e. the joint smoothness factor is $j_s = 2$
 - undulating/interlocking joint planes ², i.e. $j_w = 2 - 3$
 - the joint alteration factor ² $j_A = J_a = 3 - 4$
 - small joints (length ≈ 0.15 m), partly discontinuous (a continuity factor 1.5 seems adequate here), gives a joint size factor between $j_L = 2 \times 1.5$ and 2.5×1.5 , i.e. $j_L = 3 - 4$
 - The joint condition factor $j_C = j_s \times j_w \times j_L / j_A$ is then $j_{C_{\min}} = 2 \times 2 \times 3/4 = 3$, $j_{C_{\max}} = 2 \times 3 \times 4/3 = 8$.
- Based on the probabilistic method for calculation described in Chapter 5 the following range has been chosen ³ $j_C = 4 - 6$
- The rock compressive strength $\sigma_c = 265$ Mpa

¹ The roughness and alteration factors have later been re-assessed by Wood (1991) to $J_r = 2$, and $J_a = 3$ after reviewing the original publication by Jaeger.

² Comment: As Jaeger has described the joints as interlocking and the joints on the photo shown appear as wavy, I have used a higher value for the planarity or waviness than Wood and probably also Hoek and Brown. With a "rather weak filling" and "open joints and veins" a rating of $J_a = 3 - 4$ has been chosen above.

³ The probability calculation gave $j_C = 4.2 - 5.7$ for 2 standard deviations (covering 68% of data).

- The average block size, assessed from description and photo published by Jaeger (1969) is found as: $V_b = 2 - 6 \text{ cm}^3$
 - The uniaxial compressive strength of the rock mass calculated from triaxial tests: $\sigma_{cm} = R_{Mi} = 3.7 \text{ MPa}$
- From the data above the jointing parameter is found as $JP = R_{Mi}/\sigma_c = 3.7/265 = 0.014$

2 Sample 2. Large, compressive laboratory test made on granitic rock from Stripa

The data used have been found from laboratory tests on a 1 meter diameter by 2 meter long sample of granitic (quartz monzonite) rock from the Stripa mine in Sweden. The sample was cut by a slot drilling technique.

The following description has been reported by Thorpe et al. (1980): *"The granitic rock in the Stripa mine is pervasively fractured. The sample was intersected by two principal sets of fractures and a large number of secondary discontinuities with lengths and spacings ranging from the scale of the core to the microscopic. There were two dominant joint sets in the sample:*

- Set 1 (A,B,C) of essentially continuous joints approximately normal to the loading
- Set 2 (D,E,F) generally discontinuous and oriented 25 - 30° to the loading. They have a wide distribution of trace lengths.
- In addition there are several small joints in the sample, generally discontinuous.

In general, joints appeared to be about a millimetre or less wide. The joint filling materials were predominantly chlorite and sericite. There were not any marked difference between the characteristics of the two sets. However, in set 2 (D,E,F) where a occasional thickening of the filling material occurred, calcite was prominent."

The behaviour of the large rock mass sample in Fig. A6-2 under uniaxial compressive stress was very complicated with stress-strain behaviour at low stresses was generally similar to that of small cores containing single healed joints. Much of the induced fracturing during compression followed the major pre-existing joints. It appeared that the observed overall failure mode was a combination of shearing failure in the Mohr-Coulomb sense and brittle fracturing typical of uniaxial failure of intact specimens. The test of the large sample was made on wet material. The pervasively jointed nature of the large sample complicated its mechanical behaviour. It is important to remember that the stress and displacement of such a compressive test are not generally representative of the boundary conditions in an in situ rock mass.

The large sample failed at a peak stress of 7.55 MPa, much lower than the typical strength measured in small cores. 2 unconfined compressive tests performed on 52 mm cores of intact rock from the big sample gave $\sigma_c = 208$ and 178 MPa. Earlier, a compressive strength of $\sigma_c = 214$ MPa and 208 MPa have been found for the Stripa granite.

The following values have been applied in the calibration of R_{Mi}:

- Joint characteristics:
 - * *Joint set 1:* (joint A, B, C in Fig. A6-3) of long, continuous joints with:
 - rough joint surface; i.e. the joint smoothness factor $j_s = 2$
 - large undulations; i.e. the joint waviness factor $j_w = 2$
 - hard chlorite coatings; i.e. the joint alteration factor $j_A = 3 - 4$
 - continuous joints with length > 1 m; i.e. $j_L = 1$
 - The joint condition factor is then $j_C = 1 - 1.3$
 - the joint spacing $S_1 = 0.25 - 1.5 \text{ m}$

