International Progress Report

IPR-01-35

Äspö Hard Rock Laboratory

Results of Q-and RMR logging and tilt testing of cores from bore holes KA2511A, KAS02 and KA2598A at Äspö HRL

Axel Makurat
NGI

Fredrik Løset
NGI

July 2001

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

Äspö Hard Rock Laboratory

Report no.
IPR-01-35

No.
F102K

Author
Axel Makurat,
Fredrik Løset

Date
01-07-31

Checked by
Christer Andersson,
Rolf Christiansson

Date
01-10-25

Approved
Christer Svemar

Date
01-11-21

Äspö Hard Rock Laboratory

Results of Q-and RMR logging and tilt testing of cores from bore holes KA2511A, KAS02 and KA2598A at Äspö HRL

Axel Makurat
NGI

Fredrik Løset
NGI

July 2001

Keywords: Autoradiography, fault breccia, fracture, micro fractures, PMMA, porosity, porosity distributions, porosity profile, TRUE Block Scale, wall rock

SUMMARY

NGI has carried out tilt testing and Q- and RMR-logging of drill cores from the boreholes KA2511A, KAS02 and KA2598A at Äspö. Totally 1040m of cores have been logged and 58 tilt tests and 149 profiles have been carried out.

The results show that the rock mass quality are rather uniform throughout the cores and only a few narrow weakness zones have been found.

The results from the tilt tests are also rather uniform throughout the cores.

SAMMANFATTNING

NGI har på Äspölaboratoriet genomfört tiltförsök samt loggning av borrkärnor med avseende på Q- och RMR-klassificering. Totalt 1040 m kärna från borrhålen KA2511A, KAS02 och KA2598A har klassificerats. Vid klassificeringen har 58 tilt försök genomförts och 149 profiler av sprickytor tagits.

Bergmassans egenskaper har vid klassificeringen befunnits vara homogena med liten rumslig fördelning och endast ett fåtal smala spröda deformationszoner har påträffats i kärnmaterialet.

Även tilt försöken påvisar en liten rumslig fördelning av bergmassans egenskaper.

CONTENTS

TABLE OF TABLES

1 Introduction

NGI has carried out Q- and RMR logging and tilt testing on cores from three boreholes at Äspö. The work has been carried out by Axel Makurat and Fredrik Løset during the period 6-14 March 2001. The following cores were logged and index tested:

Table 1. Logged and tested cores

Borehole	**Q-logging (m)**	**RMR-logging (m)**	**Tilt tests**	**Profilings**
KA2511A	3,28-293,00	83,56-293,00	15	34
KAS02	160,92-612,95	160,92-612,95	23	53
KA2598A	2,34-300,77	2,34-300,77	20	62
Sum	**1040,18**	**959,90**	**58**	**149**

The results from this work are presented in tables and spreadsheets. In addition histograms have been prepared showing the variation of the Q-parameters in the various sections of the cores.

2 Q-logging of drill cores

The Q-method is designed for description of the rock mass quality in tunnels, but can also be used for logging of drill cores. From drill cores, however, all the Q-parameters can not be determined exactly, and the Q-values obtained from cores may therefore differ somewhat from the real Q-values in the rock mass.

Before the logging starts, a longer section of the cores should be inspected and divided into suitable logging units. A logging unit should have a rather uniform rock mass quality. To get realistic Q-values, it is generally necessary to have a core with a length of some metres, and each logging unit should therefore be some metres long. For marked weakness zones (faults and fracture zones) shorter units may be necessary for detailed description. For the rather uniform Äspö cores it was convenient to use a core box as a logging unit, since each box usually contained 6 to 9m of cores. Only in case of distinct weakness zones, Q-values for shorter intervals were determined. Even in such small units as a core box there may be some variation in the parameter values, and the values for the parameters RQD, J_r and J_a were therefore given for each metre or for each section in the core box, which is usually about one meter long. The parameter J_n usually has to be evaluated for the whole logging unit, but often it is possible to describe a variation through a unit.

Tables showing previously logged RQD-values for each core metre were obtained from SKB and were used as guide during NGI's logging campaign. Since the logged cores have a rather small diameter (about 42mm) fracture lengths were usually rahter short. Consequently it was difficult to evaluate if the fracture was planar or undulating, and some of the J_r-values are therefore uncertain. In some cases there was also some question concerning the J_a –value, since clay minerals may have been washed away during drilling. The fractures usually have a coating of chlorite, epidote and calcite, and this coating usually seemed to be intact. The J_a-values are therefore considered as reliable for most cases. According to SKB the values for J_w and SRF shall be set to 1 when calculating the Q-value. This means that the calculated Q-values will not always correspond to the in situ Q-values at the actual depth since J_w and SRF may vary with the depth.

The Q-values from the different logging units are given in tables (see Appendix A). Calculation of Q-values was carried out by use of the mean RQD-value for each unit. For J_n, J_r, and J_a a more unfavourable value than the most frequent value is usually used. If the most frequent values for these three parameters were used in the calculation, the Q-values would generally be too high. For each parameter an evaluation similar to what is done during tunnel mapping is done, and a parameter value, according to the Q-parameter table, is then selected. This usually means that the most unfavourable value is selected, if this value is observed several times in the logging unit. If an unfavourable value only occurs sporadically, the most frequent value is usually selected.

