2. INTRODUCTION TO THE Q-SYSTEM OF ROCK MASS CLASSIFICATION

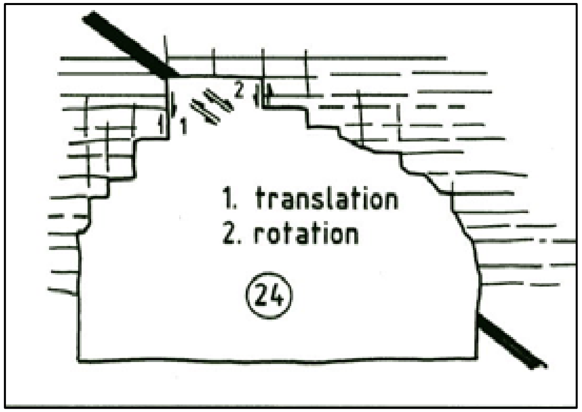
??ORIGINAL MOTIVATION FOR DEVELOPING A QUANTITATIVE ROCK MASS DESCRIPTION ??

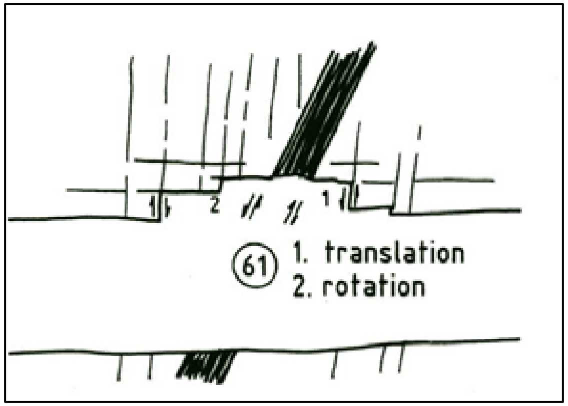
was to try to understand why different Norwegian hydropower caverns displayed widely different deformation magnitudes.

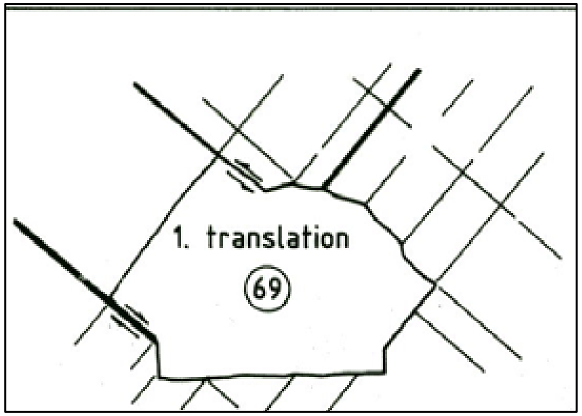
(A report was eventually written for NGI on this subject….but there was a 6 months delay due to Q-system development !)

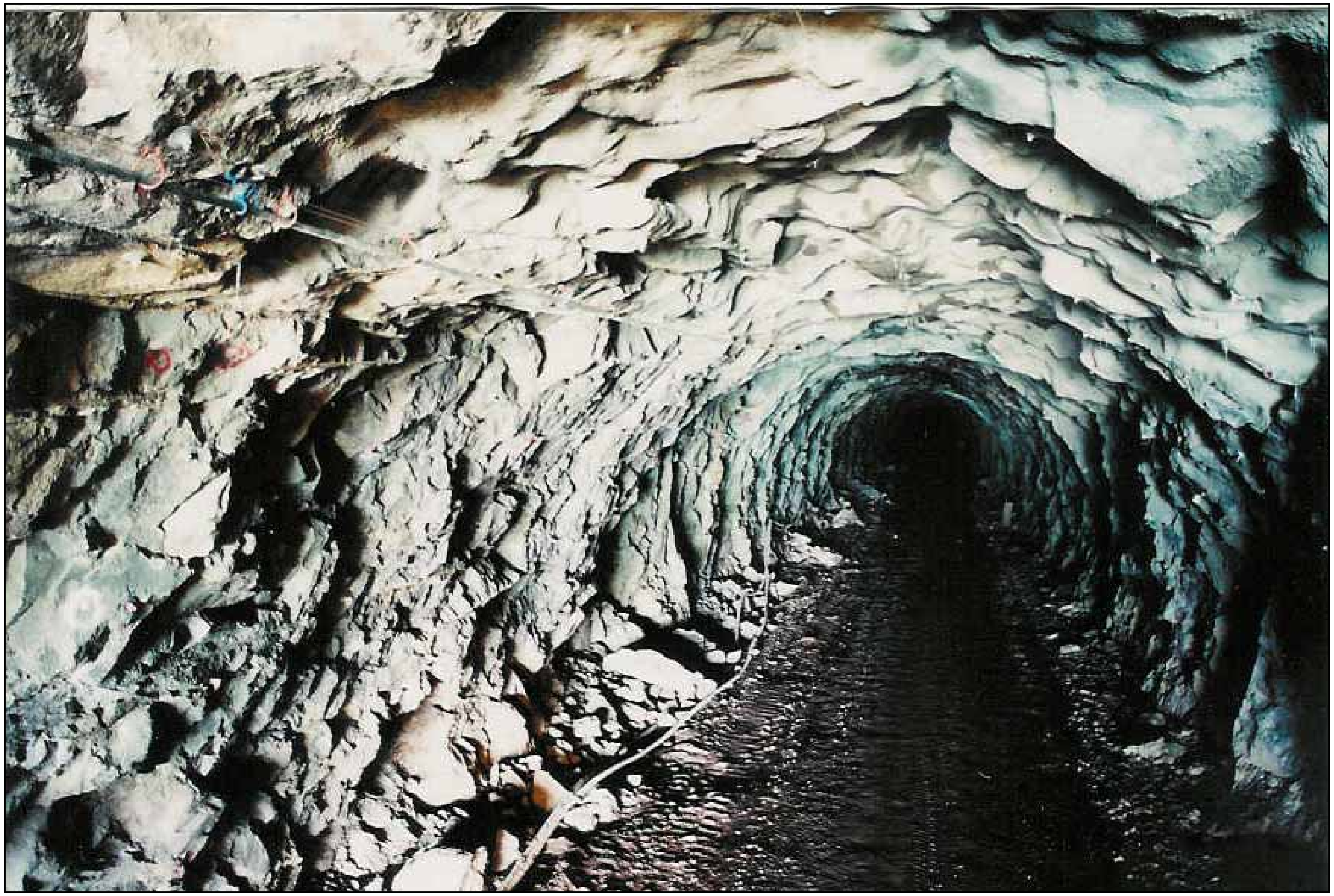
Obviously cavern support and rock quality had to be considered together. So 'Q' had to combine support needs with rock quality (and tunnel or cavern span) from the start.

CASE RECORDS (as these from CECIL 1970) were an important starting point for developing Q''….. then adding parameters to make Q'…. and re-testing new ratings until Q was eventually reached.

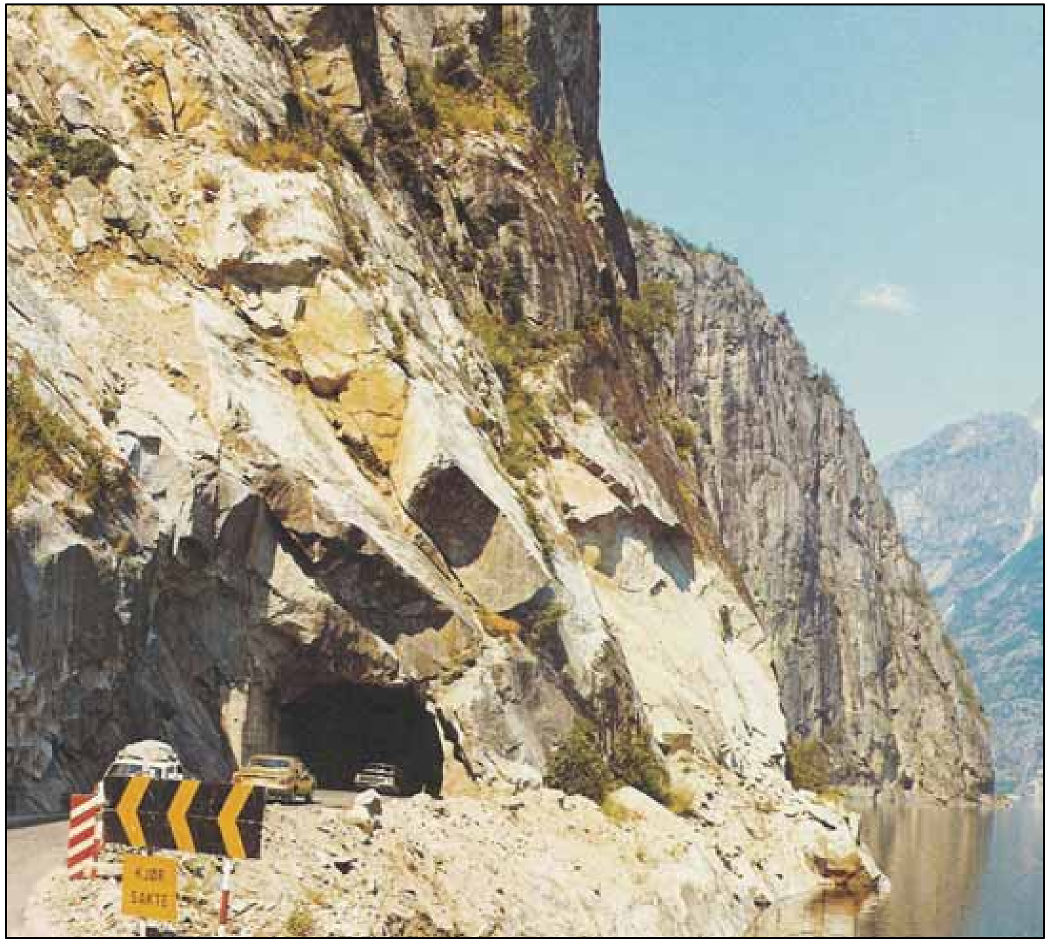




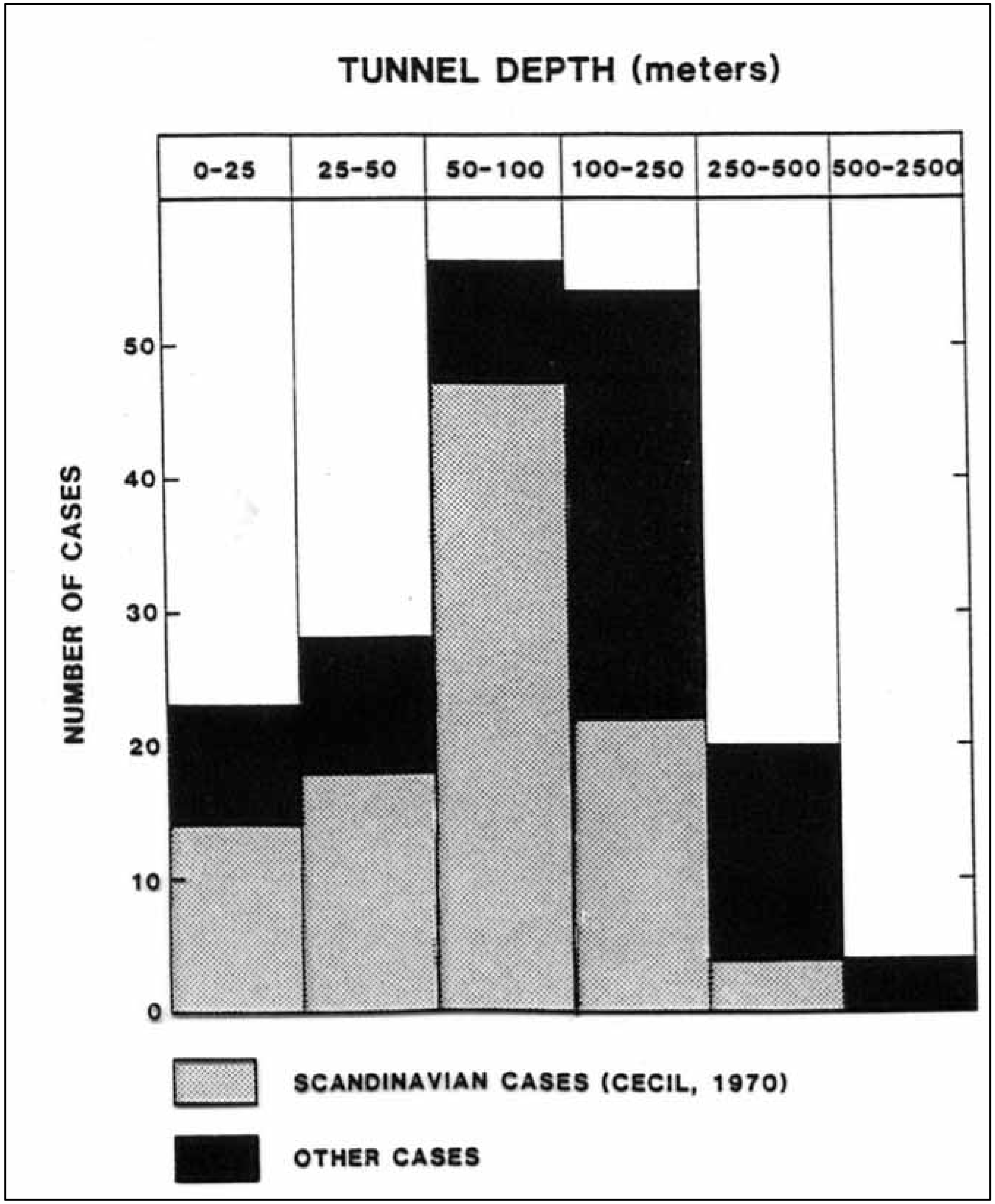




how much support…..and why?

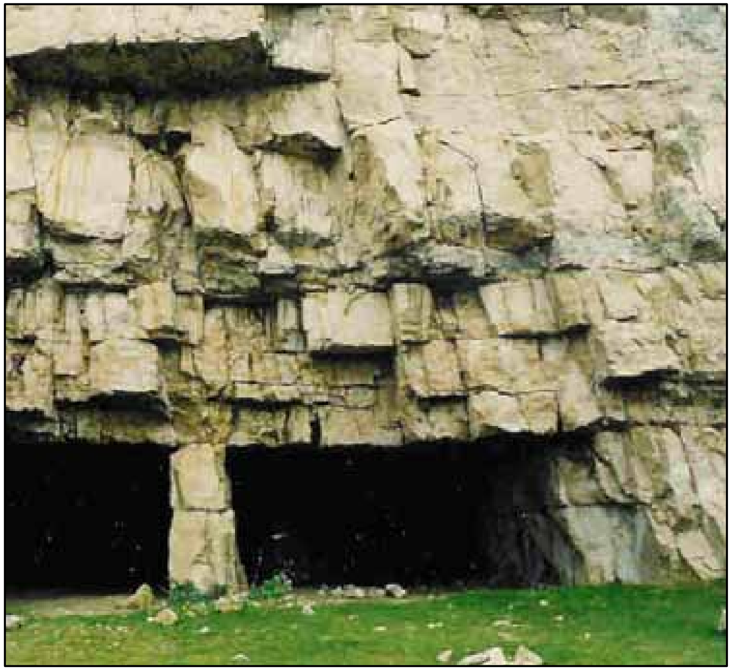


Norway – and Sweden – were ideal places for case records, with numerous road tunnels and hydropower tunnels recently constructed.

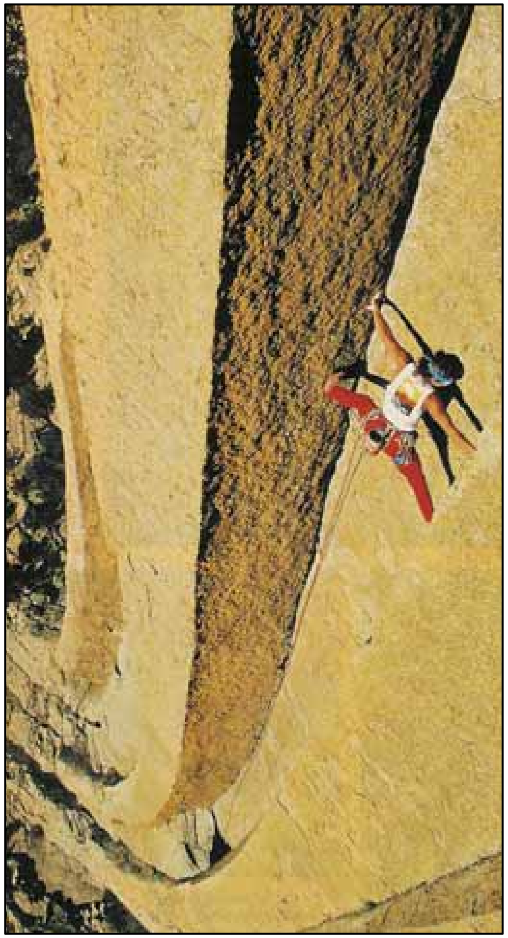

TUNNEL DEPTH (meters)
0-25
25-50
50-100
100-250
250-500
500-2500
NUMBER OF CASES
0
10
20
30
40
50
SCANDINAVIAN CASES (CECIL, 1970)
OTHER CASES

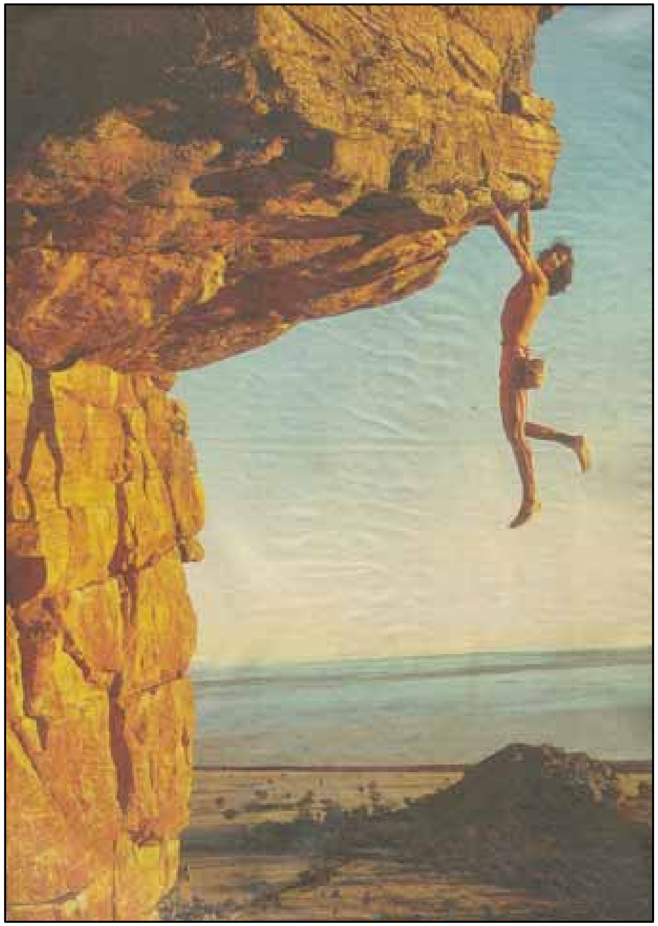
Frequency of Occurrence of Rock Types
in Examined Case Records

I. IGNEOUS		II. METAMORPHIC		III. SEDIMENTARY
Basalt	1	Amphibolite	8	Chalk
Diabase	4	Anorthosite (meta-)	1	Limestone
Diorite	2	Arkose	1	Marly Limestone
Granodiorite	1	Arkose (meta-)	3	Mudstone
Quartzdiorite	1	Claystone (meta-)	2	Calcareous Mudstone
Dolerite	1	Dolomite	1	Sandstone
Gabbro	2	Gneiss	14	Shale
Granite	46	Biotite Gneiss	1	Clay Shale
Aplitic Granite	1	Granitic Gneiss	4	Siltstone
Monzonitic Granite	1	Schistose Gneiss	2	Marl
Quartz Monzonite	2	Graywacke	1	Opalinus Clay
Quartz Porphyry	2	Greenstone	1	
Tuff	2	Schistose meta Graywacke	1	
		Quartz Hornblende	1	
		Leptite	11	
		Marble	1	
		Mylonite	4	
		Pegmatite	2	
		Syenite	1	
		Phyllite	1	
		Quartzite	13	
		Schist	17	
		Biotite Schist	1	
		Mica Schist	2	
		Limestone Schist	1	
		Sparagmite	2	

- Some fundamentals that had to be ‘quantified’ …….
- Why are these blocks not falling ? ….. are they stable?
- Is the fact that this is a mine (for limestone) a good reason for the acceptance of poor stability (hence need for ESR)





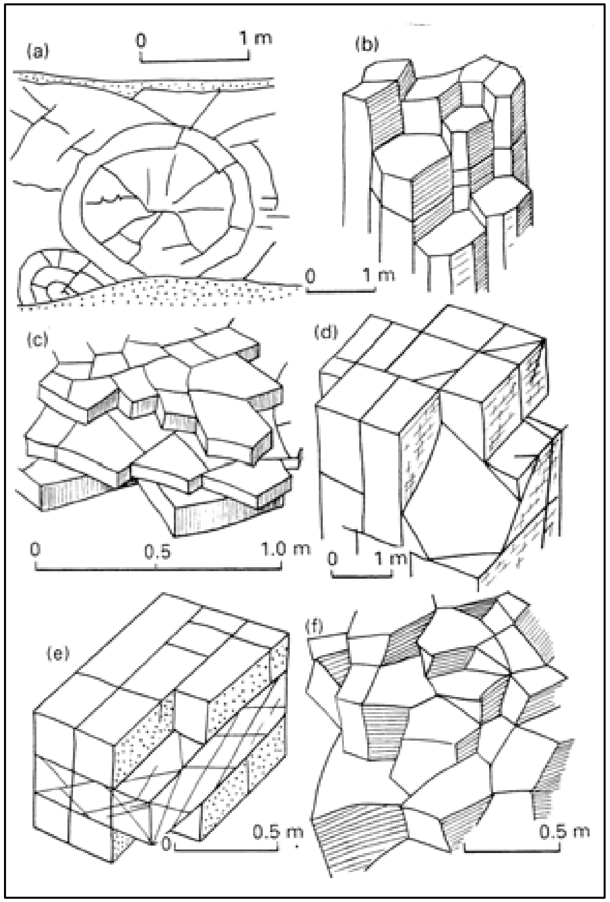
Is joint roughness important?

Are number of joint sets important?

Is joint spacing important?

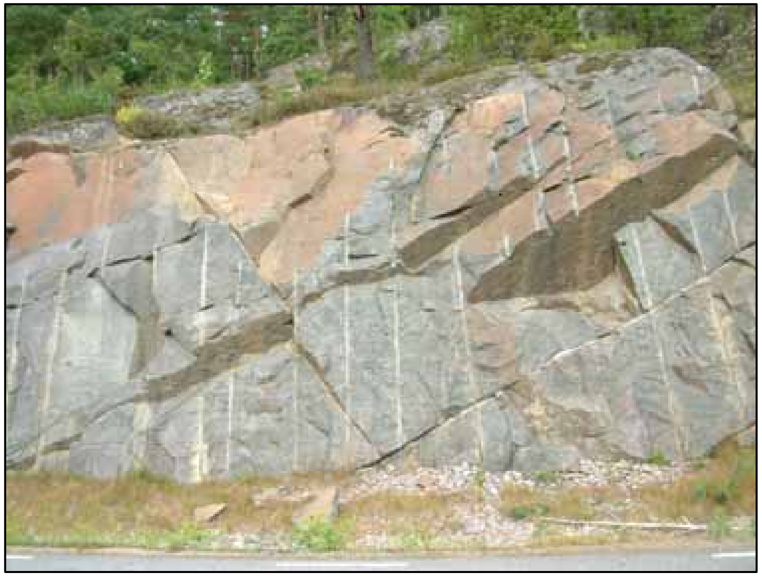
Are clay-coated joints important?

Is rock type important?

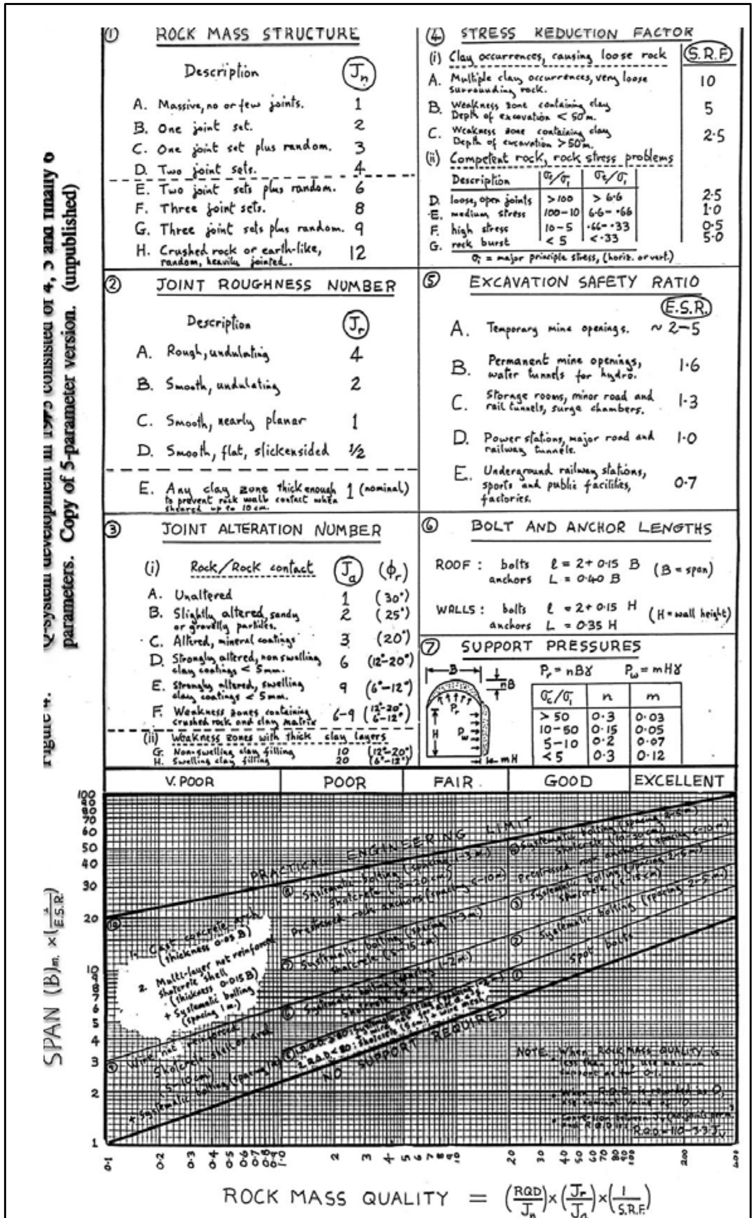


THE SAME ROCK *TYPE* CAN TAKE ON MANY COMPLEX SHAPES

For example basalt



How was one to describe all the variety…….How was one to describe core…..?

