Paper presented at the Workshop on "Reliablity of classification systems" in connection with the GeoEng2000 conference, Melbourne, 18 – 24 November 2000

BLOCK SIZE AND BLOCK SIZE DISTRIBUTION

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Summary
Block size is generally the most important feature regarding the behaviour of rock masses in underground openings and in surface cuttings. Therefore, reliable measurements of the rock blocks govern the quality rock engineering assessments, such as rock mass classification systems. The main methods for measuring block size are described as well as correlations between them.

1. INTRODUCTION

Joints are found in certain, preferred directions forming the jointing pattern. One to three prominent joint sets and one or more minor sets often occur; in addition several individual or *random joints* may be present.

Jointing is the occurrence of joint sets forming the system or pattern of joints as well as the amount or intensity of joints. *Detailed jointing* is the network of joints in the massifs between weakness zones.

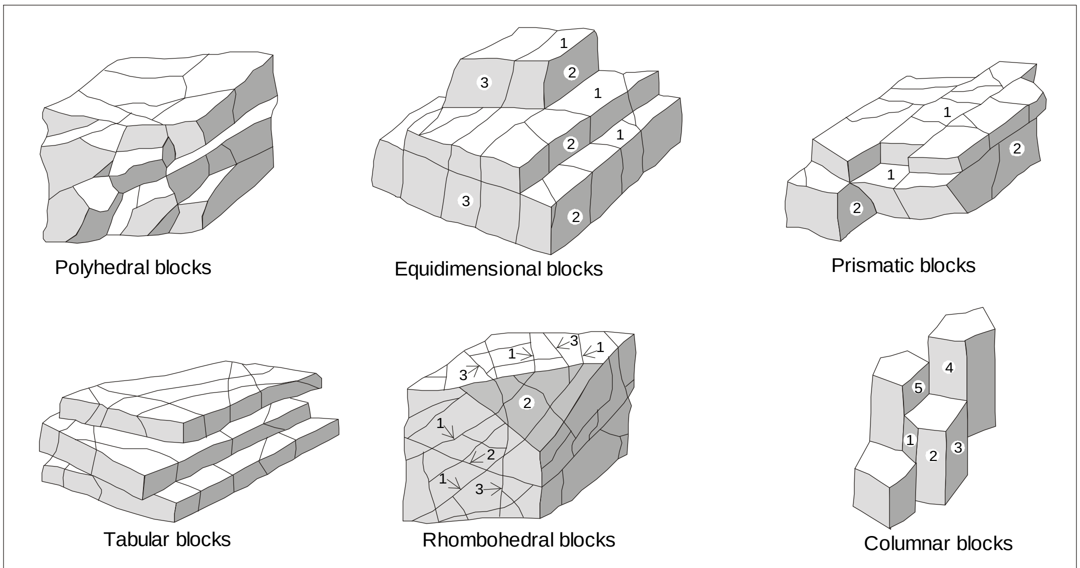

Figure 1 Examples of block shapes or the jointing pattern (from Dearman, 1991)

The joints delineate *blocks,* see Figure 1. Their dimensions and shapes are determined by the joint spacings, by the number of joint sets and by the random joints. The size or volume of the rock blocks is determined by the *degree of jointing* or the *density of joints*. The block size is an extremely important parameter in rock mass behaviour.

2. MEASUREMENTS OF JOINTING DENSITY

The size of the rock mass of interest is generally so large that it is mostly impossible to measure its mechanical properties. Therefore, the only way to obtain information on the properties of the rock mass is to perform observations in the field of the most important features influencing on the strength properties of the rock mass. The way such observations are carried out highly determines the quality of the geo-data used in the evaluations and calculations.

Figure 2 Block size has a main influence on stability in underground openings

The term "degree of jointing" used as the general term for the amount of joints in a rock mass. This includes "density of joints" with measurements of block volume, joint spacing, joint frequency, rock quality designation (RQD).

The most common methods to assess the block volume, as shown in Table 1, are:

- Observations and/or measurements in rock surfaces
- Observations and/or logging of drill cores
- Assessments from geophysical measurements, either along profiles or along bore holes

Table 1 Information on characteristic rock mass parameters obtained from various types of data collection

JOINTING FEATURE	DATA COLLECTED FROM				
	Drill cores	Adits	Underground openings	Rock outcrops (except for highly weathered rocks)	Refraction seismic profiles
Block size	- / (x)	x	x	x	-
Joint spacing or frequency	(x)	x	x	x	(x)
Joint orientation	-	x	x	x	-

here is: x parameter or task can be measured
(x) parameter or task may partly or sometimes be measured
\- not possible to measure the parameter or task

2.1 Block volume measured directly in-situ or in drill cores

Where the individual blocks can be observed in a surface, their volumes can be directly measured from relevant dimensions by selecting several representative blocks and measuring their average dimensions. For small blocks or fragments having volumes in dm^3 size or less, this method of block volume measurement is often beneficial as it is much easier to estimate volume compared to all the measurements which have to be made to include all joints.

