P-03-29

KFM 01A

Q-logging

Nick Barton, Nick Barton & Associates

March 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Summary

The first Forsmark potential repository site borehole KFM 01A provided core from 101.8 to 1000.7 m depth. This was independently Q-logged by NB&A during a two-day period (19th–20th February, 2003), without access to BORMAP results or regional jointing frequencies or orientations. The Q-logging was intended to be an independent check for subsequent BORMAP-derived Q-parameter estimation.

The Q-logging was accomplished using the manually-recorded 'histogram method' which allows the logger to enter Q-parameter ranges and depths directly into the appropriate histograms, which facilitates subsequent data processing using Excel spreadsheets. Successive pairs of core boxes, which contain an average of 11 meters of core in ten rows, were the source of ten opinions of each of the six Q-parameters, giving a total of 4920 recordings of Q-parameter values for the 164 core boxes.

Data processing was divided into several parts, with successively increasing detail. The report therefore contains Q-histograms for the whole core, for four identified fracture(d) zones combined as if one unit, and then for the whole core minus these fracture(d) zones. This background rock mass quality is subsequently divided into nine depth zones or slices, and trends of variation with depth are tabulated. The four identified fracture(d) zones, which are actually of reasonable quality, are also analysed separately, and similarities and subtle differences are discerned between them.

The overall quality of this first core is very good to excellent, with Q(mean) of 48.4, and a most frequent Q-value of 100. The range of quality is from 2.1 to 2130, which is the complete upper half of the six order of magnitude Q scale. Even the relatively fracture(d) zones, representing some 13% of the 900 m cored, have a combined Q(mean) of 13.9 and a range of quality of 2.1 to 150.

Content

1 Introduction

The writer performed Q-logging of 900 m of core from the first site characterization borehole KFM 01A on 19th and 20th February. This work was requested by Rolf Christiansson, for the purpose of supplementing the more detailed BORMAP geological logging.

It is intended that this Q-logging can provide an independent check of BORMAP-derived Q-parameter data, which is under preparation following geological logging of this first deep borehole-core.

2 Q-logging methodology

It was the intention of SKB that this Q-logging should be of an 'overview' character. For this reason time was limited, and the 900 m approx. of core (from 101.8 to 1001.7 m depth) was Q-logged using the 'histogram method' /Barton et al, 1992/. The 900 m was logged in about 12 hours.

The procedure used was to log two core boxes at a time. Due to the 1.1 m approx. length of the boxes, there were a total of 82 pairs of core boxes, giving close to 11 m of core on average.

The Q-histogram logging method, described recently in some detail by /Barton, 2002/, consists of making estimates of the variability of each of the six Q-parameters. Each of the Q-parameters are defined, and complete ratings listed, in Appendix B at the end of this report.

For each pair of core boxes, imagining there was the normal 1.0 m of core length, a total of 10 opinions were recorded concerning the visible variability of each of the the six Q-parameters. In many cases, such as RQD = 100% in excellent rock, there was of course little variation, and logging could proceed much faster. In Appendix A, scanned copies of the nine hand-filled Q-histogram logging sheets will be found. These will be seen to contain numerous entries 111111, 22222, 666, 777, 999999 etc. in the appropriate boxes. Each number, from 1 through 9, is related to a specific core depth, as listed in the left margin of each sheet. Each number is also placed in the Q-parameter box appropriate to the observed/estimated quality (or lack of quality, as the case may be). For 900 m of core, with 10 opinions of each of the six Q-parameters, there were a resulting total of 10 x 6 x 82 or nearly five thousand Q-parameter estimates.

The result is overall histograms of variability (or similarity, at deeper levels in the rock mass) plus the depth-related variability from which depth logs can be extracted if desired.

It will be noted that there are several footnotes written beneath most of the scanned logging sheets. Of particular importance is to note the *assumption* of a 'residual' one joint set plus random (J_n = 3) even for massive sections of core, due to the reasonable assumption of biased sampling (or lack of sampling) of a presumed predominant sub-vertical NW-SE trending set of joints. This assumption is carried through until the depth is reached that no more joints of any orientation are encountered in the core.

Comparison of logging sheets 8 and 9 show the dramatic improvement in the *assumed* 'joint-free' Q-value for the depth interval 884 to 1001 m (approx.), assuming that this assumption is valid.

In view of the present uncertainty caused by vertical hole orientation, there are three important question marks written next to J_n, J_r and J_a on this final depth interval. Each of these parameters are involved when 'achieving' the best possible Q-quality of 2130 for unjointed, massive rock. These are irrelevant under 3D confinement, prior to excavation, i.e. irrelevant for the presently reported *characterization.*

Emphasis here has been to *characterize* the overall variability of the rock mass, especially of the different joint sets, as opposed to a specific tunnel-related *classification* for estimating rock reinforcement and support needs. In the latter, the least favourable J_r/J_a ratio is considered, together with the tangential stress effect of the tunnel. The term SRF is evaluated considering the ratio σ_c/σ_1 when support design is the objective. When excavations are considered at this depth, there may be a significant reduction in Q-value to the *Q-classification* value, due to low potential σ_c/σ_1 ratios and elevated SRF values.

The final purpose of the *characterization* performed, is to apply empirical linkages between Q-values (more specifically Q_c values) and engineering parameters such as deformation modulus, cohesion, friction and uniaxial rock mass strengths – to the extent that these 'continuum' concepts apply.

3 Examples of joint character

A by-product of the logging was the recording of joint roughness traces for representative examples of each joint set. For present purposes, prior to obtaining joint orientation data, the jointing was categorised into three classes, namely 'sub-horizontal', '+/– 45º dip', and 'steeply dipping' (including occasional sub-vertical joints that are poorly sampled).

Physical examples of joint roughness numbers J_r equal to 1.5 and 2 (the most commonly observed) are given in Figure 3-1. These are also examples of '+/– 45º dip' and 'steeply dipping' joints respectively.

Figure 3-2 shows a typical $J_r = 3$ joint, which were commonly of 'steeply dipping' orientation. This figure also shows a discontinuity with a thin over-consolidated filling (J_a= 4), and joint wall roughness J_r of 1.0 to 1.5, in the '+/– 45º dip' orientation class. This example is from the fourth identified fracture(d) zone, termed FZ 4 here, which extends from roughly 651 to 683 m depth, judging from reduced Q-parameter qualities in this region of the hole.

Beneath several of the scanned logging sheets (Nos. 5, 7, 8 and 9 in Appendix A) another footnote will be seen concerning the Q-logging instruction to compensate (increase) the effective frictional strength of the rock mass for the case of widely spaced joints. Appendix B, Table 3 Joint Roughness, shows the empirically-derived instruction to increase by 1.0 the J_r value of the relevant joint set, if its average spacing is greater than 3 m.

This adjustment is applied later, when the Q-values of specific 100 m intervals are analysed. Its minor effects are demonstrated, with some improvement in Q_{mean} and sometimes also some improvement in $Q_{typical\ minimum}$.

Figure 3-1. *a) Example of joint roughness $J_r = 1.5$ and b) $J_r = 2$ (the most frequent), and of '+/– 45° dip' and 'steeply dipping' joints.*

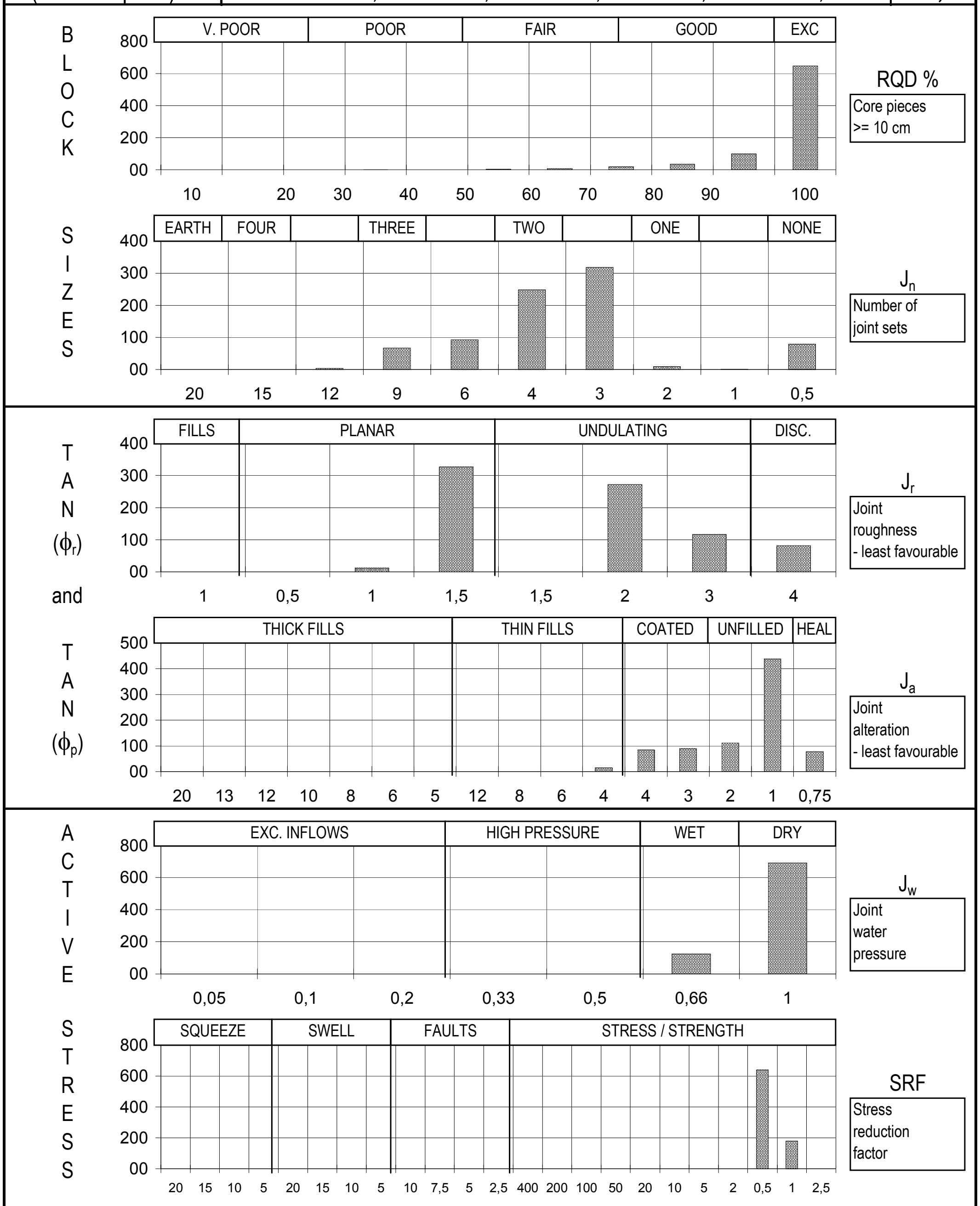
Figure 3-2. *a) Example of joint roughness J_r = 3 (typical of 'steep dipping' joints) and b) of J_r = 1.0 to 1.5 in the case of a thinly filled discontinuity (with J_a = 4). The latter is from the fourth identified fracture(d) zone, termed FZ 4 here.*

4 Overall quality of KFM 01A

The first procedure of Q-histogram analysis was to count all recordings of quality, including those of obvious fracture(d) zones, and produce Q-parameter histograms for the complete 900 m of core to 1000.7 m depth. The result is shown in Figure 4-1.

As expected, the most frequent quality is very good to exceptionally good with ($Q_{most\ frequent}$) = 100. The weighted mean (weighted downwards by four distinct fracture(d) zones) shows Q_{mean} = 48.4 (also described as very good). Typical minimum and maximum values range from about 2.1 to 2130 – poor to exceptionally good.

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	75	/	9,0	*	1,5	/	4,0	*	0,66	/	1,0	=	**2,063**
Q (typical max)=	100	/	0,5	*	4,0	/	0,8	*	1,00	/	0,5	=	**2133,3**
Q (mean value)=	97	/	3,9	*	2,1	/	1,7	*	0,95	/	0,6	=	**48,37**
Q (most frequent)=	100	/	3,0	*	1,5	/	1,0	*	1,00	/	0,5	=	**100,00**



	Rev.	Report No.	Figure No.
SKB FORSMARK		NB&A	3
KFM 01: overall quality of whole core, from 101.8 to 1000.7m depth. (includes 4 possible fracture zones)	Borehole No. : KFM 01A	Drawn by nrb	Date
	Depth zone (m) 101.8 - 1000.7	Checked nrb	
	Logg 1,0 ##	Approved 24th March 2003	

Figure 4-1. *Q-parameter histograms for the complete KFM 01A core, from 101.8 to 1000.7 m depth.*

5 Character of fracture(d) zones

Inspection of the character and distribution of individual Q-parameters – particularly lower-valued 'tails' of RQD, and higher-valued 'tails' of J_n and J_a – give a strong indication of fractured zones, which subsequently may receive the tentative notation *fracture zone.* The Q-parameter histograms for these zones show lower quality tails in the distribution that all trend to the left. Higher qualities trend only to the right. There are both skewed distributions (e.g. RQD = 100% dominating), and more normal distributions (i.e. J_n = 2 to 4 dominating).

In the present report we have identified four zones of noticeably increased fracturing, where presumably both the BORMAP geologists and the Q-logger had to take more time due to all the details of jointing and fracturing to be recorded. The present Q-parameter based identification, which is entirely independent of the geological logging assessment (whose result is unknown to the undersigned), is as follows :

FZ 1	depth 166 to 199 m (approx.)	sheet 1, ref. 7,8,9	Appendix A
FZ 2	depth 265 to 297 m (approx.)	sheet 2, ref. 7,8,9	Appendix A
FZ 3	depth 385 to 407 m (approx.)	sheet 3, ref. 9	Appendix A
		sheet 4, ref. 1	Appendix A
FZ 4	depth 651 to 683 m (approx.)	sheet 6, ref. 7,8,9	Appendix A

These have first been assembled as a typical 'unit' (combining the characteristics of all four zones) prior to individual histogram representation, which obviously is more correct. The preliminary combined result is shown in Figure 5-1.

The summary statistic of the combined FZ zones is as follows, giving immediately the (correct) impression that the rock mass quality is actually quite reasonable as jointed rock goes, but of distinctly lesser quality than the extremely good quality of the remainder. It is this contrast that is noticeable, not poor quality per se.