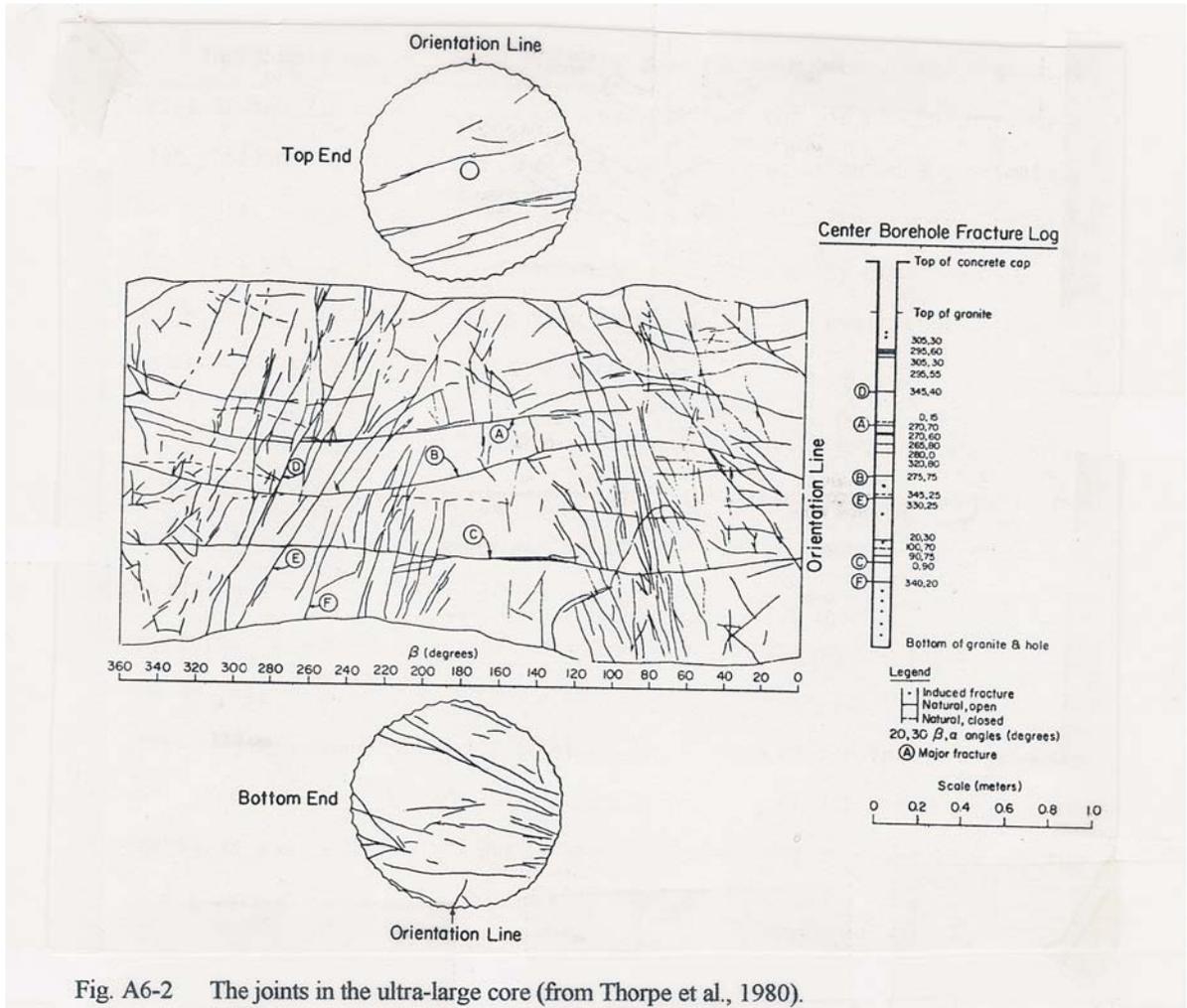


Fig. A6-2 The joints in the ultra-large core (from Thorpe et al., 1980).

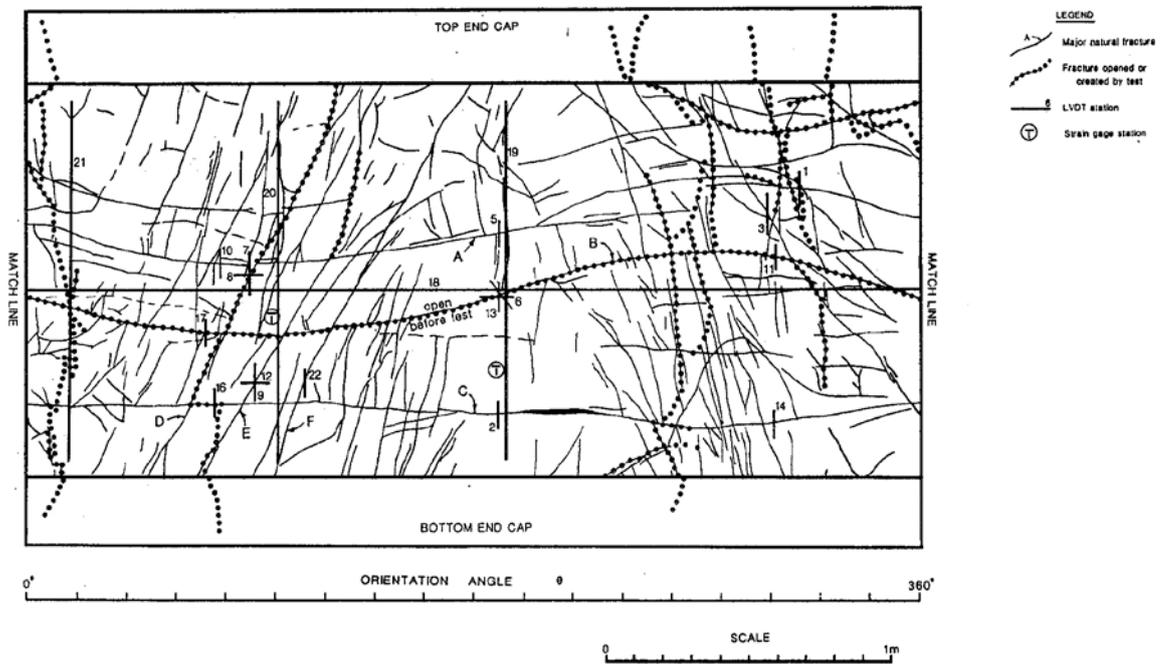


Fig. A6-3 Post failure joint map (from Thorpe et al., 1980)

