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Oskarshamn site investigation

Q-logging of KSH 01A and 01B core

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July 2003

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Summary

The first Simpevarp potential repository site borehole KSH 01A and 01B cores provided core from 1.3 to 1003.0 m depth. This was independently Q-logged by NB&A during a three-day period (12^{th}–14^{th} May, 2003), without access to BOREMAP results or regional jointing frequencies or orientations. The Q-logging was intended to be an independent check for subsequent BOREMAP-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 approximately 5400 recordings of Q-parameter values for the 180 core boxes.

Data processing was divided into several parts, with successively increasing detail. The report therefore contains Q-histograms for the whole core, for the seven 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 ten depth zones or slices, and trends of variation with depth are tabulated. From the seven identified fracture(d) zones, four principal ones are selected and analysed separately, and similarities and subtle differences are discerned between them.

The overall quality of this first core is 'good', with Q(mean) of 12.5, and a most frequent Q-value of 29, but there is significant jointing until about 700 m depth. The *typical* range of quality is from 0.3 to 600, which covers most of the upper half of the six order of magnitude Q scale. The fracture(d) zones, representing some 9% of the 1002 m cored, have a combined Q(mean) of only 1.1 ('poor') and a range of *typica*l quality of 0.02 to 21, or 'extremely poor' to 'good'.

Contents

1 Introduction

The writer performed Q-logging of 1002 m of core from the first site characterization borehole(s) KSH 01A and 01B between 12th and 14th May. This work was requested by Rolf Christiansson, for the purpose of supplementing the more detailed BOREMAP geological logging.

It is intended that this Q-logging can provide an independent check of BOREMAP-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 1002 m approx of core (1.25 to 100.8 from KSH 01B, and the remaining 902 m from KSH 01A) was Q-logged using the 'histogram method' /Barton et al, 1992/. The 1002 m was logged in about 20 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 87 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 is 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 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 ten 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 (sometimes to 10), 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 1002 m of core, with 10 opinions of each of the six Q-parameters, there were a resulting total of 10x6x87 or more than 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.

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, in particular when the rock is massive, and the 'relative block size' (represented by RQD/J_n) is significantly less than say 25.

The initial purpose of the *characterization* performed, will be 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.

For these empirical conversions, the variation of uniaxial strength for the different rock types encountered down the core will be required, as Q_c is calculated from the product of Q and the normalized (by 100 MPa) ratio of $\sigma_c/100$. Estimates from Schmidt hammer recordings, for extrapolating the concentrated sets of laboratory data, should be sufficiently accurate for this exercise.

3 Examples of joint character

Local road cuttings in the area of the nuclear power plant, such as illustrated in Figure 3-1, suggest moderate, steep and very steep dip for three or more joint sets in the monzonitic and vulcanite rock types, which show considerable variation through much of the core.

During the Q-logging of the core, joint roughness traces of representative examples of each joint set were recorded. Some selected examples are shown in Figures 3-2 and 3-3. Here we see both J_r and J_a values, due to the presence of clay coatings or thin clay fillings, which have powdered and fallen into the core boxes. We see examples of J_r = 1, 1.5, 2(–), and 3 for the moderate, steep and very steeply dipping joints.

There are several examples of vertical joints of considerable roughness (J_r = 3 to 3+) in the first 150 m of the core, but these are seldom in evidence elsewhere, and extra account of them in the form of possible hidden 'random' features has not been added to J_n, except where they are actually seen in the core.

Due to the dominance of dipping structures (as opposed to vertical structures) it can probably be assumed that vertical boreholes are good samplers of the main jointing at Simpevarp, at least in the nuclear power plant locality where the first two holes are drilled.

Figure 3-1. *Examples of joint character and orientation in local exposures.*

Figure 3-2. *Examples of J_r = 1.5 (or 2.0–) and J_a = 4 due to clay coating/thin filling.*

Figure 3-3. *a) Examples of J_r = 1.0 and 1.5. b) Example of J_r = 3 and J_a = 4.*

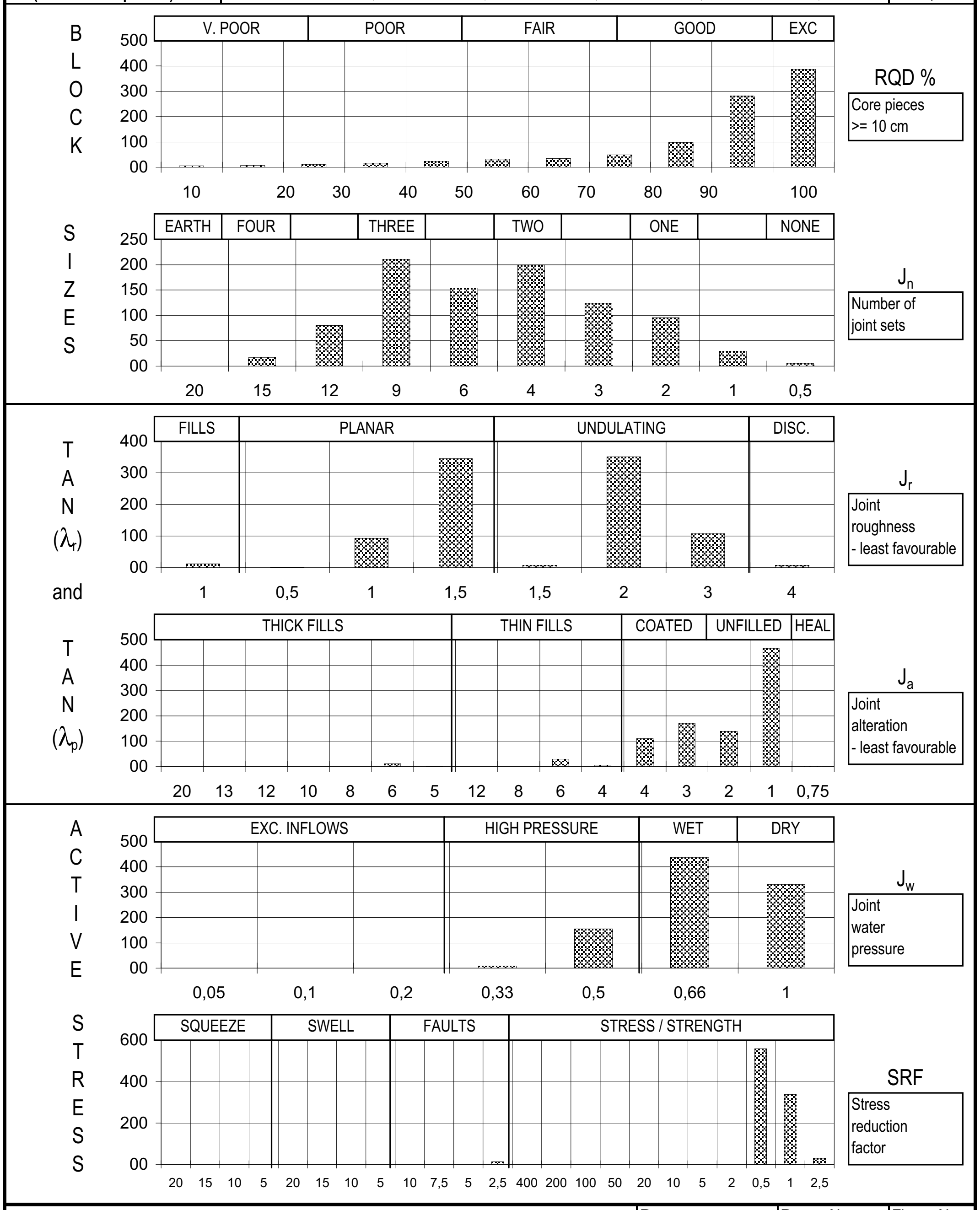
4 Overall quality of KSH 01A and 01B core

The first procedure of Q-histogram *analysis* was to count all recordings of quality from the ten logging sheets in Appendix A, including those of obvious fracture(d) zones, and produce Q-parameter histograms for the complete 1002 m of core to 1003.0 m depth. The result is shown in Figure 4-1. This is derived from the summation of the ten sheets of recordings, shown, also hand-recorded, in sheet 11 in Appendix A.

The most frequent quality is 'good' with ($Q_{\text{most frequent}}$) = 29.3. The weighted mean (weighted downwards by at least seven distinct fracture(d) zones) shows $Q_{\text{mean}} = 12.5$ (also described as 'good'). *Typical* minimum and maximum values range from about 0.3 to 600 – 'very poor' to 'exceptionally good'.

The long 'tail' on the RQD distribution, together with the dominance of three joint sets in the widely spread J_n distribution, indicates the generally jointed nature of much of the core. As will be seen in the subsequent quality-depth statistics, there are nevertheless distinct variations down the core, with particularly jointed sections in the 200 to 300 m and 400 to 500 m depth zones. Beyond 700 m the quality is consistently very good.

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	45	/	12,0	*	1,0	/	6,0	*	0,50	/	1,0	=	**0,313**
Q (typical max)=	100	/	1,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**600,0**
Q (mean value)=	88	/	5,9	*	1,8	/	2,1	*	0,75	/	0,8	=	**12,54**
Q (most frequent)=	100	/	9,0	*	2,0	/	1,0	*	0,66	/	0,5	=	**29,33**



SKB SIMPEVARP	Rev.	Report No. NB&A	Figure No. 4-1
KSH 01A and 01B : overall quality of both cores, from 1.3 to 1003.0m (includes seven more fractured zones)	Borehole No. : KSH 01 A+B	Drawn by nrb	Date
	Depth zone (m) 1.3-1000.3	Checked nrb	
	Logg 1,0 ###	Approved 20th May 2003	

Figure 4-1. Q-parameter histograms for the complete KSH 01A and B cores, from 1.3 to 1003.0 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 fracture 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 *seven* zones of noticeably increased fracturing have been identified, where presumably both the BOREMAP geologists and certainly 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 of fracture(d) zones, which is entirely independent of the geological logging assessment (whose result is unknown to the undersigned), is as follows:

FZ 1	depth 138.5 to 154.5 m (approx)	sheet 2, ref 5,6	Appendix A
FZ 2	depth 247.7 to 253.0 m (approx)	sheet 3, ref 6	Appendix A
FZ 3	depth 407.0 to 409.5 m (approx)	sheet 5, ref 1	Appendix A
FZ 4	depth 420 to 437 m (approx)	sheet 5, ref 3,4	Appendix A
FZ 5	depth 541 to 570 m (approx)	sheet 6, ref 5,6,7,8	Appendix A
FZ 6	depth 619 to 637 m (approx)	sheet 7, ref 2,3,4	Appendix A
FZ 7	depth 725 to 730 m (approx)	sheet 8, ref 4	Appendix A

NOTE: There are in addition two small regions of ‘crushed core’ at 829.5 to 830.0 (approx) and at 901.0 to 902.0 m (approx). These may be due to damage during core recovery according to BOREMAP personnel.

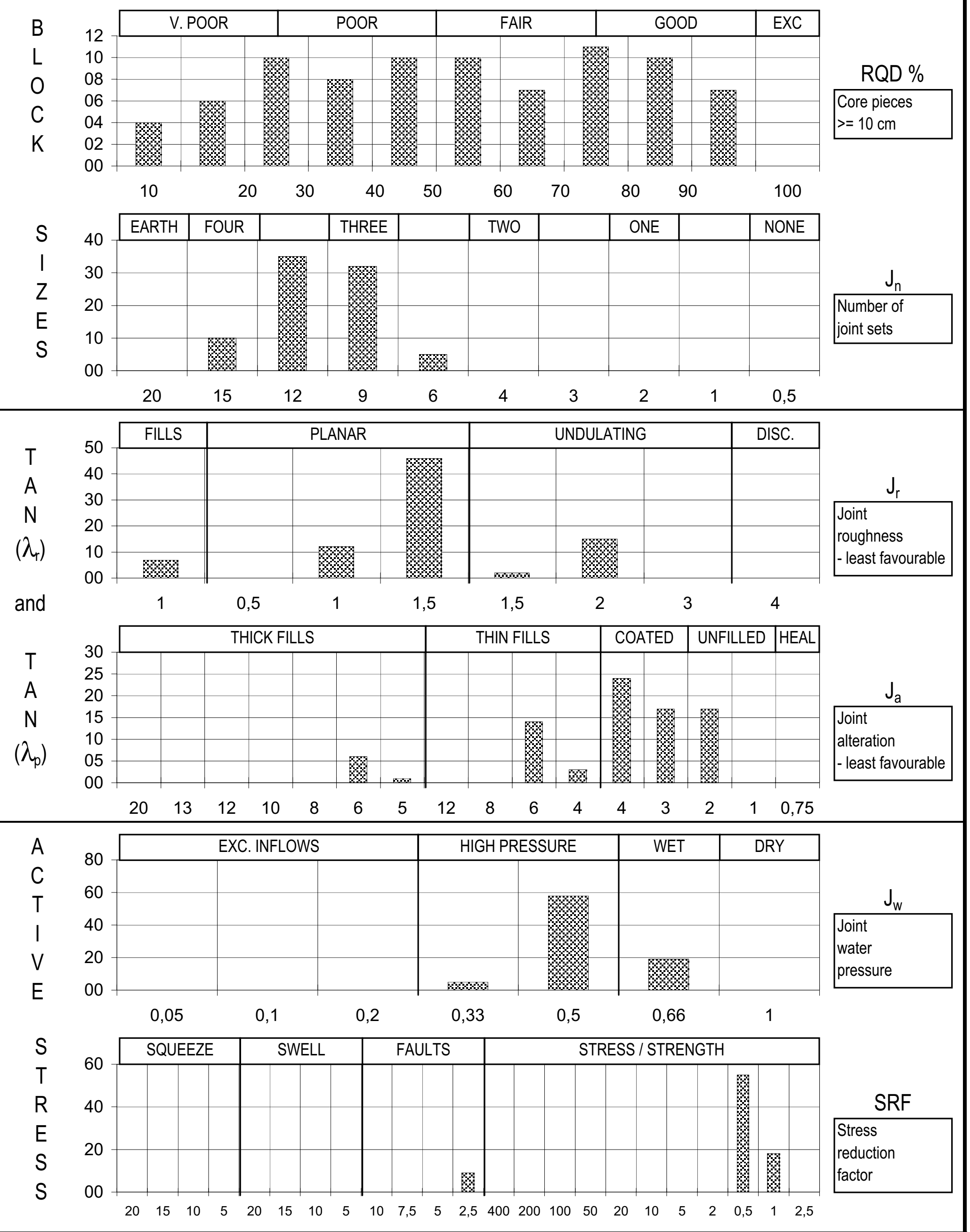
The above seven ‘fracture(d) zones’ have first been assembled as a typical ‘unit’ (combining the characteristics of all seven zones) prior to individual histogram representation, which obviously is more correct. The preliminary combined result is shown in Figure 5-1

The summary statistic of the seven combined FZ zones is as follows, giving immediately the (correct) impression that the rock mass quality is of distinctly lesser quality than the generally good quality of the remainder.

$Q_{\text{most frequent}}$ = 2.3 (poor)
Q_{mean} = 1.1 (poor)
$Q_{\text{typ. min.}}$ = 0.02 (extremely poor)
$Q_{\text{typ. max.}}$ = 21 (good)

The very wide distribution of RQD seen in Figure 5-1 shows that the joint spacing varies widely in these fracture(d) zones, but the dominance of at least three joint sets (J_n = 12) and a considerable statistic of thinly filled and coated and weathered joints, suggests also a variable but sometimes rather permeable condition.

