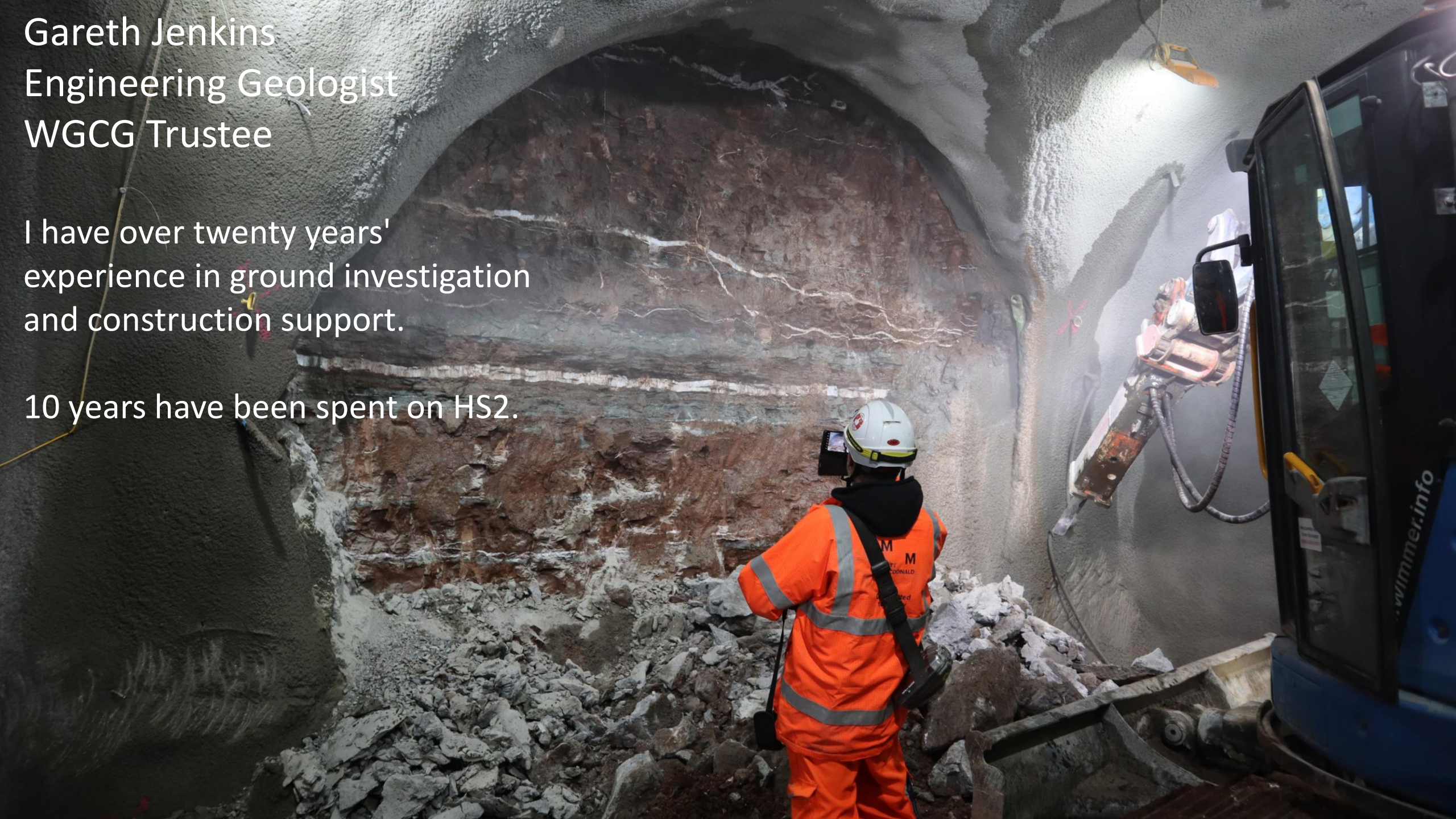
WGCG
Hidden wonders in the landscape of Warwickshire
Warwickshire Geological Conservation Group

Workshop
15th February 2025

Describing soils and rocks for ***engineering*** purposes



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I have over twenty years' experience in ground investigation and construction support.

10 years have been spent on HS2.

The presentation will focus on the following:

- British and European Standards
- Reasons why
- Soil descriptions
- Rock descriptions
- Discontinuity descriptions
- Rock mass descriptions
- Weathering
- Applications

Tile Hill Mudstone Formation (sandstone)

British Standards


BRITISH STANDARD

BS EN ISO 14688-1:2002 +A1:2013

Incorporating corrigenda nos. 1 and 2

Geotechnical investigation and testing — Identification and classification of soil —

Part 1: Identification and description


BRITISH STANDARD

BS EN ISO 14689-1:2003

Incorporating corrigendum no. 1

Geotechnical investigation and testing — Identification and classification of rock —

Part 1: Identification and description

British Standards

BS 5930:2015+A1:2020

BSI Standards Publication

Code of practice for ground investigations

Reasons why?