- * *Joint set 2*: (joint D, E, F) of short, partly discontinuous joints with
 - rough joint surface; i.e. the joint smoothness factor $j_s = 2$
 - small undulations; i.e. the joint waviness factor $j_w = 1.5$
 - hard chlorite coating; i.e. the joint alteration factor $j_A = 3 - 4$
 - partly discontinuous, short joints (0.5-3 m); i.e. $j_L = 2 \times 1.5 = 3$
 - The joint condition factor is then $j_C = 2.25 - 3$
 - the joint spacing $S_2 = 0.15 - 0.5$ m
- * *Small, discontinuous joints* (little information of these joints) with
 - rough surfaces; i.e. the joint smoothness factor $j_s = 2$
 - small undulations; i.e. the joint waviness factor $j_w = 1.5$
 - assumed fresh joints; i.e. the joint alteration factor $j_A = 1$
 - discontinuous, short joints (0.1-0.5 m); i.e. $j_L = 2 \times 2 = 4$
 - The joint condition factor is then $j_C = 15$
- Blocks are formed by the large and partly also by the small joints. Average block volume is assumed to be in the range $V_b = 5 - 15 \text{ dm}^3$.
- As most of the displacement during failure followed joint set 1 and 2 the value for the resulting joint condition factor is chosen as $j_C = 1.5 - 2.5$
- The uniaxial compressive strength of intact rock:
 - tests performed on the large sample $\sigma_c = \frac{1}{2}(208+178)\text{MPa} = 193 \text{ MPa}$
 - earlier tests $\sigma_c = \frac{1}{2}(214+208)\text{MPa} = 211 \text{ MPa}$
 From this a value of $\sigma_c = 200 \text{ MPa}$ has been applied.
- The uniaxial compressive strength of the rock mass calculated from triaxial tests was: $\sigma_{cm} = \text{RMi} = 7.55 \text{ MPa}$ (with 0.06% strain at failure)
- From the data above the jointing parameter has been calculated as $\text{JP} = \text{RMi}/\sigma_c = 7.55/200 = 0.04$

3 Sample 3. In situ tests on mine pillars of sandstone in the Laisvall mine

In the Laisvall Mine, Northern Sweden, a full scale test was conducted on 9 pillars in order to obtain realistic design values for the load bearing capacity of the roof and to check the available experience of pillar strength. The tests were performed in the Nadok orebody of the mine. The rocks of Late Precambrian age consist of sandstone interlayered with thin shale partings, overlain by Lower Cambrian clayey schists, see Fig. A6-4. Here, the roof consists of quartzitic and shaly schist which is weaker than the sandstone in the pillar. The mine roof in the test area was supported with cement grouted rebar rock bolts (dia. 25 mm, length 2.3 m with an average density of 0.42 bolts/m² roof).

The test procedure and the results from the test are described by Söder and Krauland (1990). 9 pillars were subjected to increasing stresses. This was accomplished by blasting off a slice of approximately 0.8 m thickness from two sides of all the test pillars in each mining step. The process was continued until pillar or roof/floor failure occurred. Cautious blasting was applied with 22 mm reduced charges in 51 mm holes spaced 1 m. The damage from blasting was reported minimal. Stresses, deformation and failures phenomena were monitored during the test. Some of the results have been made available by the kind help from Norbert Krauland of Boliden Mines, Sweden.

The average uniaxial compressive strength of intact rocks was found as:

- sandstone $\sigma_c = 210 \text{ MPa}$
- schist $\sigma_c = 130 \text{ MPa}$

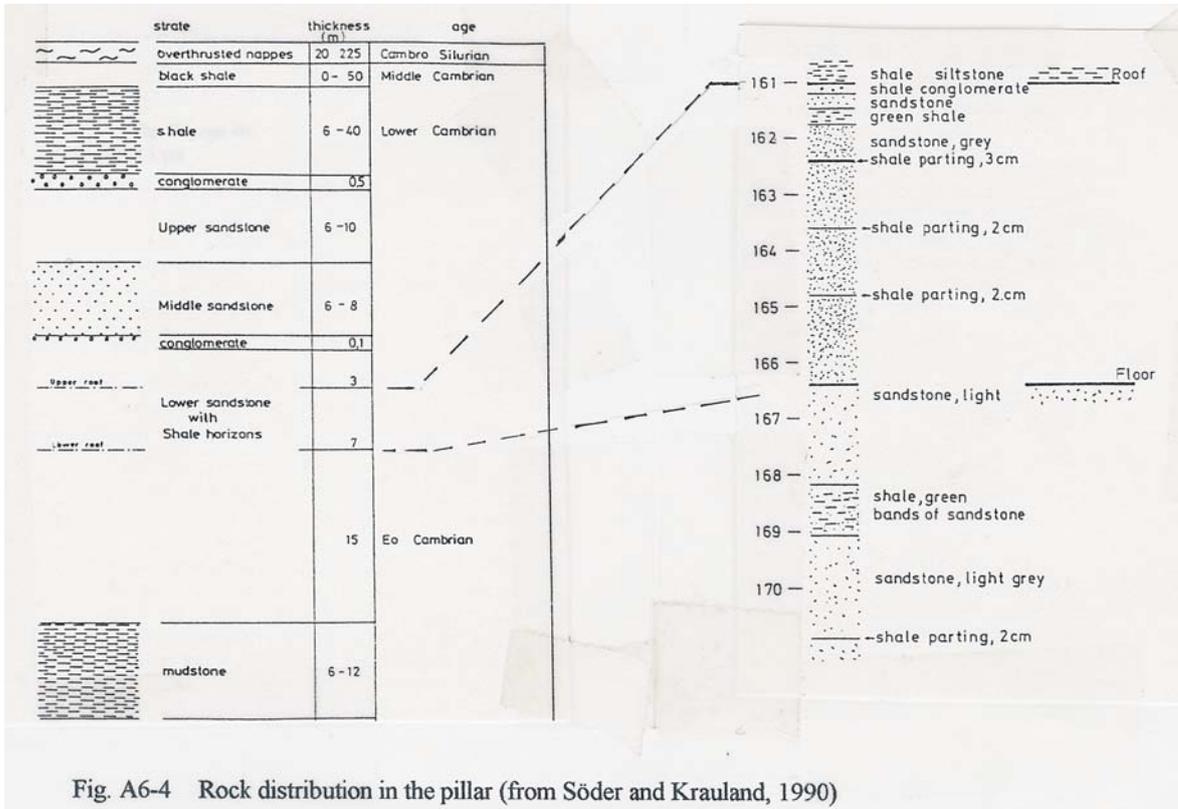


Fig. A6-4 Rock distribution in the pillar (from Söder and Krauland, 1990)

At failure the cross section of the pillar was 23.4 m² (4.8 x 4.8 m). The height of the pillar was 5 m. The average uniaxial compressive strength of the rock mass in the pillars was found as 19.8 ± 1.4 MPa.