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	10	/	15,0	*	1,0	/	6,0	*	0,33	/	2,5	=	**0,015**
Q (typical max)=	95	/	6,0	*	2,0	/	2,0	*	0,66	/	0,5	=	**20,9**
Q (mean value)=	54	/	10,8	*	1,5	/	3,9	*	0,53	/	0,8	=	**1,20**
Q (most frequent)=	75	/	12,0	*	1,5	/	4,0	*	0,50	/	0,5	=	**2,34**



	Rev.	Report No.	Figure No.
SKB SIMPEVARP		NB&A	5-1
KSH 01A and B : overall quality of seven identified fractured zones : 1) 138.5-154.5, 2) 247.7-253.0, 3) 407.0-409.5, 4) 420-437, 5) 541-570, 6) 619-637, and 7) 725-730	Borehole No. : KSH 01A and B	Drawn by	Date
	Depth zone (m) various	Checked nrb	
	Logg 1,0 ### 21st May 2003	Approved nrb	

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

6 Character of KSH 01A and 01B, minus the fracture(d) zones

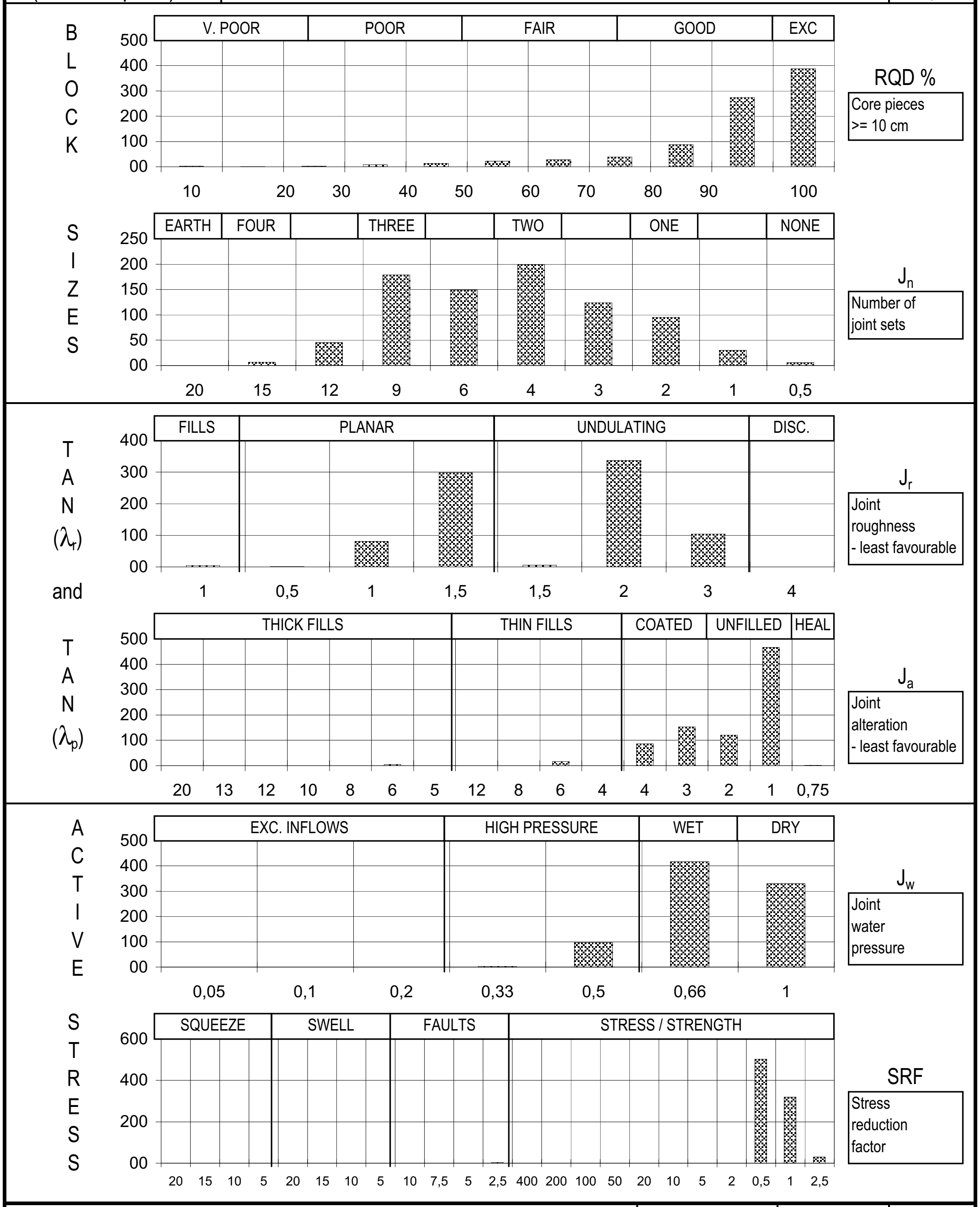
By counting overall Q-parameter observation totals (10x6x87 = 5220 (approx) in Appendix A) and ***subtracting*** the fracture(d) zone recordings listed in Section 5 (about 490 observations for the seven zones), we obtain the 'net result' for the rock mass minus the fracture(d) zones. The above numbers suggest that about 93 m/1002 m = 9.3% 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 or back-ground rock mass' result is shown in Figure 6-1, and demonstrates a generally 'good' to 'very good' quality. The following Q statistics can be noted:

$Q_{\text{most frequent}}$ = 66 ('very good')
Q_{mean} = 16.2 ('good')
$Q_{\text{typ. min.}}$ = 0.3 ('very poor')
$Q_{\text{typ. max.}}$ = 600 ('exceptionally good')

Perhaps surprisingly, there is still a wide distribution of J_n, in other words a marked number of joint sets, despite the subtraction of the seven identified fracture(d) zones. There is also still a significant 'tail' of RQD out to medium values of 60 or 70, but the extreme low values of RQD have of course been almost 'eliminated' by this subtraction of marked fractured zones.

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	45	/	12,0	*	1,0	/	6,0	*	0,50	/	1,0	=	**0,313**
Q (typical max)=	100	/	1,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**600,0**
Q (mean value)=	92	/	5,4	*	1,8	/	1,9	*	0,77	/	0,8	=	**16,13**
Q (most frequent)=	100	/	4,0	*	2,0	/	1,0	*	0,66	/	0,5	=	**66,00**



SKB SIMPEVARP

KSH 01A and B : 1.3 to 1003.0m, excluding the seven fracture(d) zones plotted in the previous figure

Rev.	Report No.	Figure No.
	NB&A	6-1
Borehole No. : KSH 01A and B	Drawn by nrb	Date
Depth zone (m) 1.3-1003.0	Checked nrb	
Logg 1,0 ### 21st May 2003	Approved	

Figure 6-1. Q-parameter histograms for the back-ground rock mass, with the seven fracture(d) zones excluded.

7 Individual character of fracture(d) zones

In this section, possible differences in character of the four principal fracture(d) zones are investigated, 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 widest of the presently identified fracture(d) zones, which from Section 5 are seen to be FZ 1, FZ 4, FZ 5 and FZ 6. These have a combined length down the borehole of approximately 16+17+29+18 m respectively, so dominate as 80 m of the 93 m total of presently delineated zones in this Q-parameter based report.

Two photographic examples of these fracture(d) zones, taken from FZ 4 and FZ 5 are shown in Figure 7-5. These boxes are from 421.1 to 431.3 m, and 557.8 to 567.9 m respectively. In terms of tunnel stability, these of course would not be serious occurrences, apart from increased inflows – or the possible need of pre-injection.

Comparison of Figures 7-1 through 7-4 shows that each of the fracture(d) zones has bimodal distributions of RQD. In other words, despite the lower general quality, they have a 'core', or several locations, of significantly worse quality. Nevertheless, the shallowest zone FZ 1 has a significantly less 'crushed' appearance than the deeper zones, with higher overall RQD distributions.

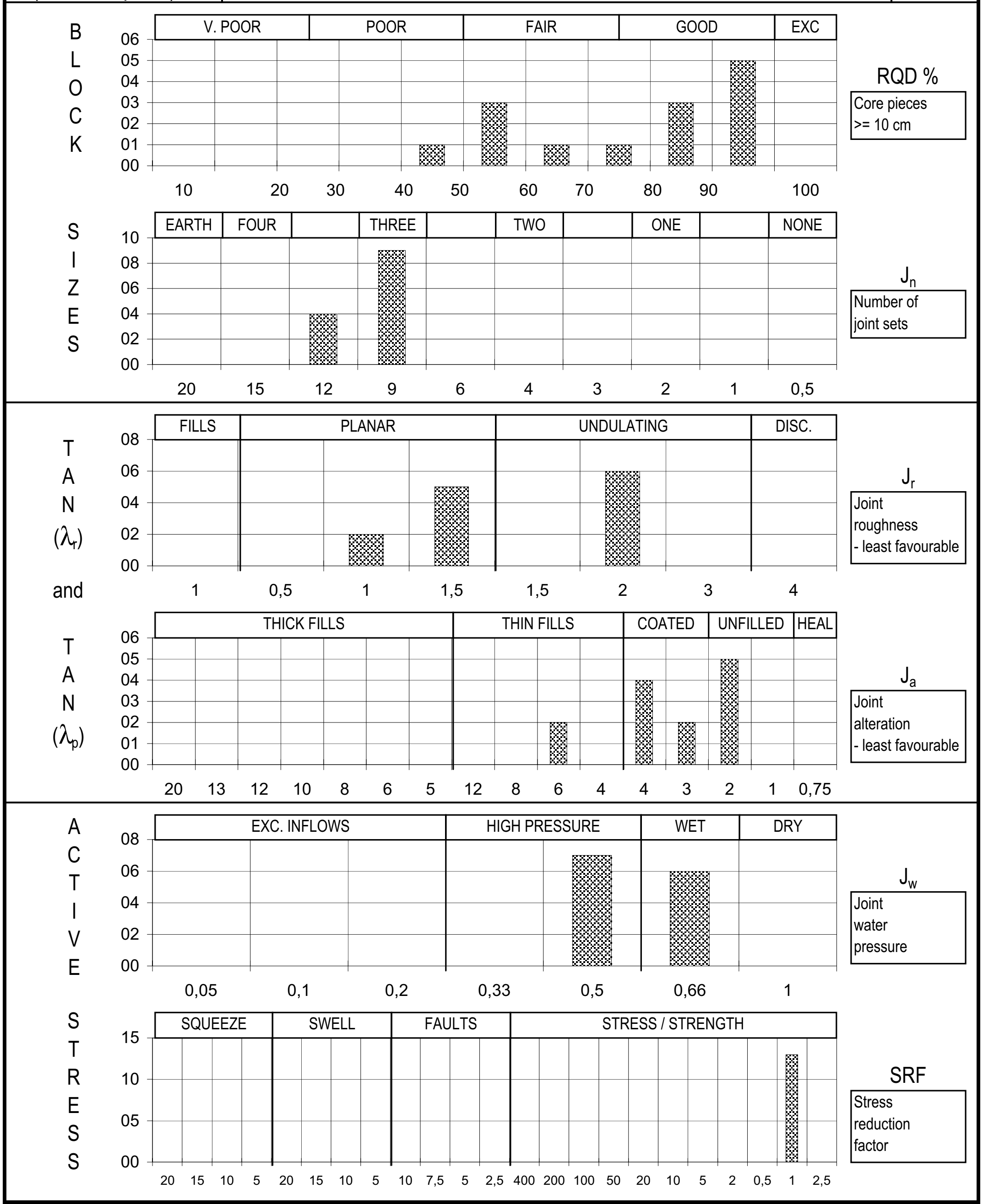
Three joint sets and random (J_n = 12) dominate in the two deepest zones FZ 5 and FZ 6, but not in the two shallower zones. Altered or stained joints, clay coatings and thin, sometimes thicker fillings are seen in all four zones, i.e. there are frequent values of J_a = 2, 3, 4 and 6. In terms of Q-value statistics, there are remarkable similarities in the *mean* and *most frequent* values for the four principal zones, as seen in the following table.

These identified fracture(d) zones are easy to see when surveying the core, and presumably will have resulted in lower terrain if intersecting the ground surface. They represent significant reductions in quality, and perhaps would result in at least 1 km/s reduction in P-wave velocity in relation to 'background' velocities. This may well be the reason for the (moderate) height differences in the local ground surface.

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

Fracture(d) zone	Depth (m)	$Q_{most\ frequent}$	Q_{mean}	$Q_{typ.\ min.}$	$Q_{typ.max.}$
FZ 1	138.5–154.5	5.3	2.2	0.3	7.0
FZ 4	420–437	3.8	1.4	0.02	24.8
FZ 5	541–570	2.3	1.3	0.02	20.9
FZ 6	619–637	2.7	1.1	0.04	10.5

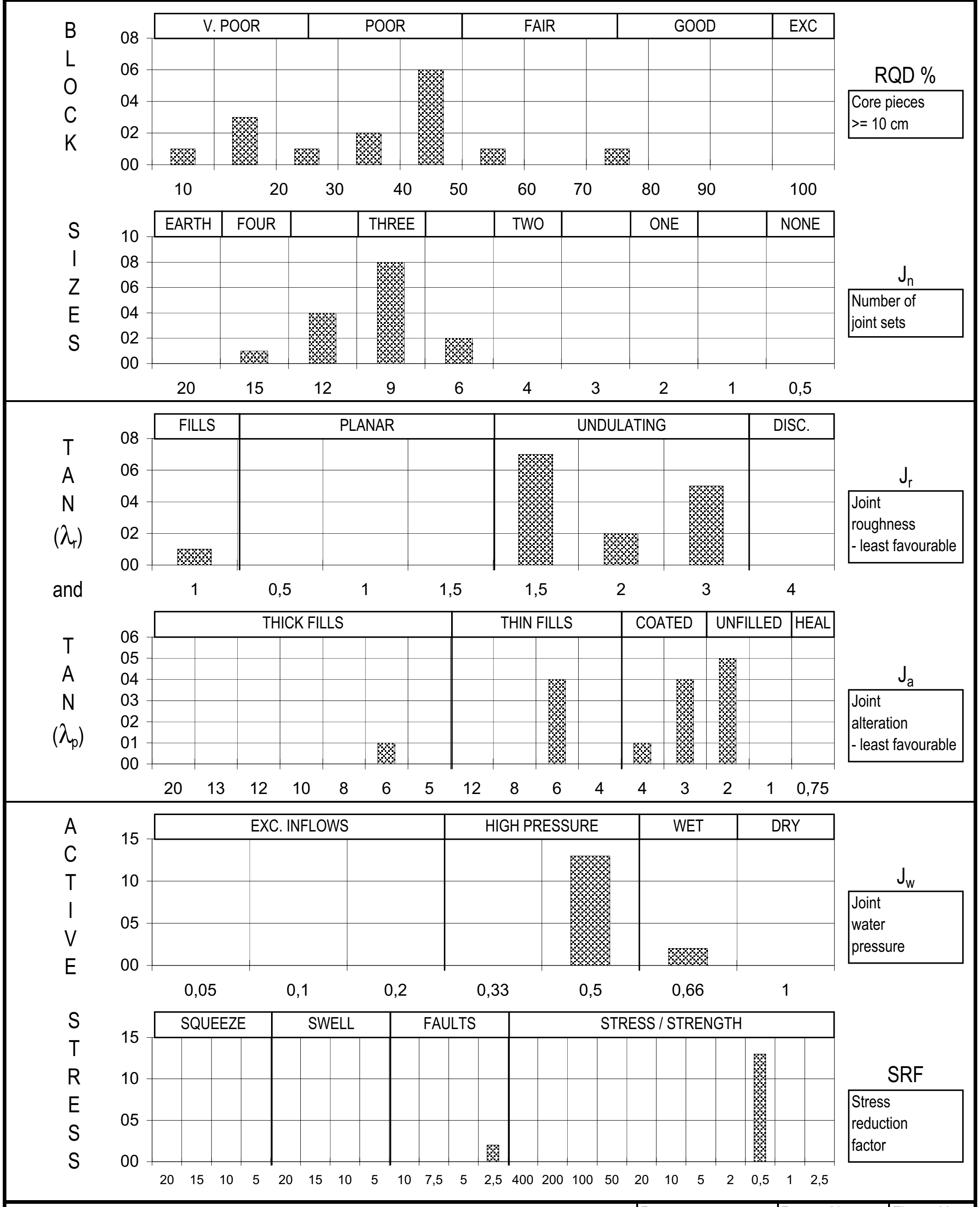
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	**Q**
Q (typical min)=	45	/	12,0	*	1,0	/	6,0	*	0,50	/	1,0	=	**0,313**
Q (typical max)=	95	/	9,0	*	2,0	/	2,0	*	0,66	/	1,0	=	**7,0**
Q (mean value)=	77	/	9,9	*	1,7	/	3,4	*	0,57	/	1,0	=	**2,18**
Q (most frequent)=	95	/	9,0	*	2,0	/	2,0	*	0,50	/	1,0	=	**5,28**



