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Maximising the value of geotechnical logging

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Introduction

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Why maximise?

1. Data quality is **critical**

2. Data collection is **complicated**

3. Data collection is **expensive**

…all data analysis, however intelligent, can only ever be as accurate as the data that went into it

Introduction

Maximising the value of geotechnical logging

1. Purpose

2. Problems

3. Solution

Why?

How?

ULS

Unified Logging System

Purpose (1/3)

*"Rock mass characterization should be used to determine the intrinsic properties of the rock mass, **independently of the application**… Rock mass characterization should be generic in nature, capturing the **basic input parameters**… Rock mass characterization is the background fieldwork **required to perform rock mass classification**."*

Potvin et al. (2012)

Purpose (2/3)

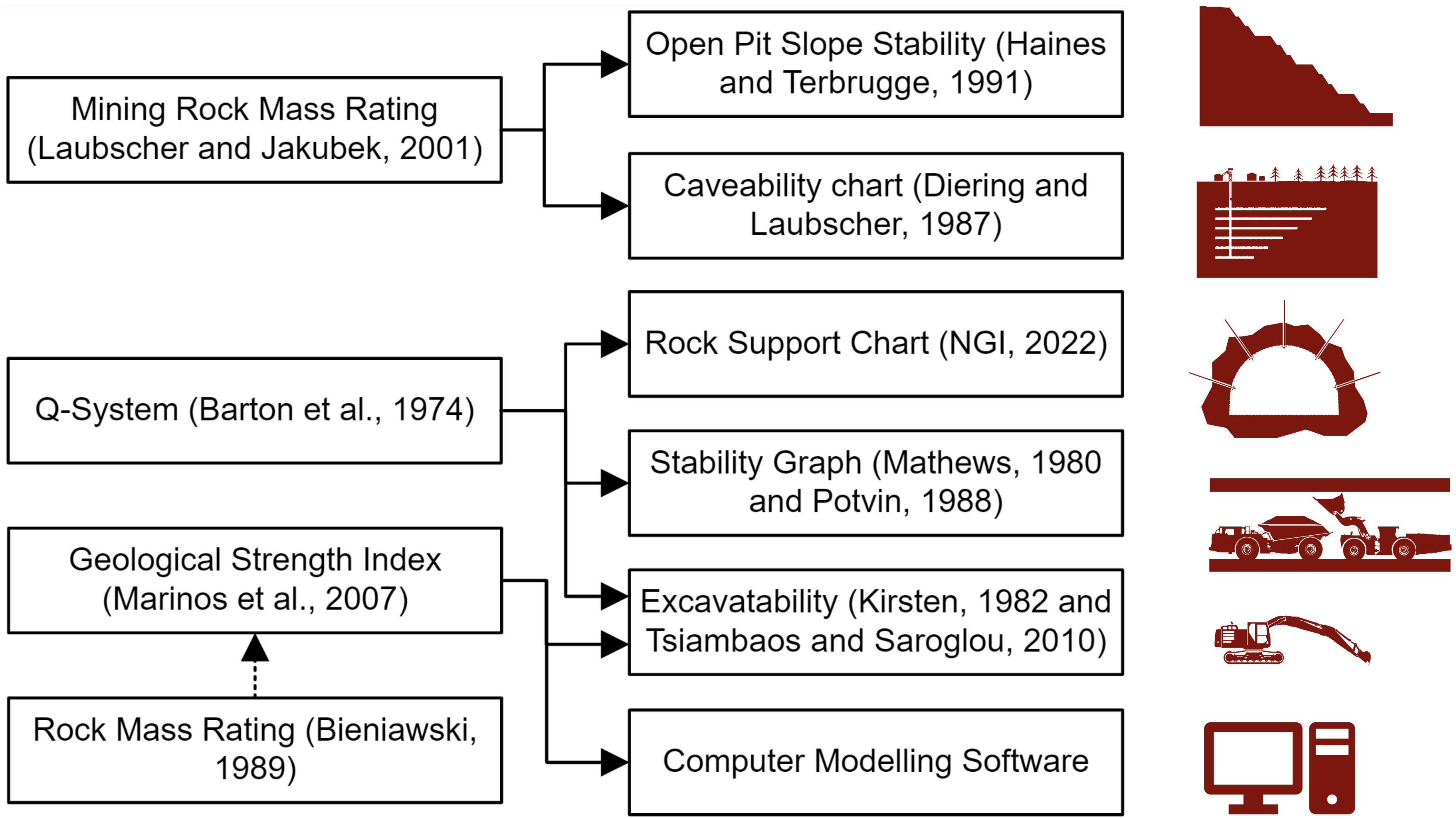
For rock materials, there are three well established classification systems that are commonly used in the mining industry:

1. **Rock Mass Rating (RMR89)** – originally published in 1976 and adjusted in 1989 (Bieniawski, 1976, 1989)

2. **Q-system (Q)** (Barton et al., 1974)

3. **Mining Rock Mass Rating (MRMR)** – published in 1990 and updated in 2000 and 2001 by Laubscher and Jakubek (Laubscher, 1990; Jakubek and Laubscher, 2000; Laubscher and Jakubek, 2001)

Purpose (3/3)

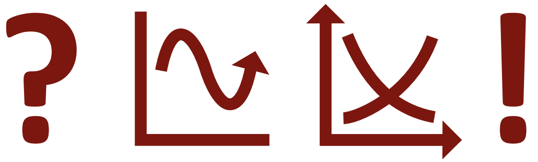

Mining Rock Mass Rating (Laubscher and Jakubek, 2001)
Q-System (Barton et al., 1974)
Geological Strength Index (Marinos et al., 2007)
Rock Mass Rating (Bieniawski, 1989)
Open Pit Slope Stability (Haines and Terbrugge, 1991)
Caveability chart (Diering and Laubscher, 1987)
Rock Support Chart (NGI, 2022)
Stability Graph (Mathews, 1980 and Potvin, 1988)
Excavatability (Kirsten, 1982 and Tsiambaos and Saroglou, 2010)
Computer Modelling Software

Problems

- Rigidity of systems
- System not generally designed for logging
- Poorly understood
- Expensive
- Time consuming
- Monotomous
- Complex
- Inconsistent
- Involves multiple personnel, varying knowledge and ability
- Difficult

Often the main problems are about ergonomics (people's efficiency in their working environment), and not ‘technical’.

Unreliable data gives unreliable outcomes.



Solution

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Unified Logging System (ULS)

Aim: Increase reliability of geotechnical logging data whilst reducing the complexity of the process

Method: Breakdown the three main logging systems into common basic inputs that can be logged efficiently, accurately and consistently

Outcome: A simplified system that produces a more reliable database that can be used to derive RMR, MRMR and Q

*Note: This is **not** a new classification system, but a new method of data capture to derive inputs for existing classifications*

Solution

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How?

‘Classic’ approach

Inputs → dRMR89 → RMR89

Inputs → Q-prime → Q-system

Inputs → iRMR → MRMR

Unified Logging System (ULS)

ULS → dRMR89 → RMR89

ULS → Q-prime → Q-system

ULS → iRMR → MRMR

Solution

Why?

Automated QAQC

Faster and better interpretation

Comparable datasets

Global database

Easier Cooperation

Raising of global standards

AI, Machine Learning

Unified Logging System

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Breakdown of classification systems:

Classification System	Author, Date	Primary Characterisation Parameter	Secondary Characterisation Parameter†	
			Name	Acronym
Mining Rock Mass Rating (MRMR)	Laubscher and Jakubek, 2001	iRMR	(1) Rock Block Strength	RBS
			(2) Fracture Frequency	FF
			(3) Joint Conditions	JC
Rock Mass Rating (RMR89)	Bieniawski, 1989	dRMR89	(1) Intact Rock Strength	IRS
			(2) Rock Quality Designation	RQD
			(2) Joint Spacing	JS
			(3) Joint Conditions	JC_{89}*
Q-system (Q)	Barton, 1974	Q-prime	(2) Rock Quality Designation	RQD
			(2) Joint Set Number	Jn
			(3) Joint Roughness Number	Jr
			(3) Joint Alteration Number	Ja

* JC_{89} denotes Joint Conditions from RMR_{89} (to distinguish from JC of MRMR)
† (1) denotes parameters assessing the "intact" rock strength, (2) the open discontinuity spacing (or block size), and (3) the conditions of the open discontinuities

Unified Logging System

Finding common basic inputs ('Primary data'):

Primary Characterisation Parameter	Secondary Characterisation Parameter	Primary data
Q-prime	RQD	Sum of intact core lengths >10 cm over interval length
	Jn	Number of joint sets
	Jr	Small-scale roughness of open discontinuities
		Large-scale surface roughness of discontinuities
	Ja	Separation of discontinuities
		Infill Thickness of open discontinuities
		Infill Strength of open discontinuities
		Infill Mineral of open discontinuities
		Weathering of open discontinuity wall
iRMR	RBS	ISRM field estimate
		Microdefect intensity
		Microdefect strength
		Spacing of closed discontinuities
		Infill strength of closed discontinuities
	FF	Spacing of open discontinuities
		Number of joint sets
	JC	Large-scale surface roughness of discontinuities
		Small-scale roughness of open discontinuities
		Separation of open discontinuities
		Infill thickness of open discontinuities
		Infill Strength of open discontinuities
		Infill mineral of open discontinuities
		Weathering of open discontinuity wall
$dRMR_{89}$	IRS	ISRM field estimate
	RQD	Sum of intact core lengths <10 cm over interval length
	JS	Spacing of open discontinuities
	JC_{89}	Small-scale roughness of open discontinuities
		Separation of open discontinuities
		Infill Thickness of open discontinuities
		Infill Strength of open discontinuities
		Weathering of open discontinuity wall
		Persistence of open discontinuities