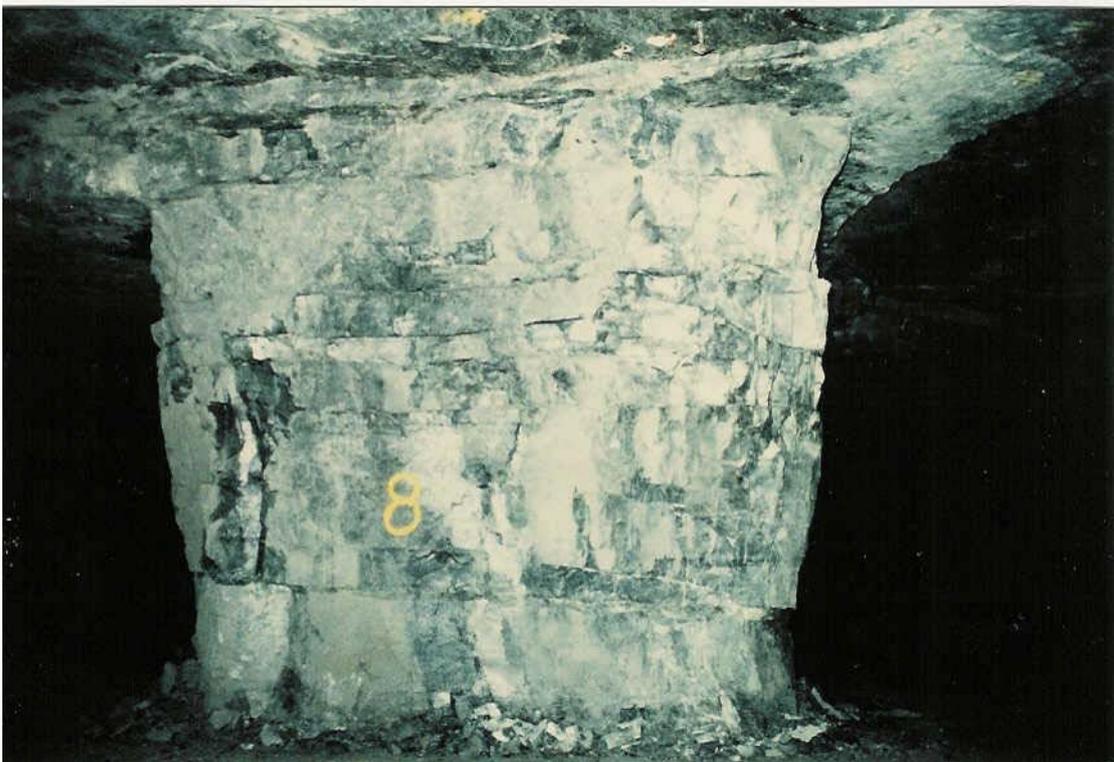


Fig. A6-5 Photo of pillar no 8 showing the horizontal joints along the foliation. Pillar height is 5 m



Fig. A6-6 Detail from Fig. A6-5.

The jointing characteristics of two of the pillars (no 8 and no 9) have been further evaluated. The characteristics of the joints have been assumed from descriptions and from several photos (Figs. A6-5 and A6-6) and from communication with Krauland (1992). The horizontal, thin shale layers approx. 2 cm thick and parallel joints form major weaknesses in both pillars. These occur almost normal to loading. In addition steep dipping, mainly short joints occur with varying intensity.

The following values have been applied in the calibration of R_{Mi}:

- The following characteristics of the joints have been assumed:
 - * *Horizontal joints* (normal to loading), mainly along the thin shale layers:
 - the presence of shale cause that the joints generally have smooth surfaces, i.e. $j_s = 1$
 - small undulations of wall, i.e. the joint waviness factor $j_w = 1.5$
 - assumed clay on joint wall, i.e. the joint alteration factor $j_A = 2$
 - mainly continuous, long joints; i.e. $j_L = 1$
 - The joint condition factor is then $j_C = 0.75$
 - The joint spacing for this set is $S_1 = 0.2 - 1.2$ m
 - * *Vertical, mainly short joints* (parallel to loading):
 - slightly rough joints, i.e. the joint smoothness factor $j_s = 1.5$
 - planar joints, the joint waviness factor $j_w = 1$
 - fresh joint walls, i.e. the joint alteration factor $j_A = 1$
 - mainly continuous joints with length in the range 0.1-3 m ; i.e. the joint size factor $j_L = 1.5$
 - The joint condition factor is then $j_C = 2.25$
 - The joint spacing for this set is $S_2 = 0.3 - 1.5$ m
- There is a wide variation in block size within the pillar. Estimated block volume is $V_b = 0.1 - 0.3$ m³.
- The uniaxial compressive strength of the sandstone in the pillars is $\sigma_c = 210$ MPa
- The uniaxial compressive strength of the rock mass found from the tests was $\sigma_{cm} = R_{Mi} = 20$ MPa
- From the data above the jointing parameter $JP = R_{Mi}/\sigma_c = 20/210 = 0.095$.