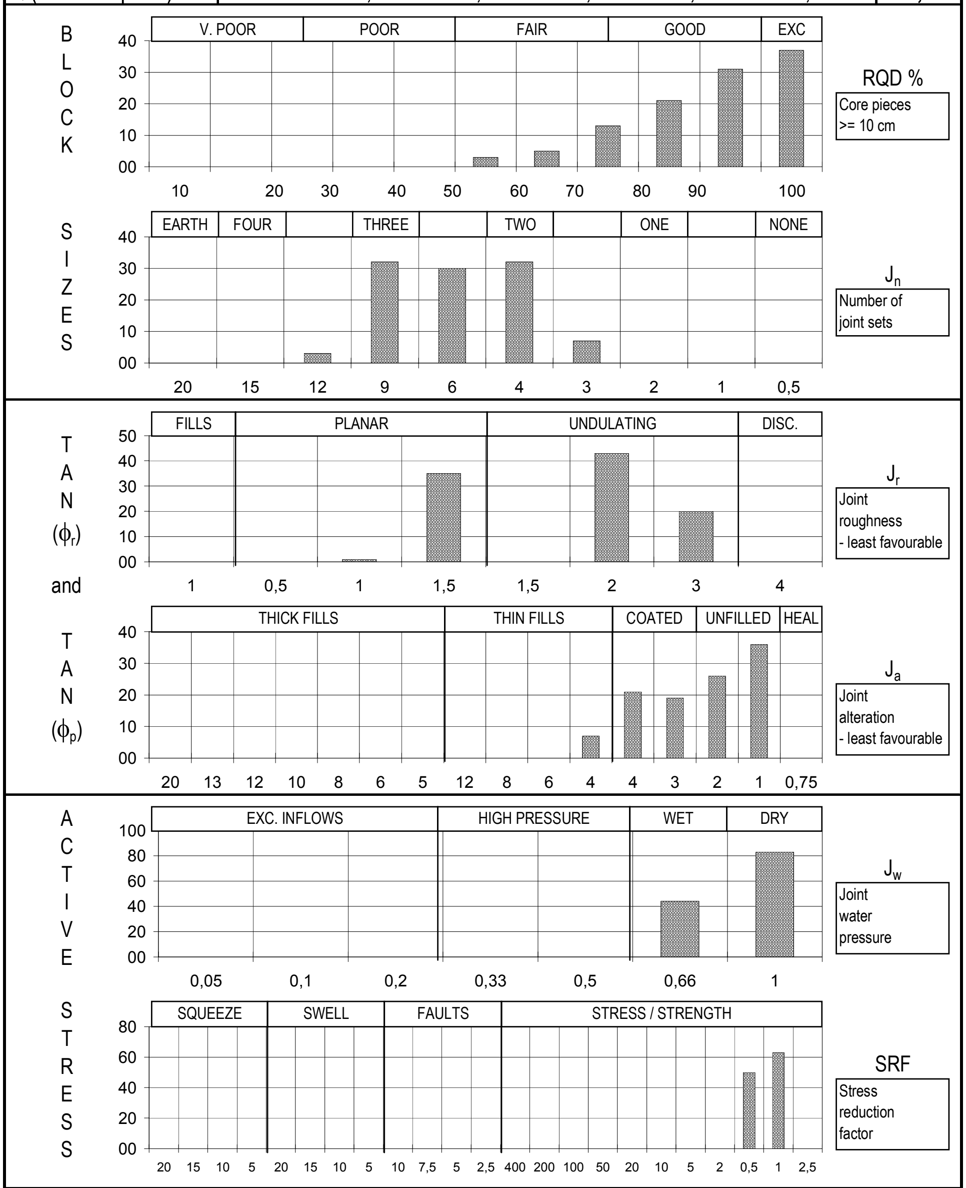
$Q_{most\ frequent}$ = 33.3 (good)

Q_{mean} = 13.9 (good)

$Q_{typ.\ min.}$ = 2.1 (poor)

$Q_{typ.\ max.}$ = 150 (extremely good)

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	75	/	9,0	*	1,5	/	4,0	*	0,66	/	1,0	=	**2,063**
Q (typical max)=	100	/	4,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**150,0**
Q (mean value)=	90	/	6,3	*	2,0	/	2,4	*	0,88	/	0,8	=	**13,87**
Q (most frequent)=	100	/	6,0	*	2,0	/	1,0	*	1,00	/	1,0	=	**33,33**



SKB FORSMARK site	Rev.	Report No. NB&A	Figure No. 4
KFM 01A drill core. Overall quality of four identified fracture zones : 166-199m, 265-297m, 385-407m and 651-683m.	Borehole No. : KFM 01A	Drawn by nrb	Date
	Depth zone (m) (various)	Checked nrb	
	Logg 1,0	Approved 24 March 2003	

Figure 5-1. *Q-parameter histograms for the four identified fracture(d) zones.*

6 Character of KFM 01A minus fracture(d) zones

By counting overall Q-parameter observation totals (10 x 6 x 82 = 4920 recorded numbers in Appendix A) and subtracting the eleven 'lines' of fracture(d) zone recordings listed above (giving 10 x 6 x 11 = 660 observations) we obtain the 'net result' for rock mass minus fracture(d) zones. The above numbers suggest that about 660/4920 x 100 = 13.4% is significantly fractured, *as measured in a down-hole direction.* If, as may be assumed, some of the zones have significant dip angles, then this percentage would be reduced with respect to perpendicular measurement.

The 'net rock mass' result is shown in Figure 6-1, and clearly demonstrates the excellent general quality. The following Q statistics can be noted:

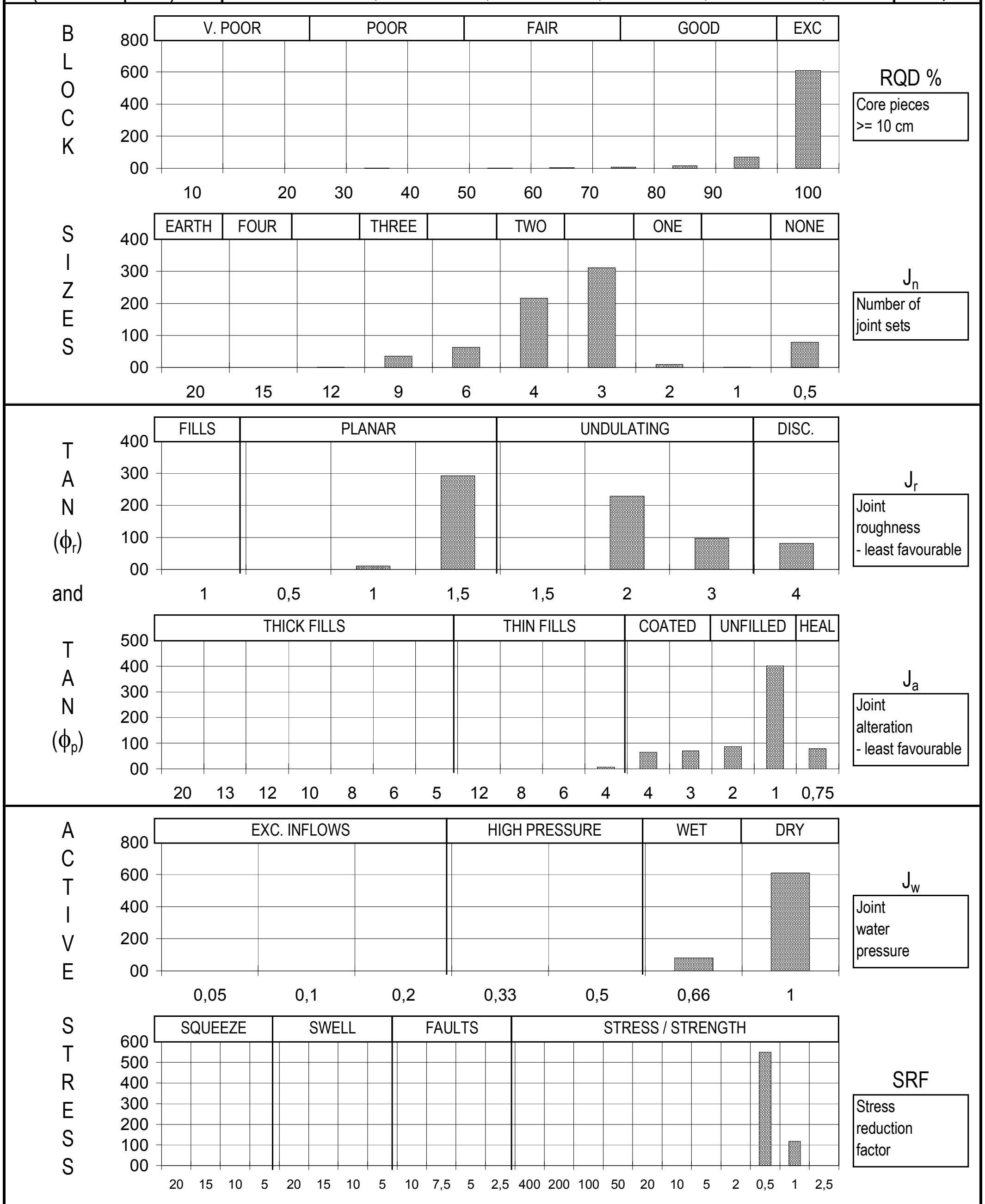
$Q_{\text{most frequent}} = 100$ (very to extremely good)

$Q_{\text{mean}} = 60.4$ (very good)

$Q_{\text{typ. min.}} = 2.3$ (poor)

$Q_{\text{typ. max.}} = 2130$ (exceptionally good)

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	85	/	9,0	*	1,5	/	4,0	*	0,66	/	1,0	=	**2,338**
Q (typical max)=	100	/	0,5	*	4,0	/	0,8	*	1,00	/	0,5	=	**2133,3**
Q (mean value)=	99	/	3,6	*	2,1	/	1,6	*	0,96	/	0,6	=	**60,38**
Q (most frequent)=	100	/	3,0	*	1,5	/	1,0	*	1,00	/	0,5	=	**100,00**



SKB FORSMARK	Rev.	Report No. NB&A	Figure No. 5
KFM 01A 101.8 to 1000.7m, excluding the four fractured zones plotted in Figure 2.	Borehole No. : KFM 01A	Drawn by nrb	Date
	Depth zone (m) 101.8-1000.7	Checked nrb	
	Logg 1,0 ## 24th March 2003	Approved	

Figure 6-1. *Q-parameter histograms for the 'average' rock mass, with the four fracture(d) zones excluded.*

7 Individual character of fracture(d) zones

As suggested earlier, it is artificial to combine four fracture(d) zones as in Section 5. In this next section we therefore investigate possible differences in character, which may be useful when subsequent deep boreholes are compared and 'cross-correlated' – if this proves possible. Figures 7-1, 7-2, 7-3 and 7-4 show individual Q-parameter histograms of the presently identified fracture(d) zones FZ 1, FZ 2, FZ 3 and FZ 4.

Two photographic examples of these fracture(d) zones, taken from FZ 1 and FZ 4 are shown in Figure 7-5. (We saw a detail of thinly filled discontinuities, also from FZ 4, in Figure 3-2b). A fairly rare occurrence of an intersected sub-vertical joint is also seen in Figure 7-5, from FZ 1.

There are in fact *some* similarities between the fracture(d) zones, and *some distinct differences.* Firstly, FZ 1 and FZ 2 have similar RQD 'tails', (or skewed distributions) with mostly RQD = 100%. They have J_a 'tails' (or skewed distributions) representing relatively few clay-coatings and thin fillings, that are also similar, with 'unaltered' joint walls (J_a = 1) as the most common condition.

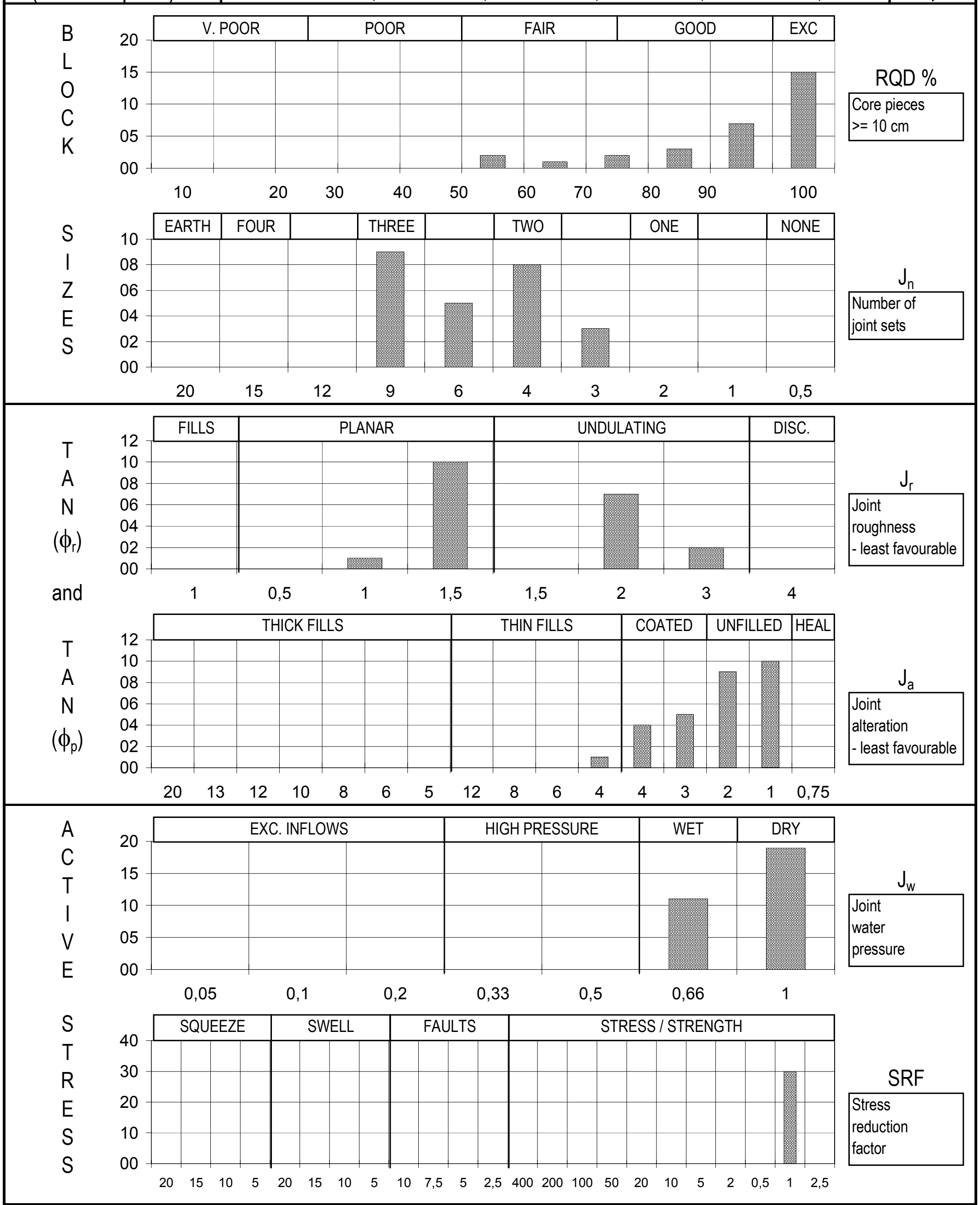
Turning to FZ 3 and FZ 4, we see a more 'normal' type of RQD distribution, with 75, 85 or 95% more common than 100%. There is a correspondingly greater tendency for three joint sets plus random (J_n = 12). There is also a greater relative proportion of clay coatings and thin fillings (J_a = 4). Possibly because of their greater depth, FZ 3 and FZ 4 nevertheless have highest $Q_{typ.\ max.}$ values and highest $Q_{mean\ values}$. By chance, identical Q_{mean} values of 18.97 are seen in FZ 3 and FZ 4, almost twice as high as in the case of FZ 1 (Q_{mean} = 10.9) and FZ 2 (Q_{mean} = 11.5).

Table 7-1. Q-statistics for four fracture(d) zones identified from Q-parameter changes.

Fracture(d) zone	$Q_{most\ frequent}$	Q_{mean}	$Q_{typ.\ min.}$	$Q_{typ.\ max.}$
FZ 1	16.7	10.9	1.0	100
FZ 2	22.0	11.5	1.8	75
FZ 3	20.9	19.0	2.7	200
FZ 4	37.8	19.0	2.3	200

Thus although these identified fracture(d) zones are easy to see when surveying the core, and would presumably have resulted in lower terrain if intersecting the ground surface, they are in fact relatively moderate reductions in quality, and perhaps would result in no more than about 1 km/s reduction in P-wave velocity in relation to 'background' qualities. This may well be the reason for the distinctive and rather limited height differences in the local ground surface, despite glaciation scouring.