Primary Data (duplicates removed)	Derived Secondary Characterisation Parameter	Parameter Group
Sum of intact core lengths >10 cm over interval length	RQD, Jn, JS, FF	Spacing of open discontinuities (block size)
Number of Joint Sets		
Spacing of Open Discontinuities		
Large-Scale Surface Roughness of Discontinuities	Jr, Ja, JC	Conditions of open discontinuities
Small-Scale Roughness of Open Discontinuities		
Separation of Discontinuities		
Infill Thickness of Open Discontinuities		
Infill Strength of Open Discontinuities		
Infill Mineral of Open Discontinuities		
Weathering of Open Discontinuity Wall		
Persistence of Open Discontinuities		
ISRM Field Estimate	RBS, IRS	Intact rock strength
Spacing of Closed Discontinuities		
Infill Strength of Closed Discontinuities		
Microdefect Intensity		
Microdefect Strength		

Unified Logging System

<table>
<tr><th rowspan="2">Parameter Group</th><th rowspan="2">Primary Data</th><th colspan="3">Derived Secondary Characterisation Parameter ('x' signifies not used)</th></tr>
<tr><th>Q-prime</th><th>iRMR</th><th>dRMR89</th></tr>
<tr><td rowspan="3">Spacing of open discontinuities (block size)</td><td>Sum of intact core lengths >10 cm over interval length</td><td>RQD</td><td>x</td><td>RQD</td></tr>
<tr><td>Number of Joint Sets</td><td>Jn</td><td rowspan="2">FF</td><td>x</td></tr>
<tr><td>Spacing of Open Discontinuities</td><td>x</td><td>JS</td></tr>
<tr><td rowspan="8">Condition of open discontinuities</td><td>Large-Scale Surface Roughness of Discontinuities</td><td rowspan="2">Jr</td><td rowspan="7">JC</td><td>x</td></tr>
<tr><td>Small-Scale Roughness of Open Discontinuities</td><td rowspan="7">JC_{89}</td></tr>
<tr><td>Separation of Discontinuities</td><td rowspan="5">Ja</td></tr>
<tr><td>Infill Thickness of Open Discontinuities</td></tr>
<tr><td>Infill Strength of Open Discontinuities</td></tr>
<tr><td>Infill Mineral of Open Discontinuities</td></tr>
<tr><td>Weathering of Open Discontinuity Wall</td></tr>
<tr><td>Persistence of Open Discontinuities</td><td>x</td><td>x</td></tr>
<tr><td rowspan="5">Intact rock strength</td><td>ISRM Field Estimate</td><td>x</td><td rowspan="5">RBS</td><td>IRS</td></tr>
<tr><td>Spacing of Closed Discontinuities</td><td>x</td><td>x</td></tr>
<tr><td>Infill Strength of Closed Discontinuities</td><td>x</td><td>x</td></tr>
<tr><td>Microdefect Intensity</td><td>x</td><td>x</td></tr>
<tr><td>Microdefect Strength</td><td>x</td><td>x</td></tr>
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Example simplification – Joint infill conditions:

Joint Alteration Number		Ja
	a. Rock wall contact	
A	Tightly healed, hard, non-softening, impermeable filling, i.e., quartz or epidote.	0.75
B	Unaltered joint walls, surface staining only.	1
C	Slightly altered joint walls. Non-softening mineral coatings; sandy particles, clay-free disintegrated rock, etc.	2
D	Silty or sandy clay coatings, small clay fraction (non-softening).	3
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.	4
	b) Rock-wall contact before 10 cm shear (thin mineral fillings)	
F	Sandy particles, clay-free disintegrated rock, etc.	4
G	Strongly over-consolidated, non-softening, clay mineral fillings (continuous, but <5 mm thickness).	6
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5 mm thickness).	8
J	Swelling-clay fillings, i.e., montmorillonite (continuous, but <5 mm thickness). Value of Ja depends on percent of swelling clay-size particles.	8.0 - 12.0
	c) No rock-wall contact when sheared (thick mineral fillings)	
K	Zones or bands of disintegrated or crushed rock. Strongly over-consolidated.	6
L	Zones or bands of clay, disintegrated or crushed rock. Medium or low over-consolidation or softening fillings.	8
M	Zones or bands of clay, disintegrated or crushed rock. Swelling clay. Ja depends on percent of swelling clay-size particles.	8.0 - 12.0
N	Thick continuous zones or bands of clay. Strongly over-consolidated.	5
O	Thick, continuous zones or bands of clay. Medium to low over-consolidation.	10.0 - 13.0
P	Thick, continuous zones or bands with clay. Swelling clay. Ja depends on percent of swelling clay-size particles.	6.0 - 24.0