		Rev.	Report No.	Figure No.
SKB SIMPEVARP	**KFM 01A**		NB&A	7-1
Individual character of FZ 1		Borehole No. :	Drawn by	Date
		KSH 01A	nrb	
		Depth zone (m) 138.5-154.5m	Checked nrb	
		Logg 1,0	Approved	
		###	22nd May 2003	

Figure 7-1. Individual character of FZ 1 (138.5–154.5 m).

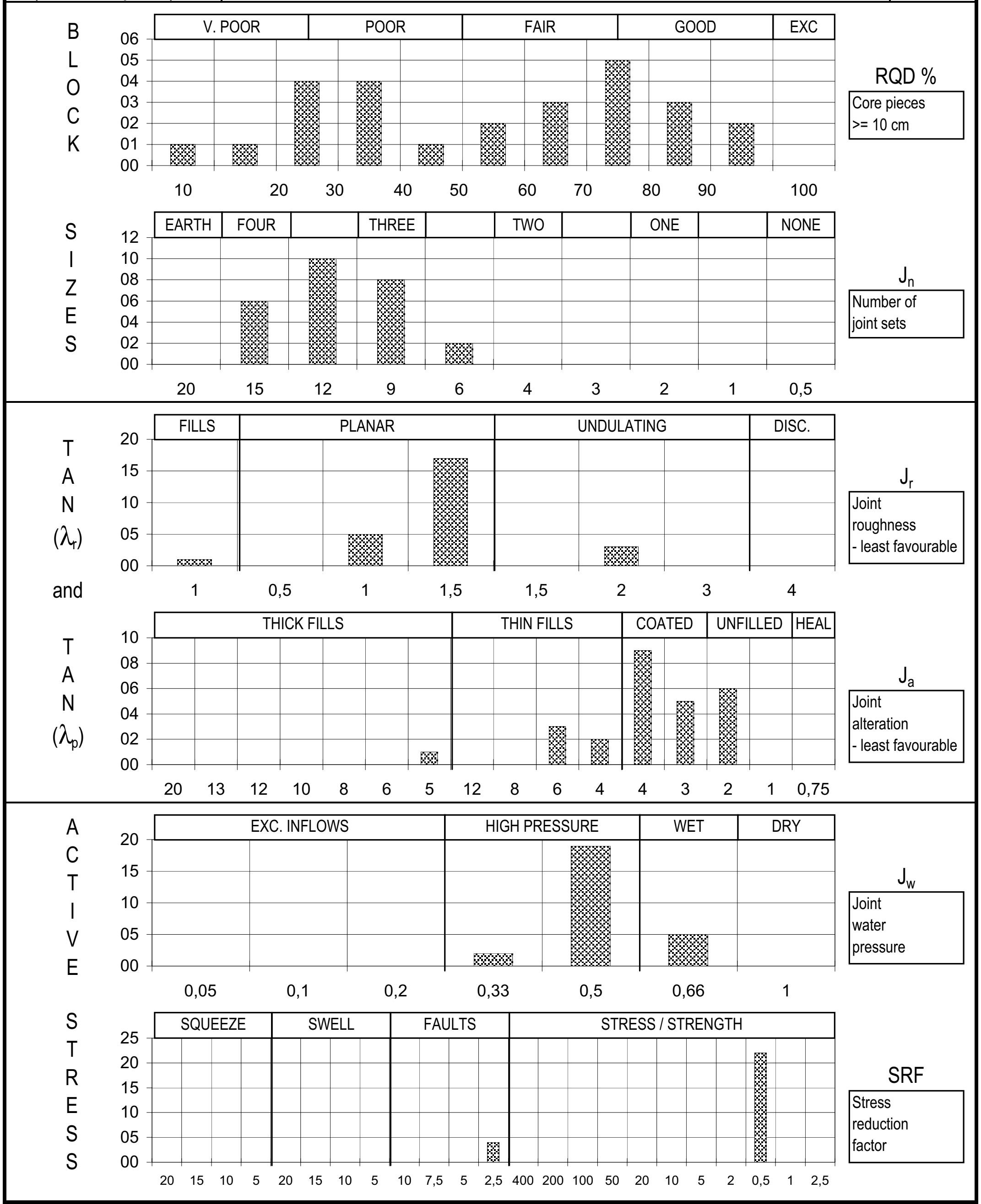
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	10	/	15,0	*	1,0	/	6,0	*	0,50	/	2,5	=	**0,022**
Q (typical max)=	75	/	6,0	*	3,0	/	2,0	*	0,66	/	0,5	=	**24,8**
Q (mean value)=	37	/	9,8	*	2,0	/	3,7	*	0,52	/	0,8	=	**1,39**
Q (most frequent)=	45	/	9,0	*	1,5	/	2,0	*	0,50	/	0,5	=	**3,75**



SKB SIMPEVARP KSH 01A	Rev.	Report No.	Figure No. 7-2
Individual character of FZ4	Borehole No. : KSH 01A	Drawn by nrb	Date
	Depth zone (m) 420-437m	Checked nrb	
	Logg 1,0 ###	Approved 22nd May 2003	

Figure 7-2. Individual character of FZ 4 (420–437 m).

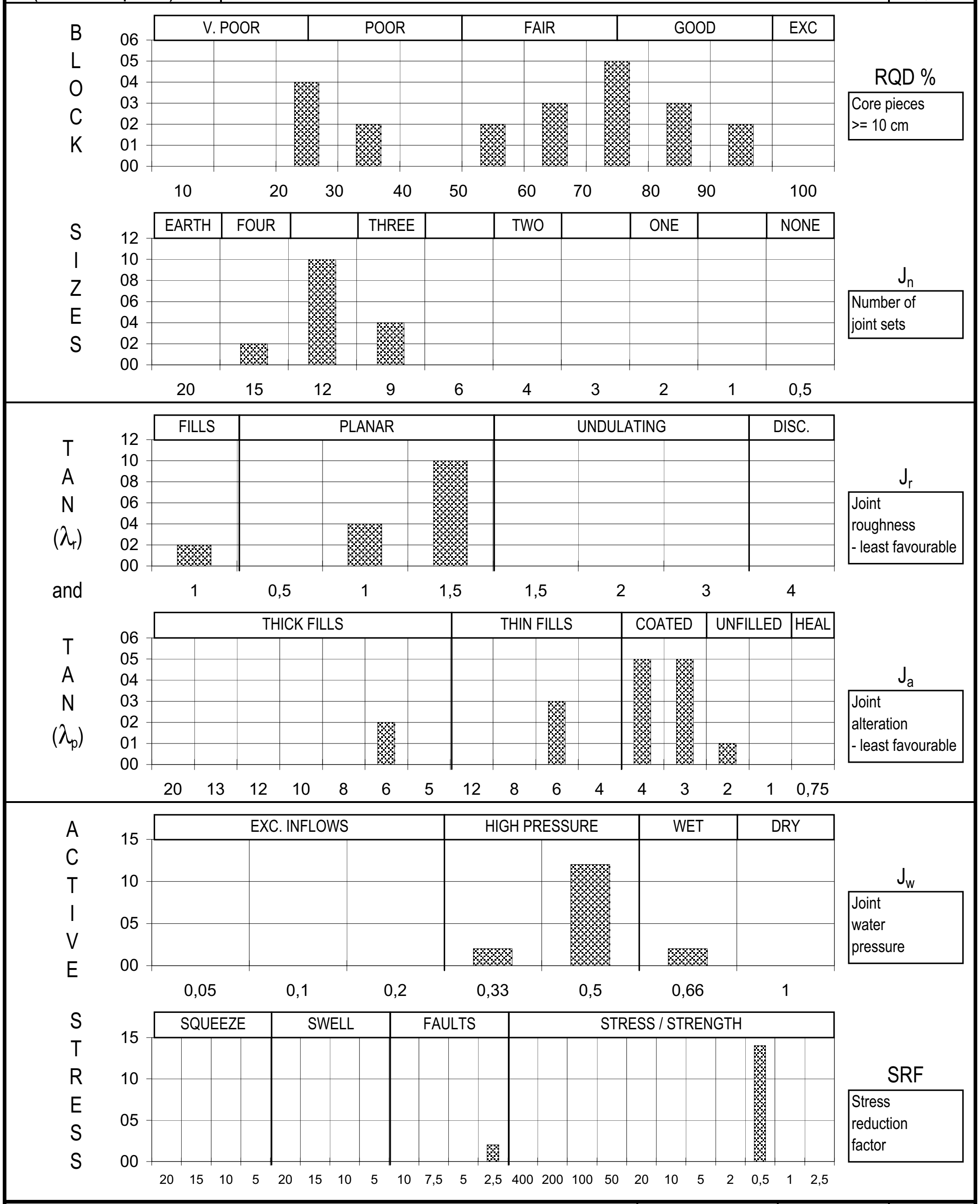
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	10	/	15,0	*	1,0	/	6,0	*	0,33	/	2,5	=	**0,015**
Q (typical max)=	95	/	6,0	*	2,0	/	2,0	*	0,66	/	0,5	=	**20,9**
Q (mean value)=	55	/	11,3	*	1,4	/	3,6	*	0,52	/	0,8	=	**1,25**
Q (most frequent)=	75	/	12,0	*	1,5	/	4,0	*	0,50	/	0,5	=	**2,34**



SKB SIMPEVARP KSH01A	Rev.	Report No. NB&A	Figure No. 7-3
Individual character of FZ 5	Borehole No. : KSH 01A	Drawn by nrb	Date
	Depth zone (m) 541-570	Checked nrb	
	Logg 1,0 ### 22nd May 2003	Approved	

Figure 7-3. *Individual character of FZ 5 (541–570 m).*

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	25	/	15,0	*	1,0	/	6,0	*	0,33	/	2,5	=	**0,037**
Q (typical max)=	95	/	9,0	*	1,5	/	2,0	*	0,66	/	0,5	=	**10,5**
Q (mean value)=	62	/	11,6	*	1,3	/	4,2	*	0,50	/	0,8	=	**1,11**
Q (most frequent)=	75	/	12,0	*	1,5	/	3,5	*	0,50	/	0,5	=	**2,68**



SKB SIMPEVARP KSH01A	Rev.	Report No. NB&A	Figure No. 7-4
Individual character of FZ 6	Borehole No. : KSH 01A	Drawn by nrb	Date
	Depth zone (m) 619-637	Checked nrb	
	Logg 1,0 ###	Approved 22nd May 2003	

Figure 7-4. Individual character of FZ 6 (619–637 m).

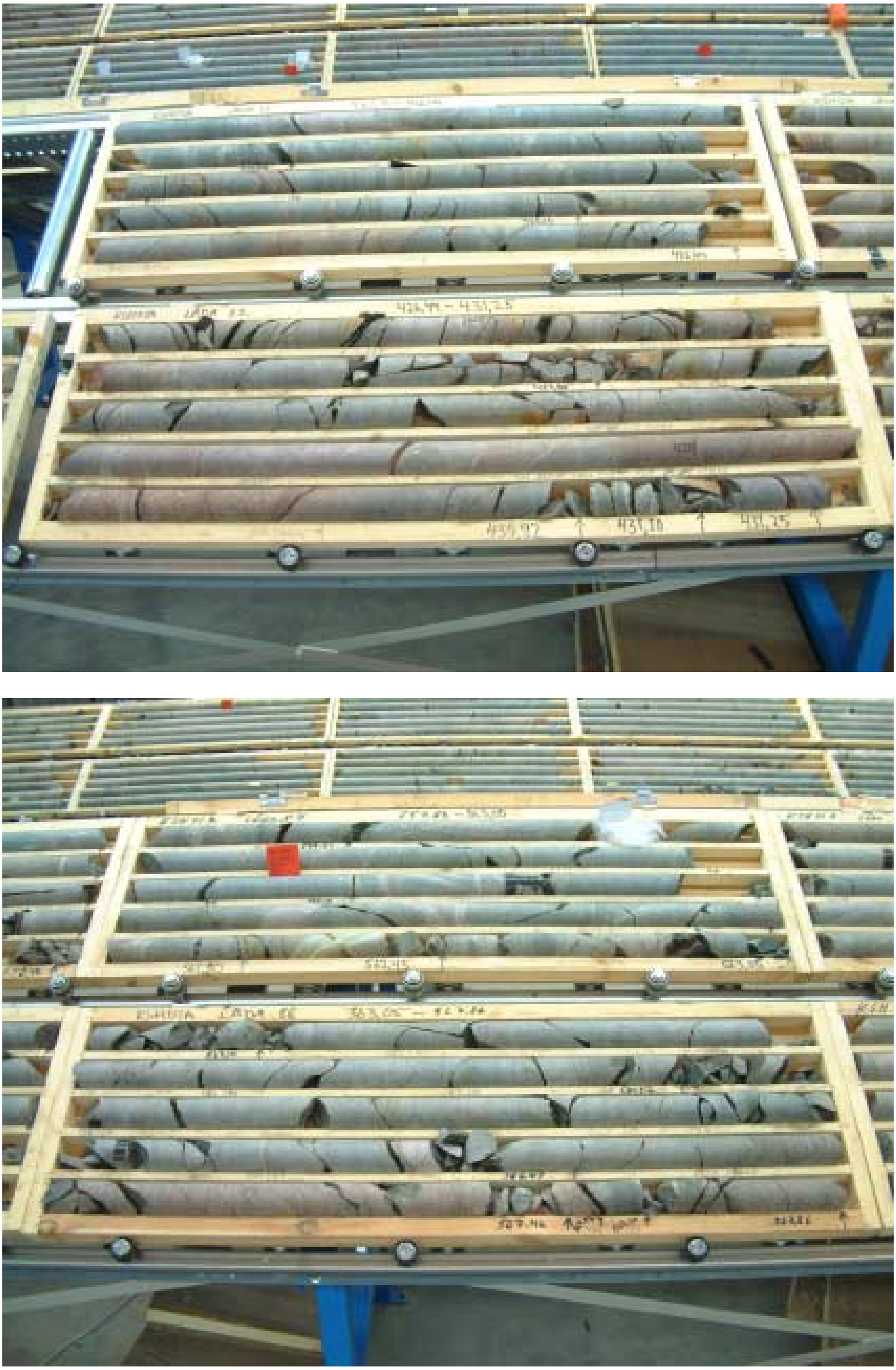


Figure 7-5. Examples from FZ 4 and FZ 5.