The block volume can also be found in drill cores where small fragments have been formed as a result of crushed rock.

2.2 Block volume found from joint spacings

The block volume can be measured from the three main joint sets as

$$Vb = S1 \times S2 \times S3 \times (\sin\alpha \times \sin\beta \times \sin\gamma)$$

where S1, S2, S3 are joint spacing for each joint set and α, β, γ are the angle between the joint sets. Often these angles are approximately 90^o. Therefore, for practical purposes

$$Vb = Vb = S1 \times S2 \times S3$$

The terms *joint spacing* and *average joint spacing* are often used in the description of rock masses. Joint spacing is the distance between individual joints within a joint set. Where more than one set occurs, this measurement is, in the case of surface observations, often given as the average of the spacings for these sets. There is often some uncertainty as to how this average value is found; for instance, the average spacing for the following 3 joint sets having spacings S1 = 1 m, S2 = 0.5 m, and S3 = 0.2 m is Sa = 0.125 m, and not 0.85 m which initially may seem appropriate.[1]

When logging drill cores the average length of core pieces [2] are seldom true spacings, as joints of different sets probably are included in the measurement. In addition, random joints, which do not necessarily belong to any joint set, have an influence.

As the term 'joint spacing' does not indicate what it includes, it is frequently difficult to determine whether a 'joint spacing' referred to in the literature represents the true joint spacing. Thus, there is often much confusion related to joint spacing recordings.

Especially where irregular jointing occurs, it is time-consuming to measure all (random) joints in a joint survey. In such cases, as well as for other jointing patterns, it is often much quicker - and also more accurate - to measure the block volume directly in the field.

2.3 Block volume found from joint frequency measurements

When the frequency is given for each joint set, it is as for joint spacings, possible to find the block volume directly. In other cases, when an 'average frequency' is given, it is uncertain whether this frequency value refers to one-, two- or three-dimensional measurements; hence no accurate correlation can be presented. The use of joint frequency measurements is similar to the joint spacing measurements, since the joint frequency Jf = 1/S.

2.4 Block volume (Vb) calculated from the volumetric joint count (Jv)

The volumetric joint count (Jv) has been described by Palmström (1982, 1985, 1986). It is a measure of the number of joints within a unit volume of rock mass, defined by

$$Jv = \frac{1}{S1} + \frac{1}{S2} + \frac{1}{S3} + \dots$$

where S1, S2, S3 are the joint spacings.

Also random joints can be included by assuming a random spacing (Sr) for each of these. Experience indicates that this can be set to Sr = 5 m; thus, the volumetric joint count can be generally expressed as

[1] The average spacing is found from 1/Sa = 1/S1 + 1/S2 + 1/S3

[2] Joint or fracture intercept is the appropriate term for measurement of the distance between joints along a line or bore hole.

$$Jv = \frac{1}{S1} + \frac{1}{S2} + \frac{1}{S3} + ... + \frac{Nr}{5}$$

where Nr = the number of random joints.

Jv can easily be calculated from common joint observations, since it is based on measurements of joint spacings or frequencies. In the cases where mostly random or irregular jointing occur, Jv can be found by counting all the joints observed in an area of known size.

2.4.1 Correlation between block volume (Vb) and volumetric joint count (Jv)

The block volume for three joint sets with intersecting angles 90^o is expressed as

$$Vb_o = \beta \times Jv^{-3}$$

It is often appropriate to use Jv in the correlation between joint frequency measurements and block volume estimates. Important here is the block shape factor, which is included in all correlations to estimate the block volume from other jointing measurements.

2.5 Block types and shapes

The types of blocks delineated by joints have in the literature been characterized in different ways and by different terms. Where relatively regular jointing exists, it may be possible to give adequate characterization of the jointing pattern according to the system presented in Figure 1. In most cases, however, there is no regular jointing pattern; a rough characterization of the blocks is therefore often more practical, for example a division into four main groups only, as shown in Figure 2.

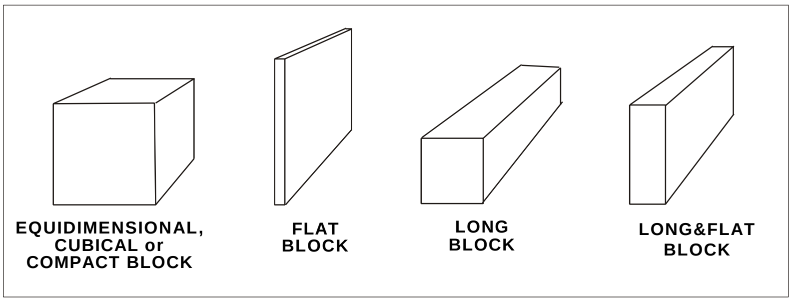

Figure 2 Main types of block (from Palmström, 1995)

The following simplified method to estimate β has been developed by Palmström (1995), in which the longest (a3) and shortest (a1) dimensions of the block are applied:

$$\beta = 20 + 7\ a3/a1$$

For very flat to extremely flat blocks this equation has limited accuracy. Where β is not known, it is recommended to use a 'common' value of β = 35 - 40.

