PRE-GROUTING for WATER CONTROL and for ROCK MASS PROPERTY IMPROVEMENT

10th Nonveiller lecture, Zagreb, 2011

- PRE-GROUTING FOR WATER CONTROL – EXAMPLES
- CONSEQUENCES OF SHALLOW TUNNELS
- COMPARING PARTICLE SIZE WITH JOINT APERTURE
- LUGEON TESTING FOR APERTURE ESTIMATION (e and E)
- WHY *HIGH-PRESSURE* GROUTING WORKS BEST
- ROCK MASS QUALITY IMPROVEMENT BY GROUTING?
- VERIFICATION BY SEISMIC VELOCITY?
- TYPICAL HIGH-PRESSURE GROUTING QUANTITIES

(“Fighting high pressure inflows”….but this is too late when they are experienced at the face of the tunnel)

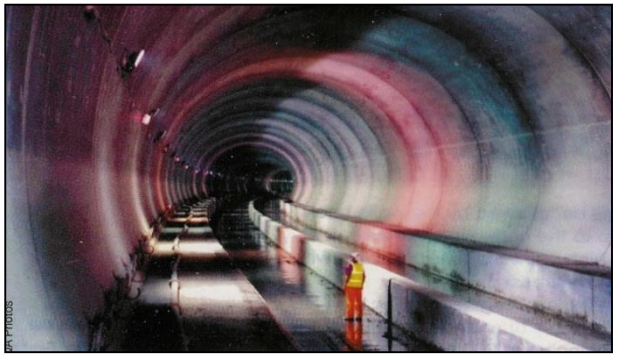
Attempting to post-grout
.....is almost impossible in practice)

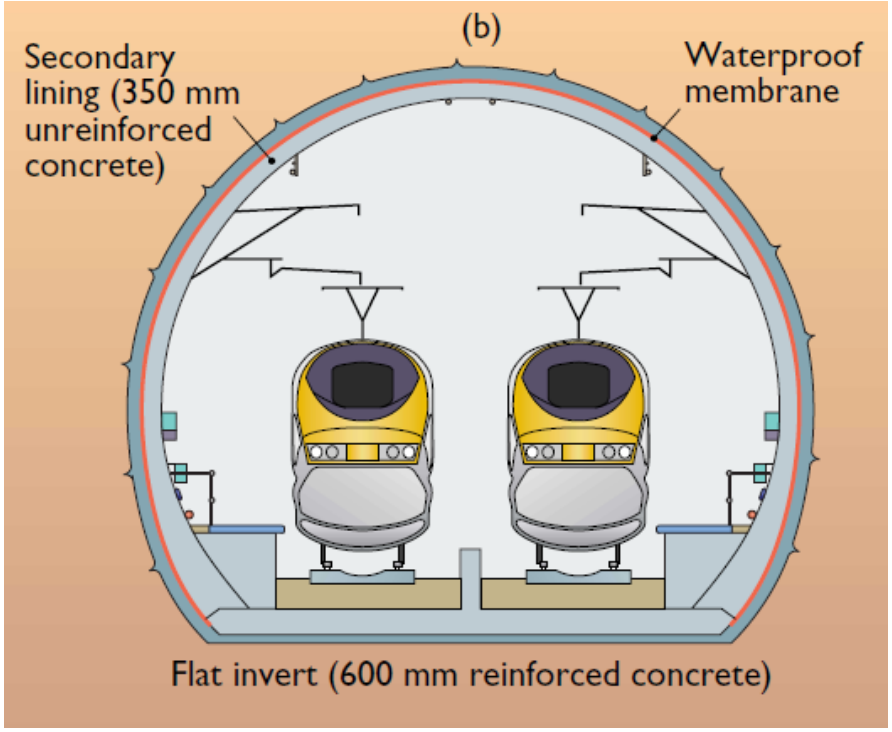
A pre-injection ‘umbrella’ could probably have prevented this (several weeks/months) delay

Water control methods

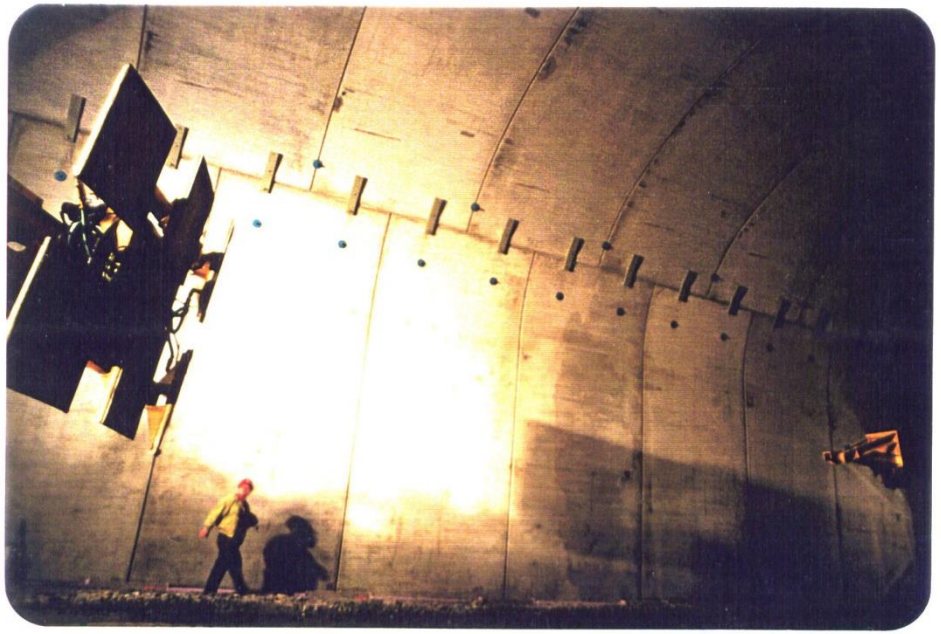
- **1. hydrostatic or drained membrane behind cast concrete liner**
- **2. free-standing (drained-tunnel) liner elements**
- **3. pre-injection 'umbrella' (to reduce access to H_2O)**
- **4. sprayed membrane in S(fr) sandwich**

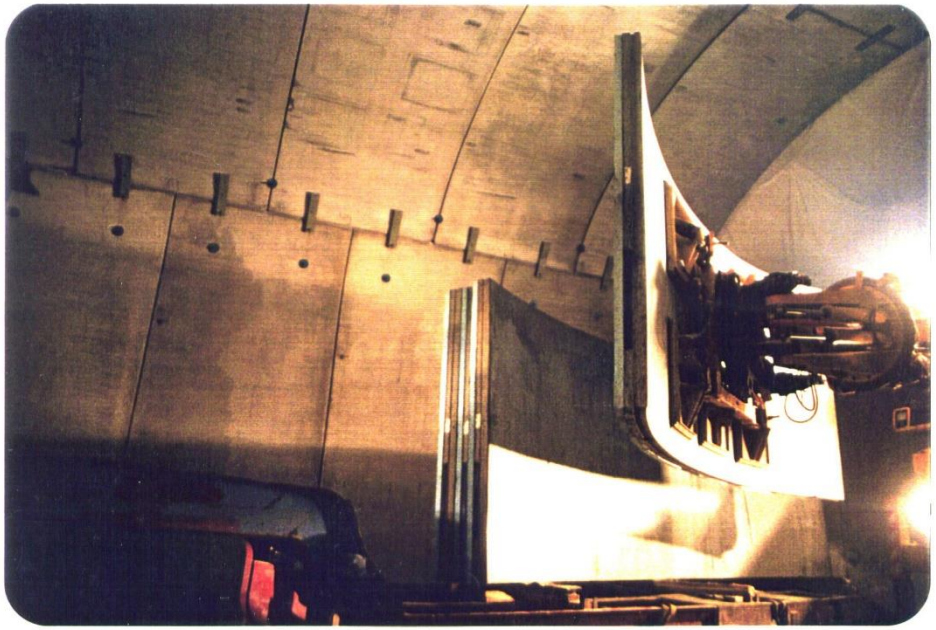
These four solutions to *the water* problem,
have widely different prices.....#1 most, #4 least.....
but #4 is best applied after #3. Control the water first !





- **Example of expensive tunnelling solution: conventional NATM, with B+S(mr) for primary support, and *drainage fleece-and-membrane* behind final cast concrete secondary lining.**
- High-speed rail tunnel, jointed chalk, S. England, final cost US$ 123M /3.2 km, or about $ 40,000 per metre (1999-2000 price)
- **(≈ 2½ times higher than typical NMT (single-shell) tunnel, with similar Q-value rock, using B+S(fr) as permanent support, plus PC-element+ membrane liner, *or pre-injection,* for a drained-but-dry solution.**
- ***Some NATM tunnels today cost US $ 100,000/m !***



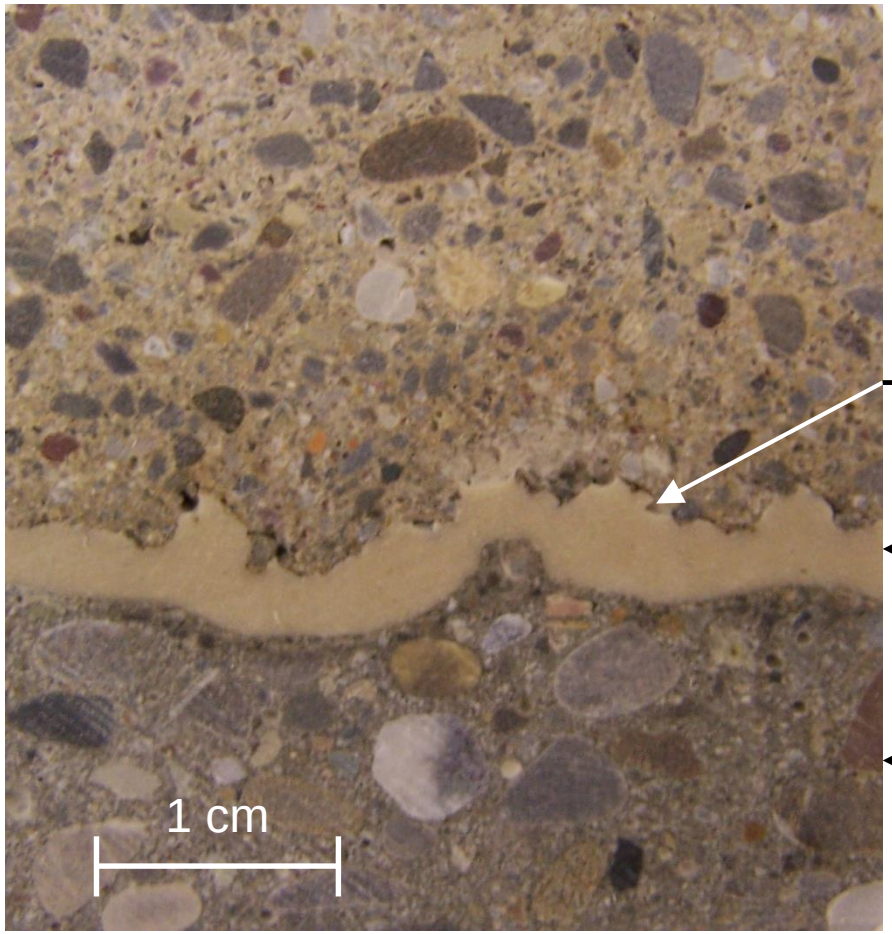


When water is not well controlled….need PC element drip-shield

2 x 220 km/hr airport link, Oslo. 15 km long tunnel.

This also provides a dry-but drained tunnel.

BASF 345 sprayed membrane in sandwich



Primary rock support sprayed concrete .....S or S(fr)

Concrete-membrane interface: clean surface of the primary S or S(fr)

Spray-applied waterproofing membrane Masterseal®345, minimum thickness 3mm

Secondary sprayed concrete S or S(fr) inner layer

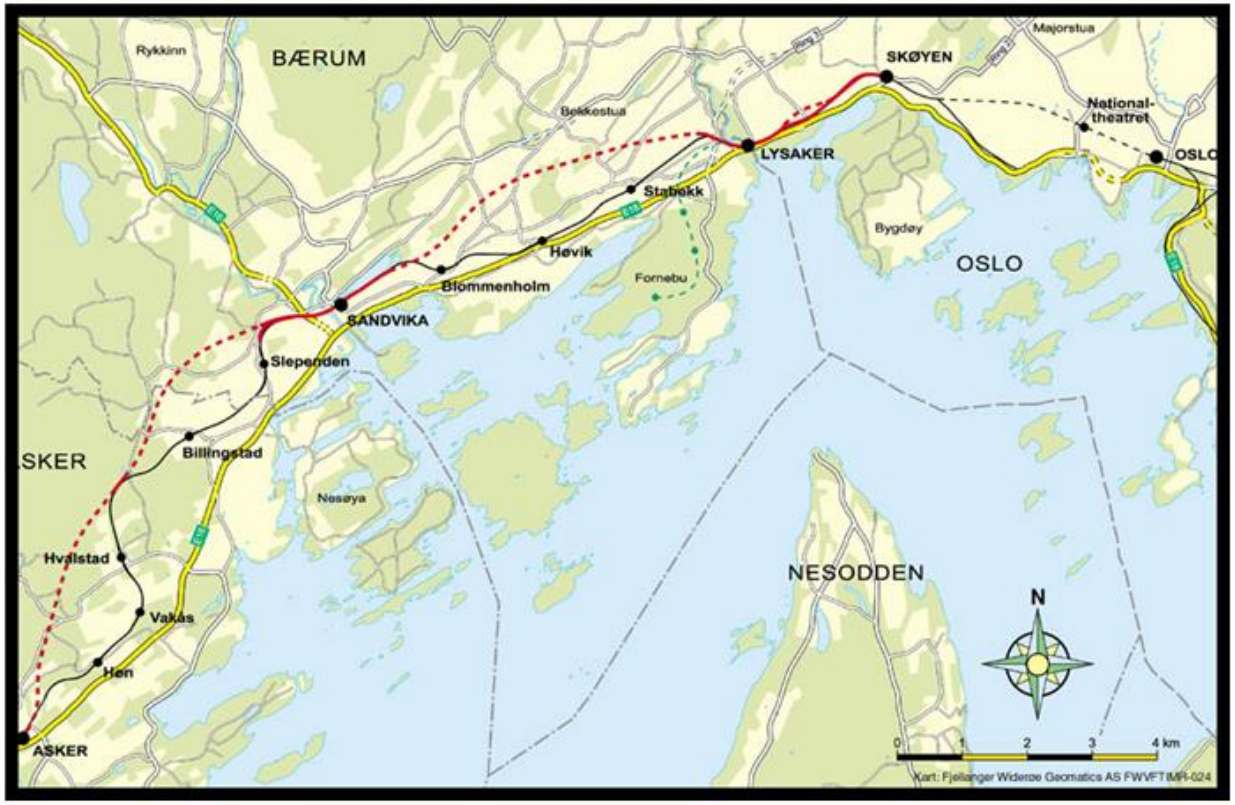
Two examples of single-shell tunnels with sprayed membrane as final seal against water.

- Lausanne Metro
- Hinehead Tunnel, UK

- These resemble NMT in Norway

SOME EXAMPLES OF SYSTEMATICALLY PRE-INJECTED TUNNELS, before looking at design aspects.

FROM RECENT NORWEGIAN JERNBANEVERKET TWIN-TRACK RAIL TUNNELS NEAR OSLO



19.5 km of new twin-track including three stations and three tunnels 2001-2011 1.1 billion US $

2.7 + 3.6 + 5.5 km tunnels A = 105 m²,

Tunnel #1:Jong-Asker
2.7 km, 18 months for completion from two faces (105 m²)
(depth 2 to 50 m)

Note dry rock behind jumbo (already pre-grouted)……see several examples that follow

A SEQUENCE OF (*NMT-STYLE*) PHOTOGRAPHS FROM THE CONSTRUCTION *(and pre-grouting of)* THE BAERUM TUNNEL

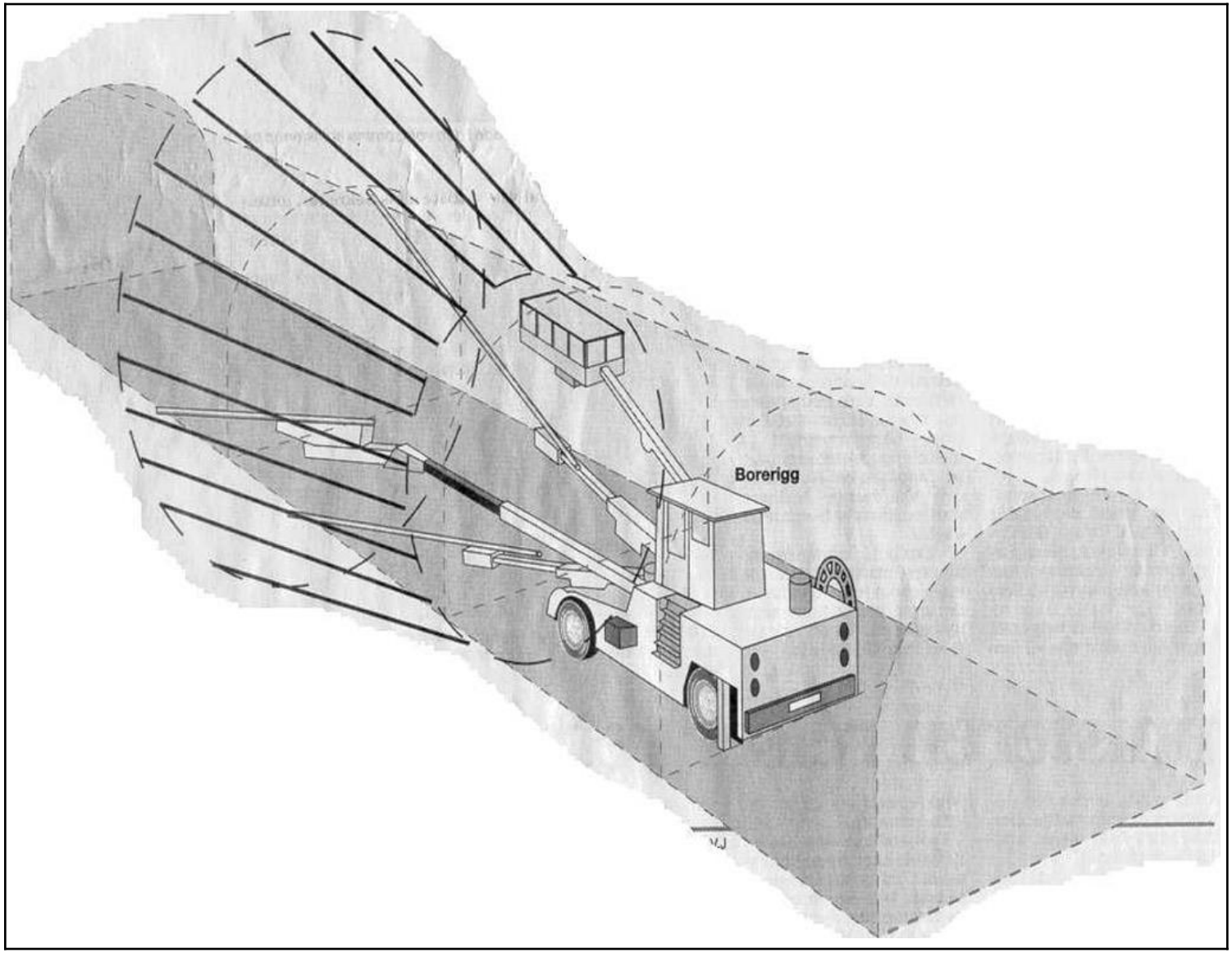
(Tunnel #3, L = 5.5 km)

SCANIA

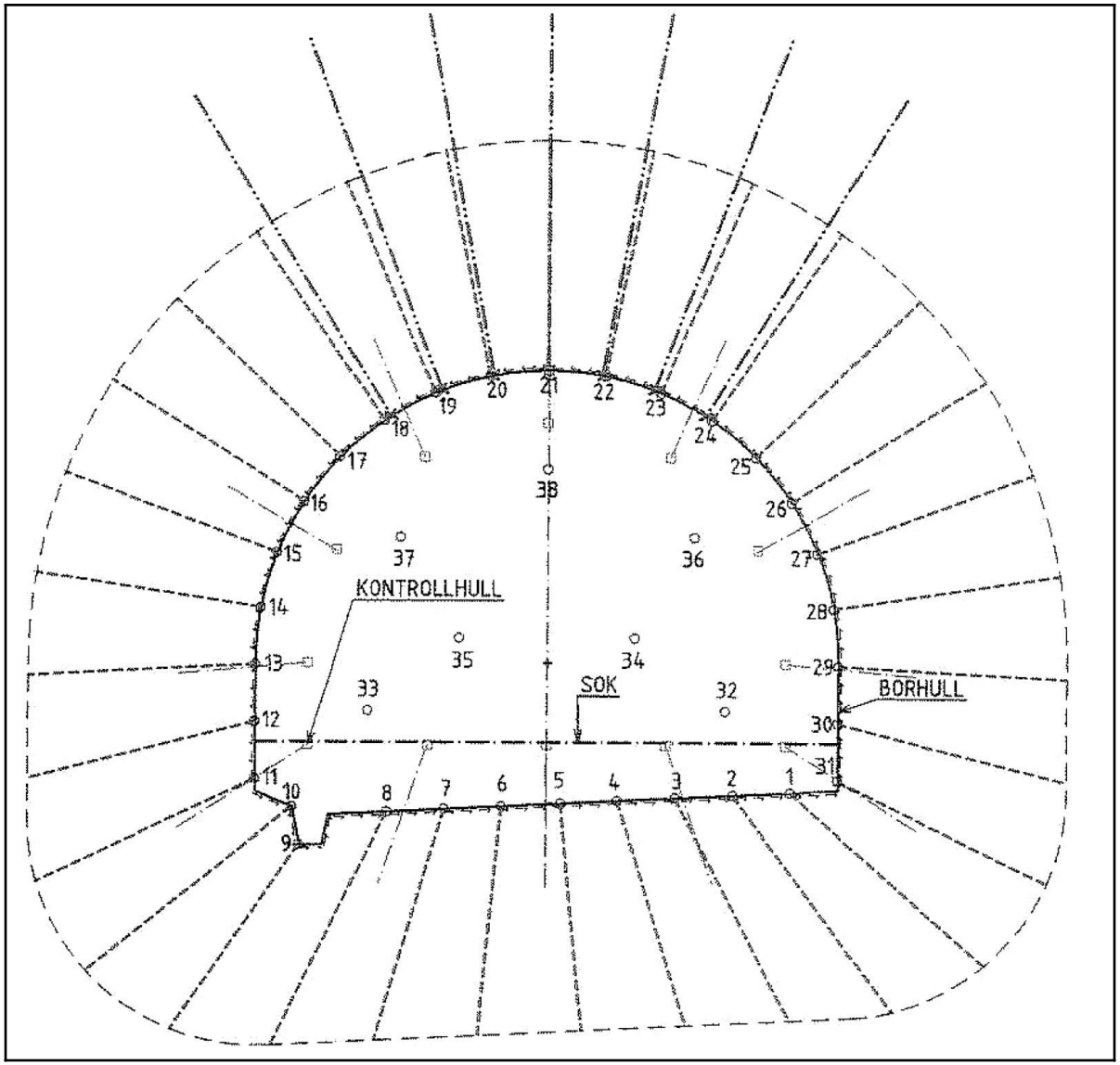
Sandvika-Skøyen: #3 twin-track rail tunnel: Jernbaneverket, Photo of specialized rig for pre-injection. Note contour holes.

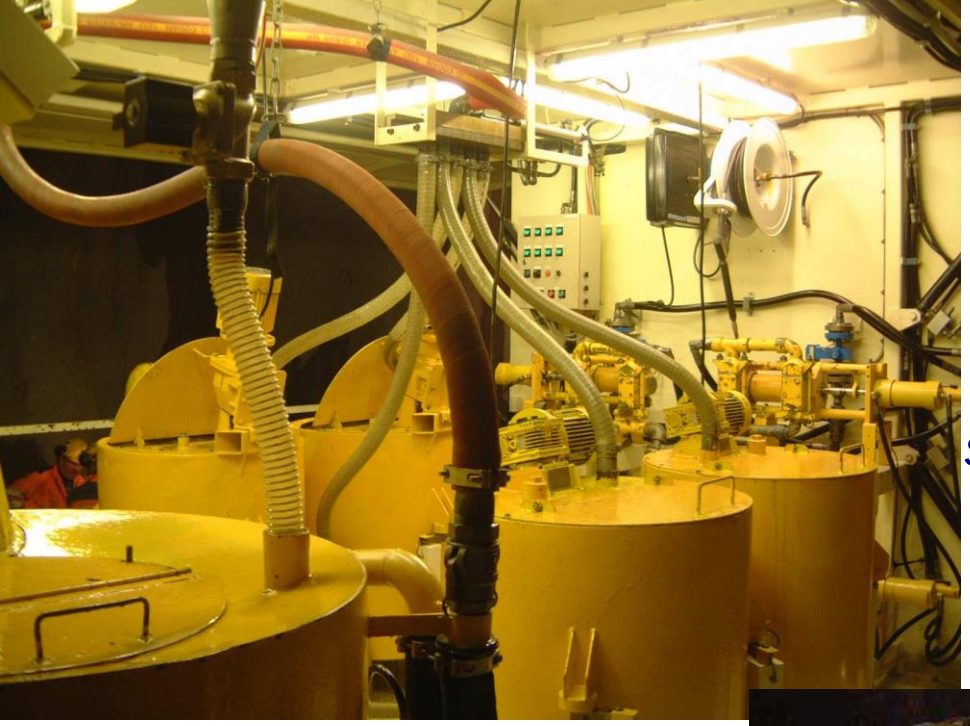
Pre-injection screen 30-70 holes, 20-30m long, 0.5-1.0 m c/c

(Hognestad and Frogner, 2005)



Fan for **Class 3** inflow control (< 4 litres/min/100 m)





Specialised rig for pre-injection
(AF Spesialprojekt A/S, SRG)
as used at the Jong-Asker tunnels.