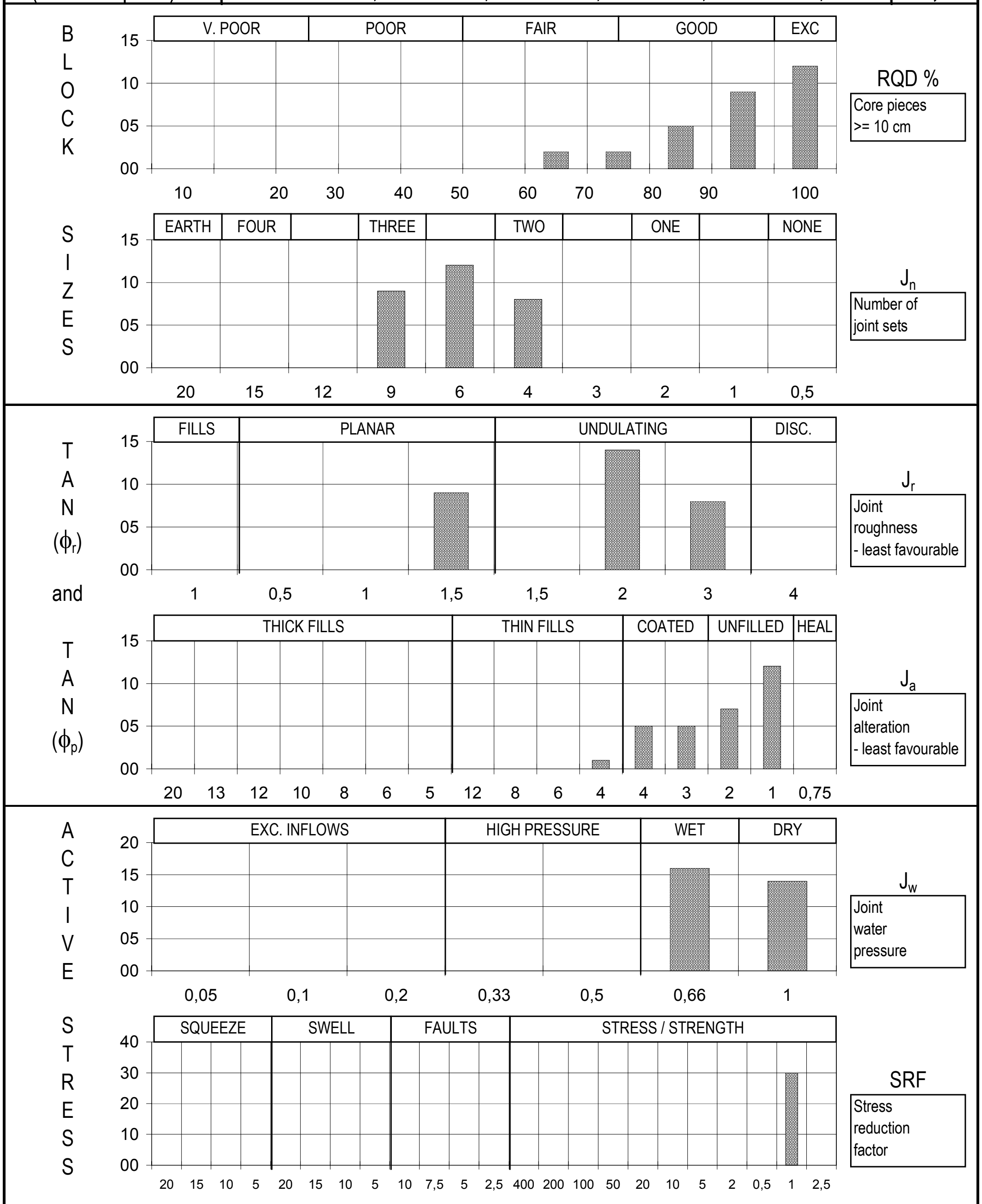
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	55	/	9,0	*	1,0	/	4,0	*	0,66	/	1,0	=	**1,008**
Q (typical max)=	100	/	3,0	*	3,0	/	1,0	*	1,00	/	1,0	=	**100,0**
Q (mean value)=	92	/	6,1	*	1,8	/	2,2	*	0,88	/	1,0	=	**10,91**
Q (most frequent)=	100	/	9,0	*	1,5	/	1,0	*	1,00	/	1,0	=	**16,67**



SKB FORSMARK site	**KFM 01A**	Rev.	Report No. NB&A	Figure No. 6
Individual character of FZ 1		Borehole No. : KFM 01A	Drawn by nrb	Date
		Depth zone (m) 166-199m	Checked nrb	
		Logg 1,0 ##	Approved 27th March 2003	

Figure 7-1. *Individual character of FZ 1 (166–199 m).*

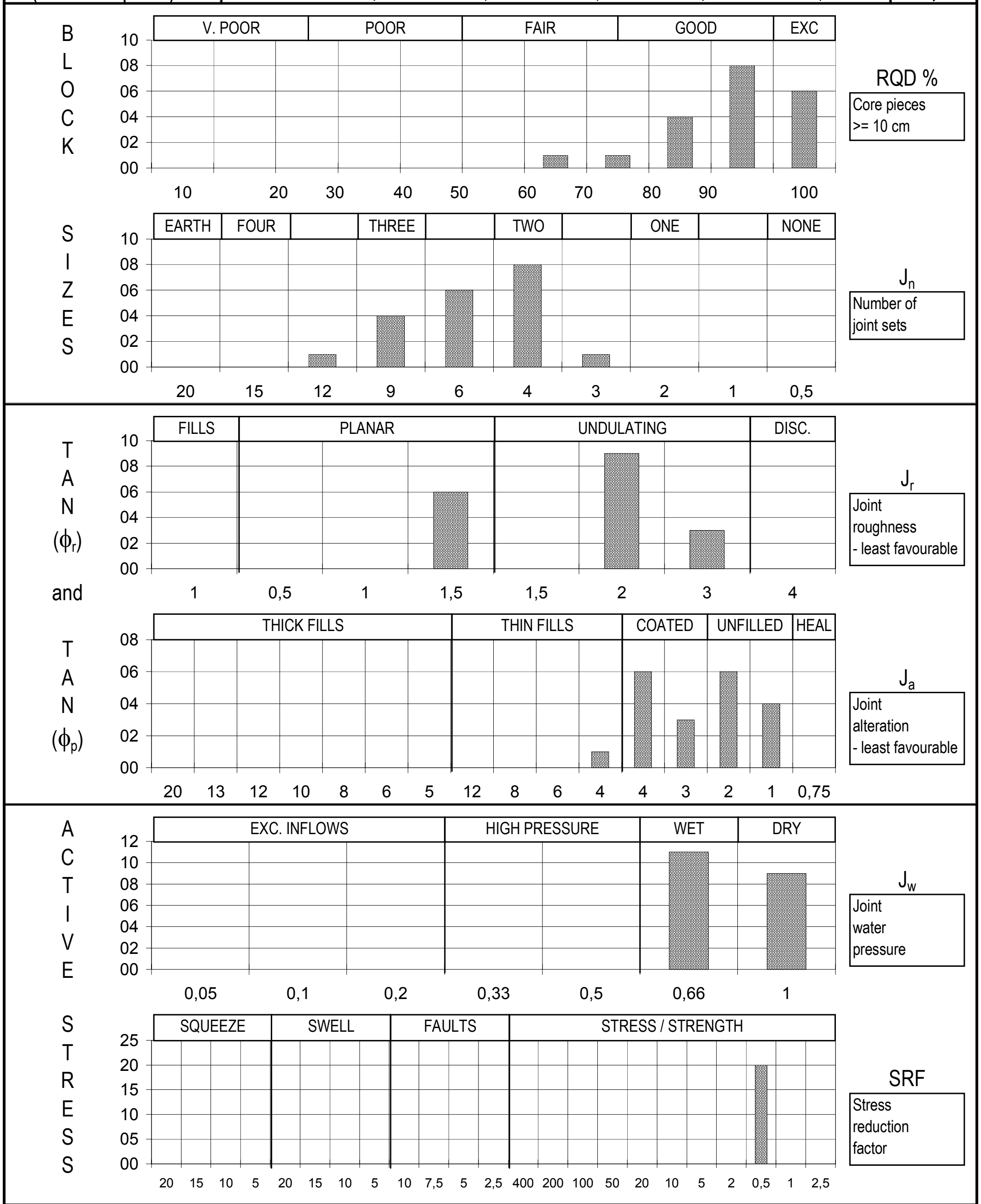
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	65	/	9,0	*	1,5	/	4,0	*	0,66	/	1,0	=	**1,788**
Q (typical max)=	100	/	4,0	*	3,0	/	1,0	*	1,00	/	1,0	=	**75,0**
Q (mean value)=	92	/	6,4	*	2,1	/	2,2	*	0,82	/	1,0	=	**11,51**
Q (most frequent)=	100	/	6,0	*	2,0	/	1,0	*	0,66	/	1,0	=	**22,00**



SKB FORSMARK site	**KFM 01A**	Rev.	Report No. NB&A	Figure No. 7
Individual character of FZ 2		Borehole No. : KFM 01A	Drawn by nrb	Date
		Depth zone (m) 265-297m	Checked nrb	
		Logg 1,0	Approved	
		##	27th March 2003	

Figure 7-2. Individual character of FZ 2 (265–297 m).

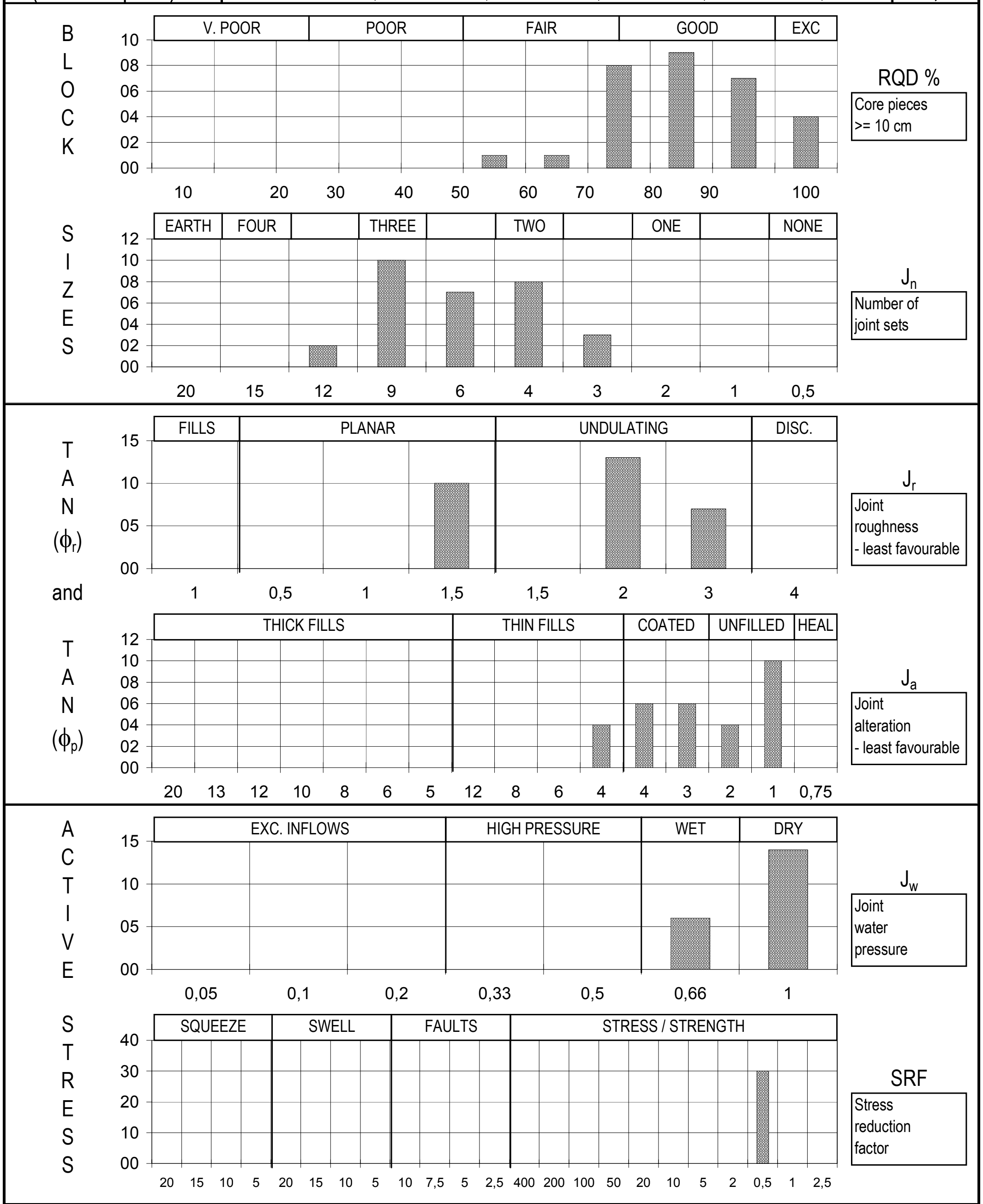
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	65	/	12,0	*	1,5	/	4,0	*	0,66	/	0,5	=	**2,681**
Q (typical max)=	100	/	3,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**200,0**
Q (mean value)=	92	/	6,0	*	2,0	/	2,7	*	0,81	/	0,5	=	**18,97**
Q (most frequent)=	95	/	4,0	*	2,0	/	3,0	*	0,66	/	0,5	=	**20,90**



SKB FORSMARK site	**KFM 01A**	Rev.	Report No. NB&A	Figure No. 8
Individual character of FZ 3		Borehole No. : KFM 01A	Drawn by nrb	Date
		Depth zone (m) 385-407m	Checked nrb	
		Logg 1,0 ##	Approved 27th March 2003	

Figure 7-3. *Individual character of FZ 3 (385–407 m).*

n	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	55	/	12,0	*	1,5	/	4,0	*	0,66	/	0,5	=	**2,269**
Q (typical max)=	100	/	3,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**200,0**
Q (mean value)=	85	/	6,6	*	2,1	/	2,5	*	0,90	/	0,5	=	**18,97**
Q (most frequent)=	85	/	9,0	*	2,0	/	1,0	*	1,00	/	0,5	=	**37,78**



SKB FORSMARK site **KFM 01A**	Rev.	Report No. NB&A	Figure No. 9
Individual character of FZ 4	Borehole No. : KFM 01A	Drawn by nrb	Date
	Depth zone (m) 651-683m	Checked nrb	
	Logg 1,0 ##	Approved 27th March 2003	

__Figure 7-4.__ Individual character of FZ 4 (651–683 m).

Figure 7-5. *Examples from FZ 1 and FZ 4.*

8 General variation with depth (minus fractured zones)

Since the fracture(d) zones have been analysed in some detail above, it is logical to finally separate them from the remaining 87% (approx.) of the better quality core, and investigate if there are significant trends of variation in the ‘background rock quality’ with depth. This can be done at this stage only in relation to the Q-logging. Geological variation, and rock type changes (i.e. also potential strength changes) cannot be evaluated at this stage.

The procedure adopted to extract the required ‘background rock mass quality’ data, was to take each Q-logging sheet in turn (approx. 100 m of core per sheet, see Appendix A) and subtract the Q-parameter recordings of the four identified fracture(d) zones as appropriate. An example of the raw data has been scanned and is presented as the last sheet of Appendix A.