The block shapes and the block shape factor is not often used in rock mechanics and rock engineering. It is, however, a main feature of the jointing, and may be of interest in numerical modelling and in general descriptions.

2.6 Correlation between RQD and the volumetric joint count (Jv)

It is not possible to obtain good correlations between RQD and Jv or between RQD and other measurements of jointing. Palmström (1982) presented the following simple expression:

$$RQD = 115 - 3.3\ Jv$$

Here RQD = 0 for Jv > 35, and RQD = 100 for Jv < 4.5

Especially where many of the core pieces have lengths around 0.1 m, the correlation above may inaccurate. However, when RQD is the only joint data available, it probably the best simple transition from RQD via Jv to block volume.

2.7 Methods to find the block volume where joints do not delimit blocks

Often, it is not possible to observe the whole individual block in an outcrop or in the surface of an underground opening, especially where less than three joint sets occur. Random joints and/or cracks formed during the excavation process will often result in defined blocks. In such cases a "spacing" of the random joints Sr = 5 to 10 times the spacing of the main set can often be used to estimate the block volume.

Example: Where only one joint set (S1) can be seen, $Vb \approx S1 \times 5S1 \times 10S1 = 50\ S1^3$
For two joint sets (S1 and S2), $Vb \approx S1 \times S2 \times 10S1 = 10\ S1^2 \times S2$

2.8 Weighted jointing density measurements (wJd)

The weighted joint density method is developed to achieve better information from bore hole and surface observations. In principle, it is based on the measurement of the angle between each joint and the surface or the bore hole.[3] To simplify the observations, the angles have been divided into the four intervals shown in Table 2, for which a rating of f_i is given.

Each joint along the core is given a rating f_i for its the actual angle interval. It is easy to be familiar with the 5 intervals in Table 2 after some training, as common angles have been selected.

Table 2 Angle intervals and ratings of the factor f_i

Angle (δ) between joint and surface or bore hole	Rating of the factor fi
> 60°	1
31 - 60°	1.5
16 - 30°	3.5
< 16°	6

The weighted jointing density method requires only small additional efforts over currently adopted logging practices. This is to determine the angle interval in Table 2 for each joint. The method reduces the inaccuracy caused by the attitude of joints and thus leads to a better characterization of the rock mass.

The weighted jointing density value is approximately similar to the volumetric joint count, i.e. wJd ≈ Jv.

[3] A similar idea has earlier been published by R. Terzaghi (1965) who suggested to take into account the orientation of the joints and the probability for them to be cut by the observation plane or the drill hole.

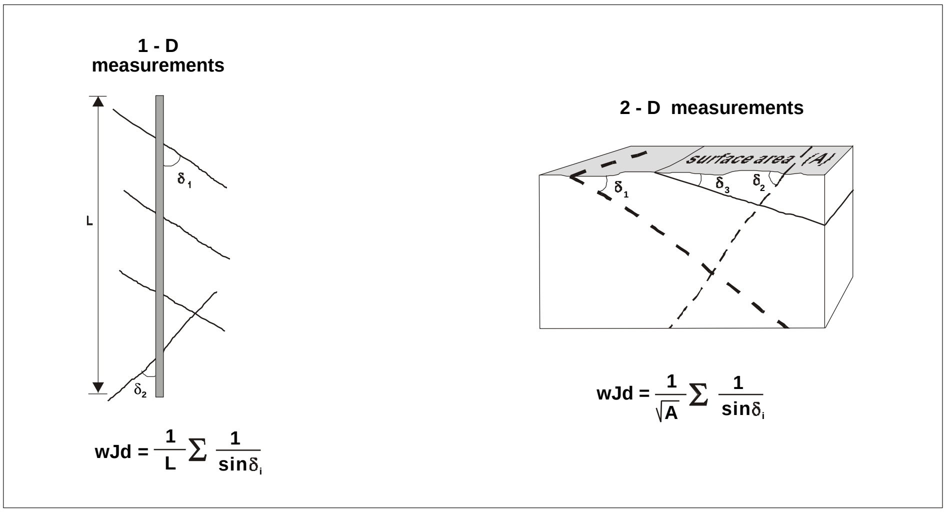

Figure 3 Principle of the weighted jointing density method (from Palmström, 1995).

d = the intersection angle between the observation plane or bore hole and the individual joint.
A = the size of the observed area in m^2,
L = the length of the measured section along the drill core,
f_i = a rating factor, its values are shown in Table 2

2.9 Block size distribution

In an actual volume of rock masses the blocks will have various sizes. If the blocks could be sieved, a curve similar to Figure 4 would be found. Within the maximum and minimum block sizes, *the block size range*, it is important that the blocks are characterized with representative volume(s). Ideally, the average Vb_{50} plus Vb_{25} and Vb_{75} should in the best way characterize the block size. In practice, it is seldom to know the full range of sizes in a certain *structural region* (i.e. rock masses with similar characteristics). Increased amount of observations will, however, give better measurements. During a joint survey the maximum, average and minimum spacing of the joints within each set should be noted, and these values are often used to calculate the appropriate block sizes.