The variation in the Q-parameters is shown by means of histograms (see figures in Appendix B). In each histogram several logging units with about the same rock mass quality have been combined to larger units. Each figure gives a review of a section that typically is 20-30m long. Separate histograms are given for weakness zones. The figures contain a calculation of the minimum-, maximum-, mean- and most frequent Q-values. The minimum Q-value is calculated by using the most unfavourable value for each parameter, and for the maximum Q-value the most favourable parameter values are used. These Q-values will only occur if all the most unfavourable or the most favourable parameter values occur at the same position in the core, which not necessarily will be the case. The mean Q-value is calculated by using the mean values of the various parameters, and for the most frequent Q-value the most frequent values observed in the unit are used. Experience shows that the real Q-value for a logging unit often will be lower than the so-called mean value in the histograms. However, the values in the histograms are important information, demonstrating parameter variation in various sections of core. The various histograms can easily be linked so that longer sections of a borehole can be compiled.

In addition to the Q-parameters the histograms also show the degree of weathering in the rock mass, the fracture frequency, i.e. number of fractures per meter and fracture spacing for the two most prominent fracture sets. During the logging the real orientation of fractures was not known, but the various fractures were classified according to their angle of intersection with the core in the following way:

Set 1: Angle of intersection 60-90^o
Set 2: Angle of intersection 0-30^o
Set 3: Angle of intersection 30-60^o

This principle is used for the three boreholes, but since the boreholes have different orientation, the fracture sets may not be the same from borehole to borehole.

The histograms also contain results from the tilt tests and the profiles and values of JRC, JCS, Schmidthammer readings, ó$_c$ and roughness amplitudes are also shown.

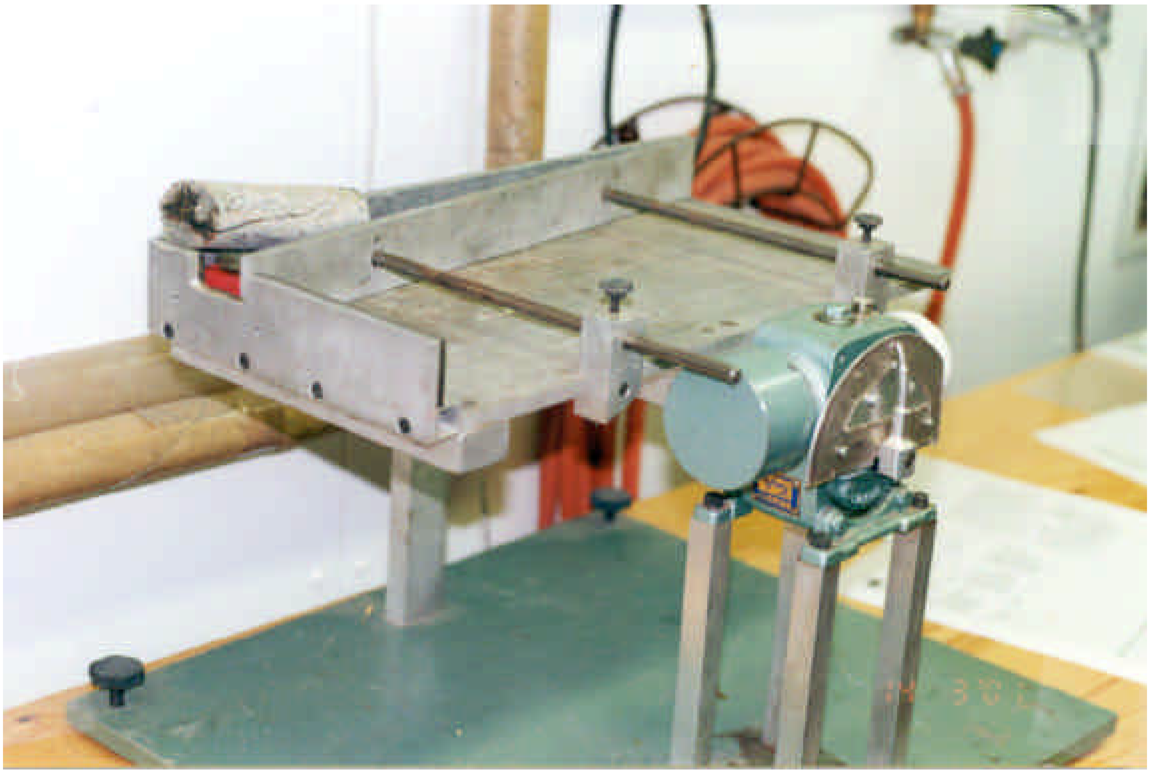
3 RMR-logging

The RMR-values are calculated for the same units as the Q-values, i.e. usually for each core box, see tables in Appendix A. The uniaxial compressive strength of the rock is the base for one of the parameters in the RMR-system. Since most of the rocks seem to have about the same strength, the parameter value 13 has generally been used in the calculation of RMR. This corresponds to a uniaxial compressive strength of about 170 MPa. This is the mean value for the Äspö diorite found by laboratory testing carried out by SKB. The same tests show somewhat higher values for the granite (more than 200 MPa). The Schmidthammer readings carried out during the tilt testing often give strength values of about 150 MPa. Since core diameter is small, these results are expected to be on the lower side since the clamping of the small cores may in some cases be difficult.