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 91% (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 seven identified fracture(d) zones as appropriate.

The results of key Q-value statistics for the ten '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 seven fracture(d) zones are subtracted as they occur. This means that one of the ten 'slices' is reduced to only about 70 m in (down-hole measured) thickness, due to the maximum 29 m length of identified fracture(d) zone FZ 5.

Table 8-1 reflects the general improvement of 'back-ground' rock from 500 m depth and beyond. It may also be emphasised that beyond 700 m depth – the last three 100 m slices – there is only one small fracture(d) zone (FZ 7 of 5 m thickness).

Table 8-1. Variations with depth for the 'background rock mass' (minus 7 x FZ).

Depth down hole	$Q_{most\ frequent}$	Q_{mean}	$Q_{typ.\ min.}$	$Q_{typ.\ max.}$
1.3–100.8 m	24.8	6.3	0.9	75
100.8–199.9 m	31.4	12.9	2.6	100
199.9–302.9 m	13.9	6.0	0.3	75
302.9–398.8 m	31.4	16.8	1.8	150
398.8–500.1 m	15.8	15.3	2.7	150
500.1–600.6 m	49.5	17.9	4.0	200
600.6–699.5 m	62.7	14.0	2.3	200
699.5–798.8 m	133	48.3	2.6	600
798.8–901.2 m	133	59.4	7.1	300
901.2–1003.0 m	150	71.7	13.9	1200

The typical appearance of two parts of the 'background rock mass' is shown in Figure 8-1. The depths shown are (top) 302.9 to 313.4 m (moderately jointed), and (bottom) 983.0 to 994.1 m (massive). The local Q-parameters were estimated to be within the following ranges for these two 10 m slices of the rock mass:

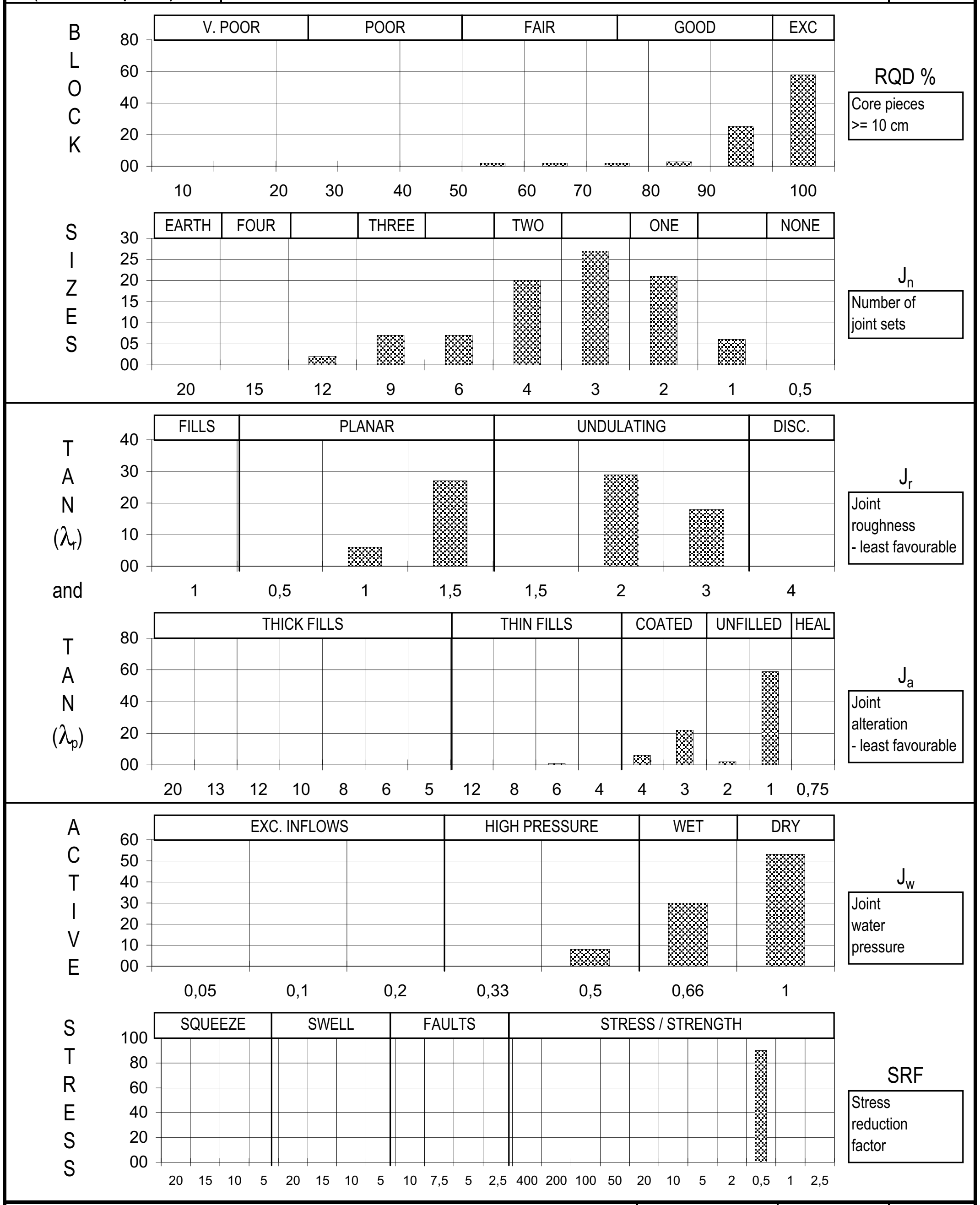
1. (above) $Q = (80–100)/4 \times 2/1 \times 0.66/0.5 = 53–66$ ('very good'),
2. (below) $Q = 100/1 \times (2–4)/1 \times 1/0.5 = 400–800$ ('exceptionally good').

There is considerable uncertainty about the most massive rock, as joint continuity cannot be assessed, and J_r has also been given the possible value of 4, which represents 'discontinuous'. If the rock mass was relatively free of joints for distances of many tens of meters, the effective Q-value as regards rock mass parameters appropriate to engineering-scale problems is likely to be greater than 1000, as reflected by the $Q_{\text{typical maximum}}$ value of 1200 given in the last row of Table 8-1.

The Q-parameter histograms for the three deepest '100 m slices' are finally given in Figures 8-2, 8-3 and 8-4. This is the best quality region, based on a sum of 11 out of 12 of the top-score Q-value criteria (i.e. 3x $Q_{\text{most frequent}}$, 3x Q_{mean}, 2x $Q_{\text{typical minimum}}$ and 3x $Q_{\text{typical maximum}}$), as can be seen by checking Table 8-1.

Figure 8-1. *Examples of jointed and massive 'back-ground' rock mass.*

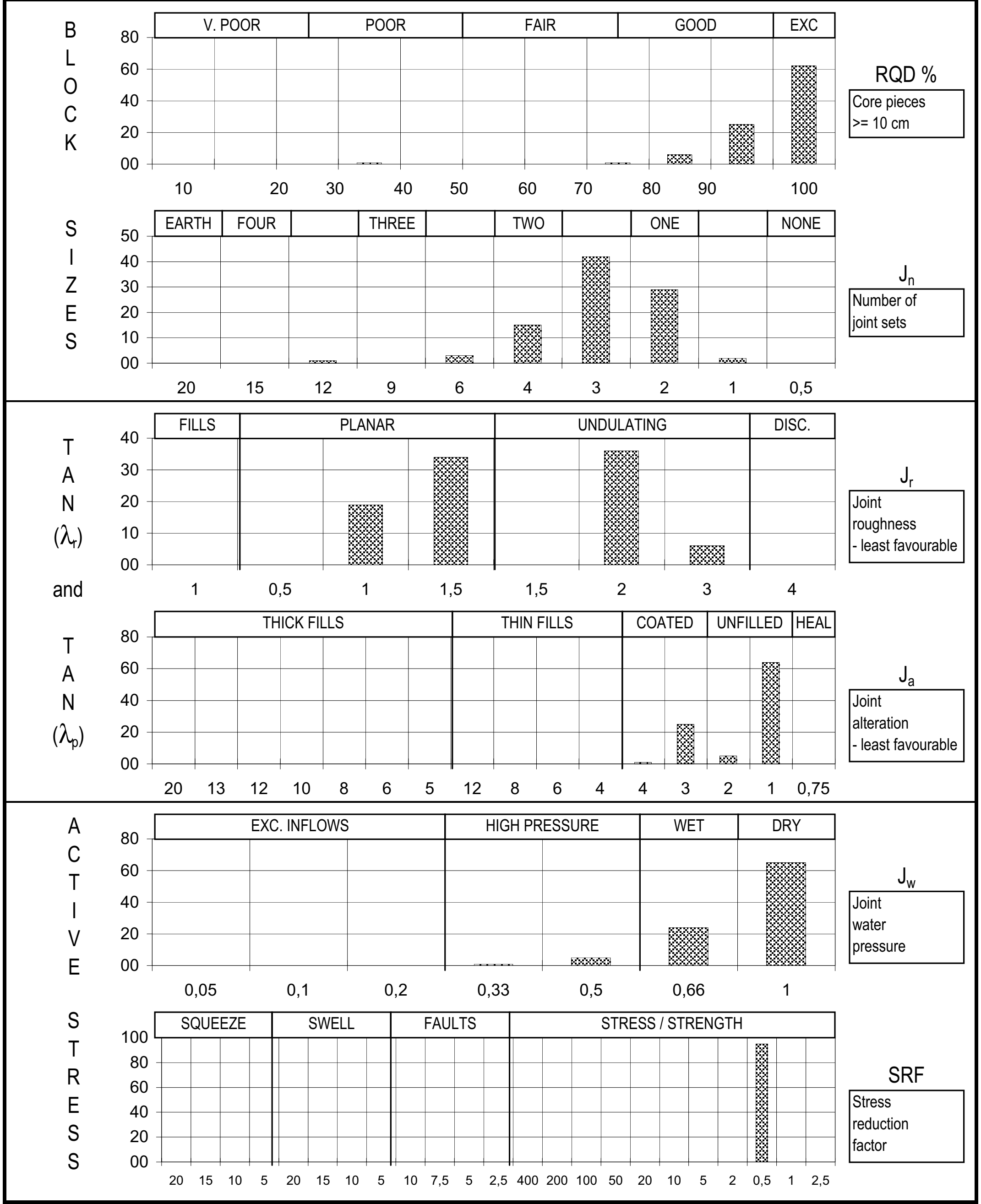
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	95	/	9,0	*	1,0	/	4,0	*	0,50	/	0,5	=	**2,639**
Q (typical max)=	100	/	1,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**600,0**
Q (mean value)=	96	/	3,8	*	2,0	/	1,8	*	0,84	/	0,5	=	**48,32**
Q (most frequent)=	100	/	3,0	*	2,0	/	1,0	*	1,00	/	0,5	=	**133,33**



	Rev.	Report No.	Figure No.
SKB SIMPEVARP		NB&A	8-2
Background ı rock : 699.5-798.8 m	Borehole No. :	Drawn by	Date
	KSH 01A and B	nrb	
	Depth zone (m)	Checked	
	699.5-798.8	nrb	
	Logg 1,0	Approved	
	### 23rd May 2003		

Figure 8-2. Q-histograms for 700–800 m (approx).

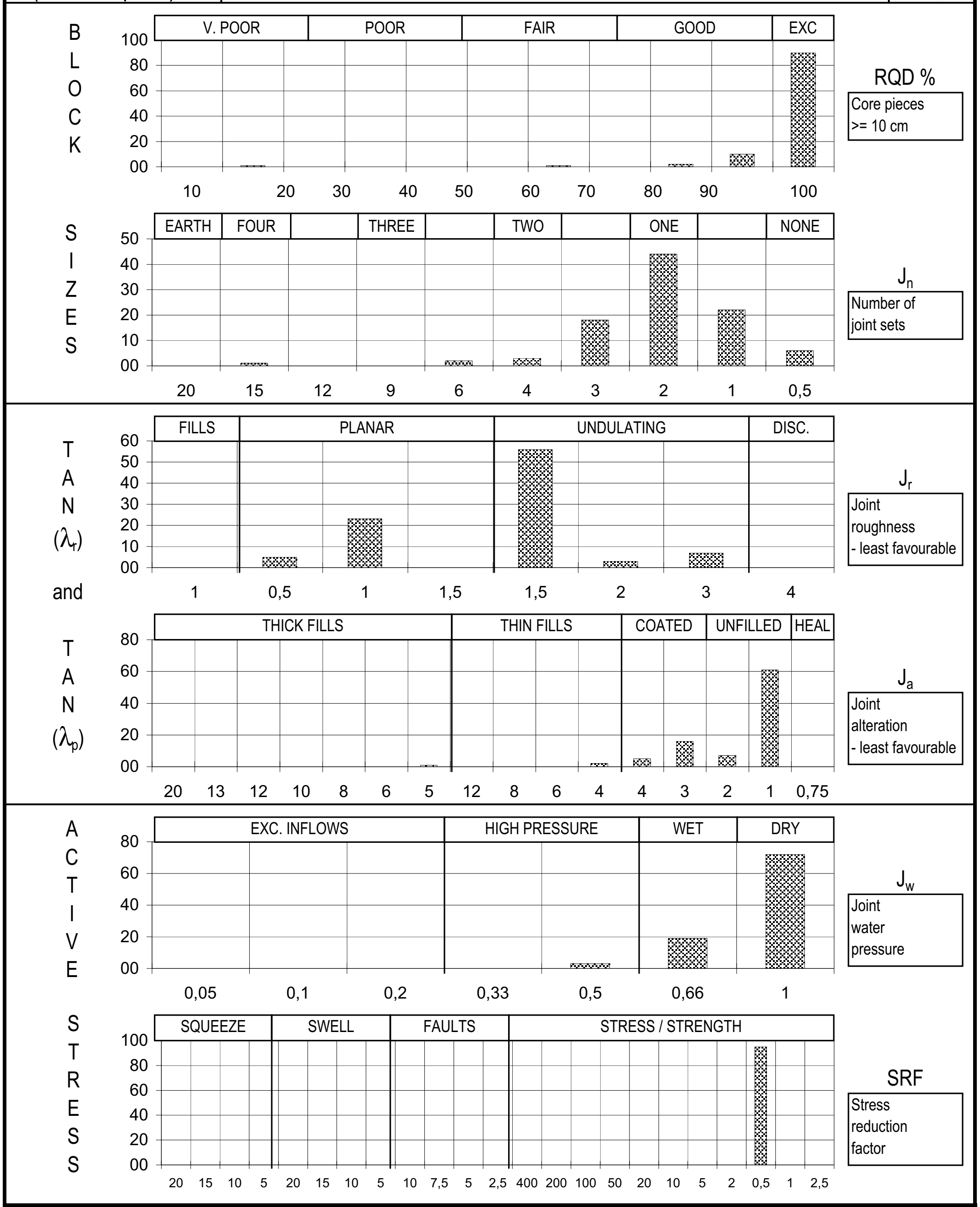
Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	Q
Q (typical min)=	85	/	4,0	*	1,0	/	3,0	*	0,50	/	0,5	=	**7,083**
Q (typical max)=	100	/	2,0	*	3,0	/	1,0	*	1,00	/	0,5	=	**300,0**
Q (mean value)=	97	/	3,0	*	1,7	/	1,6	*	0,88	/	0,5	=	**59,43**
Q (most frequent)=	100	/	3,0	*	2,0	/	1,0	*	1,00	/	0,5	=	**133,33**