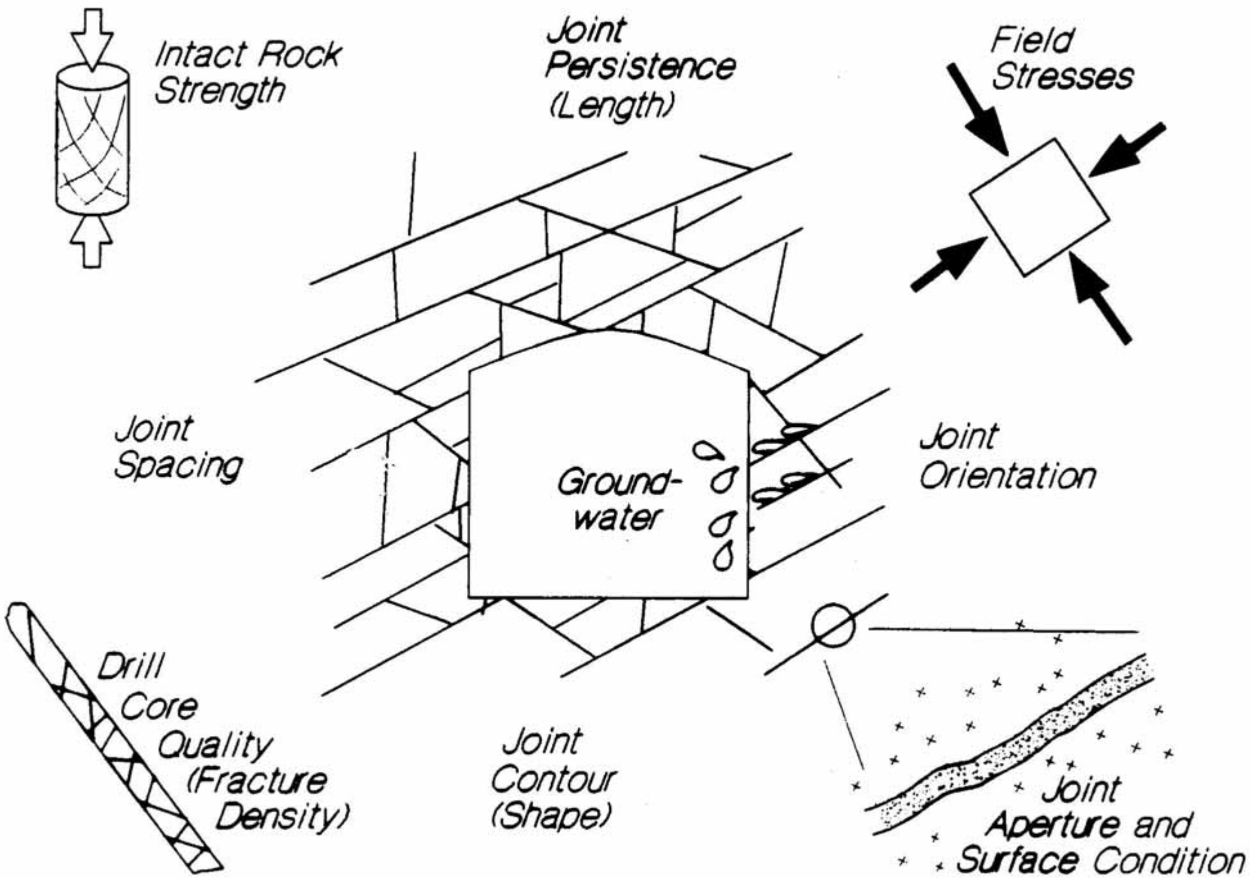


- Starting with RQD and *number of joint sets* (Cecil's important suggestion – perhaps not popular with his Ph.D. supervisor, Don Deere),
- 'Q' parameters were added and tested with different ratings.
- This is the third or fourth version following several months 'trial-and-error work. There is no 'Jw' term at this stage – and ratings are not yet 'today's ratings'.
- An important point to note is that the case records 'suggested the need' for the chosen parameters – and for the ratings – with some NB guidance.
- $\tan^{-1}$ Jr/Ja ≈ friction angle
- (actually 'φ+i', or 'φ-i') is a direct result of this cooperation.

SOME Q-SYSTEM BACK-GROUND

- Initial data base was 212 cases of nominally unlined tunnels and caverns, for hydropower, road, rail, storage, sewage. (Since 1993 it is 1250 cases).
- About 60% of the initial Q-cases were from Scandinavia
- About 40% were from Europe, USA, etc.
- *About 50% were from hydropower tunnels in Norway and Sweden*
- 50 rock types were initially represented
- Numerous shear zones and faults containing clay
- Numerous cases with clay-coated and clay-filled joints
- Numerous cases of weathered rock masses
- A smaller number of weak sedimentary rocks
- A larger number of igneous and metamorphic rocks

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF}$$

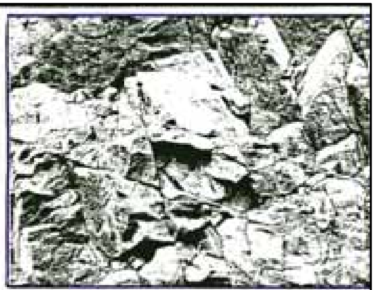


$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

- **RQD** is the % of *competent* drill-core sticks > 100 mm in length in a selected domain. (In tunnel mapping imagine cores or scan-lines).
- **Jn** = the rating for the number of joint sets (9 for 3 sets, 4 for 2 sets etc.) in the same domain.
- **Jr** = the rating for the roughness of the *least favourable* of these joint sets or filled discontinuities.
- **Ja** = the rating for the degree of alteration or clay filling of the *least favourable* of these joint sets or filled discontinuities.
- **Jw** = 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 *in soft rock.*

1. GRANITE

Q = 90/9 x 1.5/1.0 x 0.66/1.0
= 10 (fair/good)
(1E/2F, 3E/4B, 5B/6J)

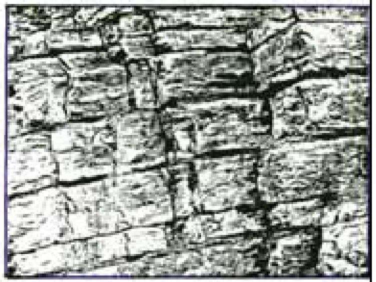


2. GRANITE

Q = 70/15 x 3.0/1.0 x 0.66/1.0
= 9.2 (fair)
(1C/2H, 3B/4B, 5B/6J)

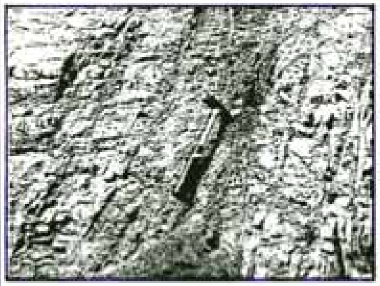
3. SANDSTONE-CLAYSTONE

Q = 40/9 x 1.0/2.0 x 0.66/1.0
= 1.5 (poor)
(1B/2F, 3F/4C, 5B/6J)



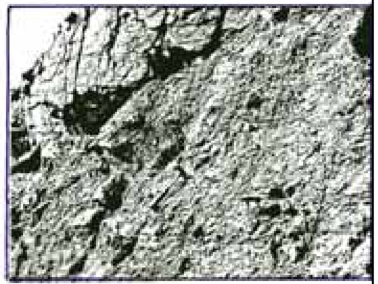
4. NODULAR-LIMESTONE

Q = 80/9 x 1.0/5 x 0.66/5
= 0.24 (very poor)
(1D/2F, 3J/4N, 5H/6G)



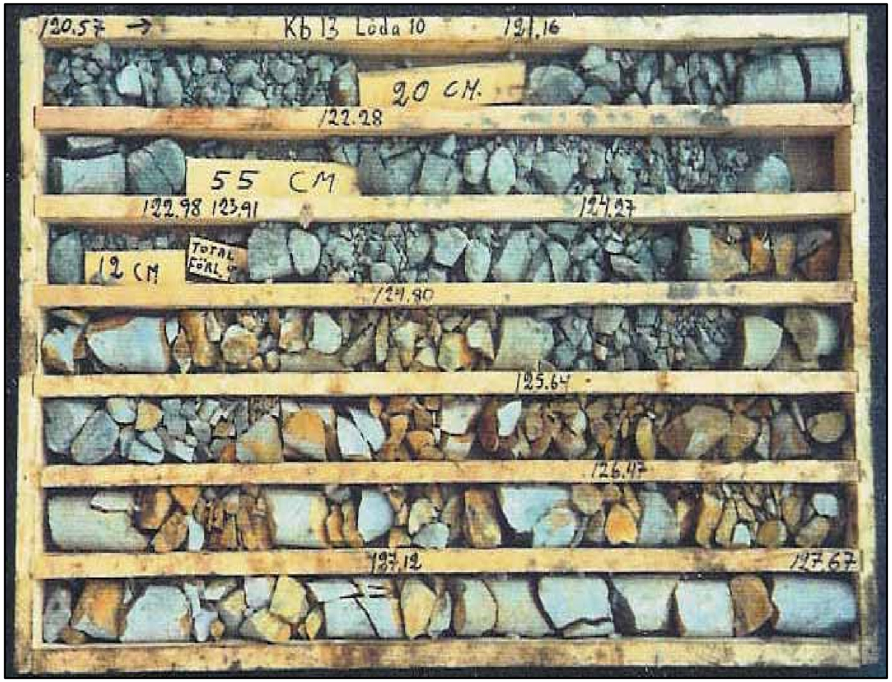
6. MUDSTONE (overall RQD=30)

Q = 30/9 x 1.0/5 x 0.66/5
= 0.09 (extremely poor)
(1B/2F, 3J/4N, 5B/6B)



6. GRANITE (decomposed) RQD=0

Q = 10/20 x 1.0/6 x 0.66/6
= 0.009 (exceptionally poor)
(1A/2J, 3J/4K, 5B/6N)



Weathering has reduced RQD, increased Jn, increased Ja, reduced Jw, increased SRF

(each of these changes reduce Q, since Q = RQD/Jn x Jr/Ja x Jw/SRF)

Q = 1000 (or better)

Q = 0.001 (or worse)

Q = 100/0.5 x 4/0.75 x 1/1

Q = 10/20 x 1/8 x 0.5/ 20

(The wide numerical range of Q reflects differences in rock mass properties much more realistically than RMR or GSI – which vary by only one order of magnitude.)

THE FIRST TWO PAIRS OF PARAMETERS HAVE DIRECT PHYSICAL MEANING:

RQD / Jn = relative block size (useful for distinguishing massive, rock-burst-prone rock from more jointed rock).

Jr / Ja = relative frictional strength (of the least favourable joint set or filled discontinuity). Closely resembles a friction coefficient.

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

RQD/Jn also represents <u>degree of freedom (and size) for potential block-falls</u>

Jr/Ja represents <u>frictional strength of the nearly planar sides of the blocks</u>

THE Q PARAMETER RATINGS

THE 1ST AND 2ND PARAMETERS RQD and Jn

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

Note: 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 - 1.0
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

Note: i) For intersections, use ($3.0 \times J_n$)
ii) For portals, use $2.0 \times J_n$)

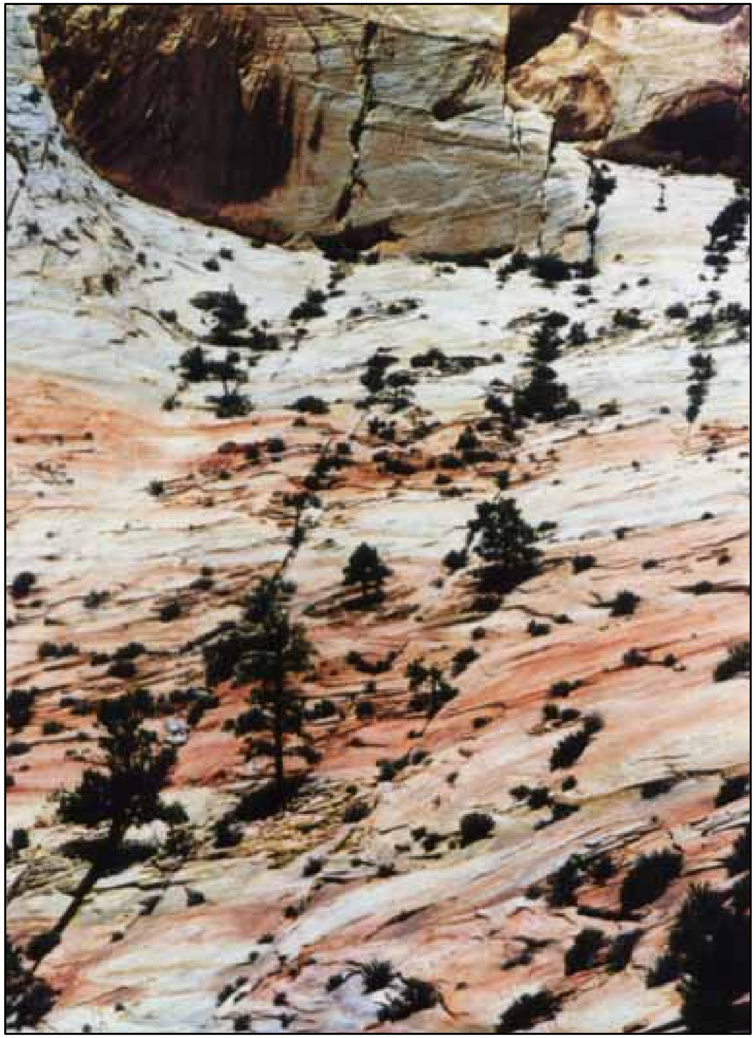
RQD varies from 0 to 100
Jn varies from 12 to 4

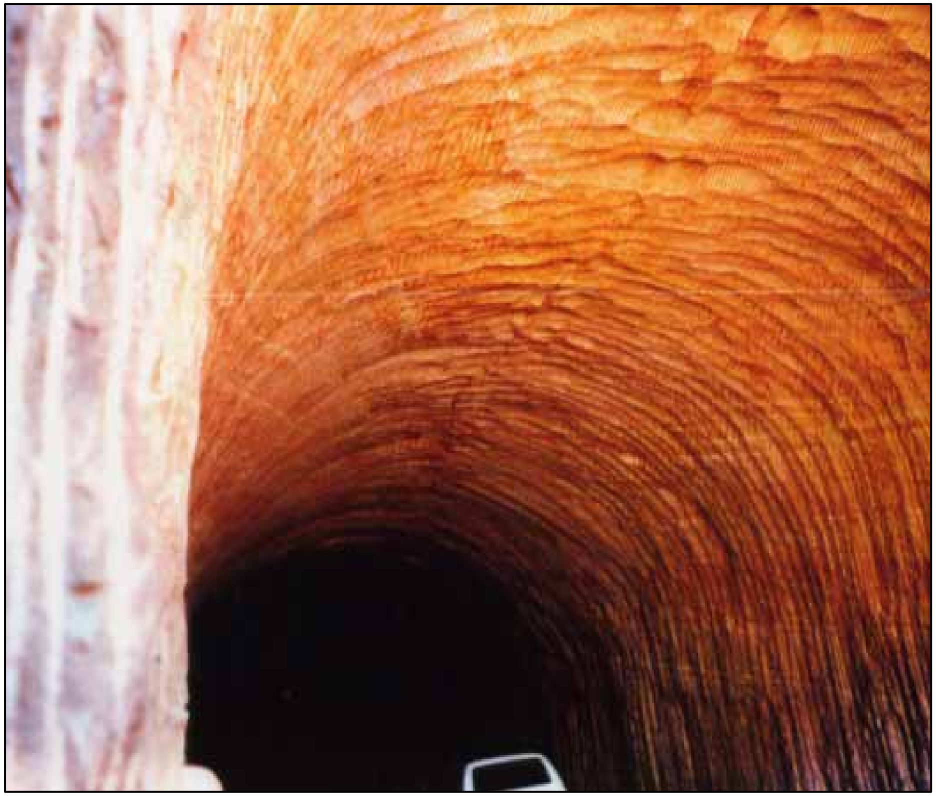
(2m window: RQD = 20 to 50 …. May need to measure)

(Jn = 4 → 6 → 9 ….a lot is blast damage)

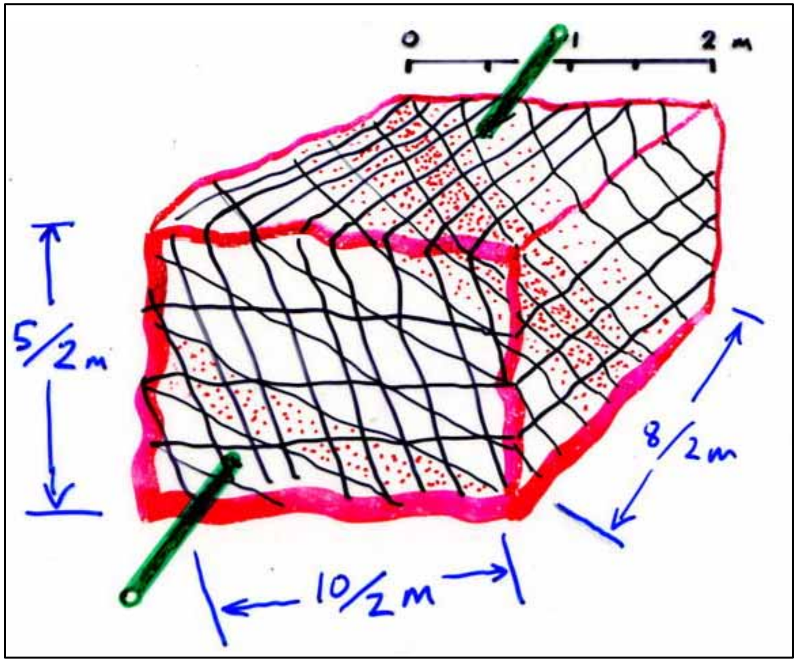
(3 to 4m window)

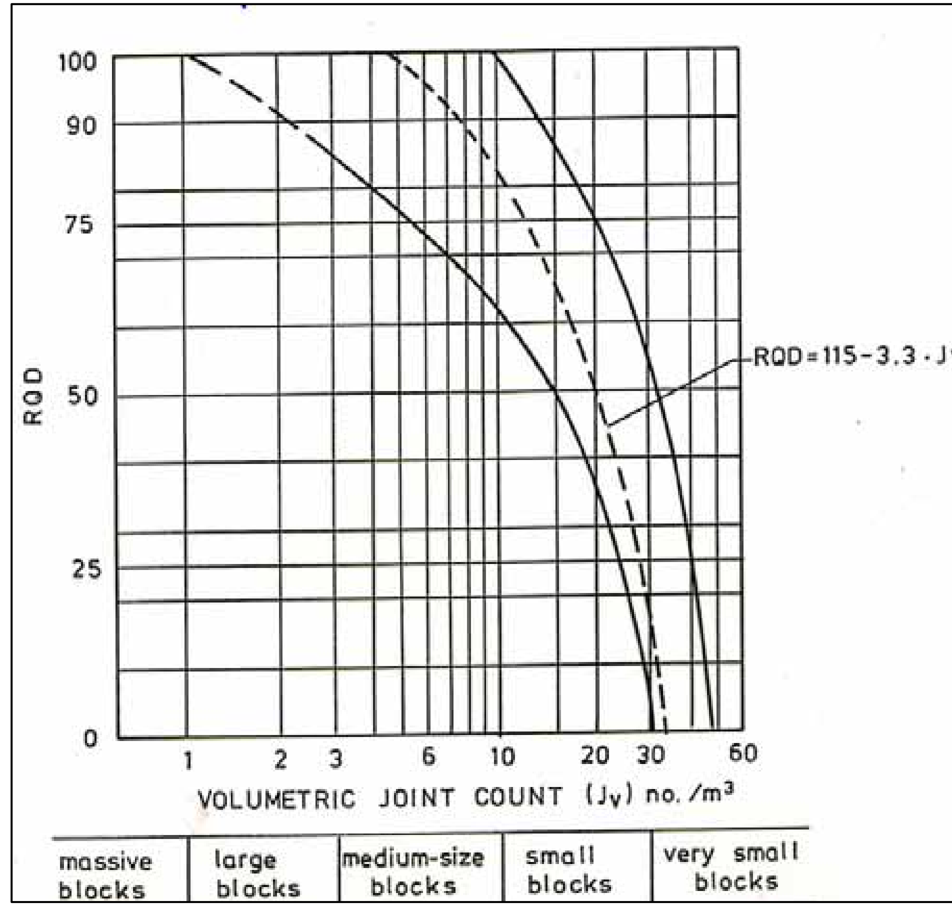
Jn = 15 (at least!)





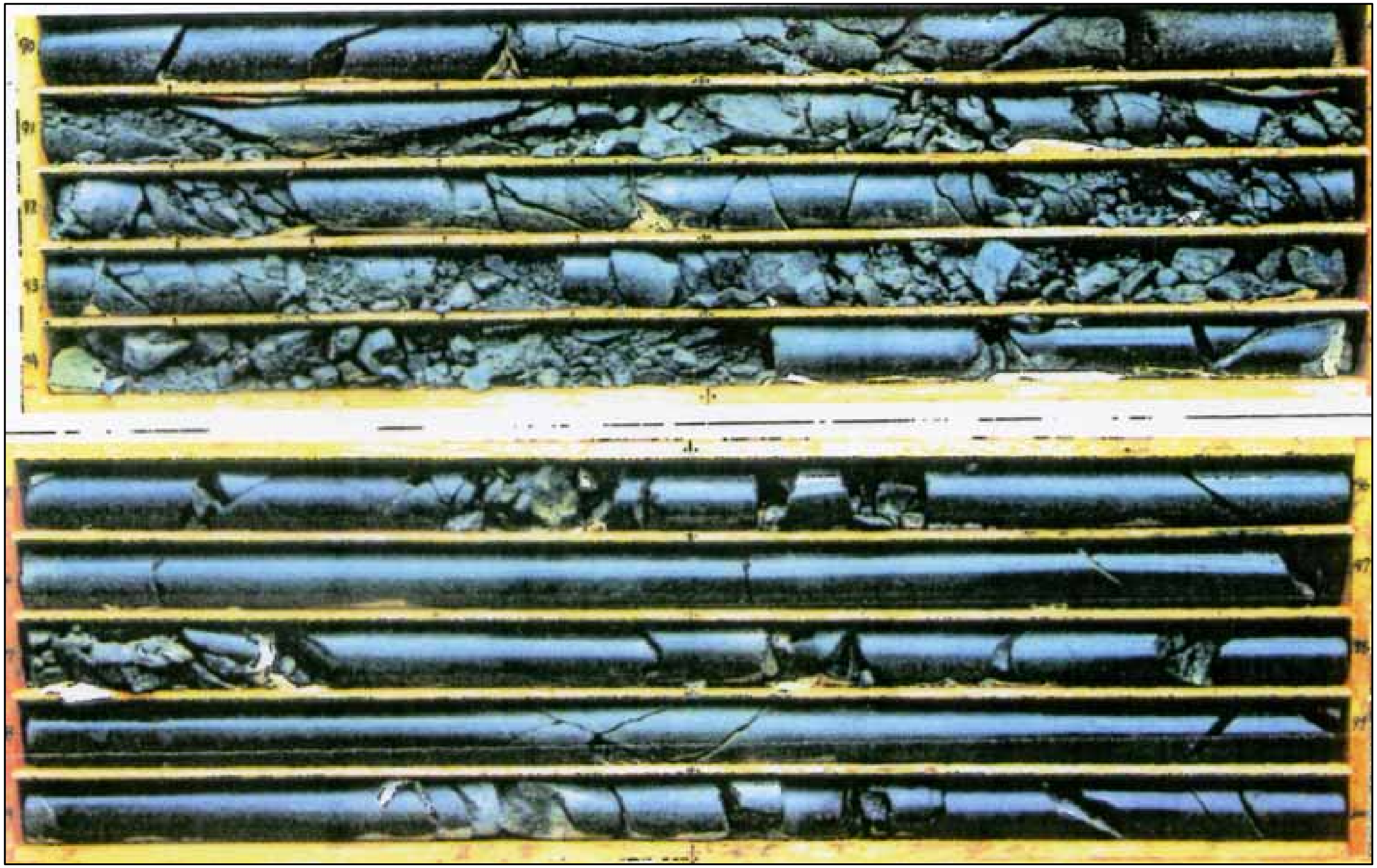
(Massive sandstones in Zion National Park, USA. Jn = 2 ⟶3)





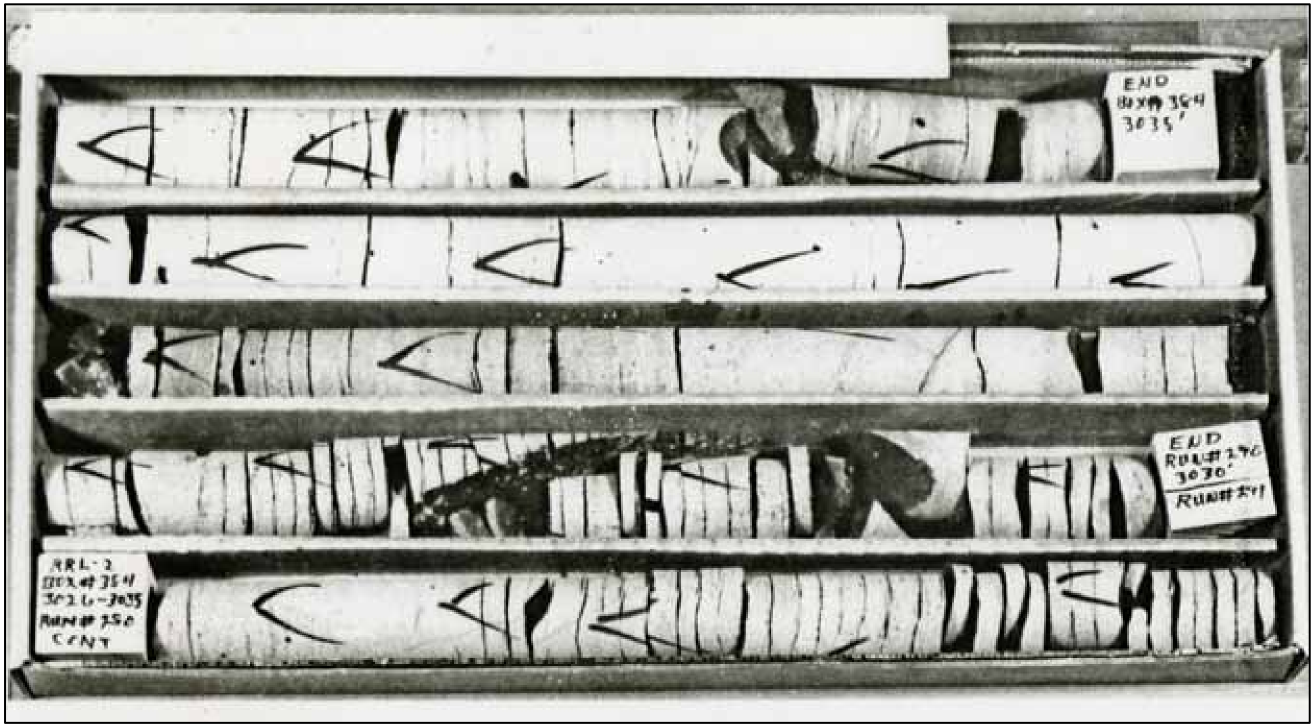
$J_v = 2.5 + 5.0 + 4.0 = 11.5/\ m^3$

RQD ≈ 77 %



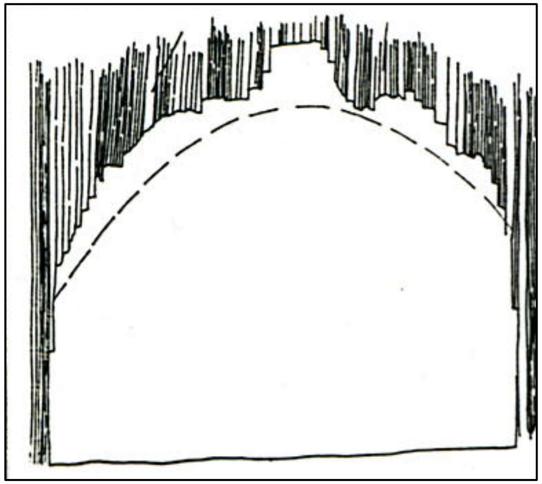
competent rock……or not?……RQD may be ZERO… even for L>10cm

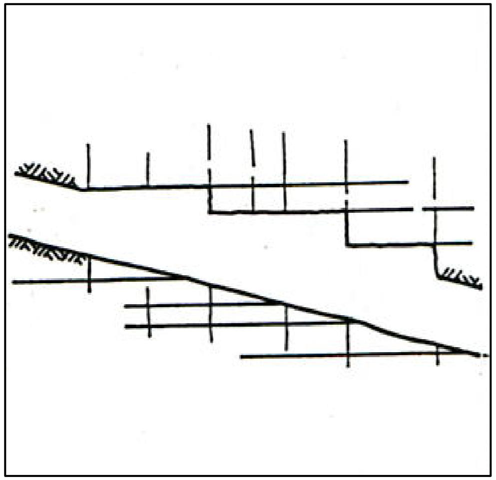
(but in Q-calculation minimum Q = 10)

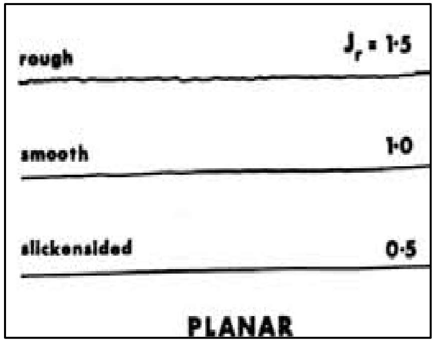


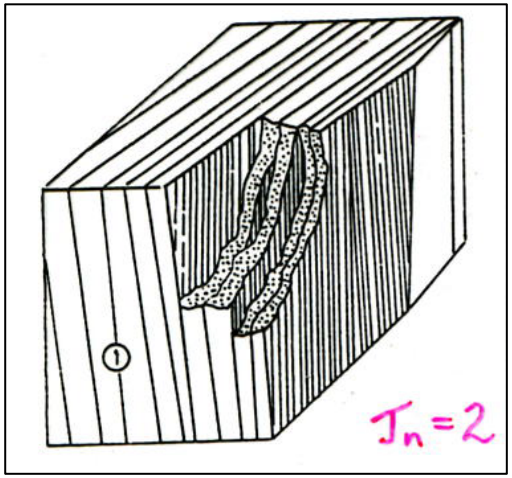
(Upper Cohasset Flow, BWIP, Hanford, 900m depth)

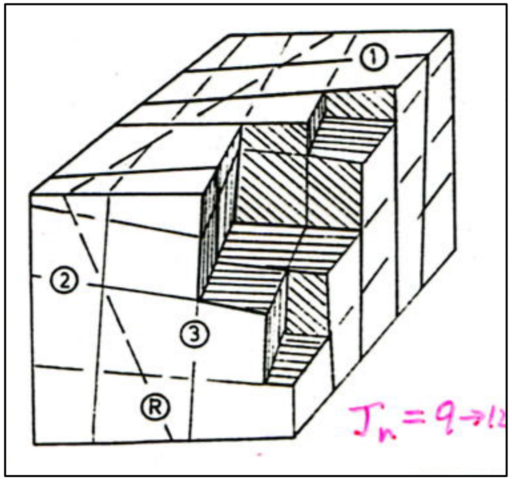
$$Q = \frac{100\,?}{9\,?} \times \frac{1.5 - 2}{1 - 2} \times \frac{0.66}{1 - 50\,?!}$$

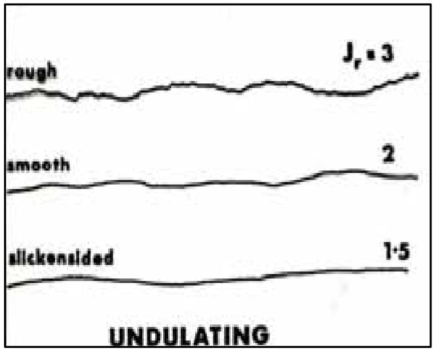












Jn and Jr and the possibility of instability are intimately linked

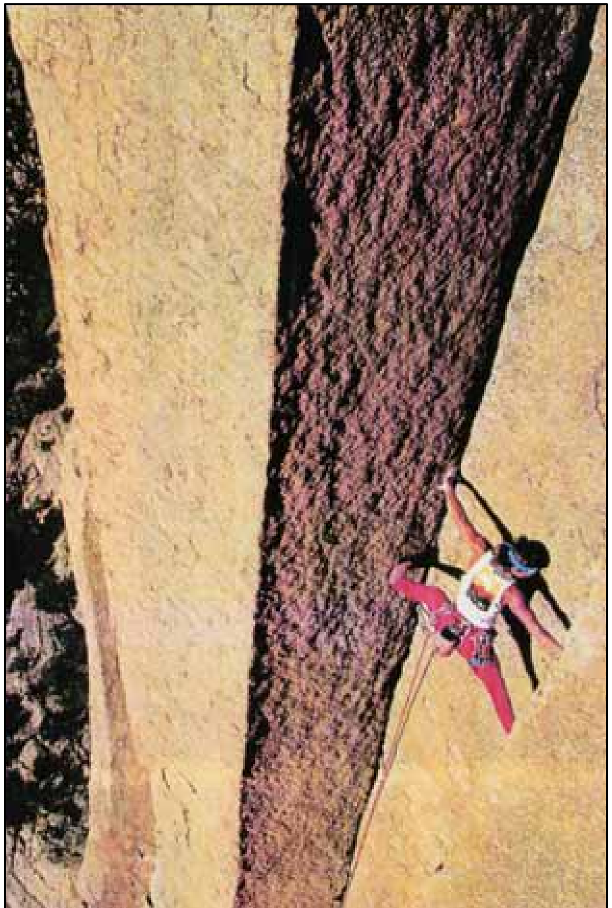
NOTE POTENTIALLY *ANISOTROPIC* RQD
Jn is obviously 9 (three sets)

The low roughness of the bedding planes – *together* with the three sets, would make roof stability in a tunnel very poor, without rock bolt reinforcement.