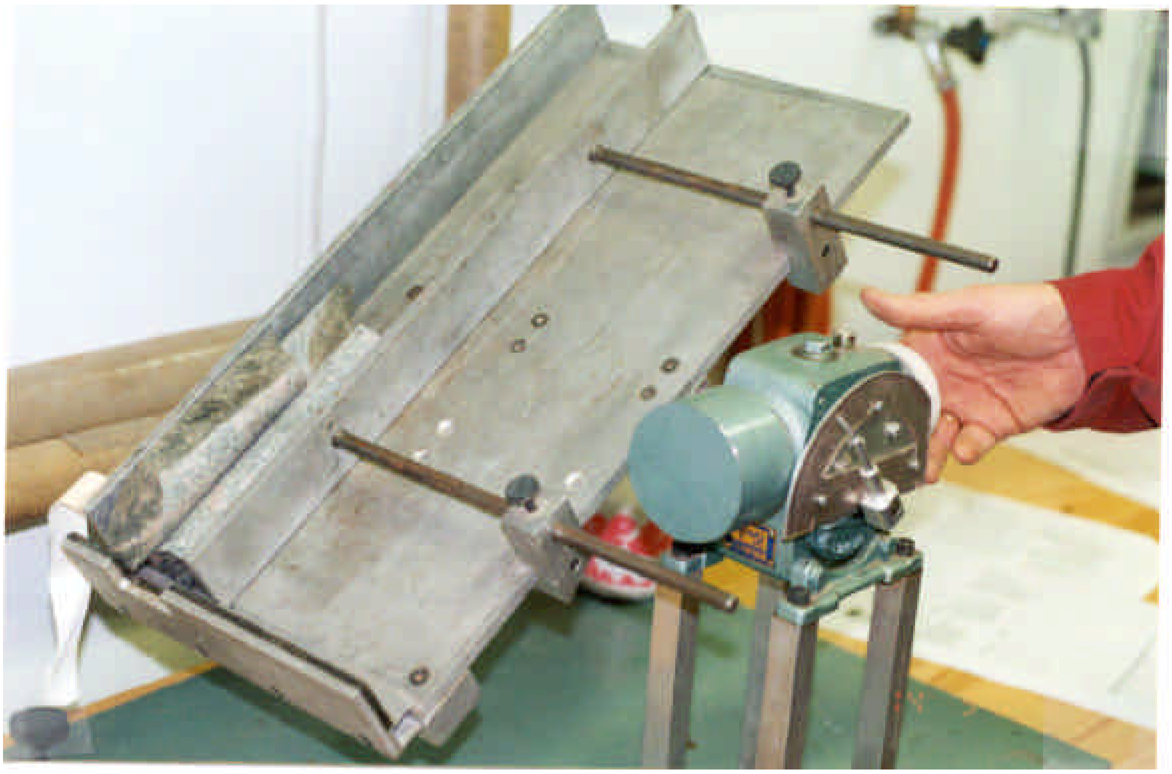
When calculating the RMR-values the same RQD-values as for Q have been used. An evaluation of the discontinuity length is not possible from drill cores, and therefore the value 1 has consequently been used for this parameter. This value corresponds to a discontinuity length of 10-20m. For most of the other parameters rather reliable values were found during logging. As instructed by SKB the parameter value for groundwater was set to 15 and for discontinuity orientation to 0 for the calculation of the RMR-values.

4 Tilt testing and profiling

The JRC and JCS-values of fractures are determined by tilt testing. By means of the simple tilt apparatus the tilt angle ($\hat{o}_a$) is measured (see Photograph No. 1). For tilting, a sample containing both faces of a fracture is needed. To prepare the sample usually sawing is necessary. The sample is then fixed to the tilt apparatus and tilted. At least three tilts are carried out on each sample and the tilt angle should not vary more than 3^o in these tests. However, in some cases the sample changes during the testing, for example fracture coating may be removed, and therefore variation of more than 3^o may (in some cases) be accepted. The same procedure is used for determining $\hat{o}_b$ which is the tilt angle core to core (see Photograph No. 2).



Photograph No. 1. Tilt apparatus



Photograph No. 2. Core to core tilting

JCS is calculated from Schmidthammer readings on the fracture face (r). Ten readings shall be taken, and the mean value of the five highest is used for the JCS-calculation. As a base for the determination of the compressive strength of the rock ($ó_c$), Scmidthammer reading on a fresh core near the fracture (R) is used. Ten readings are taken, and the mean value of the five highest is used for the calculation of JCS.

The weight of the tilting block and the rock density are measured, and the fracture surface area is measured with of a planimeter.

Profiling of the tilt tested fractures is carried out, and in addition, profiling is carried out on a number of fractures that are not tilt tested. The profiling is carried out by means of a profilometer (see Photograph No. 3), and the profiles are drawn on a paper by pulling a pencil along the edge of the profilometer. For each fracture three parallel profiles are drawn; one along the centre of the sample and one to the left and one to the right of the centre line (see Fig 1). From the profile the roughness amplitude (a) and profile length (L) are measured. As base for the estimation of JRC the mean a- and L-values from the three profiles are used.

JRC is calculated from the tilt tests, and estimated from the profiles. This can be done by plotting the roughness amplitude (a) versus the profile length (L) into the diagram shown in Fig 2. However, this diagram can only be used for profiles longer than 10 cm. For profiles shorter than 10cm the JRC-values have been estimated by comparing the profiles with the profiles shown in Fig. 3.

A few density measurements of the rock were carried out during tilt testing and the results were in the range 2,65-2,80 g/cm^3. In the calculations 2,70 g/cm^3 has been used for all samples.

Because of the small core diameter, it was rather difficult to find good samples for tilt testing. This is specifically valid for Fracture Set 1 and partly Set 3. The majority of the tilt tests are therefore from Fracture set 2. In addition many fractures were very rough and tilt testing was impossible because toppling of the top block occurred before sliding.