Mineral Thickness

x

Mineral Strength (Mohs)

x

Mineral Type

x

Joint Wall Weathering

→ Ja, JC, JC_{89}

Other adjustments

Interval determination (geotechnical domaining):

Interval Determination	Description	Advantages	Disadvantages
Run by run	Intervals are begun and ended at the beginning and end of each drill run (typically 1.50 or 3.00 m length)	• **Simple** and **systematic** - it is easy to determine the start and end of intervals for non-experienced loggers • Enables record of **orientation quality** (which is performed for each individual run) • More consistent lengths make **scale-dependent parameters**, such as RQD, more directly comparable across intervals • Reduces opportunity to 'lump' intervals into larger intervals, which may **mask important features**, such as faults	• Often more **time intensive** and potentially less efficient, as more intervals will ultimately be logged, many of which may have similar or the same properties as the runs before and after them • Features shorter than the run scale may be **averaged-out** or masked in the interval as it does not change for varying geotechnical properties
Geotechnical properties (‘domains’)	Intervals are begun and ended where the geotechnical properties of the core, such as strength, structural composition or lithology change	• Can be **faster** and more efficient as intervals of similar or the same geotechnical properties can be massed together, saving repetition • Smaller features can be given their own intervals and thereby **highlighted** as having different geotechnical properties (where they may have otherwise been averaged out) • Enables early definition of **geotechnical domains**	• Requires a degree of **experience** and geotechnical **understanding** to determine start and end • Can encourage the ‘**lumping**’ together of geotechnically dissimilar zones to save time • A **separate** log is required to record orientation quality, as many orientation lines with exist in one interval • Scale-dependent parameters such as RQD are not measured over **consistent lengths** • The preliminary geotechnical domains that are defined by the intervals **cannot be easily altered** as changing these will require altering the interval length and thereby recalculating scale-dependent parameters such as RQD.

Other adjustments

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Flexible 'hybrid' domaining:

BHID	From (m)	To (m)	TCR (m)	RQD (m)	Length (m)	TCR (%)	RQD (%)	IRS	Ori confidence	Jn
GT001	30.00	33.00	3.00	3.00	3.00	100	100	R3	High	One set
GT001	33.00	36.00	3.00	2.67	3.00	100	89	R3	High	One set
GT001	36.00	39.00	3.00	2.98	3.00	100	99	R3	High	One set
GT001	39.00	42.00	3.00	1.79	3.00	100	60	R3	High	One set
GT001	42.00	45.00	3.00	3.00	3.00	100	100	R2	Medium	One set
GT001	45.00	48.00	3.00	3.00	3.00	100	100	R2	Medium	One set
GT001	48.00	51.00	2.00	1.20	3.00	67	40	R1	Low	Three + R
GT001	51.00	54.00	1.50	1.00	3.00	50	33	R1	Low	Three + R
GT001	54.00	57.00	1.40	0.87	3.00	47	29	R1	Low	Three + R
GT001	57.00	60.00	2.90	2.00	3.00	97	67	R1	Low	Three + R
GT001	60.00	63.00	3.00	3.00	3.00	100	100	R3	Medium	Two sets
GT001	63.00	66.00	2.90	2.80	3.00	97	93	R3	Medium	Two sets

Logging with a maximum interval length of the run length enables the capture of recovery, RQD and orientation confidence, whilst these intervals can then be further reduced to capture smaller details within runs. The use of Jn to define preliminary domains across these intervals generates '**flexible**' geotechnical domains that can be adjusted if deemed necessary.

Summary & Conclusions

1. Attaining reliable geotechnical data from core logging is critical to effective mine design and safety

2. Geotechnical core logging is a costly, complex and difficult process and standards vary greatly across the mining industry

3. Human factors such as knowledge, understanding, fatigue, time-constraints and ergonomics must be considered as critical to data collection quality

4. A system that records the basic inputs common to the three main logging systems has been shown to increase **efficiency**, **accuracy** and **consistency** of geotechnical logging, whilst also increasing the granularity of the dataset produced and their downstream use – i.e the **value** of the datasets is **maximised**.