THE 3RD PARAMETER Jr

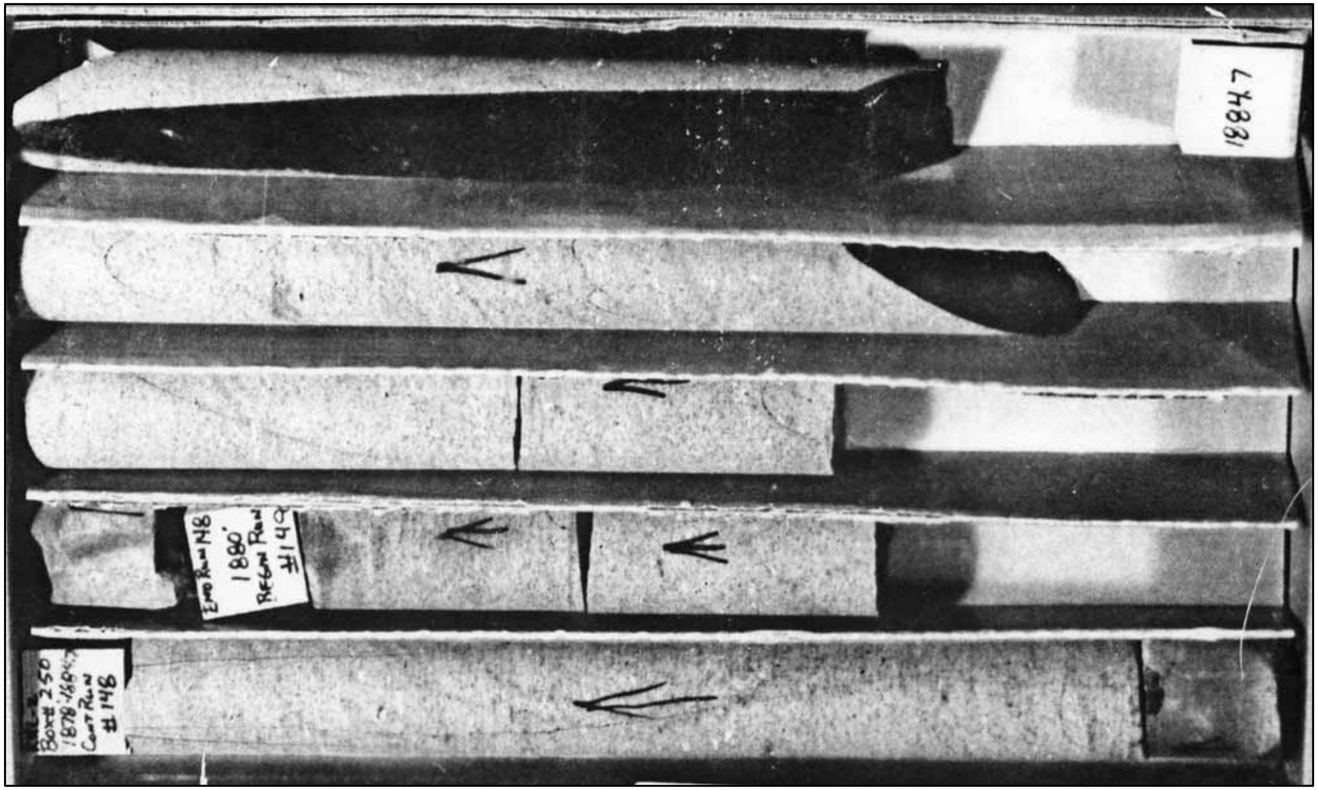
3. Joint Roughness Number		J_r
a) Rock-wall contact, and b) rock-wall contact before 10 cm shear		
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1.5
E	Rough or irregular, planar	1.5
F	Smooth, planar	1.0
G	Slickensided, planar	0.5
Note: i) Descriptions refer to small scale features and intermediate scale features, in that order.		
c) No rock-wall contact when sheared		
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1.0
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1.0
Note: i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3m. ii) J_r = 0.5 can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength.		

Jr = 3 (at least!)

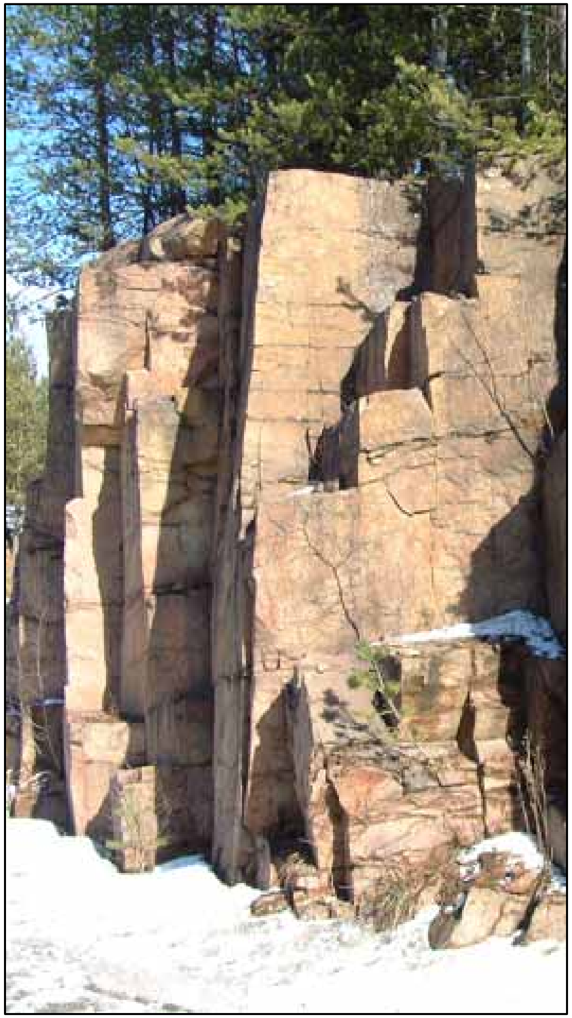


Jr = 3

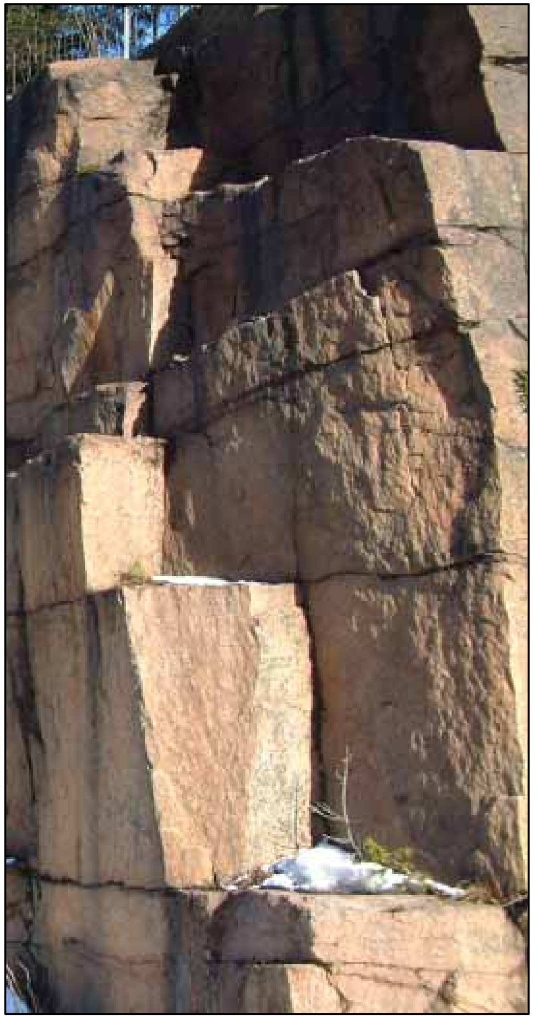
Jr = 1.5 and 2



Jr = 1.0 to 1.5



Jr = 1.5 (joints in sun)

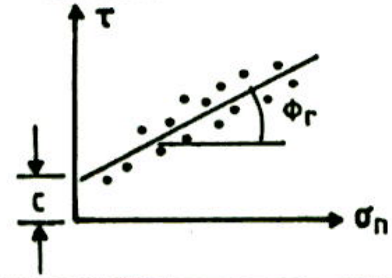


Jr = 2+ (half shadow)

What about relation of Jr to JRC?

(1) $\tau = \sigma_n \tan \Phi_r + c$

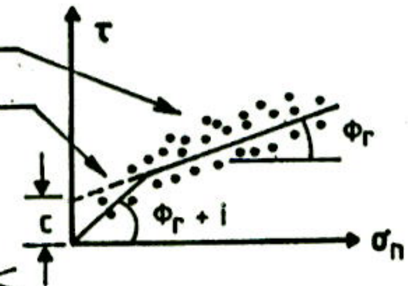
Mohr - Coulomb



(2) $\tau = \sigma_n \tan \Phi_r + c$

$\tau = \sigma_n \tan (\Phi_r + i)$

Patton

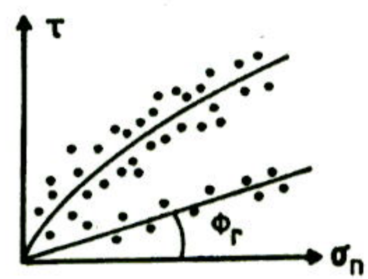


(3) $$\tau = \sigma_n \tan \left[JRC \log \left(\frac{JCS}{\sigma_n} \right) + \Phi_r \right]$$

JRC = joint roughness coefficient

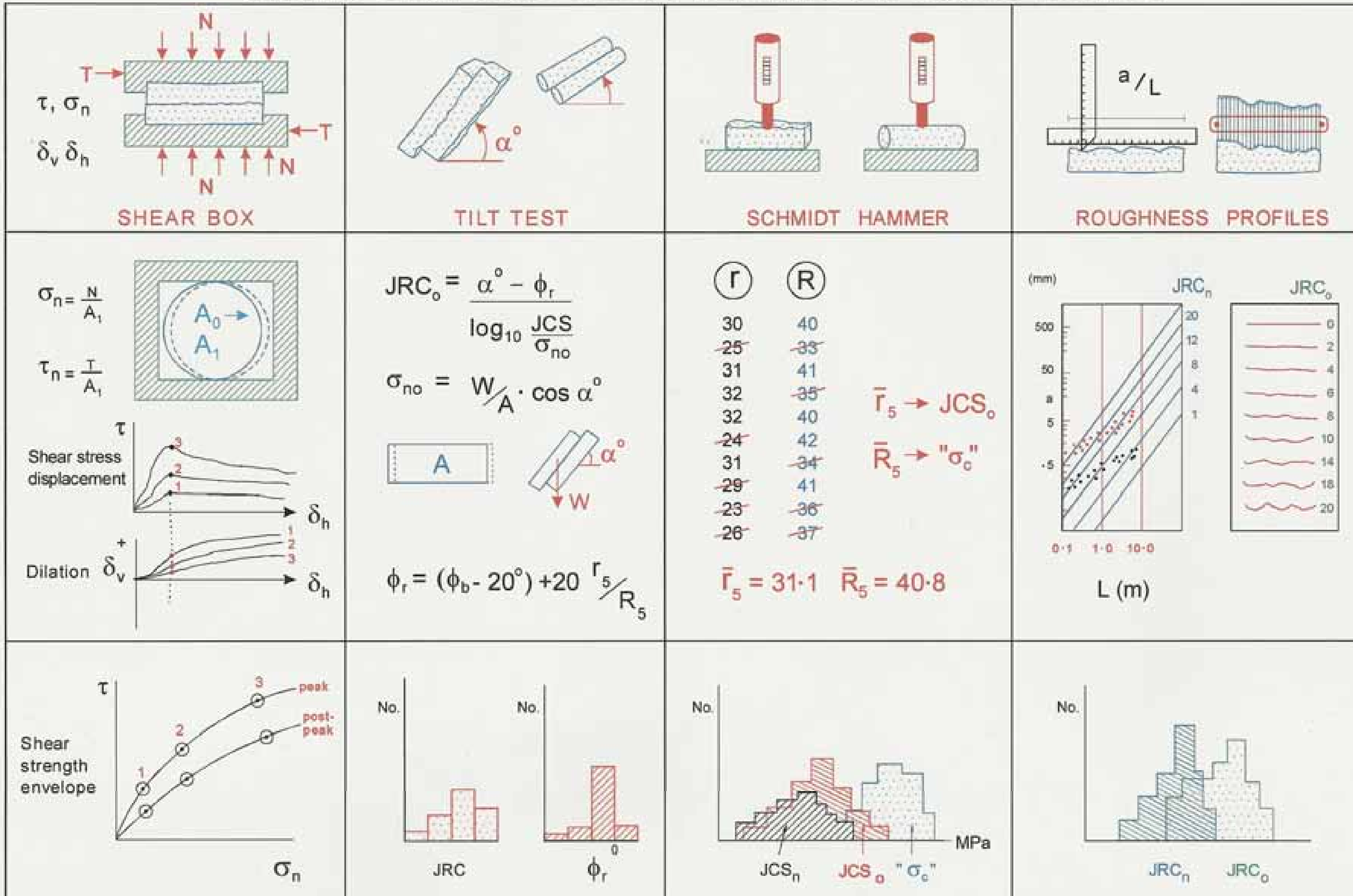
JCS = joint wall compression strength

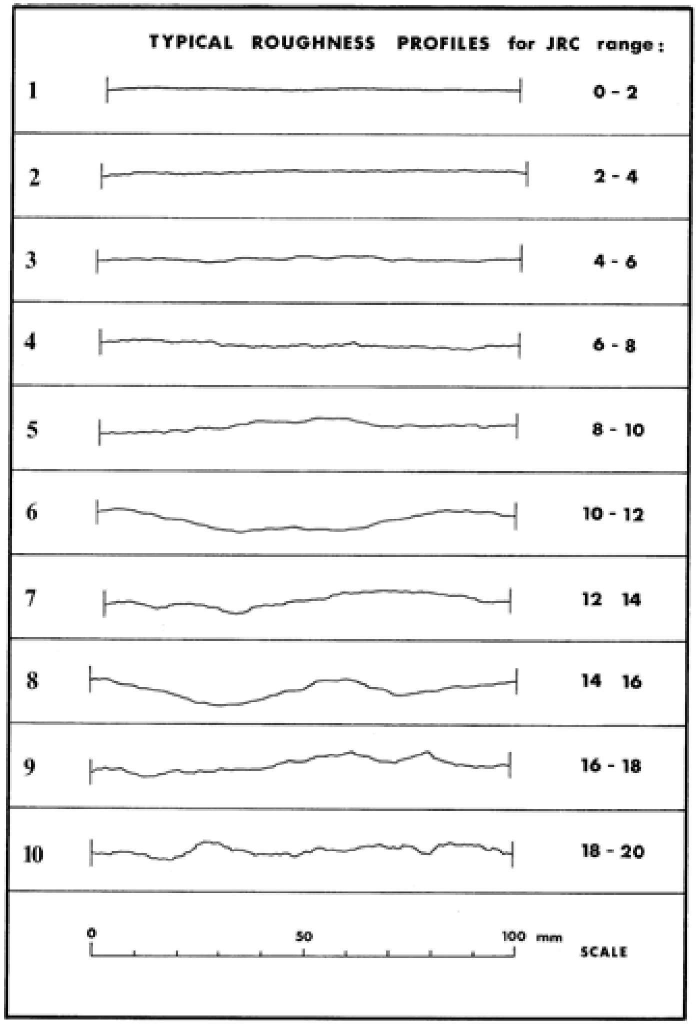
Φ_r = residual friction angle

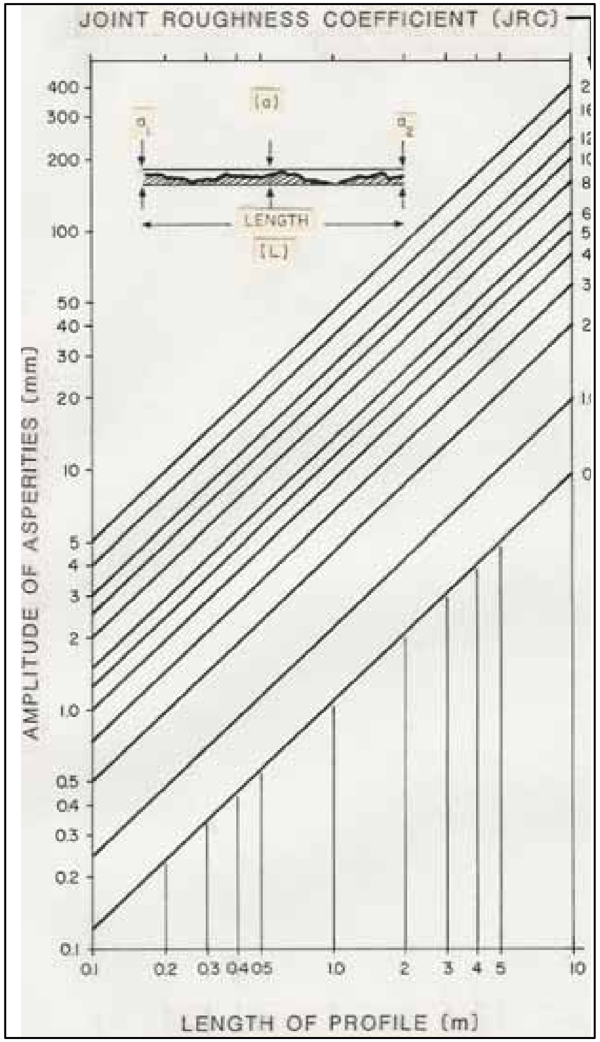


Relation between J_r and JRC_n Subscripts refer to block size (cm)				J_r	JRC_{20}	JRC_{100}
I	rough		4	4	20	11
II	smooth		3	3	14	9
III	slickensided		2	2	11	8
		Stepped				
IV	rough		3	3	14	9
V	smooth		2	2	11	8
VI	slickensided		1.5	1.5	7	6
		Undulating				
VII	rough		1.5	1.5	2.5	2.3
VII	smooth		1.0	1.0	1.5	0.9
IX	slickensided		0.5	0.5	0.5	0.4
		Planar				

SHEAR BOX AND INDEX TESTING OF ROCK JOINTS







100 mm approx.

100 mm up to 10 m

THE 4th PARAMETER Ja

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 <5mm thickness)	16-24°	6.0
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness)	12-16°	8.0
J	Swelling-clay fillings, *i.e.*, montmorillonite (continuous, but <5mm thickness). Value of J_a depends on percent of swelling clay-size particles, and access to water, *etc.*	6-12°	8-12
c) No rock-wall contact when sheared (thick mineral fillings)			
KL M	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
OP R	Thick, continuous zones or bands of clay (see G, H, J for description of clay condition)	6-24°	10, 13, or 13-20

a) rock-to-rock contact

b) rock-to-rock after shearing

c) no rock-to-rock contact

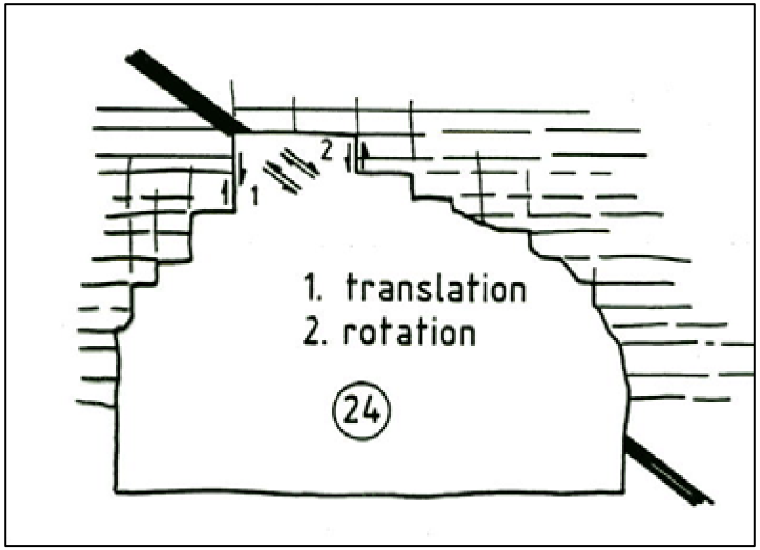
(deformed paving-stone analogy to clay-bearing rock mass)

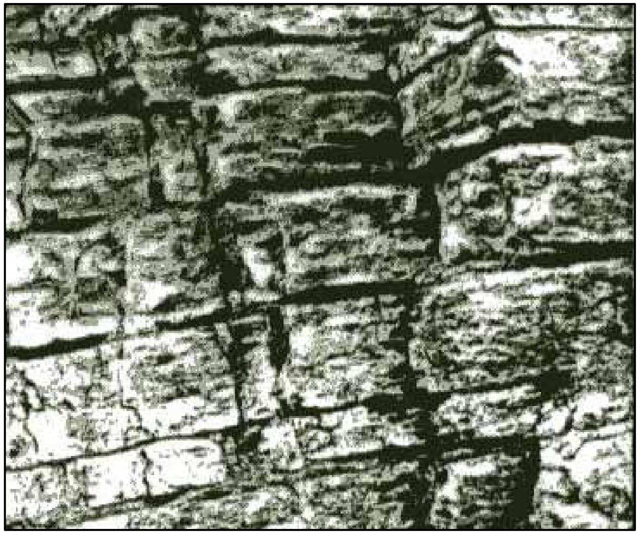
Ja = ?? definitely 2 for weathered, maybe 4 or 6 for sandy or clay fillings (both the latter with ‘correct Jr = ?? 1.5 ??)
The core loss zones (3) probably have Jr/Ja = 1/8 or worse.