- To standardise the way engineering geologists describe soil and rock - to ensure consistency across the ground engineering sector and provide insight into likely material properties.
- It doesn’t really work!
- Two engineering geologists will always give you two different descriptions.
- However, it is better than the pre-standardised descriptions.

Soil and rock descriptions

- The description process involves a specific word order.
- Each word conveys some information such as dimensions or ranges of strength.
- This information can be used to assess different geotechnical properties.
- These can be used for a variety of assessments as we shall see later.

Soil and rock descriptions

- There are a lot of charts and technical data coming up.
- The purpose of this presentation is just to give an overview of the what an engineering geologist is looking for when logging soil or rock.
- Don’t feel that you need to absorb all the detail. There is a two-day logging course available in the UK but it takes experience to be good.

Soil and rock descriptions

BS EN ISO 14688-1:2002+A1:2013
EN ISO 14688-1:2002+A1:2013

NOTE 1 The term is also applied to made ground consisting of replaced natural soil or man-made materials exhibiting similar behaviour, e. g. crushed rock, blast-furnace slag, fly-ash.

NOTE 2 Soils may have rock structures and textures may exist but soils are usually of lower strength than rocks.

3.2
identification of soil
naming and description of a soil on the basis of its grading, type of material and characteristics of mineral and/or organic constituents and plasticity

EN ISO 14689–1:2003

This presentation focusses on sediments. Ther

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Additional terms and definitions are given in EN 12670.

3.1
rock
a naturally occurring assemblage of minerals, consolidated, cemented, or otherwise bonded together, so as to form material of generally greater strength or stiffness than soils

Soil descriptions

Table 7 — *Field identification and description of soils*

SOIL GROUP	Very coarse soils			Coarse soils						Fine soils					
PRIMARY SOIL FRACTION	BOULDERS		COBBLES	GRAVEL			SAND			SILT			CLAY		
Particle size (mm)	Large boulder	Boulder	Cobble	Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine			
	>630	630–200	200–63	63–20	20–6.3	6.3–2.0	2.0–0.63	0.63–0.2	0.2–0.063	0.063–0.02	0.02–0.0063	0.0063–0.002	<0.002		
Visual identification	Only seen complete in pits or exposures. Difficult to recover whole from boreholes.			Easily visible to naked eye; particle shape can be described; grading can be described.			Visible to naked eye; no cohesion when dry; grading can be described.			Only coarse silt visible with hand lens; exhibits little plasticity and marked dilatancy; slightly granular or silky to the touch; disintegrates in water; lumps dry quickly; possesses cohesion but can be powdered easily between fingers.			Dry lumps can be broken but not powdered between the fingers; dry lumps disintegrate under water but more slowly than silt; smooth to the touch; exhibits plasticity but no dilatancy; sticks to the fingers and dries slowly; shrinks appreciably on drying usually showing cracks		
Density/ Consistency	No terms defined. Qualitative description of packing by inspection and ease of excavation.			Classification of relative density on the basis of N value (Table 10), or field assessment using hand tests may be made (Table 11).						**Term**	Very soft	Soft	Firm	Stiff	Very stiff
										Field test	Finger easily pushed in up to 25 mm. Exudes between fingers	Finger pushed in up to 10 mm. Moulded by light finger pressure	Thumb makes impression easily. Cannot be moulded by fingers. Rolls to thread	Can be indented slightly by thumb. Crumbles in rolling thread. Remoulds	Can be indented by thumb nail. Cannot be moulded, crumbles
Discontinuities	Describe spacing of features such as fissures, shears, partings, isolated beds or laminae, desiccation cracks, rootlets, etc. Fissured: Breaks into blocks along unpolished discontinuities. Sheared: Breaks into blocks along polished discontinuities.						**Scale of spacing of discontinuities**		**Term**	very widely	widely	medium	closely	very closely	extremely closely
									Mean spacing (mm)	>2 000	2 000–600	600–200	200–60	60–20	<20
Bedding	Describe thickness of beds in accordance with geological definition. Alternating layers of materials are Inter-bedded or Inter-laminated and should be described by a thickness term if in equal proportions, or by a thickness of and spacing between subordinate layers where unequal.						**Scale of bedding thickness**		**Term**	very thickly bedded	thickly bedded	medium bedded	thinly bedded	very thinly bedded	thickly laminated / thinly laminated
									Mean thickness (mm)	>2 000	2 000–600	600–200	200–60	60–20	20–6 / <6
Colour	**HUE** can be preceded by **LIGHTNESS** and/or **CHROMA**			Red / Pink / Orange / Yellow / Cream / Brown / Green / Blue / White / Grey / Black Light / - / Dark Reddish / Pinkish / Orangeish / Yellowish / Brownish / Greenish / Bluish / Greyish						Colours may be mottled More than 3 colours is multicoloured					
Secondary constituents	For mixtures involving very coarse soils see **33.4.4.2**			**Term in coarse soils**	slightly (sandy)[B]	(sandy)[B]	very (sandy)[B]	SAND AND GRAVEL		**Term in fine soils**	slightly (sandy)[D]	(sandy)[D]	very (sandy)[F]	Silty CLAY / Clayey SILT	Terms used to reflect secondary fine constituents where this is important
				Proportion secondary[A]	<5%	5-20%[C]	>20%[C]	About 50%		**Proportion secondary**[A]	<35%	35–65%[E]	>65%[E]		
Mineralogy	Terms can include: glauconitic / micaceous / shelly / organic / calcareous. For example: slightly (glauconitic) / (glauconitic) / very (glauconitic) Carbonate content: slightly calcareous – weak or sporadic effervescence from HCl / calcareous – clear but not sustained effervescence from HCl / highly calcareous – strong, sustained effervescence from HCl. Organic soils contain secondary finely divided or discrete particles of organic matter, often with distinctive smell, might oxidize rapidly. For example: slightly organic – grey / organic – dark grey / very organic – black														
Particle shape	Very angular/Angular/Sub-angular/Sub-rounded/Rounded/Well-rounded A dominant shape can be described, for example: Cubic/Flat/Elongate														
PRIMARY SOIL FRACTION	LARGE BOULDERS	BOULDERS	COBBLES	GRAVEL			SAND			SILT			CLAY		
Tertiary constituents	Example terms include: shell fragments / pockets of peat / gypsum crystals / pyrite nodules / calcareous concretions / flint gravel / brick fragments / rootlets / plastic bags Qualitative proportions can be given: with rare / with occasional / with numerous/ frequent/ abundant. Proportions are defined on a site or material specific basis, or subjectively														
Geological unit	Name in accordance with published geological maps, memoirs or sheet explanations. For example: RIVER TERRACE DEPOSITS / GLACIAL SAND AND GRAVEL / MADE GROUND / LANGLEY SILT MEMBER / WEATHERED CHARMOUTH MUDSTONE FORMATION / CLAY-WITH-FLINTS / LOWESTOFT FORMATION / EMBANKMENT FILL / ALLUVIUM / TOPSOIL / LAMINATED BEDS, WOOLWICH FORMATION / SHERWOOD SANDSTONE GROUP														