The 'Tanum' and 'Skaugum' tunnels (#1, 2) driven in Cambro-Silurian schists, calcitic schists, then shales and nodular limestones and ≈ one hundred igneous dykes in the Oslo geology. Typical Q = 0.01 to100.

TYPICAL DATA / MATERIALS

- 50 to100 bar pressure.
- Typical consumption : 600-1200 kg of grout per tunnel meter.
- *Microcement, d95 = 12 µm*

Pre-injection costs are approximately as follows :

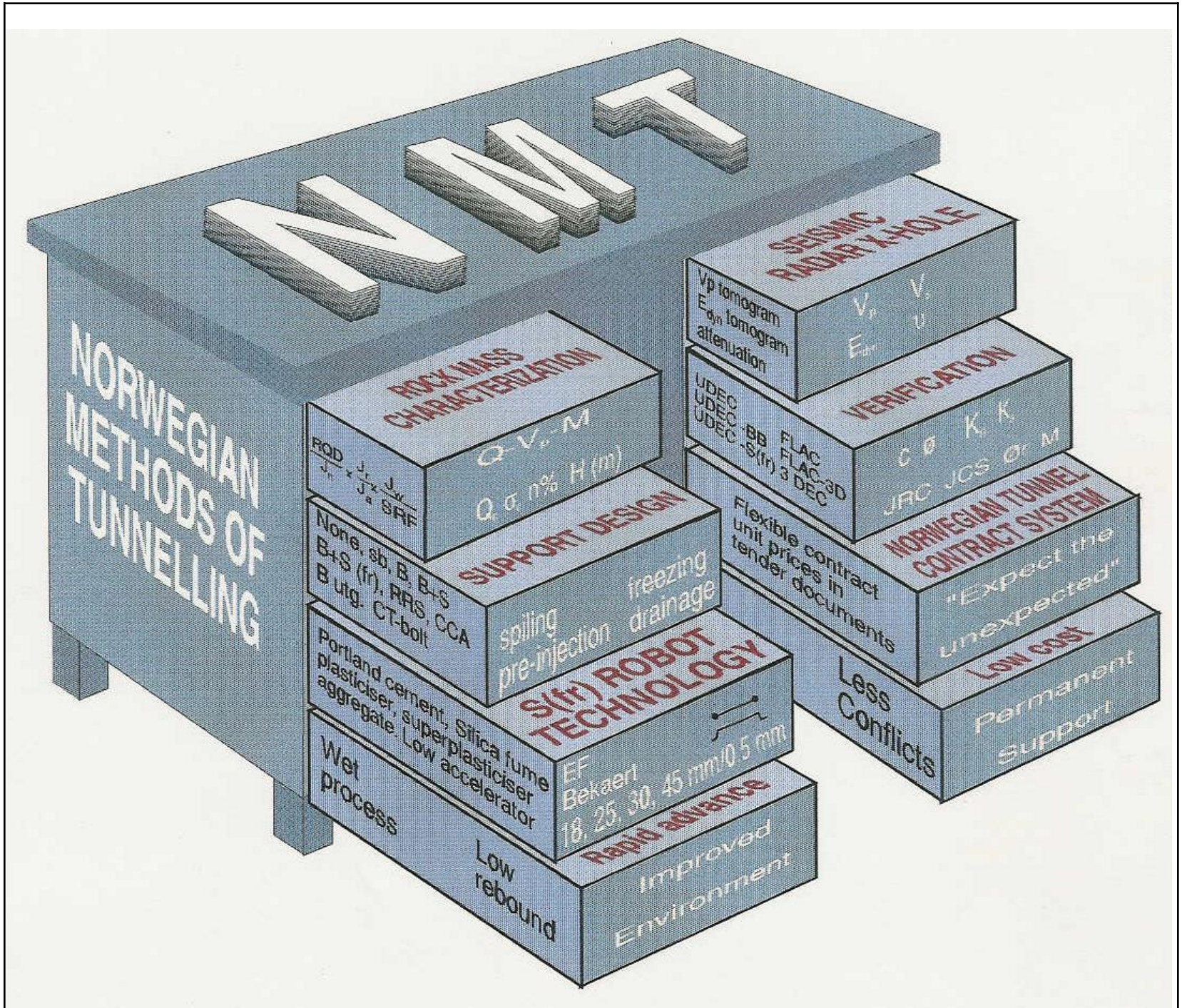
- ***1,400 US $ /m for equivalent 20 l/min/100m***
- ***2,300 US $ /m for equivalent 10 l/min/100m***
- ***3,500 US $ /m for equivalent 5 l/min/100m***
- ***≈ 5,000 US $ /m for equivalent 1 to 2 l/min/m/100m***

(in "T10.5", 90 m2 tunnels).

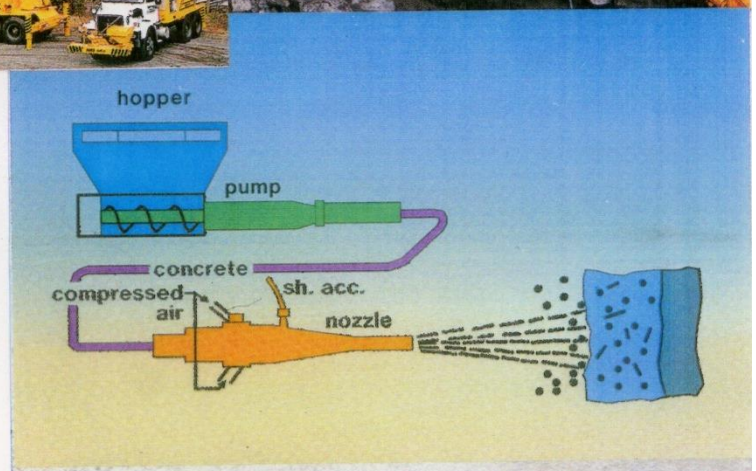
(In some zones, the contractor achieved tightness of less than *1 litre/min/100m tunnel (≈ 10^{-9} m/s)*

THE ABOVE WERE EXAMPLES OF *SINGLE-SHELL TUNNELLING* (NMT), BASED ON Q-SYSTEM-BASED SELECTION OF PERMANENT REINFORCEMENT AND SUPPORT

(this includes pre-injection when absolute requirement of no water is needed due to e.g. railway lines)



Barton & Itoh, 1995



A typical mix design for shotcrete used in Norway:

Portland cement (c)	450 – 550 kg/m³
Silica fume (s)	3 – 10 % of cement weight
Aggregate	0 – 10 mm
Plasticizer	0.3 – 1.0 % of cement weight
Superplasticizer	0.3 – 1.0 % of cement weight
Steel fibre	50 kg/m³ (dependent on toughness requirements)
Water/(c+s)	0.40 – 0.45
Slump	15 – 18 cm
Air content	< 4%
Temperature	15 – 20 °C

NMT =

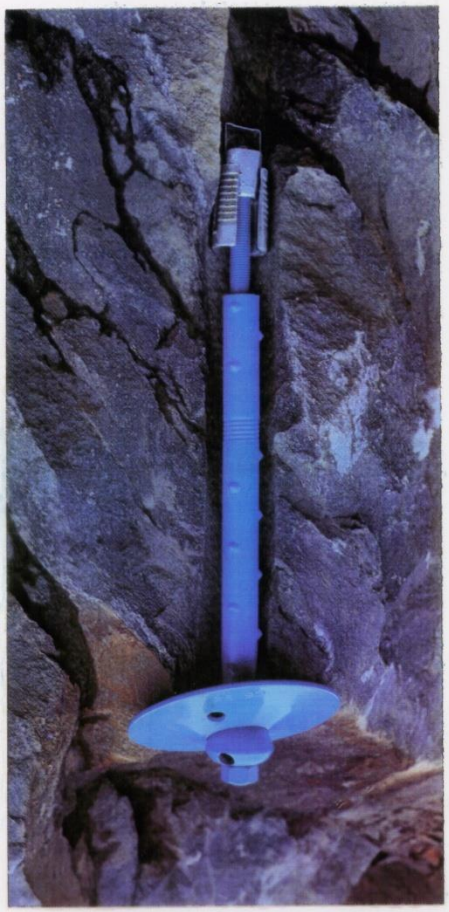
P E R M A N E N T

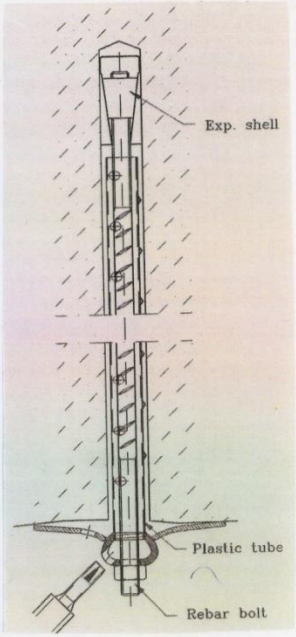
B + S(fr)

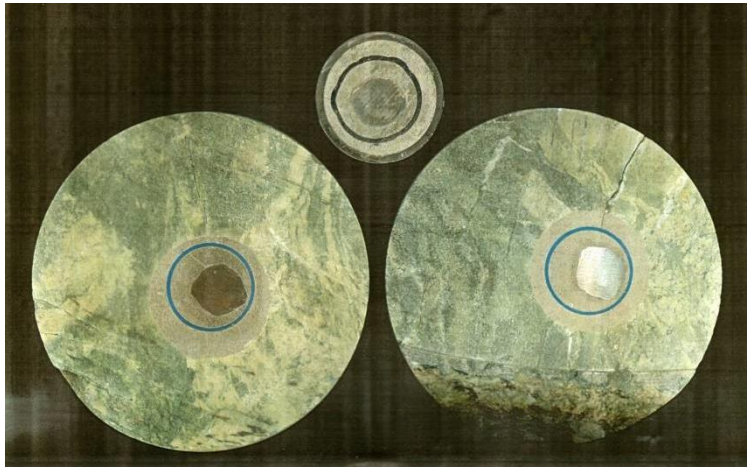
(C35 to C55) S(fr)

&

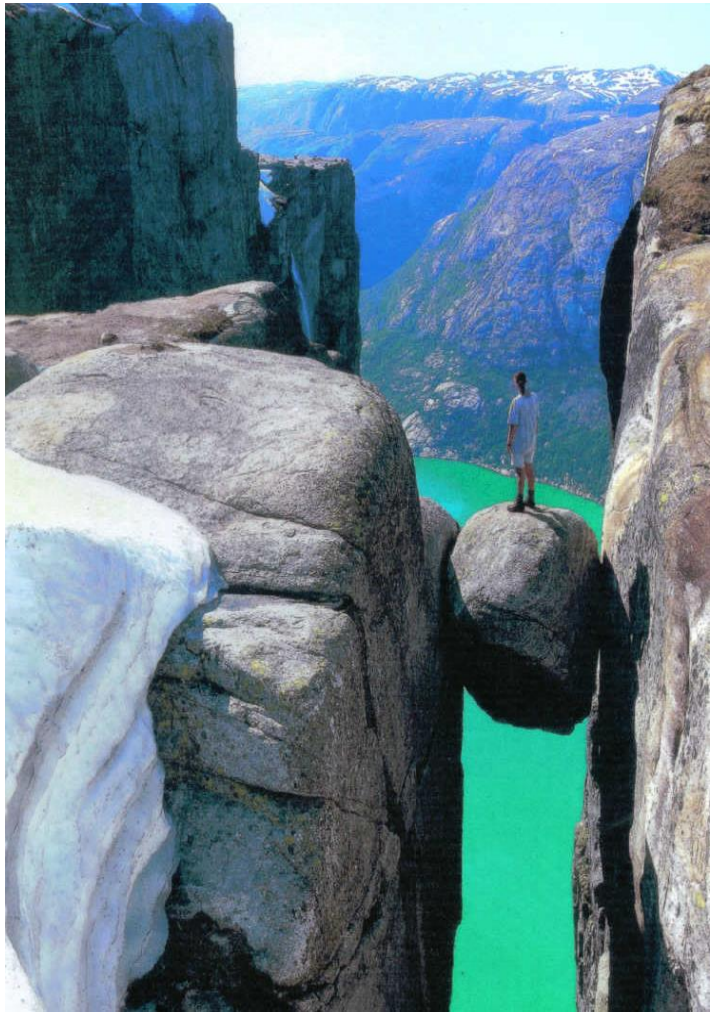
CT-bolts



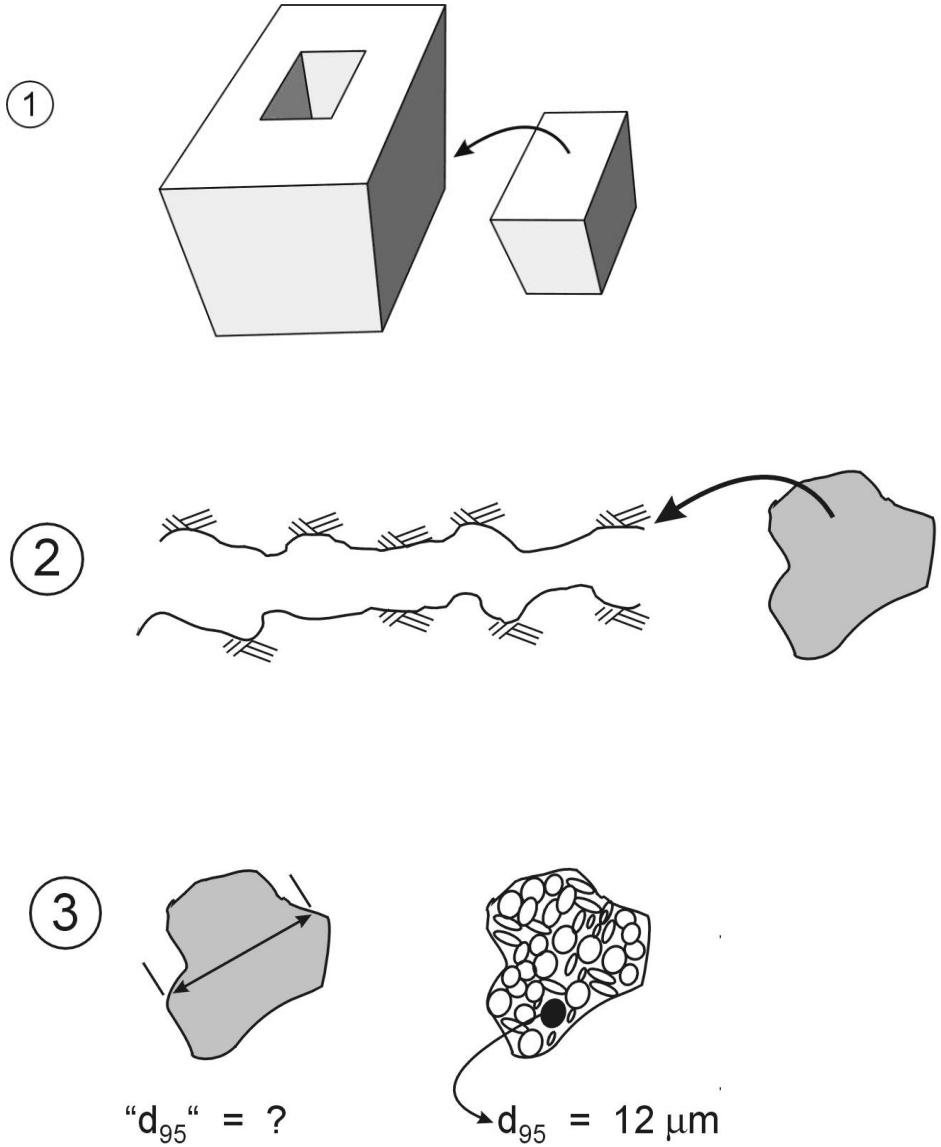




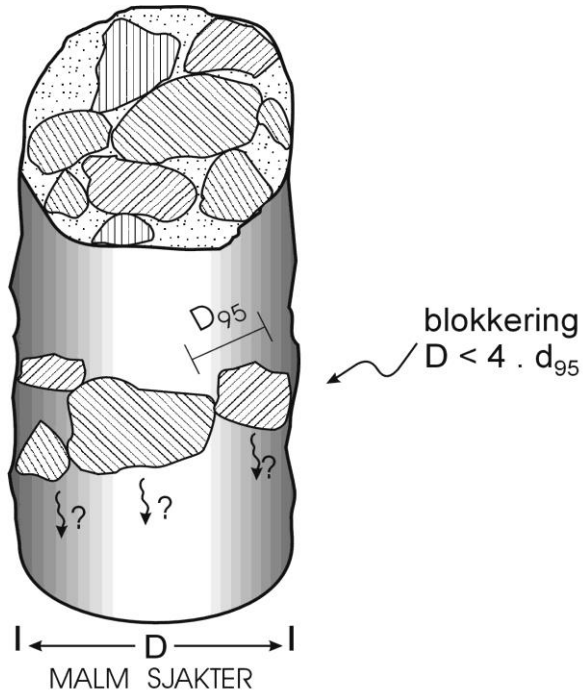
HOW TO DETERMINE APPROPRIATE GROUT SIZE

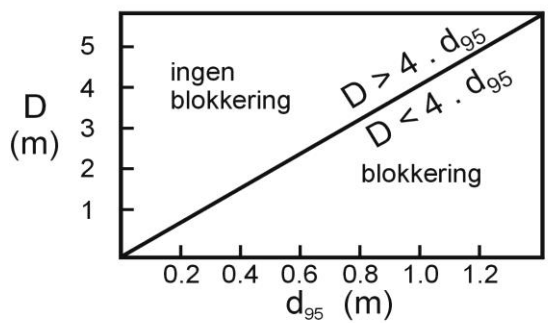


The dilemma is how to get blocks (i.e. particles) that are too large in joints that are too tight.



…..smaller particles! ….. wider joints!





Ore passes in mines also have problems with large blocks and wall roughness

Before leaving large blocks and concentrating on cement particles……..note problems with 'hang-up' of blocks in <u>mine ore passes</u>!

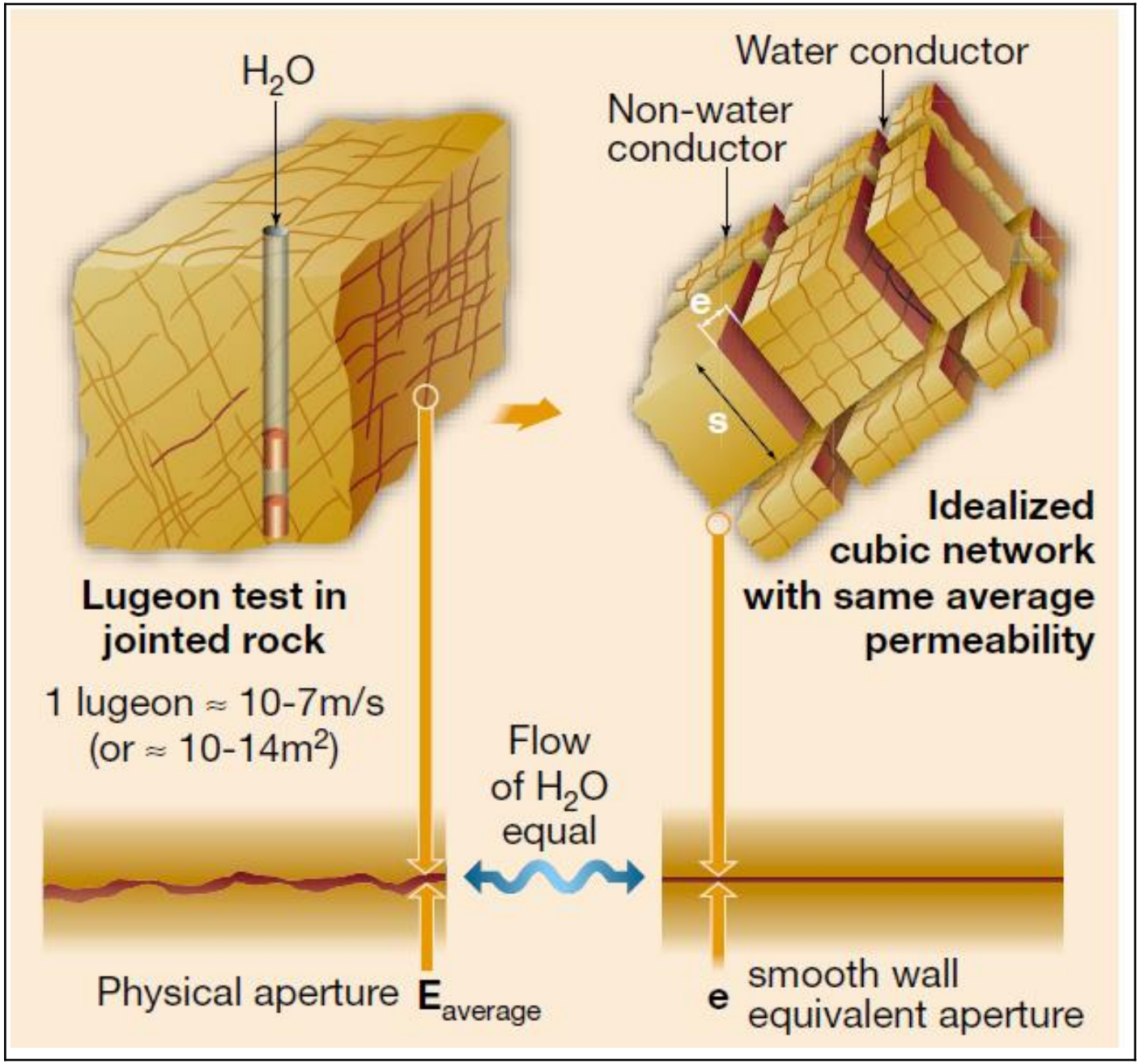
Blockage if $D < 4.d_{95}$

- Boundary layer
- Wall roughness
- 'Slow' particles

FLOW IN ROCK MASSES IS COMPLEX!
SOME SIMPLIFICATIONS ARE NEEDED!

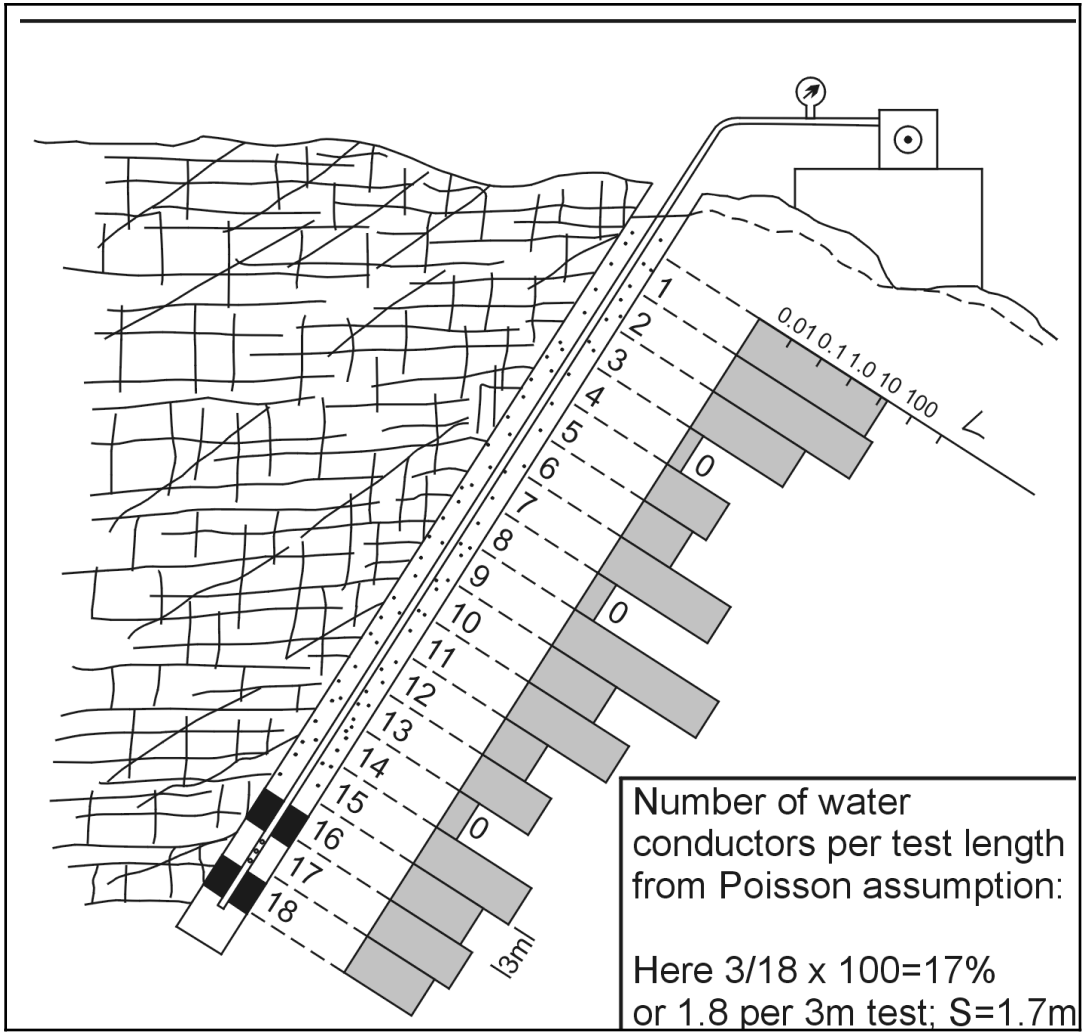
(BECAUSE WE ARE ENGINEERS – WE NEED A SOLUTION!)