Ja category a)

b) b) or c)

c)

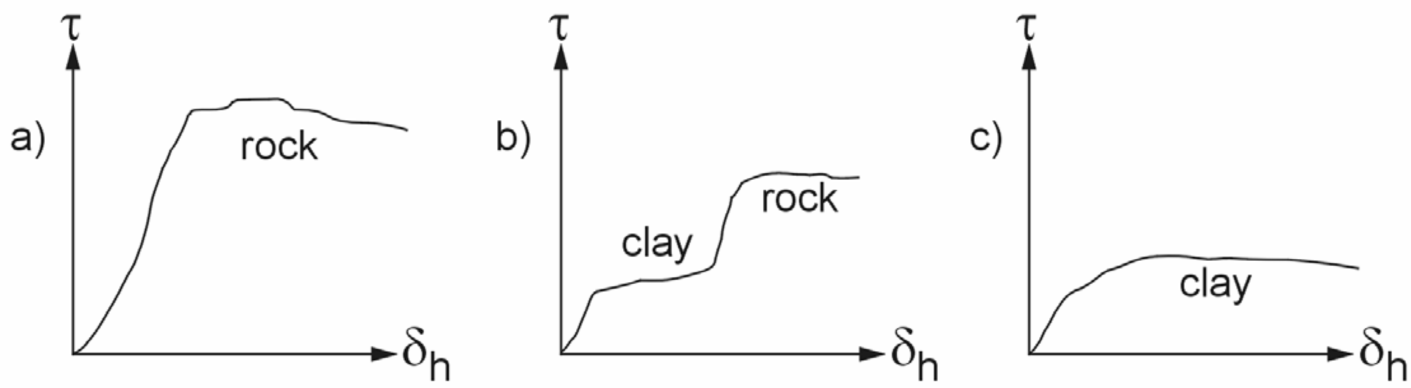




Jr/Ja = 1/5 (Category c – no rock-to-rock contact)

(3 to 4m window)

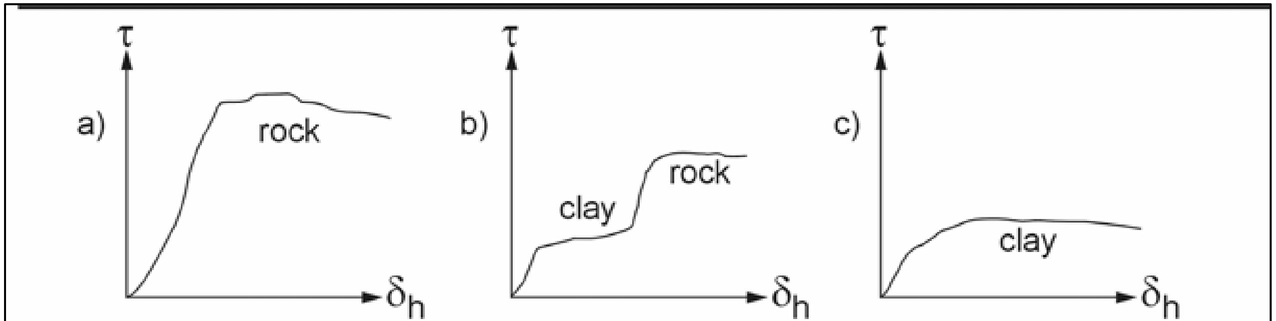
$$Q' = \frac{15-30}{15} x \frac{1.0}{1-2}$$



(a) Rock wall contact

	Jr	(thin coatings)				
	J_a/J_r =	0.75	1.0	2	3	4
		$\tan^{-1}(J_r/J_a)^\circ$				
A. Discontinuous joints	4	79°	76°	63°	53°	45°
B. Rough, undulating	3	76°	72°	56°	45°	37°
C. Smooth, undulating	2	69°	63°	45°	34°	27°
D. Slickensided, undulating	1.5	63°	56°	37°	27°	21°
E. Rough, planar	1.5	63°	56°	37°	27°	21°
F. Smooth, planar	1.0	53°	45°	27°	18°	14°
G. Slickensided, planar	0.5	34°	27°	14°	9.5°	7.1°

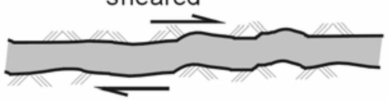
MOSTLY φ + i (*dilating-during-shear* joints)



(b) Rock wall contact when sheared

(thin fillings)	J_a/J_r =	4	6	8	12
		$\tan^{-1}(J_r/J_a)^\circ$			
A. Discontinuous joints	4	45°	34°	27°	18°
B. Rough, undulating	3	37°	27°	21°	14°
C. Smooth, undulating	2	27°	18°	14°	9.5°
D. Slickensided, undulating	1.5	21°	14°	11°	7.1°
E. Rough, planar	1.5	21°	14°	11°	7.1°
F. Smooth, planar	1.0	14°	9.5°	7.1°	4.7°
G. Slickensided, planar	0.5	7°	4.7°	3.6°	2.4°

(c) No rock wall contact when sheared



(thick fillings)	J_a/J_r =	5	6	8	12	13	16	20
		$\tan^{-1}(J_r/J_a)^\circ$						
Nominal roughness of discontinuity rock walls	1.0	11.3°	9.5°	7.1°	4.8°	4.4°	3.6°	2.9°

MOSTLY φ-i (*contracting-during-shear* filled discontinuities

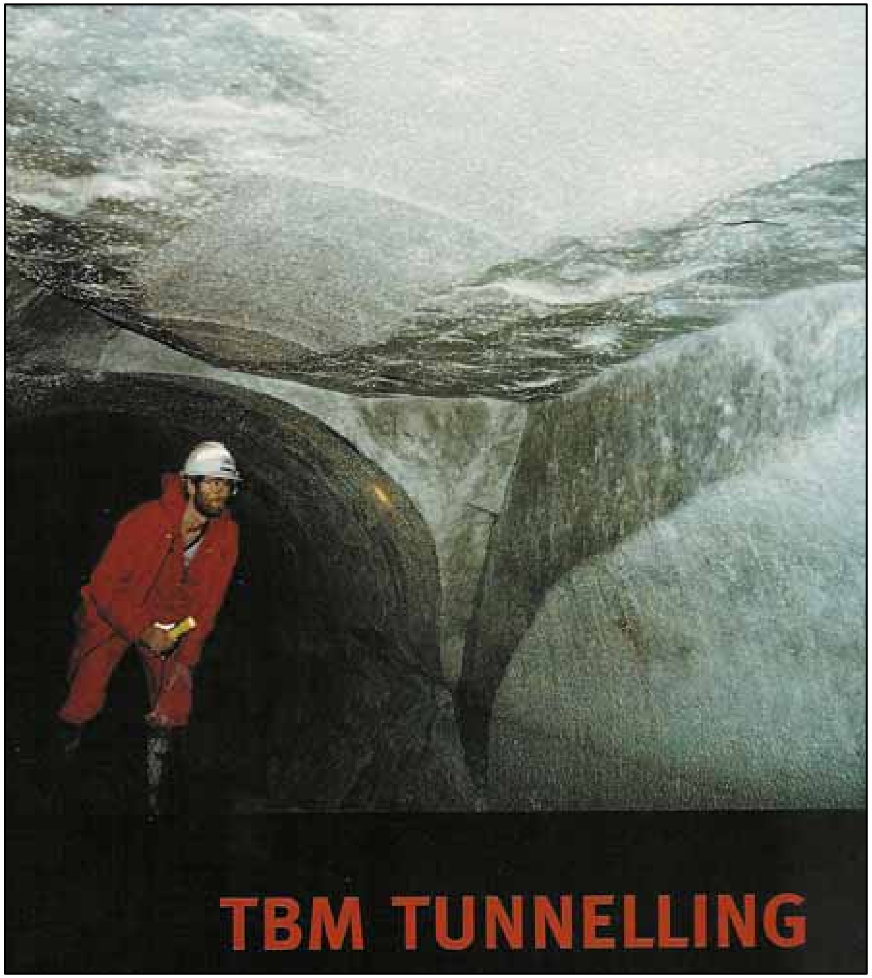
Core from UK Nirex Ltd. Planned Rock Characterization Facility, central hole RCF 1

Jr/Ja = 1.5/1.0, 1.0/2.0, 2.0/2.0

(but with histogram logging it is easier to express genuine doubts about whether Jr is 1.5 or 2, and whether Ja is 1 or 2 i.e slightly weathered)

BLOCK DEFINITION AND WALL STRENGTH

from RQD/Jn, Jr/Ja



(125 years old Beaumont Tunnel)

1) RQD=100, Jn = 9 (3 joint sets)

(relative block size = 100/9 =*11.1*

If RQD was 45, if Jn was 15 (4 sets)

then RQD/Jn = 45/15 = 3 = smaller blocks

2) Jr = 1, Ja = 1

(frictional strength = 1/1 = *1*)

IF THERE WAS WEATHERING:

Ja ► 2 ►3 ►4 ►6 ►8 ……

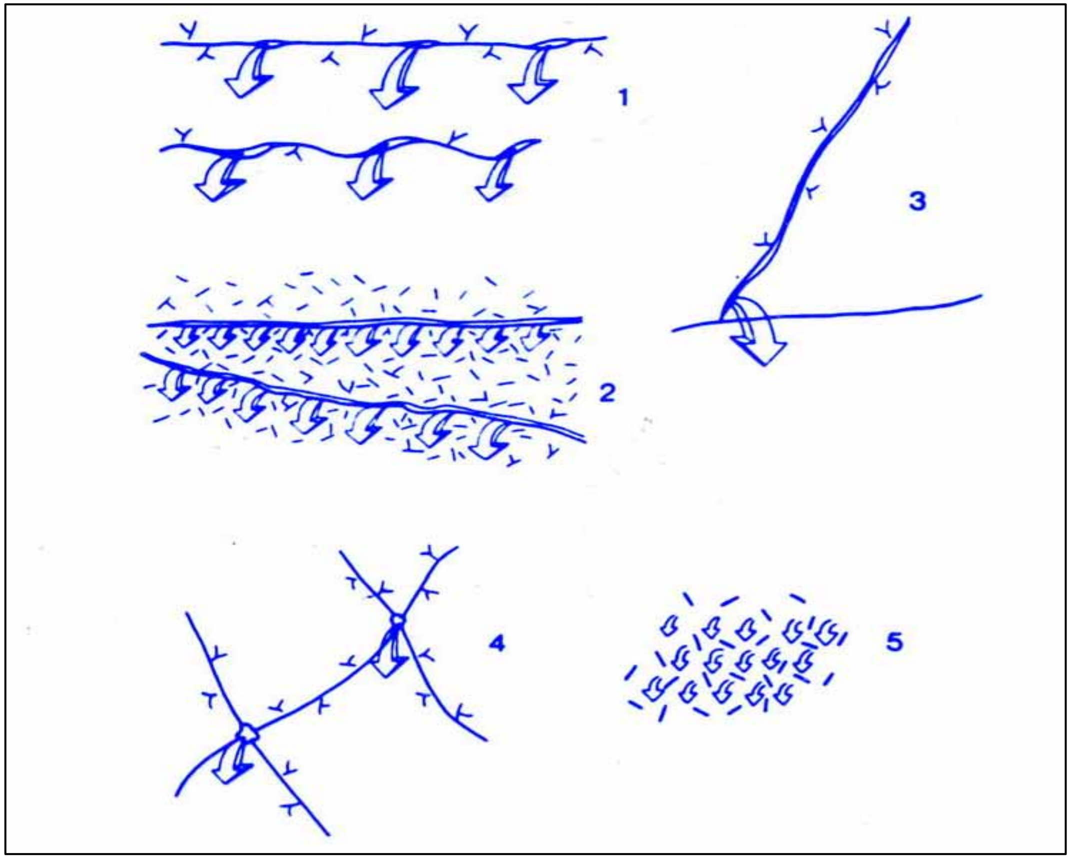
(Maybe the block/wedge fell when Ja was reduced to 2)

Jr/Ja ►*0.5*, 0.33, 0.25, 0.17, 0.13

THE 5TH PARAMETER Jw

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

Note: 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.



Forsmark cooling water tunnel. Carlsson and Olsson, 1977

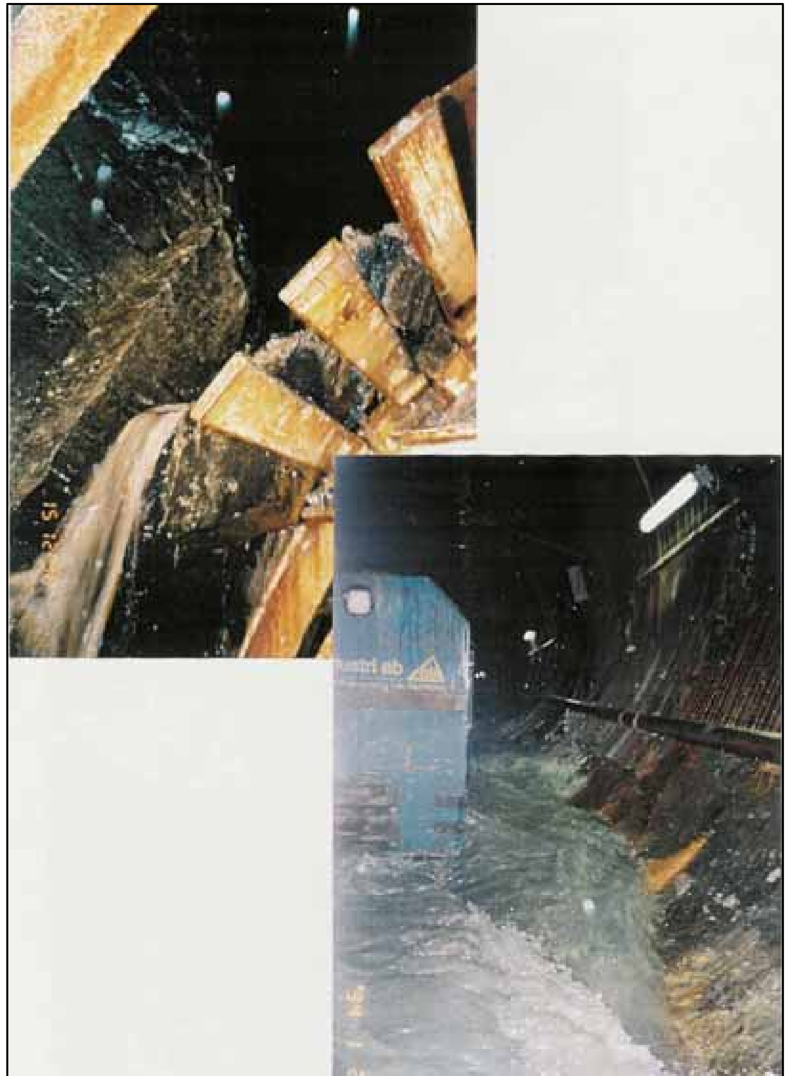
Jw = 1 or 0.66

Jw = 0.5

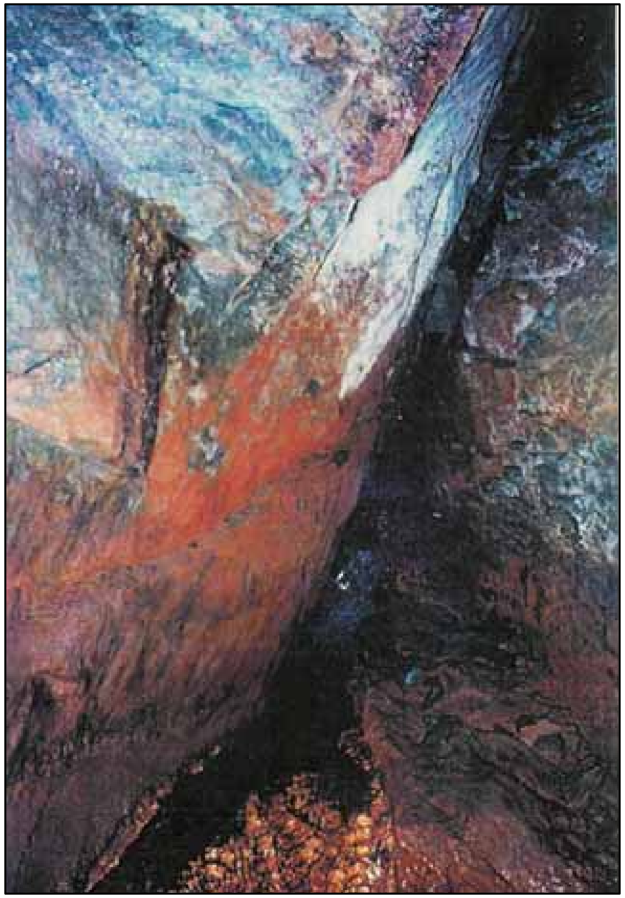
Jw = 0.2

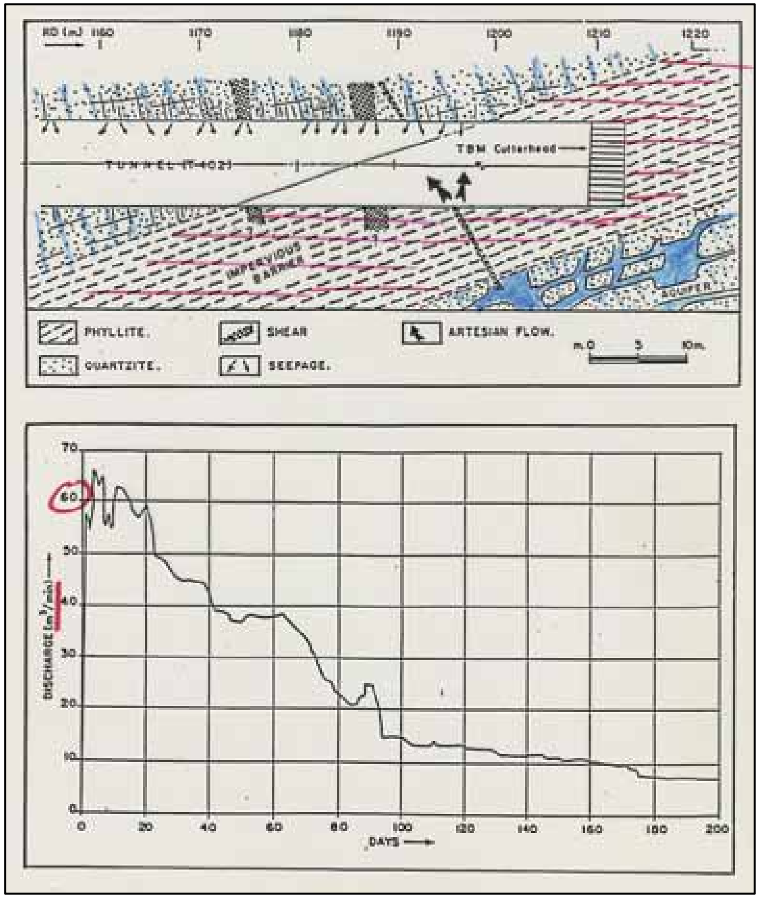
Jw = 0.66

Jw = 0.1 or 0.2



Most of tunnel was $J_w < 0.5$





(Dul Hasti HEP, Kashmir)

280 days delay due to Jw = 0.05 event

Finally SRF

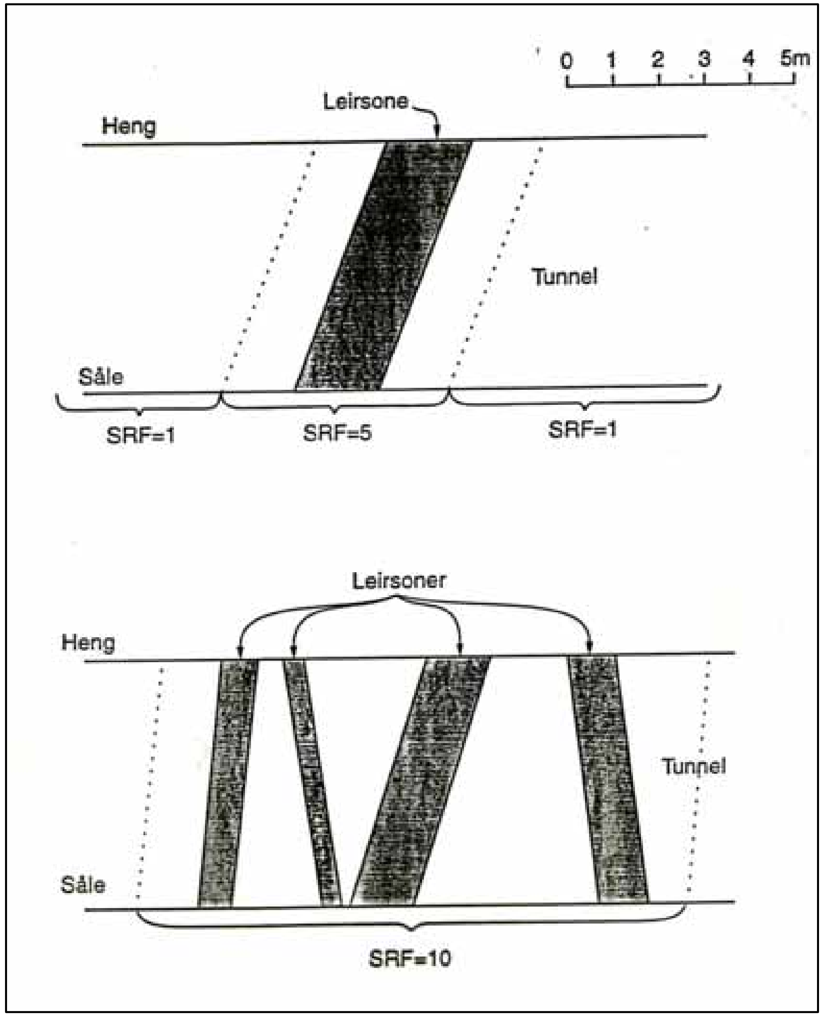
The 6th parameter – and the one that causes the most trouble.

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 ≤ 50m)			5
C	Single weakness zones containing ***clay*** or chemically disintegrated rock (depth of excavation > 50m)			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 ≤ 50m)			5.0
F	Single shear zones in competent rock (***clay-free***) (depth of excavation > 50m)			2.5
G	Loose, open joints, heavily jointed or "sugar cube", *etc.* (any depth)			5.0
Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.				
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
Note: 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 SRF increase from 2.5 to 5 for such cases (see H).				
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
Note: iv) Cases of squeezing rock may occur for depth $H > 350\ Q^{1/3}$ (Singh *et al.*, 1992). Rock mass compression strength can be estimated from $q \approx 7\ \gamma\ Q^{1/3}$ (MPa) where γ = rock density in gm/cc (Singh, 1993).				
d) Swelling rock: chemical swelling activity depending on presence of water				
R	Mild swelling rock pressure			5-10
S	Heavy swelling rock pressure			10-15

SRF category a)

FAULTING

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 ≤ 50m)	5
C	Single weakness zones containing ***clay*** or chemically disintegrated rock (depth of excavation > 50m)	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 ≤ 50m)	5.0
F	Single shear zones in competent rock (***clay-free***) (depth of excavation > 50m)	2.5
G	Loose, open joints, heavily jointed or "sugar cube", *etc.* (any depth)	5.0
Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.		



Advice from Løset, NGI concerning SRF 'extension' into side rock

Not a fault – affects Jr/Ja only (2/4 → 1/8)

(Brazilian HEP tailrace tunnel – incorrect mapping – therefore – incorrect support)

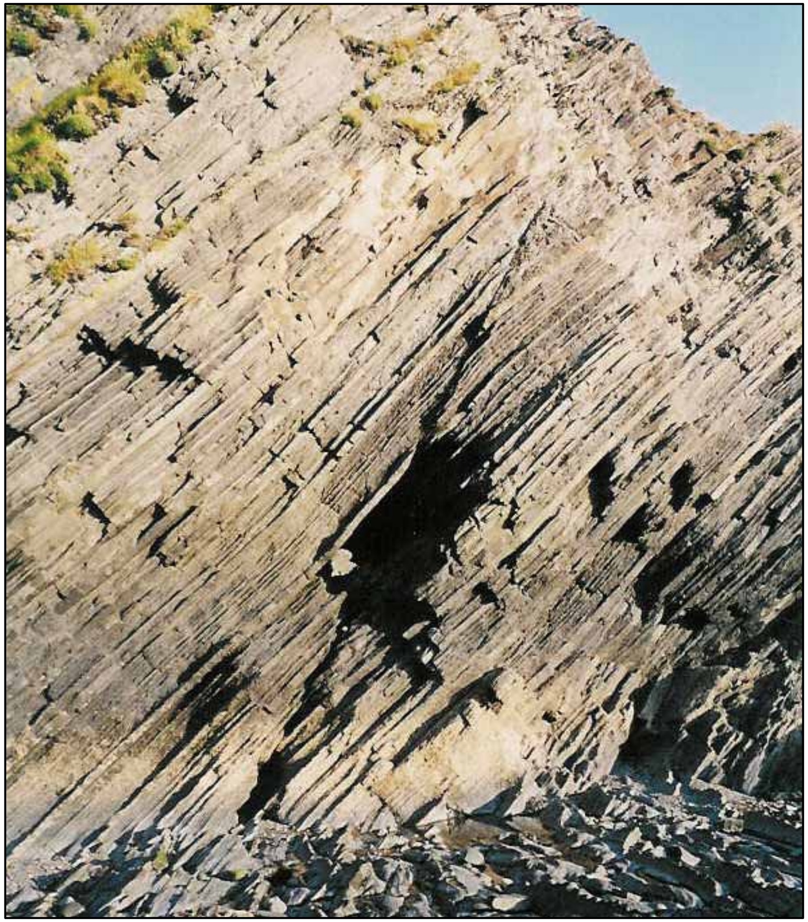
Multiple faults (at least two): SRF = 10

PRESUMED SUB-SURFACE FAULT

(Jr/Ja = 1/8, SRF = 2.5 or 5 according to depth)

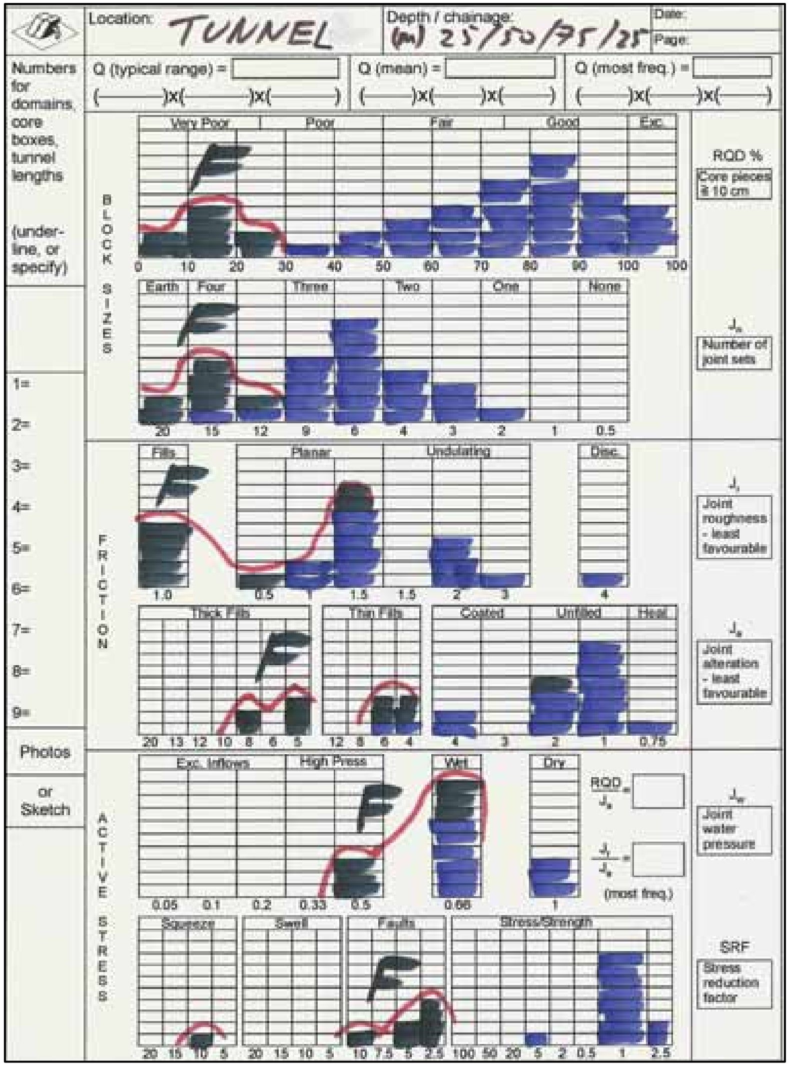
In the context of faulting (note core loss) this rockmass suggests SRF = 2.5 or 5, depending on tunnel depth

$$Q = \frac{10}{15-20} \text{ x } \frac{1}{8} \text{ x } \frac{0.5}{5} = 0.006 - 0.008$$



A shear (minor fault) without clay. Try following:

$$Q = \frac{20-60}{3} \text{x} \frac{1.0}{0.75-1} \text{x} \frac{1}{2.5} = 2.7-10.7$$



(A glimse ahead at Q-histograms: faults plot on the left = black)

SRF category b)

STRESS FRACTURING IN (mostly) MASSIVE ROCK

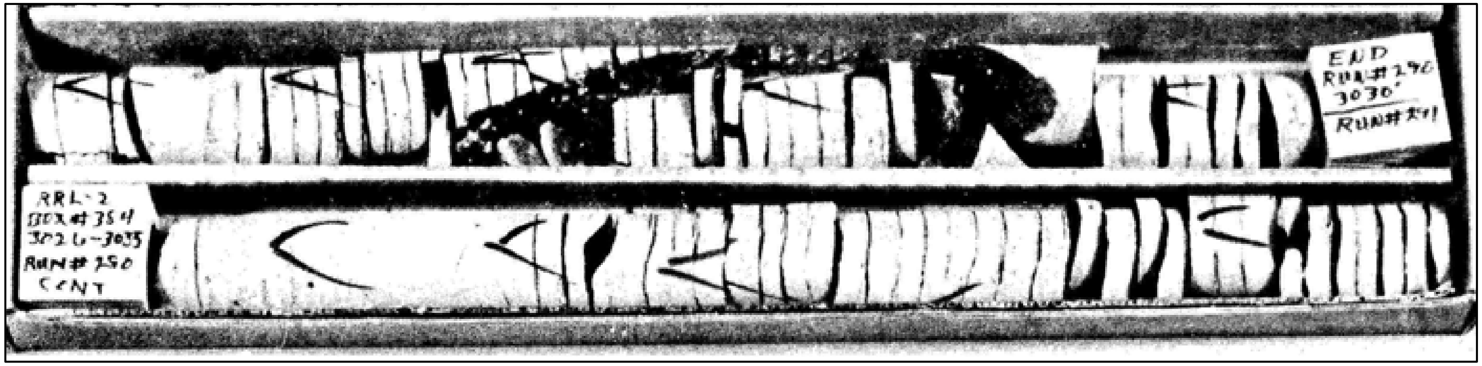
Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.				
b) Competent rock, rock stress problems		σ_c / σ_1	σ_θ / σ_c	**SRF**
H	Low stress, near surface, open joints	>200	<0.01	2.5
J	Medium stress, favourable stress condition	200-10	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

Note: 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).

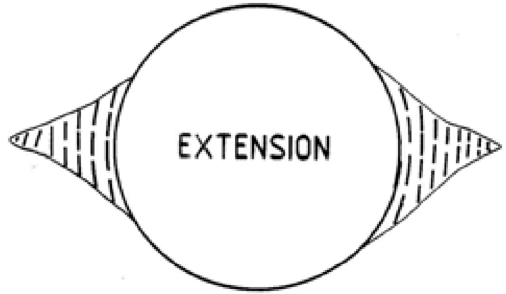
iii) Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2.5 to 5 for such cases (see H).