A) Percentage coarse or fine soil type assessed excluding cobbles and boulders.
B) Gravelly or sandy and/or silty or clayey.
C) Can be described as fine soil depending on mass behaviour.
D) Gravelly and/or sandy.
E) Can be described as coarse soil depending on mass behaviour.
F) Gravelly or sandy

Soil descriptions word order:

- Consistency (fine soil) or relative density (coarse soil)
- Strength
- Discontinuities
- Bedding
- Colour
- Secondary constituents
- Name
- Geological Formation
- Particle shape and composition

Firm medium strength closely fissured thinly bedded greyish-brown slightly micaceous slightly gravelly CLAY (THRUSSINGTON TILL FORMATION). Gravel is subrounded fine to medium coarse metaquartzite and coal fragments.

Soil descriptions

Table 8 — *Terms for description of consistency*

Field description term	Consistency description definition [A1] [after BS EN ISO 14688-1:2018, Table 4] [A1]
Very soft	Finger easily pushed in up to 25 mm Exudes between fingers
Soft	Finger pushed in up to 10 mm Moulded by light finger pressure
Firm	Thumb makes impression easily Cannot be moulded by fingers, rolls in the hand to a 3 mm thick thread without breaking or crumbling
Stiff	Can be indented slightly by thumb Crumbles in rolling a 3 mm thick thread, but can then be remoulded into a lump
Very stiff	Can be indented by thumb nail Cannot be moulded but crumbles under pressure

NOTE 1 These subdivisions can be approximate, particularly in material of low plasticity.