SKB SIMPEVARP	Rev.	Report No. NB&A	Figure No. 8-3
Background rock : 799.8-901.2 m	Borehole No. : KSH 01A and B	Drawn by nrb	Date
	Depth zone (m) 798.8-901.2	Checked nrb	
	Logg 1,0	Approved	
	###	23rd May 2003	

Figure 8-3. *Q-histograms for 800–900 m (approx).*

Q - VALUES:	(RQD	/	Jn)	*	(Jr	/	Ja)	*	(Jw	/	SRF)	=	**Q**
Q (typical min)=	95	/	3,0	*	1,0	/	3,0	*	0,66	/	0,5	=	**13,933**
Q (typical max)=	100	/	0,5	*	3,0	/	1,0	*	1,00	/	0,5	=	**1200,0**
Q (mean value)=	98	/	2,1	*	1,5	/	1,7	*	0,92	/	0,5	=	**71,65**
Q (most frequent)=	100	/	2,0	*	1,5	/	1,0	*	1,00	/	0,5	=	**150,00**



SKB SIMPEVARP	Rev.	Report No. NB&A	Figure No. 8-4
Background ı rock : 901.2-1003.0 m	Borehole No. : KSH 01A and B	Drawn by nrb	Date
	Depth zone (m) 901.2-1003.0	Checked nrb	
	Logg 1,0 ###	Approved 23rd May 2003	

Figure 8-4. Q-histograms for 900–1000 m (approx).

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 a little over 1000 m of core. Eighty seven pairs of core boxes, each containing about 11 m of core, were logged with ten allowable opinions of the local rock mass conditions (+/– a few meters). Since there are six Q-parameters, this data set consists of 10x6x87 = 5,220 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 ten 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 1002 m of core, the seven identified fracture(d) zones termed FZ 1 to 7, and the whole core minus the seven principal fracture(d) zones.

3. The whole core displayed 'good' quality, with Q_{mean} = 12.5, and $Q_{most\ frequent}$ equal to 29. The typical range of Q-values for the whole core was about 0.3 to 600, the latter based on the assumption of virtually no jointing in the lowest portions of the hole. The seven identified fracture(d) zones, if treated as one unit, showed Q_{mean} and $Q_{most\ frequent}$ as low as 1.1 and 2.3 respectively (i.e. 'poor'). They also displayed, collectively, the complete range of RQD from zero to 100%. These fracture(d) zones constituted some 9% of the core, and when excluded, the remaining 91% or 910 m of core showed Q_{mean} = 16.2.

4. Individual histogram treatment of four of the principal fracture(d) zones revealed that they each displayed bimodal distributions of RQD. In other words, despite lower general quality, they also each had a 'core', or several locations, of significantly more jointed or fractured conditions. Three joint sets plus random dominated in the two deepest zones FZ 5 and FZ 6, and relative mean block size ratios (RQD/J_n) of the four selected zones were only 7.8, 3.8, 4.9 and 5.3, signifying small average block sizes, with typical minima on either side of 1.0 (e.g. 10/15, and 25/15).

5. The whole core mean value of J_w was 0.75, and for the seven fracture(d) zones only 0.52, implying 'high pressure inflows' in the tunnelling context – i.e. the possible need for pre-injection of such zones. The 91% of 'background rock mass' (with seven fractured zones excluded) had a mean estimated J_w of 0.77, which is little improved due to the general level of jointing, and therefore potential connectivity, in the 'background rock mass'.

6. 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. Since RQD/J_n values were easily as low as the stipulated range (0.5 to 25) and often in the range 10 to 15, implying good connectivity, J_w values as low as 0.5 and even 0.33 were applied where this seemed appropriate due to intersecting, frequent jointing. There could be exceptions to this in portions of fracture(d) zones containing clay fillings.

7. An overall comparison of the whole 1002 m of core, and about 90 m total of fracture(d) zones, reveals weighted mean values of RQD/J_n (relative block size) and J_r/J_a (friction coefficient) declining from whole sample (1002 m) values of 88/5.9 and 1.8/2.1, to only 54/10.8 and 1.4/3.9 for the fractured zones. The implied reductions in block size and shear strength are quite significant.

10 Recommendations

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 $Q_c = Q \text{ x } \sigma_c/100$). 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.

Reference

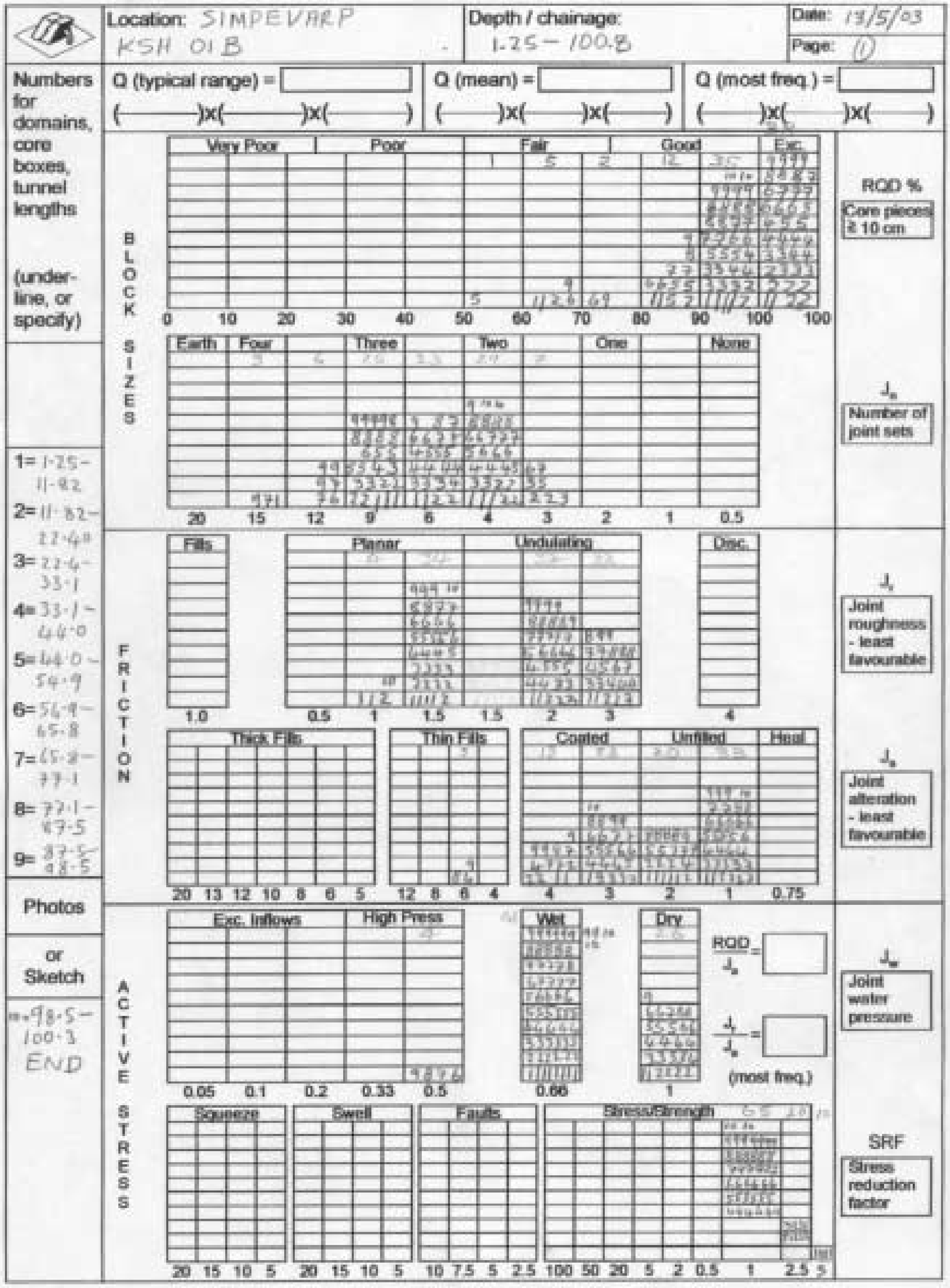
Barton N, Løsel F, Smallwood A, Vik G, Rawlings C, Chryssanthakis P, Hansteen H, Ireland T, 1992. Geotechnical Core Characterisation for the UK Radioactive Waste Repository Design. 1992 Proc. of ISRM Symp. EROCK, Chester, UK.

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

1. Ten hand-filled Q-histogram logging sheets containing the raw data from which subsequent EXCEL calculations were performed.

2. One hand-filled Q-histogram of total numbers-of-observations for the ten ‘100m slices’, with exact depths given on the left.



Location: SIMPEVARP
KSH 01B

Depth / chainage:
1.25 – 100.8

Date: 13/5/03
Page: (1)

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= 1·25–11·82
2= 11·82–22·40
3= 22·4–33·1
4= 33·1–44·0
5= 44·0–54·9
6= 56·9–65·8
7= 65·8–77·1
8= 77·1–87·5
9= 87·5–98·5

Photos

or Sketch

=98·5–100·3
END

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

$\frac{RQD}{J_n}$ = ☐

$\frac{J_r}{J_a}$ = ☐

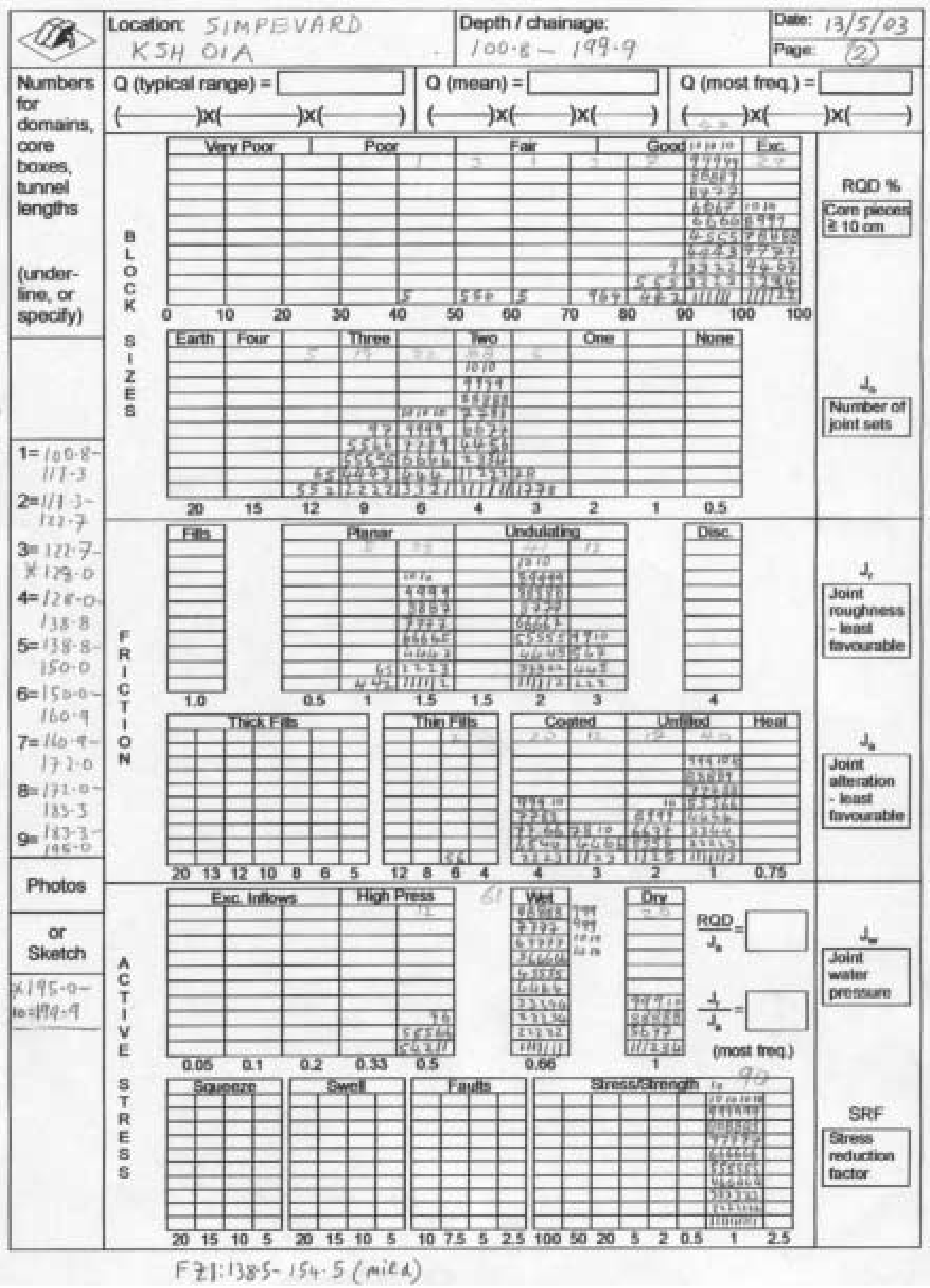
(most freq.)

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 5

SRF
Stress reduction factor



Location: SIMPEVARD KSH 01A

Depth / chainage: 100·8 – 199·9

Date: 13/5/03

Page: ②

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

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

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

Numbers for domains, core boxes, tunnel lengths

(underline, or specify)

1= 100·8–117·3
2= 117·3–122·7
3= 122·7–128·0
4= 128·0–138·8
5= 138·8–150·0
6= 150·0–160·9
7= 160·9–173·0
8= 173·0–183·3
9= 183·3–195·0
10= 195·0–199·9

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

$\frac{RQD}{J_n}$ =

$\frac{J_r}{J_a}$ = (most freq.)