Photograph No. 3. Profiling by the use of profilometer

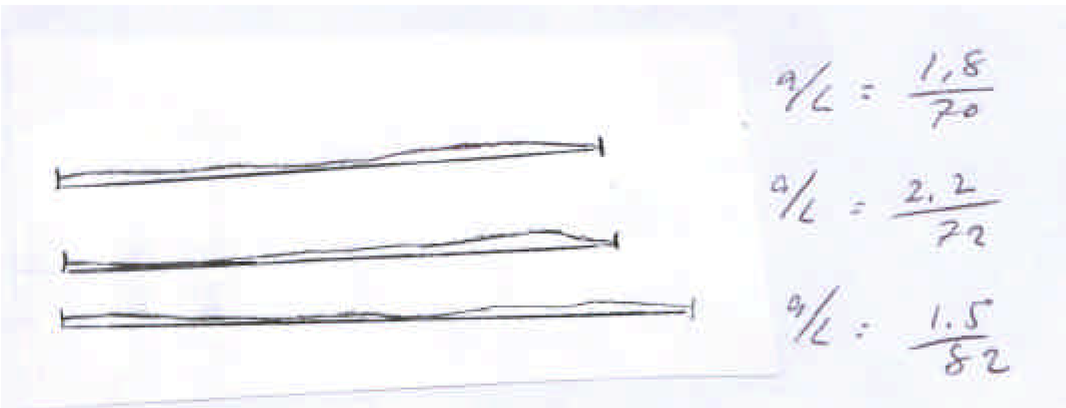


Figure 1. Fracture profiles

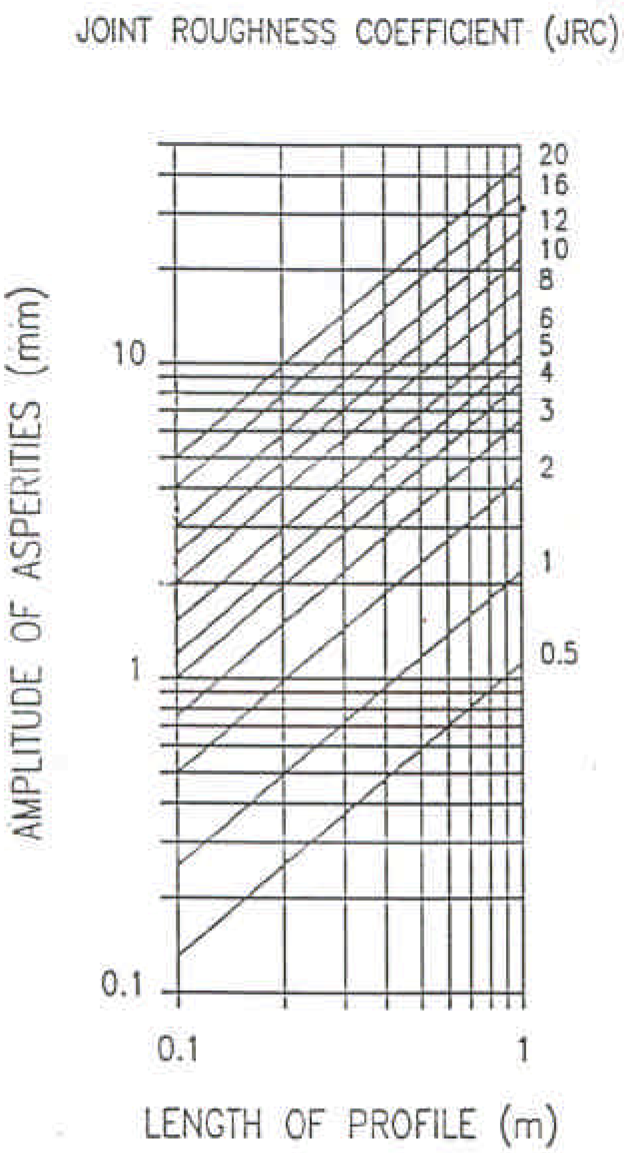


Figure 2. Diagram for determination of JRC from roughness amplitude and profile length