The next screen shows how (modified from Snow, 1968) one can visualize a conducting 3D network of joints **.....much fewer** ***conductors*** **than total number of joints.....the** ***mean e and S*** **match permeability test results**

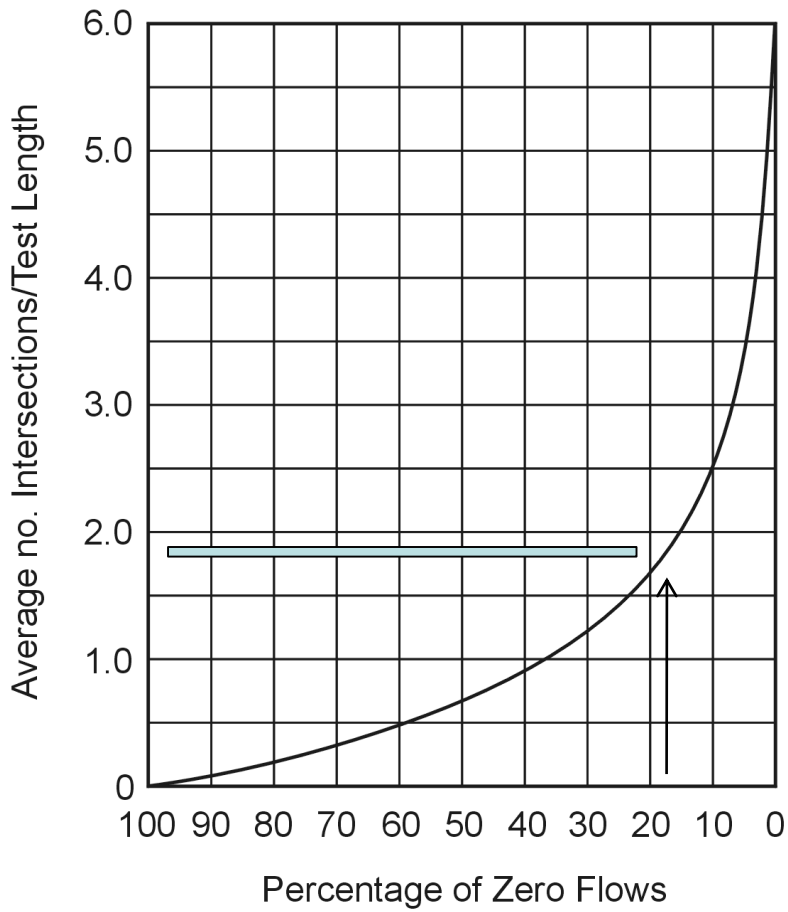

H_2O
Water conductor
Non-water conductor
e
s
Lugeon test in jointed rock
1 lugeon ≈ 10-7m/s
(or ≈ 10-14m²)
Idealized cubic network with same average permeability
Flow of H_2O equal
Physical aperture $E_{average}$
e smooth wall equivalent aperture

WATER INJECTION TESTS – LUGEON METHOD

(what % of test stages show zero flow?.....gives clue about **S** (m)…….*numbers "1.8 per 3m test, S = 1.7 m" from next screen!*



The % of zero flow sections is utilized in an
ASSUMED POISSON DISTRIBUTION – FOR ESTIMATING
AVERAGE SPACING OF WATER CONDUCTING JOINTS



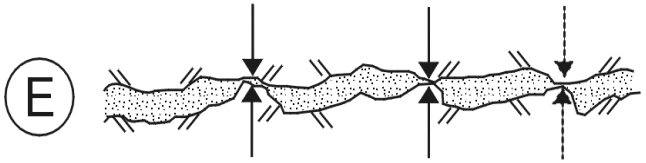
17% of 'zero' flow stages means 1.8 conducting joints per test length……on average

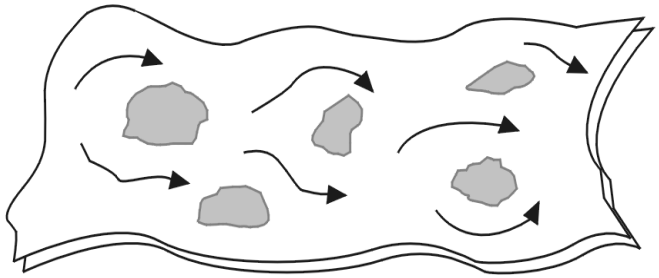
Can apply to packer spacings of 3 m, 5 m, etc.

THE TWO DIFFERENT JOINT APERTURES……. ‘e’ and ‘E’

E is real and can be grouted

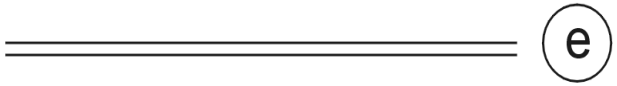
Stress transfer !





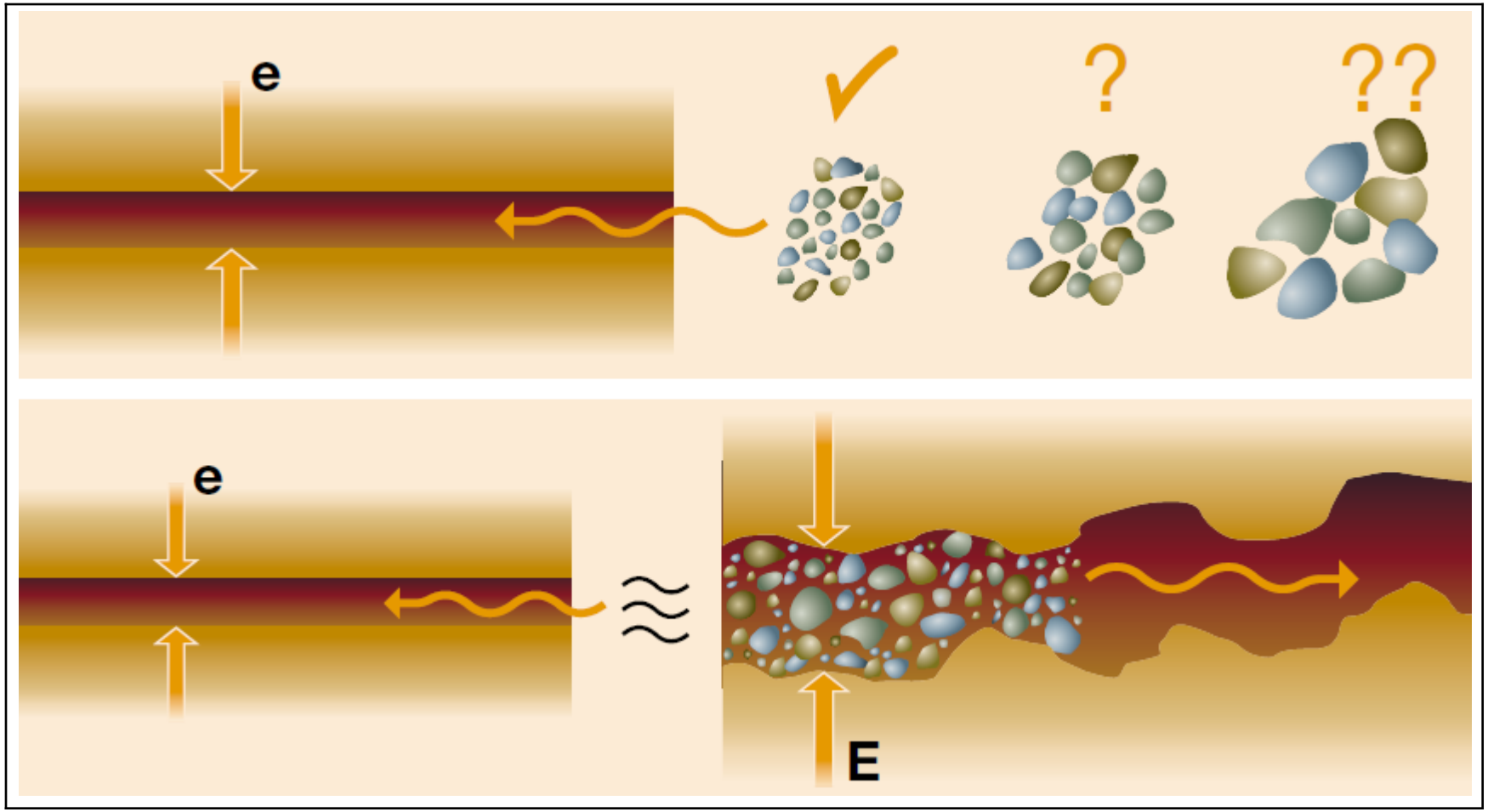
e is imaginary and ungroutable

Both E and e respond
to injection pressure

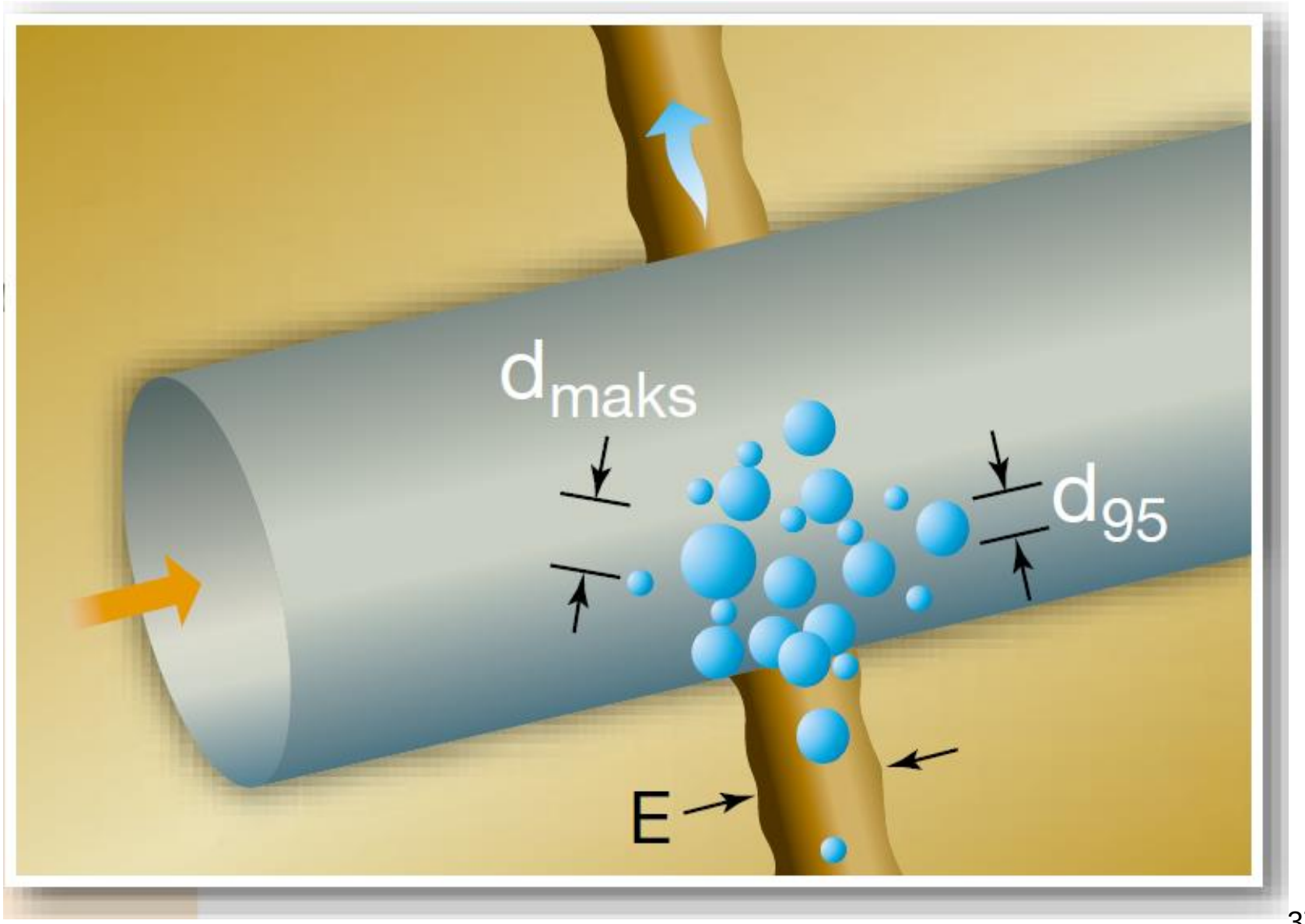


No points
of contact

BECAUSE (e) << (E), larger cement particles than expected can often be used……..but high pressure helps!



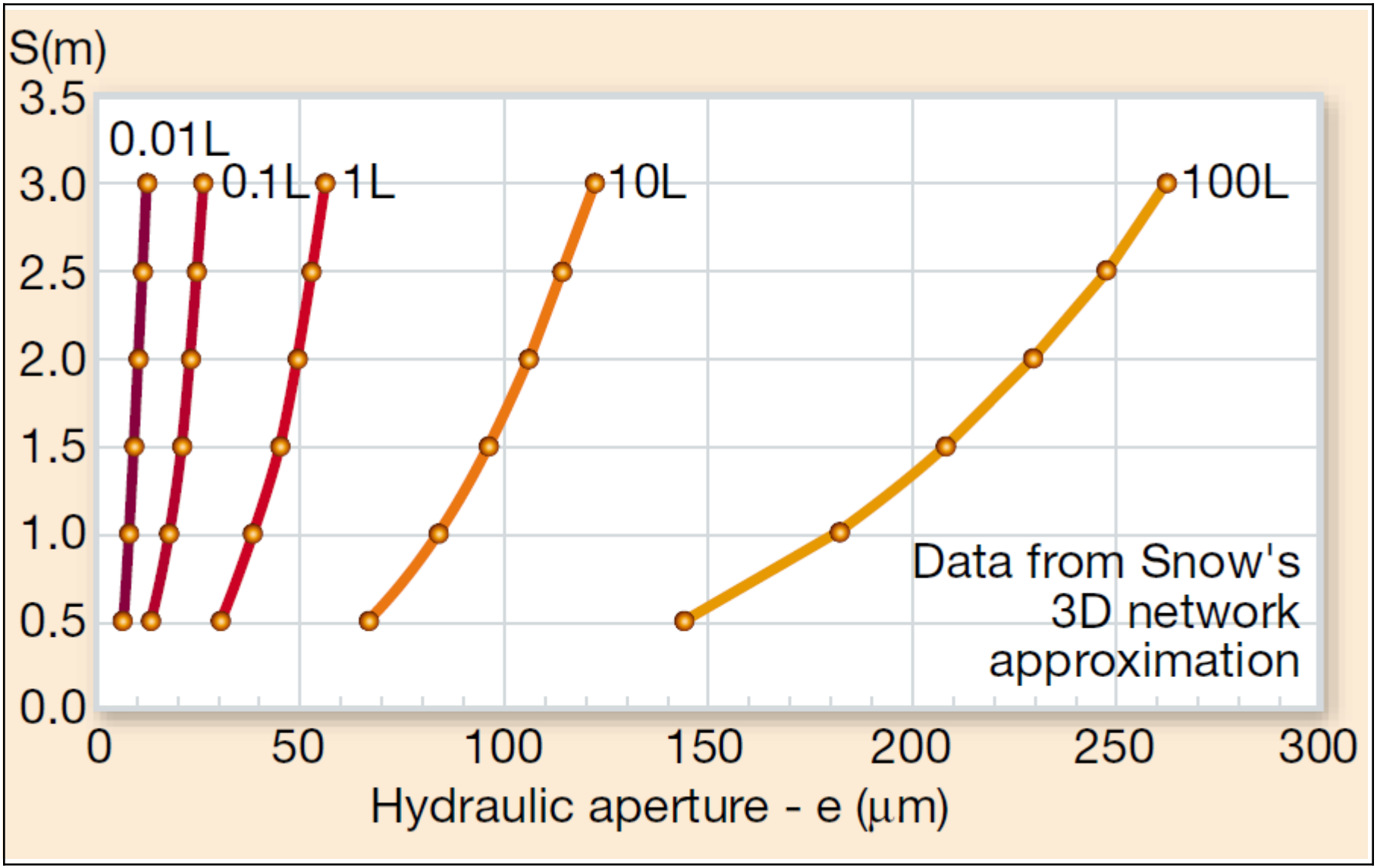
Of course……a *joint-intersection*, not a tube is expected!



THEORETICAL INTERPRETATION (IN 3D) OF LUGEON RESULTS

- based on Snow (1968), and the hydraulic theory of Louis 1967 :
- permeability of one smooth parallel plate : **$k = e^2/12$**
- permeability of 1 set of parallel plates : **$K_1 = e^2/12 \times e/S$**
- permeability of 'the conducting rock mass' (3 sets) : **$K_{mass} \approx 2e^3/12\ S$**
- 1 Lugeon ≈ 10^{-7}m/s, 10^{-7}m/s ≈ 10^{-14} m², laminar flow
- 3D interpretation of Lugeon tests **$e \approx (6LS \times 10^{-8})^{1/3}$**
- (e) and (S) in millimeters, L is average Lugeon value…each apply to local domain, rock type, or borehole depth

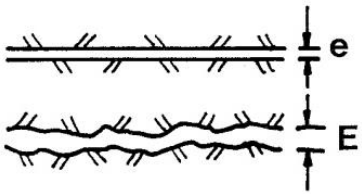
The equation $e \approx (6LS \times 10^{-8})^{1/3}$ looks like this for typical S-values of 0.5 to 3.0m



Obviously it is difficult to inject cement particles into e.g. < 0.1 Lugeon rock masses

……unless E (the physical joint aperture) >> e (the hydraulic aperture)

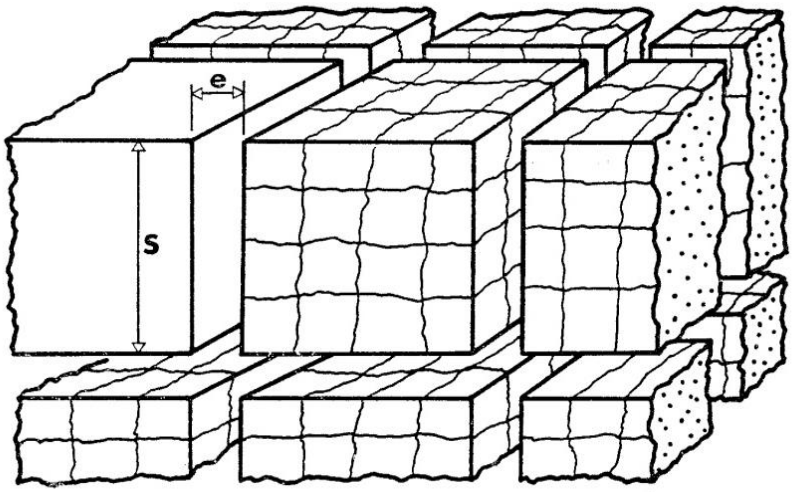
Depth zones	S(m)	e(μm)	E(μm)
5 - 15m	0.3	150	218
15 - 25m	0.4	110	186
25 - 45m	0.6	80	159
45 - 60m	0.7	60	138

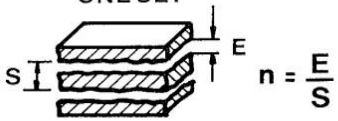


$$E = \sqrt{e.\ JRC^{2.5}}$$

Grout-Take Estimates / 1m³ rockmass

Depth zone	5 - 15m	15 - 25m	25 - 45m	45 - 60m
Grout (litres)	2.2	1.4	0.8	0.6



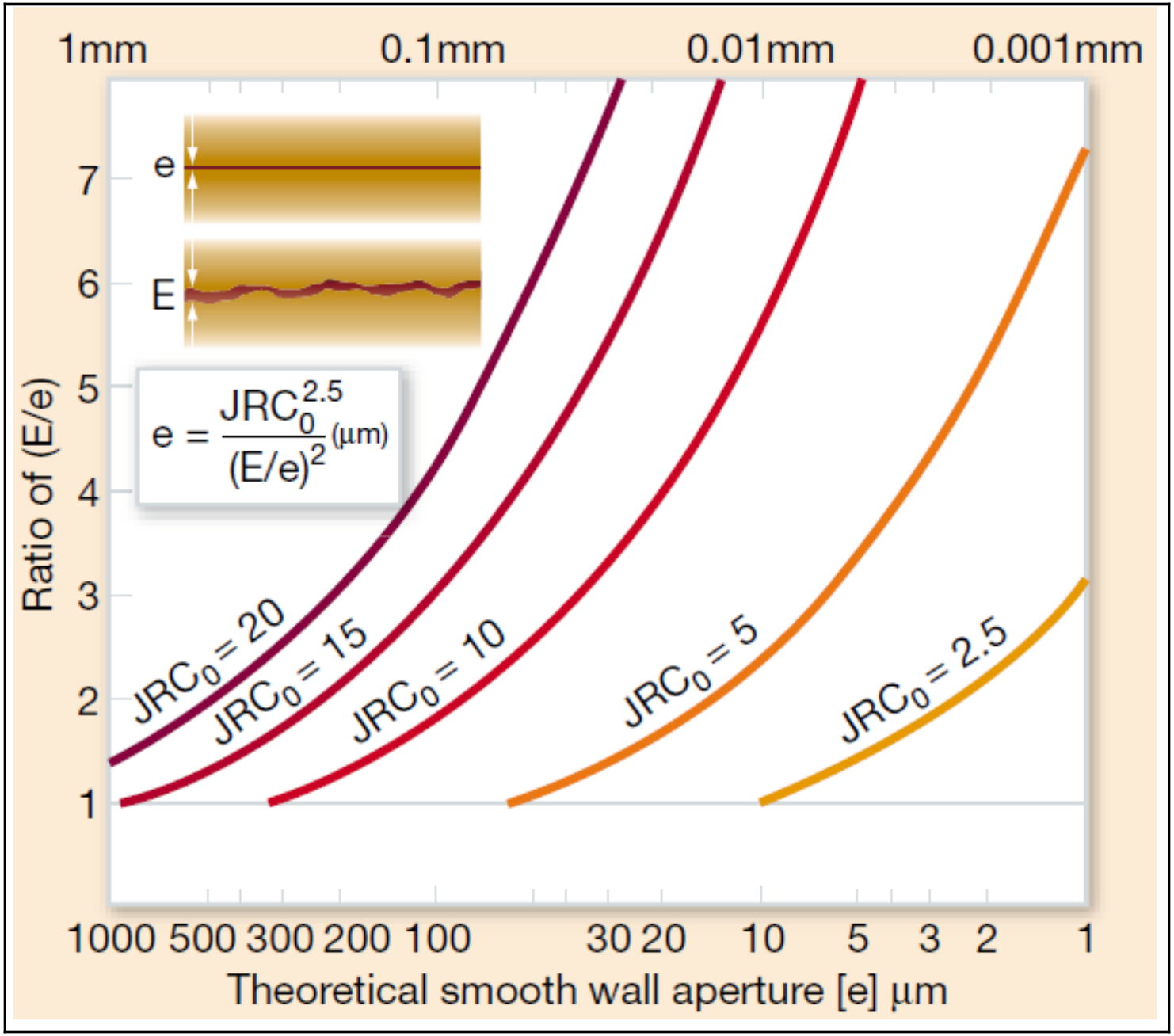


THREE SETS

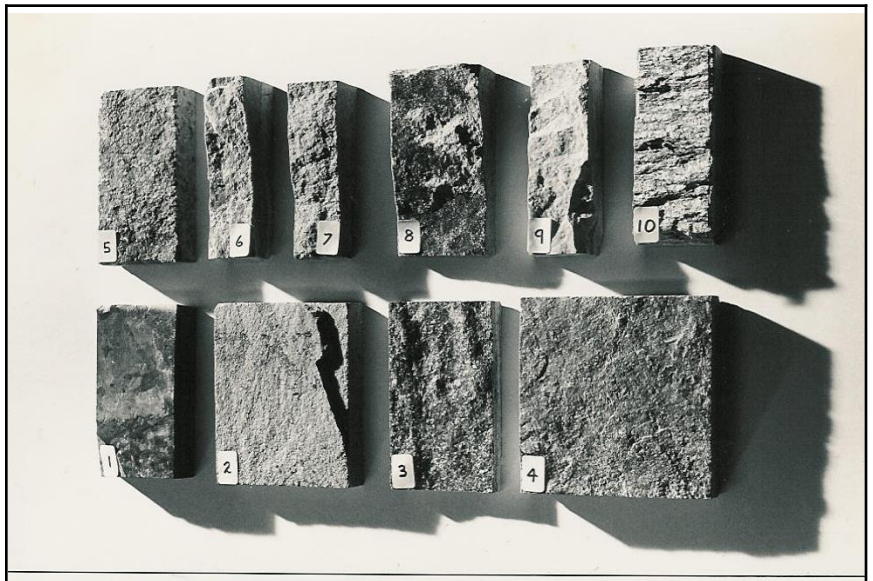
POROSITY OF ROCK MASS $n = \frac{3E}{S}$ (E > e)

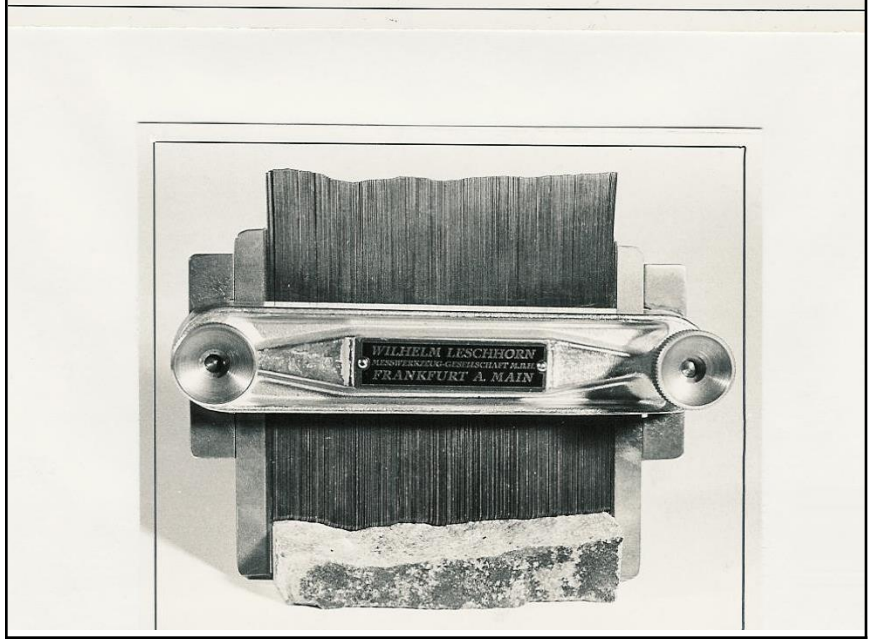
Here we have Lugeon results from 4 depth zones at a permeable dam site