The results of key Q-value statistics for the nine ‘100 m thick’ slices down the borehole are presented in Table 8-1. Each logging sheet represents a maximum of about 100 m of core, from which the four fracture(d) zones are subtracted as they occur. This means that some of the nine ‘slices’ are reduced to only about 70 m in (down-hole measured) thickness, due to the maximum 32 m lengths of identified fracture(d) zones. The typical appearance of a small part of the ‘background rock mass’ is shown in Figure 8-1. The depth shown is 357 to 369 m (approx.) where the local Q-parameters were estimated to be:

Q = (100 / 4) x (1.5 / 1) x (1 / 0.5) = 75 (i.e. ‘very good’ in Q-system terminology)

This local characterization assumes the near-by presence of sub-vertical jointing, hence the ‘elevated’ J_n value in relation to the observable, sparse jointing in these two particular core boxes. When performing the Q-logging, this knowledge of adjacent steeply dipping joints carries over from observation of adjacent core boxes.

Judging by the values of Q_{mean} in Table 8-1, there is a mid-depth zone of very good rock, in which even the weighted mean values are consistently high, with values of 73, 65 and 89 (approx.). This rock is found at 297 to 585 m depth. Even typical minimum values are of ‘fair’ to ‘good’ quality, with only one relatively narrow fracture(d) zone from 385 to 407. Q-parameter histograms for these three excellent quality mid-depth ‘slices’ are given in Figures 8-2, 8-3 and 8-4. The narrowest fracture(d) zone FZ 3 (Figure 7-3) is also within this mid-depth region.

As discussed earlier, there is considerable uncertainty concerning the Q-values appropriate to the last 115 m (sheet 9, Appendix A). However if the rock mass is free of joints for e.g. distances of many tens of meters, the effective quality as regards rock mass parameters appropriate to engineering-scale problems is likely to be of this order.

Table 8-1. Variations with depth for 'background rock mass qualities' (minus FZ 1–4).

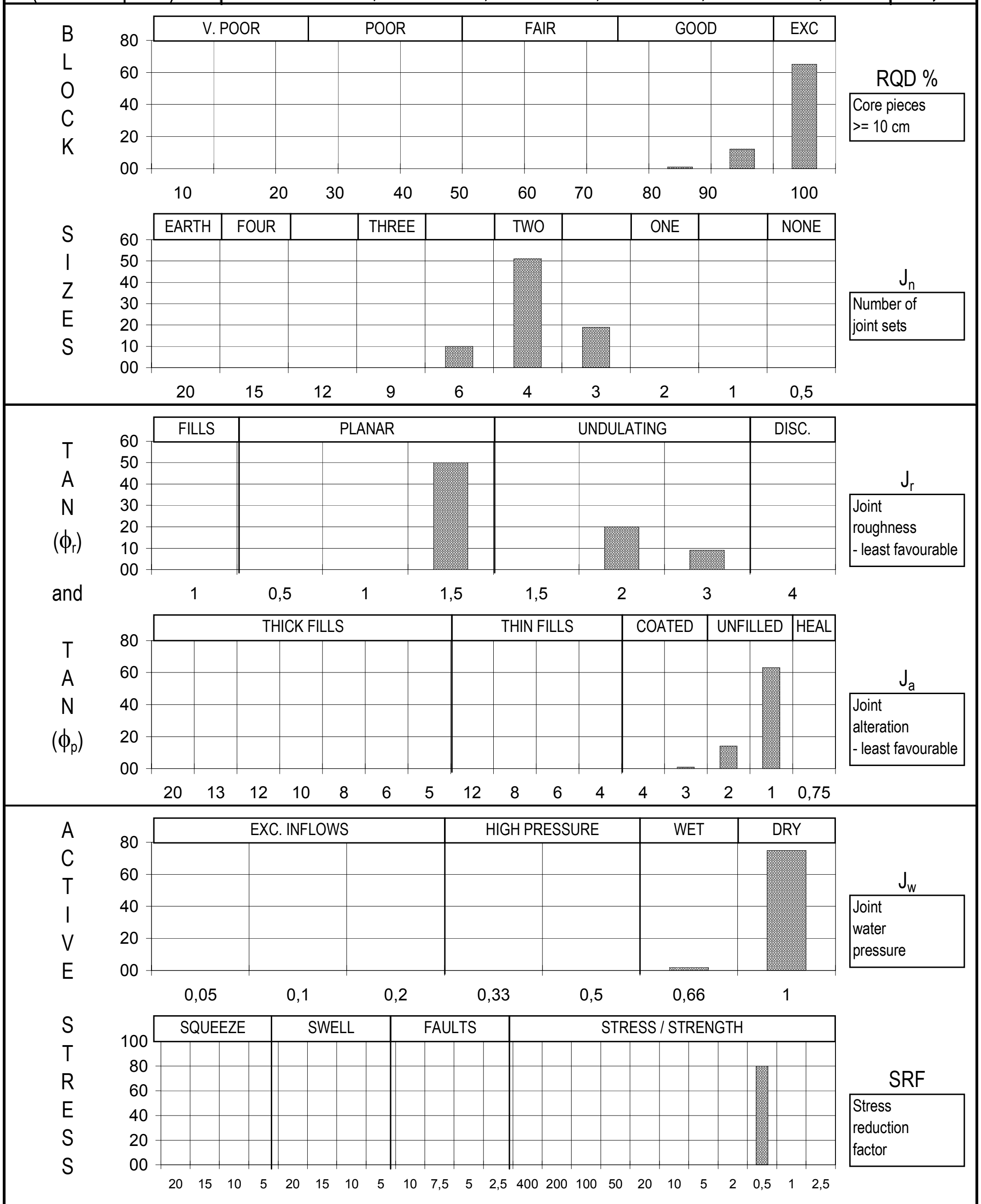
Depth down hole	$Q_{most\ frequent}$	Q_{mean}	$Q_{typ.\ min.}$	$Q_{typ.\ max.}$
102–166 m	10.7	11.2	1.2	200
199–265 m	37.5	18.5	1.1	150
297–385 m	75.0	73.0	9.4	200
407–496 m	75.0	65.3	4.7	200
496–585 m *	75.0	88.6 (76.9)	11.9	267
585–651 m	100	52.0	7.0	267
683–784 m *	58.3	53.1 (43.5)	4.7	100
784–884 m **	133	68.4 (58.7)	21.3 (15.9)	200
884–1001 m **	2000	672 (657)	33.3 (25)	2130

Notes on Table 8-1 (* **)

Where mean joint spacing has appeared to be at least 3 meters in deeper sections of the core, the Q-system footnote referred to earlier (adding 1.0 to J_r) has been tested in the data set presented in Table 8-1. This has been applied to data sheets 5, 7, 8 and 9 (Appendix A). It was not required for sheet 6 (585.1 to 683.1 m) due to the generally closer spacing of joints. For obvious reasons, this correction to J_r was not usually applied to the most frequently occurring joint set, but to the less frequent ones, because of their larger spacing. These subjective judgements resulted in modestly increased values of $\mathbf{Q}_{\mathbf{mean}}$ in each case (uncorrected values of Q given in parentheses in Table 8-1). In deepest parts of the core, $\mathbf{Q}_{\mathbf{typ.\ min.}}$ was also affected, due to the estimation that all the sets had spacing greater than 3 meters.

Figure 8-1. *Example of 'background rock mass quality', from 357 to 369 m.*

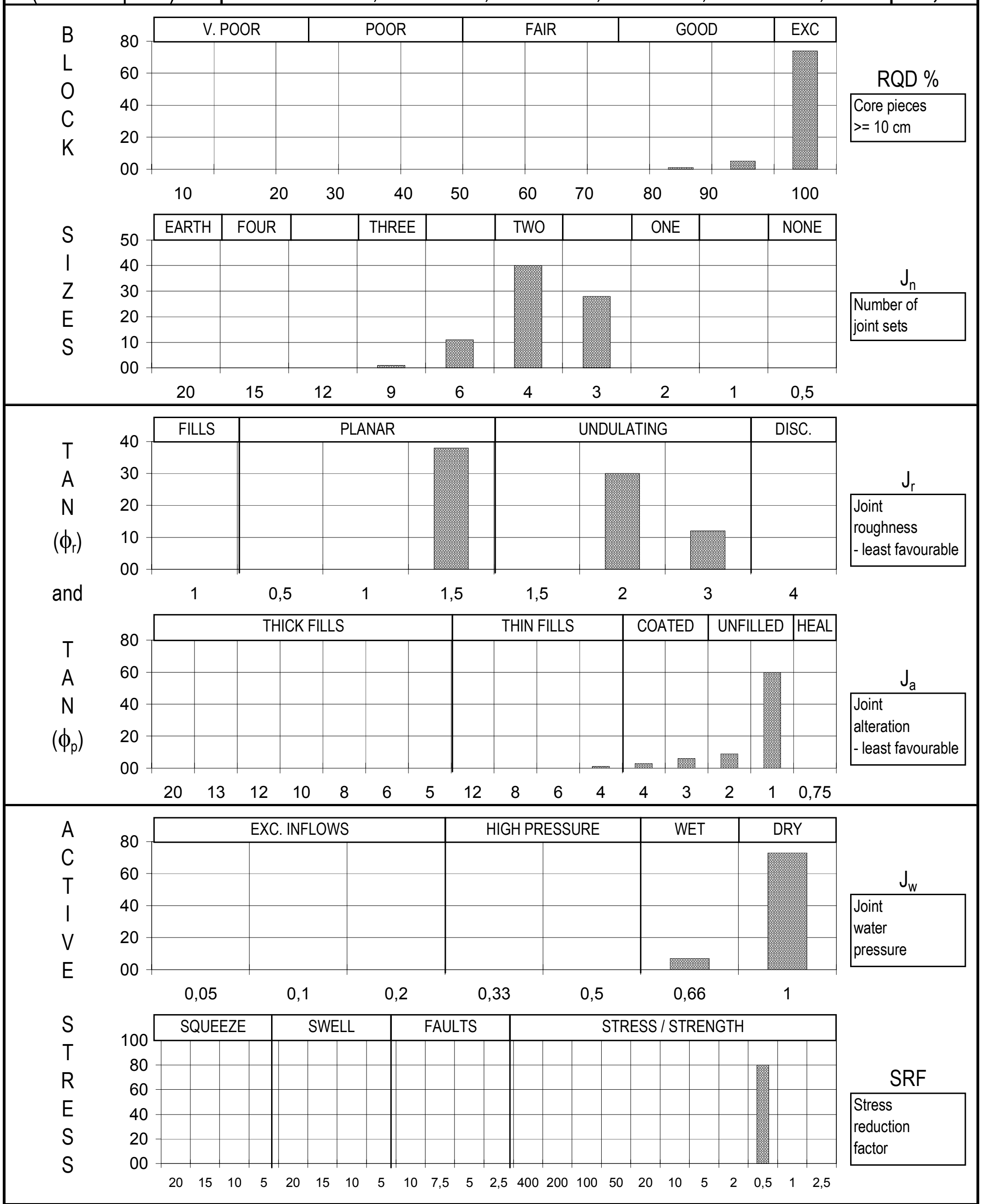
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	**Q**
Q (typical min)=	85	/	6,0	*	1,5	/	3,0	*	0,66	/	0,5	=	**9,350**
Q (typical max)=	100	/	3,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**200,0**
Q (mean value)=	99	/	4,0	*	1,8	/	1,2	*	0,99	/	0,5	=	**72,98**
Q (most frequent)=	100	/	4,0	*	1,5	/	1,0	*	1,00	/	0,5	=	**75,00**



SKB FORSMARK site **KFM 01A**	Rev.	Report No. NB&A	Figure No. 12
297 to 396m, but with part of fracture zone 385 to 396 excluded (- part of FZ 3)	Borehole No. : KFM 01A	Drawn by nrb	Date
	Depth zone (m) 297-385m	Checked nrb	
	Logg 1,0 ##	Approved 25th March 2003	

***Figure 8-2.** Q-histograms for mid-depth 'slice' 297–385 m.*

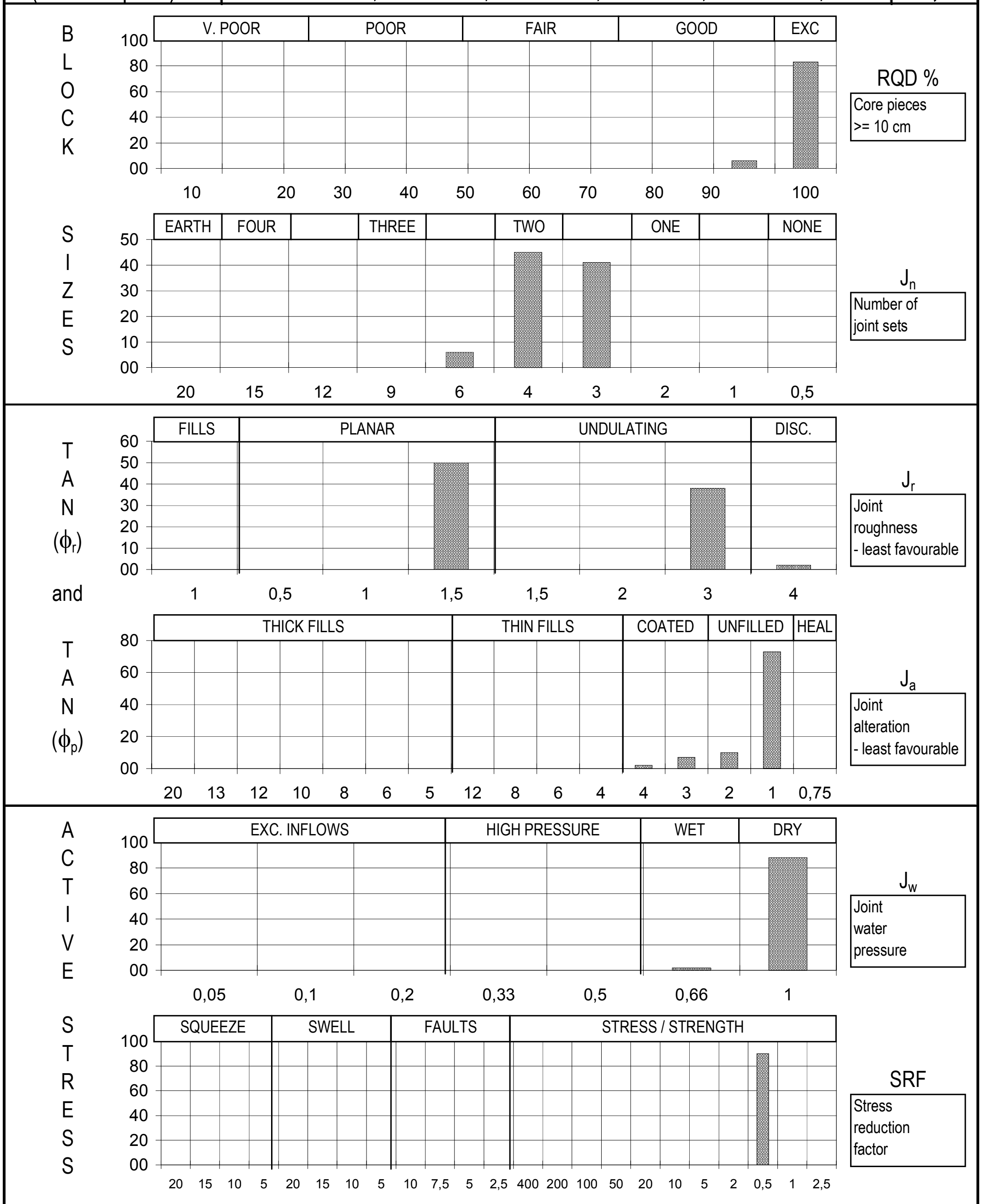
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	85	/	9,0	*	1,5	/	4,0	*	0,66	/	0,5	=	**4,675**
Q (typical max)=	100	/	3,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**200,0**
Q (mean value)=	100	/	4,0	*	1,9	/	1,4	*	0,97	/	0,5	=	**65,32**
Q (most frequent)=	100	/	4,0	*	1,5	/	1,0	*	1,00	/	0,5	=	**75,00**