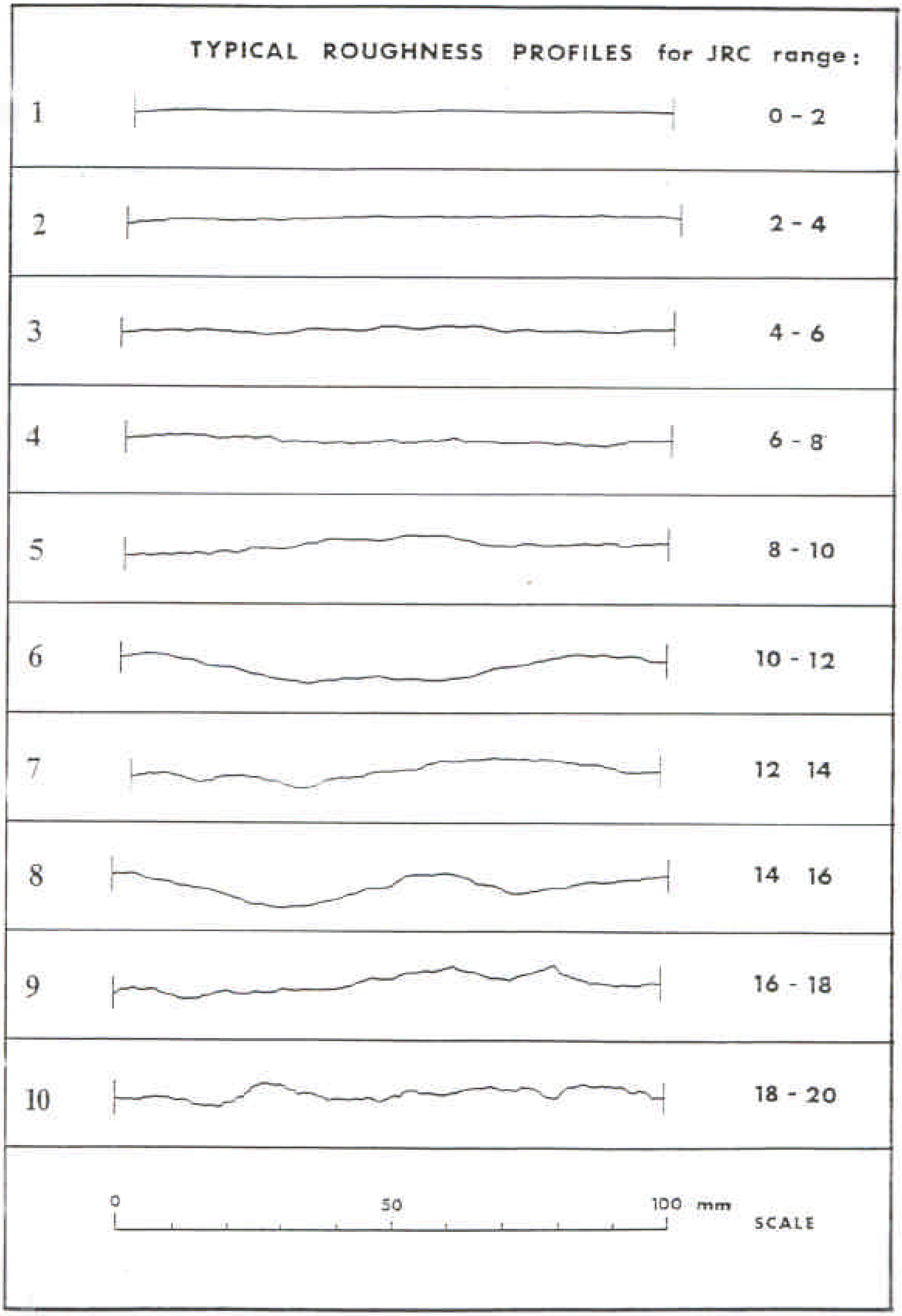


Figure 3. Roughness profiles for JRC rage

5 Results from the logging and the tilt testing

5.1 General

All together 1040 m of core material has been logged and 58 tilt tests and 149 profiles have been carried out. The rock type is rather similar in the three boreholes. The rocks can be classified as diorite, granite and amphibolite, but since geological logging of the core has been carried out by SKB, no detailed geological description has been made by NGI.

The rock mass qualities are also rather similar in the three boreholes and only narrow weakness zones were observed. The mean-, min-, and max-, values below are based on the tables in Appendix A:

KA2511A:	Q_{mean} =	18,94	Q_{min} = 3,9	Q_{max} = 50,00
KAS02:	Q_{mean} =	32,80	Q_{min} = 1,9	Q_{max} = 75,00
KA2598A:	Q_{mean} =	27,58	Q_{min} = 0,3	Q_{max} = 150,00

As mentioned before, the fractures have been classified in three sets according to the angle of intersection with the core. Each set may however consist of fractures with different dip directions (see Photograph No. 4).

The typical fracture coating consists of chlorite, epidote or calcite. Chlorite is the most common mineral, but all three minerals occur on some of the fractures, (see Photograph No. 5).

The results of the Q- and RMR-logging are given in the tables in Appendix A, and the results from the tilt testing and profiling are found in the tables in Appendix C.

Histograms showing the variation in parameter values from the Q-logging and results from the tilt testing and profiling is found in Appendix 1. In Appendix 2 the spreadsheets with the input and output data from the tilt testing and profiling are found.

Photograph No 4. Fractures of Set 2 with different dip direction

Photograph No. 5. Fracture with coating of chlorite and some calcite

5.2 Borehole KA2511A

The section 3,28-293m has been logged.
A summary of the Q- and RMR-logging is found in Table 2. The complete results of this logging is found in Appendix A and B. The first 80 m of borehole KA2511A was not logged concerning RMR because SKB found out that RMR-logging should be carried out after the logging had started.

Table 2. Q- and RMR-values, Borehole KA2511A

Depth from (m)	Depth to (m)	Q	RMR
3,28	9,7	12,3	Not logged
9,7	16,39	25,0	Not logged
16,29	23,14	16,3	Not logged
23,14	29,85	16,0	Not logged
29,85	36,62	50,0	Not logged
36,62	43,38	24,0	Not logged
43,32	50,04	10,6	Not logged
50,04	56,86	10,6	Not logged
56,86	63,35	4,5	Not logged
63,35	70,14	5,1	Not logged
70,14	76,7	11,9	Not logged
76,7	83,56	11,9	Not logged
83,56	90,26	36,8	76
90,26	97	15,3	74
97	103,8	37,5	81
103,8	110,32	3,9	69
110,32	117	23,5	75
117	123,79	14,7	74
123,79	130,53	24,0	77
130,53	137,2	35,6	78
137,2	143,98	24,8	80
143,98	150,62	10,1	70
150,62	157,41	25,0	79
157,41	164,23	12,4	79
164,23	171	8,2	78
171	177,65	16,3	78
177,65	184,29	10,9	77
184,29	190,98	7,8	72
190,98	197,73	25,0	81
197,73	204,36	24,8	77
204,36	211,33	24,0	78
211,33	218,09	23,8	78
218,09	224,88	15,8	78
224,88	231,83	22,5	75

Depth from (m)	Depth to (m)	Q	RMR
231,83	238,54	37,5	80
238,54	245,29	11,6	74
245,29	250	24,5	76
250	258,4	4,4	61
258,4	265,1	23,3	76
265,1	271,81	16,0	76
271,81	278,29	23,5	75
278,29	285,03	24,3	75
285,03	293	9,0	72

From this borehole 15 tilt tests and 34 profilings have been carried out. The results are shown in Table 3. Complete data from tilt tests and profiling are found in Appendix C.