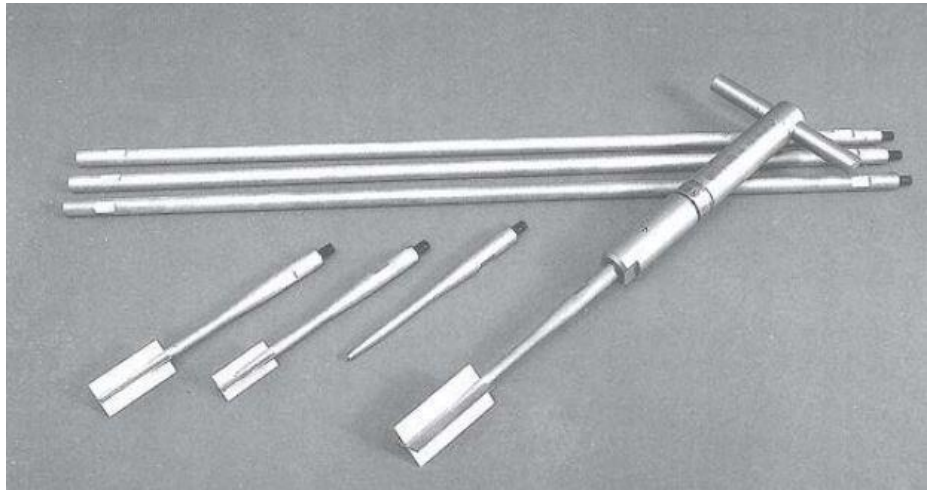
NOTE 2 The description of materials of higher consistency than very stiff should use rock strengths and material names.

NOTE 3 Soils varying around the boundary between soil (very stiff consistency) and rock (extremely weak strength) can be described as, for example, "very stiff CLAY/extremely weak MUDSTONE". A boundary on the log at rockhead if it is a simple transition is preferable.

Soil descriptions

Table 9 — *Terms for classification of strength*

Term based on measurement	Undrained strength classification definition, s_u, in kPa [A1] [from BS EN ISO 14688-2:2018, Table 6] [A1]
Extremely low strength	<10
Very low strength	10 – 20
Low strength	20 – 40
Medium strength	40 – 75
High strength	75 – 150
Very high strength	150 – 300

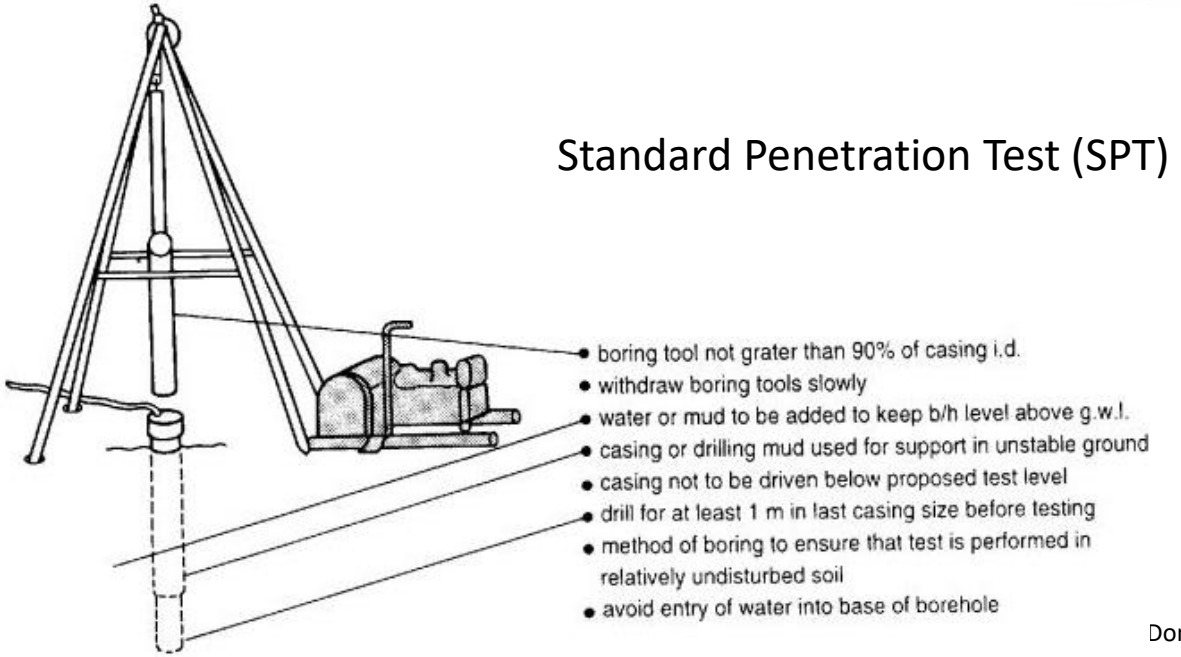


Hand shear vanes

Soil descriptions

Table 10 — *Terms for classification of relative density*

Term	Classification based on uncorrected SPT N-values for use of borehole logs
Very loose	0 – 4
Loose	4 – 10
Medium dense	10 – 30
Dense	30 – 50
Very dense	>50