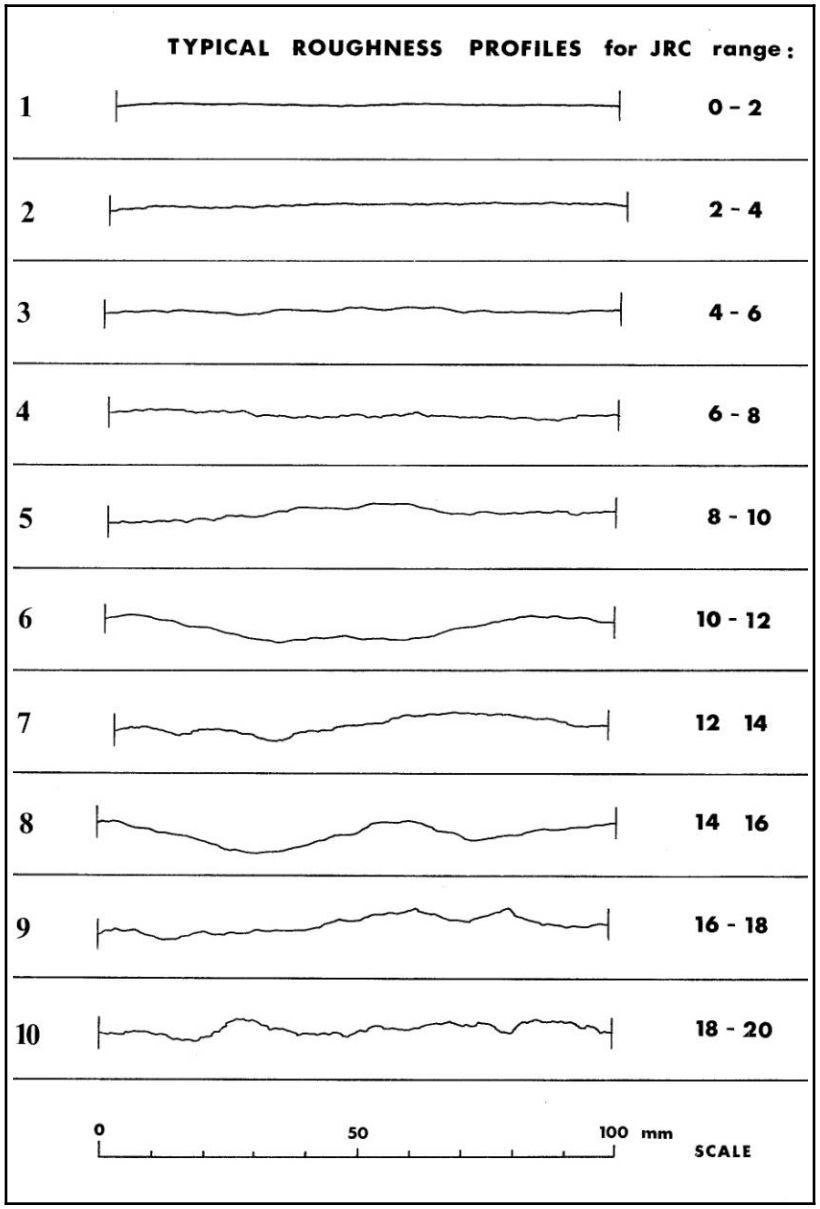
- *(e) and (S) have been interpreted as previously explained*
- *(e) is converted to (E) using JRC (the joint roughness coefficient)*
- *Note that the 'Grout-Take' estimate (from this 1978 example) assumes the same grout pressure as the Lugeon test…….. i.e. ΔP_W = 1 MPa*


1mm
0.1mm
0.01mm
0.001mm
e
E
$e = \frac{JRC_0^{2.5}}{(E/e)^2}$ (µm)
JRC0 = 20
JRC0 = 15
JRC0 = 10
JRC0 = 5
JRC0 = 2.5
Ratio of (E/e)
1
2
3
4
5
6
7
1000 500 300 200 100 30 20 10 5 3 2 1
Theoretical smooth wall aperture [e] µm

JRC estimation from profile matching





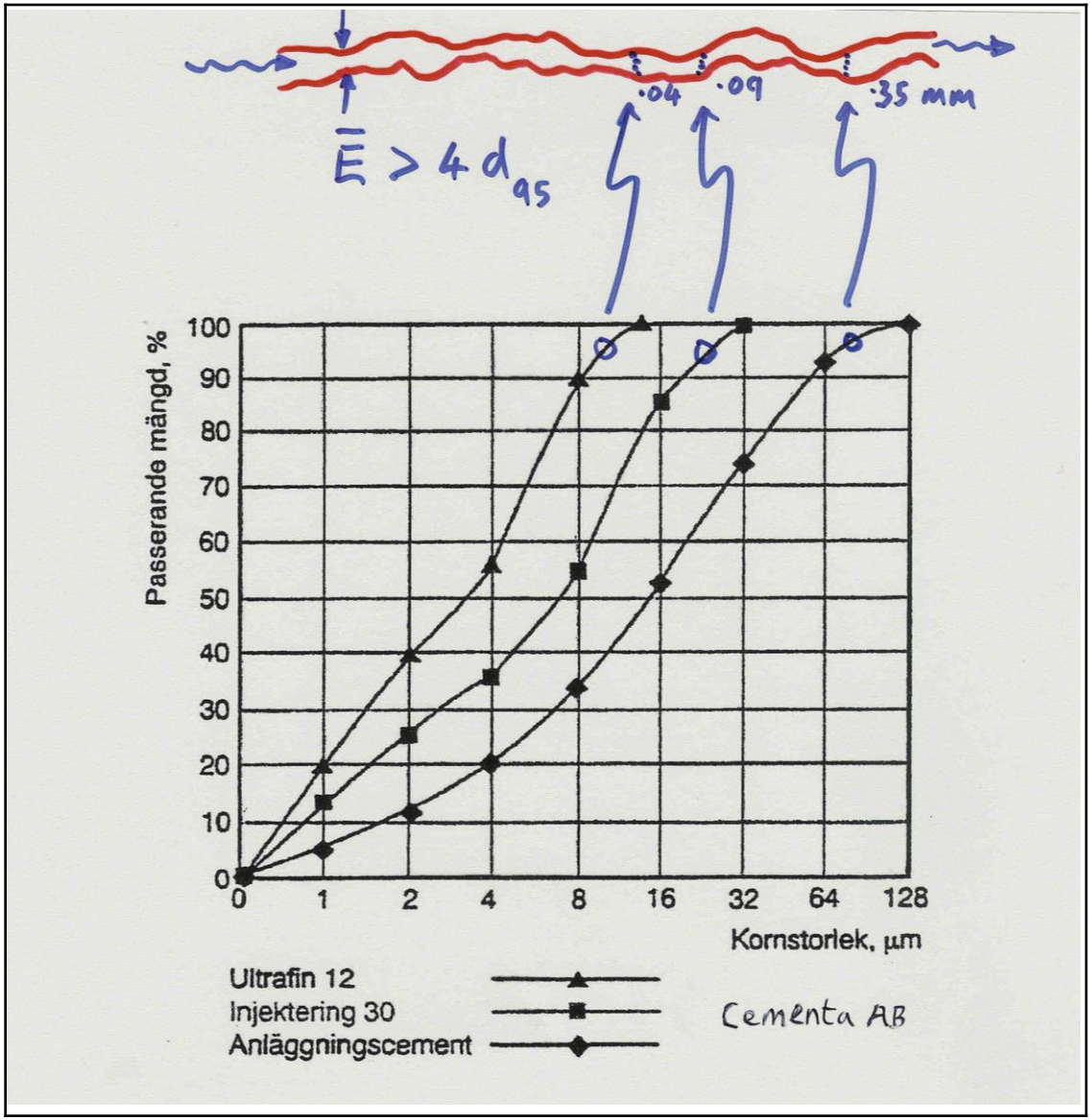


HOW TO ESTIMATE …. **JRC – THE JOINT ROUGHNESS COEFFICIENT**

Can be done on core from ahead of the face, or in the tunnel close to the face

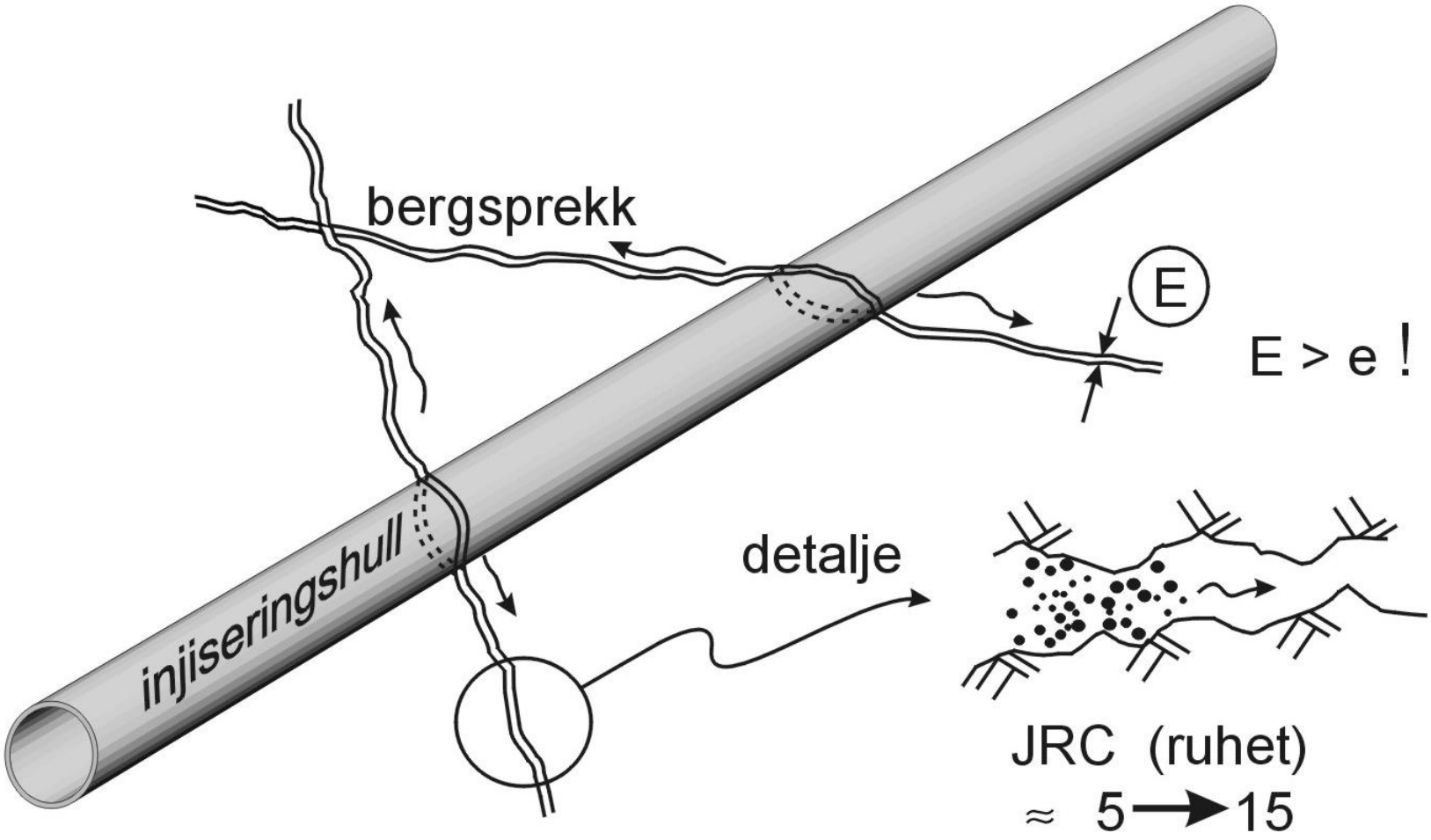
WHAT CEMENTS / CEMENT-PARTICLE GRADING CURVES ARE READILY AVAILABLE IN REGION?

THE (approx.) LIMITS FOR INJECTION of *ULTRAFINE*, *MICRO* and industrial cement

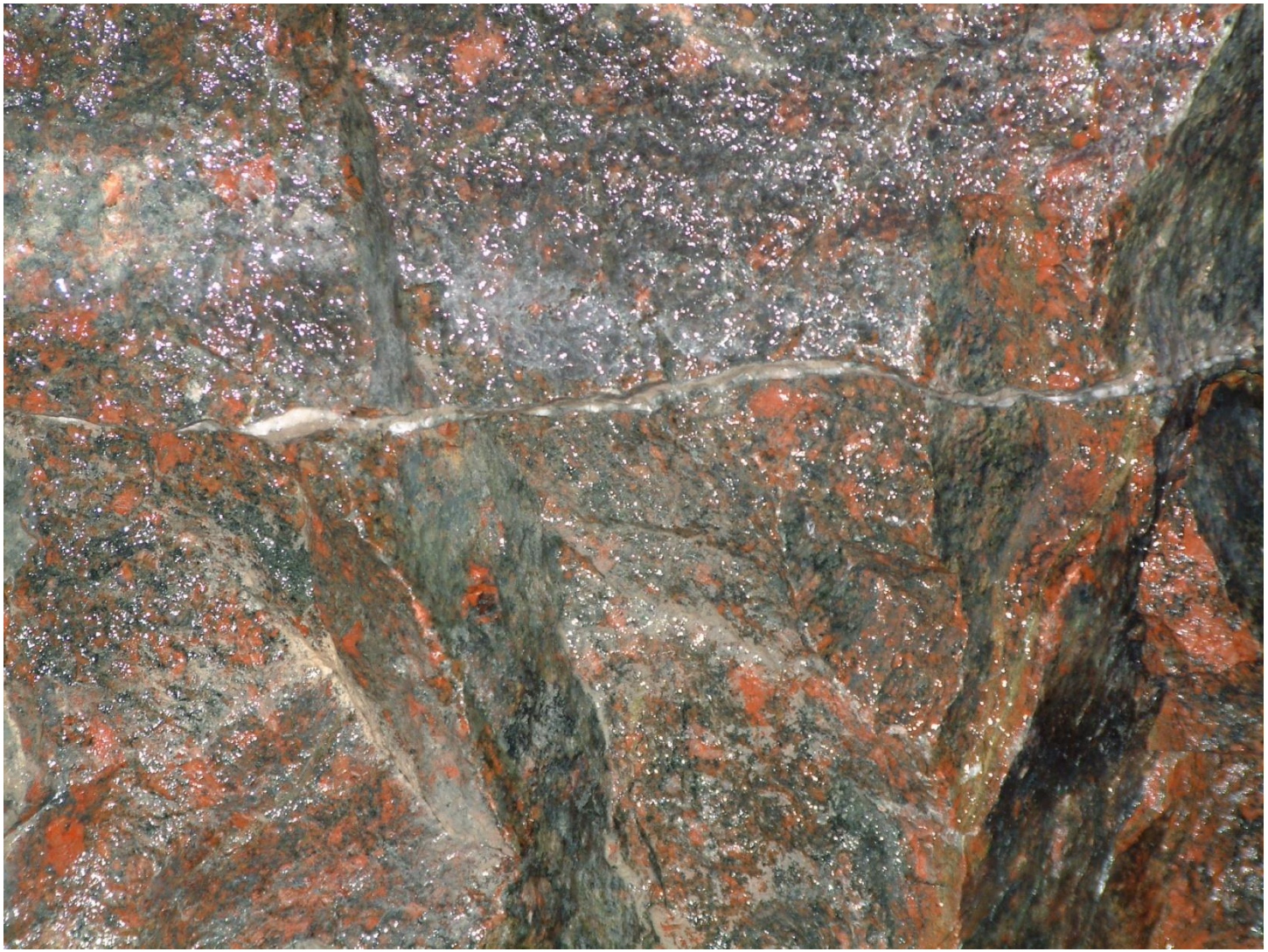


50, 100 and 400µm limits are simpler to remember

GROUTING *BETWEEN* THE JOINT SETS IS ACHIEVED WITH HIGHER PRESSURES

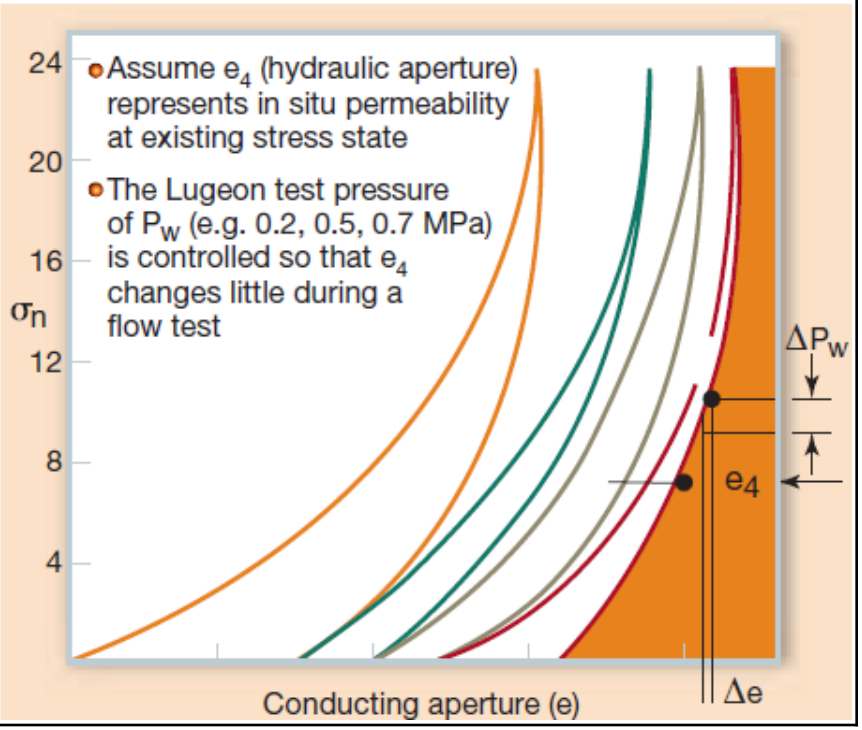


WHEN GROUTING PRESSURE IS TOO LOW…ONLY 1 SET IS INJECTED?

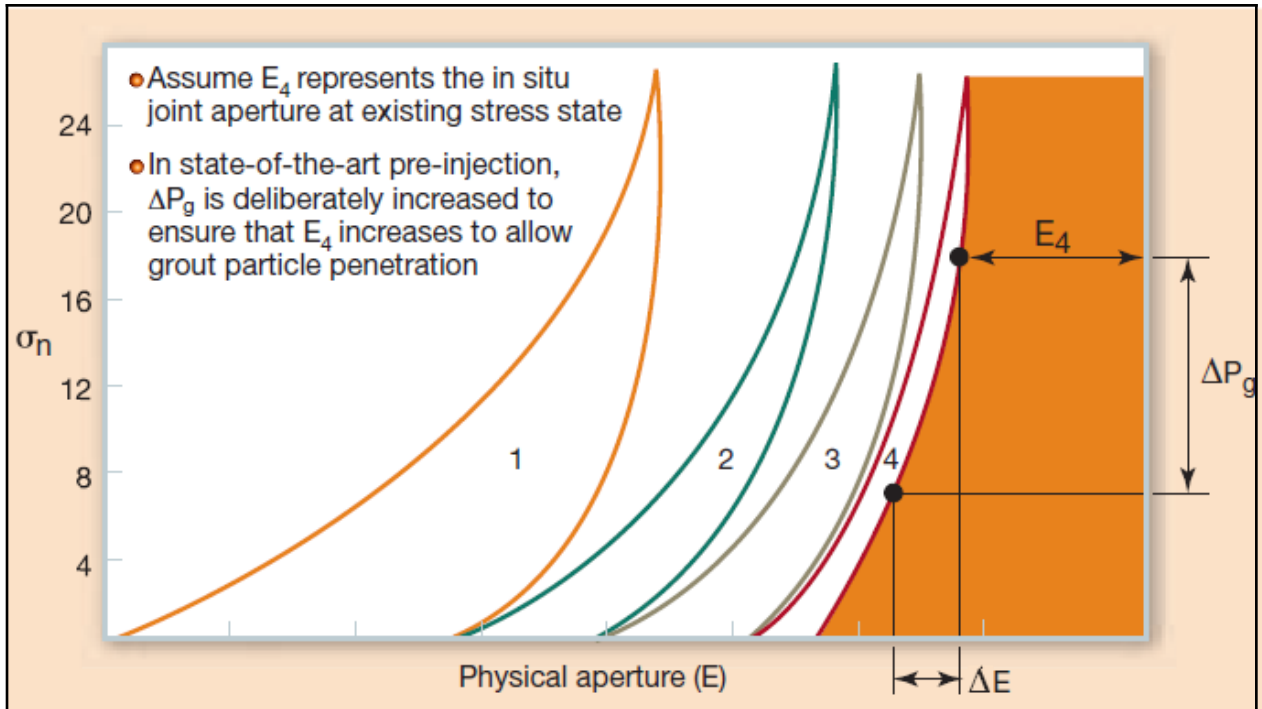


THE MECHANISM OF JOINT OPENING WITH REDUCED EFFECTIVE STRESS……. i.e. WITH INCREASED GROUTING PRESSURE……..

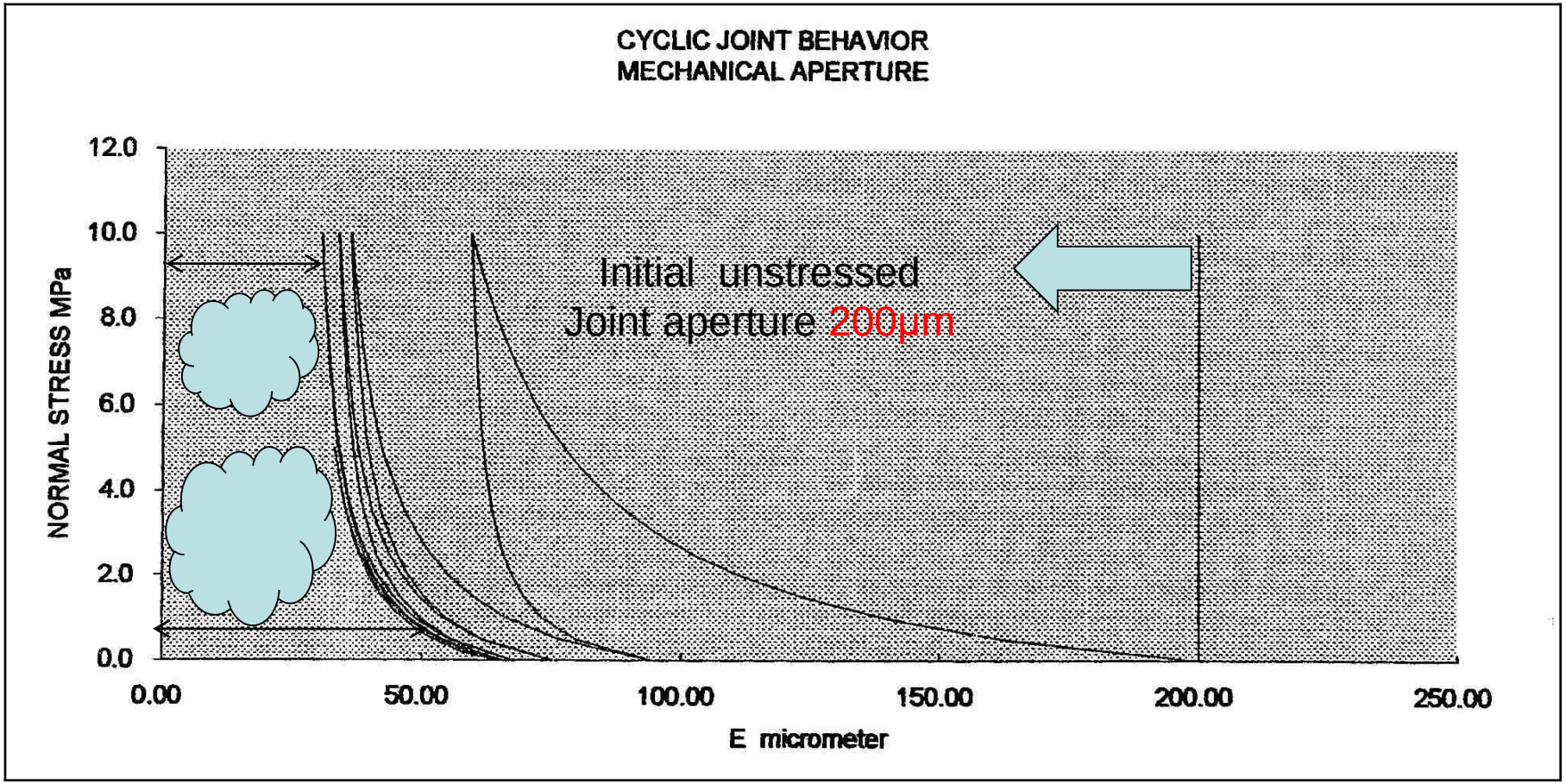
(MODELLING EXAMPLES)



SMALL JOINT DEFORMATION WHEN LUGEON TESTING…….LARGER JOINT DEFORMATION WHEN PRE-INJECTING



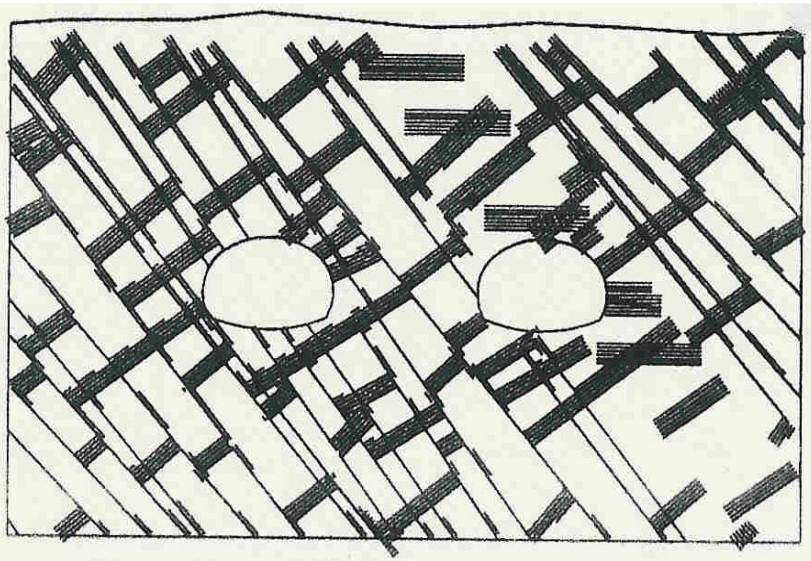
THE ADVANTAGE OF AN INCREASE OF PRESSURE ON ***ΔE***



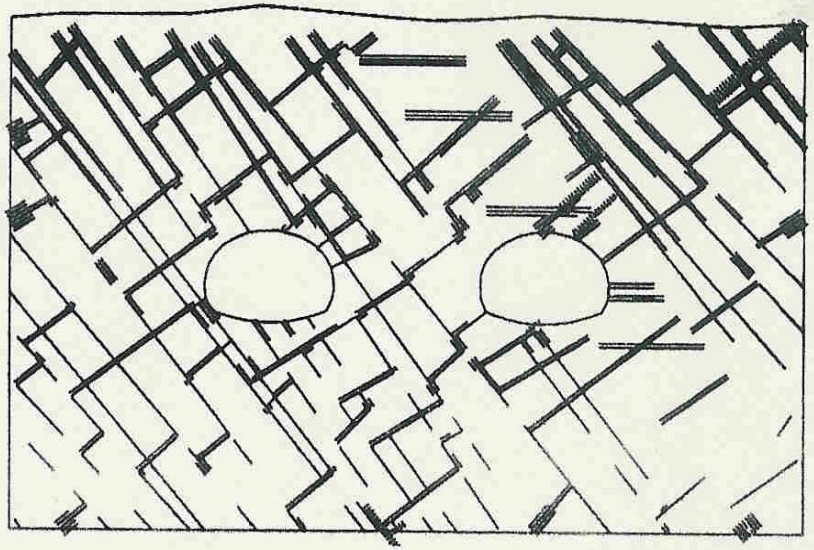
Note that E can be almost doubled from 30 to 60µm
…… now OK for ULTRAFINE CEMENT?