Table 3. Results from tilt test and profiling, Borehole KA2511A

Depth	Fracture set Set No	Ô$_r$ (^{o})	JRC$_o$	JCS$_o$ MPa
21,85	3	28,1	4,42	109,25
42,05	3	30,5	6,03	68,83
44,4	1	28,3	5,78	67,75
49,75	2	25,1	6,64	57,85
108,07	3	33,0	4,74	163,98
111,59	2	26,6	6,35	74,23
147,25	3	33,3	3,79	90,95
150	2	30,5	5,61	103,48
186,12	2	30,1	6,06	67,59
186,7	3	27,9	4,33	65,59
216,33	3	30,4	3,75	102,31
242,58	2	23,1	0,98	53,71
259,1	2	26,4	5,19	101,81
268,3	2	23,3	6,19	80,82
291,14	2	24,3	5,74	57,27
8,25	1		*3,75*	
8,29	1		*5.45*	
15,83	3		*5.62*	
29,4	3		*7,37*	
36,49	1		*7,04*	
49,75	2		*7,68*	
54,92	3		*10,62*	
59,85	3		*3.84*	
69,55	2		*8.76*	
70,8	3		*4.73*	
78,37	2		*5,79*	

Depth	Fracture set Set No	Ô$_r$ (°)	JRC$_o$	JCS$_o$ MPa
84,1	1		*6.99*	
96,7	3		*6,45*	
102,09	3		*5.25*	
117,3	2		*11,23*	
128,97	3		*7.31*	
133,9	3		*4,67*	
143,56	2		*9,79*	
155,3	2		*8,04*	
157,46	3		*3,81*	
166,65	1		*5.44*	
171,76	3		*10.53*	
178,12	3		*7,29*	
192,23	3		*11,79*	
200,45	1		*9,09*	
208,18	2		*7.84*	
216,33	3		*5,70*	
221,48	3		*10,49*	
226,82	3		*6,44*	
243,76	3		*8.13*	
250,12	3		*7,92*	
252,74	2		*5,76*	
276,71	3		*5,42*	
278,6	2		*12.57*	

A summary of the tilt tests and profiling is given in Table 4.

Table 4. Mean JRC$_o$ - and JCS$_o$-values, Borehole KAS02

Fracture set	JRCo (tilt)	Number (tilt)	JRC$_o$ (profile)	Number (profiles)	JCS$_o$ MPa
Set 1	5,8	1	6.2	6	67,75
Set 2	5.3	8	8.6	9	74,59
Set 3	4,5	6	7.0	19	100,15
Total/mean	**5.0**	**15**	**7.3**	**34**	**84,36**

5.3 Borehole KAS02

The section 160.92 - 612.95m has been logged.
A summary of the Q- and RMR-logging is found in Table 5. The complete results of the logging is found in Appendices A and B.

Table 5. Q- and RMR-values, Borehole KAS02

Depth from (m)	Depth to (m)	Q	RMR
160,92	168,5	50,0	80
168,5	177,85	37,1	80
177,85	186,51	24,5	80
186,51	195,1	14,7	72
195,1	203,33	16,3	77
203,33	211,91	35,6	77
211,91	220,51	35,3	77
220,51	229,07	15,2	74
229,07	237,72	36,8	80
237,72	246,34	24,0	77
246,34	254,93	36,8	80
254,93	263,5	46,5	78
263,5	272,84	23,8	77
272,84	280,78	35,6	78
280,78	289,55	25,0	80
289,55	298,6	37,1	80
298,6	306,96	23,8	79
306,96	313	22,5	77
313	317	1,9	56
317	323,9	23,3	76
323,9	332,3	24,0	77
332,3	340,35	24,3	78
340,35	348,64	37,5	79
348,64	356,74	19,5	75
356,74	364,9	7,1	67
364,8	373,36	22,8	74
373,36	375,45	2,1	57
375,45	381,93	35,6	78
381,93	390,5	36,4	78
390,5	398,99	37,1	80
398,99	407,43	13,5	72
407,43	415,57	36,8	81
415,57	424,12	34,5	79
424,12	432,68	36,8	81
432,68	441,13	49,5	81
441,13	449,74	36,8	81
449,74	458,33	36,0	79
458,33	466,96	24,3	79
466,96	475,5	37,5	79
475,5	483,95	11,1	73
483,95	492,54	15,5	76
492,54	501,24	74,3	84

Depth from (m)	Depth to (m)	Q	RMR
501,24	509,85	49,0	82
509,85	518,25	37,1	80
518,25	526,93	75,0	83
526,93	535,55	46,5	81
535,55	544,21	24,5	80
544,21	552,88	36,8	82
552,88	561,46	14,7	73
561,46	564,46	6,3	70
564,46	569,85	37,5	79
569,85	578,45	50,0	83
578,45	587,13	75,0	85
587,13	595,63	75,0	84
595,63	604,16	75,0	84
604,16	612,95	16,2	76

From this borehole 23 tilt tests and 53 profilings have been carried out. The results are shown in Table 6. Complete data from tilt testing and profiling are found in Appendix C.

Table 6. Results from tilt test and profiling, Borehole KAS02

Depth	Fracture set Set No	$\hat{O}_r$ (^{o})	JRC_o	JCS_o MPa
170,05	2	26,09	6,88	86,94
199,6	2	25,21	5,55	47,14
237,12	2	26,91	3,80	105,85
244,55	2	21,07	8,67	68,66
268,52	3	28,29	4,42	61,41
305,74	2	29,90	6,93	89,59
329,44	2	34,00	3,67	79,84
360,16	2	32,00	3,22	135,69
361,55	2	32,96	3,88	134,94
403,06	3	26,96	3,92	68,02
406,39	3	31,41	5,00	57,90
414,5	3	35,00	4,12	114,73
419,95	2	30,52	5,20	102,56
455,06	2	28,91	6,51	84,86
476,42	2	34,00	5,30	140,32
491,1	2	30,00	*6,03*	151,49
513,05	3	31,06	*5,75*	67,62
543,14	2	25,87	*6,42*	67,21
543,87	2	32,00	*3,62*	137,47
557,25	2	27,87	*4,56*	89,29
565,18	2	34,50	*4,38*	116,71