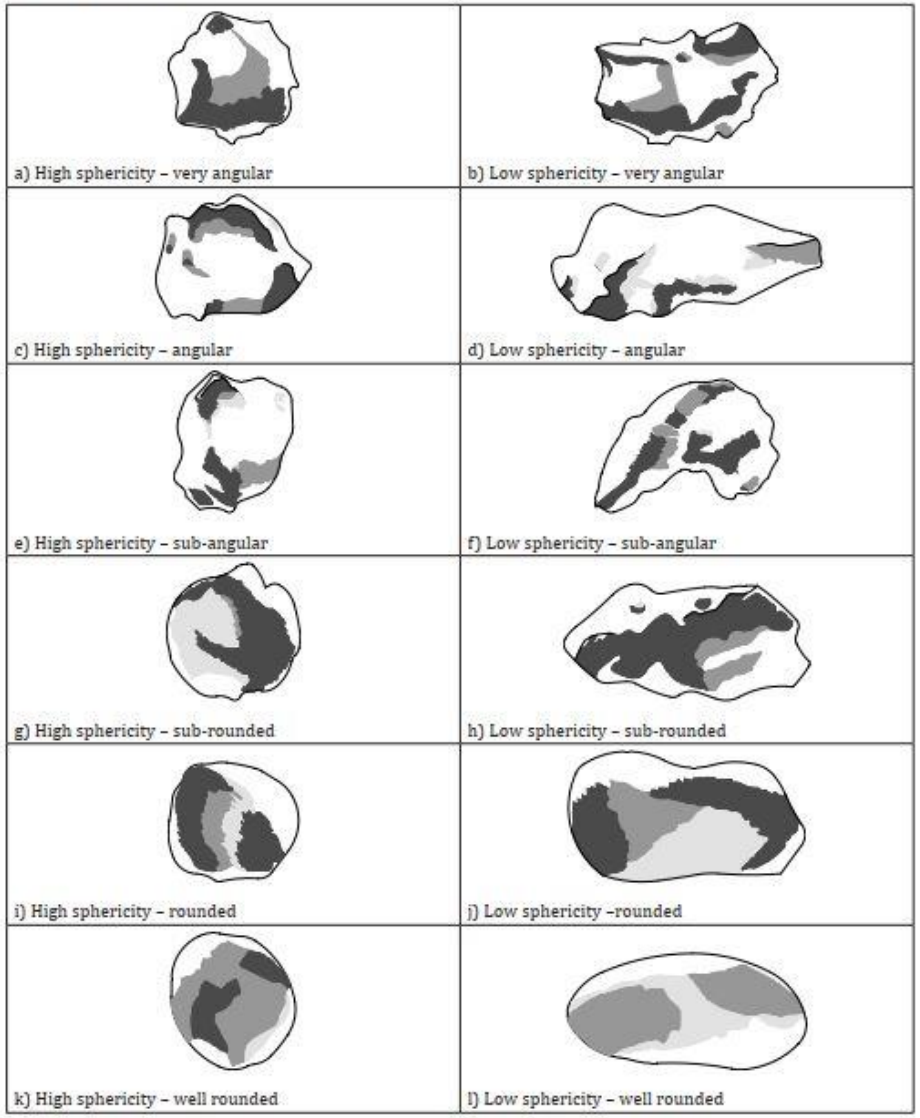


- boring tool not grater than 90% of casing i.d.
- withdraw boring tools slowly
- water or mud to be added to keep b/h level above g.w.l.
- casing or drilling mud used for support in unstable ground
- casing not to be driven below proposed test level
- drill for at least 1 m in last casing size before testing
- method of boring to ensure that test is performed in relatively undisturbed soil
- avoid entry of water into base of borehole

Standard Penetration Test (SPT)

Soil descriptions

Figure 7 — *Angularity terms*



Soil descriptions

EXAMPLES:

- Firm closely fissured yellowish brown CLAY (LONDON CLAY FORMATION).
- Medium dense light greyish brown sandy slightly clayey subrounded fine to coarse GRAVEL of various lithologies with low cobble content. Cobbles are subrounded of strong sandstone (RIVER TERRACE DEPOSIT).
- Greenish brown gravelly fine to coarse slightly glauconitic SAND. Gravel is rounded fine and medium of black flint (BLACKHEATH MEMBER).
- Firm to stiff brown slightly sandy slightly gravelly CLAY with occasional lenses (5 mm by 15 mm to 15 mm by 50 mm) of yellow silty sand. Gravel is subangular to subrounded fine and medium of various [A1⟩ flints (GLACIAL TILL, Lowestoft Formation). ⟨A1]

Rock descriptions

36.1.2 Description

Rocks seen in natural outcrops, cores and excavations should be described in the following sequence:

a) material characteristics (see **36.2**):
   1) strength;
   2) structure;
   3) colour;
   4) ~~texture;~~
   5) grain size;
   6) rock name (in capitals, e.g. "GRANITE");

b) general information (see **36.3**):
   1) additional information and minor constituents;
   2) geological formation;

c) mass characteristics (see **36.4**):
   1) state of weathering;
   2) discontinuities;
   3) fracture state.