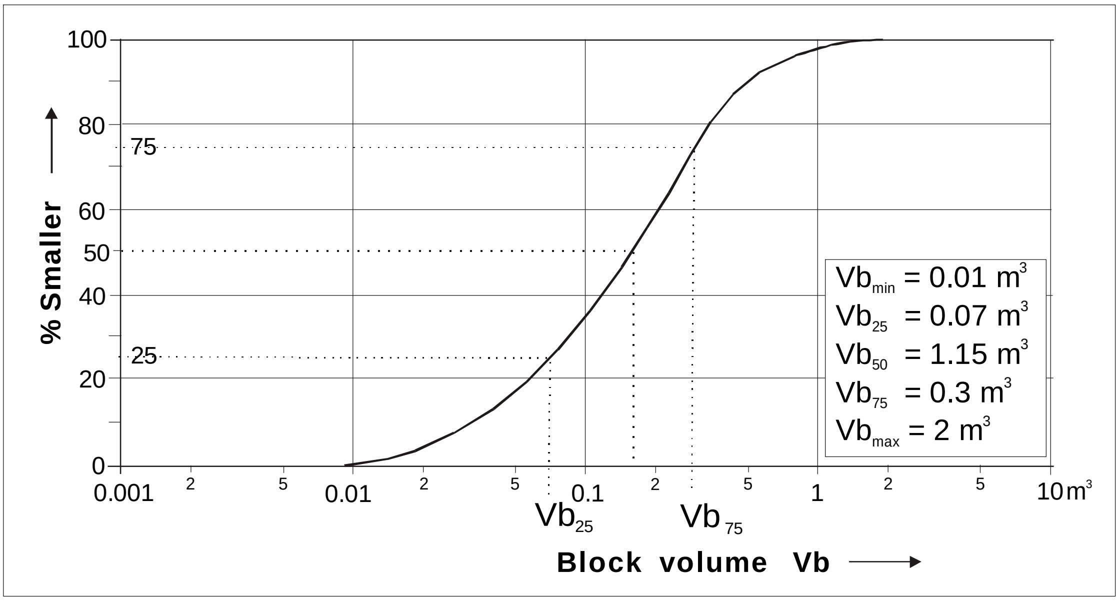

Figure 4 A distribution curve for the blocks in a (large) volume of rock masses

2.10 Example: Measurements of jointing in a horizontal and a vertical surface

The density of joints is measured in 5 x 5 m areas as shown in Figure 5. As one joint set (set 3) is sub-horizontal, only one joint of this set is observed on the horizontal surface, therefore this joint is regarded as a random joint in the observation in this surface.