Depth	Fracture set Set No	$\hat{O}_r$ (°)	JRC_o	JCS_o MPa
578,3	2	30,99	*5,63*	134,78
609,77	2	32,21	*3,59*	109,06
163,37	2		*10,18*	
176,68	2		*6,74*	
192,45	2		*17,19*	
206,8	2		*9,27*	
221,75	2		*13,33*	
222,7	2		*5,96*	
246,6	2		*7,27*	
261,92	1		*5,33*	
273,19	3		*5,39*	
287,25	2		*9,31*	
297,66	2		*9,40*	
311,92	2		*8,26*	
321,27	2		*9,83*	
332,65	2		*5,75*	
346,6	2		*9,79*	
353,47	2		*7,87*	
360,16	2		*4,13*	
373,26	2		*5,92*	
377,64	2		*9,24*	
382,12	3		*7,11*	
396,02	2		*7,52*	
398,53	2		*5,71*	
398,55	2		*4,88*	
407,89	3		*7,21*	
423,49	3		*7,07*	
425,02	3		*7,18*	
435,41	3		*8,45*	
436,73	2		9,92	
439,25	3		8,37	
454,8	2		12,67	
455,66	2		13,03	
465,84	3		7,41	
470,84	2		14,32	
471,03	3		7,31	
482,38	2		11,76	
485,83	3		5,57	
486,74	3		4,70	
494,42	3		6,99	
507,07	3		7,50	
511	3		7,23	

Depth	Fracture set Set No	$\hat{O}_r$ (^{o})	JRC_o	JCS_o MPa
517,65	2		12,46	
521,92	2		7,57	
529,78	2		5,98	
547,61	2		6,76	
558,62	2		9,96	
559,48	2		7,62	
563,68	2		9,56	
574,04	3		8,52	
578,3	2		9,11	
578,65	2		5,73	
580,96	2		10,27	
592,15	2		7,52	
611,52	2		4,93	

Table 7. Mean JRC_o - and JCS_o-values, Borehole KAS02

Fracture set	JRC_o (tilt)	Number (tilt)	JRCo (profile)	Number (profiles)	JCS_o MPa
Set 1		0	5,3	1	
Set 2	5,2	18	8.8	37	104.6
Set 3	4.6	5	7.1	15	80.2
Total	5.5	23	8.2	53	99.3

5.4 Borehole KA2598A

The section 2.34 – 300.77m has been logged.
A summary of the Q- and RMR-logging is found in Table 8. The complete results of the logging is found in Appendix A and B.

Table 8. Q- and RMR-values, Borehole KA2598A

Depth from (m)	Depth to (m)	Q	RMR
2,34	9,06	24,5	79
9,06	15,82	24,8	79
15,82	22,58	24,5	80
22,58	29,07	24,8	80
29,07	35,75	24,5	80
35,75	42,65	24,8	79
42,65	49,5	36,8	77
49,5	56,3	7,6	72

Depth from (m)	Depth to (m)	Q	RMR
56,3	63,05	11,3	74
63,05	70,77	7,6	73
70,77	72,95	0,3	36
72,95	76,2	7,3	71
76,2	82,84	11,4	72
82,84	89,57	18,0	78
89,57	96,3	15,8	76
96,3	102,84	15,8	75
102,84	109,59	23,0	76
109,59	116,38	15,8	76
116,38	123,14	23,0	74
123,14	129,94	24,3	76
129,94	136,66	22,8	74
136,66	143,49	37,1	80
143,49	150,27	36,4	80
150,27	157,02	17,1	76
157,02	163,83	36,0	80
163,83	170,56	24,3	77
170,56	177,29	37,1	79
177,29	184,07	37,1	81
184,07	190,88	49,5	84
190,88	197,73	36,0	79
197,73	204,56	49,5	83
204,56	211,36	36,0	78
211,36	217,94	14,8	73
217,94	224,75	12,1	77
224,75	231,43	4,6	65
231,43	238,24	24,5	80
238,24	245,09	17,8	77
245,09	251,96	150,0	91
251,96	258,73	37,5	86
258,73	265,52	50,0	86
265,52	272,08	18,8	85
272,08	278,58	18,8	84
278,58	285,39	49,5	83
285,39	292,16	50,0	83
292,16	300,77	8,3	81

From this borehole 20 tilt tests and 62 profilings have been carried out. The results are shown in Table 9. Complete data from tilt tests and profiling are found in Appendix C.

Table 9. Results from tilt test and profiling, Borehole KA2598A

Depth	Fracture set Set No	$\hat{O}_r$ (°)	JRC_o	JCS_o MPa
15,45	2	25,79	2,85	55,84
25,3	2	32,95	3,64	81,10
34,08	2	35,50	4,27	97,22
42,23	2	31,79	6,11	124,33
56,3	3	29,32	5,03	159,53
59,75	2	28,86	5,15	97,78
96,92	2	29,99	5,90	102,99
112,8	3	30,77	4,66	112,65
124,72	2	29,62	3,82	72,00
134,1	3	26,92	3,92	50,20
145,05	2	34,13	3,65	103,51
168,45	3	28,56	3,53	72,99
172,07	2	33,00	4,54	147,67
198,82	2	31,50	4,90	133,53
212,65	2	31,54	5,49	106,66
219,32	3	30,03	*4,56*	85,66
268,63	3	25,84	*6,54*	54,78
270	2	28,72	*3,77*	68,44
296,69	2	26,20	*7,65*	47,77
296,82	2	17,80	*6,36*	60,20
3,2	2		*7,82*	
5,77	2		*3,78*	
11,66	2		*5,68*	
17,33	2		*17,49*	
21,8	2		*5,49*	
26,18	2		*17,17*	
32,4	2		*13,53*	
43,53	2		*5,79*	
59,07	2		*6,06*	
66,84	3		*2,85*	
74,92	2		*2,93*	
82,45	2		*6,32*	
85,4	1		*3,72*	
87,6	2		*16,82*	
94,88	2		*4,93*	
95,6	2		*12,30*	
97,62	2		*17,53*	
104,42	3		*5,58*	
107,7	2		*10,32*	
109,9	2		*4,03*	