NOTE Further information on rock identification is given in BS EN ISO 14689-1.

Very weak thickly laminated reddish-brown fine medium grained SANDSTONE (KENILWORTH SANDSTONE FOMRATION)

Rock descriptions

Table 25 — *Terms for description of rock strength*

Term	Identification by hand test	Unconfined compressive strength MPa
Extremely weak	Scratched by thumbnail, breaks in brittle manner, gravel sized lumps can be crushed between finger and thumb.	0.6 – 1.0
Very weak	Scratched by thumbnail, lumps can be broken by heavy hand pressure, can be peeled easily by a pocket knife, hand-held specimen crumbles under firm blows with the point of a geological hammer.	1 – 5
Weak	Thin slabs, corners or edges can be broken off with hand pressure, can be peeled by a pocket knife with difficulty, easily scratched by pocket knife, shallow indentations made in hand-held specimen by firm blow with the point of a geological hammer.	5 – 12.5
Moderately weak	Thin slabs, corners or edges can be broken off with heavy hand pressure, can be scratched with difficulty by pocket knife, hand-held specimen can be broken with a single firm blow of a geological hammer.	12.5 – 25
Medium strong	Cannot be scraped with a pocket knife, specimen on a solid surface can be fractured with a single firm blow of a geological hammer.	25 – 50
Strong	Specimen requires more than one blow of a geological hammer to fracture it.	50 – 100
Very strong	Specimen requires many blows of a geological hammer to fracture it.	100 – 250
Extremely strong	Specimen can only be chipped with a geological hammer.	>250

Rock descriptions

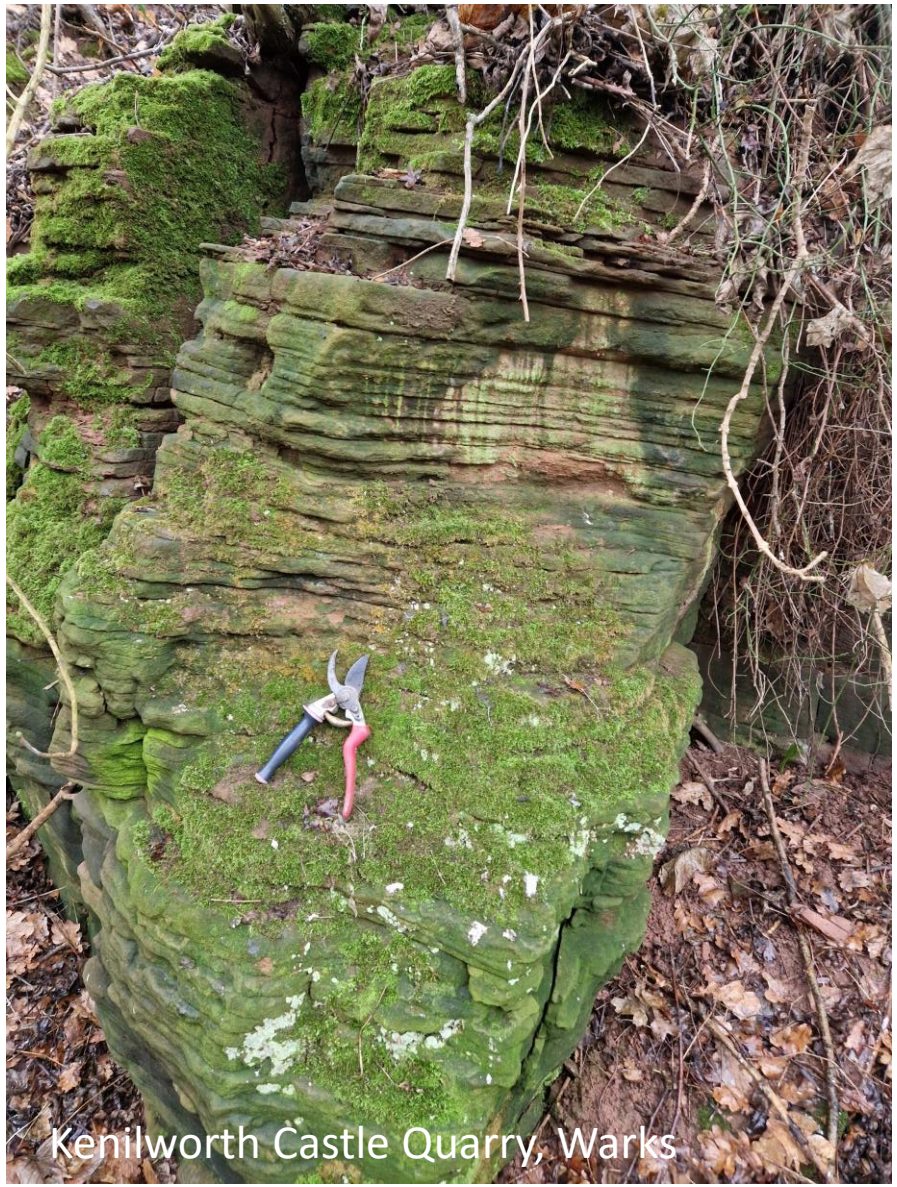
Table 26 — *Terms for description of thickness and spacing of structure*