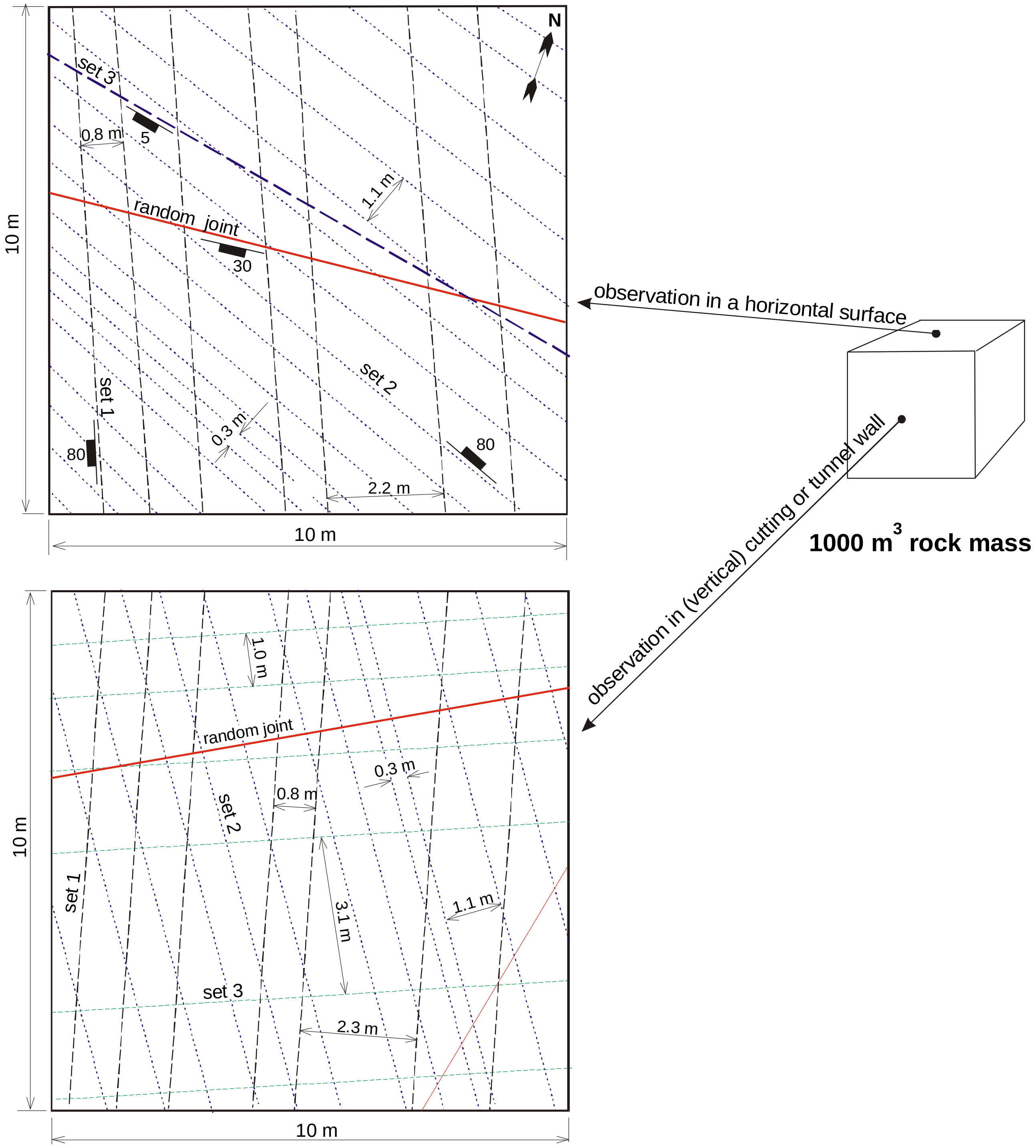

Figure 5 Joint observations in a horizontal and a vertical surface

The measurements made are shown in Table 3. As the 2-D observations (on the horizontal surface) do not include joint set 3 properly, it is a poor correlation between Jv and Vb.

Table 3 The measured jointing in Figure 5 and the calculated Jv and Vb. Note: to simplify in the example only short and long spacing have been used.

Measured:	**Horizontal surface**		**Vertical surface**	
	min	max	min	max
Spacing in joint set 1	0.8	2.2	0.8	2.3
Spacing in joint set 2	0.3	1.1	0.3	1.1
Spacing in joint set 3	-	-	1	3.1
Number of random joints [1)]	2 joints (one is from joint set 3)		2 joints	
Calculated:	high	low	high	low
Volumetric joint count (Jv)	5	1.4	6	1.7
Block volume (Vb) [2)]	small	large	small	large
- from joint spacings	0.36 m^3 [*)]	13.3 m^3 [*)]	0.24 m^3	7.8 m^3
- from Jv (with β = 40)	0.32 m^3	14.6 m^3	0.19 m^3	8.1 m^3

[1)] A spacing of 5 m is used in the calculation of Jv for each of the random joints. For the low value of Jv (largest blocks) random joints have not been included.