SKB FORSMARK site KFM 01A	Rev.	Report No. NB&A	Figure No. 13
396 to 496m, but with part of fracture zone 396 to 407m	Borehole No. : KFM 01A	Drawn by nrb	Date
excluded (- part of FZ 3)	Depth zone (m) 407-496m	Checked nrb	
	Logg 1,0 ##	Approved 25th March 2003	

Figure 8-3. *Q-histograms for mid-depth 'slice' 407–496 m.*

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	95	/	6,0	*	1,5	/	4,0	*	1,00	/	0,5	=	**11,875**
Q (typical max)=	100	/	3,0	*	4,0	/	1,0	*	1,00	/	0,5	=	**266,7**
Q (mean value)=	100	/	3,7	*	2,2	/	1,3	*	0,99	/	0,5	=	**88,62**
Q (most frequent)=	100	/	4,0	*	1,5	/	1,0	*	1,00	/	0,5	=	**75,00**



SKB FORSMARK site KFM 01A	Rev.	Report No. NB&A	Figure No. 14
496 to 585m	Borehole No. : KFM 01A	Drawn by nrb	Date
	Depth zone (m) 496-585m	Checked nrb	
	Logg 1,0 ## 25th March 2003	Approved	

Figure 8-4. *Q-histograms for mid-depth 'slice' 496–585 m.*

9 Conclusions

1. Q-logging using the histogram method is found to be an efficient way of collecting the extensive range of rock mass characteristics represented in 900 m of core. Eighty two pairs of core boxes, each containing 11 m of core, were logged with ten allowable opinions of the local (+/– a few meters) rock mass conditions. Since there are six Q-parameters, this data set consists of 10 x 6 x 82 = 4920 observations. Concerning RQD, the ten data per pair of core boxes related to each 1.1 m length of core.

2. The hand-recorded data, giving depth and joint character in each box of the histograms, required nine data sheets, one for each 100 m of core. This was processed in Excel spreadsheet format. The data was initially divided into three parts, namely the whole core, the four identified fracture(d) zones termed FZ 1 to 4, and the whole core minus FZ 1 to 4.

3. The whole core displayed very good to excellent quality Q_{mean} = 48.4, and $Q_{most\ freq.}$ equal to 100. The four identified fracture(d) zones, if treated as one unit, showed Q_{mean} and $Q_{most\ freq.}$ as high as 13.9 and 33.3. These fracture(d) zones constituted some 13% of the core, and when excluded, the remaining 87% or 780 m of core showed Q_{mean} = 60.4. The typical range of Q-values for the whole core was about 2.1 to 2130, the latter based on the assumption of no jointing or healed jointing in the lowest portions of the hole.

4. Individual histogram treatment of the four fracture(d) zones revealed that the two shallowest zones, at approximately 166 to199 m (FZ 1) and 265 to 297 m (FZ 2) had skewed distributions of RQD and J_a, with most frequent values of 100% and 1.0 (unaltered) respectively. By comparison, FZ 3 (385 to 407 m) and FZ 4 (651 to 683 m) had more normal distributions of RQD and J_a. Values of RQD were typically 75, 85 or 95%, and J_a were frequently 4 (thinly clay-filled), 3 (coated) and 2 (stained/altered).

5. Perhaps due to greater depth and good rock incorporated in the zones, the Q_{mean} of these two deepest fracture(d) zones was 19.0 (both cases), which is about twice that of FZ 1(10.9) and FZ 2(11.5). The terminology ‘fracture(d) zone’ is therefore a relative term, as lowest values of Q are no lower than about 1 or 2 for any of the zones, and due to over-consolidated clay fillings, permeability is expected to be low.

6. The whole core mean value of J_w was 0.95, and for the four fracture(d) zones 0.86. The 87% of background rock mass therefore had an estimated J_w of 0.96, which is still closer to 'dry excavations or minor inflow' in the context of tunnel excavation. There is a recent Q-logging 'footnote' /Barton, 2002/ relevant for *characterization* (distant from excavations) for potential reduction of J_w with successive depth zones. If RQD/J_n values had been as low as the stipulated range (0.5 to 25) to imply good connectivity, such reductions could have been applied here.

7. For the most part RQD/J_n was greater than 25, and most commonly was 33. Largely for this reason of generally poor connectivity, J_w was not given lower values than 0.66. There could be exceptions to this in portions of fracture(d) zones not containing clay fillings. The mean fracture(d) zone ratio of RQD/J_n was 90/6.3 or 14.3, which, *in the absence of clay fillings,* could imply sufficient local connectivity for wet conditions. Since hole KFM 01A was reportedly dry, making water sampling impossible, the clay sealing has obviously been very effective.

10 Recommendations

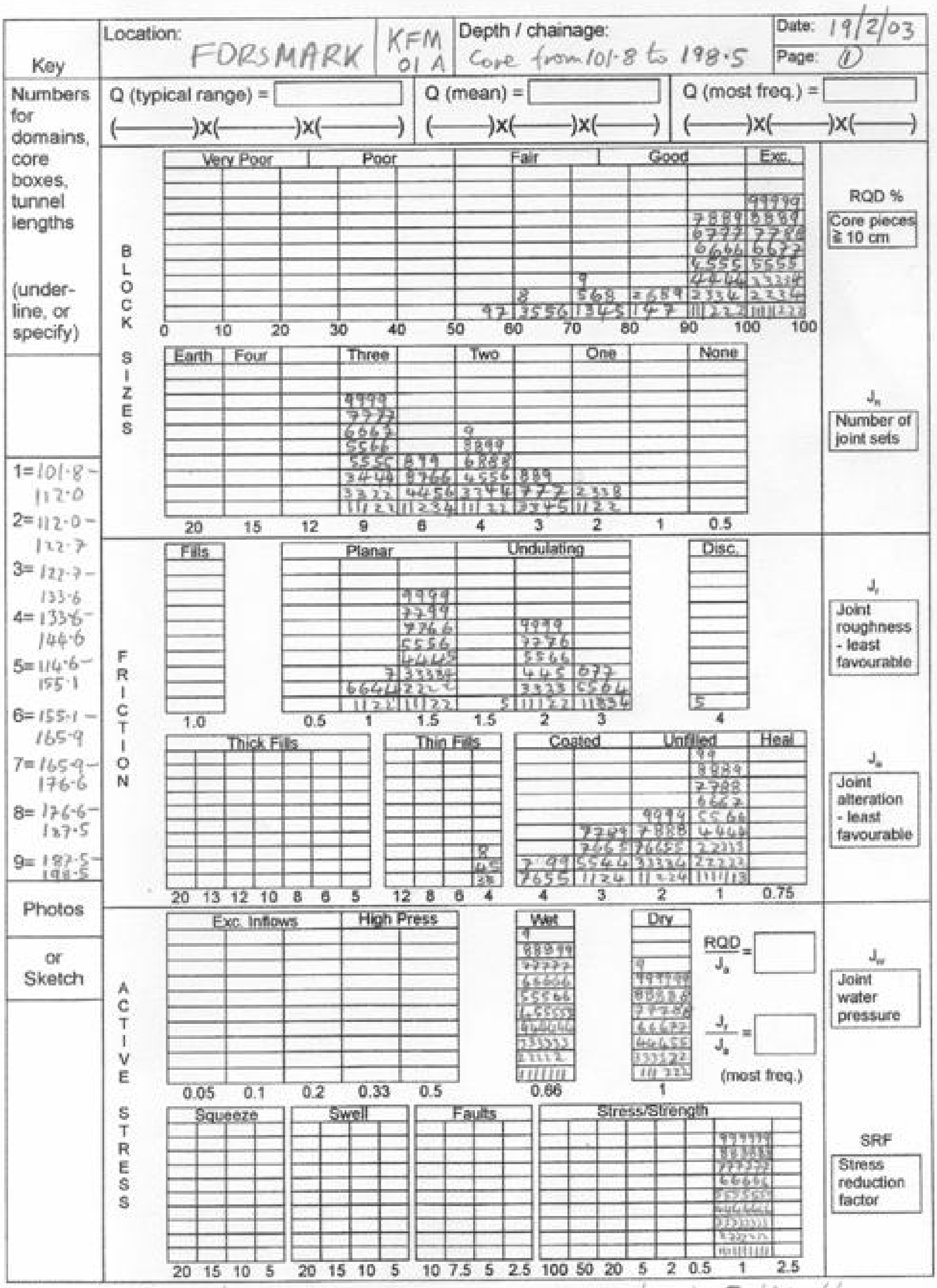
In fact for the empirical Q-system correlations to rock mass properties that are to be assessed in later reports, it is essential to have some level of knowledge of rock strength variation down the length of the core, so that the presently reported Q-value variations can be converted to Q_c values, which forms the main basis of full characterization and rock mass property estimation (where $Q_c = Q \times \sigma_c/10$). It should be sufficient to utilize estimates of σ_c from point load or even Schmidt hammer testing, once reliable site specific correlations to σ_c are determined or agreed.

If using BORMAP to develop a Q-rating after the geological logging, the equivalent operation to estimate J_n would presumably be to look up the *local* joint-pole stereogram.

Reference

Barton N, 2002. Some new Q-value correlations to assist in site characterization and tunnel design. Int. J. Rock Mech. & Min. Sci. 39, 185–216, Pergamon.

Appendix A



Key

Location: FORSMARK KFM 01 A

Depth / chainage: Core from 101·8 to 198·5

Date: 19/2/03

Page: (1)

Numbers for domains, core boxes, tunnel lengths (under-line, or specify)

Q (typical range) = ( )x( )x( )

Q (mean) = ( )x( )x( )

Q (most freq.) = ( )x( )x( )

1= 101·8 – 112·0
2= 112·0 – 122·7
3= 122·7 – 133·6
4= 133·6 – 144·6
5= 144·6 – 155·1
6= 155·1 – 165·9
7= 165·9 – 176·6
8= 176·6 – 187·5
9= 187·5 – 198·5

Photos

or Sketch

BLOCK SIZES

Very Poor | Poor | Fair | Good | Exc.

0 10 20 30 40 50 60 70 80 90 100 100

RQD %

Core pieces ≥ 10 cm

Earth | Four | Three | Two | One | None

20 15 12 9 6 4 3 2 1 0.5

J_n

Number of joint sets

FRICTION

Fills | Planar | Undulating | Disc.

1.0 0.5 1 1.5 1.5 2 3 4

J_r

Joint roughness - least favourable

Thick Fills | Thin Fills | Coated | Unfilled | Heal

20 13 12 10 8 6 5 12 8 6 4 4 3 2 1 0.75

J_a

Joint alteration - least favourable

ACTIVE STRESS

Exc. Inflows | High Press | Wet | Dry

0.05 0.1 0.2 0.33 0.5 0.66 1

$\frac{RQD}{J_a}$ =

$\frac{J_r}{J_a}$ =

(most freq.)

J_w

Joint water pressure

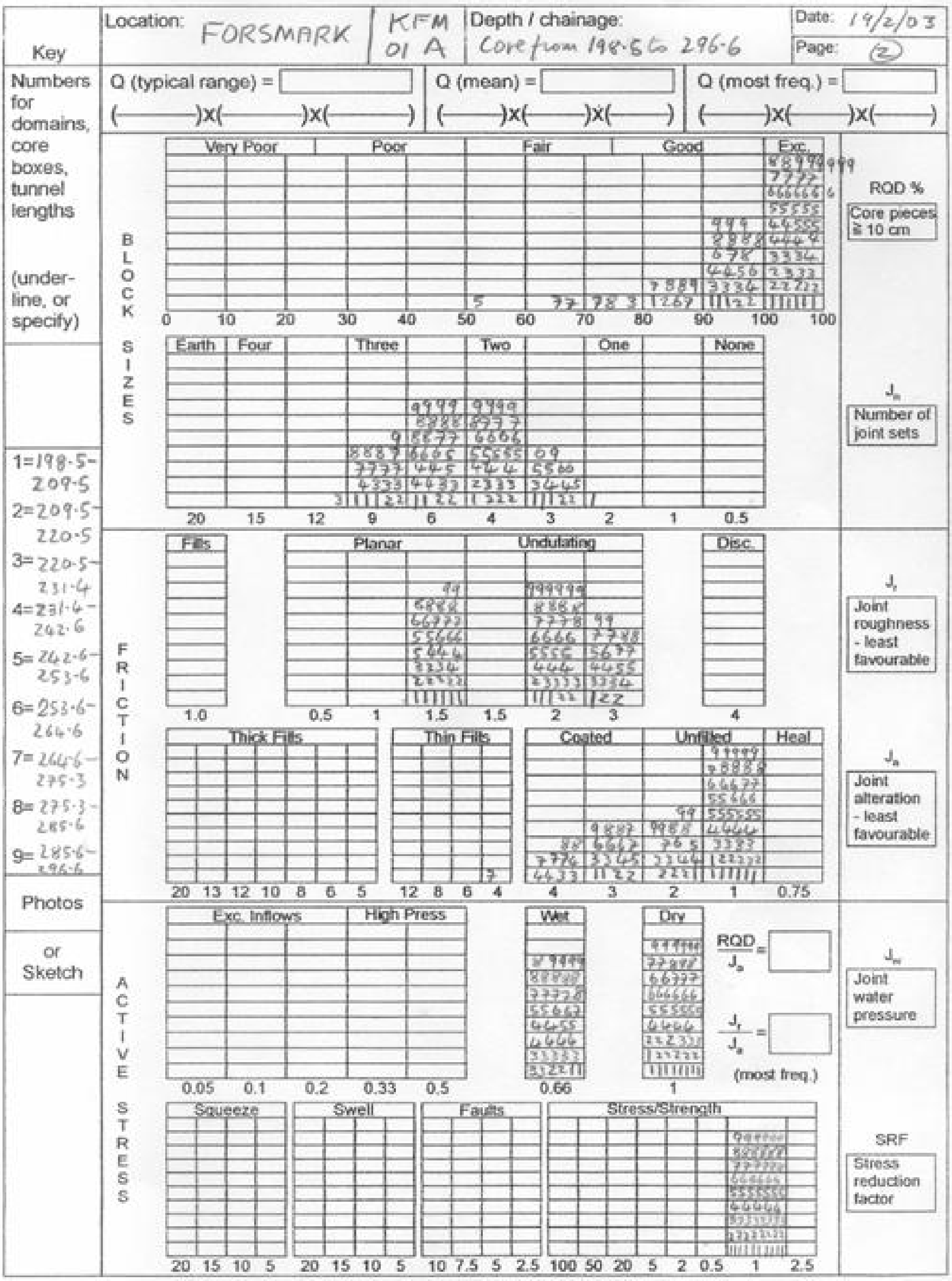
Squeeze | Swell | Faults | Stress/Strength

20 15 10 5 20 15 10 5 10 7.5 5 2.5 100 50 20 5 2 0.5 1 2.5

SRF

Stress reduction factor

Notes: • most core boxes 5·4 → 5·7 m core (≈ 1·1 m boxes), 5 sticks / box.
• Assume sub-vertical joints (1 set ?) missed in deeper levels.
• NW–SE sub-vertical are dominant



Notes: • As core becomes more massive, and even fewer sub-vertical joints are sampled, have assumed 1 set + random $J_n \simeq 3$ as minimum.
• 1, 2 – first intact 1.1 m core sticks since 100 m depth.
• set SRF = 0.5 for H > 300 m – corresponds to more massive rock.