J_w

Joint water pressure

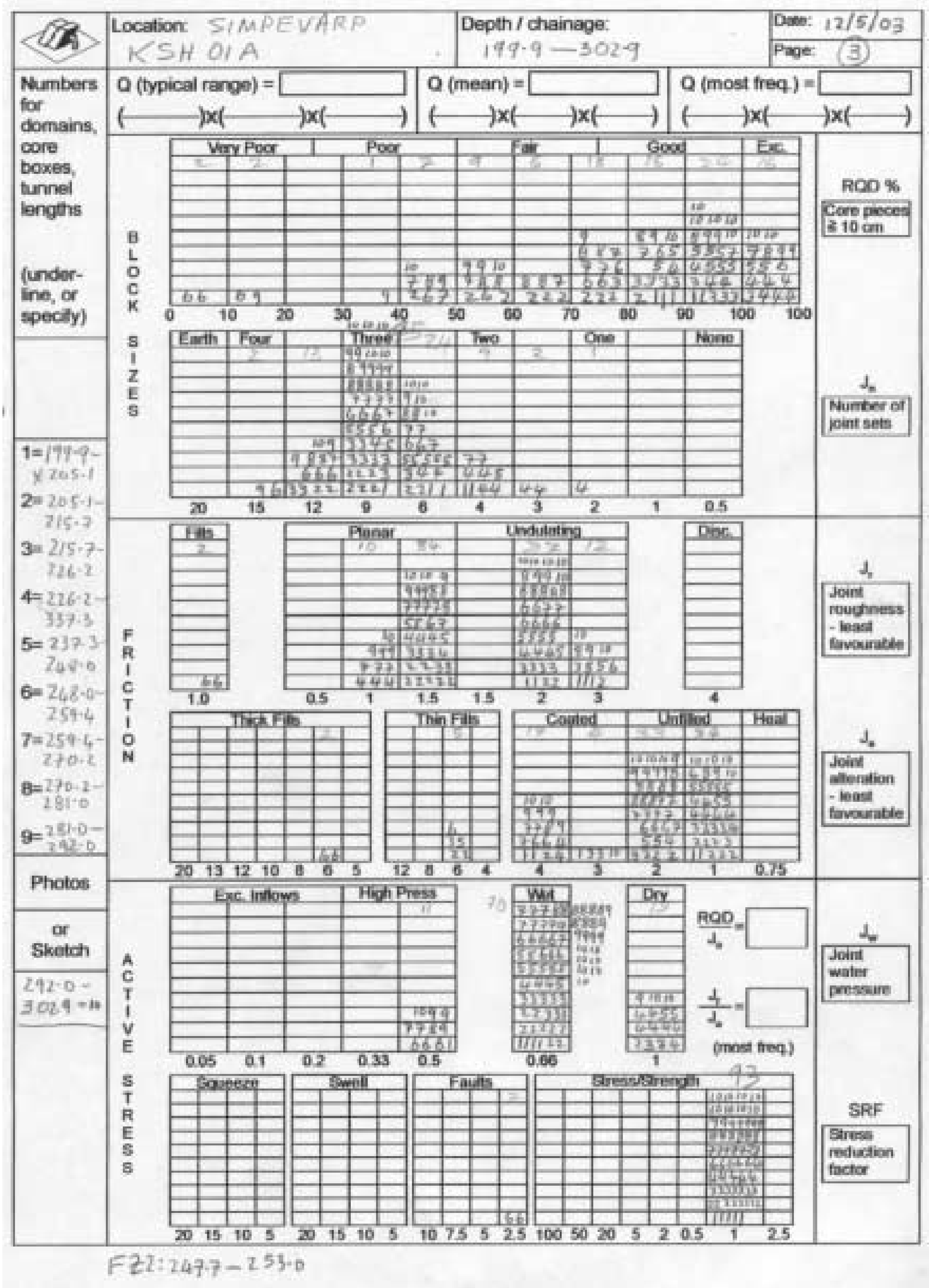
Squeeze | Swell | Faults | Stress/Strength

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

FZ1: 138.5 – 154.5 (mild)



Location: SIMPEVARP KSH 01A

Depth / chainage: 199·9 — 302·9

Date: 12/5/03

Page: ③

Q (typical range) = ☐ (——)x(——)x(——)

Q (mean) = ☐ (——)x(——)x(——)

Q (most freq.) = ☐ (——)x(——)x(——)

Numbers for domains, core boxes, tunnel lengths

(underline, or specify)

1= 199·9–205·1
2= 205·1–215·7
3= 215·7–226·2
4= 226·2–237·3
5= 237·3–248·0
6= 248·0–259·4
7= 259·4–270·2
8= 270·2–281·0
9= 281·0–292·0

Photos

or Sketch

292·0–302·9 =10

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.)

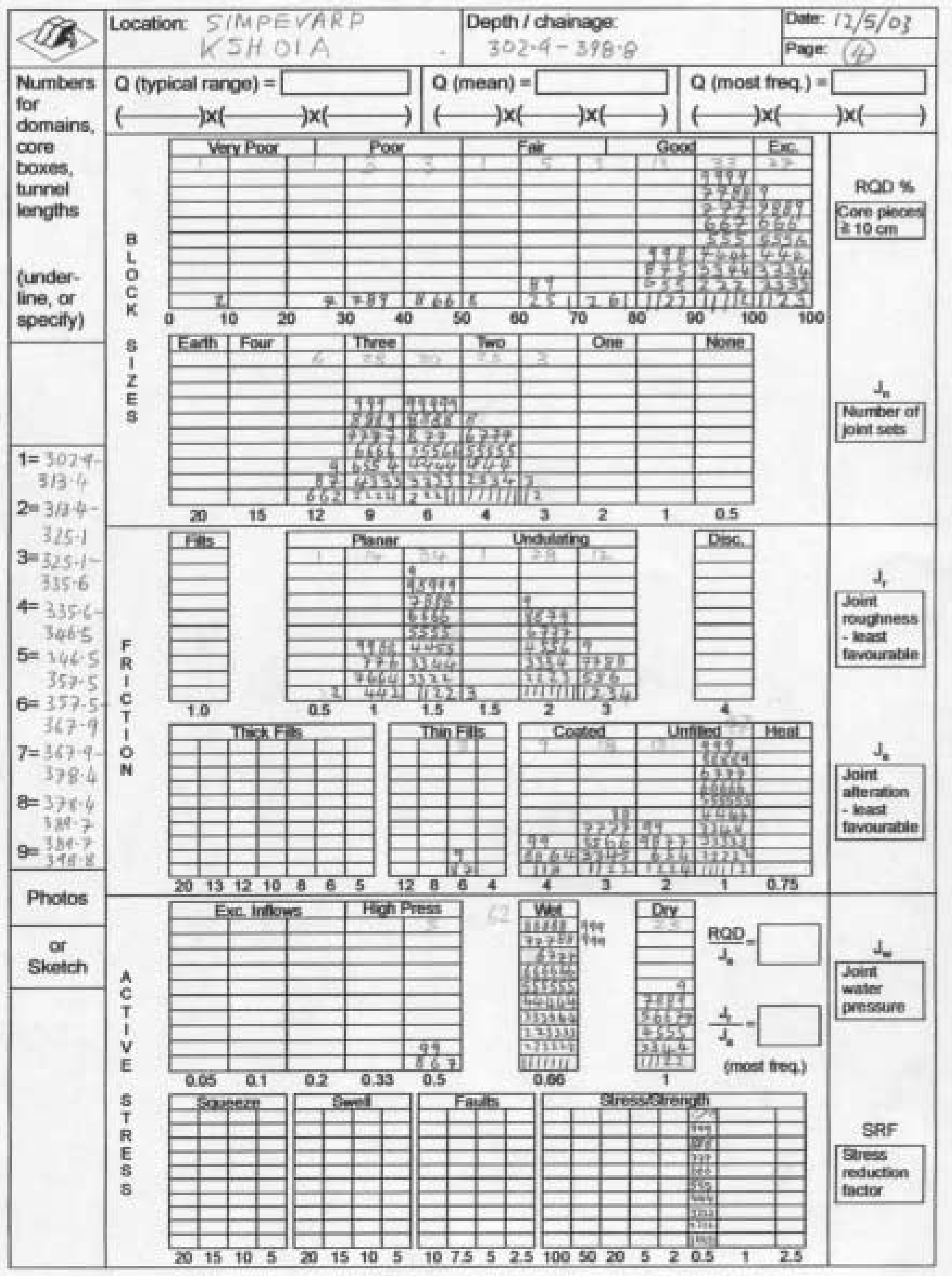
J_w
Joint water pressure

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

FZ1: 247·7 – 253·0



Location: SIMPEVARP KSH 01A

Depth / chainage: 302.4 – 398.8

Date: 12/5/03

Page: ④

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

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

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

Numbers for domains, core boxes, tunnel lengths

(underline, or specify)

1= 302.4–313.4

2= 313.4–325.1

3= 325.1–335.6

4= 335.6–346.5

5= 346.5–357.5

6= 357.5–367.9

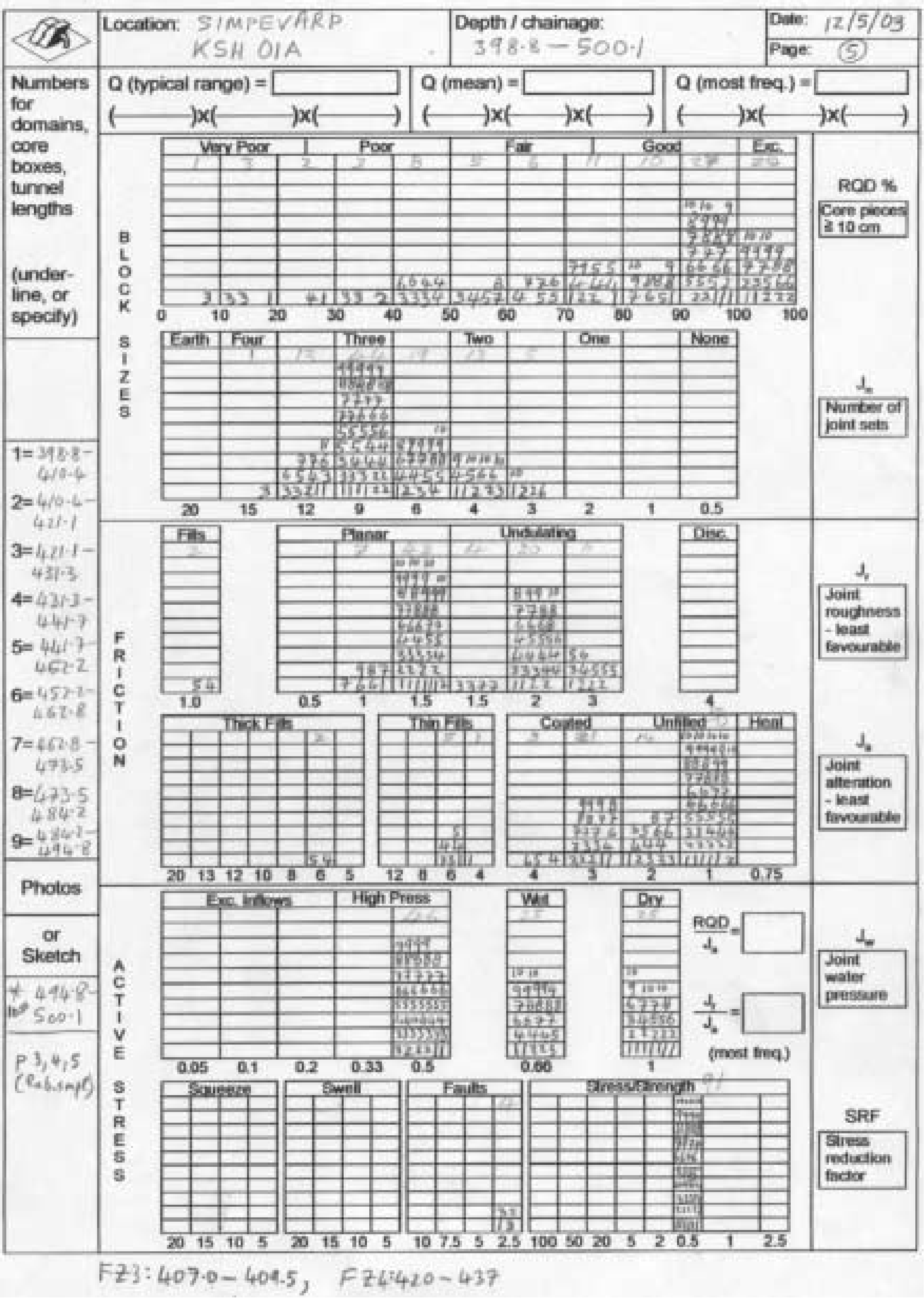
7= 367.9–378.4

8= 378.4–388.7

9= 388.7–398.8

Photos

or Sketch



Location: SIMPEVÄRP KSH 01A

Depth / chainage: 398·8 – 500·1

Date: 12/5/03

Page: ⑤

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= 398·8–410·4
2= 410·4–421·1
3= 421·1–431·3
4= 431·3–441·7
5= 441·7–462·2
6= 452·2–462·8
7= 462·8–473·5
8= 473·5–484·2
9= 484·2–494·8

Photos or Sketch

10= 494·8–500·1

P 3,4,5 (Resampl)

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.)