*Examples of apertures E and **e***
in a UDEC-BB model of twin tunnels

(Makurat and Barton, 1988: Oslo Tunnel)



joint mech. aper.
max mech aper = 1.160E-03
each line thick = 2.000E-05



joint hydr. aper.
max hydr aper = 1.160E-03
each line thick = 2.000E-05

SOME RECENT ESTIMATES OF (e) – from LUGEON TESTS and (E) – *from Jr to JRC conversion.*

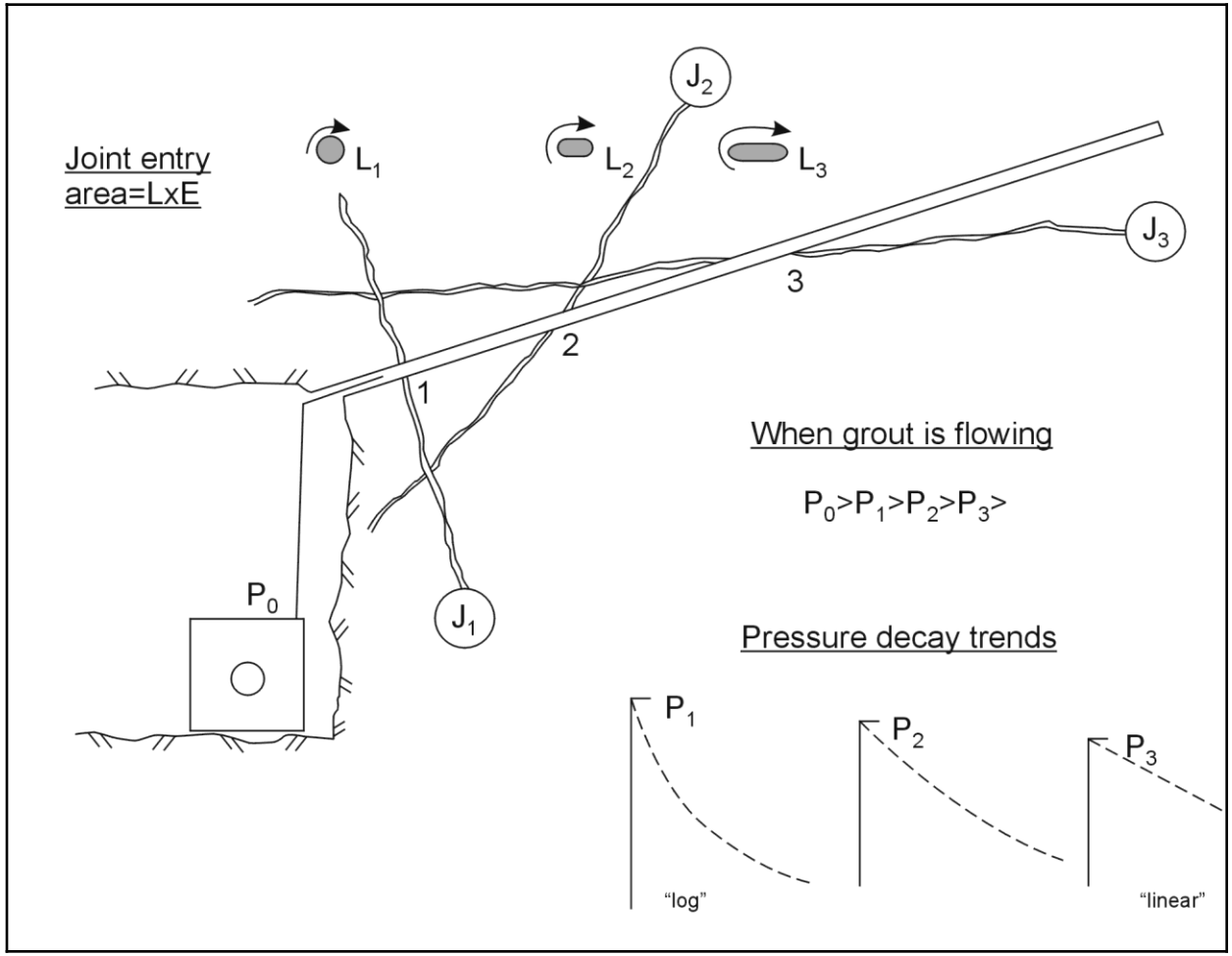
Large (E) due to high Lugeon values...and roughness.

(ORANGE and PINK are easiest to grout)

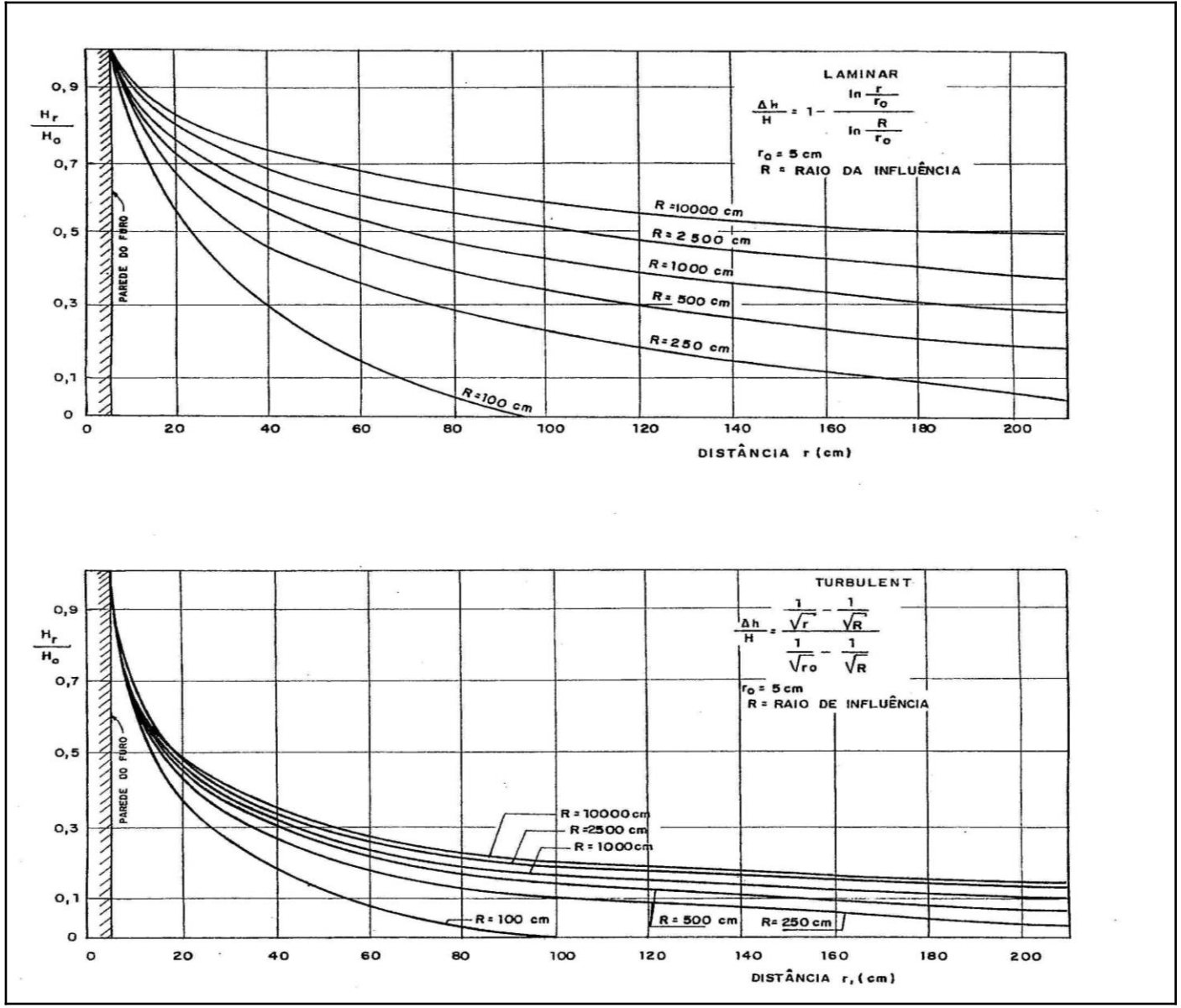
YELLOW (OK)→GREEN→BLUE
needs higher pressure or finer micro/ultrafine

$JRC_{Gjennomsnitt}$	3.5 (Jr=1)	7.5 (Jr=1.5)	12.5 (Jr=2)	17.5 (Jr=3)
Hydraulisk åpning (e)	Fysisk åpning E µm	E µm	E µm	E µm
45 µm	45	80	160	240
75 µm	75	110	200	310
90 µm	90	120	220	340
160 µm	160	160	300	450

HIGH PRESSURE GROUTING IS UNLIKELY TO CAUSE UNWANTED DEFORMATION i.e. uncontrolled hydraulic opening…….
due to HYDRAULIC (Newtonian fluid) pressure decay mechanisms

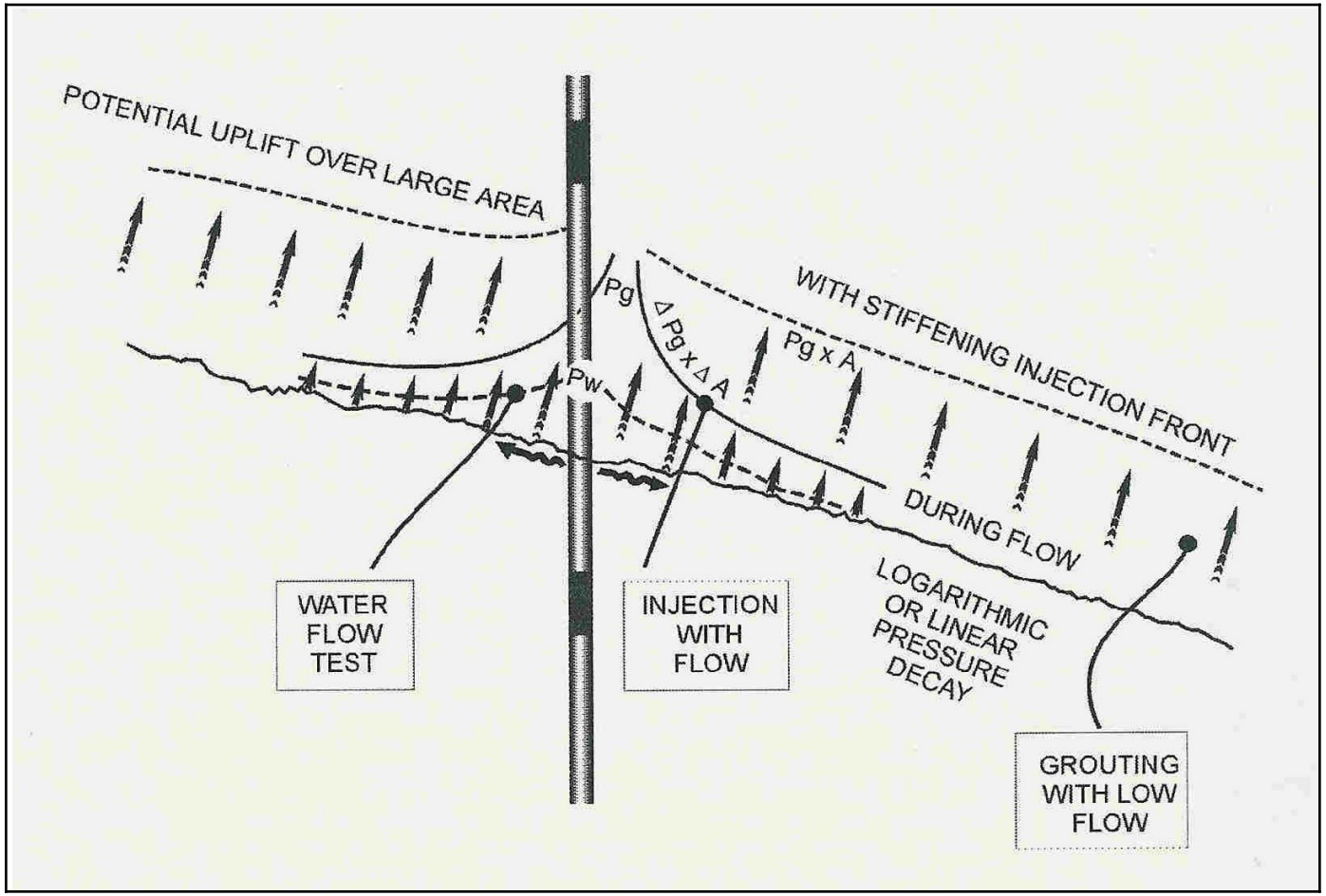


THE LOGARITHMIC PRESSURE DECAY IS A 'SAFETY MECHANISM' for high pressure grouting…….w***hile flow is still occurring***….. and is extra effective with cohesive + frictional fluids like grout

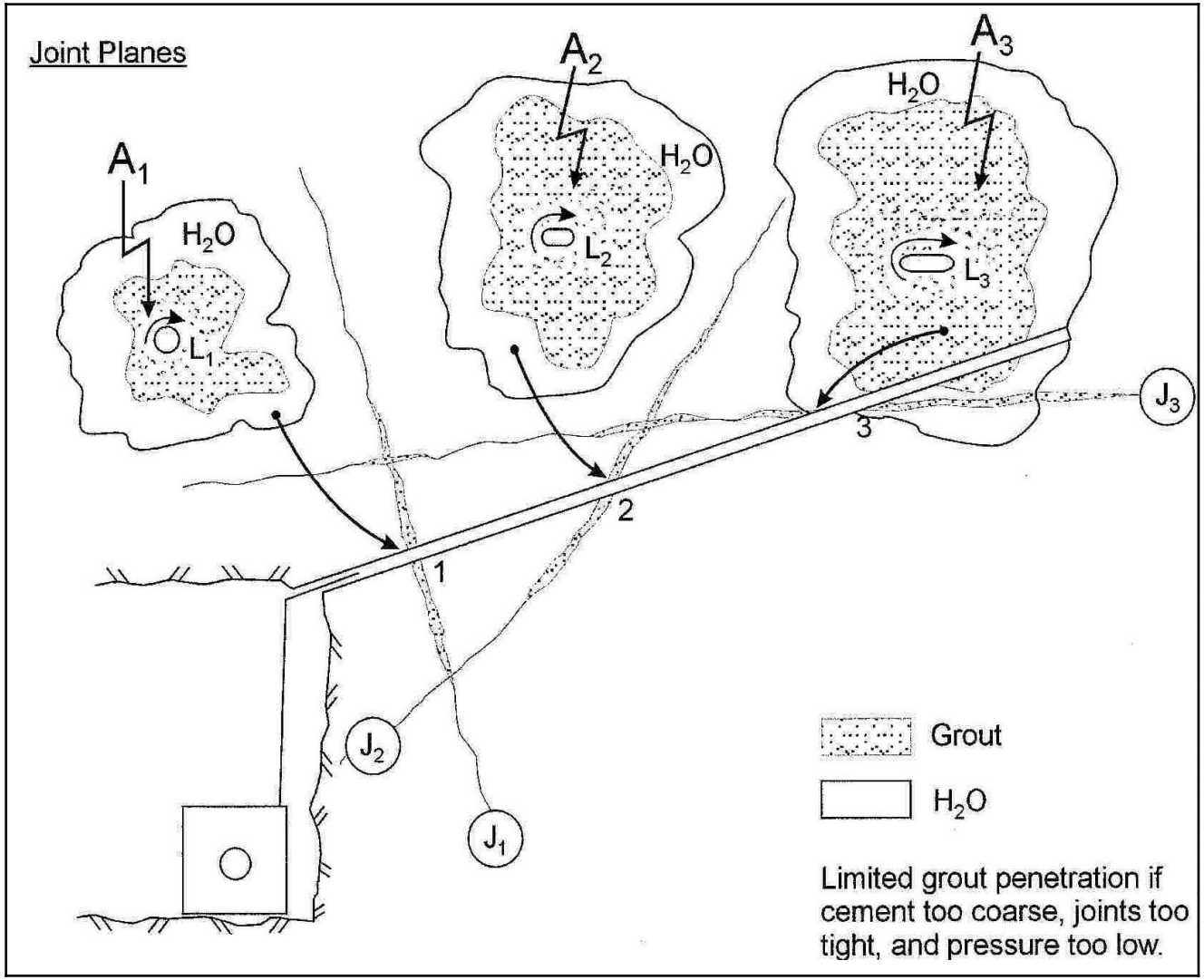


Logarithmic pressure decay with radial, laminar or turbulent flow (e.g. Cruz, 1979)

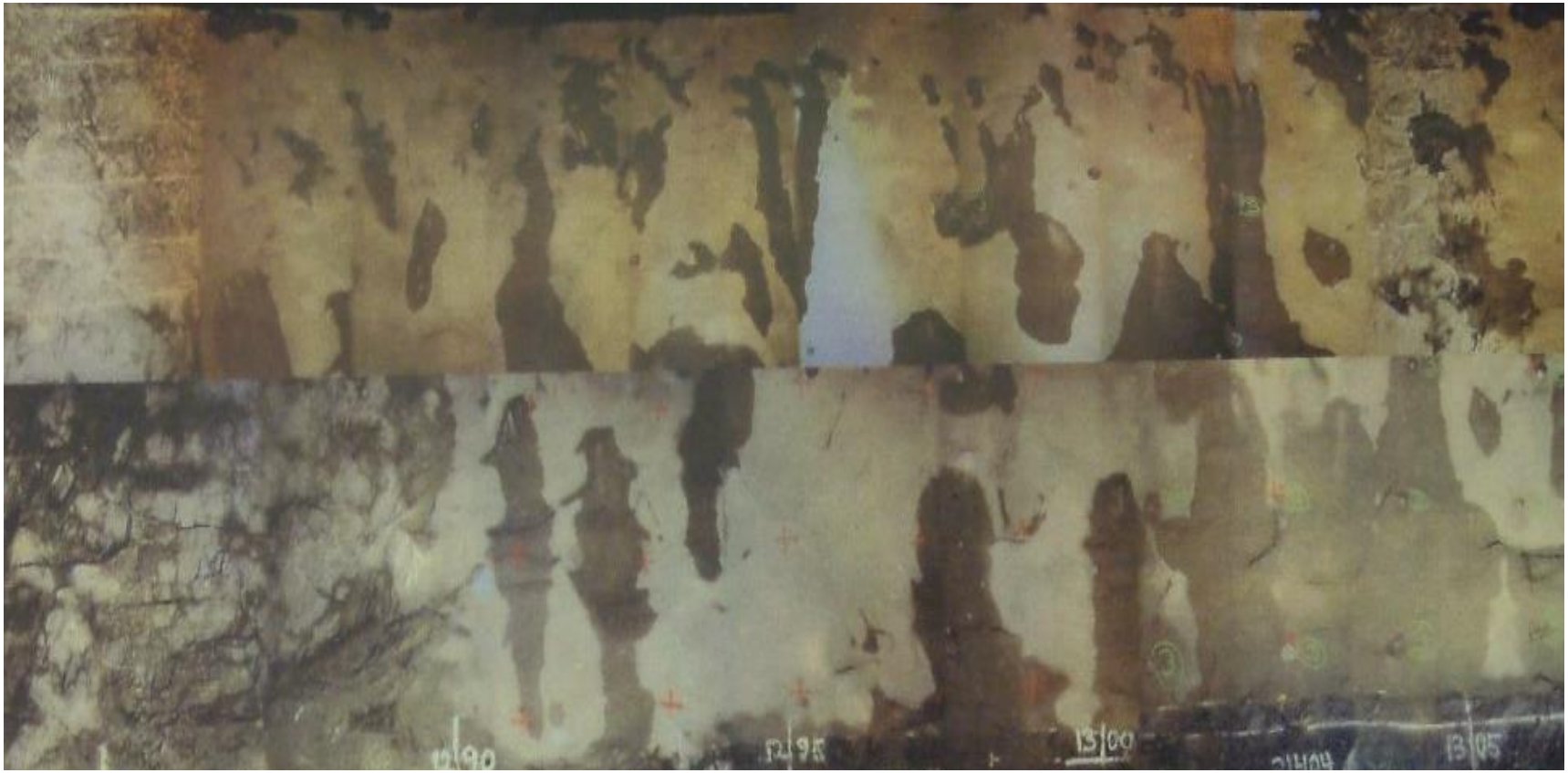
IT IS IMPORTANT TO BE AWARE OF UPLIFT (OR TUNNEL FACE) DEFORMATION THAT MAY OCCUR IF FLOW HAS CEASED AND PRESSURE IS MAINTAINED



WHAT HAPPENS WITH TOO LOW PRESSURE, TOO TIGHT JOINTS, TOO LARGE CEMENT PARTICLES…..AND UNSTABLE GROUTS…… THAT BLEED WATER?



‘WATER-SICK ROCK’.....MORE WATER AFTER PRE-GROUTING, THAN BEFORE !