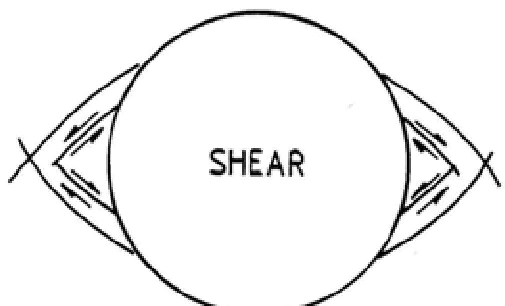
Tell-tale signs of high (valley-side-parallel) stresses in mountain-side

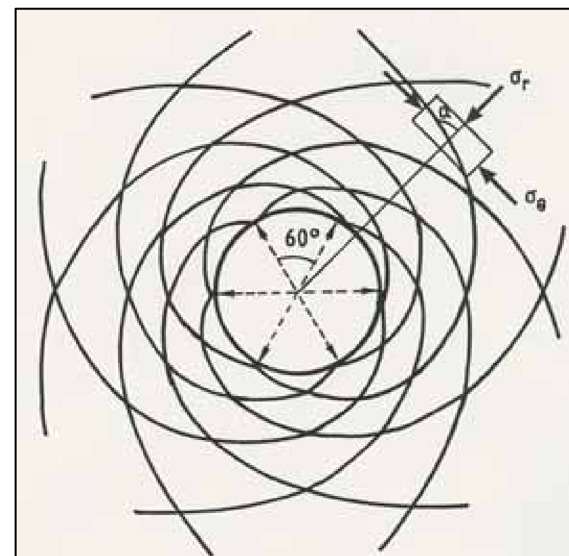
An old way to protect against stress-slabbing (today use B+S fr)



Tell-tale signs of high stress (and anisotropic stress) in core-disking



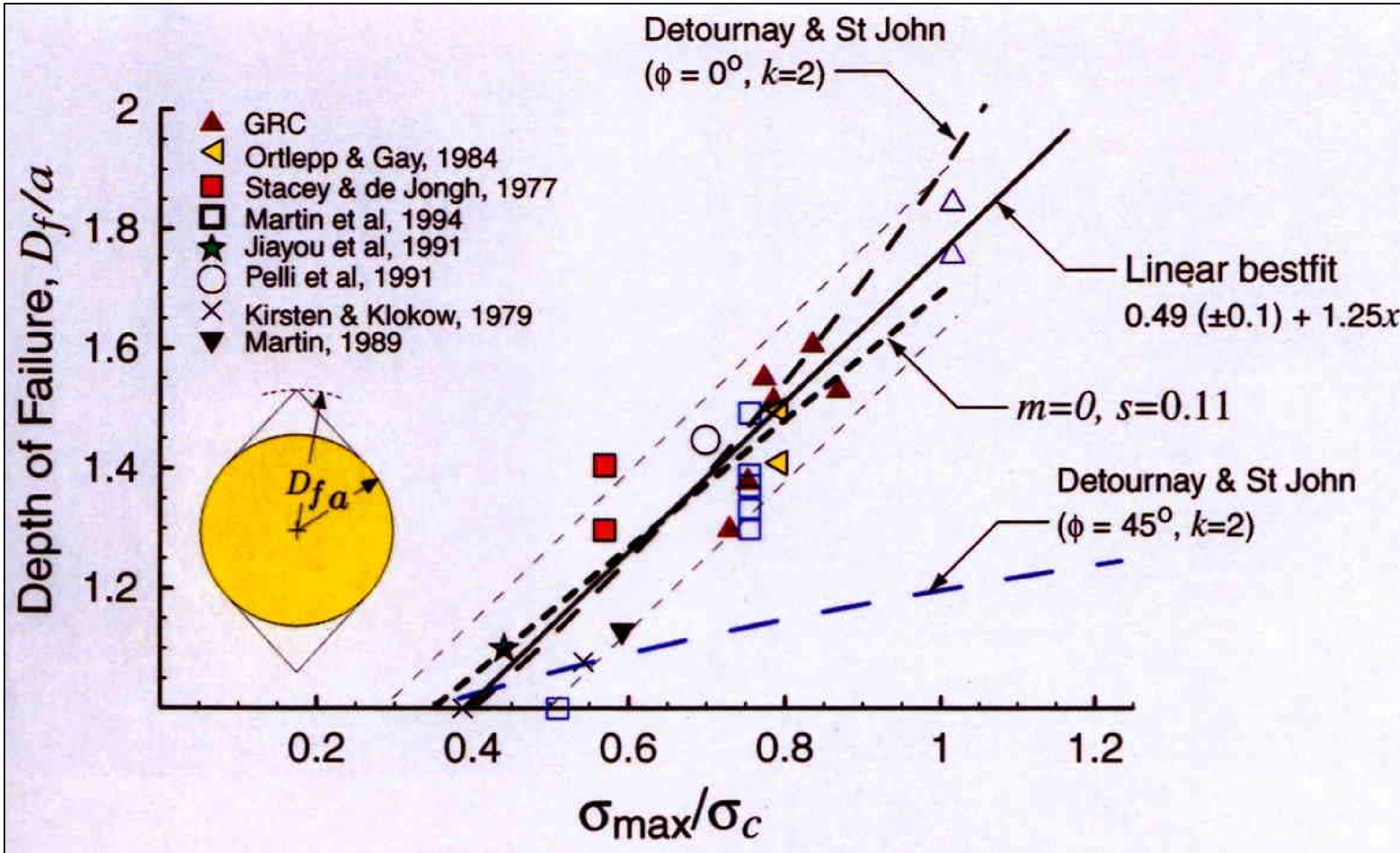




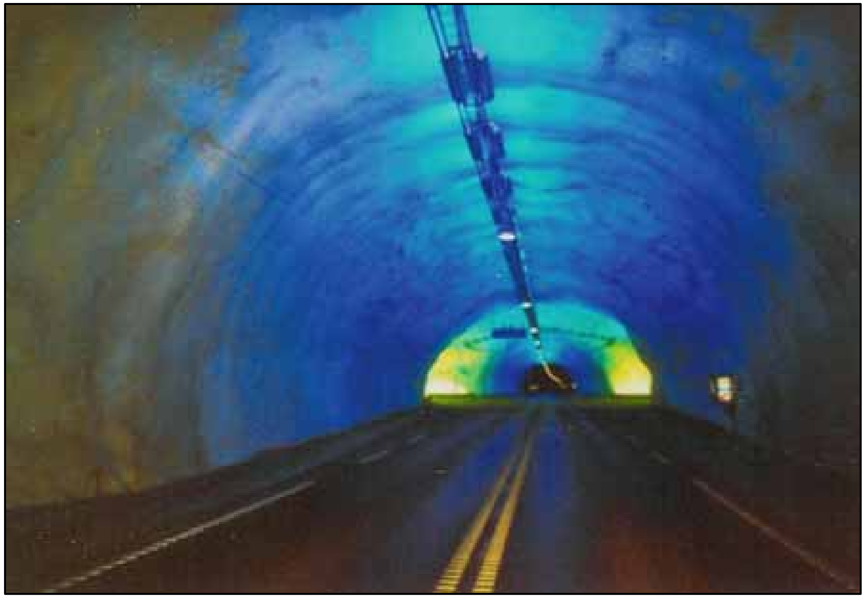
Stress-induced failures in tunnels, a model and theory

Ita HEP, Brazil $\sigma_H \approx 40$ MPa, $\sigma_V \approx 1.5$ MPa at 50m depth (!)
$\sigma_\varphi / \sigma_c \approx 115/200 \approx 0.6$ SRF ≈ 25 to 35
depth of failure/ 'radius' (D_f/a) ≈ (3+7m)/7m ≈1.4
($\sigma_{max} / \sigma_c \approx 0.6$) – see next figure



(from Martin et al. 2002)



Lærdal Tunnel, Norway L =24.5km **1.0 to 1.4km depth $\sigma\varphi / \sigma c \approx 0.6$**

STRESS LEVEL	σ_c/σ_1	σ_θ/σ_c	SRF (old)	SRF (new)
Moderate slabbing after > 1 hour in massive rock	5-3	0.5-0.65	5-9	5-50

See next table for case records

Name	Rock type	Overburden in m	σ_1 MPa	σ_3 MPa	σ_c MPa	Maxσ_θ MPa	σ_c/σ_1	σ_θ/σ_c
Strynefjellet	Banded gneiss	230-600 •	20.4	3.5	47-127	56	4.3	0.4-1.2
Høyanger I	Granitic gneiss	650-800 •	33.4	8.1	100-177	92	3-5.3	0.5-0.9
Høyanger II	Banded gneiss	900-1100 •	29	14	55-126	73	1.9-4.3	0.6-1.3
Kobbskaret	Granite	200-600 *•	26	11.5	90	67	3.5	0.7
Svartisen I	Granite	700 •	21.4	12.1	181	52	8.4	0.3
Svartisen II	Mica gneiss	500 ▽	10.9	8.1	27	25	2.5	0.9
Tafjord	Gneiss, amphib.	500-1200 *▽	24.8	6.6	82-185	68	3.3-7.4	0.4-0.8
Fjærland	Granitic gneiss	600-1200 •	25.7	6.5	110	71	4.2	0.7
Frudalen	Granitic gneiss	900-1200 •▽	30?	20?	70-150	ca. 70	2,3-6.0	0.4-1,0
Tosen	Silicate gneiss	400-600 •	20?	10?	110-200	ca. 50	5.5-10	0.3-0.5
Fodnes	Gabbro, diorite	650-1100 *▽	30?	15?	100-150	ca. 75	3.3-5.0	0.5-0.8
Amla	Gabbro diorite	100-400 •	20?	5-10?	100-150	ca. 50	5-7,5	0.3-0.5
Lærdalstunn.	Banded gneiss	800-1400 •	40?	22?	100-150	ca. 100	2,5-3,8	0,7-1,0
Stetind	Granite	300-500? *▽	9,3	3,8	90	24	10	0,3
Pehuenche, Chile	Andesite ✣	400-1200 ▽	35?	15?	100-150	ca. 75	2.9-4,3	0.5-0.8
Ertan, China	Gabbro, diorite	300 -400 *•	40?	15?	105-160	ca. 90	2.7-4.5	0.6-0.9

Survey of deep Norwegian road tunnels with stress fracturing (Grimstad, 1996)

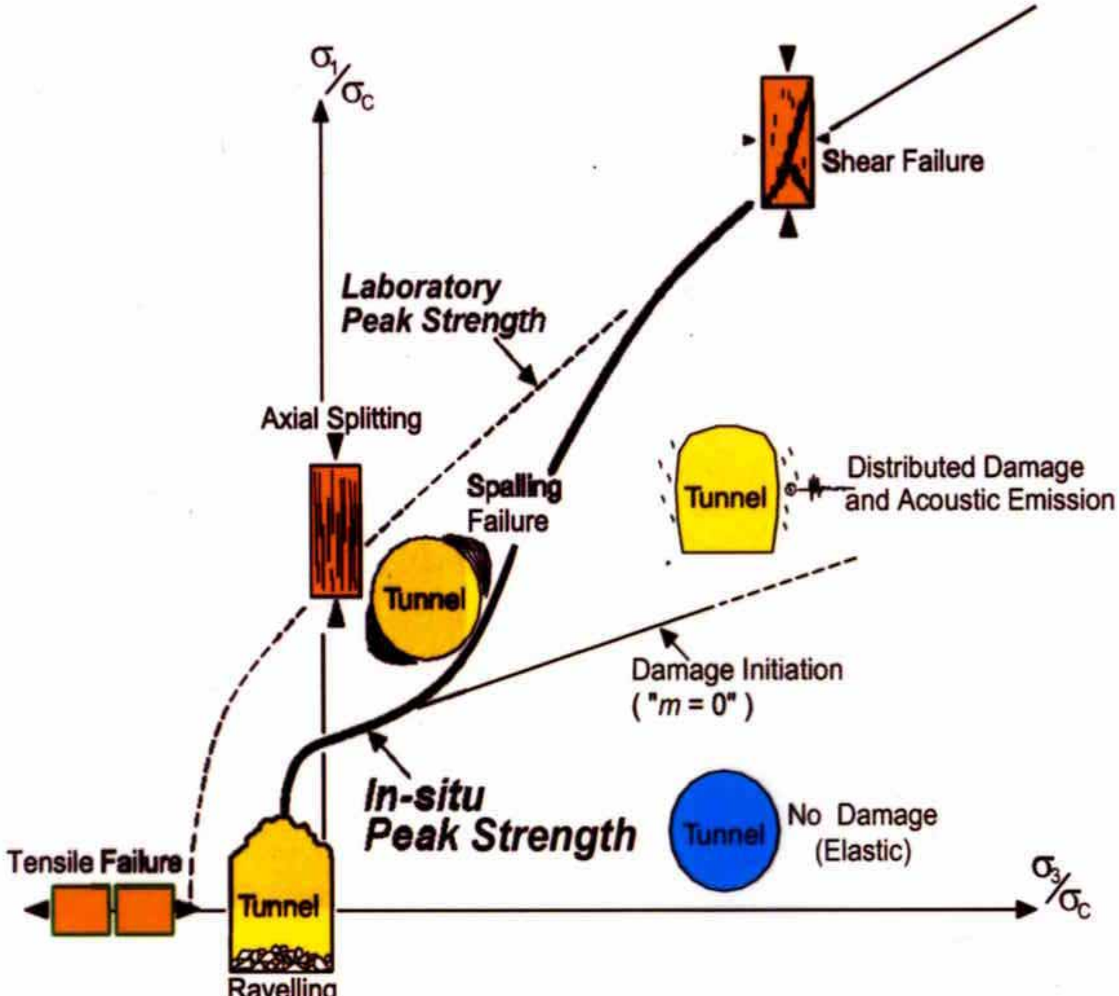
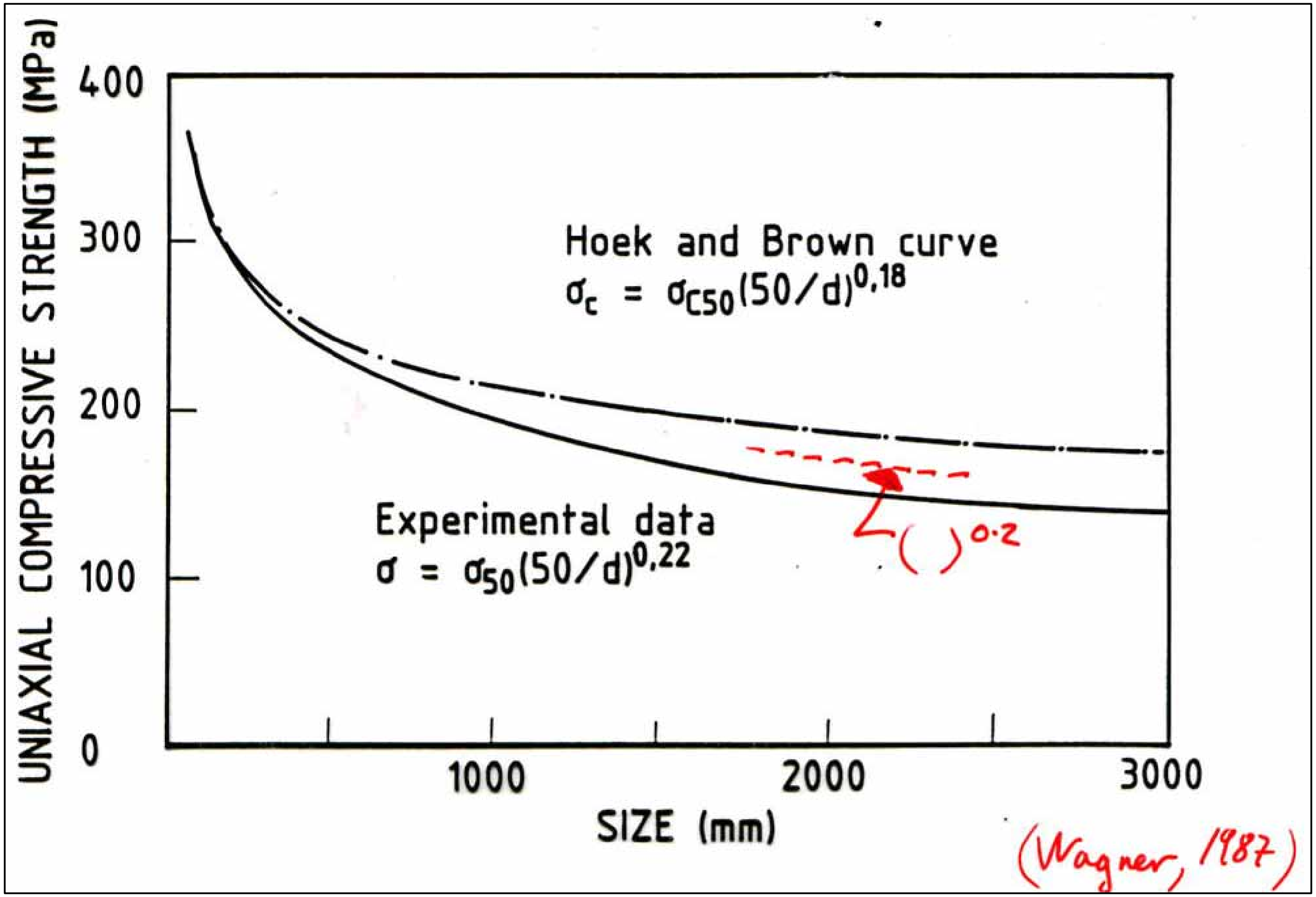
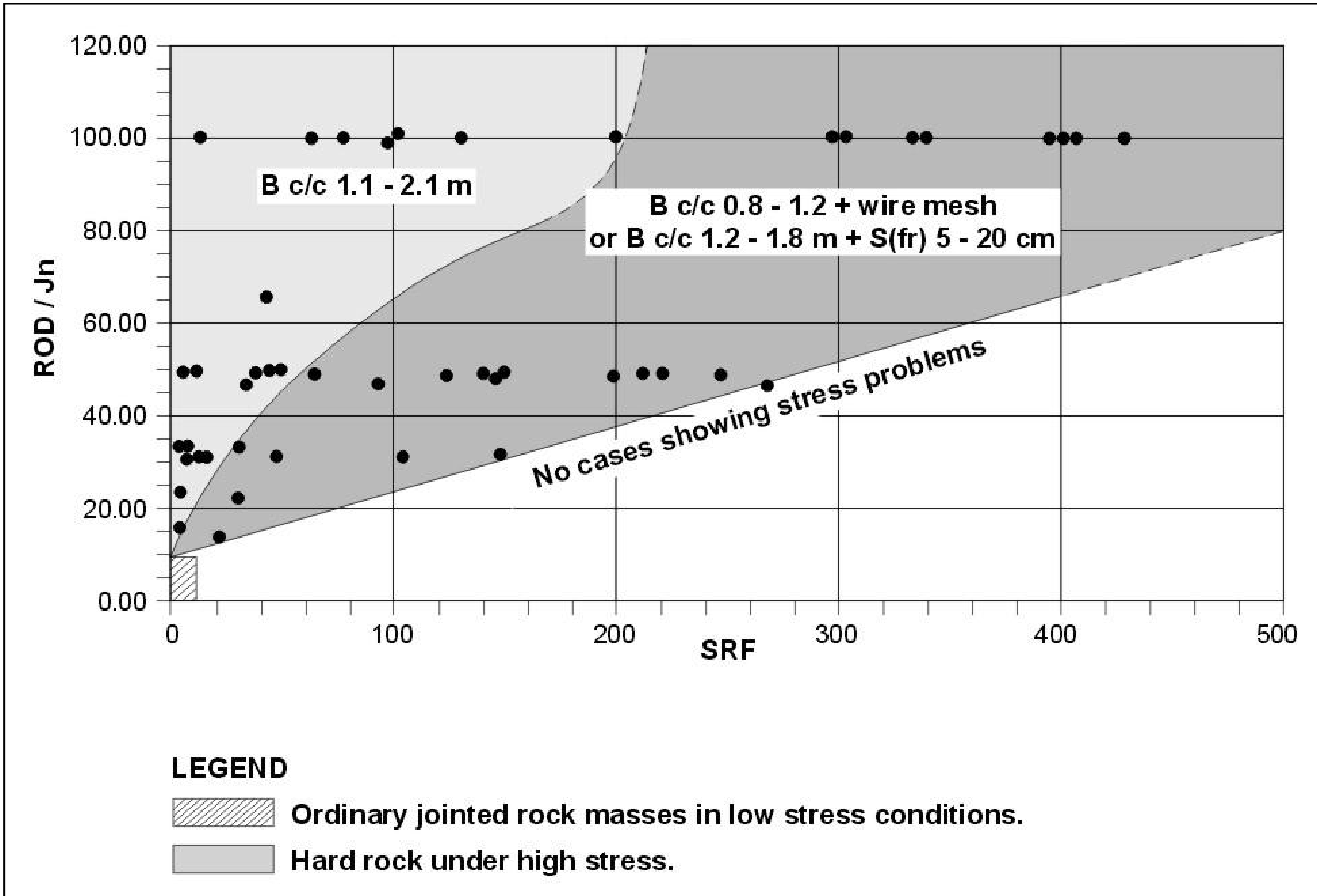


Figure 11: *Schematic of failure envelope for brittle failure, showing four zones of distinct rock mass failure mechanisms: no damage, shear failure, spalling, and unravelling (after Diederichs*

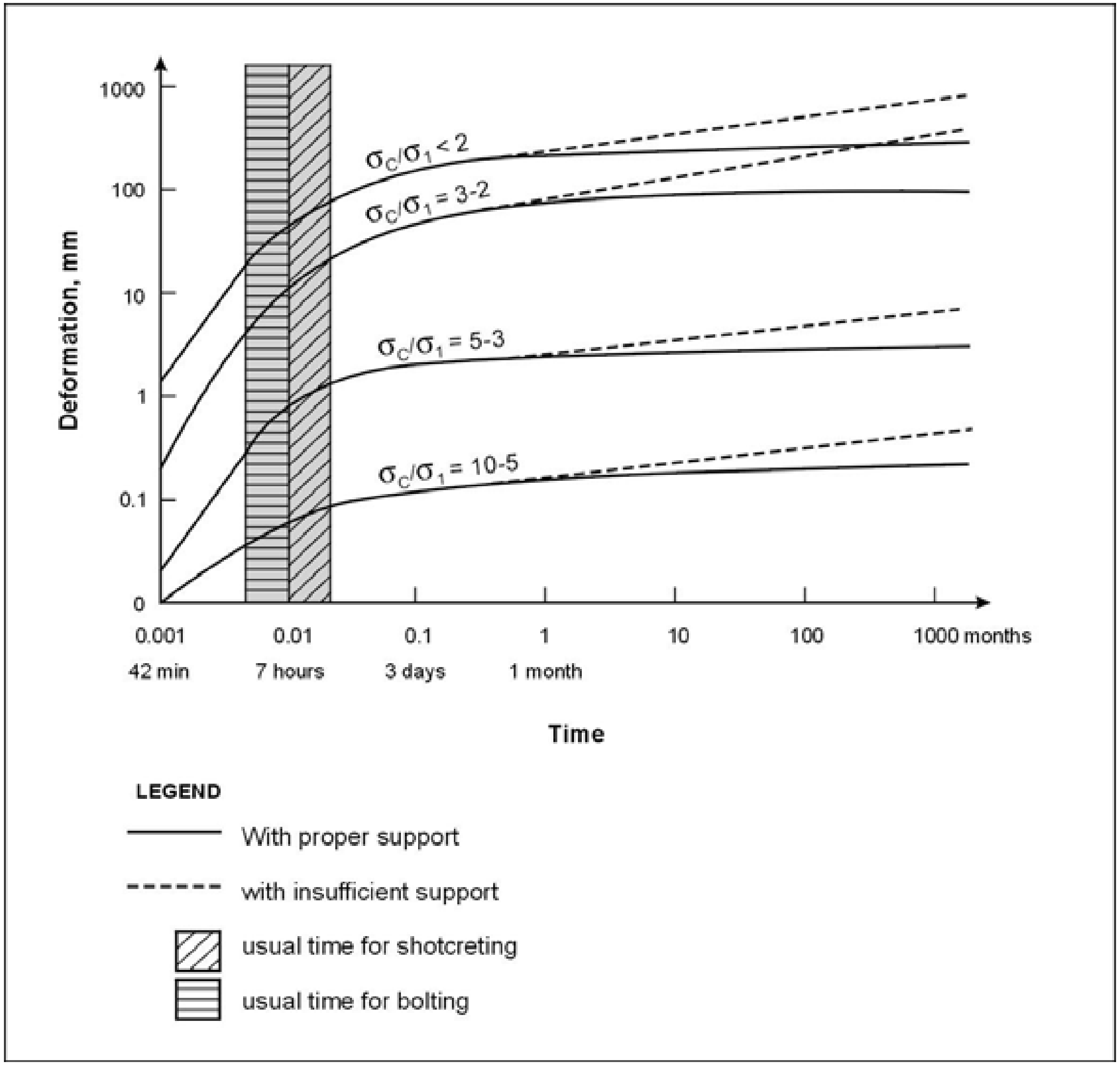


Hoek and Brown UCS scaling curve, Wagner mining data, NB 1987 '0.2' suggestion



Grimstad and Barton 1993.

Near-surface example of high tangential stresses. NB'71



Grimstad, 1996

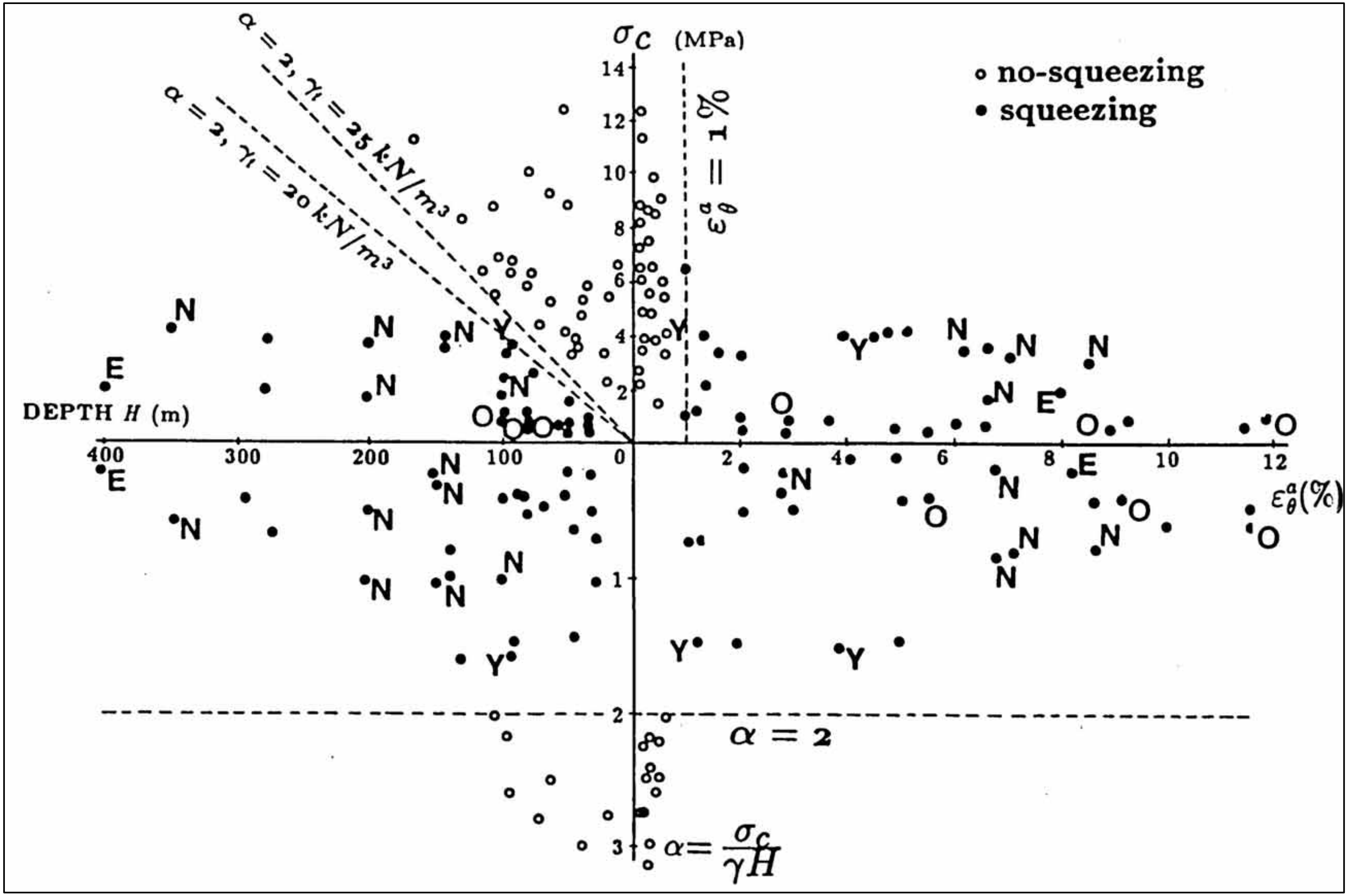
SRF category c)

SQUEEZING and SWELLING

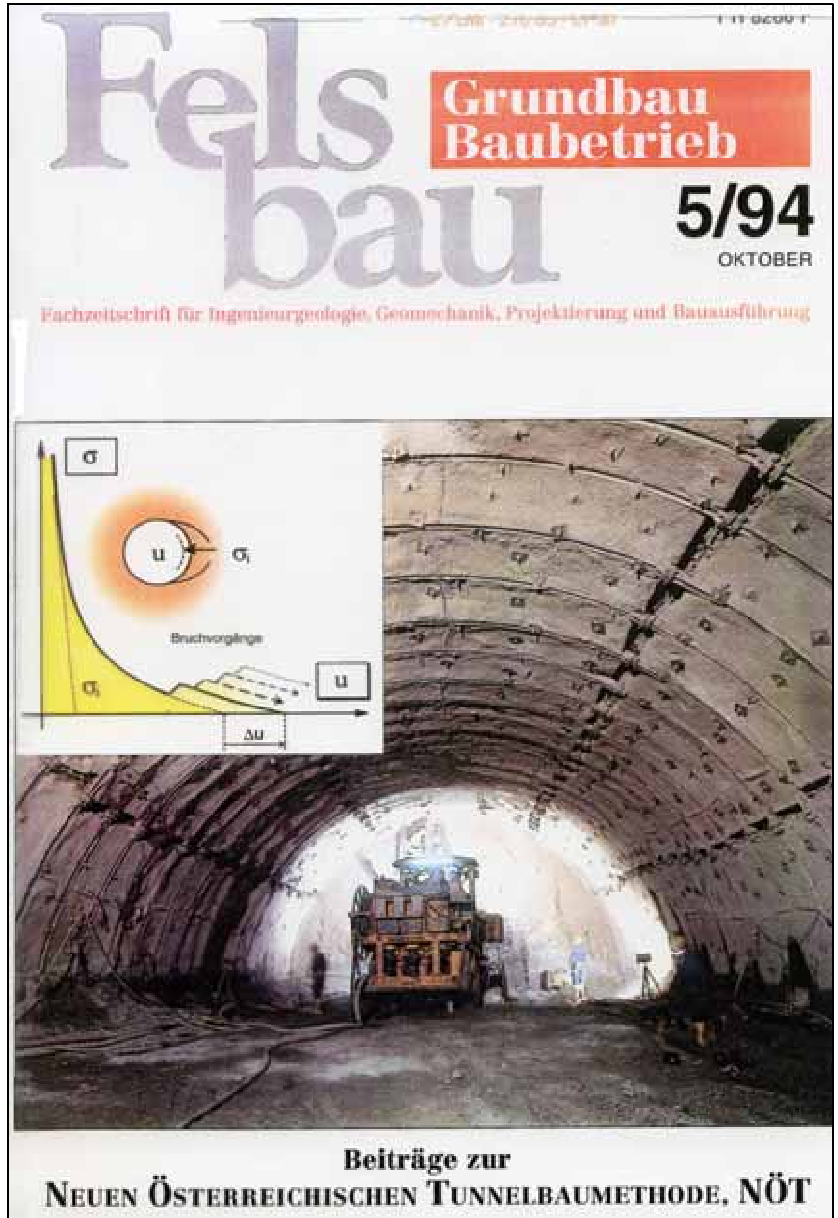
c) ***Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure***		σ_θ / σ_c	SRF
O	Mild squeezing rock pressure	1-5	5-10
P	Heavy squeezing rock pressure	>5	10-20
Note: iv) Cases of squeezing rock may occur for depth $H > 350\ Q^{1/3}$ (Singh *et al.*, 1992). Rock mass compression strength can be estimated from $q \approx 7\ \gamma\ Q^{1/3}$ (MPa) where γ = rock density in gm/cc (Singh, 1993).			
d) ***Swelling rock: chemical swelling activity depending on presence of water***			
R	Mild swelling rock pressure		5-10
S	Heavy swelling rock pressure		10-15

Hydrothermally altered granite containing montmorillonite
(SRF = 15, or higher? - extreme tunnel closure of 4m!)