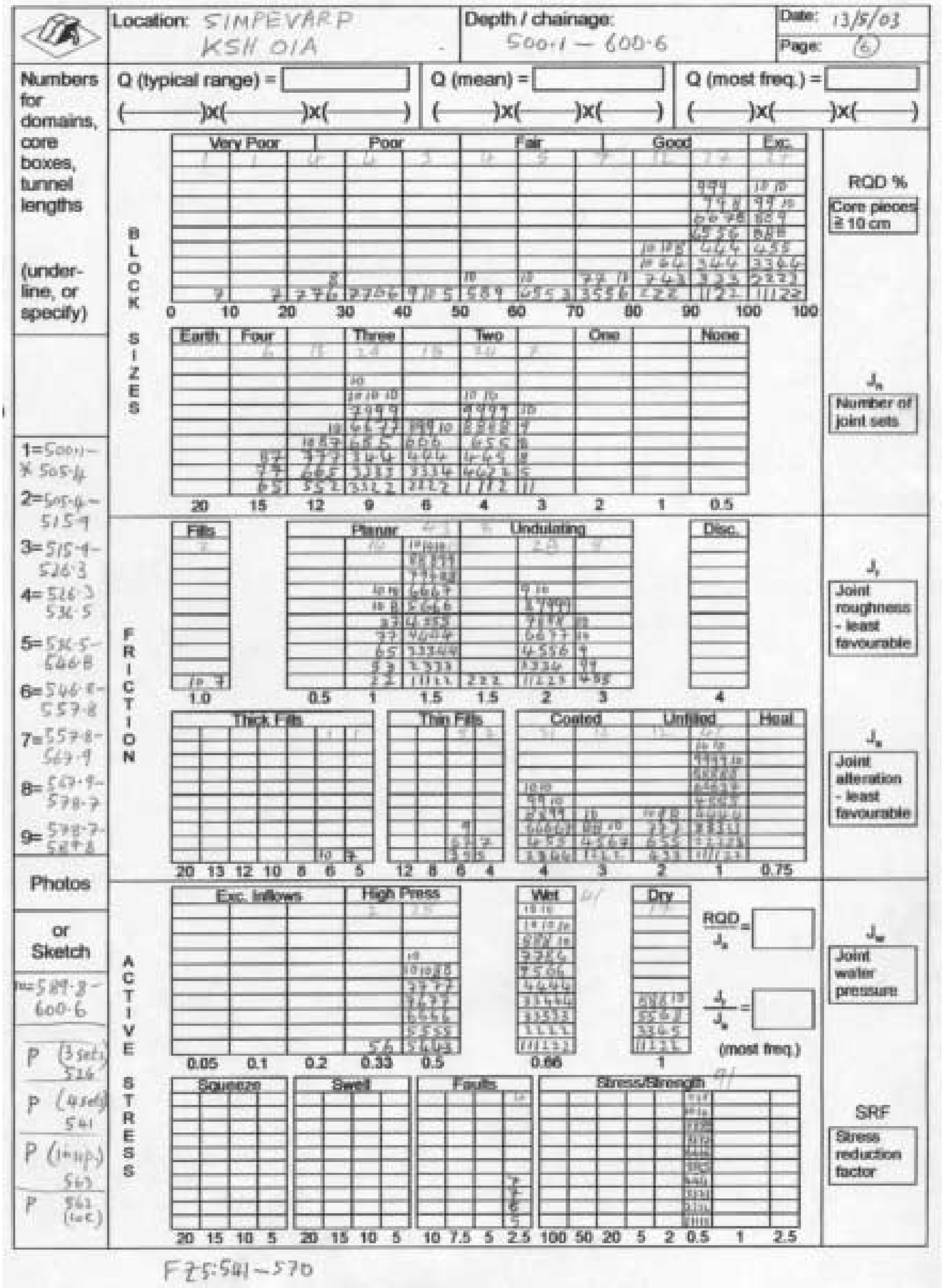
J_w Joint water pressure

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

FZ3: 407·0 – 409.5, FZ4: 420 – 437



Location: SIMPEVARP KSH 01A

Depth / chainage: 500·1 – 600·6

Date: 13/5/03

Page: 6

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

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

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

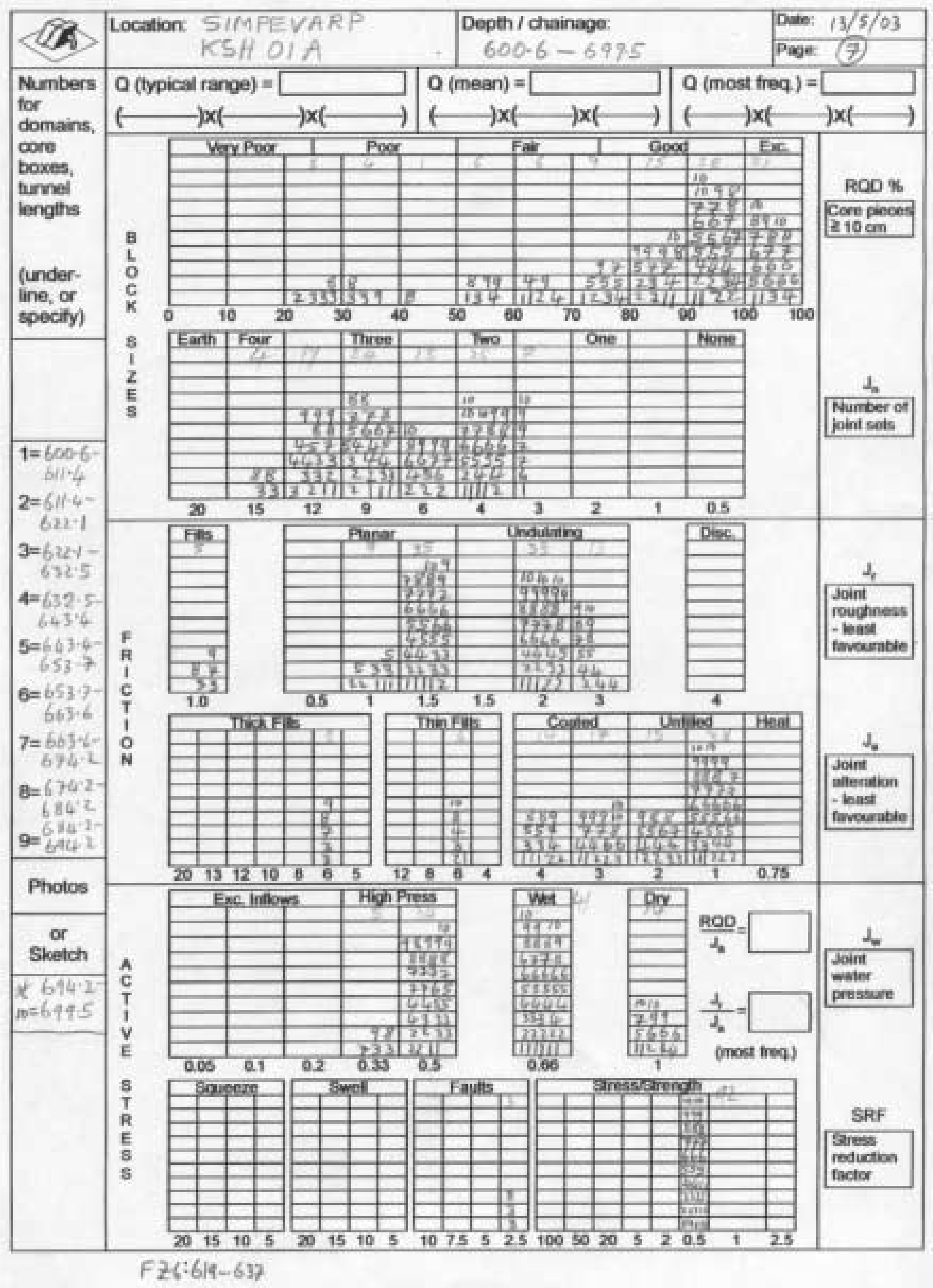
Numbers for domains, core boxes, tunnel lengths (under-line, or specify)

1=500·1–505·4
2=505·4–515·9
3=515·9–526·3
4=526·3–536·5
5=536·5–546·8
6=546·8–557·8
7=557·8–567·9
8=567·9–578·7
9=578·7–589·8
10=589·8–600·6

Photos or Sketch

P (3 sets) 526
P (4 sets) 541
P (1+sp) 563
P 563 (loc)

FZ 5: 541 – 570



Location: SIMPEVARP KSH 01A

Depth / chainage: 600·6 – 699·5

Date: 13/5/03

Page: ⑦

Numbers for domains, core boxes, tunnel lengths

(underline, or specify)

1=600·6–611·4
2=611·4–622·1
3=622·1–632·5
4=632·5–643·6
5=643·6–653·7
6=653·7–663·6
7=663·6–674·2
8=674·2–684·2
9=684·2–694·2

Photos

or Sketch

X 694·2–
10=699·5

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.)

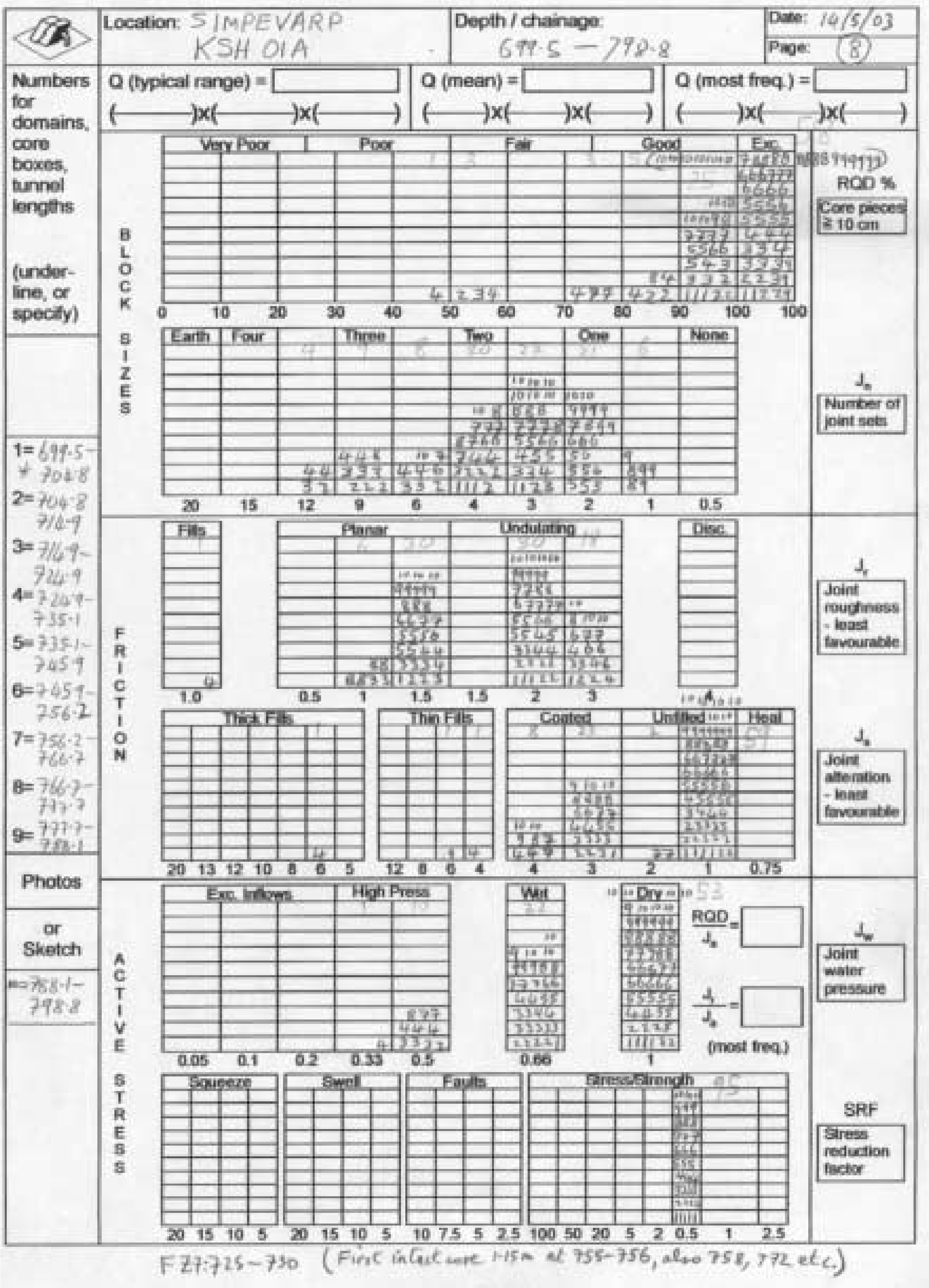
J_w
Joint water pressure

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

FZ6: 619–637



Location: SIMPEVARP KSH 01A

Depth / chainage: 699·5 – 798·8

Date: 14/5/03

Page: 8

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

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

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

Numbers for domains, core boxes, tunnel lengths

(underline, or specify)

1= 699·5 – 704·8

2= 704·8 – 716·9

3= 716·9 – 726·9

4= 726·9 – 735·1

5= 735·1 – 745·9

6= 745·9 – 756·2

7= 756·2 – 766·7

8= 766·7 – 777·7

9= 777·7 – 788·1

Photos

or Sketch

= 758·1 – 798·8

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

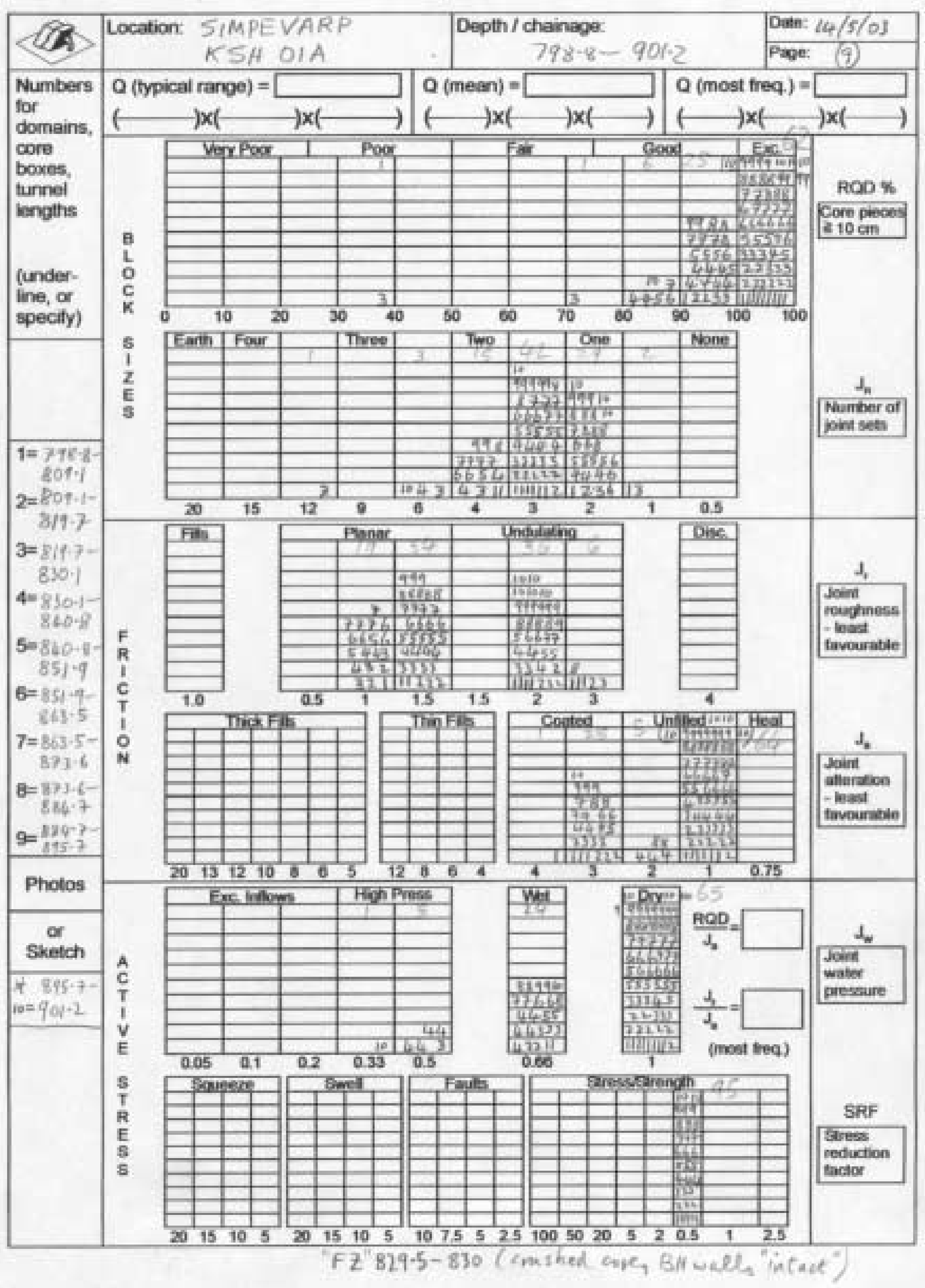
Squeeze | Swell | Faults | Stress/Strength

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

FZ?: 725–730 (First intact core 1·15m at 755–756, also 758, 772 etc.)