Depth	Fracture set Set No	Ô$_r$ (^{o})	JRC$_o$	JCS$_o$ MPa
121,25	2		*7,79*	
123,32	3		*3,78*	
128,85	1		*4,64*	
134,22	1		*2,89*	
137,35	3		*7,09*	
138,7	2		*8,68*	
149,93	3		*7,39*	
153,42	3		*3,82*	
155,95	2		*4,80*	
158,07	2		9,86	
161,35	3		8,97	
168	2		16,59	
171,45	3		6,56	
181,17	3		3,72	
183,39	2		5,63	
185,49	2		9,23	
190,46	3		3,85	
192,26	3		5,53	
197,45	2		9,79	
202,52	1		5,47	
206,12	2		9,92	
211,2	3		7,07	
217,35	2		7,42	
218,4	2		9,44	
226,85	2		23,08	
231,15	2		3,87	
231,3	2		3,90	
233,2	2		7,47	
238,62	3		5,63	
241,05	2		19,67	
246,36	2		7,66	
252,21	3		3,82	
252,46	2		6,88	
259,75	2		17,14	
261,1	3		7,25	
276,14	3		7,29	
276,4	2		10,37	
284,33	2		7,50	
286,25	2		9,28	
287,54	2		6,93	
290,45	2		7,73	
292,66	2		8,42	

Table 10. Mean JRC_o - and JCS_o-values, Borehole KA2598A

Fracture set	JRC_{tilt}	Number (tilt)	$JRC_{profile}$	Number (profiles)	JCS_o MPa
Set 1		0	4,2	4	
Set 2	4,7	14	9.4	42	92,79
Set 3	4,7	6	5.6	16	89,30
Total	4.7	20	8.1	62	91,74

6 Evaluation of the results

The rock mass qualities are rather uniform in the cores and only a few weakness zones were observed. Since all the parameters can not be logged from the cores, the in situ Q- and RMR-values may be somewhat different from the logged values.

The joint faces are rather similar concerning mineralisation, and the tilt tests show rather uniform JRC – and JCS values. Because of the small core diameter the results are associated with some uncertainty since the standard length for such tests is 10cm. Tilting of samples with high JRC-values is often impossible because toppling takes place before sliding. This is one of the reasons why samples where only profiling has been carried out, generally show higher JRC- values compared to the values from tilt testing. This means that the sample selection for tilt testing is less representative than the sample selection for profiling, since the rougher fractures are not included in the tilt selection.

As mentioned before, the JRC-values can be estimated from the profiles by help of the diagrams shown in Fig. 2 and 3. Profiling has also been carried out for the tilt test samples, and in the Tables 11-14 the JRC-values from tilt testing have been compared with the JRC-values estimated from the profiles. As can be seen, the differences are rather small. This indicates that JRC estimation from profiles can be used as a reasonable reliable method if tilt test data are not available. However, while the JRC-values from tilt tests are directly measured, the JRC-values from the profiles are based on a visual estimation and threrefore strongly dependent on the observers experience.

Table 11. KA2511A JRC from tilt and profiles

Depth	JRC tilt	JRC profile
21,85	4,4	3,9
42,05	6,0	3,5
44,4	5,8	6,0
49,75	6,6	4,9
108,07	4,7	4,9
111,59	6,4	6,7
147,25	3,8	4,3
150	5,6	5,5
186,12	6,1	3,5
186,7	4,3	4,8
216,33	3,8	3,4
242,58	1,0	1,9
259,1	5,2	6,4
268,3	6,2	6,0
291,14	5,7	7,7
Mean	**5,0**	**4,9**

Table 12. KAS02 JRC from tilt and profiles

Depth	JRC tilt	JRC profiles
178,05	6,9	6,6
199,6	5,6	5,0
237,12	3,8	4,3
244,55	8,7	6,2
268,52	4,4	6,3
305,74	6,9	7,5
329,44	3,7	4,3
360,16	3,2	4,3
361,55	3,9	3,6
403,06	3,9	6,0
406,39	5,0	3,5
414,5	4,1	6,1
419,95	5,2	7,9
455,06	6,5	7,9
476,42	5,3	7,6
491,1	6,0	8,7
513,05	5,7	5,6
543,14	6,4	2,7
543,87	4,6	2,9
557,25	4,6	6,5
565,18	4,4	3,6
578,3	5,6	4,9
609,77	3,6	6,5
Mean	**5,1**	**5,6**

Table 13. KA2598A JRC from tilt and profiles

Depth	JRC tilt	JRC profile
14,45	2,8	5,9
25,3	3,6	6,3
34,08	4,3	6,6
42,23	6,1	5,1
56,3	5,0	6,5
59,75	5,1	5,5
96,92	5,9	6,3
112,8	4,7	5,8
124,72	3,8	2,9
134,1	3,9	3,8
145,05	3,6	3,9
168,45	3,5	4,7
172,07	4,5	5,8
198,82	4,9	8,6
212,65	5,5	7,9
219,32	4,6	9,1
268,63	6,5	4,7
270	3,8	3,9
296,69	7,7	8,1
296,82	6,4	8,1
Mean	**4,8**	**6,0**

Table 14. JRC from tilt and profiles

Borehole	JRC tilt	JRC profile
KA2511A	5,0	4,9
KAS02	5,1	5,6
KA2598A	4,8	6,0
Mean	**5,0**	**5,6**