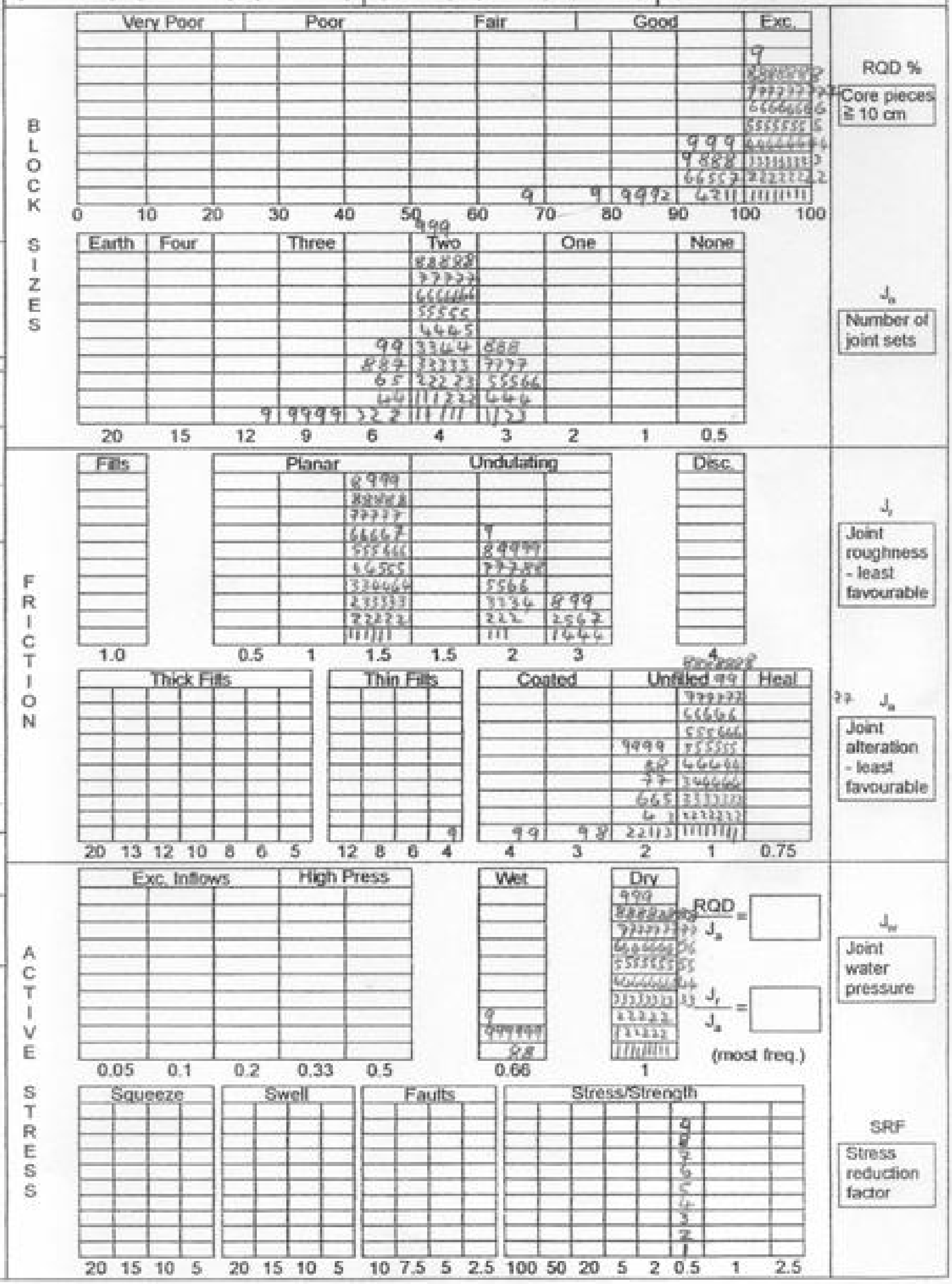
Key	Location: FORSMARK KFM 01A	Depth / chainage: Core from 296·6 to 396·0	Date: 20/2/03 Page: 3
	Q (typical range) = ( )x( )x( )	Q (mean) = ( )x( )x( )	Q (most freq.) = ( )x( )x( )

Numbers for domains, core boxes, tunnel lengths

(under-line, or specify)

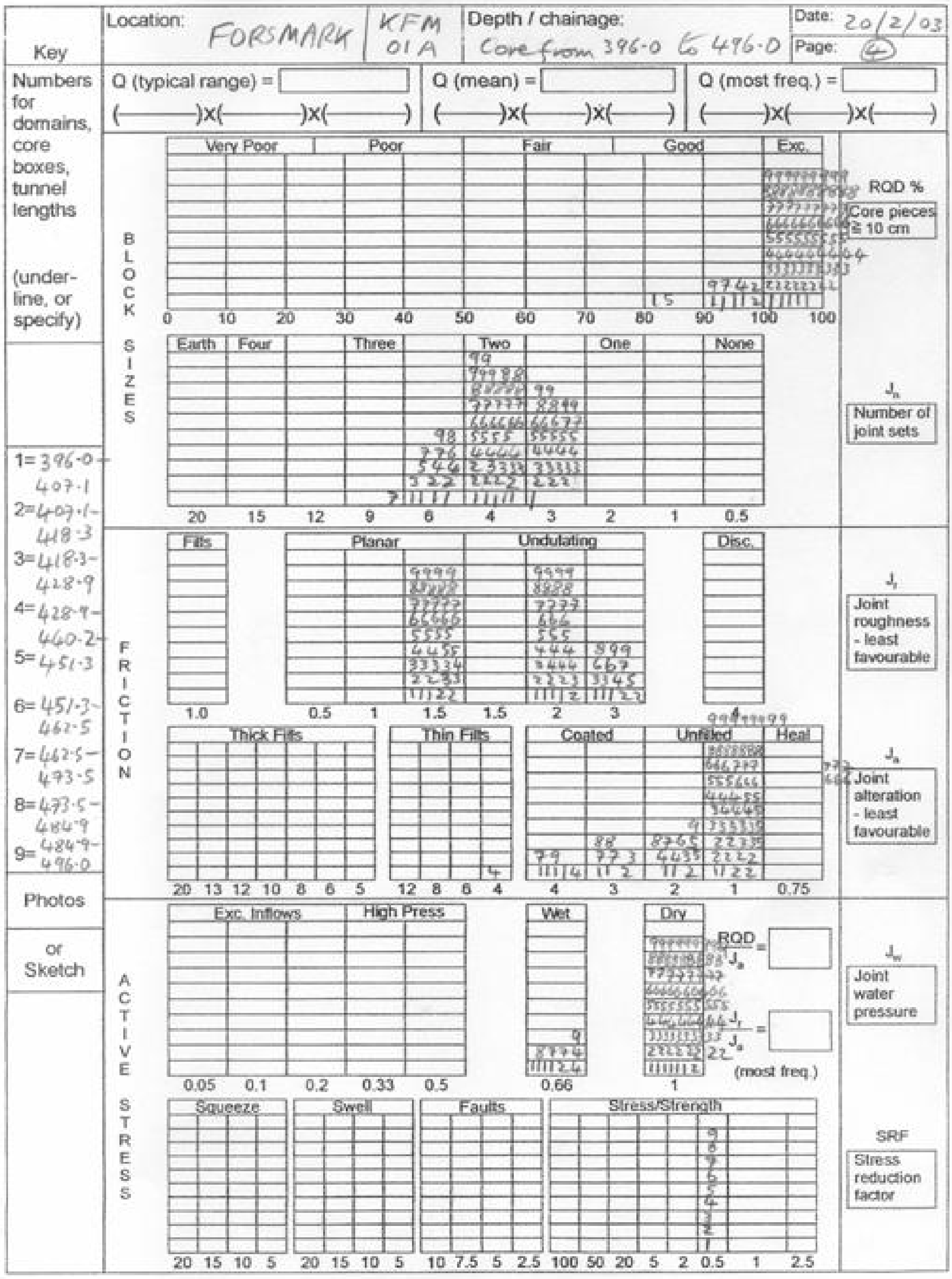
1= 296·6–307·4
2= 307·4–318·5
3= 318·5–329·7
4= 329·7–340·8
5= 340·8–351·7
6= 351·7–362·9
7= 362·9–374·1
8= 374·1–385·3
9= 385·3–396·0

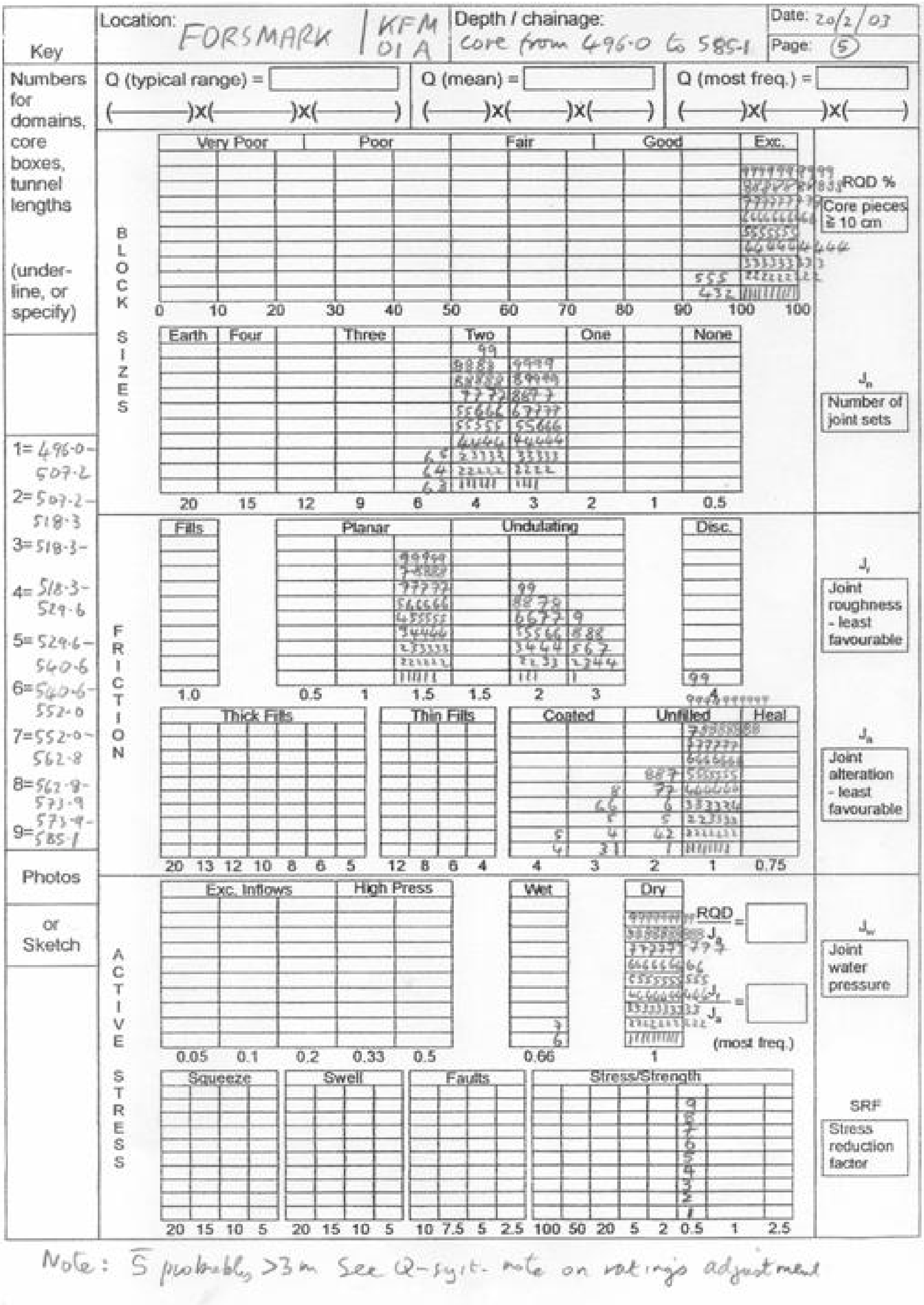
Photos or Sketch



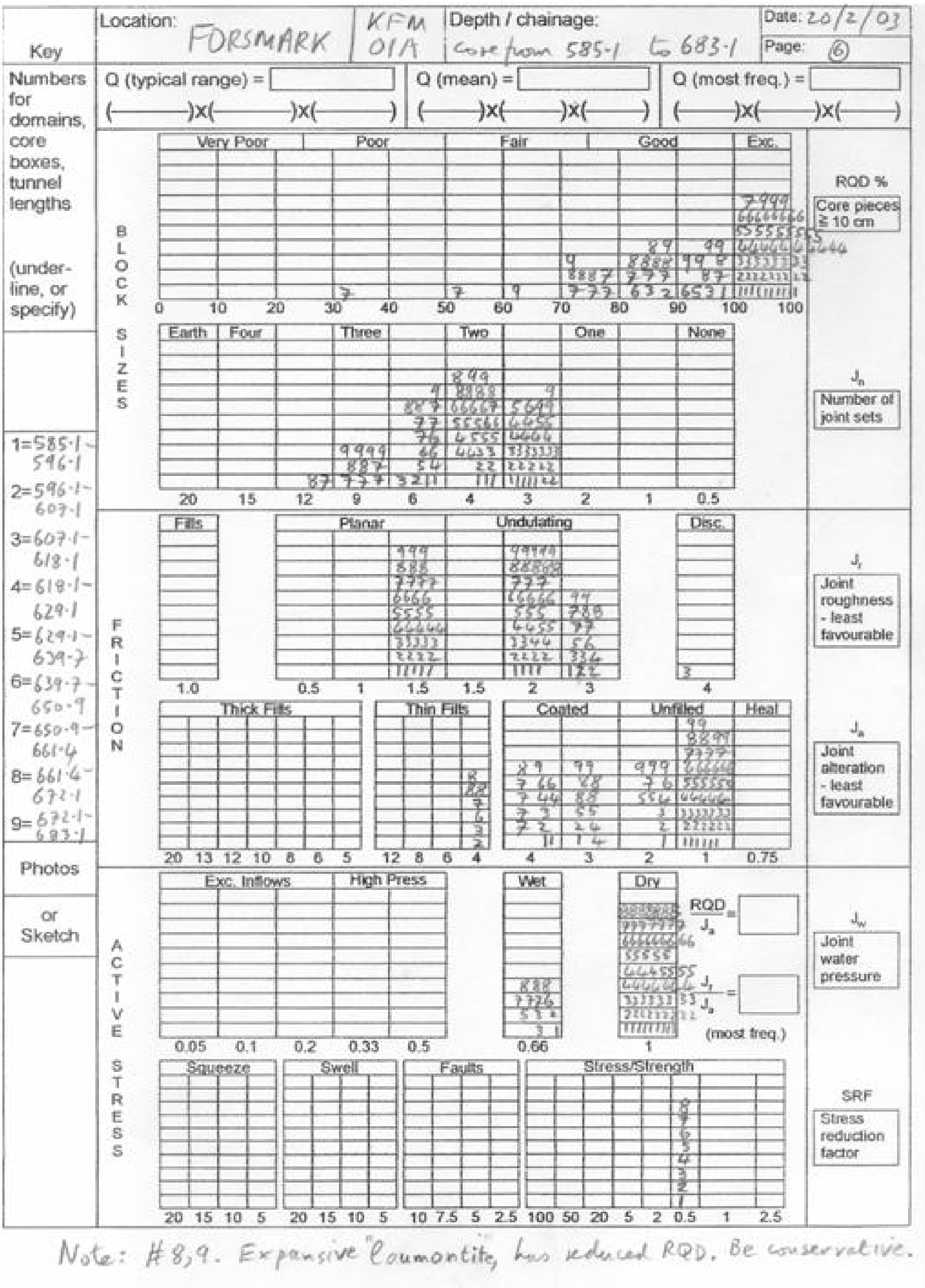
• SRF set to 0·5 for >300 m depth (Not at 250 m due to continued presence of marked jointing.)