[2)] The joints intersect approximately at right angles

[*)] The block volume is found from Vb = S1 x S2 x 5S1

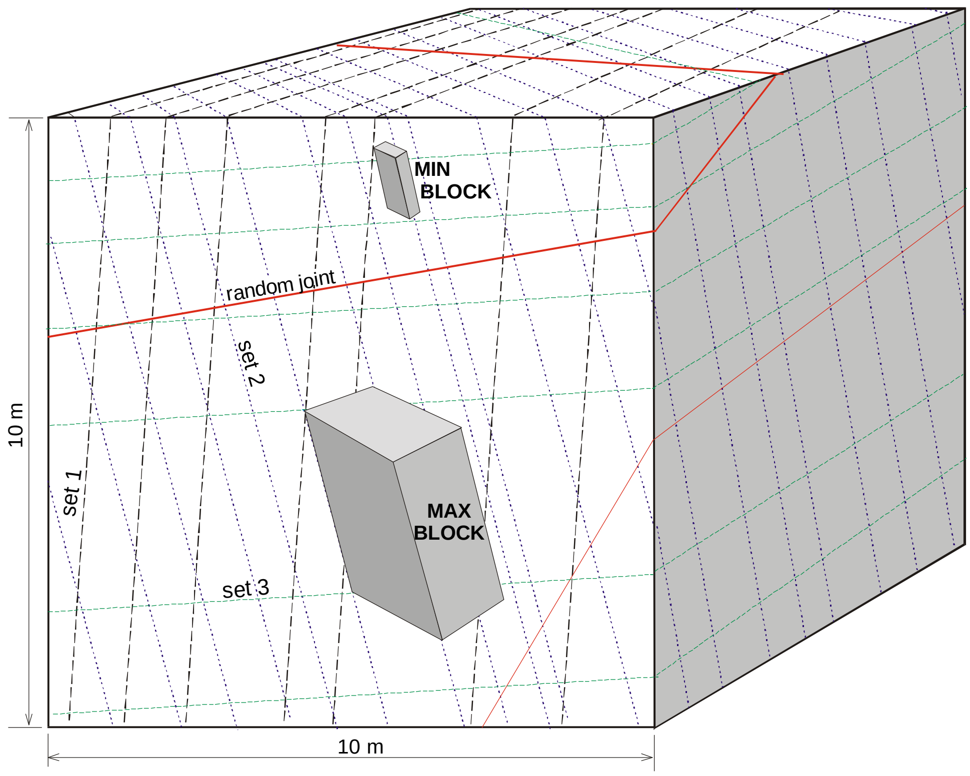

Figure 6 The "solution" of Figure 5. The min. block has long&flat shape, while the max. block has long shape.

2.11 Errors and inaccuracies in core drilling and logging

When making drill holes, the angle between the hole and the main joint set may strongly influence on the jointing encountered in the drill cores, see Figure 7. The weighted jointing measurement will reduce this type of error.

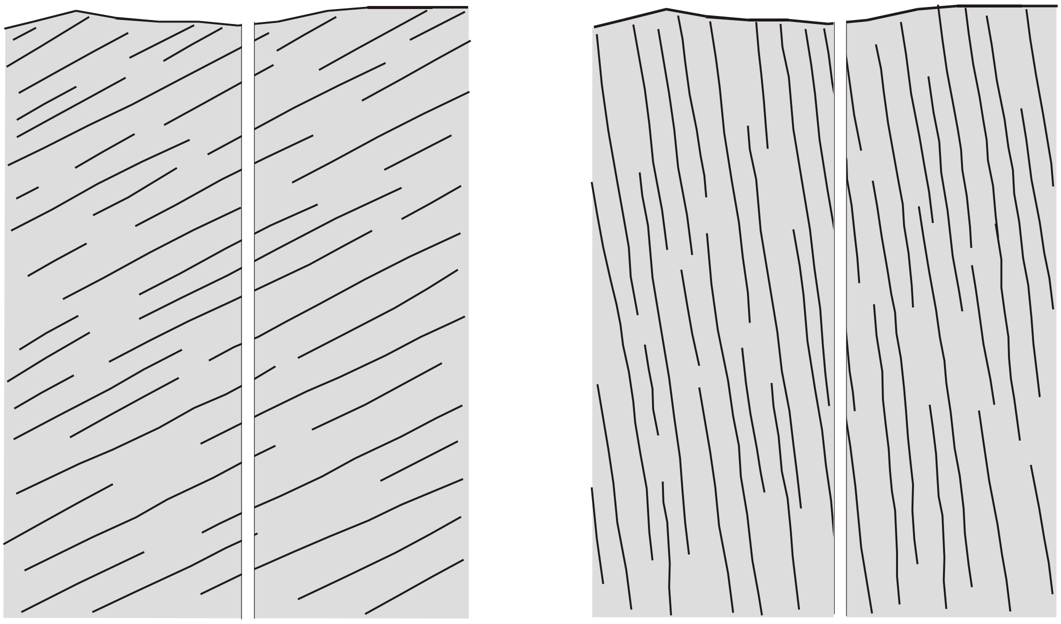

Figure 7 The angle between the main joint set and the bore hole may strongly influence the density of joints along the drill core. The weighted jointing density measurement reduces this source of error

Careless core drilling will introduce errors, as additional breaks will be created along the core. If the cores are not analysed properly during logging, a higher degree of jointing will be measured (lower RQD values).

Most core logging is performed by measuring the joints along each meter of the core. If there are alternating sections with lower and higher densities of joints, this type of logging will easily introduce measurement errors, as shown in Figure 8 and Table 4.