4 Sample 4. Strength data found from back analysis of a slide in the Långsele mine

A large slide occurred in the Långsele mine, Sweden in 1975. In connection with stability analyses and recommendation for further mining, analysis of the rock mass compressive strength was performed. The analysis was based on stress measurements and laboratory test in the mine. The slide has been described and evaluated by Eriksson and Krauland (1975). It had the shape of a large prism about 100 m long, 60 m thick, and 80 m deep and the involved volume was approximately 300,000 m³. The rocks included in the slided material are:

- sericite-quartzite (1 - 5 m thick) $\sigma_c = 80 - 280$ MPa
- dacite-tuff (25 - 30 m thick) $\sigma_c = 100 - 270$ MPa
- grey schist and greenstone, in which
- most of the slide plane is located $\sigma_c = 110 - 160$ MPa

The foliation is steeply dipping (60 - 70°). The schistosity and foliation partings are significant weaknesses. The failure plane seems in the upper part to partly pass through intact rock. Where it crosses the dacite-tuff, the plane mainly followed existing joint planes. Also in its the lower part the failure plane partly cut through intact rock. The result of the stability calculation (Eriksson and Krauland, 1975) gave an uniaxial compressive strength of the rock mass $\sigma_{cm} = 1.85 \pm 0.4$ MPa.

There are no complete description of the jointing. The assessments made are based on colour photos in the report by Eriksson and Krauland (1975) and on the rock mass descriptions. Figs. A6-7 to A6-9 show some details from the mine and the slide.

The following values have been applied in the calibration of RMI:

- Joint set 1 occurs along foliation. The joint characteristics have been assessed as:
 - * In schist and quartzite:
 - very smooth surfaces; i.e. the joint smoothness factor $j_s = 0.75$
 - planar joint walls; i.e. the joint waviness factor $j_w = 1$
 - altered or clay coatings; i.e. the joint alteration factor $j_A = 4$
 - generally 1-10 m long, i.e. continuous joints $j_L = 1$
 - The joint condition factor is then $j_C \approx 0.2$
 - * In dacite and greenstone:
 - smooth surfaces; i.e. the joint smoothness factor $j_s = 1$
 - planar joint walls; i.e. the joint waviness factor $j_w = 1$
 - altered or clay coating; i.e. the joint alteration factor $j_A = 4$
 - 5-20 m long, continuous joints, i.e. $j_L = 0.75$
 - The joint condition factor is then $j_C \approx 0.2$
- Cross joints are short, continuous planar, smooth joints. They seem to occur in two directions and occur:
 - * In schist and quartzite with:
 - smooth surfaces; i.e. the joint smoothness factor $j_s = 1$
 - planar joint walls; i.e. the joint waviness factor $j_w = 1$
 - altered and clay coating; i.e. the joint alteration factor $j_A = 4$
 - 1 -10 m long, continuous joints, i.e. $j_L = 1$
 - The joint condition factor is then $j_C = 0.25$.

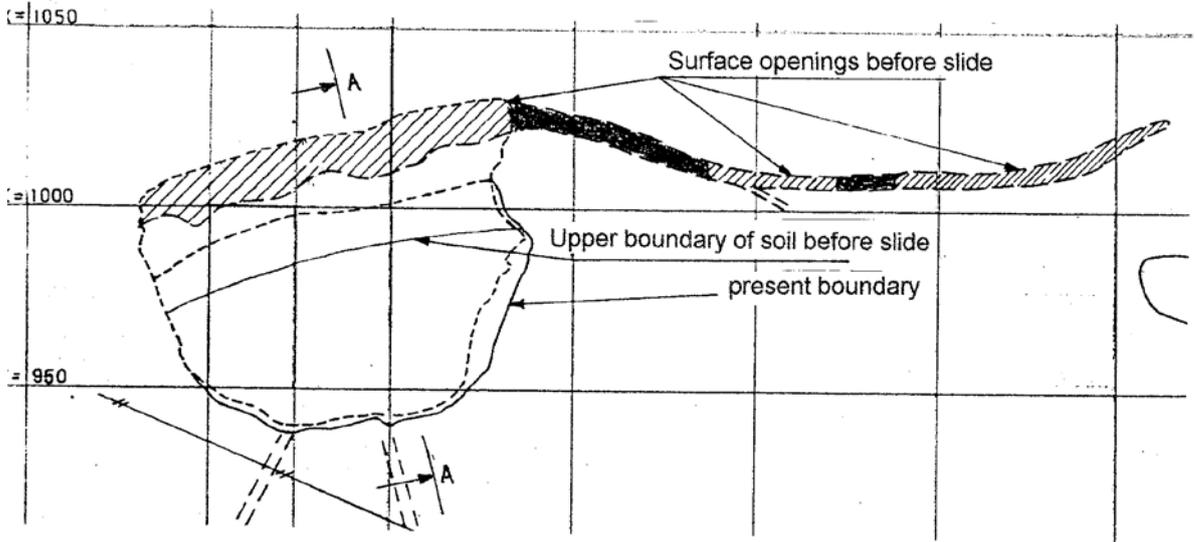


Fig. A6-7 Plan of the mine where the slide occurred (from Eriksson and Krauland, 1975)