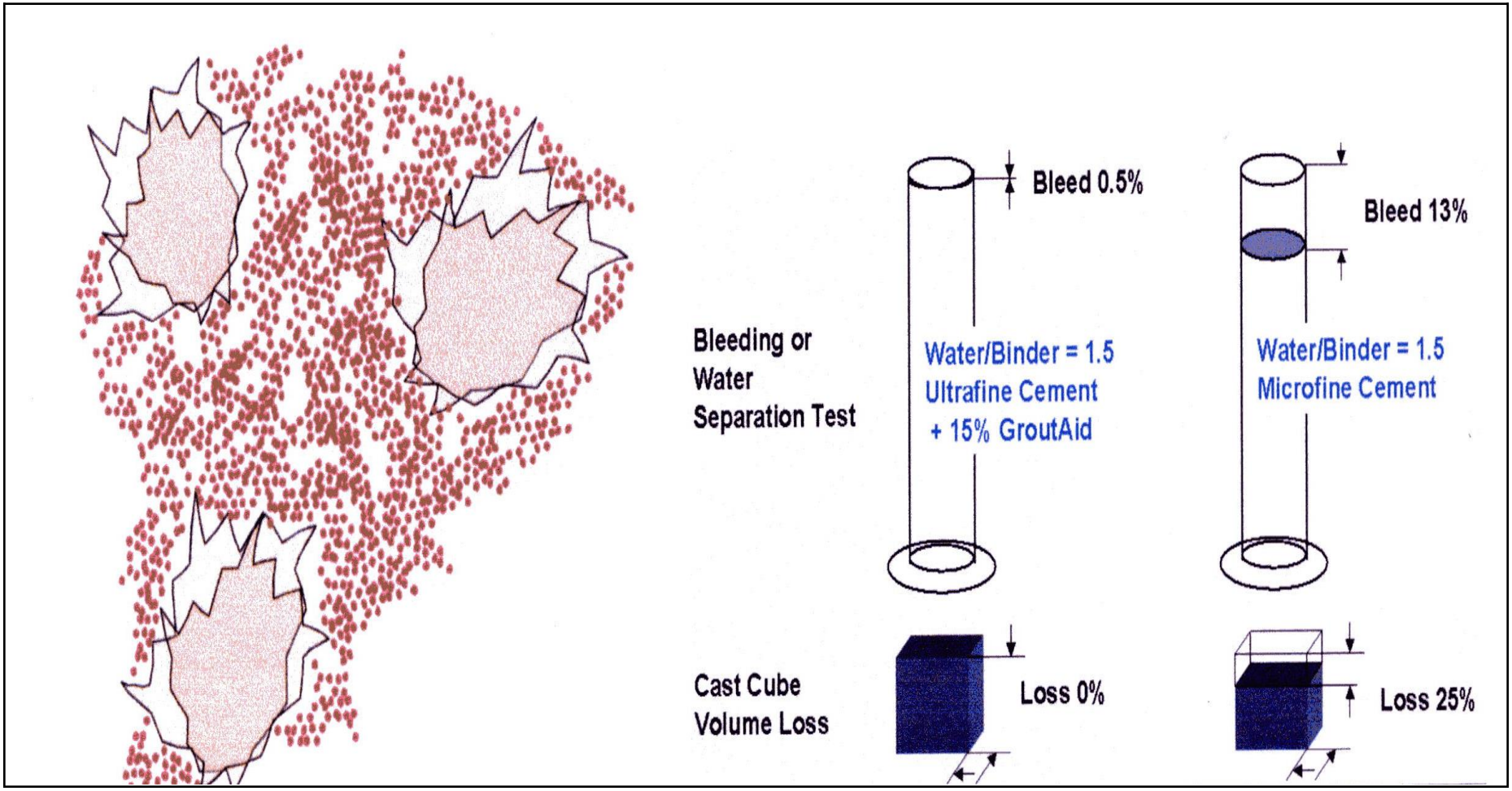


BUT……THE NEXT SCREENS SHOW WHAT OCCURS WHEN DOING SUCCESSFUL INJECTION – when the grout penetrates as expected

Technology development steps (after Garshol, ICE/HK 2010)

FROM:	TO:
High w/c-ratio up to 4.0 bleeding grout	Stable, non-bleeding grout (0.5-1.5)
3-5% Bentonite (to reduce bleeding)	Zero Bentonite; use of admixtures
Typically, Ordinary Portland Cement	Use of **Micro Cement**
Requires "grout to refusal" to squeeze surplus water out of the grout	Stop on pre-defined cement quantity **or** maximum pressure
Typically, low maximum pressure (5-10 bar)	High maximum pressure (**50-100 bar**)*
No **GOOD** chemical grout available	Colloidal Silica: **A Quantum Leap!**

STABLE NON-BLEEDING GROUTS ARE ESSENTIAL FOR PREVENTING *' WATER-SICK' ROCK (Elkem/*



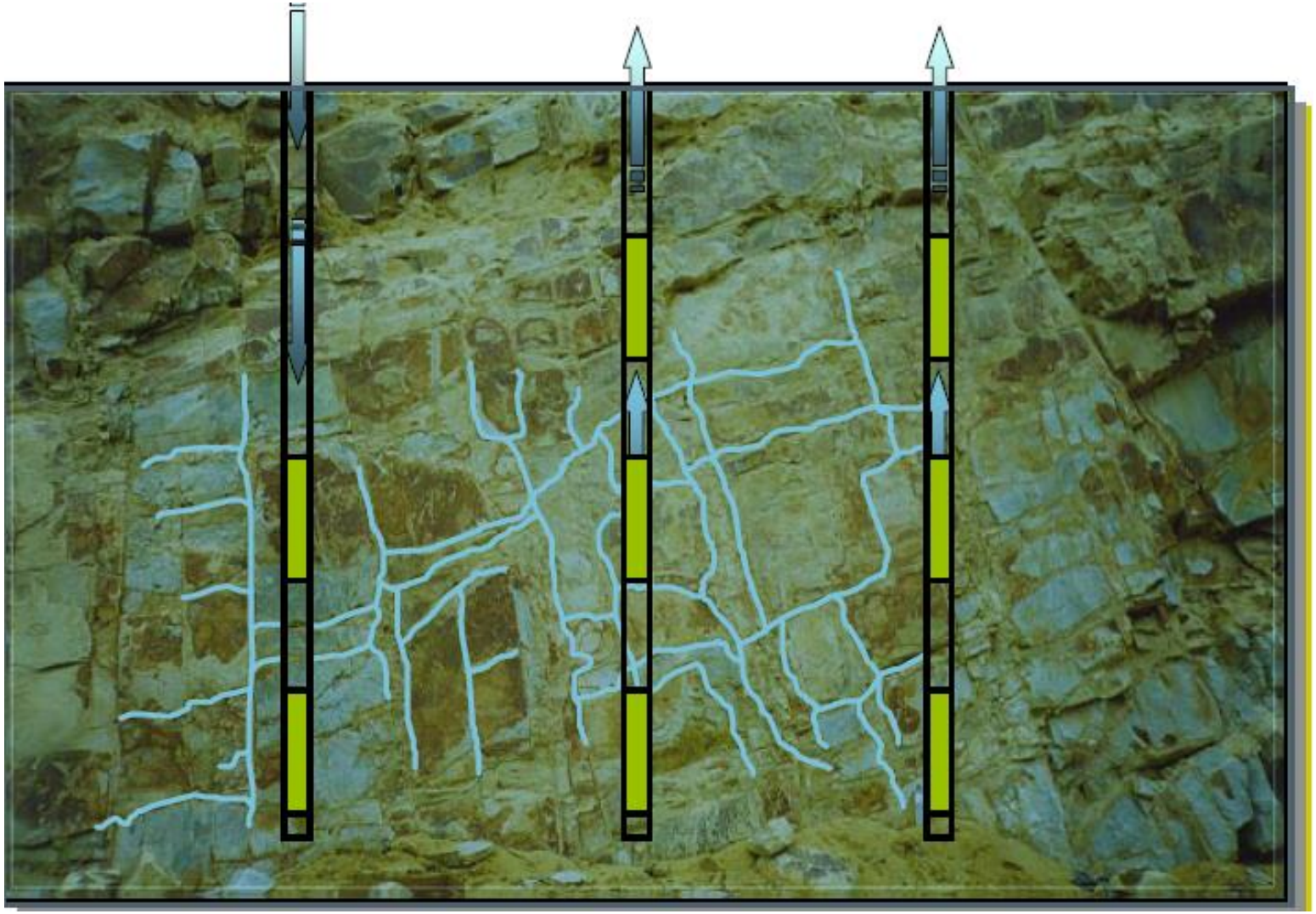
WHAT ABOUT ROCK MASS *PROPERTY IMPROVEMENT*

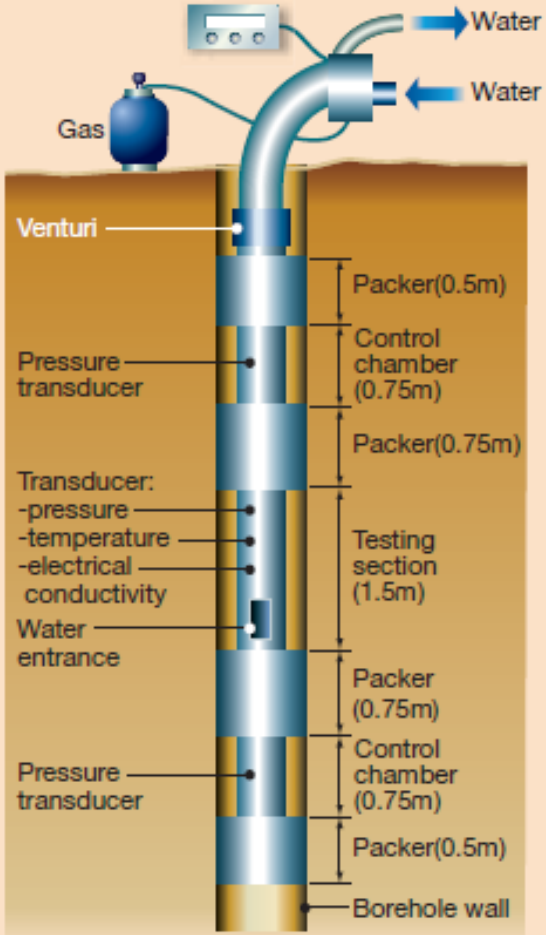
CAUSED BY SUCCESSFUL GROUTING ?

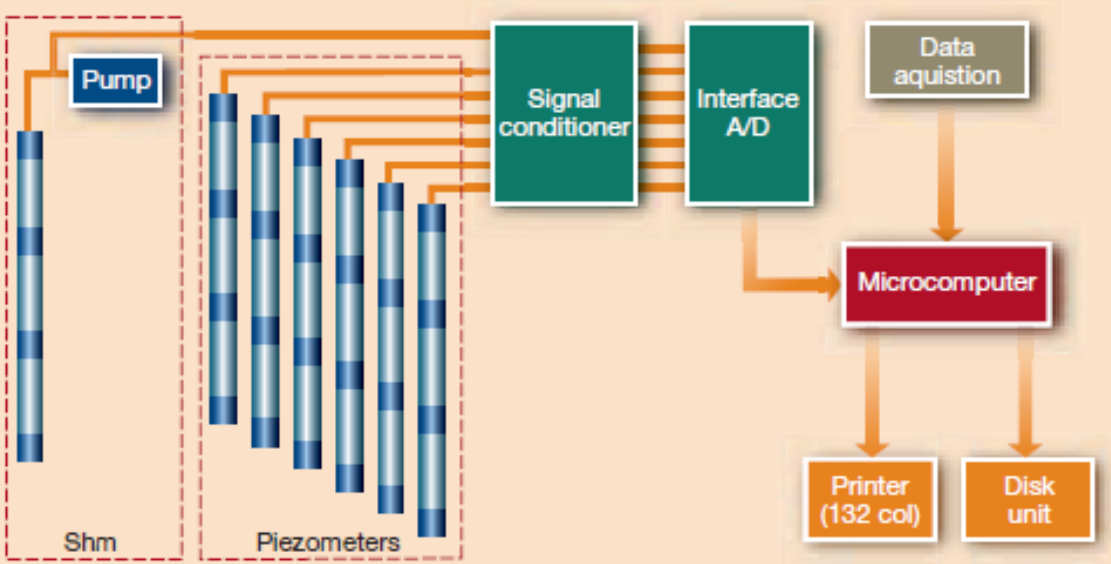
(First some indirect indications of the sealing of joint sets by grout)

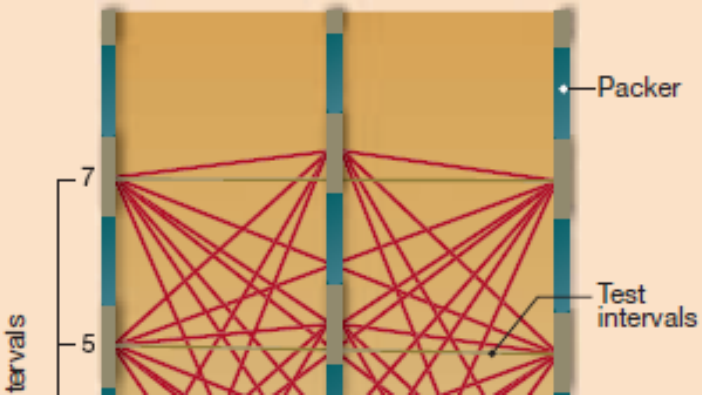
IPT/Brazil multi-probe-multi-hole measurement of grouting 3D permeability testing (utilizing multiple holes simultaneously)

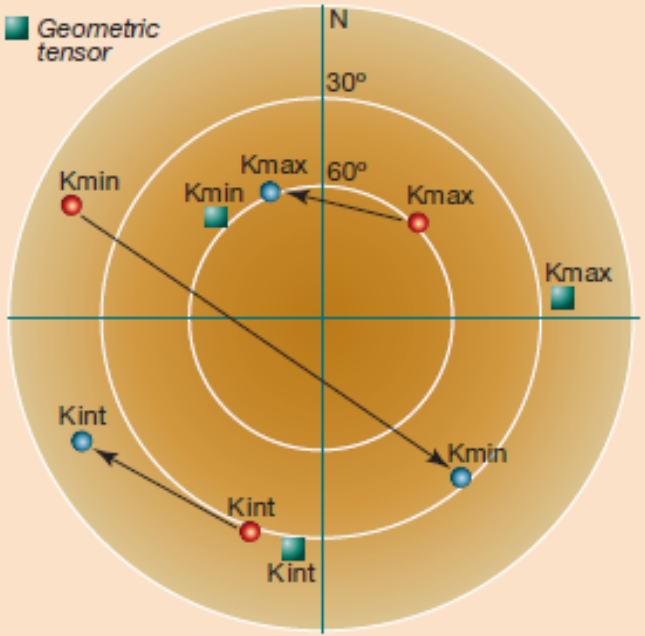
(Quadros and Correa Filho, 1995)

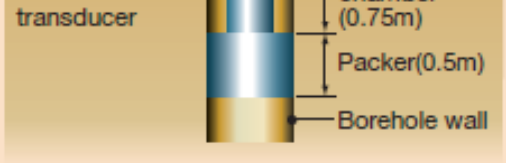


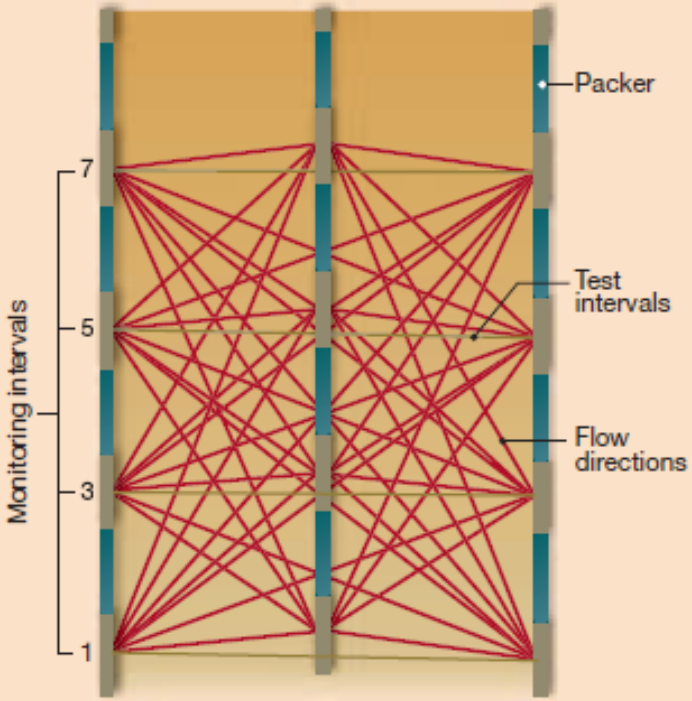

Water
Water
Gas
Venturi
Packer(0.5m)
Control chamber (0.75m)
Pressure transducer
Packer(0.75m)
Transducer:
-pressure
-temperature
-electrical conductivity
Testing section (1.5m)
Water entrance
Packer (0.75m)
Control chamber (0.75m)
Pressure transducer
Packer(0.5m)
Borehole wall

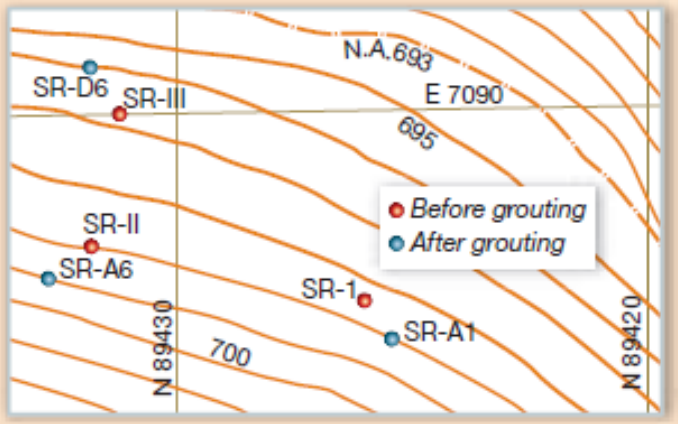

Pump
Signal conditioner
Interface A/D
Data aquistion
Microcomputer
Printer (132 col)
Disk unit
Shm
Piezometers

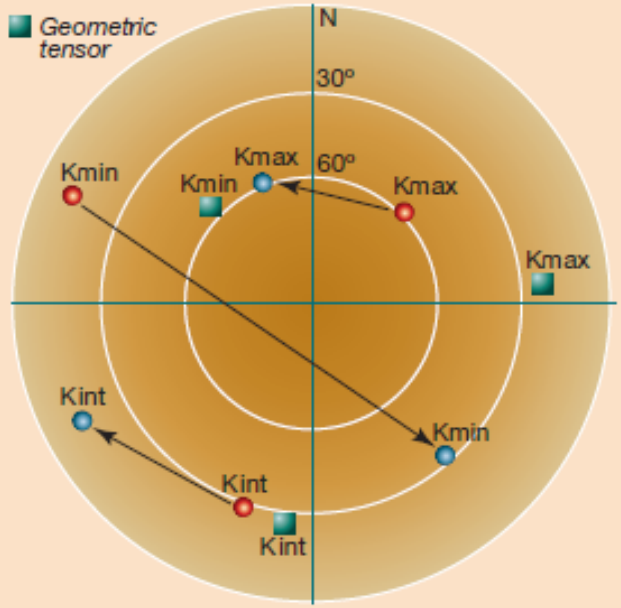

Packer
7
5
Test intervals
tervals


Geometric tensor
N
30°
60°
Kmin
Kmax
Kmin
Kmax
Kmax
Kint
Kmin
Kint
Kint







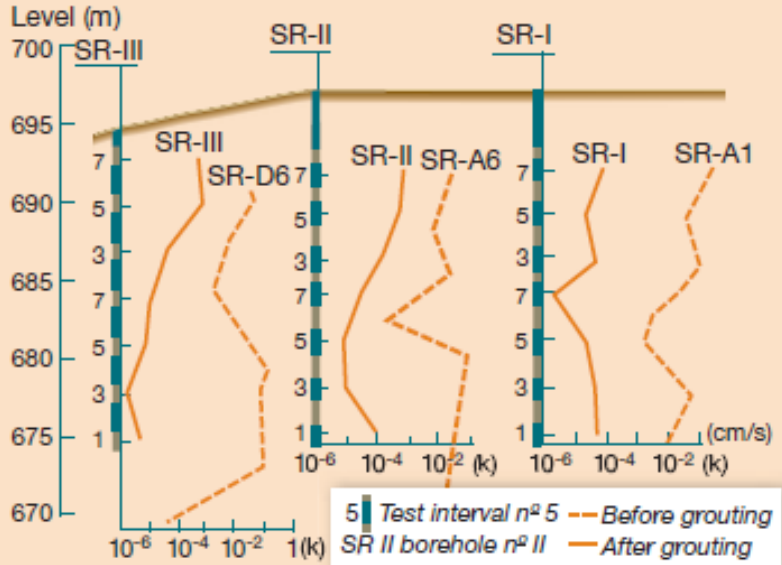


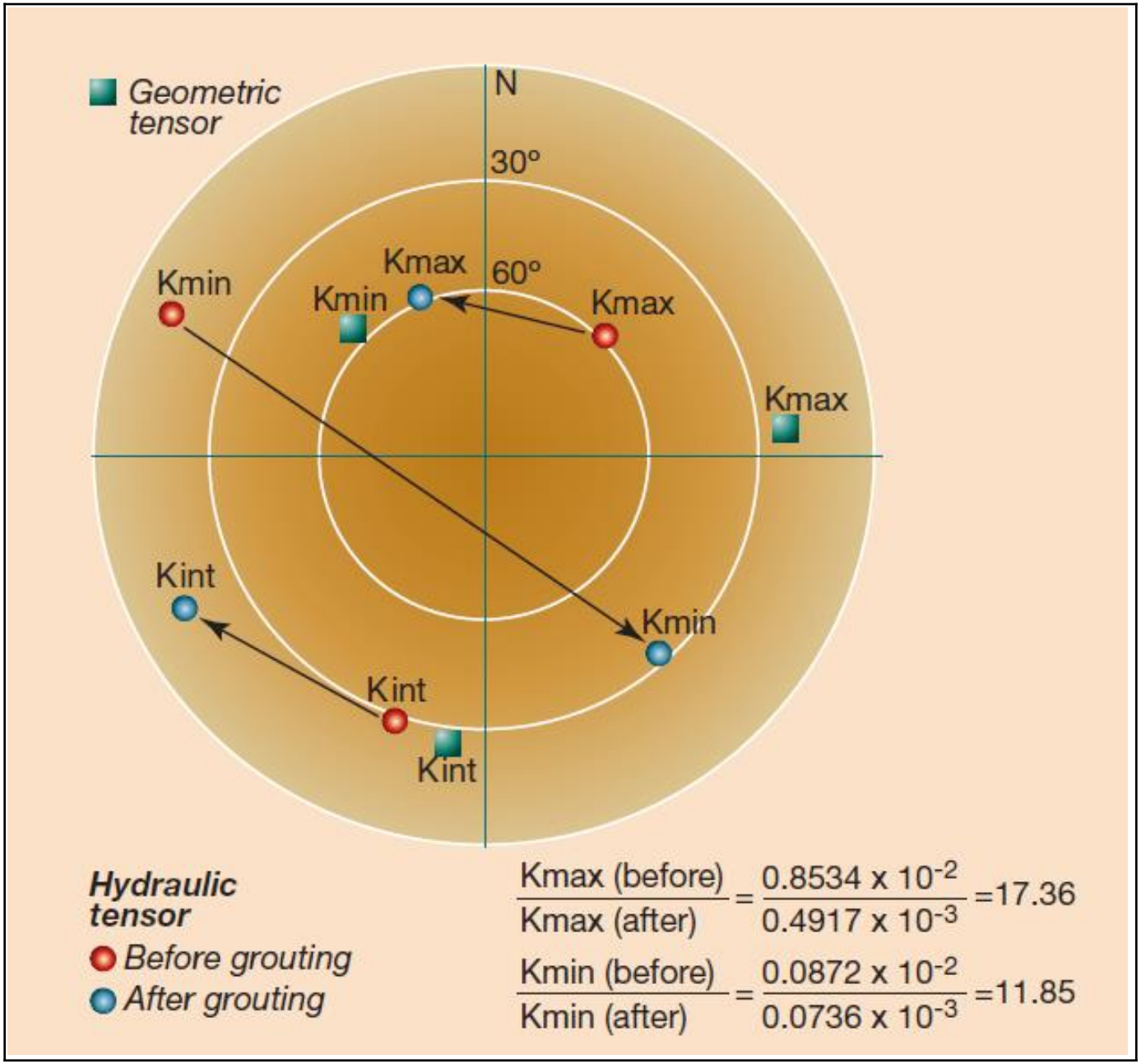
Hydraulic tensor

- *Before grouting*
- *After grouting*

$$\frac{K_{max}\ (before)}{K_{max}\ (after)} = \frac{0.8534 \times 10^{-2}}{0.4917 \times 10^{-3}} = 17.36$$

$$\frac{K_{min}\ (before)}{K_{min}\ (after)} = \frac{0.0872 \times 10^{-2}}{0.0736 \times 10^{-3}} = 11.85$$




Geometric tensor
N
30°
60°
Kmin
Kmax
Kmin
Kmax
Kmax
Kint
Kmin
Kint
Kint
Hydraulic tensor
Before grouting
After grouting
Kmax (before) / Kmax (after) = 0.8534 x 10-2 / 0.4917 x 10-3 =17.36
Kmin (before) / Kmin (after) = 0.0872 x 10-2 / 0.0736 x 10-3 =11.85

Suppose the following small improvements occur to individual Q-parameters, due to pre-grouting…….*these assumptions are so* *<u>conservative</u> they must be erroneous*…….*the Q-parameter improvements are usually greater !!* *(Barton, 2002)*

Improvement of rock mass properties with pre-grouting

effective	RQD	increases	e.g.	30 to 50%	
effective	J_n	reduces	e.g.	9 to 6	
	J_r	increases	e.g.	1 to 2	(changed set)*
	J_a	reduces	e.g.	2 to 1	(changed set)*
	J_w	increases	e.g.	0.5 to 0.66	(perhaps Jw = 1 is achieved)

SRF would reduce only near surface e.g. 2.5 to 1

(* it may be appropriate to qualify with the word "perhaps" in several cases here)

Before pre-grouting $Q \approx \frac{30}{9} \times \frac{1}{2} \times \frac{0.5}{2,5}$

≈ 0.3

After pre-grouting $Q \approx \frac{50}{6} \times \frac{2}{1} \times \frac{0.66}{1 \text{or} 2.5}$

≈ 11 (or 4·4)