ANTICIPATED SQUEEZING. MOTORWAY UP-AND-DOWN LANES DIVERGED BY ABOUT 3 (OR 4?) TUNNEL DIAMETERS (SRF = 20 ?)



Squeezing criteria for Japanese tunnels (Aydan)



Felsbau

Grundbau Baubetrieb

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Beiträge zur

NEUEN ÖSTERREICHISCHEN TUNNELBAUMETHODE, NÖT

Fig. 2. Yielding steel elements in the laboratory test; left: at the beginning of buckling, right: after approx. 120 mm of axial deformation

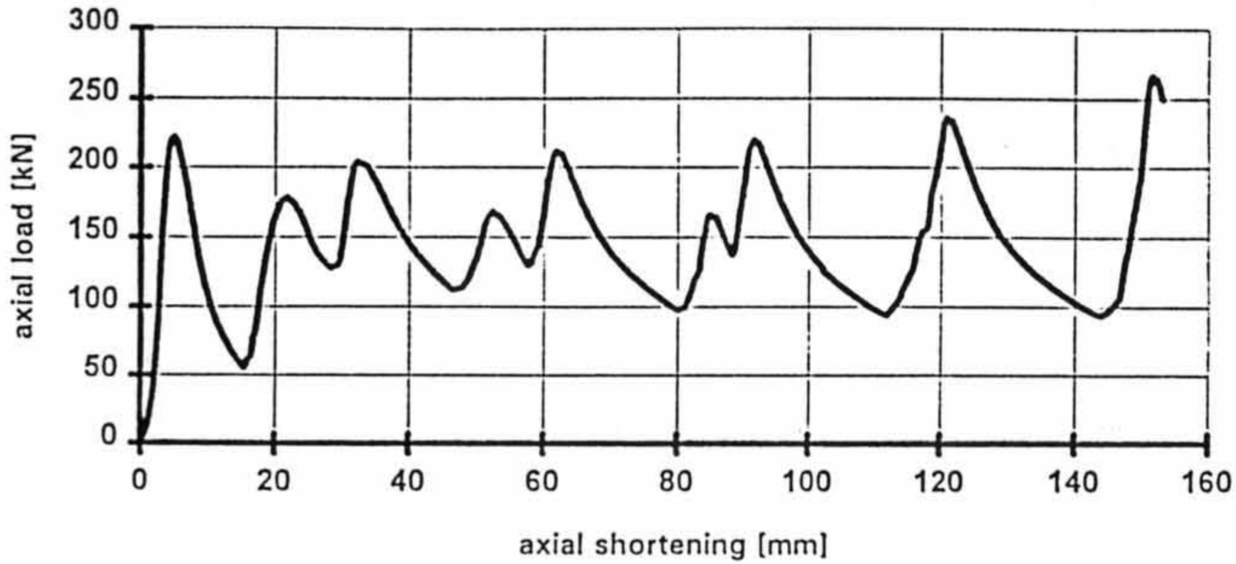
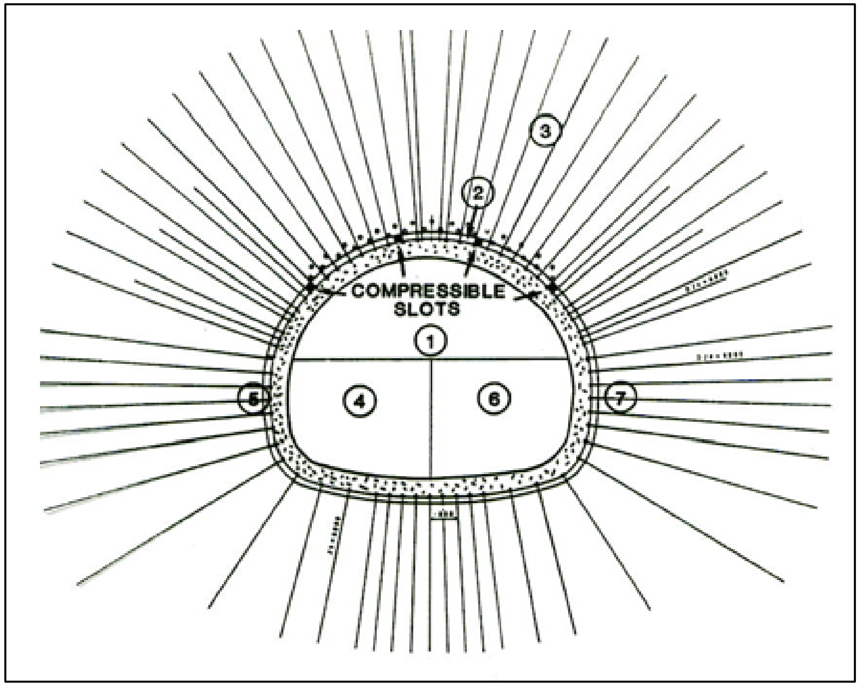
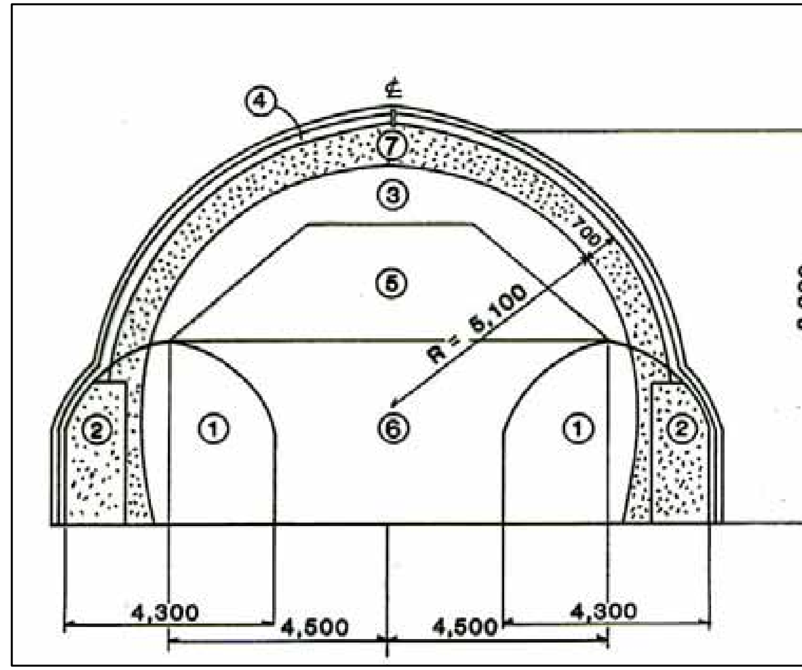


Fig. 3. Load line of perforated yielding element





ENESAN TUNNEL, JAPAN

(1000m cover, squeezing and swelling)

1.2km bolts/m! due to breakage

Failure modes typical in tunnels
(see examples in accompanying Figures)

	Description	Mode of behaviour
1	Hard, massive, brittle rocks that dilate during failure even when stresses are high. Stress-induced failure may be delayed as ‘strength corrosion’ occurs	Extension failure, thin-walled stress-slabbing, dynamic ejection, bursting. The symmetric ‘dog-eared’ fall-out due to the anisotropic stresses may have a ‘nose’. Deformations can be large.
2	Hard or medium hard, bedded and jointed rock that can shear and dilate along structural planes, while under moderate to high stress levels	Anisotropic response. Shear stress dissipates by slight shear on bedding planes and joints. Deformations are moderate. Block falls can occur.
3	Soft, massive, non-brittle rocks that may, or may not dilate during shear failure. Typical for young e.g. Tertiary rocks such as the mudstones and siltstones in Japan	Failure may occur by log-spiral shear development and tangential strain. Radial deformations are large, and pressure on support is high. (Twin tunnels need pillars 4 to 5 times their span c.f. Japan, Taiwan)
4	Very soft, plastic rocks (and clays) that contract when sheared under significant stress levels.	Post peak strength loss reaches an extreme of virtual “flow”, tunnel closure can occur.

Q RMR comparison

RMR – ROCK MASS RATING

	(MPa)		(%)		(m)		(-)		(-)
=	σ_C	+	RQD	+	S	+	$J_{condition}$	+	Water
	(0 – 15)		(3 – 20)		(5 – 20)		(0 – 30)		(0 – 15)

+ orientation adjustment (0 to *minus* 12) for tunnels
(0 to *minus* 60) for slopes

Theoretical range of RMR ≈ 5 to 100

$$Q = RQD/Jn \times J_r/J_a \times J_w/SRF$$

RQD%	Joint roughness	Water
number of sets	Joint alteration	Stress/Strength

10 to 100 (actual)	**0.5 to 5**	**0.05 to 1.0**
0.5 to 20	**0.75 to 20**	**0.5 to 400**

Theoretical range of Q ≈ 0.001 to 2000

Note that 'σ_c' and 'S' (spacing) do not occur in the Q-value estimate, only indirectly in stress/strength (SRF) and in RQD

Note that 'Jn' (number of sets) and 'stress' do not occur in RMR

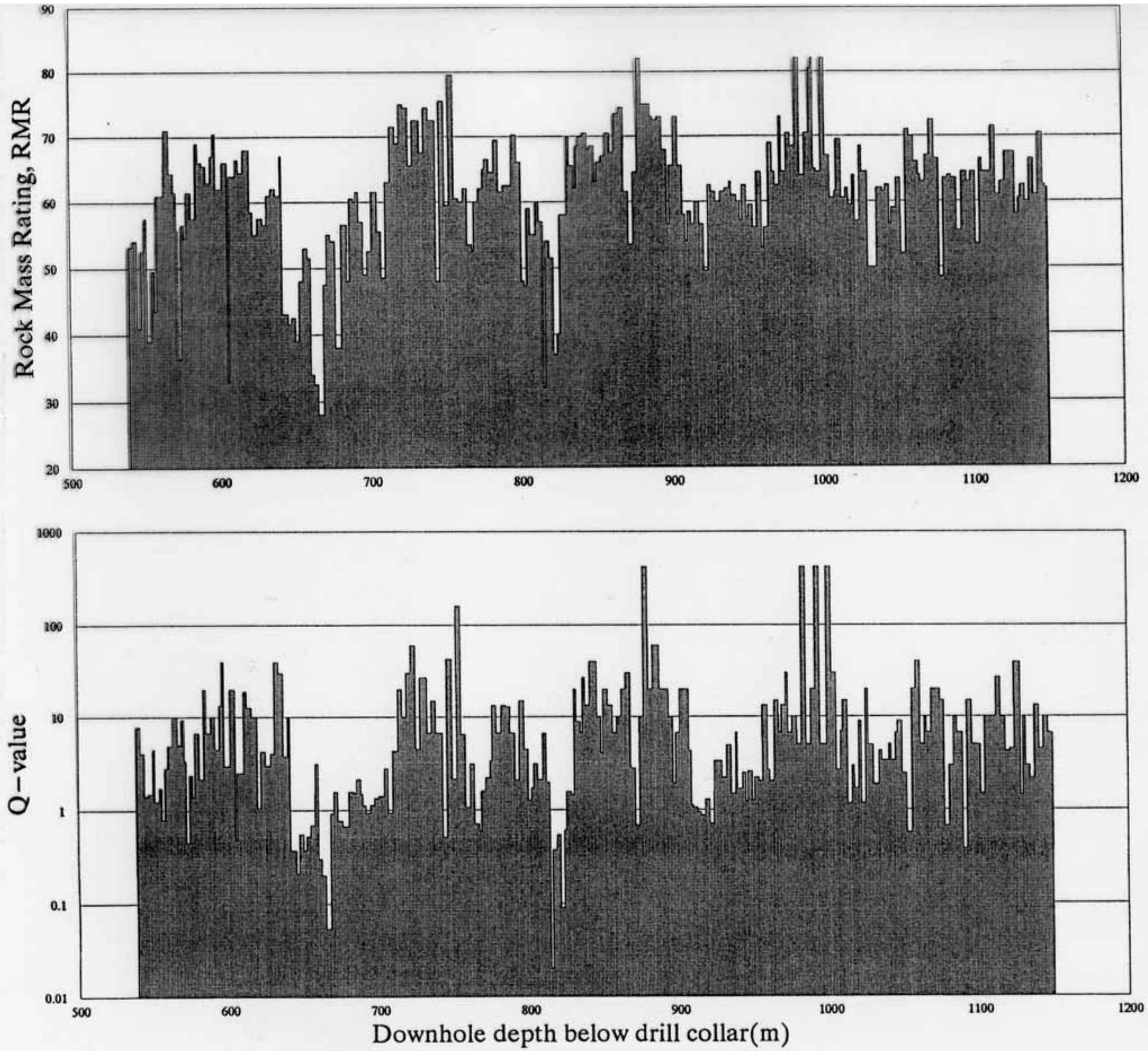
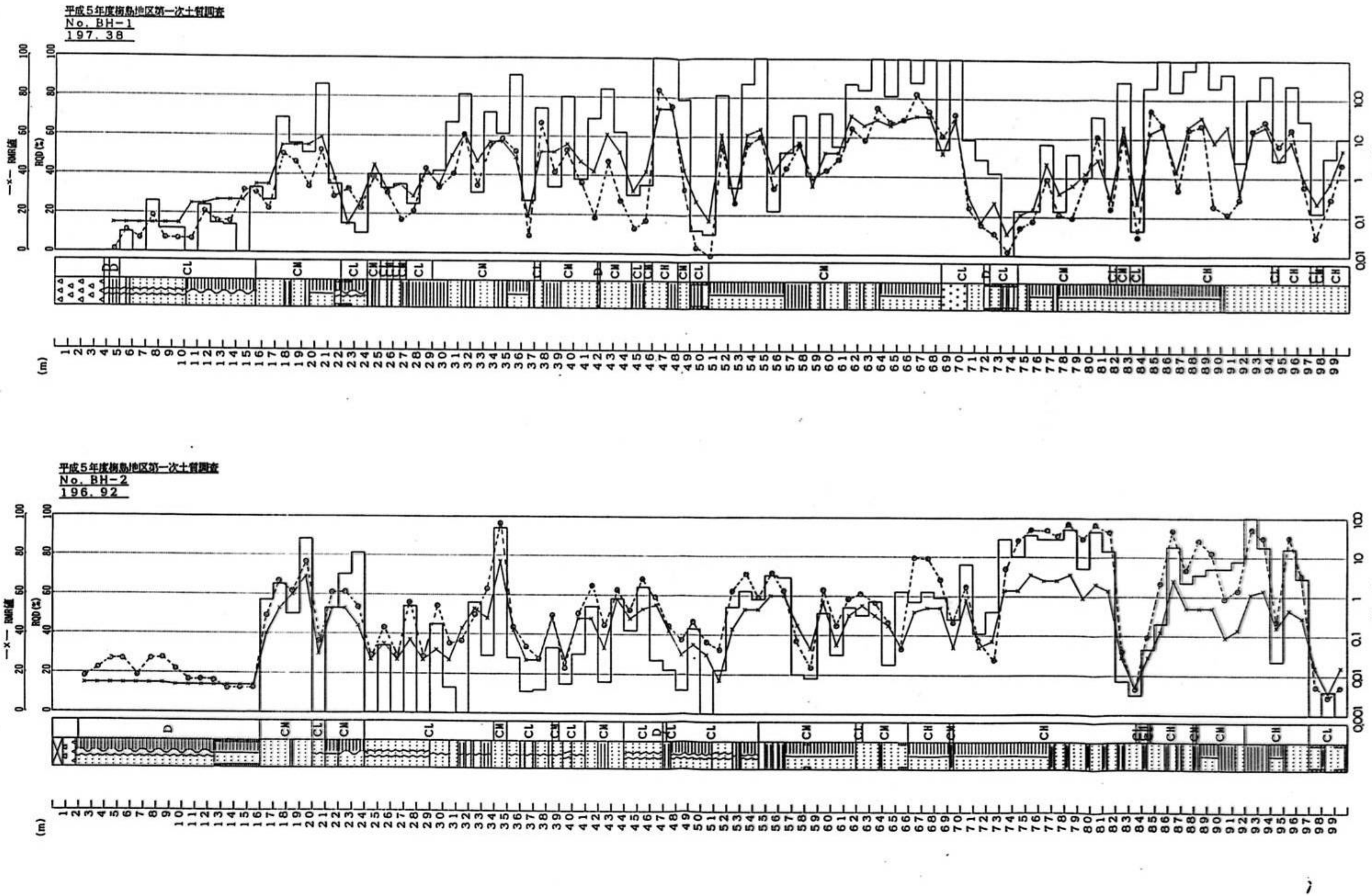
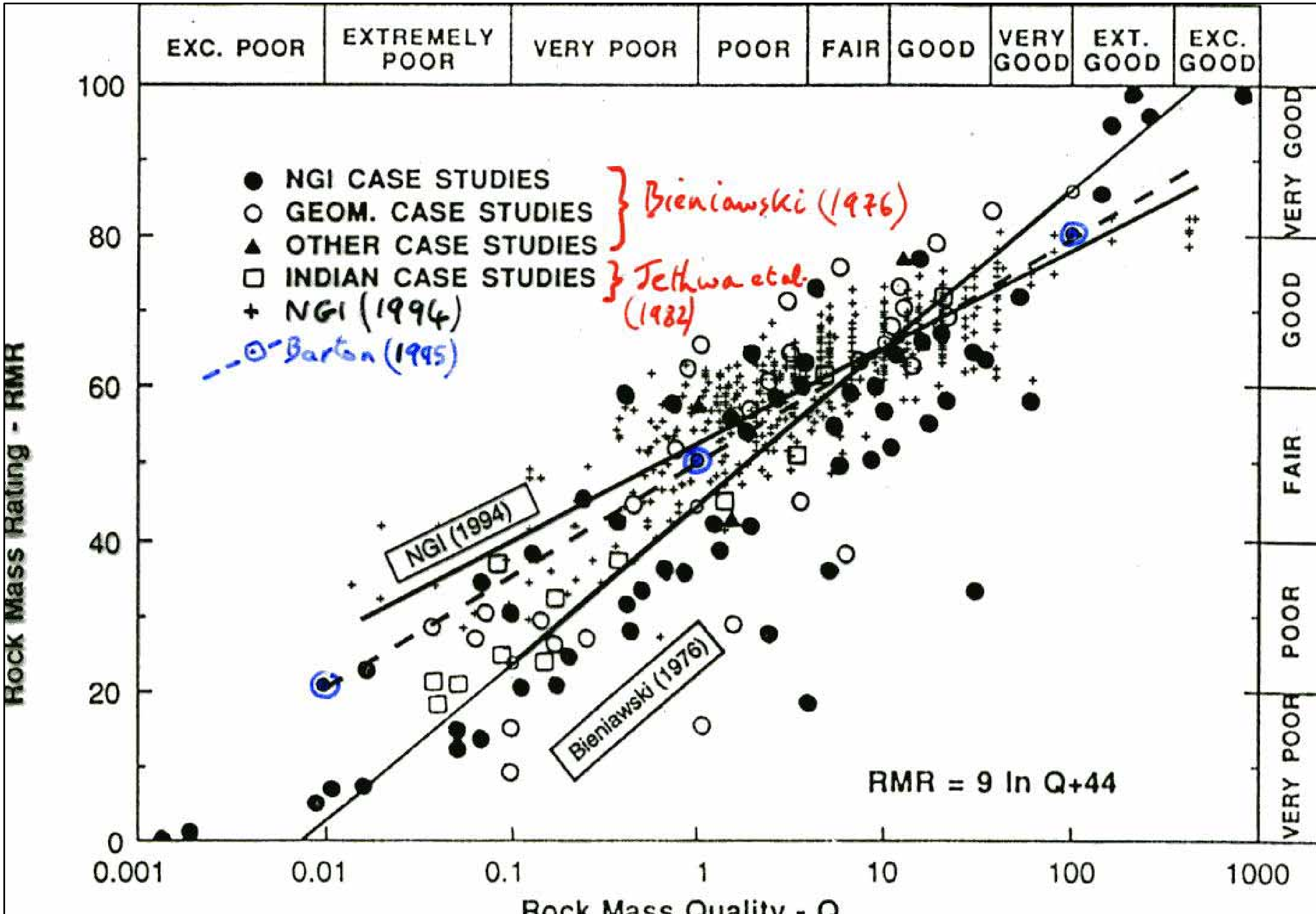


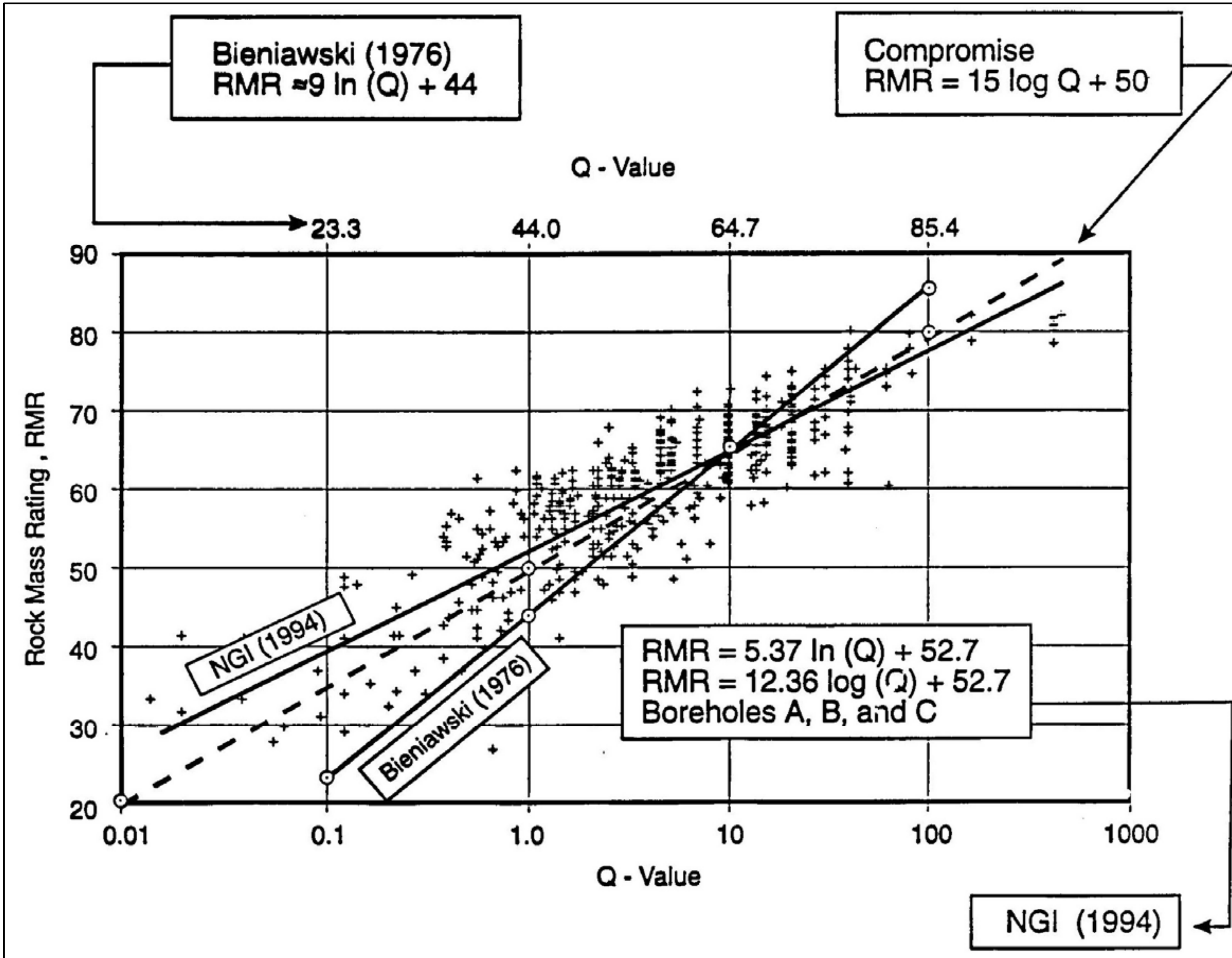
Figure 19 A comparison of Q and RMR logging. NGI Contract Report, 1994.