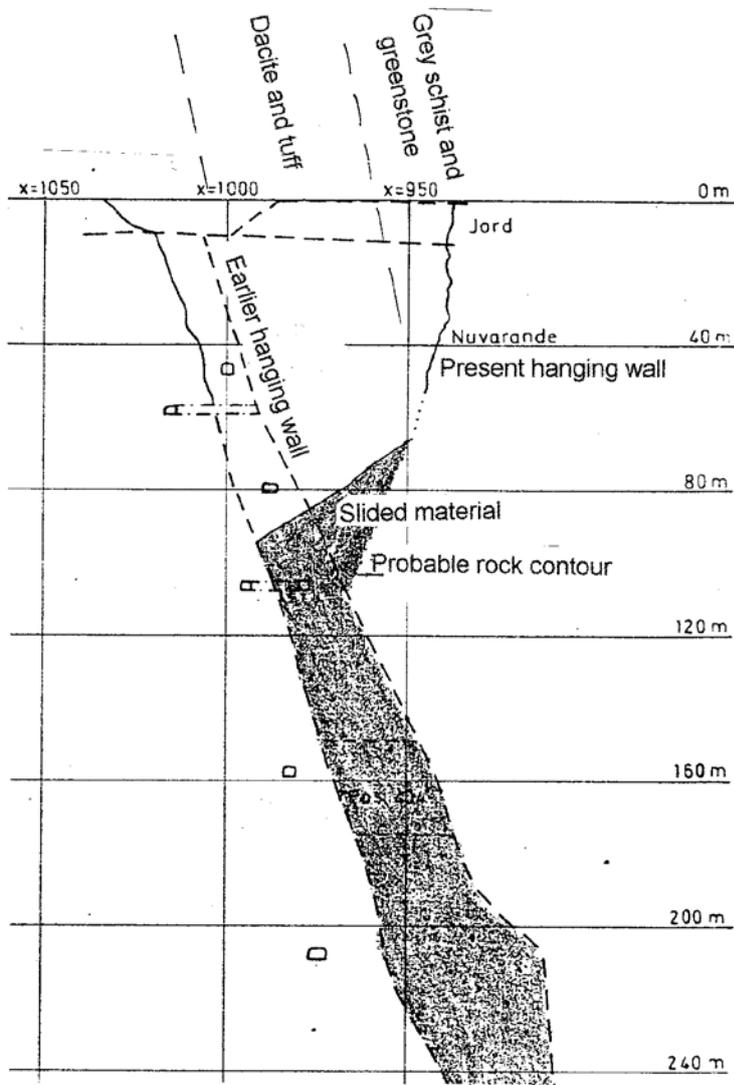


Fig. A6-8 Section A - A in Fig. A6-7 (after Eriksson and Krauland, 1975)

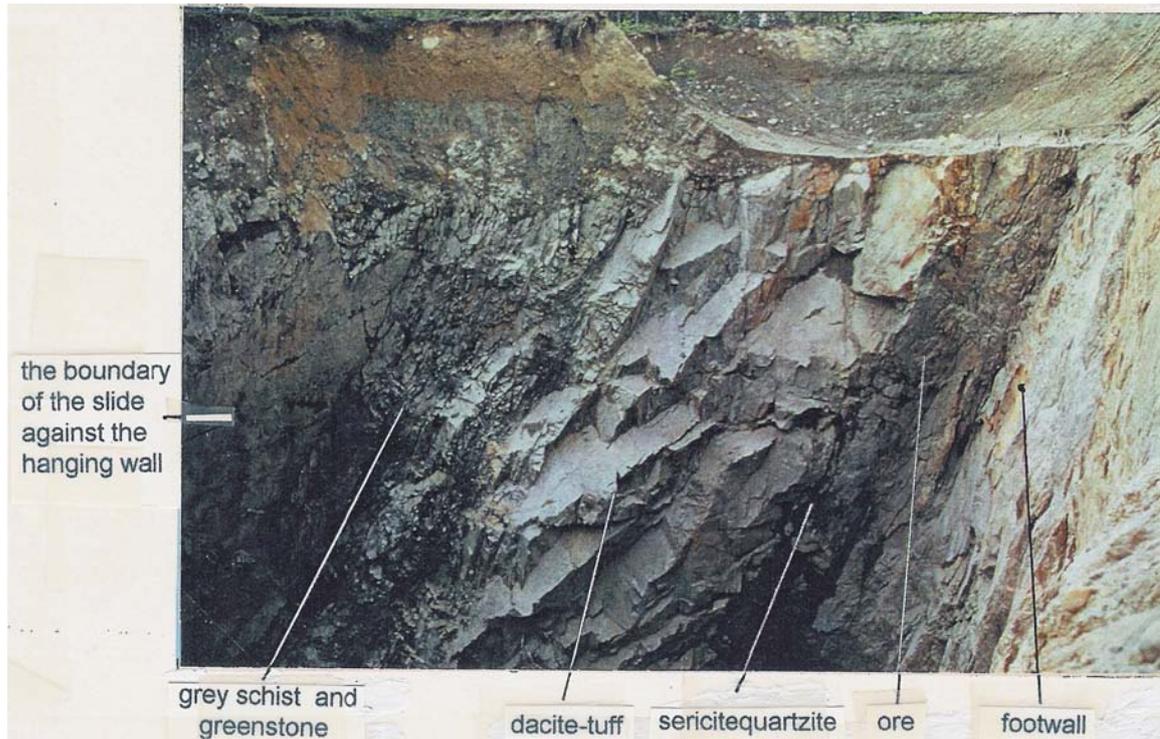


Fig. A6-9 The rock masses in the slide surface.

- * In dacite and greenstone with:
 - smooth surfaces; i.e. the joint smoothness factor: $j_s = 1$
 - planar joint walls; i.e. the joint waviness factor: $j_w = 1$
 - clay coating; i.e. the joint alteration factor: $j_A = 4$
 - 5-20 m long, continuous joints, i.e. $j_L = 0.75$
 - The joint condition factor is then $j_C \approx 0.2$
- Assessed average block volume:
 - in schist and quartzite $V_b = 0.008 - 0.02 \text{ m}^3$
 - in dacite and greenstone $V_b = 5 - 25 \text{ m}^3$
- As the uniaxial compressive strength of the rock mass found from the back analyses was $\sigma_{cm} = R_{Mi} = 1.85 \text{ MPa}$, the jointing parameter is $JP = R_{Mi}/\sigma_c = 1.85/160 = 0.01$
- It is probable that the block size of the schist and quartzite had the bearing effect on the slide. The following data have therefore been used:
 - the intact compressive strength: $\sigma_c = 160 \text{ MPa}$
 - the block volume: $V_b = 0.008 - 0.02 \text{ m}^3$
 - the joint condition factor: $j_C = 0.2 - 0.3$
 - the jointing parameter $JP = 0.01$

5 Sample 5 - 7. Results from large-scale laboratory triaxial tests

The large scale laboratory tests were carried out at the University of Karlsruhe, Germany. The test procedure and apparatus (in Fig. A6-10a) are described in ISRM (1989) and in Natau et al. (1983) and Mutschler and Natau (1989). Many of the following data have been kindly given by Mutschler (1993) during a visit to the University of Karlsruhe. The assessments are also backed by descriptions and several photos taken of the sites as well as of the samples (Fig. A6-10b) before and after the tests.