Thickness term	Spacing term	Thickness or spacing
Very thickly	Extremely wide	>6 m
Very thickly	Very wide	2 m – 6 m
Thickly	Wide	600 mm – 2 m
Medium	Medium	200 mm – 600 mm
Thinly	Close	60 mm – 200 mm
Very thinly	Very close	20 mm – 60 mm
Thickly laminated (Sedimentary)	Extremely close	6 mm – 20 mm
Narrowly (Metamorphic and Igneous)		
Thinly laminated (Sedimentary)	Extremely close	<6 mm
Very narrowly (Metamorphic and Igneous)		

NOTE A spacing of less than 20 mm or a bed thinner than 6 mm is still large in some deposits. Where finer features are observed, their spacing or thickness can also be given in mm, or additional terms used. For example, a parting is a bed which is only one or two grains thick.


Newham, Gloucs


Cleeve Hill, Gloucs


Kenilworth Castle Quarry, Warks

Rock descriptions

Table 27 — *Aid to identification of rocks for engineering purposes*

Grain size		Bedded rocks (mostly sedimentary)						
mm		Grain size description			At least 50% of grains are of carbonate		At least 50% of grains are of volcanic rock	SALINE ROCKS
Grain size boundaries approximate	20 – 6.3	RUDACEOUS		CONGLOMERATE Rounded boulders cobbles and gravel cemented in a finer matrix Breccia Angular rock fragments in a finer matrix	LIMESTONE AND DOLOMITE (undifferentiated)	Calcirudite	Fragments of volcanic ejecta in a finer matrix. Rounded grains AGGLOMERATE Angular grains VOLCANIC BRECCIA	HALITE ANHYDRITE GYPSUM
	6.3 – 2							
	2 – 0.63	ARENACEOUS	Coarse	SANDSTONE Angular or rounded grains commonly cemented by clay, calcitic or iron minerals Quartzite Quartz grains and siliceous cement Arkose Many feldspar grains Greywacke Many rock chips		Calcarenite	Cemented volcanic ash TUFF	
	0.63 – 0.2		Medium					
	0.2 – 0.063		Fine					
	0.063 – 0.002	ARGILLACEOUS		SILTSTONE Mostly silt MUDSTONE		Calcisiltite	Fine-grained TUFF	
	<0.002					Calcilutite	Very fine-grained TUFF	
						CHALK		
Amorphous or crypto-crystalline				Flint: occurs as bands of nodules in the Chalk Chert: occurs as nodules and beds in limestone and calcareous sandstone				COAL LIGNITE
				Granular cemented – except amorphous rocks				
				SILICEOUS	CALCAREOUS		SILICEOUS	CARBONACEOUS

SEDIMENTARY ROCKS

Granular cemented rocks vary greatly in strength, some sandstones are stronger than many igneous rocks. Bedding might not show in hand specimens and is best seen in outcrop. Only sedimentary rocks, and some metamorphic rocks derived from them, contain fossils.

Calcareous rocks contain calcite (calcium carbonate) which effervesces with dilute hydrochloric acid.