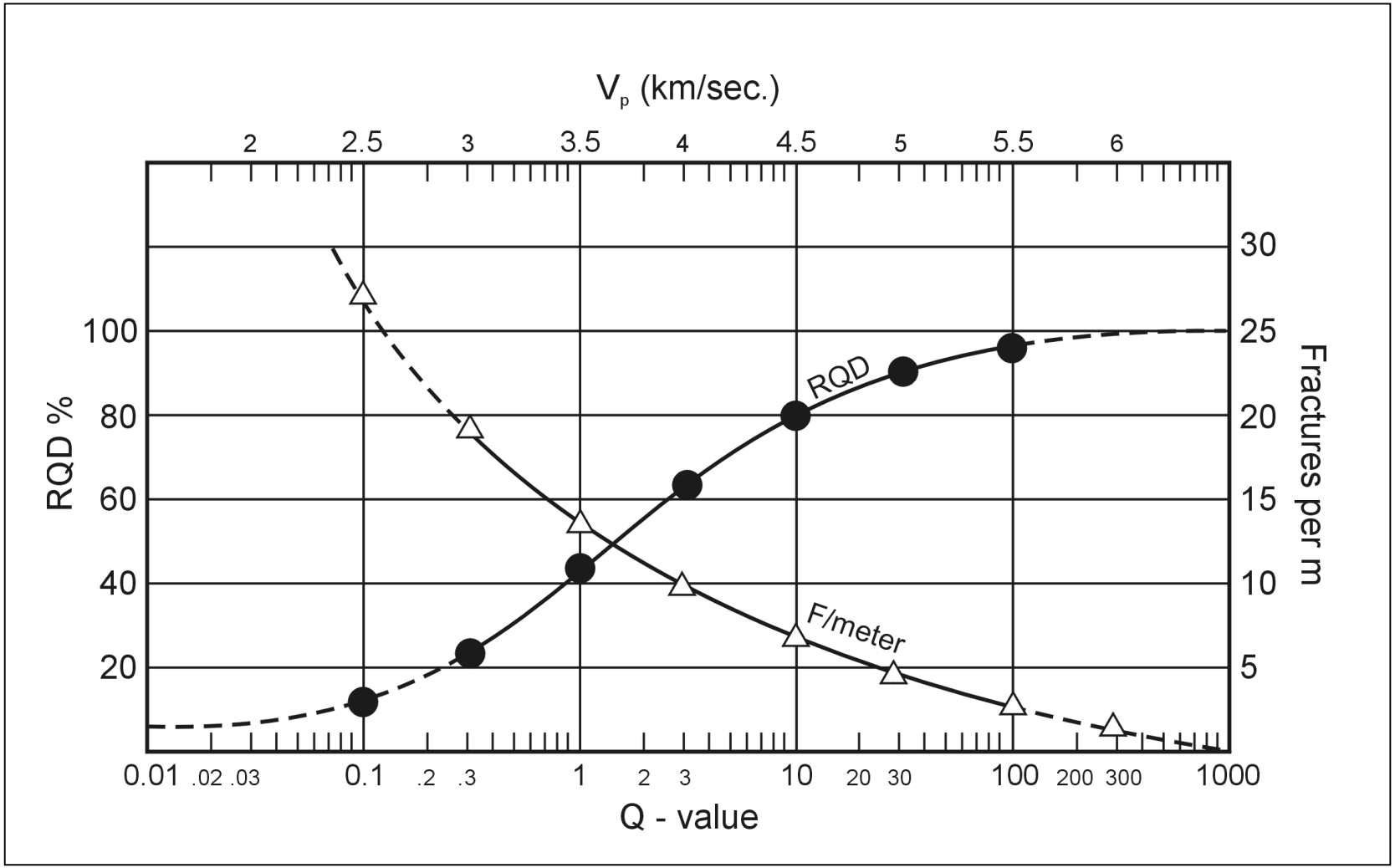
POSSIBLE BENEFITS OF PRE-GROUTING from logical Q-parameter changes, for two different rock masses:	
RQD increases e.g. 30 to 50%	RQD increases e.g. 30 to 70%
Jn reduces e.g. 9 to 6	Jn reduces e.g. 12 to 4
Jr increases e.g. 1 to 2 (due to sealing of most of set #1)	Jr increases e.g. 1.5 to 2 (due to sealing of most of set #1)
Ja reduces e.g. 2 to 1 (due to sealing of most of set #1)	Ja reduces e.g. 4 to 1 (due to sealing of most of set #1)
Jw increases e.g. 0.5 to 1	Jw increases e.g. 0.66 to 1
SRF unchanged e.g.1.0 to 1.0	SRF improves e.g. 2.5 to 1.0 due to consolidation of loose material
Before pre-grouting *Q = 30/9 x 1/2 x 0.5/1 = 0.8* *Vp ≈ 3.4 km/s* $E_{mass} \approx 9.3$ *GPa*	*Before pre-grouting* Q = 30/12 x 1.5/4 x 0.66/2.5 = 0.2 *Vp ≈ 2.8 km/s* $E_{mass} \approx 5.8$ *GPa*
After pre-grouting Q = 50/6 x 2/1 x 1/1 = 17 *Vp ≈ 4.7 km/s* $E_{mass} \approx 25.7$ *GPa*	*After pre-grouting* Q = 70/4 x 2/1 x 1/1 = 35 *Vp ≈ 5.0 km/s* $E_{mass} \approx 32.7$ *GPa*

HIGH-PRESURE PRE-GROUTING ADVANTAGES

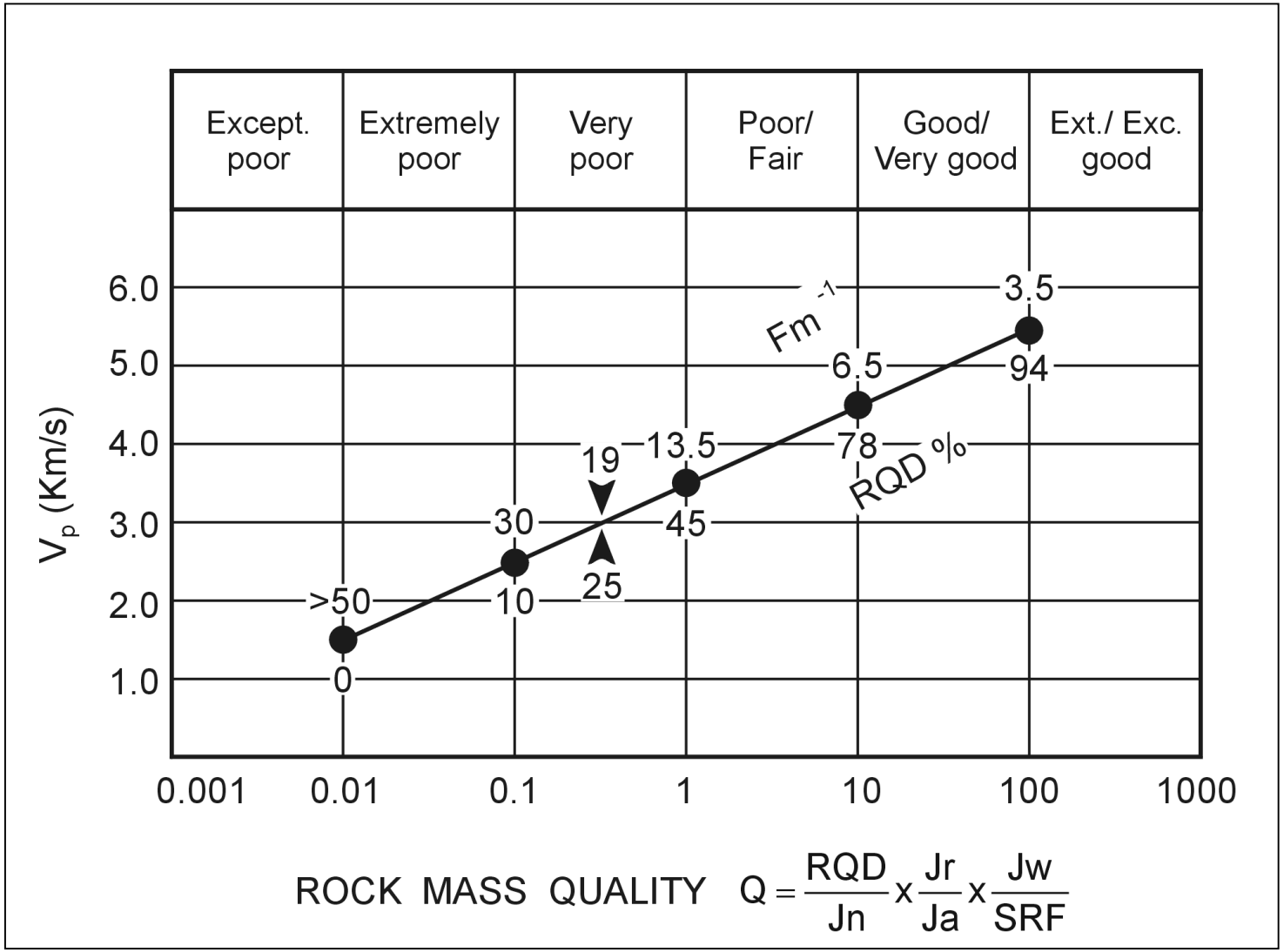
- *gives TROUBLE-FREE TUNNELLING that is faster and cheaper and needs LESS SUPPORT*
- *because it is the basis of a PERMANENT SINGLE SHELL (NMT) SOLUTION that is applied into/onto an IMPROVED ROCKMASS*

HOW COULD WE VERIFY IN SITU, THE ASSUMED BENEFICIAL EFFECTS OF PRE-GROUTING?

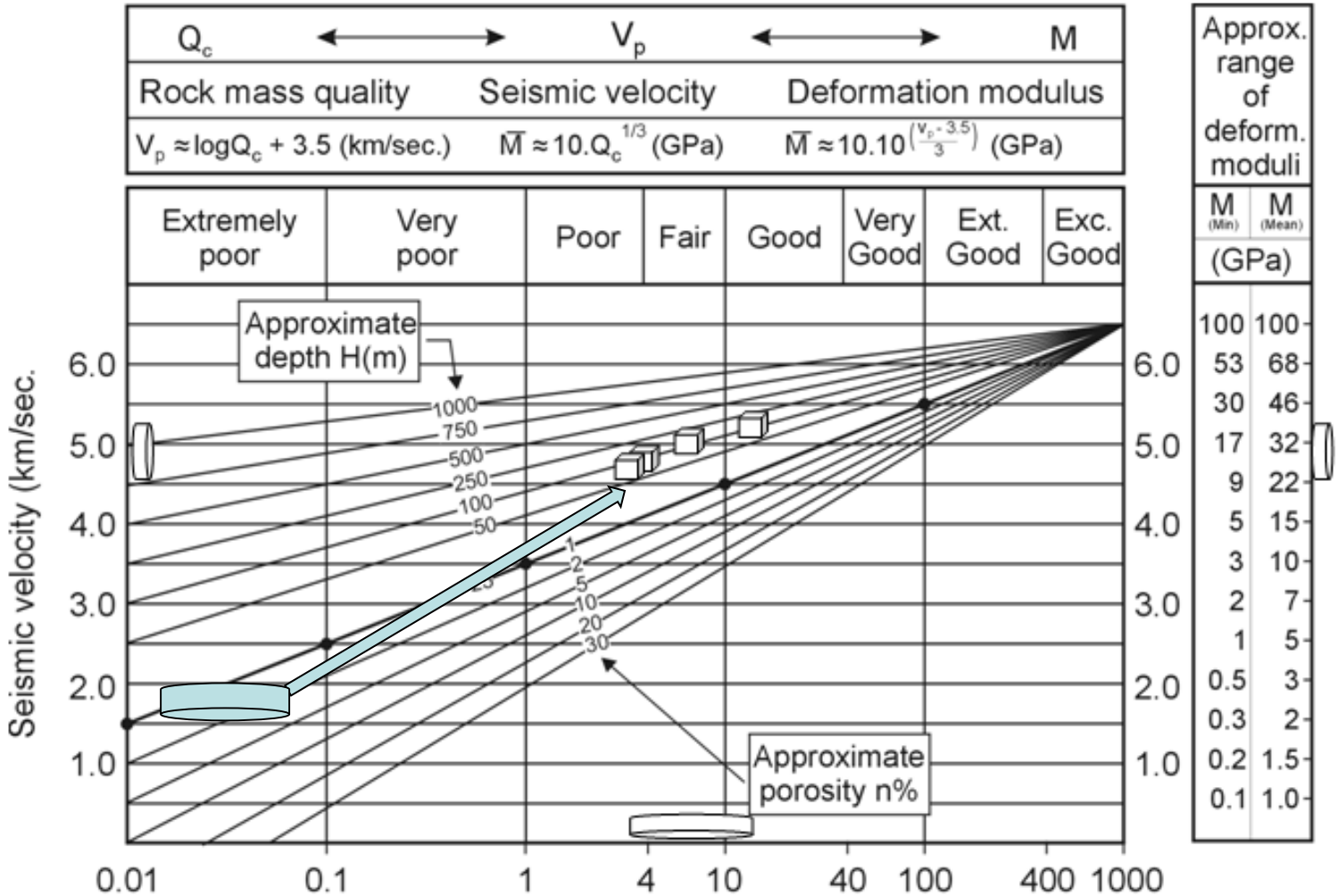
The starting point from ....120 km seismic profiles, 2.8 km core



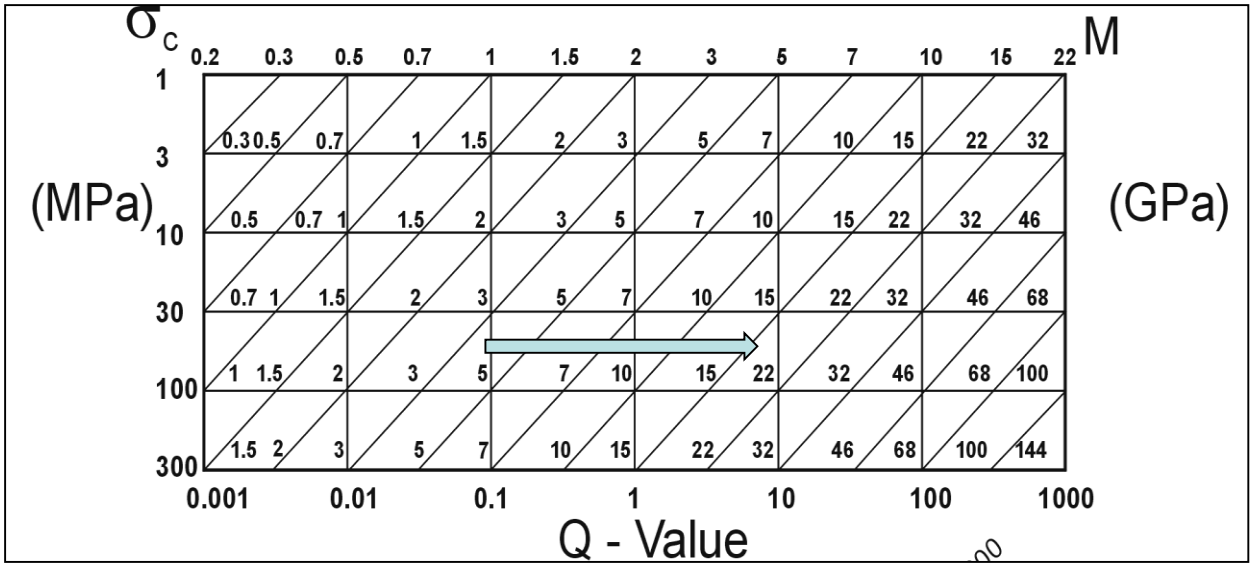
(After Sjøgren et al. 1979, with Barton, 1995 addition of Q)



(As with all Sjøgren data: hard rock, near-surface)



$$Q_c = \left[\frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} \right] \frac{\sigma_c}{100}$$



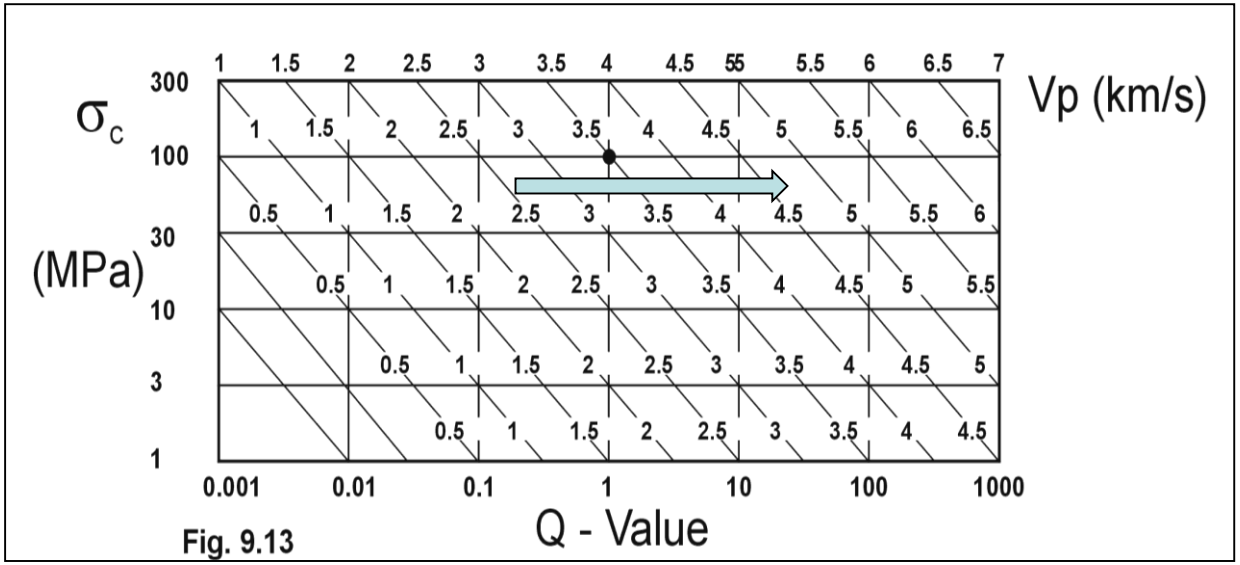
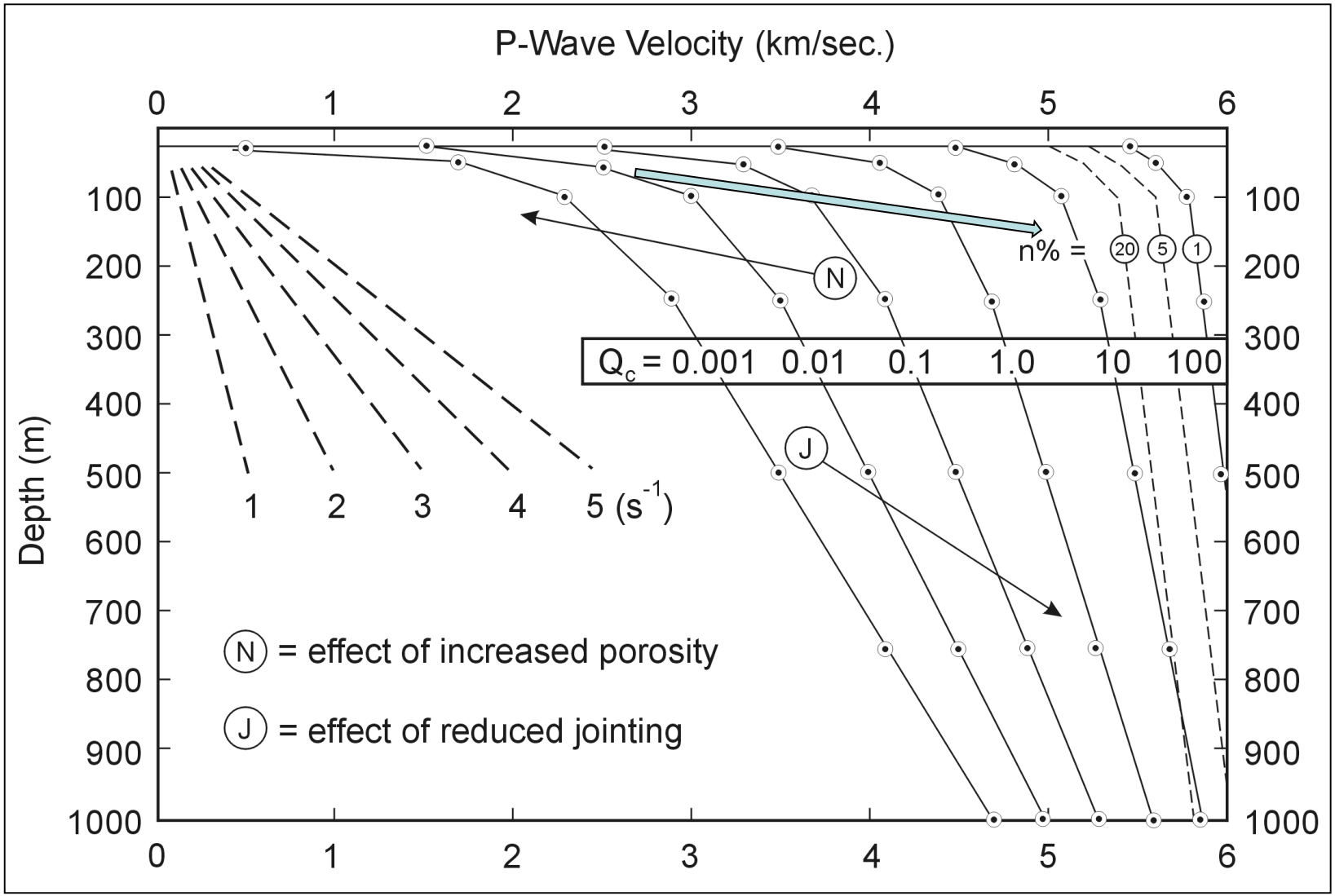
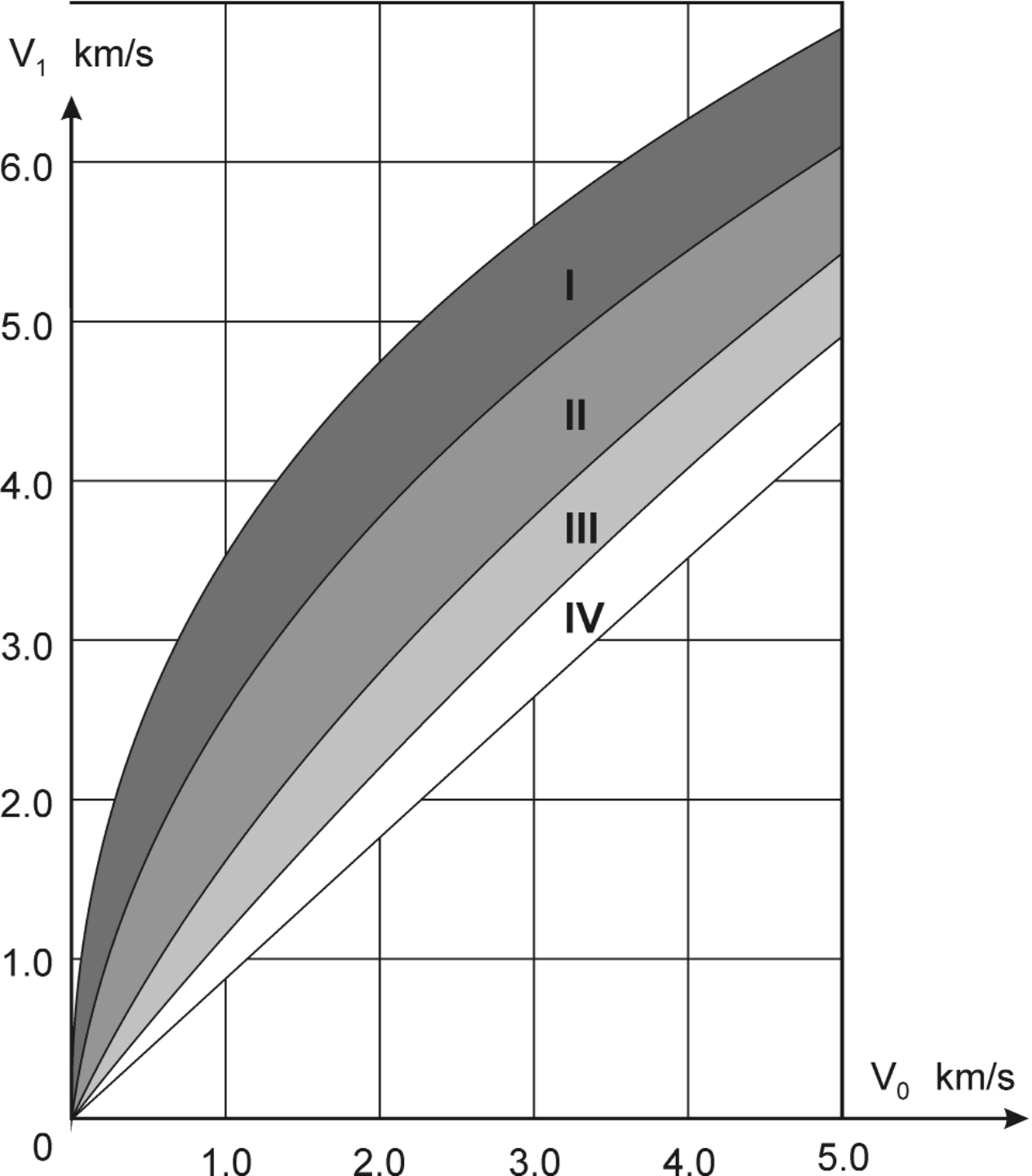


Fig. 9.13

NOTE: NO CORRECTION FOR DEPTH (OR STRESS) – from central diagonal in previous figure – nominal depth 25m


P-Wave Velocity (km/sec.)
0
1
2
3
4
5
6
Depth (m)
100
200
300
400
500
600
700
800
900
1000
n% =
20
5
1
N
Q$_c$ = 0.001 0.01 0.1 1.0 10 100
J
1 2 3 4 5 (s^{-1})
N = effect of increased porosity
J = effect of reduced jointing



Grouting efficiency

I= excellent, II= good,
III = Satisfactory,
IV = unsatisfactory)
……

based on velocity monitoring at the Inguri arch dam.

Savich et al., 1983.