5.1 Sample 5. Caledonian clay-schist, Germany

This is a dark, fine-quartzitic, striped to banded clay-silt schist from Thüringer Wald. It belongs to the 'Phycodenschiefer' of Ordovician - Silurian (Caledonian) age. Two test series were performed, each of three tests, as described by Natau et al. (1995). The first series was parallel to schistosity on cylinders dia. 0.6 m and length 1.2 m, the other normal to schistosity on prismatic samples 0.6 x 0.6 x 1.2 m .

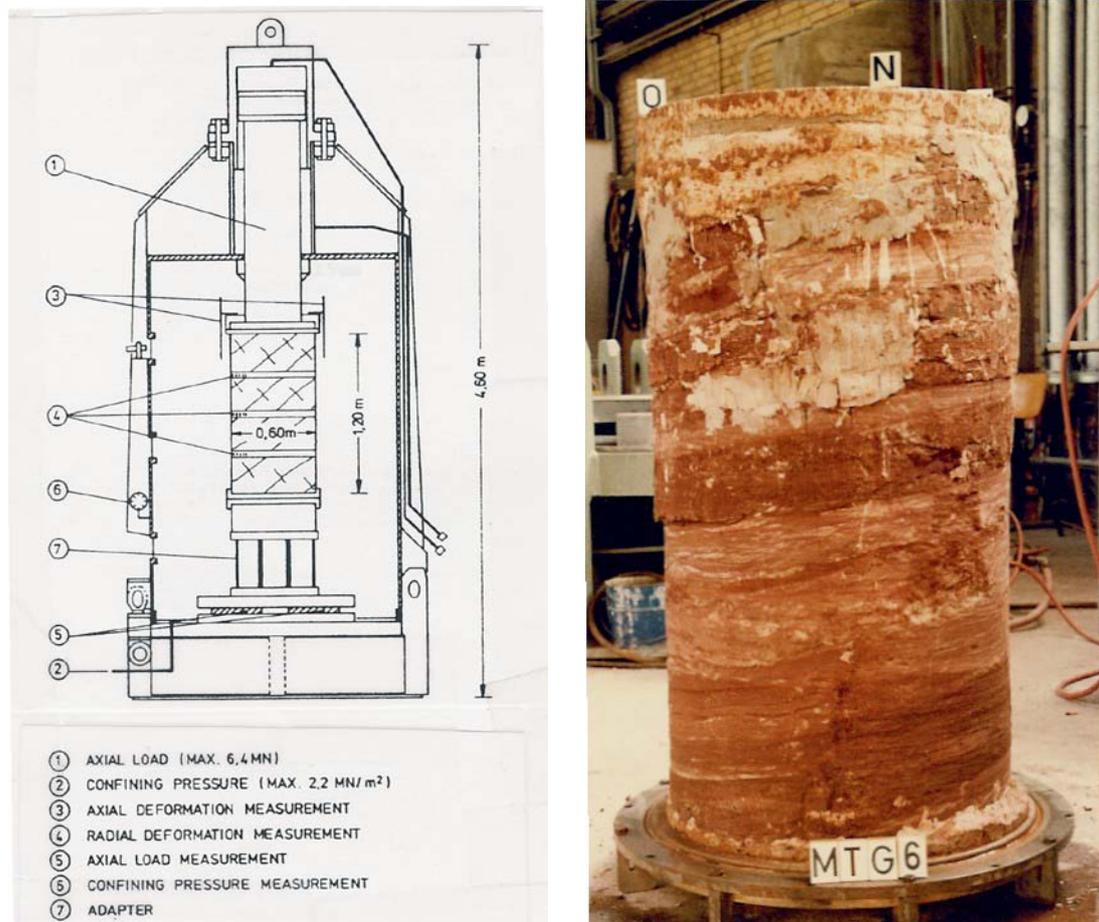


Fig. A6-10 a. Test equipment used in the large scale triaxial tests at the University of Karlsruhe (from Mutschler and Natau, 1991).
 b. Photo of a typical test sample with dimensions 0.6 m diameter and 1.2 m length.

The following values have been applied in the calibration of R_{Mi}:

- Three joint sets occur. (The indication of strike/dip is the orientation of the joint sets measured in the field):
 - * The main joint set occurs along the steep-dipping schistosity with spacing less than 20 cm. The joint characteristics are:

- smooth surfaces; i.e. the joint smoothness factor:	js = 1
- small undulations of joint wall; i.e. the joint waviness factor	jw = 1.5
- fresh joint walls with some rust, no coating or filling; i.e.	jA = 1
- short - medium, continuous joints; i.e.	jL = 1 - 1.5
- The joint condition factor is then	jC ≈ 1.5 - 2 .
 - * The two other sets consist of:
 - Joints along the layering (strike/dip = 70/15) of mainly 'welded', dm-long joints.
 - Other joints with strike/dip = 215/75 with cm - m size.

Both sets have similar joint characteristics with:

- slightly rough surfaces; i.e. the joint smoothness factor $j_s = 1.5$
 - slightly undulating joint walls; i.e. the joint waviness factor $j_w = 1.5$
 - fresh joint walls with some rust, but no coating or filling;
i.e. the joint alteration factor $j_A = 1$
 - short - medium, continuous joints; i.e. $j_L = 1 - 1.5$
 - The joint condition factor is then $j_C \approx 2 - 3$
- The block sizes are in the range of 100 cm^3 to several dm^3 . According to Mutschler (1993) the average size has been estimated as $V_b = 5 - 10 \text{ dm}^3$.
(This means that there were only 35 - 70 blocks in the cylindrical sample tested, and 45 - 90 blocks in the prismatic sample.)