• Jr/Ja for steep sets (not seen) is estimated from previous


Location: FORSMARK
KFM 01A
Depth / chainage: Core from 396-0 to 496-0
Date: 20/2/03
Page: 4
Key
Numbers for domains, core boxes, tunnel lengths
(under-line, or specify)
1= 396-0 - 407-1
2= 407-1 - 418-3
3= 418-3 - 428-9
4= 428-9 - 440-2
5= 451-3
6= 451-3 - 462-5
7= 462-5 - 473-5
8= 473-5 - 484-9
9= 484-9 - 496-0
Photos
or Sketch
Q (typical range) =
Q (mean) =
Q (most freq.) =
BLOCK SIZES
Very Poor
Poor
Fair
Good
Exc.
RQD %
Core pieces ≥ 10 cm
Earth
Four
Three
Two
One
None
J_n
Number of joint sets
FRICTION
Fills
Planar
Undulating
Disc.
J_r
Joint roughness - least favourable
Thick Fills
Thin Fills
Coated
Unfilled
Heal
J_a
Joint alteration - least favourable
ACTIVE STRESS
Exc. Inflows
High Press
Wet
Dry
RQD / J_n =
J_r / J_a =
(most freq.)
J_w
Joint water pressure
Squeeze
Swell
Faults
Stress/Strength
SRF
Stress reduction factor



Key
Location: FORSMARK | KFM 01A
Depth / chainage: Core from 496-0 to 585-1
Date: 20/2/03
Page: 5
Numbers for domains, core boxes, tunnel lengths (under-line, or specify)
1= 496-0-507-2
2= 507-2-518-3
3= 518-3-
4= 518-3-529-6
5= 529-6-540-6
6= 540-6-552-0
7= 552-0-562-8
8= 562-8-573-9
9= 573-9-585-1
Photos
or Sketch
Q (typical range) =
Q (mean) =
Q (most freq.) =
BLOCK SIZES
Very Poor
Poor
Fair
Good
Exc.
RQD %
Core pieces ≥ 10 cm
0 10 20 30 40 50 60 70 80 90 100 100
Earth
Four
Three
Two
One
None
J_n
Number of joint sets
20 15 12 9 6 4 3 2 1 0.5
FRICTION
Fills
Planar
Undulating
Disc.
J_r
Joint roughness - least favourable
1.0 0.5 1 1.5 1.5 2 3 4
Thick Fills
Thin Fills
Coated
Unfilled
Heal
J_a
Joint alteration - least favourable
20 13 12 10 8 6 5 12 8 6 4 4 3 2 1 0.75
ACTIVE STRESS
Exc. Inflows
High Press
Wet
Dry
RQD / J_n =
J_r / J_a =
(most freq.)
J_w
Joint water pressure
0.05 0.1 0.2 0.33 0.5 0.66 1
Squeeze
Swell
Faults
Stress/Strength
SRF
Stress reduction factor
20 15 10 5 20 15 10 5 10 7.5 5 2.5 100 50 20 5 2 0.5 1 2.5
Note: 5 probably >3m See Q-syst. note on ratings adjustment



Key | Location: FORSMARK | KFM 01A | Depth / chainage: core from 585-1 to 683-1 | Date: 20/2/03 | Page: 6

Numbers for domains, core boxes, tunnel lengths (under-line, or specify)

1=585·1–596·1
2=596·1–607·1
3=607·1–618·1
4=618·1–629·1
5=629·1–639·7
6=639·7–650·9
7=650·9–661·4
8=661·4–672·1
9=672·1–683·1

Photos or Sketch

Q (typical range) = ( )x( )x( )
Q (mean) = ( )x( )x( )
Q (most freq.) = ( )x( )x( )

BLOCK SIZES
Very Poor | Poor | Fair | Good | Exc.
0 10 20 30 40 50 60 70 80 90 100 100
RQD % — Core pieces ≥ 10 cm

Earth | Four | Three | Two | One | None
20 15 12 9 6 4 3 2 1 0.5
J_n — Number of joint sets

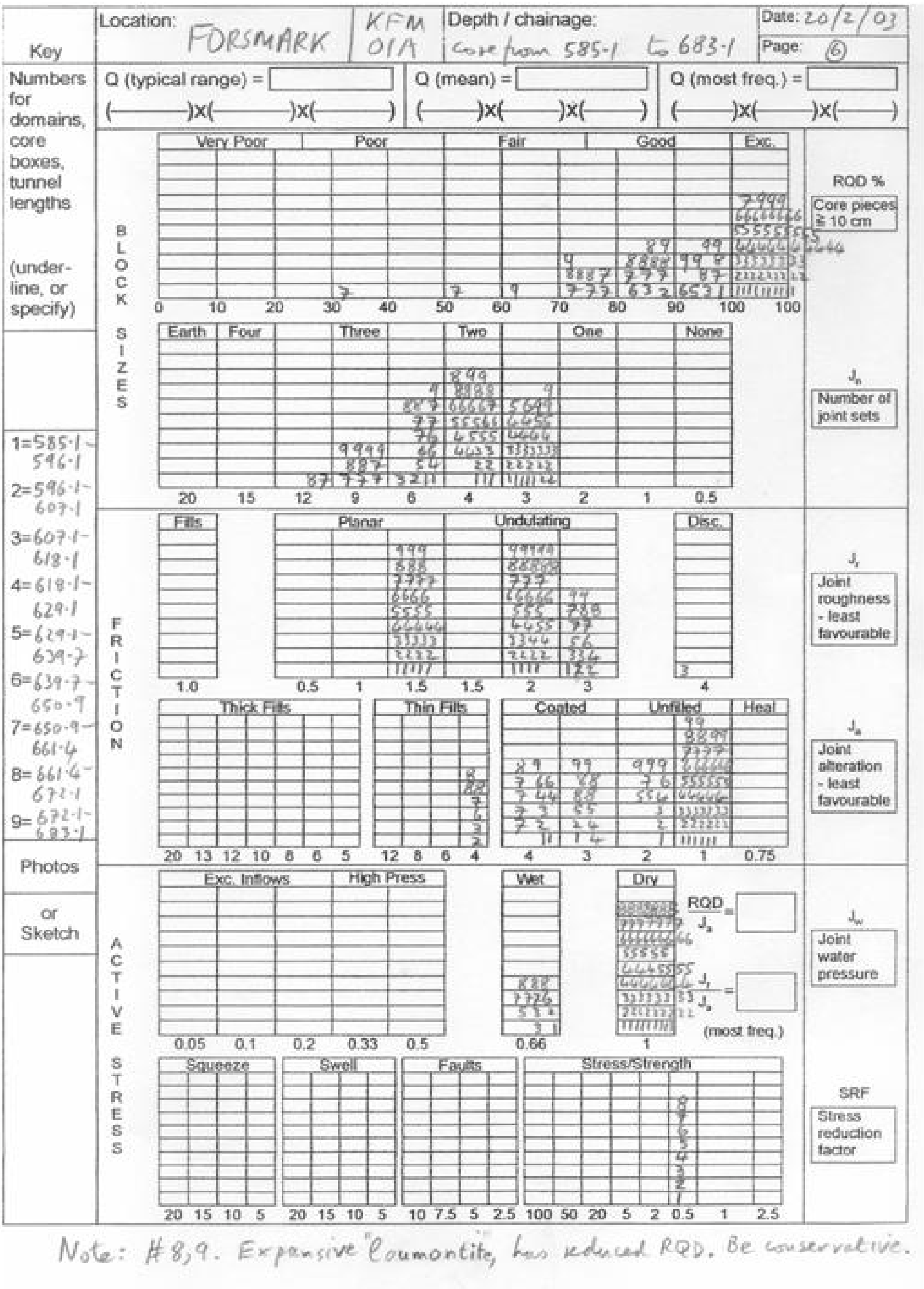
FRICTION
Fills | Planar | Undulating | Disc.
1.0 0.5 1 1.5 1.5 2 3 4
J_r — Joint roughness - least favourable

Thick Fills | Thin Fills | Coated | Unfilled | Heal
20 13 12 10 8 6 5 | 12 8 6 4 | 4 3 2 1 0.75
J_a — Joint alteration - least favourable

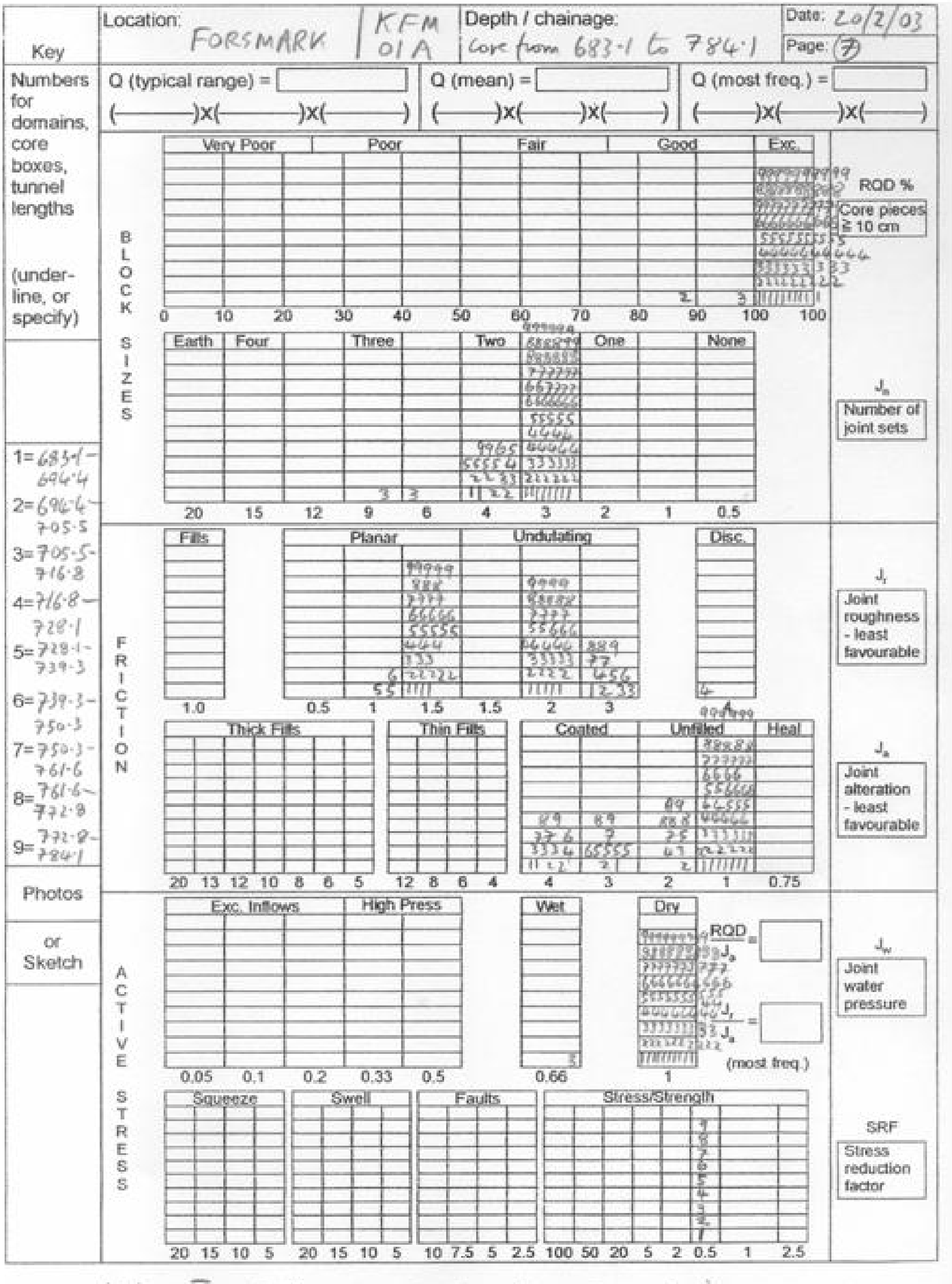
ACTIVE STRESS
Exc. Inflows | High Press | Wet | Dry
0.05 0.1 0.2 0.33 0.5 0.66 1
$\frac{RQD}{J_n}$ = $\frac{J_r}{J_a}$ = (most freq.)
J_w — Joint water pressure

Squeeze | Swell | Faults | Stress/Strength
20 15 10 5 | 20 15 10 5 | 10 7.5 5 2.5 | 100 50 20 5 2 0.5 1 2.5
SRF — Stress reduction factor

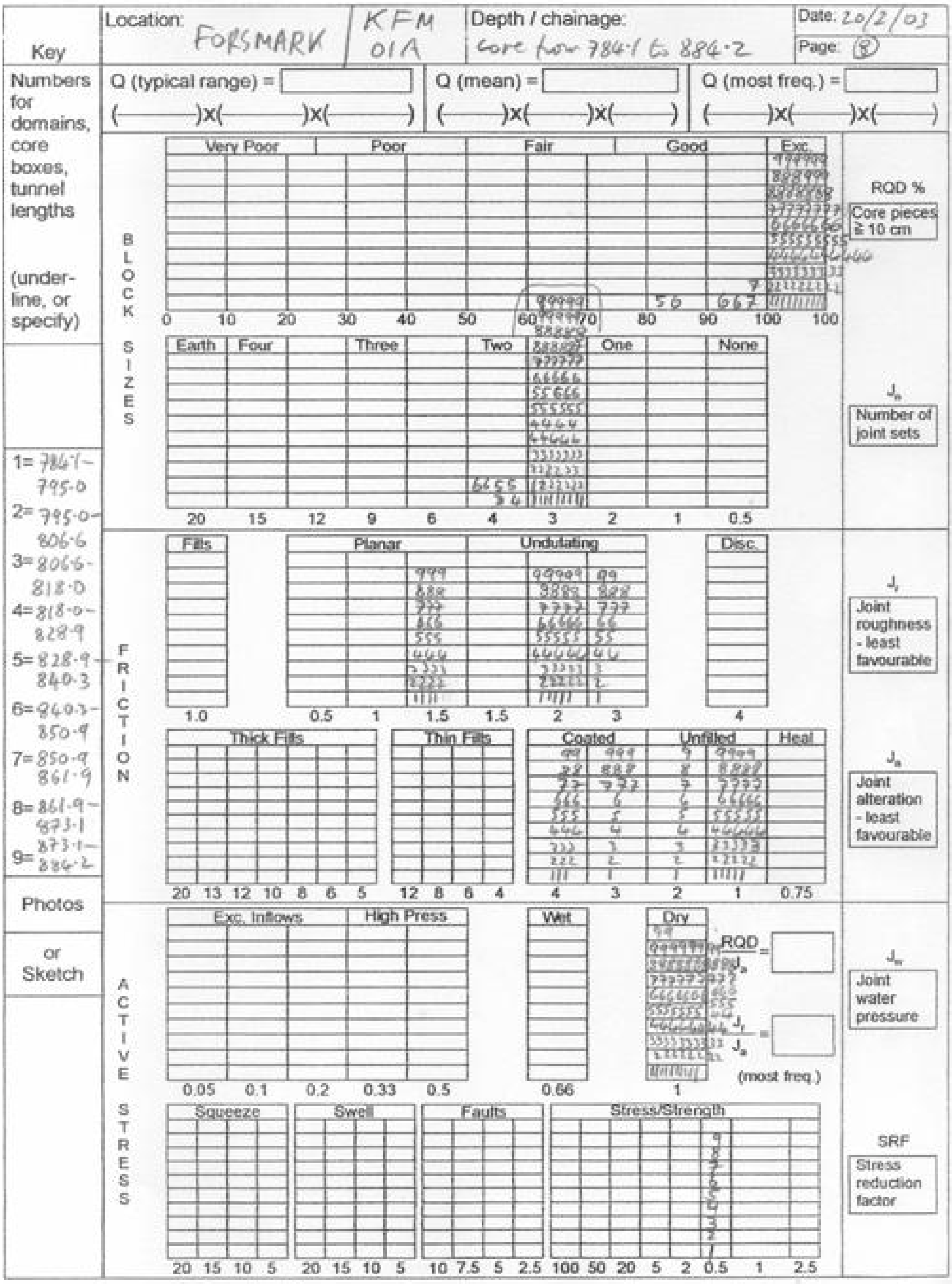
Note: #8,9. Expansive "laumontite" has reduced RQD. Be conservative.