図－5.3.4　水平ボーリング孔のＲＱＤとＲＭＲ，Ｑ値の変化図

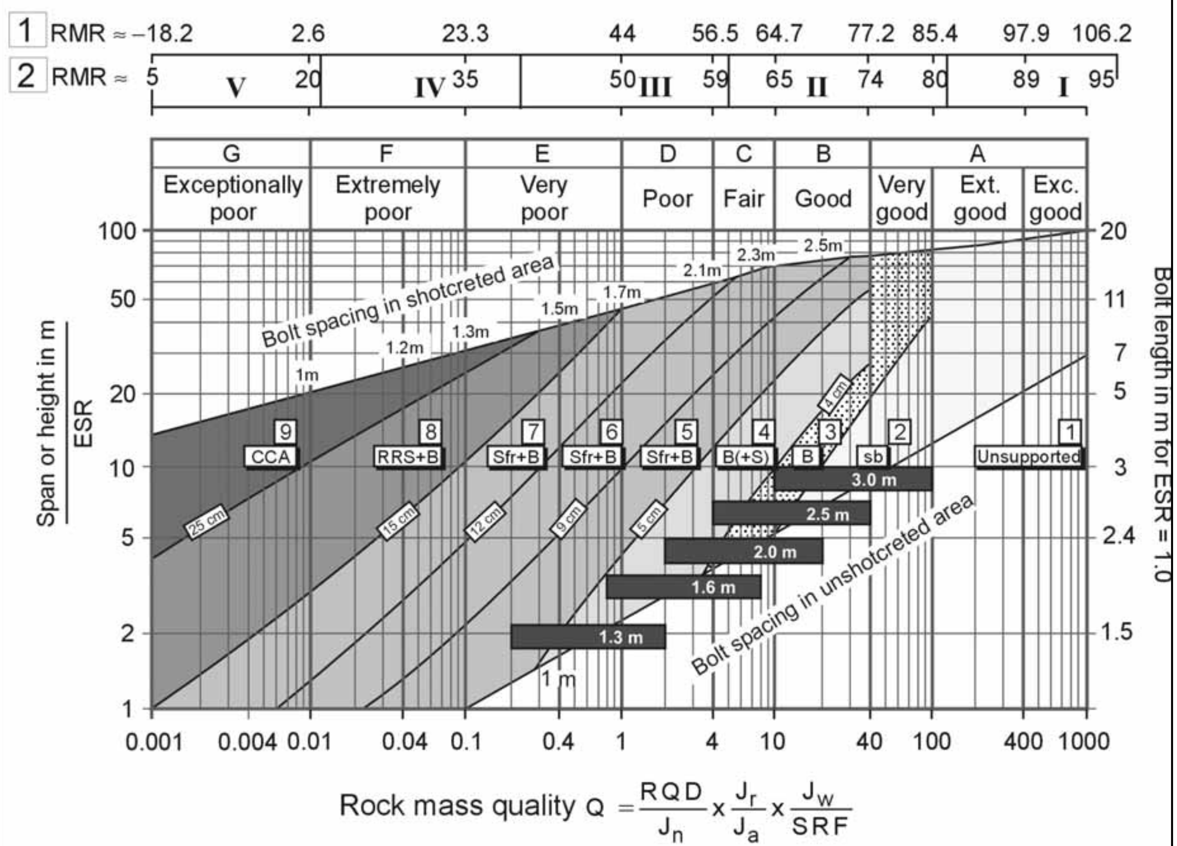


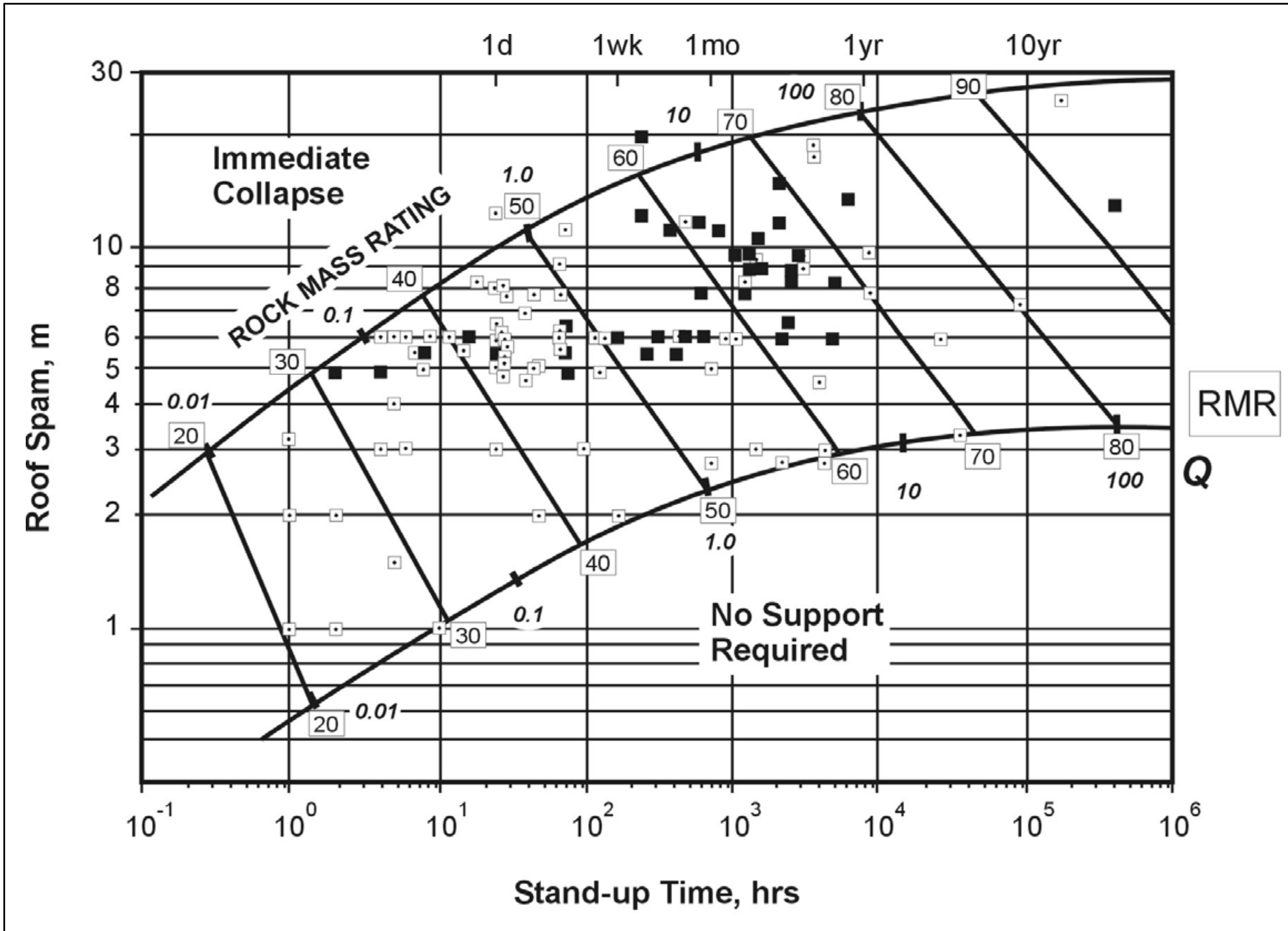
EXC. POOR
EXTREMELY POOR
VERY POOR
POOR
FAIR
GOOD
VERY GOOD
EXT. GOOD
EXC. GOOD
NGI CASE STUDIES
GEOM. CASE STUDIES
OTHER CASE STUDIES
INDIAN CASE STUDIES
NGI (1994)
Barton (1995)
Bieniawski (1976)
Jethwa et al. (1982)
NGI (1994)
Bieniawski (1976)
RMR = 9 ln Q+44
Rock Mass Rating - RMR
Rock Mass Quality - Q
0
20
40
60
80
100
0.001
0.01
0.1
1
10
100
1000
VERY POOR
POOR
FAIR
GOOD
VERY GOOD


Bieniawski (1976)
RMR ≈9 ln (Q) + 44
Compromise
RMR = 15 log Q + 50
Q - Value
23.3
44.0
64.7
85.4
Rock Mass Rating , RMR
90
80
70
60
50
40
30
20
NGI (1994)
Bieniawski (1976)
RMR = 5.37 ln (Q) + 52.7
RMR = 12.36 log (Q) + 52.7
Boreholes A, B, and C
0.01
0.1
1.0
10
100
1000
Q - Value
NGI (1994)

$RMR \approx 9 \ln Q + 44$ (Bieniawski, 1989) $\quad Q \approx e^{\frac{(RMR-44)}{9}}$ [1]

$RMR \approx 15 \log Q + 50$ (Barton, 1995) $\quad Q \approx 10^{\frac{(RMR-50)}{15}}$ [2]

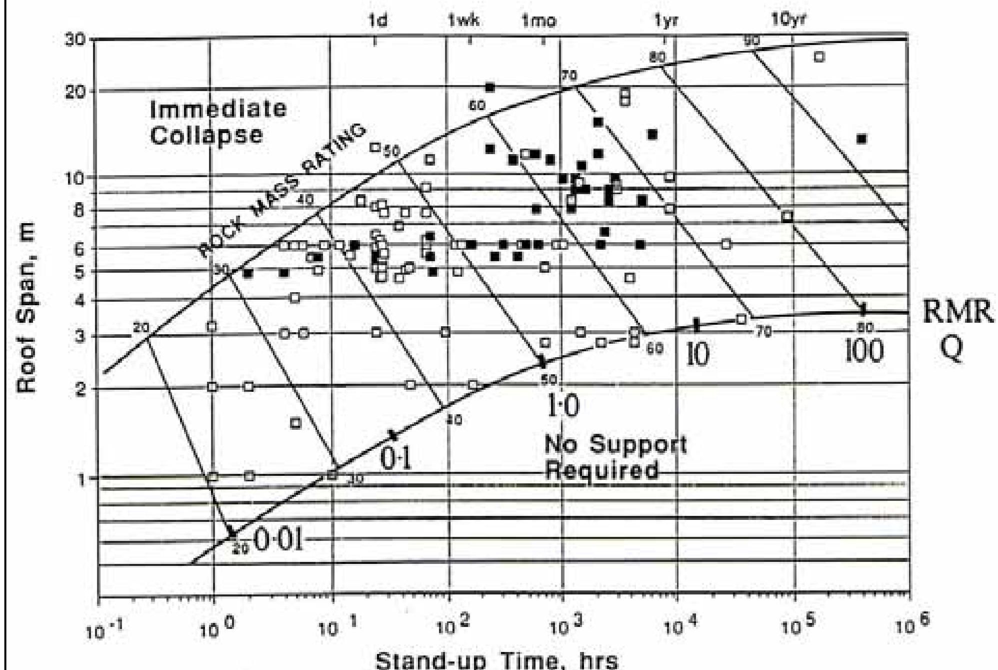




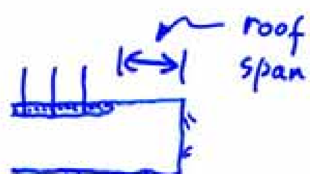
1d
1wk
1mo
1yr
10yr
Immediate Collapse
ROCK MASS RATING
No Support Required
RMR
Q
Roof Spam, m
Stand-up Time, hrs

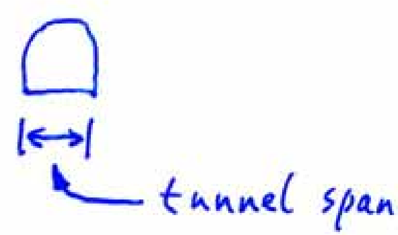
Assume $RMR \approx 15 \log_{10} Q + 50$

NB'95



Bieniawski 1989





HISTOGRAM LOGGING TO CAPTURE VARIATION …….. AND TO SPEED LOGGING

(for use on surface, on core, or in tunnel)

NB! Decide if characterization or classification for tunnel support

1. **<u>For general *characterization* of rock masses</u> 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.**

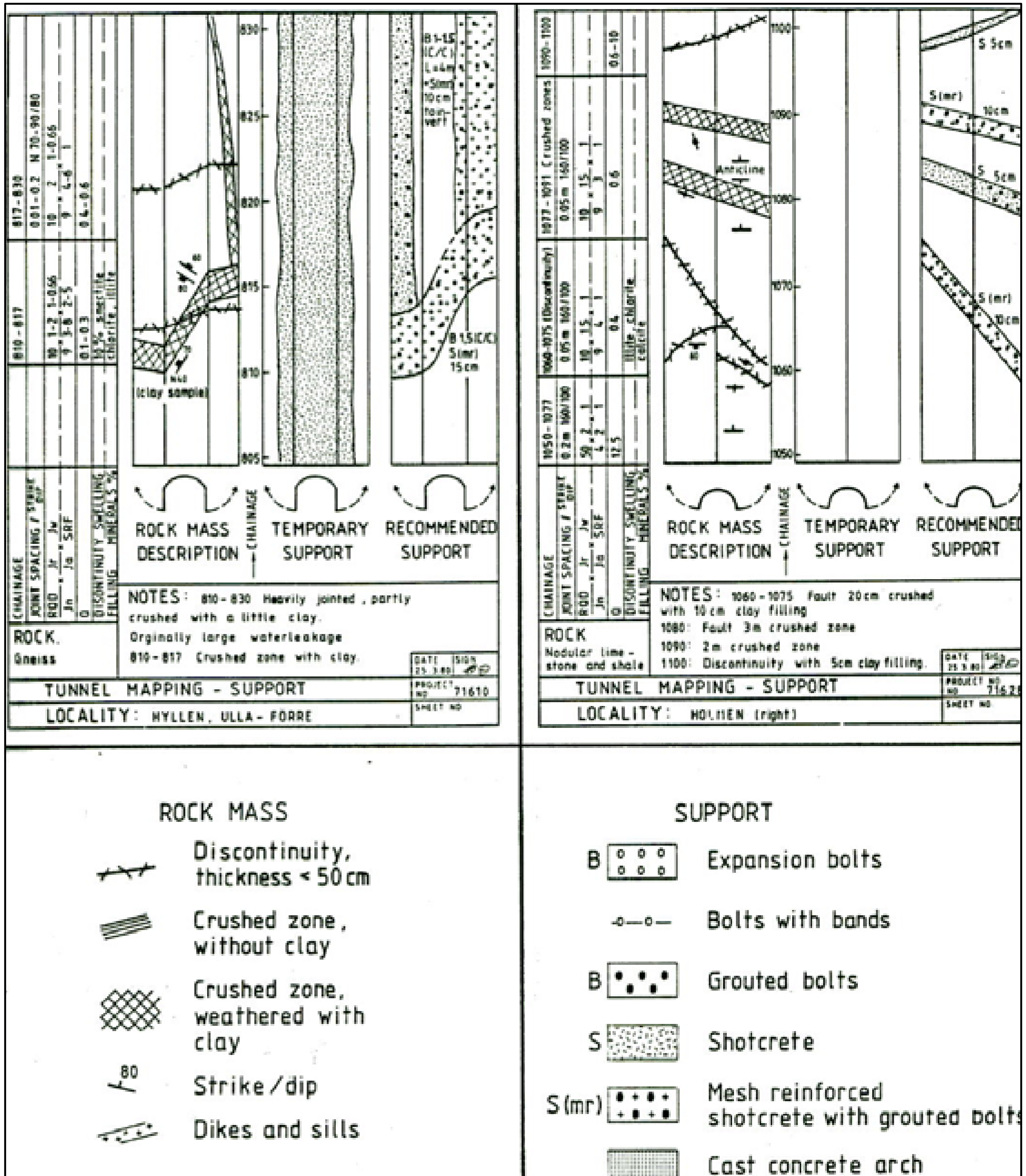
2. **<u>For general *characterization* of rock masses</u> distant from excavation influences, the use of SRF = 5, 2.5, 1.0, and 0.5 is recommended as depth increases from say 0-5m, 5-25m, 25-250m to >250m.**

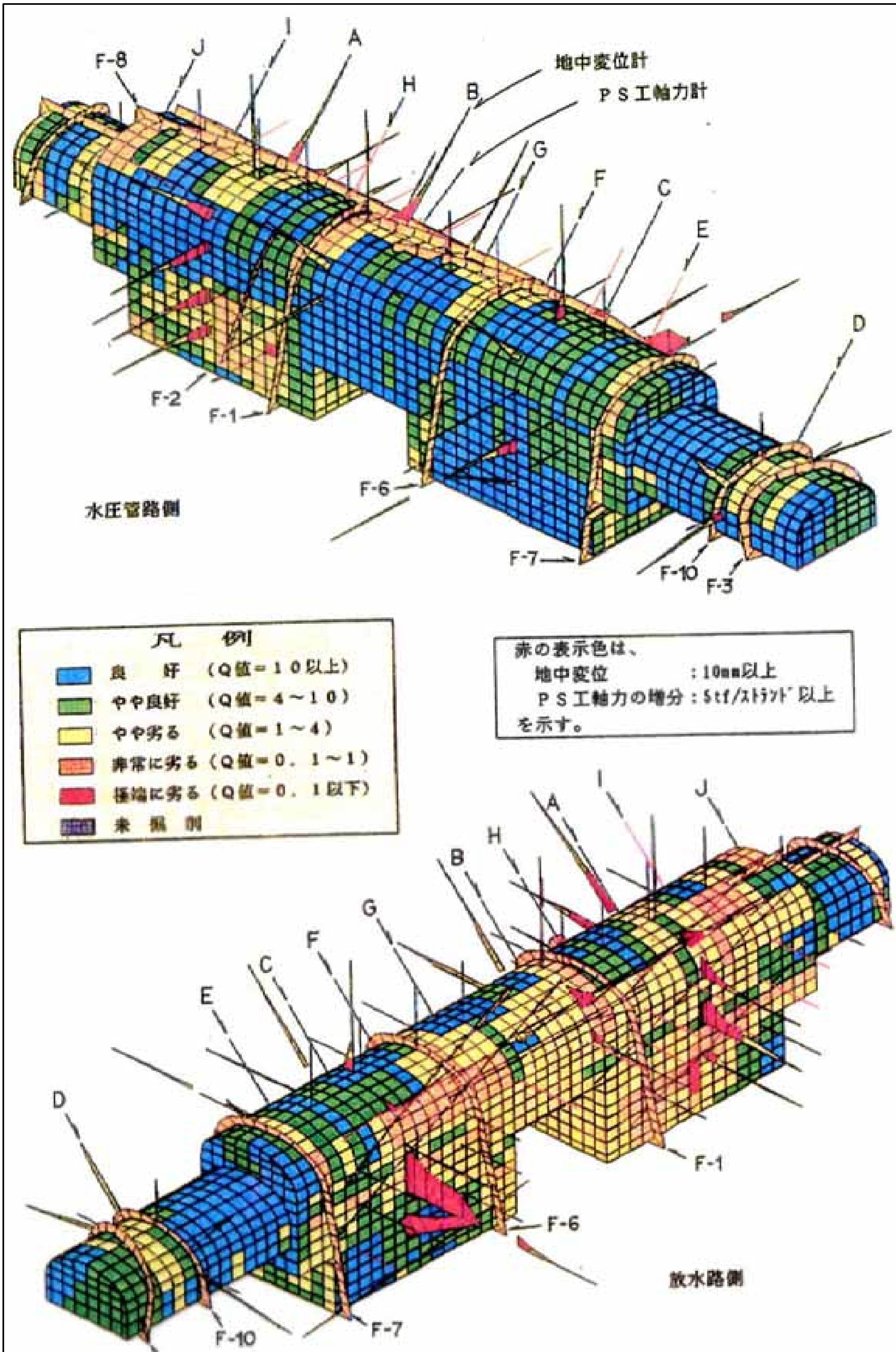
- **Remember RQD/Jn represents relative block size – and this may be different in *classification* (for tunnel support), and in *characterization* (no tunnel). SRF will also be different.**

- ***Massive, highly stressed rock masses with high cohesive strength suffer the greatest reduction in block-size and cohesive strength, as a result of stress-induced fracturing around deep excavations.***

- **However, this does not occur prior to excavation, so the *characterization* rating and the empirical tunnel design *classification* rating may differ considerably.**

Now we will see some Q-logging methods →


ROCK MASS DESCRIPTION
CHAINAGE
TEMPORARY SUPPORT
RECOMMENDED SUPPORT
NOTES: 810 - 830 Heavily jointed, partly crushed with a little clay. Orginally large waterleakage 810 - 817 Crushed zone with clay.
ROCK. Gneiss
TUNNEL MAPPING - SUPPORT
LOCALITY: HYLLEN, ULLA-FORRE
NOTES: 1060 - 1075 Fault 20cm crushed with 10 cm clay filling
1080: Fault 3m crushed zone
1090: 2m crushed zone
1100: Discontinuity with 5cm clay filling.
ROCK Nodular lime-stone and shale
LOCALITY: HOLMEN (right)
ROCK MASS
Discontinuity, thickness < 50 cm
Crushed zone, without clay
Crushed zone, weathered with clay
Strike / dip
Dikes and sills
SUPPORT
Expansion bolts
Bolts with bands
Grouted bolts
Shotcrete
Mesh reinforced shotcrete with grouted bolts
Cast concrete arch



地質観察・計測結果の３次元表示

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

Note: ii) Where RQD is reported or measured as ≤ 10 (including 0), a nominal value of 10 is used to evaluate Q.

i) 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 - 1.0
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

Note: i) For 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 10cm 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

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

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

Note: i) Add 1.0 if the mean spacing of the relevant joint set is greater than 3m.
ii) $J_r = 0.5$ can be used for planar slickensided joints having lineations, provided the lineations are oriented for minimum strength.

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 10cm 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 <5mm thickness)	16-24°	6.0
H Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness)	12-16°	8.0
J Swelling-clay fillings, i.e., montmorillonite (continuous, but <5mm thickness). Value of J_a depends on percent of swelling clay-size particles, and access to water, etc.	6-12°	8-12
c) No rock-wall contact, when sheared (thick mineral fillings)		
K, L, M 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
O, P, R 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 pressure in competent rock with unfilled joints	2.5-10	0.5
D Large inflow or high pressure, considerable outwash of joints 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

Note: 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.

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 ≤ 50m)	5
C Single weakness zones containing clay or chemically disintegrated rock (depth of excavation > 50m)	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 ≤ 50m)	5.0
F Single shear zones in competent rock (clay-free) (depth of excavation > 50m)	2.5
G Loose, open joints, heavily jointed or "sugar cube", etc. (any depth)	5.0

Note: i) Reduce these values of SRF by 25-50% if the relevant shear zones only influence but do not intersect the excavation.

b) Competent 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

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

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

Note: iv) Cases of squeezing rock may occur for depth $H > 350\,Q^{1/3}$ (Singh et al., 1992). Rock mass compression strength can be estimated from $q \approx 0.7\,\gamma\,Q^{1/3}$ (MPa) where γ = rock density in kN/m³ (Singh, 1993).

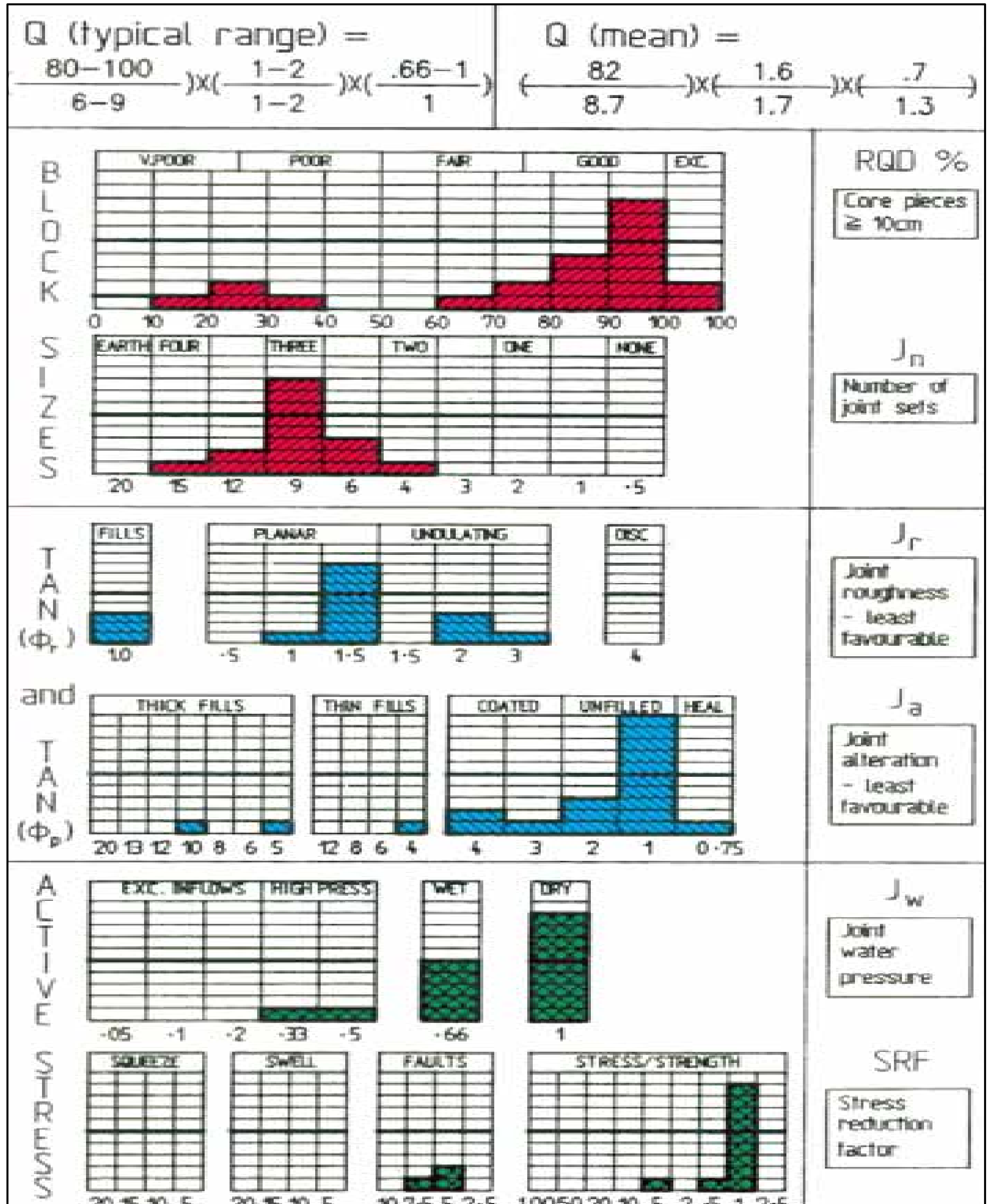
d) Swelling rock: chemical swelling activity depending on presence of water	SRF
R Mild swelling rock pressure	5-10
S Heavy swelling rock pressure	10-20

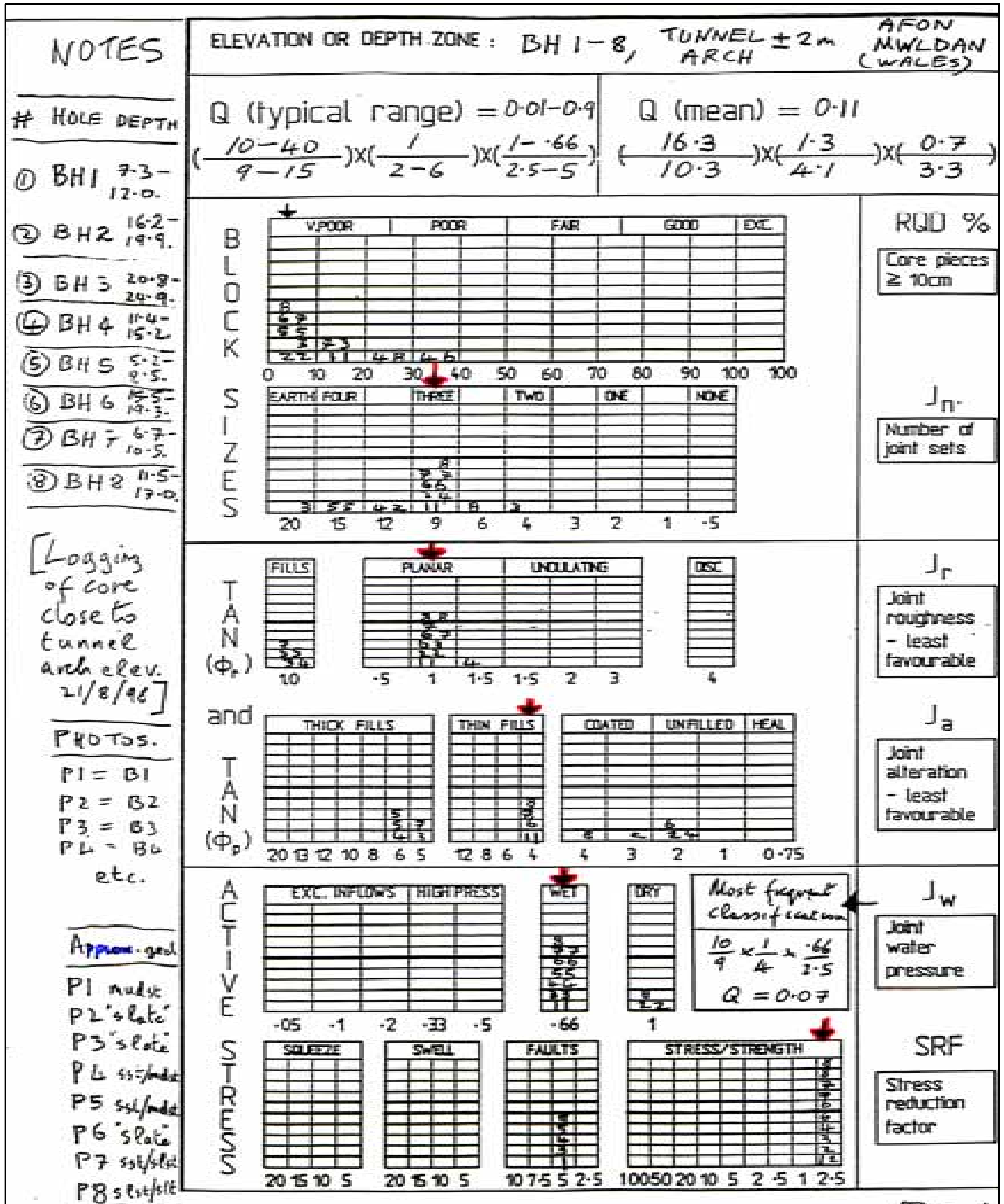
Note: J_r and J_a classification is applied to the joint set or discontinuity that is least favourable for stability both from the point of view of orientation and shear resistance, τ (where $\tau \approx \sigma_n \tan(J_r/J_a)$).