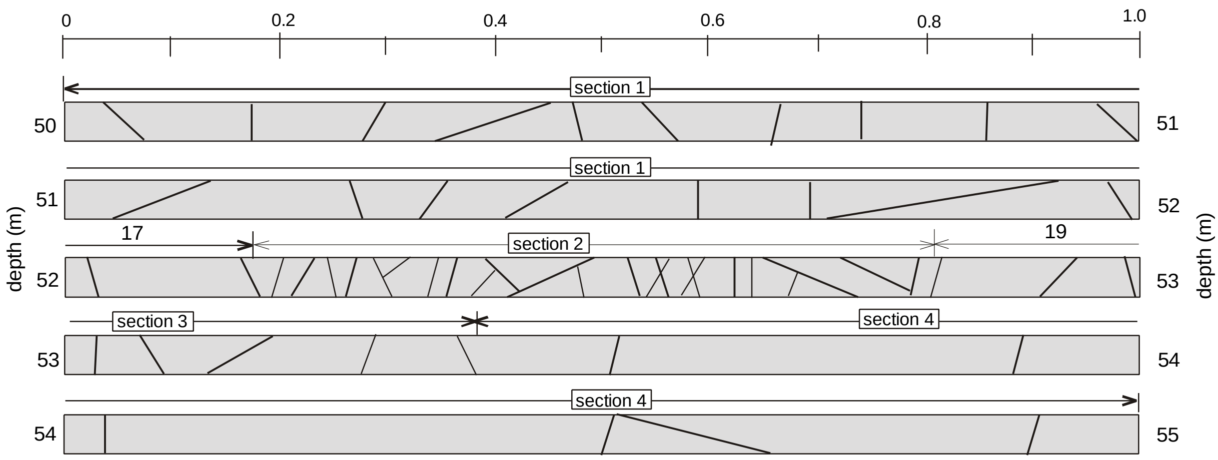

Figure 8 It is important to divide the cores onto intervals of similar jointing and log each of them separately

Table 4 The measured RQD values in Figure 8.

MEASUREMENT IN SECTIONS			
Section	Length	Core pieces > 10 cm	RQD
1	2.17 m	1.62 m	75
2	0.63 m	0 m	0
3	0.56 m	0.23 m	41
4	1.63 m	1.55 m	95

MEASUREMENT EVERY METRE			
Section	Length	Core pieces > 10 cm	RQD
50 - 51 m	1 m	0.66 m	66
51 - 52 m	1 m	0.82 m	82
52- 53 m	1 m	0.26 m	26
53 - 54 m	1 m	0.75 m	75
54 - 55 m	1 m	0.92 m	92

As presented in Figure 9 the measurement of joint density every meter levels out the variation in jointing along the core.

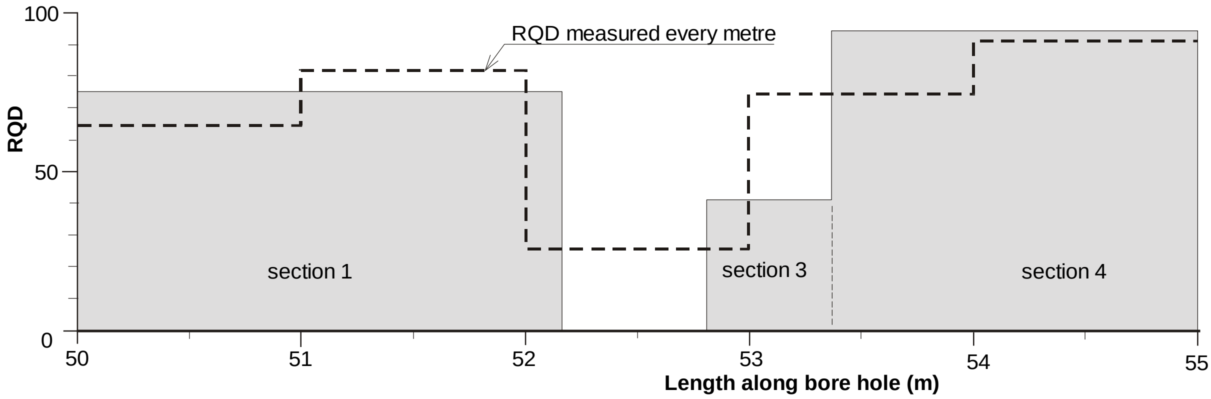

Figure 9 The graphic presentation of the jointing shown in Figure 8, RQD measured in sections compared to RQD measured every metre

The RQD is easy and quick to measure along the drill cores, and it is therefore frequently applied in core logging, often being the only method for measuring the degree of jointing along the core. Being discontinuous by definition, RQD is not very suitable in calculations. The application of RQD as input in the calculations made may also lead to errors. Another issue is that the RQD covers only a limited part of the jointing range, as shown in Figure 10. Also this reduces the applicability of RQD in characterizing the jointing density.

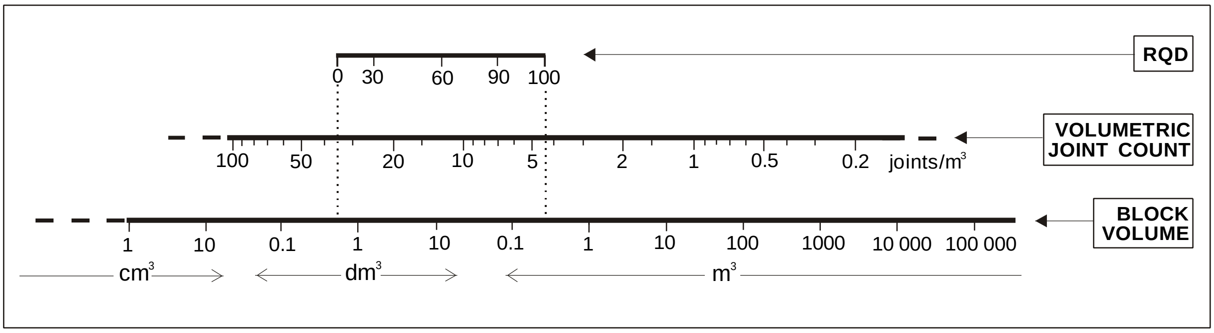

Figure 10 Block size (Vb) and volumetric joint count (Jv) cover a significantly larger interval of the jointing range than the RQD.