The results from the tests are:

- Uniaxial compressive strength of intact rock:
 - parallel to schistosity $\sigma_c = 55 \text{ MPa}$
 - normal to schistosity $\sigma_c = 100 \text{ MPa}$.
- Uniaxial compressive strength of jointed block mass:
 - parallel to schistosity $RM_i = \sigma_{cm} = 3 \text{ MPa}$
 - normal to schistosity $RM_i = \sigma_{cm} = 8 \text{ MPa}$
- From the test results above the jointing parameter is found as:
 - $JP = RM_i/\sigma_c = 3/55 = 0.055$ parallel to schistosity; and
 - $JP = RM_i/\sigma_c = 8/100 = 0.08$ normal to schistosity.
- The difference in JP for the two directions can probably be explained by the difference in the joint condition for the schistosity joints and the other joints. The joint condition is, therefore, estimated as:
 - $j_C = 1.5 - 2$ for the test parallel to schistosity, and
 - $j_C = 2 - 2.5$ for the test normal to schistosity
- The values used for calibration in Fig. 4-3 are:
 - * Tests parallel to schistosity:
 - the joint condition factor: $j_C = 1.5 - 2$
 - the block volume: $V_b = 5 - 10 \text{ dm}^3$
 - the jointing parameter: $JP = 0.055$
 - * Tests normal to schistosity:
 - the joint condition factor: $j_C = 2 - 2.5$
 - the block volume: $V_b = 5 - 10 \text{ dm}^3$
 - the jointing parameter: $JP = 0.08$

5.2 Sample 6. Mesozoic sandstone from Germany

This is a Lower Triassic sandstone with intercalations of silty claystone from Hessen. The tests (named MTG) were performed normal to the layering on cylindrical samples of 0.6 m diameter and 1.2 m length. They have been published by Natau et al. (1983).

The following values have been applied in the calibration of RM_i :

- The following joints were present:
 - * Joints along the layering are most prominent, they had the following characteristics:
 - slightly rough - rough surfaces; i.e. the joint smoothness factor $j_s = 1.5 - 2$
 - planar joint walls; i. e. the joint waviness factor: $j_w = 1$
 - unaltered walls without coating/filling; i.e. the joint alteration factor $j_A = 1$
 - continuous, medium length (1 - 10 m) joints; i.e. $j_L = 1$
 - The joint condition factor is then $j_C = 1.5 - 2$.

- * Cross joints, partly discontinuous with the following characteristics:
- rough surfaces; i.e. the joint smoothness factor: $j_s = 2$
 - undulating joint walls; i.e. the joint waviness factor: $j_w = 1.5 - 2$
 - unaltered, often 'welded'; i.e. the joint alteration factor: $j_A = 0.75$
 - short (< 1 m) joints, often discontinuous; i.e. $j_L = 2 \times 1.5 = 3$
 - The joint condition factor is then $j_C = 12 - 16$
- There is a great difference between the j_C for the two types of joints. Therefore it is difficult to decide what will be the resulting j_C during the test. It is assumed that $j_C = 5 - 10$.
 - Based on information from Mutschler (1993) the average block size is $V_b = 1 - 5 \text{ dm}^3$

The results of the triaxial tests are:

- Uniaxial compressive strength of intact rock
 - sandstone $\sigma_c = 10.5 \text{ MPa}$
 - claystone $\sigma_c = 4.8 \text{ MPa}$
- Uniaxial compressive strength of jointed rock mass performed on cylindrical samples $\sigma_{cm} = R_{Mi} = 1.33$

The sample consists of two types of rock with different strength and it is therefore uncertain what compressive strength should be used in this case with such inhomogeneous rock mass. An assumed value of $\sigma_c = 8 \text{ MPa}$ may be reasonable. This gives $JP = R_{Mi}/\sigma_c = 1.33/8 \approx 0.17$

Based on this the values used for calibration are:

- the joint condition factor: $j_C = 5 - 10$ (?)
- the block volume: $V_b = 1 - 5 \text{ dm}^3$
- the jointing parameter: $JP = 0.17$

5.3 Sample 7. Palaeozoic siltstone from Germany

This is a Carboniferous, dark siltstone from Hagen in Germany. The tests were carried out on cylindrical samples 0.6 m diameter and 1.2 m long. According to Mutschler (1993) no prominent joint set occurred in this sample where mainly short joints were orientated in various directions.

The following values have been applied in the calibration of R_{Mi} :

- The joints have the following characteristics:
 - slightly rough joint surfaces; i.e. the joint smoothness factor $j_s = 1.5$
 - small to large undulation of walls; i.e. the joint waviness factor $j_w = 1.5 - 2$
 - fresh joint surface without coating or fillings; i.e. the joint alteration factor: $j_A = 1$
 - continuous joints with average length approx. 1 m; i.e. $j_L = 1.5$
 - The joint condition factor is then $j_C \approx 3.5 - 4.5$
- The average block volume (Mutschler, 1993) is in the range $V_b = 5 - 10 \text{ dm}^3$

The laboratory tests on intact rock and on jointed rock mass gave the following results:

- Uniaxial compressive strength of intact rock $\sigma_c = 65 \text{ MPa}$
- Uniaxial compressive strength on cylindrical samples of jointed rock mass $R_{Mi} = \sigma_{cm} = 6.8 \text{ MPa}$
- From this the jointing parameter is found as $JP = R_{Mi}/\sigma_c = 6.8/65 = 0.10$

The values used in the calibration are:

- the joint condition factor: $j_C = 3.5 - 4.5$
- the block volume: $V_b = 5 - 10 \text{ dm}^3$
- the jointing parameter: $JP = 0.10$