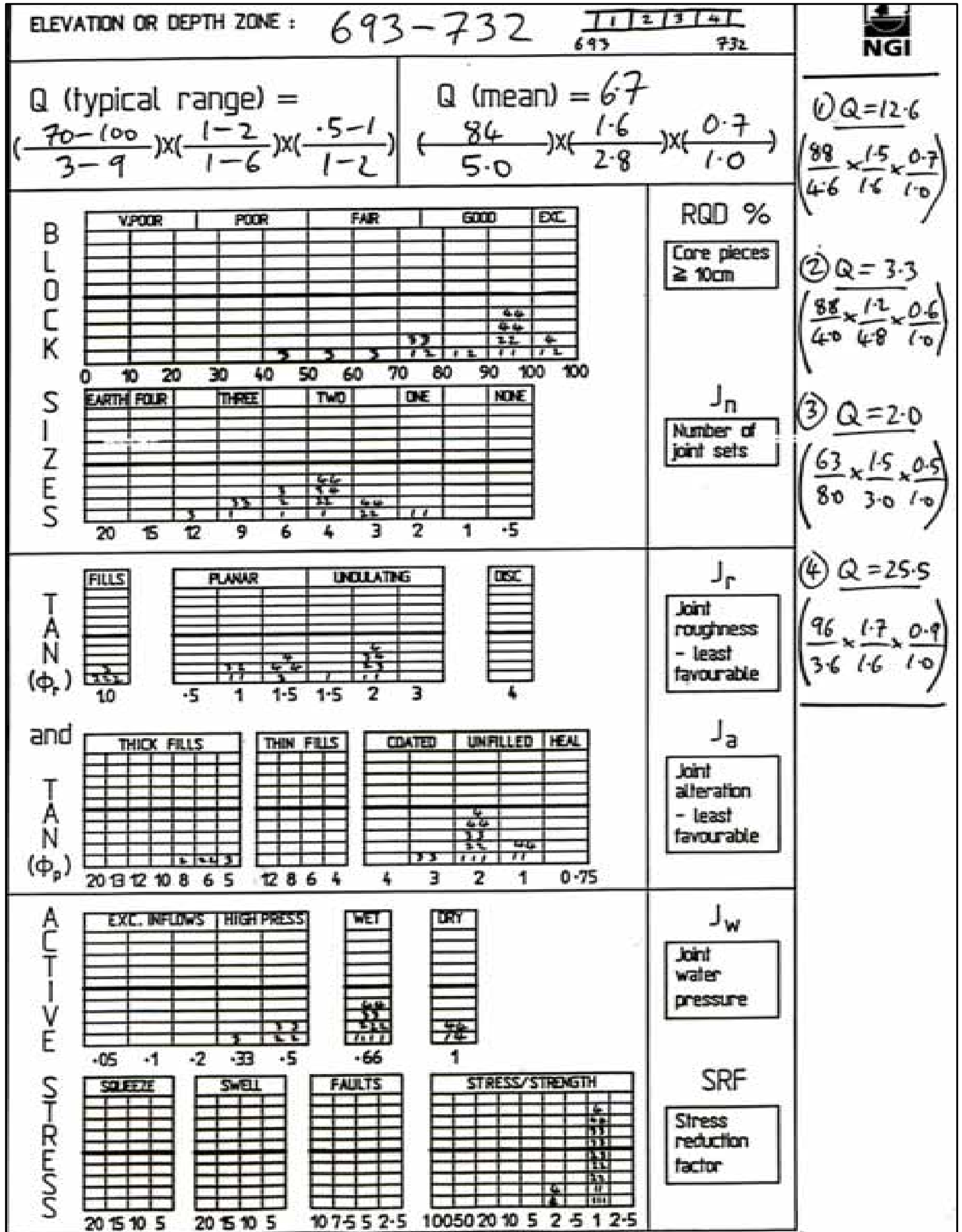
$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Table 2. Ratings for the six Q-system parameters (SRF updates by Grimstad and Barton, 1993).

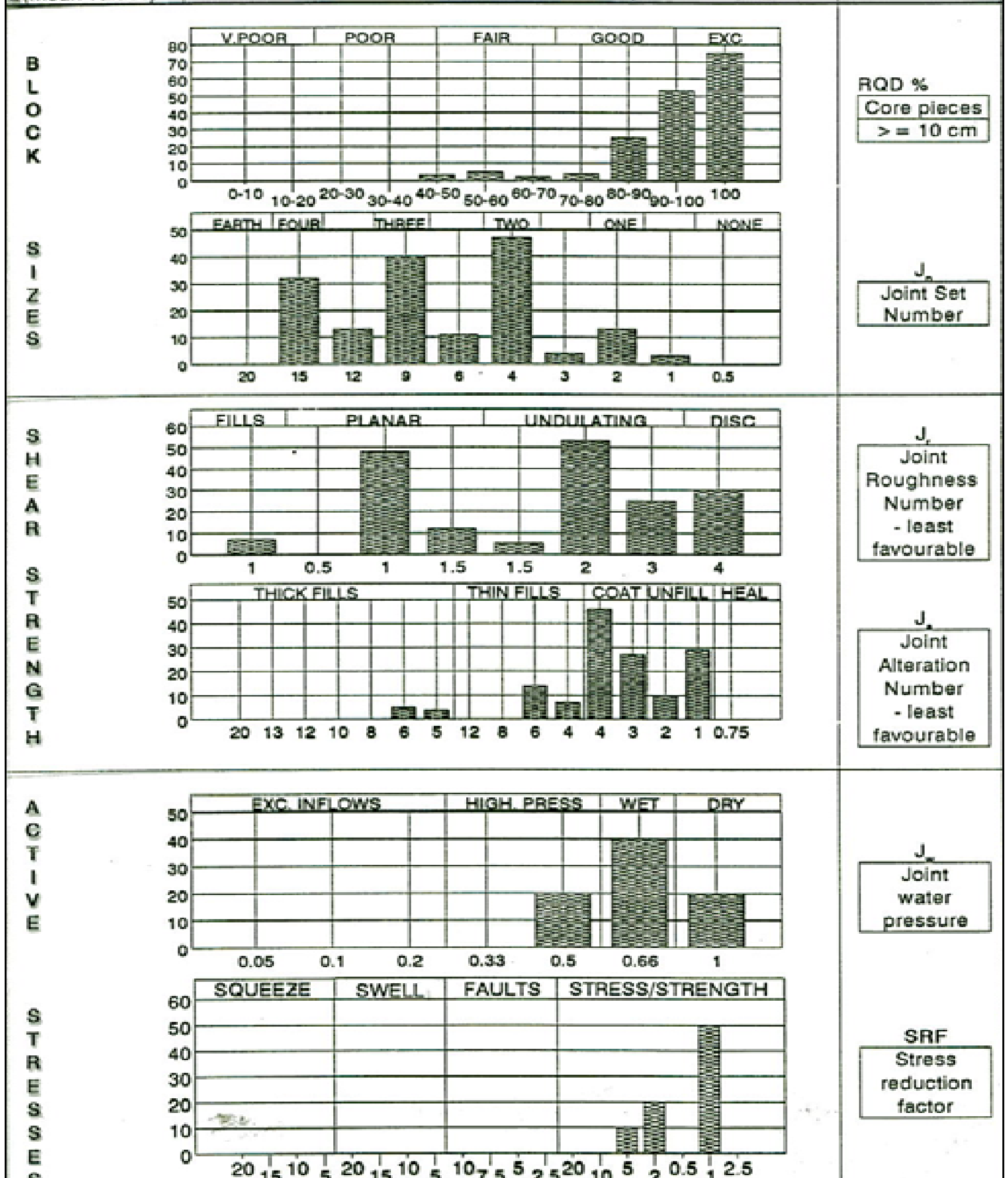
$$\bar{Q} \approx \frac{60}{6} \times \frac{2}{2} \times \frac{1.0}{2.5} \approx 4 \qquad Q_c \approx 4 \times \left(\frac{10 \to 20}{100}\right) \text{ MPa}$$

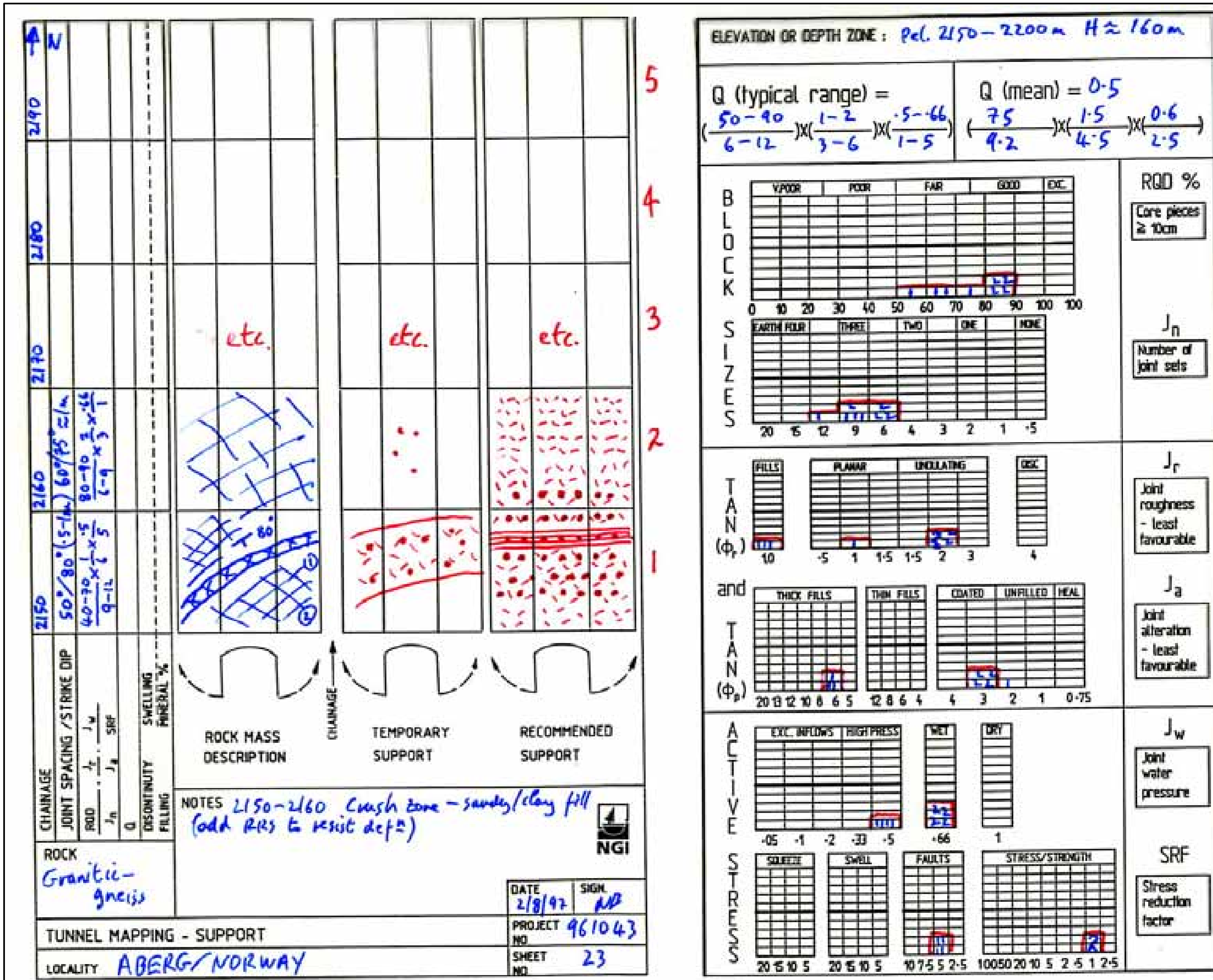

Q (typical range) =
80–100 / 6–9)x(1–2 / 1–2)x(.66–1 / 1)
Q (mean) =
(82 / 8.7)x(1.6 / 1.7)x(.7 / 1.3)
BLOCK SIZES
V.POOR
POOR
FAIR
GOOD
EXC.
0 10 20 30 40 50 60 70 80 90 100 100
RQD %
Core pieces ≥ 10cm
EARTH
FOUR
THREE
TWO
ONE
NONE
20 15 12 9 6 4 3 2 1 ·5
Jn
Number of joint sets
TAN (Φr)
FILLS
PLANAR
UNDULATING
DISC
1.0
·5 1 1·5 1·5 2 3
4
Jr
Joint roughness - least favourable
and
TAN (Φp)
THICK FILLS
THIN FILLS
COATED
UNFILLED
HEAL
20 13 12 10 8 6 5
12 8 6 4
4 3 2 1 0·75
Ja
Joint alteration - least favourable
ACTIVE STRESS
EXC. INFLOWS
HIGH PRESS
WET
DRY
·05 ·1 ·2 ·33 ·5
·66
1
Jw
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 10 5 2 ·5 1 2·5
SRF
Stress reduction factor


NOTES
ELEVATION OR DEPTH ZONE: BH 1-8, TUNNEL ARCH ± 2m
AFON MWLDAN (WALES)
HOLE DEPTH
① BH1 7·3-12·0.
② BH2 16·2-19·9.
③ BH3 20·8-24·9.
④ BH4 11·4-15·2.
⑤ BH5 5·2-9·5.
⑥ BH6 15·5-19·3.
⑦ BH7 6·7-10·5.
⑧ BH8 11·5-17·0.
[Logging of core close to tunnel arch elev. 21/8/98]
PHOTOS.
P1 = B1
P2 = B2
P3 = B3
P4 = B4
etc.
Approx. geol
P1 mudst
P2 'slate'
P3 'slate'
P4 sst/mdst
P5 sst/mdst
P6 'slate'
P7 sst/slate
P8 sst/slate
Q (typical range) = 0·01-0·9
(10-40 / 9-15) x (1 / 2-6) x (1-·66 / 2·5-5)
Q (mean) = 0·11
(16·3 / 10·3) x (1·3 / 4·1) x (0·7 / 3·3)
BLOCK SIZES
V.POOR
POOR
FAIR
GOOD
EXC.
0 10 20 30 40 50 60 70 80 90 100 100
RQD %
Core pieces ≥ 10cm
EARTH
FOUR
THREE
TWO
ONE
NONE
20 15 12 9 6 4 3 2 1 ·5
J_n
Number of joint sets
TAN (ϕ_r)
FILLS
PLANAR
UNDULATING
DISC
1·0 ·5 1 1·5 1·5 2 3 4
J_r
Joint roughness - least favourable
and
TAN (ϕ_p)
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
·05 ·1 ·2 ·33 ·5 ·66 1
Most frequent classification
10/9 x 1/4 x ·66/2·5
Q = 0·07
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 10 5 2 ·5 1 2·5
SRF
Stress reduction factor


ELEVATION OR DEPTH ZONE : 693–732
1 2 3 4
693 732
NGI
Q (typical range) = (70–100 / 3–9) x (1–2 / 1–6) x (·5–1 / 1–2)
Q (mean) = 6·7
(84 / 5·0) x (1·6 / 2·8) x (0·7 / 1·0)
① Q = 12·6
(88 / 4·6 x 1·5 / 1·6 x 0·7 / 1·0)
② Q = 3·3
(88 / 4·0 x 1·2 / 4·8 x 0·6 / 1·0)
③ Q = 2·0
(63 / 8·0 x 1·5 / 3·0 x 0·5 / 1·0)
④ Q = 25·5
(96 / 3·6 x 1·7 / 1·6 x 0·9 / 1·0)
BLOCK SIZES
V.POOR
POOR
FAIR
GOOD
EXC.
0 10 20 30 40 50 60 70 80 90 100 100
RQD %
Core pieces ≥ 10cm
EARTH
FOUR
THREE
TWO
ONE
NONE
20 15 12 9 6 4 3 2 1 ·5
J_n
Number of joint sets
TAN (ϕ_r)
FILLS
PLANAR
UNDULATING
DISC
1.0
·5 1 1·5 1·5 2 3
4
J_r
Joint roughness - least favourable
and
TAN (ϕ_p)
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
·05 ·1 ·2 ·33 ·5
·66
1
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 10 5 2 ·5 1 2·5
SRF
Stress reduction factor

Q-VALUES:	(RQD /	J_n)	* (J_r /	J_a)	* (J_w /	SRF) =	Q	Borehole 2,4,5 and 7A 650-750m below OD
Q(typical min) =	80.0 /	15.0	* 1.0 /	4.0	* 0.5 /	5.0 =	0.133	
Q(typical max) =	100.0 /	4.0	* 4.0 /	1.0	* 1 /	1.0 =	100	
Q(mean values) =	92.8 /	7.9	* 2.1 /	3.4	* 0.705 /	1.8 =	2.984	



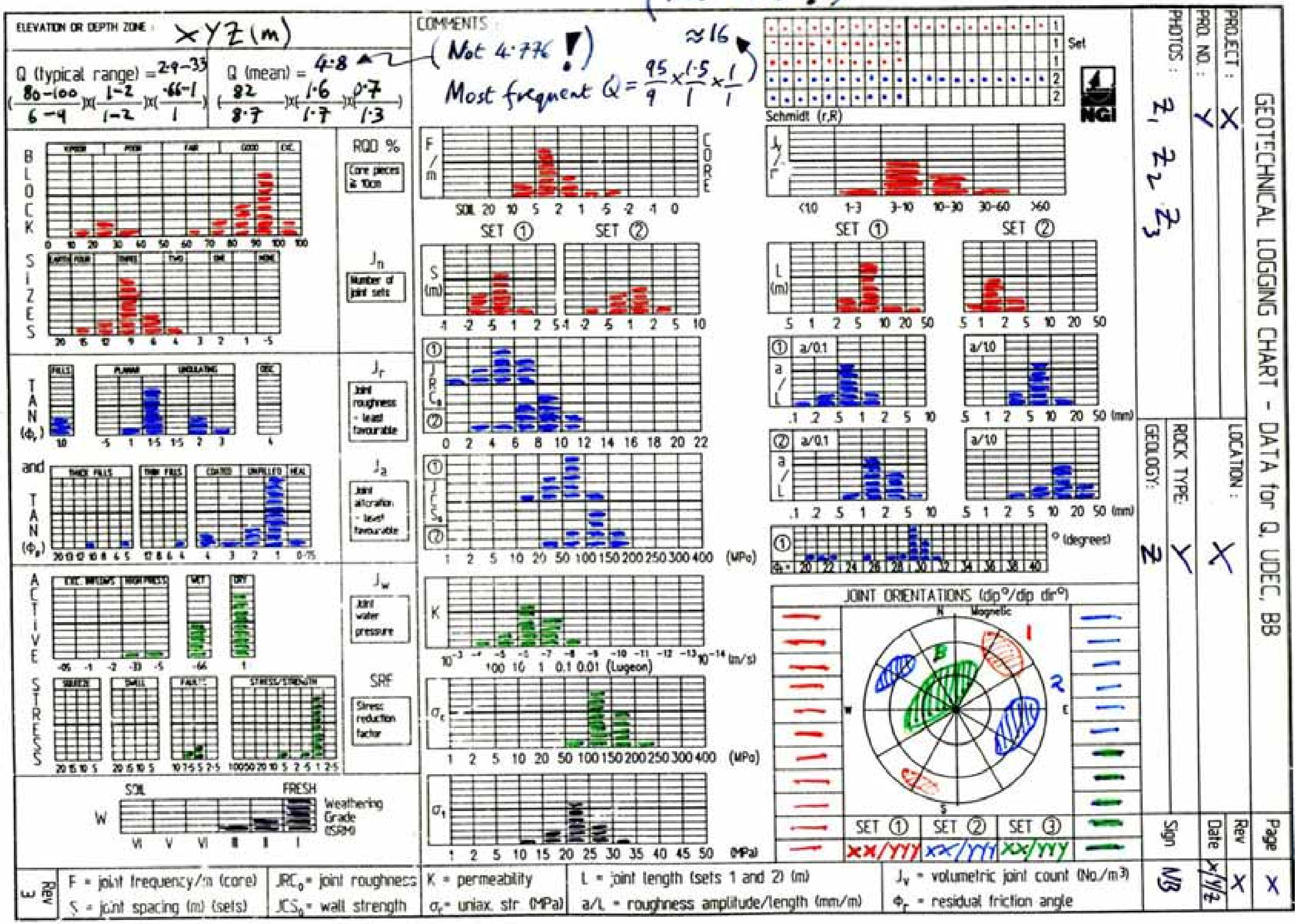


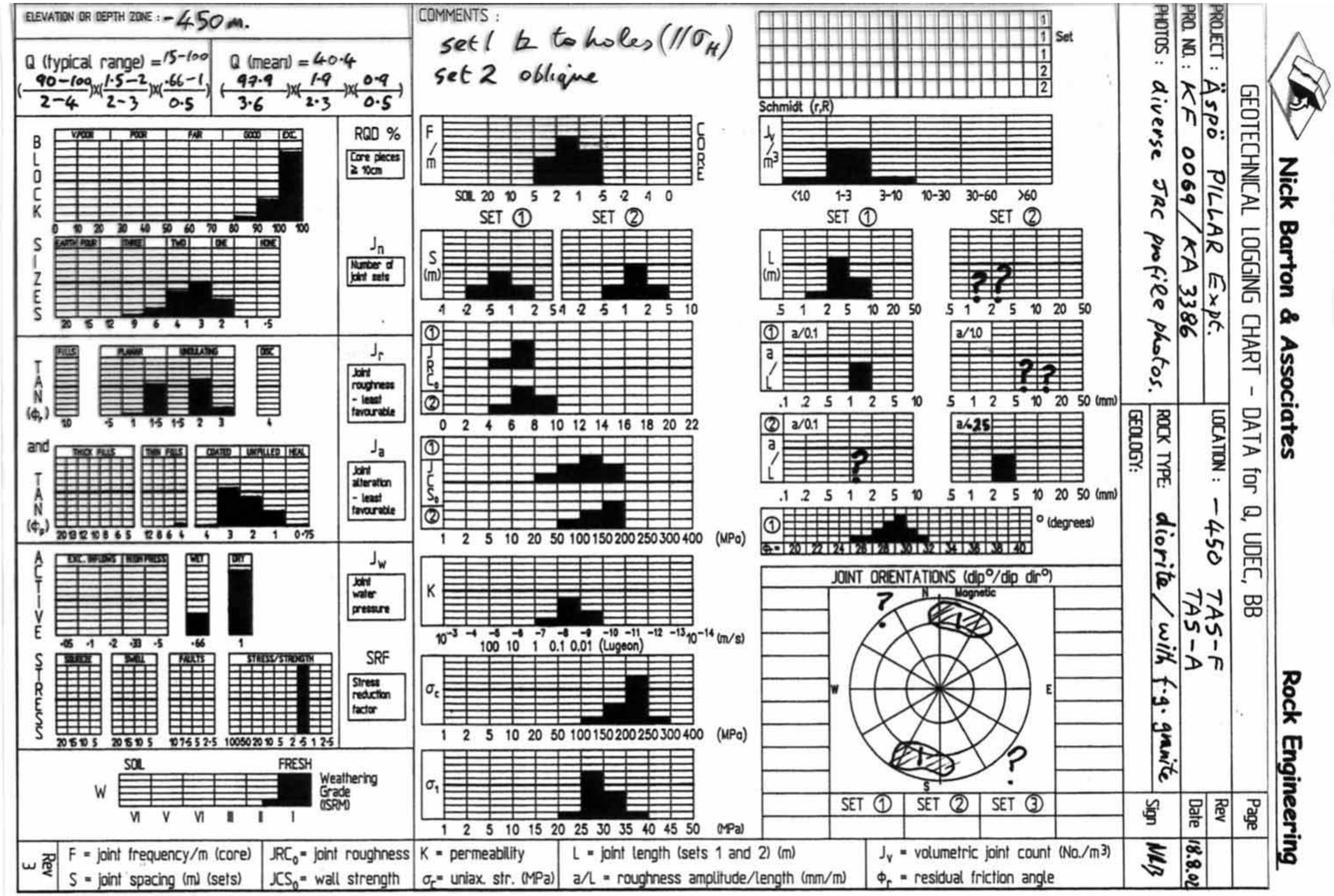
ELEVATION OR DEPTH ZONE: Pel. 2150–2200m H ≈ 160m
Q (typical range) = (50–90 / 6–12) x (1–2 / 3–6) x (.5–.66 / 1–5)
Q (mean) = 0·5 (75 / 9·2) x (1·5 / 4·5) x (0·6 / 2·5)
BLOCK SIZES
RQD %
Core pieces ≥ 10cm
Jn
Number of joint sets
TAN (φr) and TAN (φp)
Jr
Joint roughness - least favourable
Ja
Joint alteration - least favourable
ACTIVE STRESS
Jw
Joint water pressure
SRF
Stress reduction factor
CHAINAGE
JOINT SPACING / STRIKE DIP
RQD / Jn · Jr / Ja · Jw / SRF
Q
DISCONTINUITY FILLING
SWELLING MINERAL %
ROCK MASS DESCRIPTION
TEMPORARY SUPPORT
RECOMMENDED SUPPORT
etc.
NOTES 2150–2160 Crush zone – sandy/clay fill (add RRS to resist def.)
ROCK Granitic-gneiss
TUNNEL MAPPING - SUPPORT
LOCALITY ABERG/NORWAY
DATE 2/8/97
PROJECT NO 961043
SHEET NO 23
NGI

Table 2. The parameters represented in the geotechnical logging chart.

I	**ROCK MASS STRUCTURE**			
1	RQD	Deere et al., 1967)	block	Q
2	J_n	= joint set number	size	Q
3	F	= joint frequency (per metre)		
4	J_v	= volumetric joint count (Palmström, 1982)		
5	S	= joint spacing (in metres)		
6	L	= joint length (in metres)		
7	w	= weathering grade (ISRM, 1978)		
8	α/β	= dip/dip direction of joints (Schmidt diagram)		
II	**JOINT CHARACTER**			
9	J_r	= joint roughness number	shear	Q
10	J_a	= joint alteration number	strength	Q
11	JRC	= joint roughness coefficient		
12	a/L	= roughness amplitude of asperities per unit length (mm/m)		
13	JCS	= joint wall compressive strength		
14	ϕ_r	= residual friction angle		
15	r,R	= Schmidt rebound values for joint and rock surfaces		
III	**WATER, STRESS, STRENGTH**			
16	J_w	= joint water reduction factor	active	Q
17	SRF	= stress reduction factor	stress	Q
18	K	= rock mass permeability (m/s)		
19	σ_c	= compressive strength		
20	σ_1	= major principal stress		

(Not 15·833 !)


GEOTECHNICAL LOGGING CHART - DATA for Q, UDEC, BB
ELEVATION OR DEPTH ZONE : XYZ (m)
Q (typical range) = 2·9–33
Q (mean) = 4·8
COMMENTS : (Not 4·776 !)
Most frequent Q = 95/9 × 1·5/1 × 1/1 ≈ 16
BLOCK SIZES
TAN (φr) and TAN (φp)
ACTIVE STRESS
RQD %
Jn
Jr
Ja
Jw
SRF
Weathering Grade (ISRM)
JOINT ORIENTATIONS (dip°/dip dir°)
SET ① SET ② SET ③
NGI
PROJECT : X
PRO. NO. : Y
PHOTOS : Z1 Z2 Z3
LOCATION : X
ROCK TYPE: Y
GEOLOGY: Z
Sign NB
Date X/Y/Z
Rev X
Page X
F = joint frequency/m (core)
S = joint spacing (m) (sets)
JRC0 = joint roughness
JCS0 = wall strength
K = permeability
σc = uniax. str (MPa)
L = joint length (sets 1 and 2) (m)
a/L = roughness amplitude/length (mm/m)
Jv = volumetric joint count (No./m3)
φr = residual friction angle


Nick Barton & Associates
Rock Engineering
GEOTECHNICAL LOGGING CHART - DATA for Q, UDEC, BB
PROJECT : ÄSPÖ PILLAR Expt.
PRO. NO. : KF 0069 / KA 3386
PHOTOS : diverse JRC profile photos.
LOCATION : -450 TAS-F TAS-A
ROCK TYPE : diorite / with f.g. granite
GEOLOGY:
ELEVATION OR DEPTH ZONE : -450 m.
Q (typical range) = 15-100
Q (mean) = 40.4
COMMENTS :
set 1 ⊥ to holes (// σH)
set 2 oblique
BLOCK SIZES
RQD %
Core pieces ≥ 10cm
Jn
Number of joint sets
TAN (φr) and TAN (φp)
Jr
Joint roughness - least favourable
Ja
Joint alteration - least favourable
ACTIVE STRESS
Jw
Joint water pressure
SRF
Stress reduction factor
SOIL
FRESH
Weathering Grade (ISRM)
F / m
CORE
SET ①
SET ②
S (m)
JRC0
JCS0
K
σc
σ1
Schmidt (r,R)
Jv / m3
L (m)
a/L
° (degrees)
JOINT ORIENTATIONS (dip°/dip dir°)
N
Magnetic
W
E
S
SET ①
SET ②
SET ③
Rev
Date 18.8.02
Sign NB
Page
Rev 3
F = joint frequency/m (core)
S = joint spacing (m) (sets)
JRC0 = joint roughness
JCS0 = wall strength
K = permeability
σc = uniax. str. (MPa)
L = joint length (sets 1 and 2) (m)
a/L = roughness amplitude/length (mm/m)
Jv = volumetric joint count (No./m3)
φr = residual friction angle