Location: SIMPEVARP KSH 01A

Depth / chainage: 798·8 – 901·2

Date: 14/5/03

Page: 9

Q (typical range) = ☐ ( )x( )x( )

Q (mean) = ☐ ( )x( )x( )

Q (most freq.) = ☐ ( )x( )x( )

Numbers for domains, core boxes, tunnel lengths (underline, or specify)

1= 798·8–809·1
2= 809·1–819·7
3= 819·7–830·1
4= 830·1–840·8
5= 840·8–851·9
6= 851·9–863·5
7= 863·5–873·6
8= 873·6–884·7
9= 884·7–895·7
10= 895·7–901·2

Photos or Sketch

RQD % — Core pieces ≥ 10 cm

J_n — Number of joint sets

J_r — Joint roughness - least favourable

J_a — Joint alteration - least favourable

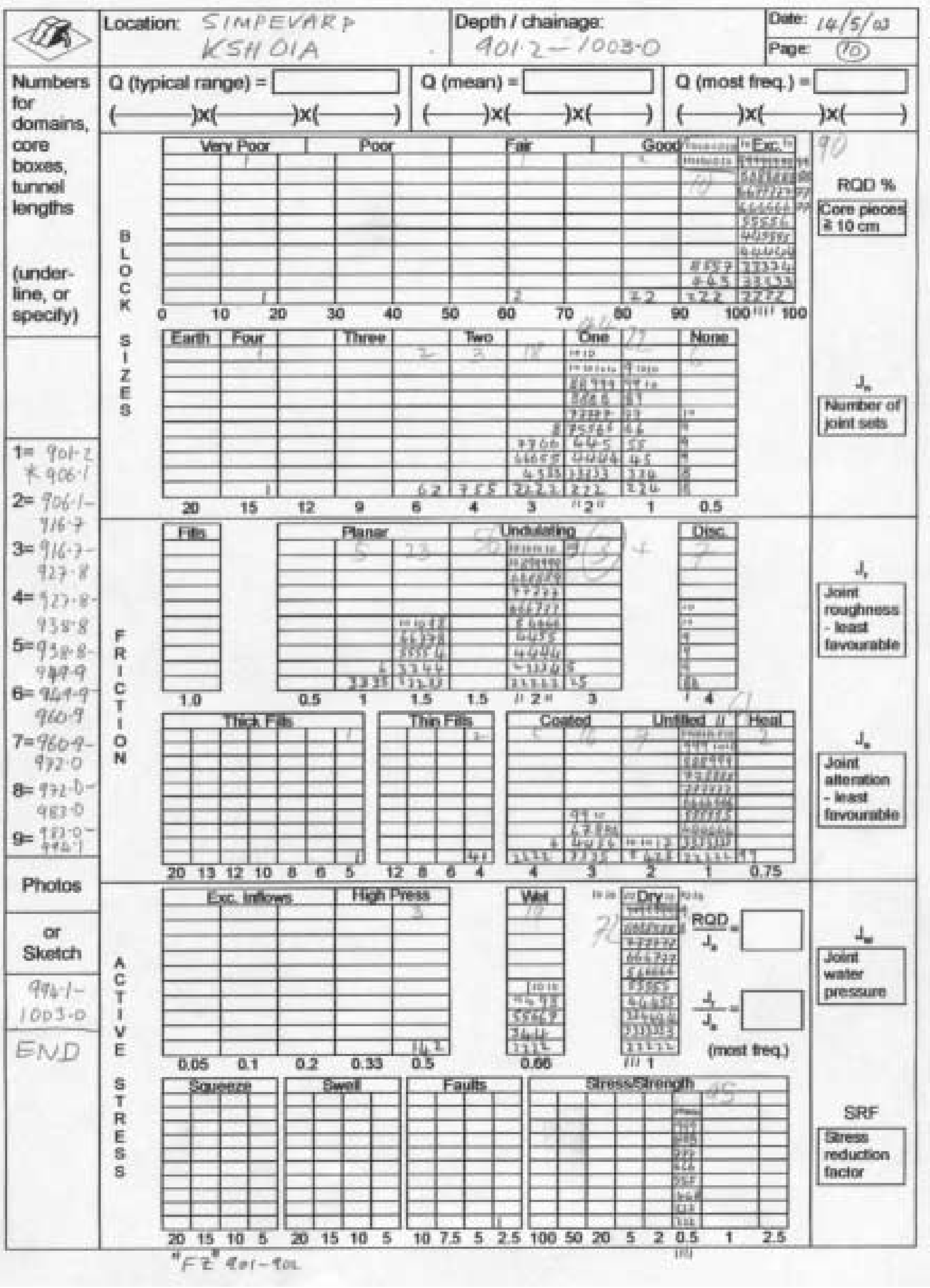
J_w — Joint water pressure

SRF — Stress reduction factor

$\frac{RQD}{J_n}$ = ☐

$\frac{J_r}{J_a}$ = ☐ (most freq.)

"FZ" 829·5 – 830 (crushed core, BH walls "intact")



Location: SIMPEVARP KSH01A

Depth / chainage: 901.2–1003.0

Date: 14/5/03

Page: 10

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

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

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

Numbers for domains, core boxes, tunnel lengths

(underline, or specify)

1= 901.2 – 906.1
2= 906.1– 916.7
3= 916.7– 927.8
4= 927.8– 938.8
5= 938.8– 949.9
6= 949.9– 960.9
7= 960.9– 972.0
8= 972.0– 983.0
9= 983.0– 994.1

Photos

or Sketch

994.1– 1003.0

END

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.)

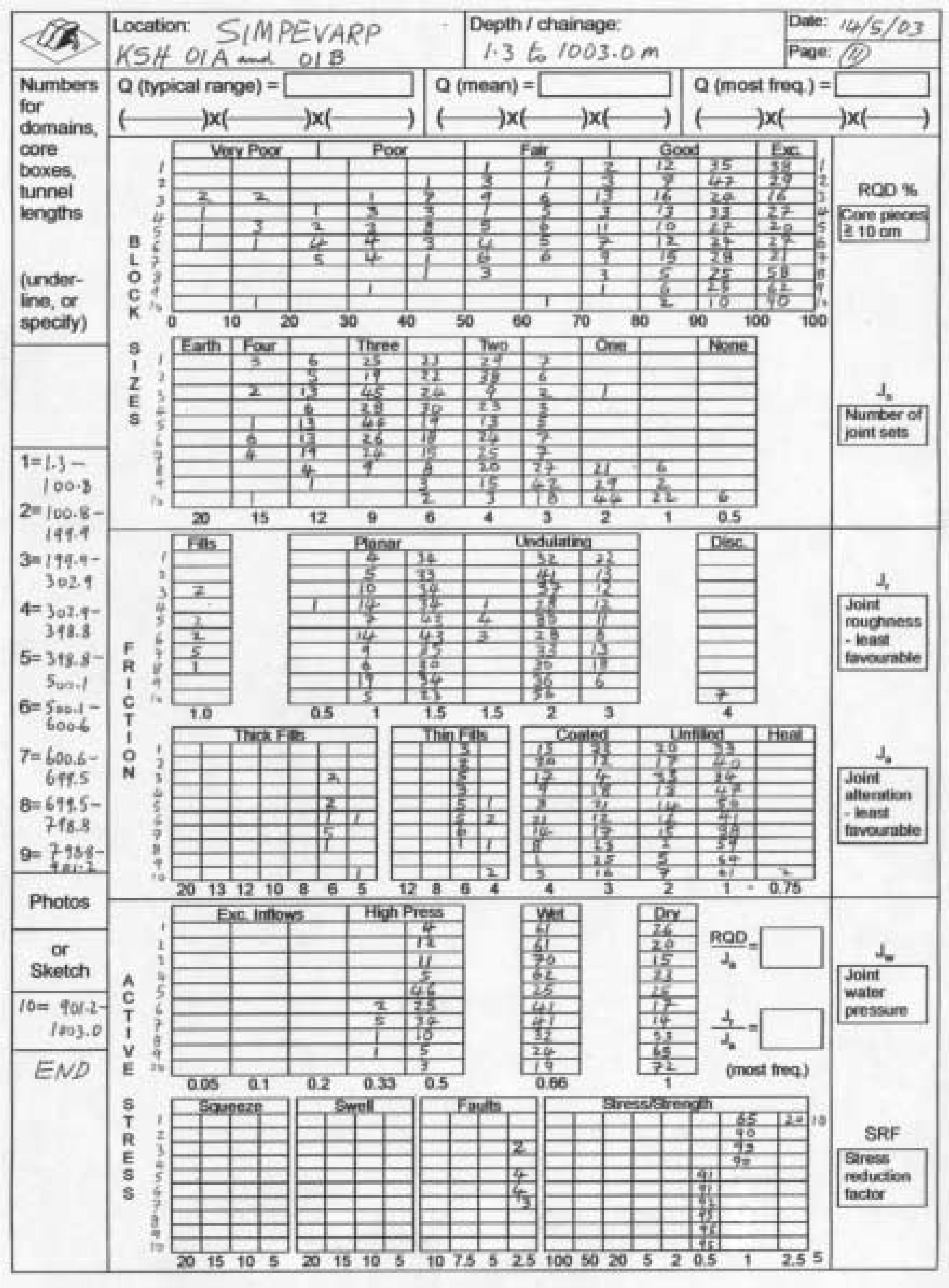
J_w
Joint water pressure

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

"FZ" 901–902



Location: SIMPEVARP KSH 01A and 01B

Depth / chainage: 1.3 to 1003.0 m

Date: 14/5/03

Page: (11)

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

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

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

Numbers for domains, core boxes, tunnel lengths (underline, or specify)

1= 1.3–100.8
2= 100.8–199.9
3= 199.9–302.9
4= 302.9–398.8
5= 398.8–500.1
6= 500.1–600.6
7= 600.6–699.5
8= 699.5–798.8
9= 798.8–901.2
10= 901.2–1003.0

Photos or Sketch

END

BLOCK — RQD % (Core pieces ≥ 10 cm)

	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100
	Very Poor		Poor			Fair			Good		Exc.
1						1	5	2	12	35	38
2					1	3	1	3	9	47	29
3	2	2		1	9	4	6	13	16	20	16
4	1		1	3	3	7	3	3	13	33	27
5	1	3	2	3	8	5	6	11	10	27	20
6	1	1	4	4	3	4	5	7	12	24	17
7			5	4	1	6	6	9	15	28	21
8					1	3		3	5	25	58
9				1				1	6	25	61
10		1					1		2	10	70

SIZES — J_n Number of joint sets

	Earth	Four		Three		Two		One		None
	20	15	12	9	6	4	3	2	1	0.5
1		5	6	25	33	29	7			
2			5	19	32	28	6			
3		2	13	45	24	9	2	1		
4			6	38	30	23	3			
5		1	13	46	19	13	5			
6		6	13	26	18	24	7			
7		4	19	24	15	25	7			
8			4	9	8	20	27	21	6	
9			1		3	15	42	29	2	
10		1			2	3	18	44	22	6

FRICTION — J_r Joint roughness - least favourable

	Fills	Planar			Undulating			Disc.
	1.0	0.5	1	1.5	1.5	2	3	4
1			4	36		32	22	
2			5	33		41	13	
3	2		10	34		37	12	
4		1	14	34	1	28	13	
5	2		9	43	4	35	11	
6	2		14	43	3	28	8	
7	5		9	25		32	13	
8	1		6	20		20	18	
9			19	34		36	6	
10			5	23		56		7

J_a Joint alteration - 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
1										3		13	33	30	33	
2										2		16	17	17	40	
3						2				2		12	4	33	34	
4										3		9	18	13	42	
5						2				5	1	9	21	14	50	
6						1	1			5	2	21	12	14	41	
7						5				6		16	17	15	38	
8						1				1	1	8	13	2	54	
9												1	15	5	64	
10							1				2	5	16	9	61	1

ACTIVE — J_w Joint water pressure

	Exc. Inflows			High Press		Wet	Dry
	0.05	0.1	0.2	0.33	0.5	0.66	1
1					4	61	26
2					13	61	20
3					11	75	15
4					5	62	23
5					46	25	26
6				2	25	41	17
7				5	39	41	19
8				1	10	32	53
9				1	5	24	65
10					3	19	72

RQD / J_n =

J_r / J_a =

(most freq.)

STRESS — SRF Stress reduction factor

	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	5 / 10
1																			65	2*	
2																			90		
3												2							93		
4																			98		
5												4						91			
6												4						91			
7												3						91			
8																		97			
9																		96			
10																		95			

Appendix B

Q-method of rock classification

Q-logging ratings for RQD, J_n , J_r , J_a , J_w and SRF
(Barton, 2002)

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

RQD is the % of competent drill-core sticks > 100 mm in length [1] in a selected domain

J_n = the rating for the number of joint sets (9 for 3 sets, 4 for 2 sets etc.) in the same domain

J_r = the rating for the roughness of the least favourable of these joint sets or filled discontinuities

J_a = the rating for the degree of alteration or clay filling of the least favourable joint set or filled discontinuity

J_w = the rating for the water inflow and pressure effects, which may cause outwash of discontinuity infillings

SRF = the rating for faulting, for strength/stress ratios in hard massive rocks, for squeezing or for swelling

RQD / J_n = relative block size (useful for distinguishing massive, rock-burst-prone rock)

J_r / J_a = relative frictional strength (of the least favourable joint set or filled discontinuity)

J_w / SRF = relative effects of water, faulting, strength/stress ratio, squeezing or swelling (an ‘active stress’ term)

An alternative combination of these three quotients in two groups only, has been found to give fundamental properties for describing the shear strength of rock masses – something close to ***the product of ‘c’ and ‘tan φ’***. By implication Q (and in particular Q_c) have units resembling ***MPa.***

Footnotes below the tables that follow, also give advice for ***site characterization*** ratings for the case of Jw and SRF, which ***must*** **not** be set to 1.0 and 1.0, as some authors have suggested. This destroys the intended multi-purposes of the Q-system, which has an entirely different structure compared to RMR.

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 $(3.0 \times J_n)$*.*

ii) For portals use $(2.0 \times J_n)$*.*

3. Joint roughness number		J_r
a) Rock-wall contact, and b) Rock-wall contact before 10 cm shear		
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°	8-12
c) No rock-wall contact when sheared (thick mineral fillings)			
KLM	Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition).	6-24°	6, 8, or 8-12
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/cm^2)**	**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 of rock mass when tunnel is excavated		
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.	10-5	0.3-0.4	0.5-2
L	Moderate slabbing after > 1 hour in **massive** rock.	5-3	0.5-0.65	5-50
M	Slabbing and rock burst after a few minutes in **massive** rock.	3-2	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 $5 \le \sigma_1/\sigma_3 \le 10$, reduce σ_c to $0.75\ \sigma_c$. When $\sigma_1/\sigma_3 > 10$, reduce σ_c to $0.5\ \sigma_c$, where σ_c = unconfined compression strength, σ_1 and σ_3 are the major and minor principal stresses, and σ_θ = 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.*

	c) Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure	σ_θ/σ_c	**SRF**
O	Mild squeezing rock pressure	1-5	5-10
P	Heavy squeezing rock pressure	> 5	10-20

Notes: vi) Cases of squeezing rock may occur for depth $H > 350\ Q^{1/3}$ according to Singh 1993 [34]. Rock mass compression strength can be estimated from $SIGMA_{cm} \approx 5\ \gamma\ Q_c^{1/3}$ (MPa) where γ = rock density in t/m^3, and $Q_c = Qx\sigma_c/100$, Barton, 2000 [29].

	d) Swelling rock: chemical swelling activity depending on presence of water	**SRF**
R	Mild swelling rock pressure	5-10
S	Heavy swelling rock pressure	10-15