Key
Location: FORSMARK
KFM 01A
Depth / chainage: core from 585·1 to 683·1
Date: 20/2/03
Page: 6
Numbers for domains, core boxes, tunnel lengths
(under-line, or specify)
1=585·1–596·1
2=596·1–607·1
3=607·1–618·1
4=618·1–629·1
5=629·1–639·7
6=639·7–650·9
7=650·9–661·4
8=661·4–672·1
9=672·1–683·1
Photos
or Sketch
Q (typical range) =
Q (mean) =
Q (most freq.) =
BLOCK SIZES
Very Poor
Poor
Fair
Good
Exc.
0 10 20 30 40 50 60 70 80 90 100 100
RQD %
Core pieces ≥ 10 cm
Earth
Four
Three
Two
One
None
20 15 12 9 6 4 3 2 1 0.5
J_n
Number of joint sets
FRICTION
Fills
Planar
Undulating
Disc.
1.0 0.5 1 1.5 1.5 2 3 4
J_r
Joint roughness - least favourable
Thick Fills
Thin Fills
Coated
Unfilled
Heal
20 13 12 10 8 6 5 12 8 6 4 4 3 2 1 0.75
J_a
Joint alteration - least favourable
ACTIVE STRESS
Exc. Inflows
High Press
Wet
Dry
0.05 0.1 0.2 0.33 0.5 0.66 1
RQD / J_n =
J_r / J_a =
(most freq.)
J_w
Joint water pressure
Squeeze
Swell
Faults
Stress/Strength
20 15 10 5 20 15 10 5 10 7.5 5 2.5 100 50 20 5 2 0.5 1 2.5
SRF
Stress reduction factor
Note: #8,9. Expansive "laumontite" has reduced RQD. Be conservative.



Note: $\bar{S}$ probably > 3 m. See Q-system note on ratings adjustment



Note: • $\bar{S}$ probably >3 m (>10 m?) Most of core has no joints (with vertical hole
• Last of steep fract. in core at 863 m (to end 1000 m)
(NO! one at 899, 45°)

Key	Location: FORSMARK	KFM 01A	Depth / chainage: Core from 884·2 to 1000·7	Date: 20/2/03 Page: (9)

Numbers for domains, core boxes, tunnel lengths (under-line, or specify)

1= 884·2–895·2
2= 895·2–906·2
3= 906·2–917·3
4= 917·3–928·2
5= 928·2–939·3
6= 939·3–950·6
7= 950·6–961·9
8= 961·9–973·0
9= 973·0–984·3
10 = 884·3–1000·7

END

Photos or Sketch

Q (typical range) = ( )x( )x( )
Q (mean) = ( )x( )x( )
Q (most freq.) = ( )x( )x( )

BLOCK SIZES

Very Poor | Poor | Fair | Good | Exc.

0 10 20 30 40 50 60 70 80 90 100 100

RQD % — Core pieces ≥ 10 cm

Earth | Four | Three | Two | One | None

20 15 12 9 6 4 3 2 1 0.5

J_n — Number of joint sets

?

FRICTION

Fills | Planar | Undulating | Disc.

1.0 0.5 1 1.5 1.5 2 3 4

J_r — Joint roughness - least favourable

?

Thick Fills | Thin Fills | Coated | Unfilled | Heal

20 13 12 10 8 6 5 | 12 8 6 4 | 4 3 2 1 0.75

J_a — Joint alteration - least favourable

?

ACTIVE STRESS

Exc. Inflows | High Press | Wet | Dry

0.05 0.1 0.2 0.33 0.5 0.66 1

RQD / J_a =

J_r / J_a = (most freq.)

J_w — Joint water pressure

Squeeze | Swell | Faults | Stress/Strength

20 15 10 5 | 20 15 10 5 | 10 7.5 5 2.5 | 100 50 20 5 2 0.5 1 2.5

SRF — Stress reduction factor

Notes: 5 probably > 3 m (> 10 m)? See Q notes re ratings

- Last steep (45°) joint at 898. No more sub-vert, or clay coated.
- Assume no joints of sub-vertical type at H > 898 m
- One 35° joint at 954·3 m

Key	Location: KFM 01A / FORSMARK	Depth / chainage: 101.8 → 1000.7 m	Date: 25/3/03 Page: (iv)

Q (typical range) = ( )x( )x( ) | Q (mean) = ( )x( )x( ) | Q (most freq.) = ( )x( )x( )

Numbers for domains, core boxes, tunnel lengths (under-line, or specify)

1=102-166
2=199-265
3=297-385
4=407-496
5=496-585
6=585-651
7=683-784
8=784-886
9=886-1001

BLOCK SIZES

RQD % (Core pieces ≥ 10 cm)

	Very Poor 0-10	10-20	Poor 20-30	30-40	Fair 50-60	60-70	70-80	Good 80-90	90-100	Exc. 100
1						4	6	4	23	23
2					1		1	3	14	40
3								1	12	65
4								1	5	74
5									6	83
6								3	4	56
7								1	1	88
8								2	4	84
9										100
10										

J_n Number of joint sets

	Earth 20	Four 15	12	Three 9	6	Two 4	3	One 2	1	None 0.5
1				24	11	14	4	7		
2			1	9	15	20	14			
3					10	51	19			
4				1	11	40	28			
5					6	45	41			
6					9	23	29			
7				1	1	17	71			
8						6	84			?
9						1	19		1	79
10										

FRICTION

J_r Joint roughness - least favourable

	Fills 1.0	Planar 0.5	Planar 1	Planar 1.5	Undulating 1.5	Undulating 2	Undulating 3	Disc. 4
1			8	24	1	17	10	1
2				26		21	13	
3				50		20	9	
4				38		30	12	
5				50		26	12	2
6				27		24	8	1
7			3	37		37	12	1
8				30		43	17	?
9				8		11	2	77
10								

J_a Joint alteration - least favourable

	Thick Fills 20	13	12	10	8	6	5	Thin Fills 12	8	6	4	Coated 4	3	Unfilled 2	1	Heal 0.75
1											4	7	8	14	28	
2												5	11	10	34	
3													1	14	63	
4											1	3	6	9	60	
5												2	7	10	73	
6											3	8	6	9	36	
7												13	10	10	56	
8												24	15	9	42	?
9												6	3	2	10	78
10																

ACTIVE STRESS

J_w Joint water pressure

	Exc. Inflows 0.05	0.1	0.2	High Press 0.33	0.5	Wet 0.66	Dry 1
1						40	20
2						23	38
3						2	75
4						7	73
5						2	88
6						6	54
7						1	89
8							90
9							100
10							

$\frac{RQD}{J_n}$ = [ ] $\frac{J_r}{J_a}$ = [ ] (most freq.)

SRF Stress reduction factor

	Squeeze 20	15	10	5	Swell 20	15	10	5	Faults 10	7.5	5	2.5	Stress/Strength 100	50	20	5	2	0.5	1	2.5
1																			60	
2																			60	
3																		80		
4																		80		
5																		80		
6																		80		
7																		90		
8																		90		
9																		100		
10																				

Photos or Sketch

Depth trends for whole core, minus 4 × FZ fracture(d) zones

Appendix B

1. Rock Quality Designation		RQD (%)
A	Very poor	0-25
B	Poor	25-50
C	Fair	50-75
D	Good	75-90
E	Excellent	90-100

Notes: i) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q.
ii) RQD intervals of 5, i.e., 100, 95, 90, etc., are sufficiently accurate.

2. Joint set number		J_n
A	Massive, no or few joints	0.5-1
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random, heavily jointed, 'sugar-cube', etc.	15
J	Crushed rock, earthlike	20

Notes: i) For tunnel intersections, use (3.0 × Jn).
ii) For portals use (2.0 × Jn).

3. Joint roughness number		J_r
a) Rock-wall contact, and b) Rock-wall contact before 10 cm		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5

Notes: i) Descriptions refer to small-scale features and intermediate scale features, in that order.

b) No rock-wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact.	1.0
J	Sandy, gravely or crushed zone thick enough to prevent rock-wall contact	1.0

Notes: ii) Add 1.0 if the mean spacing of the relevant joint set is greater than 3 m.

iii) J_r = 0.5 can be used for planar, slickensided joints having lineations, provided the lineations are oriented for minimum strength.

*iv) J_r **and** J_a classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance, τ (where $\tau \approx \sigma_n \tan^{-1} (J_r/J_a)$).*

4. Joint alteration number		ϕ_r approx.	J_a
a) Rock-wall contact (no mineral fillings, only coatings)			
A	Tightly healed, hard, non-softening, impermeable filling, i.e., quartz or epidote.	--	0.75
B	Unaltered joint walls, surface staining only.	25-35°	1.0
C	Slightly altered joint walls. Non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	25-30°	2.0
D	Silty- or sandy-clay coatings, small clay fraction (non-softening).	20-25°	3.0
E	Softening or low friction clay mineral coatings, i.e., kaolinite or mica. Also chlorite, talc, gypsum, graphite, etc., and small quantities of swelling clays.	8-16°	4.0
b) Rock-wall contact before 10 cm shear (thin mineral fillings).			
F	Sandy particles, clay-free disintegrated rock, etc.	25-30°	4.0
G	Strongly over-consolidated non-softening clay mineral fillings (continuous, but < 5 mm thickness).	16-24°	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but < 5 mm thickness).	12-16°	8.0
J	Swelling-clay fillings, i.e., montmorillonite (continuous, but <5 mm thickness). Value of J_a depends on per cent of swelling clay-size particles, and access to water, etc.	6-12°	8/dez
c) No rock-wall contact when sheared (thick mineral fillings)			
KLM	rock and clay (see G, H, J for description of clay condition).	6-24°	6, 8, or 8/dez
N	Zones or bands of silty- or sandy-clay, small clay fraction (non-softening).	---	5.0
OPR	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition).	6-24°	10, 13, or 13-20

	5. Joint water reduction factor	approx. water pres. (kg/cm²)	J_w
A	Dry excavations or minor inflow, i.e., < 5 l/min locally.	< 1	1.0
B	Medium inflow or pressure, occasional outwash of joint fillings.	1-2.5	0.66
C	Large inflow or high pressure in competent rock with unfilled joints.	2.5-10	0.5
D	Large inflow or high pressure, considerable outwash of joint fillings.	2.5-10	0.33
E	Exceptionally high inflow or water pressure at blasting, decaying with time.	> 10	0.2-0.1
F	Exceptionally high inflow or water pressure continuing without noticeable decay.	> 10	0.1-0.05

Notes: i) Factors C to F are crude estimates. Increase J_w if drainage measures are installed.

ii) Special problems caused by ice formation are not considered.

iii) For general ***characterization*** *of rock masses distant from excavation influences, the use of Jw = 1.0, 0.66, 0.5, 0.33 etc. as depth increases from say 0-5m, 5-25m, 25-250m to >250m is recommended, assuming that RQD/Jn is low enough (e.g. 0.5-25) for good hydraulic connectivity. This will help to adjust Q for some of the effective stress and water softening effects, in combination with appropriate* ***characterization*** *values of SRF. Correlations with depth-dependent static deformation modulus and seismic velocity will then follow the practice used when these were developed.*

6. Stress Reduction Factor		SRF
a) Weakness zones intersecting excavation, which may cause loosening		
A	Multiple occurrences of weakness zones containing **clay** or chemically disintegrated rock, very loose surrounding rock (any depth).	10
B	Single weakness zones containing **clay** or chemically disintegrated rock (depth of excavation ≤ 50 m).	5
C	Single weakness zones containing **clay** or chemically disintegrated rock (depth of excavation > 50 m).	2.5
D	Multiple shear zones in competent rock (**clay-free**), loose surrounding rock (any depth).	7.5
E	Single shear zones in competent rock (**clay-free**), (depth of excavation ≤ 50 m).	5.0
F	Single shear zones in competent rock (**clay-free**), (depth of excavation > 50 m).	2.5
G	Loose, open joints, heavily jointed or 'sugar cube', etc. (any depth)	5.0

Notes: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do *not intersect the excavation*. This will also be relevant for **characterization.**

b) Competent rock, rock stress problems		σ_c/σ_1	σ_θ/σ_c	SRF
H	Low stress, near surface, open joints.	> 200	< 0.01	2.5
J	Medium stress, favourable stress condition.	200-10	0.01-0.3	1
K	High stress, very tight structure. Usually favourable to stability, may be unfavourable for wall stability.	10/mai	0.3-0.4	0.5-2
L	Moderate slabbing after > 1 hour in **massive** rock.	5/mar	0.5-0.65	mai/50
M	Slabbing and rock burst after a few minutes in **massive** rock.	3/fev	0.65-1	50-200
N	Heavy rock burst (strain-burst) and immediate dynamic deformations in **massive** rock.	< 2	> 1	200-400

Notes: ii) For strongly anisotropic virgin stress field (if measured): When 5 ≤ $\sigma 1/\sigma 3$ ≤ 10, reduce σc to 0.75 σc. When $\sigma 1/\sigma 3$ > 10, reduce σc to 0.5 σc, where σc = unconfined compression strength, $\sigma 1$ and $\sigma 3$ are the major and minor principal stresses, and $\sigma\theta$ = maximum tangential stress (estimated from elastic theory).

iii) Few case records available where depth of crown below surface is less than span width Suggest an SRF increase from 2.5 to 5 for such cases (see H).

iv) Cases L, M, and N are usually most relevant for support design of deep tunnel excavations in hard massive rock masses, with RQD /Jn ratios from about 50 to 200.

v) For general **characterization** of rock masses distant from excavation influences, the use of SRF = 5, 2.5, 1.0, and 0.5 is recommended as depth increases from say 0-5m, 5-25m, 25-250m to >250m. This will help to adjust Q for some of the effective stress effects, in combination with appropriate **characterization** values of Jw. Correlations with depth - dependent static deformation modulus and seismic velocity will then follow the practice used when these were developed.