Considering the high costs for core drilling it is remarkable that so little has been done to refine the conventional surface observation and core logging methods, for enabling better information of the jointing to be obtained.

Figure 11 shows the correlations between various measurements of jointing measurements.

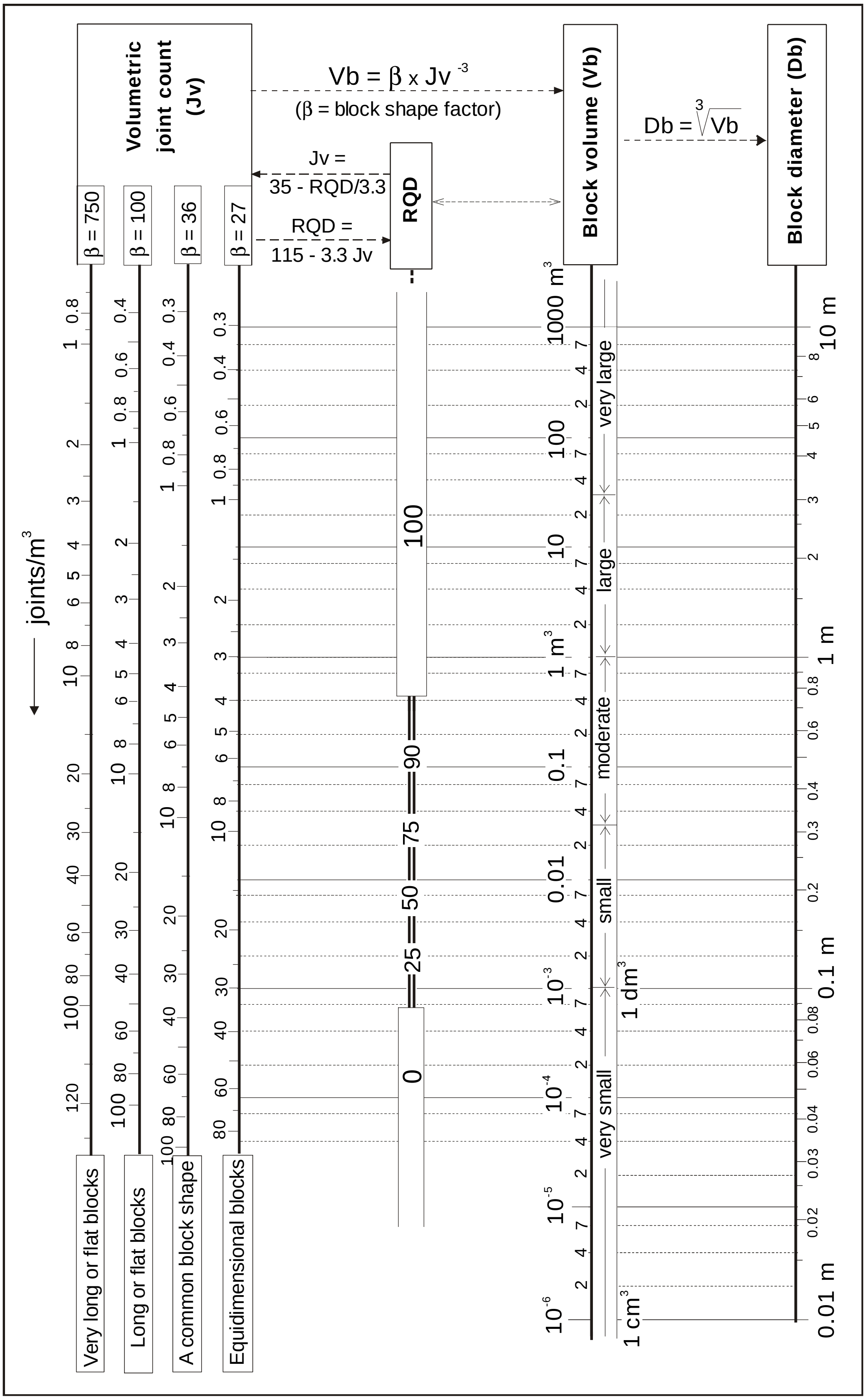

Figure 11 Chart with connections between some joint density measurements

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See also www.rockmass.net