“The average values for the whole foundation were 3.18 km/s before grouting and 4.74 km/s after grouting which imply an effective Q-value increase from (very approximately) 0.5 to 17, or a Lugeon value reduction from perhaps 2 to 0.06”

(Many more cases in Barton, 2006)

SOME OF THE EMPIRICAL EQUATIONS RELATING Q-value and rock mass property estimates (Note also following:

$$\Delta_v = \frac{SPAN}{100Q}\sqrt{\frac{\sigma_v}{\sigma_c}}$$

$$Q_c = Q \times \sigma_c / 100$$

$$(Km/s)\ V_p \approx \log Q_c + 3.5 \quad \left(\begin{matrix}+\text{depth}\\ \text{effect}\end{matrix}\right)$$

$$(GPa)\ E_{mass} \approx 10\, Q_c^{1/3} \quad (+\text{depth})$$

$$SIGMA_{cm} = 5\gamma\, Q_c^{1/3}\ (MPa)$$

$$P_r \approx 0.1\, Q^{-1/3} \approx \frac{10^{-3}}{E_{mass}}\ (MPa)$$

$$L \approx 1/Q_c$$

$$K \approx 10^{-7} \times L\ (m/s)$$

$$\Delta_{max} \approx SPAN(m)/Q$$

$$FC = \tan^{-1}(J_r/J_a \times J_w)^{\circ}$$

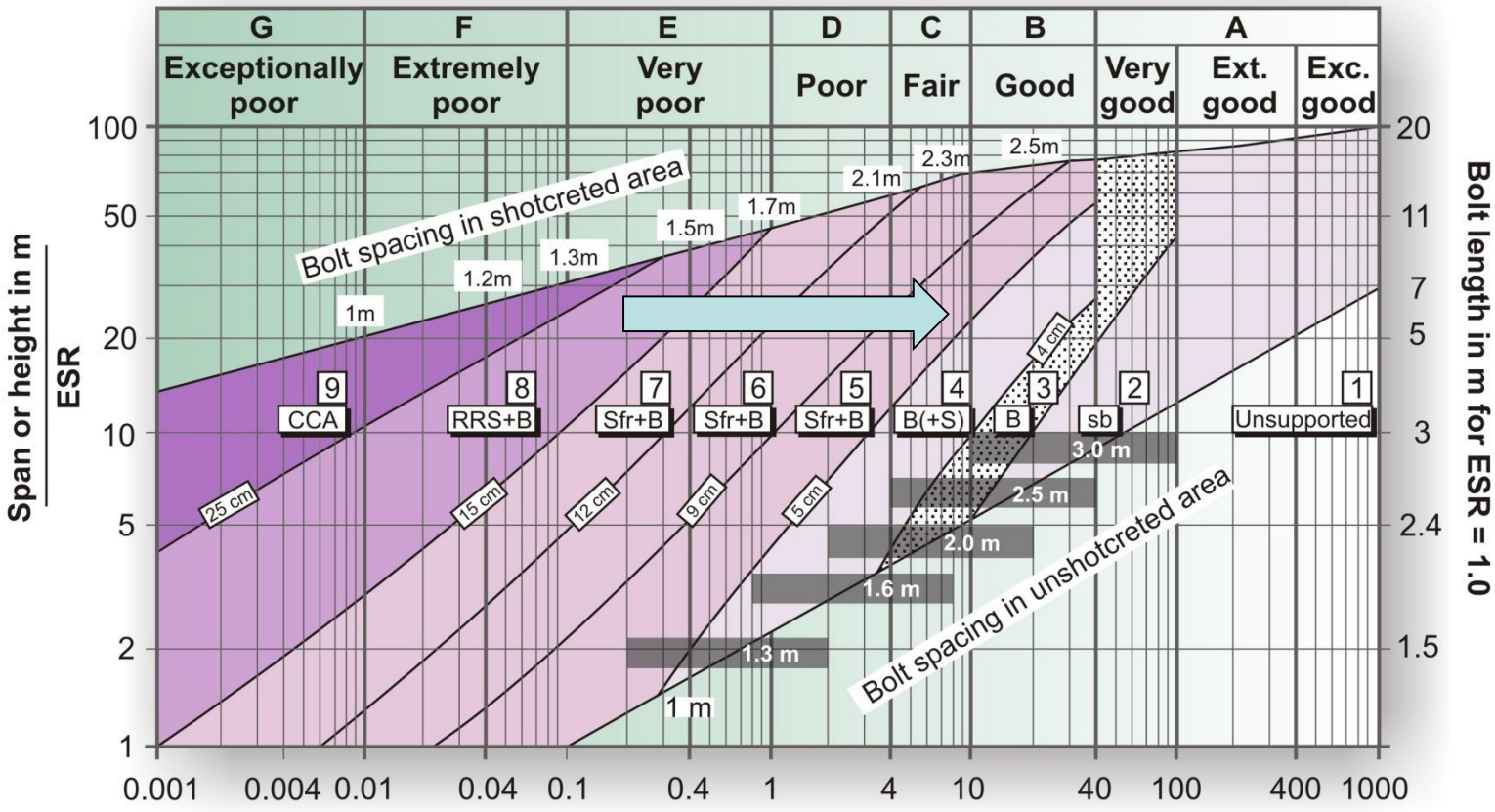
$$CC = RQD/J_n \times 1/SRF \times \sigma_c/100\ MPa$$

These could give the following improvements in rock mass properties ……?

Before pre-grouting	*After pre-grouting*	*(alternative)*
$Q \approx 0.3$	$Q \approx 11$	$(Q \approx 4{\cdot}4)$
$V_p \approx 3.0$ km/sec	$Vp \approx 4.5$ km/sec	$(V_p \approx 4{\cdot}1)$ km/sec
$L \approx 3$ (3×10^{-7} m/s	$L \approx 0{\cdot}1$ (10^{-8} m/s)	$(L \approx 0{\cdot}2)$ 2×10^{-8} m/s
$M \approx 7$ GPa	$M \approx 22$ GPa	$(M \approx 16)$ GPa
$P_r \approx 14$ tnf/m^2	$Pr \approx 4{\cdot}5$ tnf/m^2	$(P_r \approx 6{\cdot}1)$ tnf/m^2
$\Delta \approx 33$ mm	$\Delta \approx 0{\cdot}9$ mm	$(\Delta \approx 2{\cdot}3)$ mm

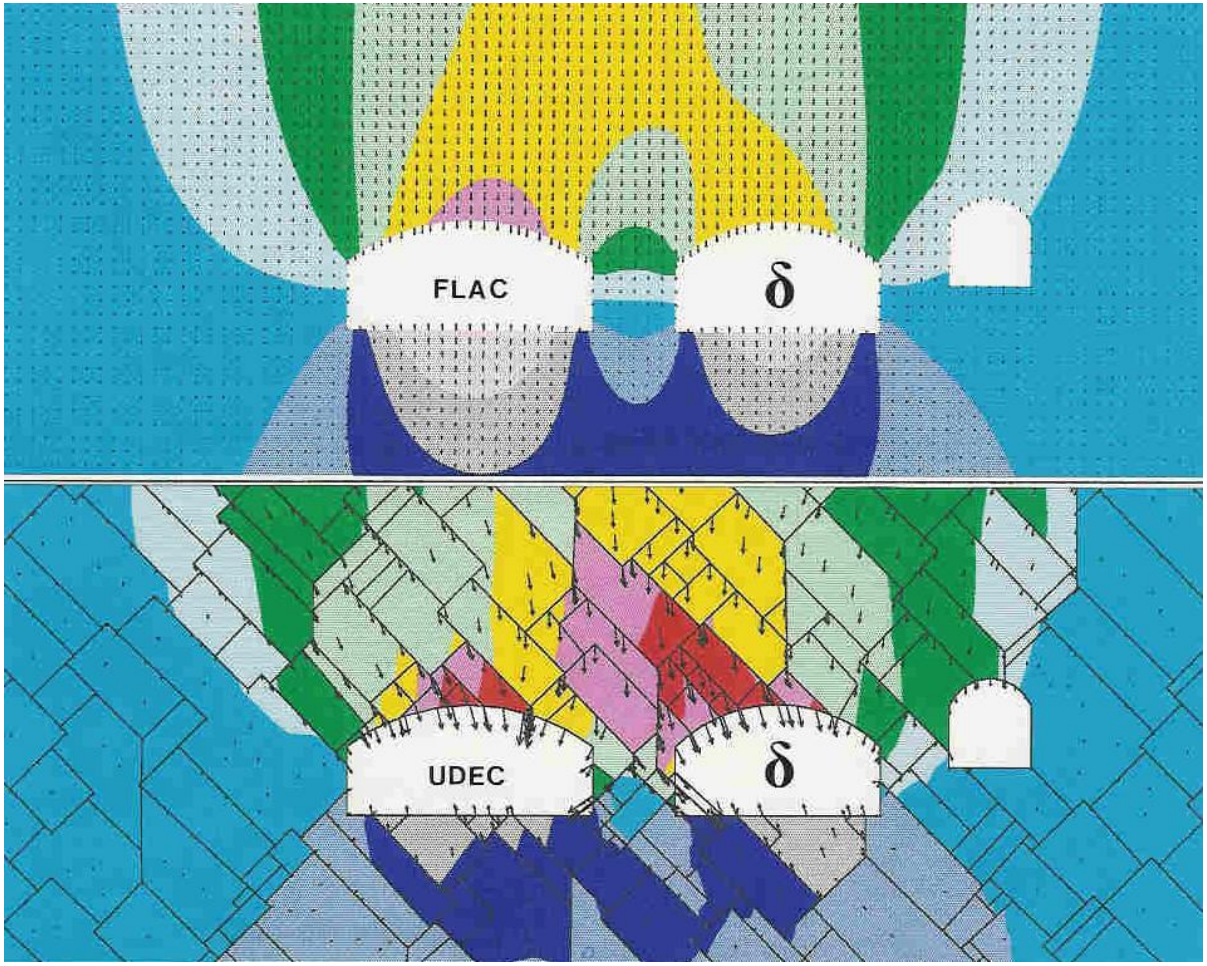
Without pre-grouting	*With pre-grouting*	*(alternative)*
B 1·5 m/sec	B 2·4 m c/c	B 2·1 m c/c
S (fr) 12 cm	S (fr) 4 cm	S (fr) 5 cm

HERE WE SEE THE POTENTIAL FOR REDUCED TUNNEL SUPPORT ……. IF THE EFFECTIVE Q-VALUE CAN BE IMPROVED



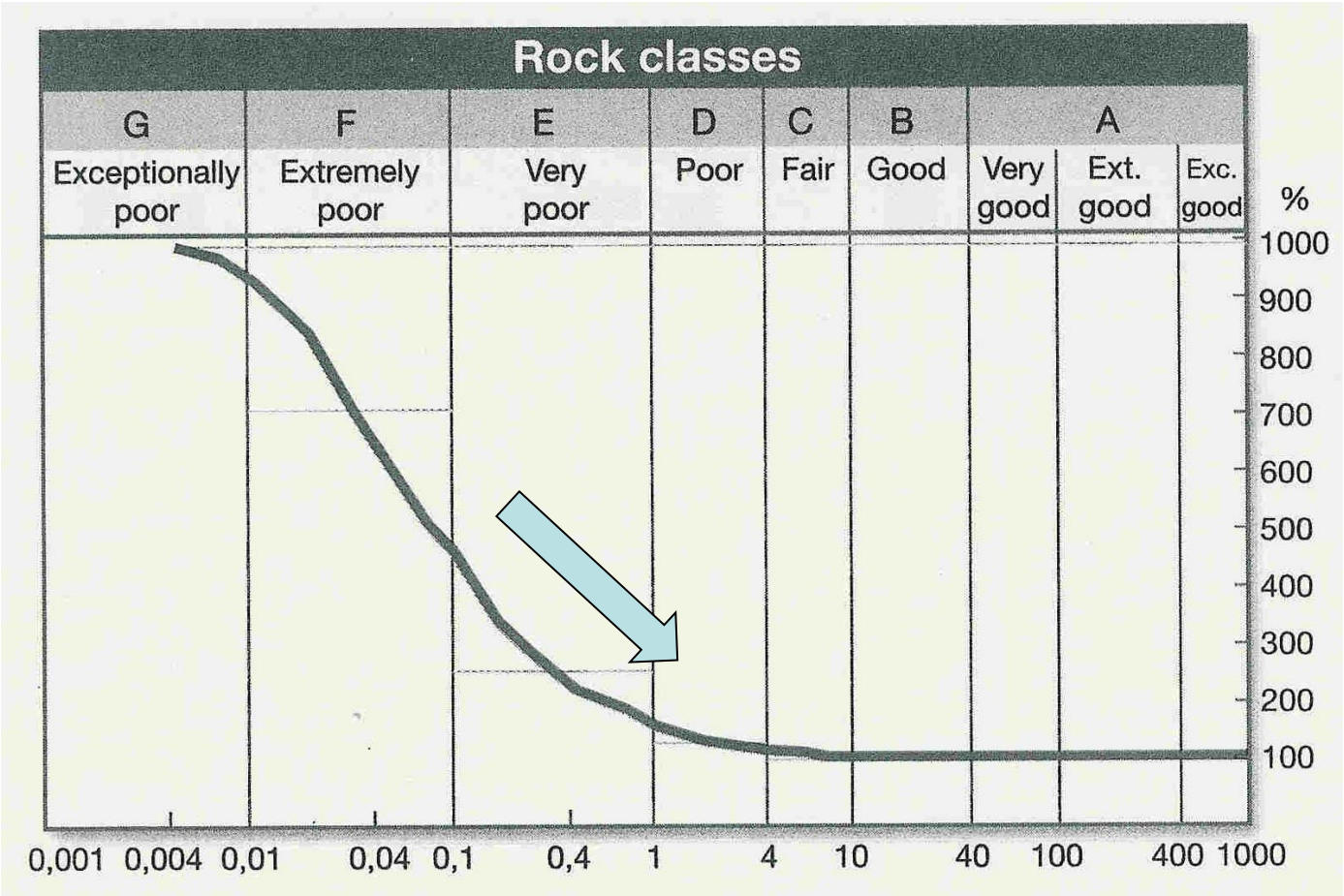
Rock mass quality $Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$

REDUCED TUNNEL DEFORMATION…. WOULD ALSO BE SEEN IN MODELS !



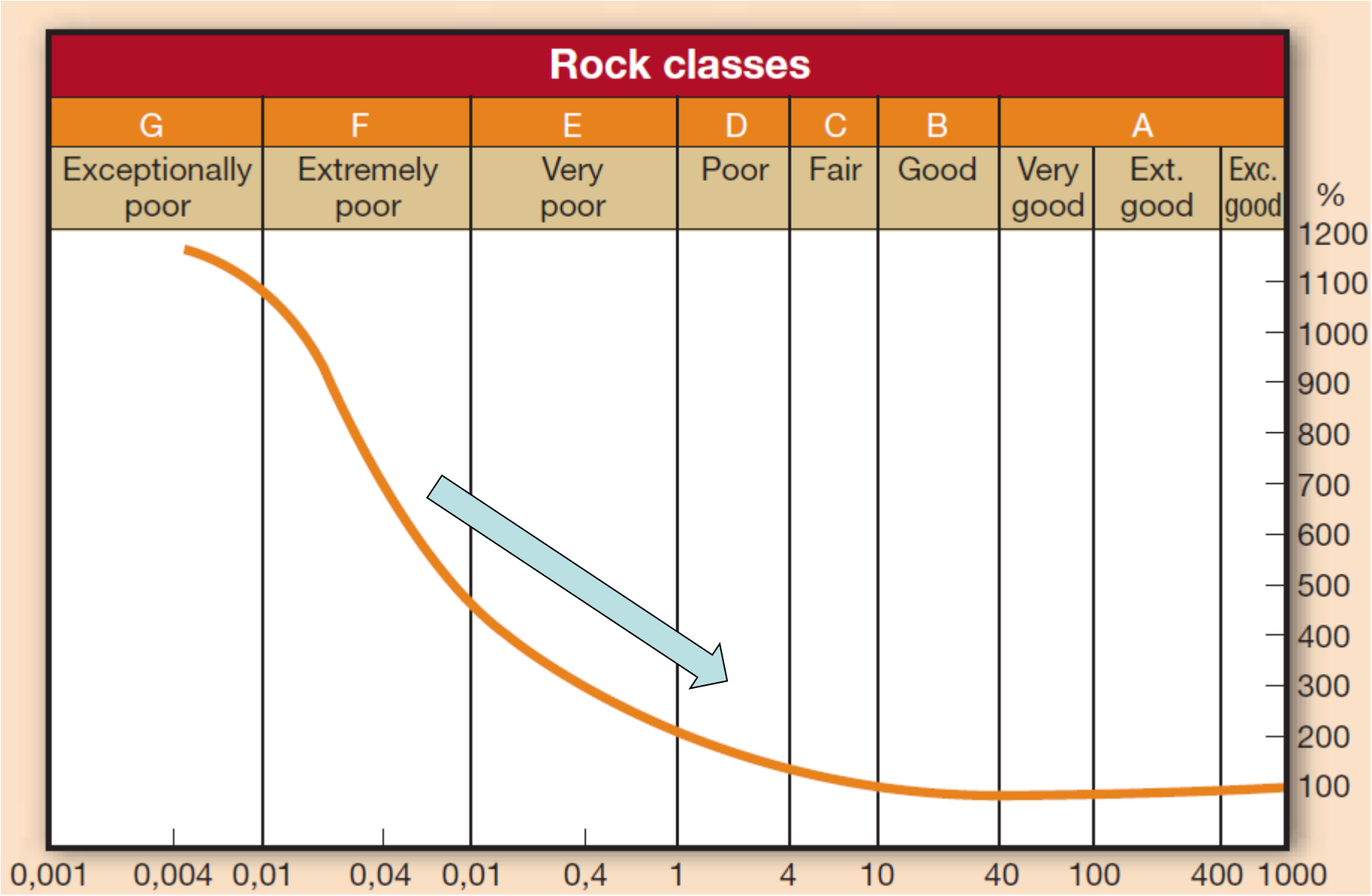
RELATIVE ***TIME*** FOR TUNNEL EXCAVATION AND SUPPORT
……potential benefits of pre-grouting, especially if Q ≈ 0.1

N Barton, B Buen & S Roald, 2001/2002.
"Strengthening the case for grouting"
T&T International, Dec 2001 & Jan 2002.



RELATIVE ***COST*** FOR TUNNEL EXCAVATION AND SUPPORT

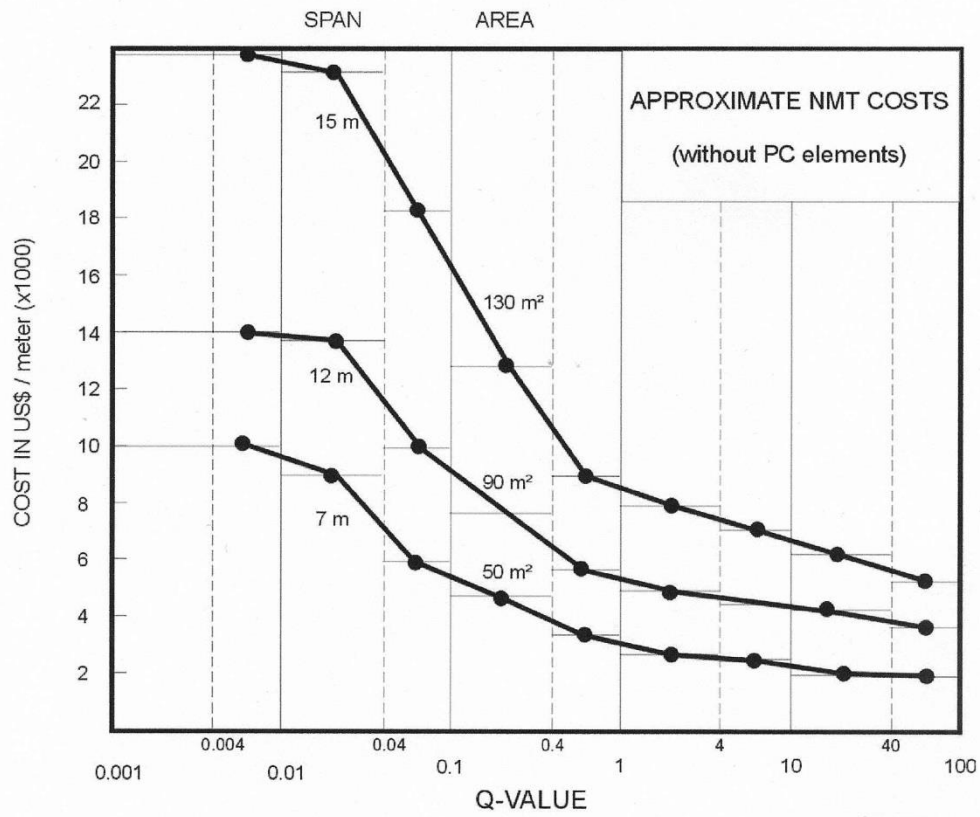
……potential benefits of pre-grouting, especially if Q ≈ 0.1

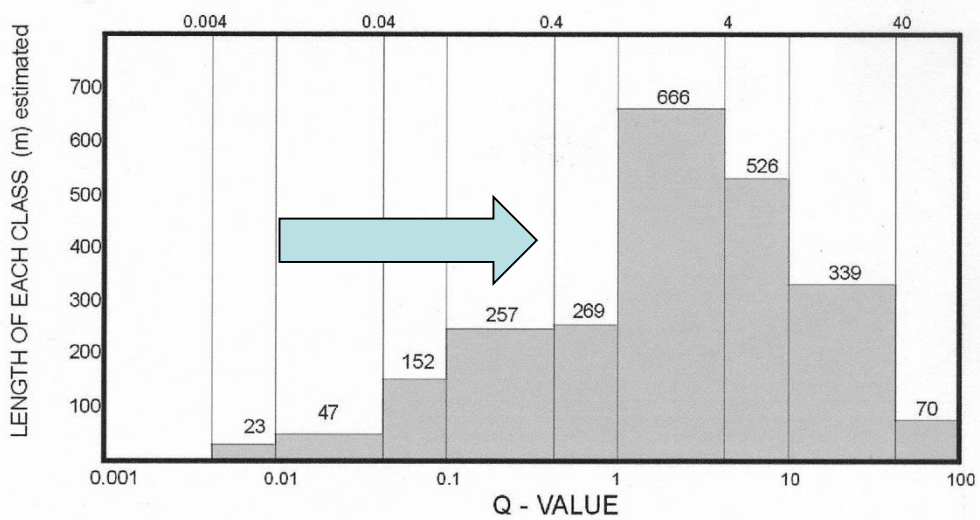


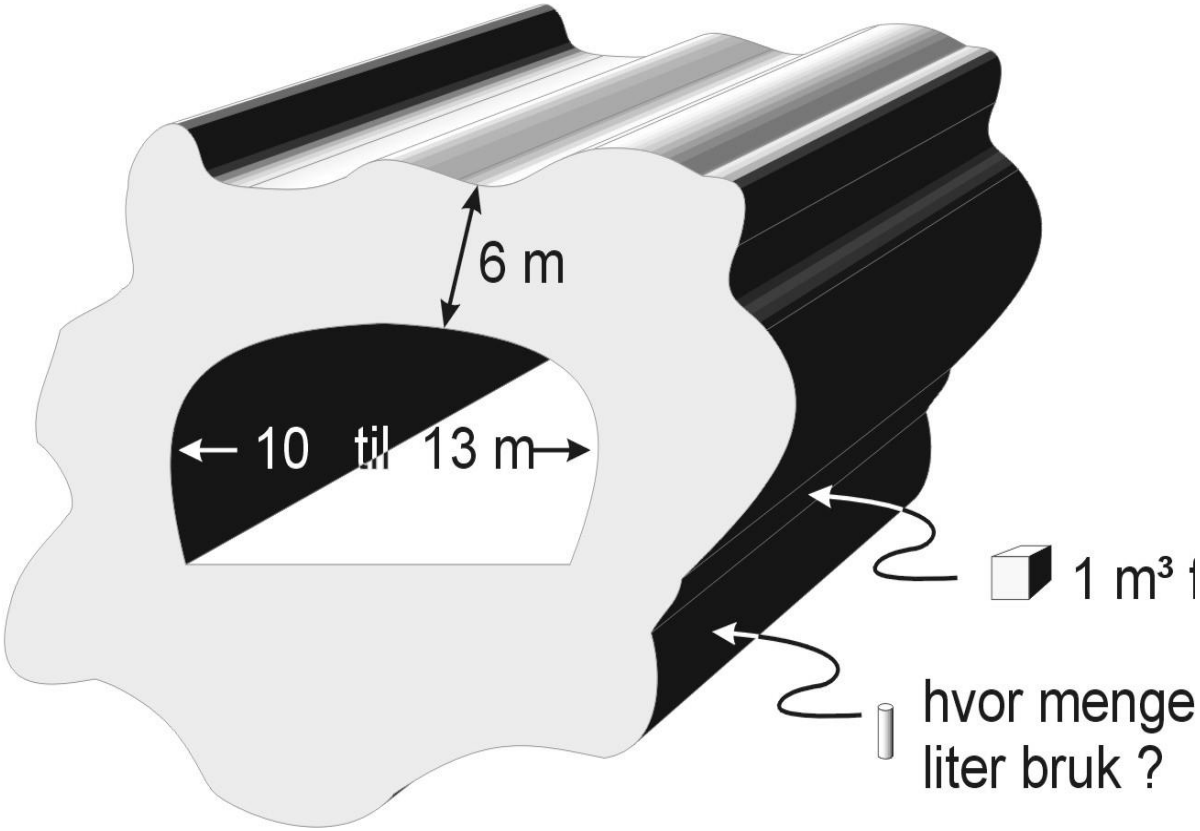
CONSEQUENCES OF PRE-INJECTION ON COST..... IF *EFFECTIVE* Q-VALUE CAN BE INCREASED

TRY TO ELIMINATE MOST OF THE LOW Q-VALUE ROCK i.e. Q< 1

THEN GET LOWER COST BECAUSE OF LESS PROBLEMS WITH CONSTRUCTION







How many litres of grout per m³ of rock mass? …… with 6m cylinder assumption usually 1 to 5 liters/m³.

Table 1: Pre-grouting data derived from Åndal et al. 2001			
Rock type	kg/m^2 tunnel surface	≈kg/m^3 *	≈Litres/m^3 *
Gneiss	11.0 to 16.5	1.8-2.8	1.0-1.6
Granite	12.0 to 52	2.0-8.7	1.1-5.0
Phyllite	26	4.3	2.5
Rhomb porphyry	28 to (99)	4.7-(16.5)	2.7-(9.4)
Syenite (dike)	30 to (186)	5.0-(31)	2.9-(17.7)
Fracture zone	19 to 50	3.-8.3	1.8-4.7

THE END
9 MAI 2009