Discontinuity descriptions

Table 29 — *Types of discontinuity*

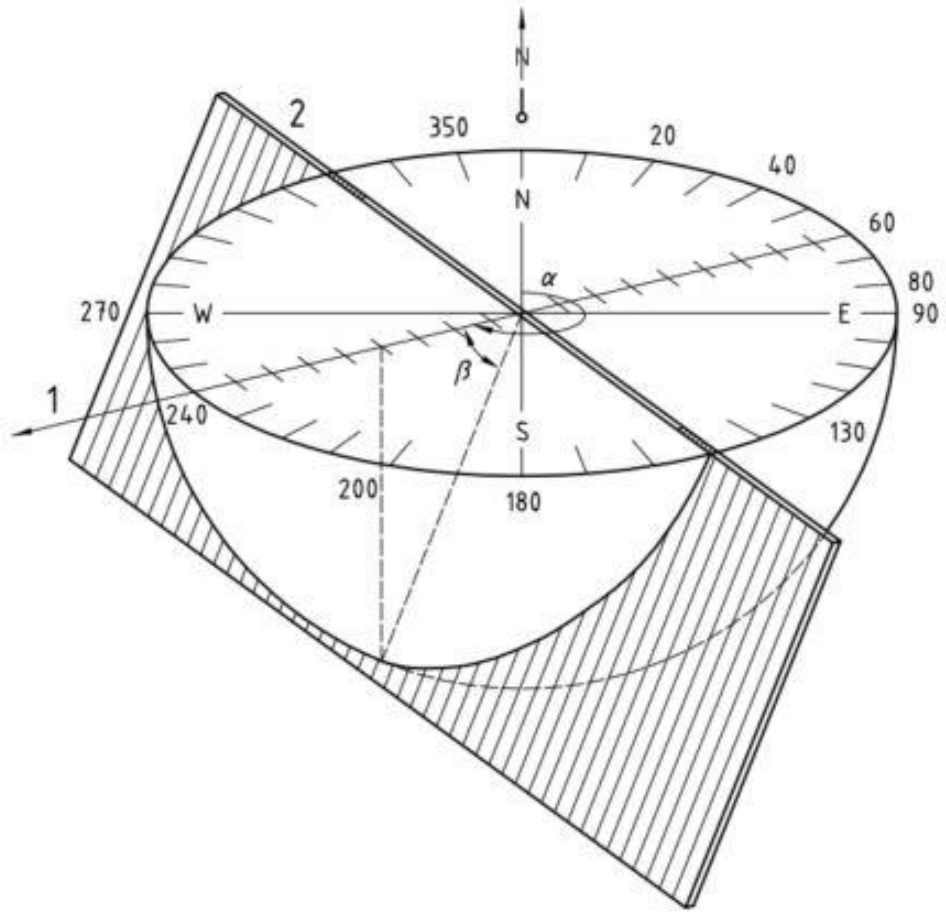
Type of discontinuity	Description
Joint	A discontinuity in the body of rock along which there has been no visible displacement. Joints are synonymous with fissures in soils.
Fault	A fracture or fracture zone along which there has been recognizable displacement.
Bedding fracture	A fracture along the bedding (bedding is a surface parallel to the plane of deposition).
Cleavage fracture	A fracture along a cleavage (cleavage is a set of parallel planes of weakness often associated with mineral realignment).
Induced fracture	A discontinuity of non-geological origin, e.g. brought about by coring, blasting, ripping, etc.
Incipient fracture	A discontinuity which retains some tensile strength, which might not be fully developed or which might be partially cemented. Many incipient fractures are along bedding or cleavage.

Discontinuity descriptions (another table!)

Table 30 — *Terminology and checklist for rock discontinuity description*

Orientation	Discontinuity spacing	Persistence	Type of termination	Roughness	Wall strength	Aperture	Filling	Seepage	No. of sets
Dip amount only in cores		Discontinuous	Cannot normally be described in cores	**Intermediate scale (cm) and small scale (mm)**	Schmidt hammer	Cannot normally be described in cores		Cannot be described in cores	Can be described or summarized in cores where sets of different dip are present
				Stepped					
		Continuous in cores		Rough					
				Smooth	Point load test				
				Striated					
	Extremely wide >6 m		Termination				Clean		
	Very wide 2 m – 6 m			**Undulating**		Extremely wide > 1 m	Surface staining (colour)		
	Wide 600 mm – 2 m	Very high >20 m		Rough		Very wide 0.1 m – 1 m		Moisture on rock surface	
Take number of readings of dip direction/ dip, e.g. 015/18°	Medium 200 mm – 600 mm	High 10 m – 20 m	x (outside exposure)	Smooth	Other index tests	Wide 0.01 m – 0.1 m	Soil infilling (describe in accordance with Clause **33**)	Dripping water	
				Striated					
	Close 60 mm – 200 mm	Medium 3 m – 10 m		**Planar**		Moderately wide 2.5 mm – 10 mm		Water flow measured per time unit on and individual discontinuity or set of discontinuities	
			r (within rock)	Rough			Mineral coatings (e.g. calcite, chlorite, gypsum, etc.)		Record orientation and spacing of individual sets and all details for each set
	Very close 20 mm – 60 mm	Low 1 m – 3 m		Smooth		Open 0.5 mm – 2.5 mm			
Report as ranges and on stereo net if appropriate				Striated					
	Extremely close <20 mm	Very low <1 m	d (against discontinuity)	**Large scale (m)**		Partly open 0.25 mm – 0.5 mm	Other (specify)	Small flow 0.5 l/s – 5.0 l/s	
				Waviness					
	Take number of readings and state min, average and max.			Curvature		Tight 0.1 mm – 0.25 mm		Medium flow 0.05 l/s – 0.5 l/s	
			Record also size of discontinuity	Straightness	Visual assess-ment		Record width and continuity of infill		
				Measure amplitude and wavelength of feature		Very tight <0.1 mm		Large flow >5 l/s	

Discontinuity descriptions



Key

1 dip direction
2 strike
α dip direction (dip azimuth) = 240°
β dip (dip angle) = 50°

plane of discontinuity 240/50

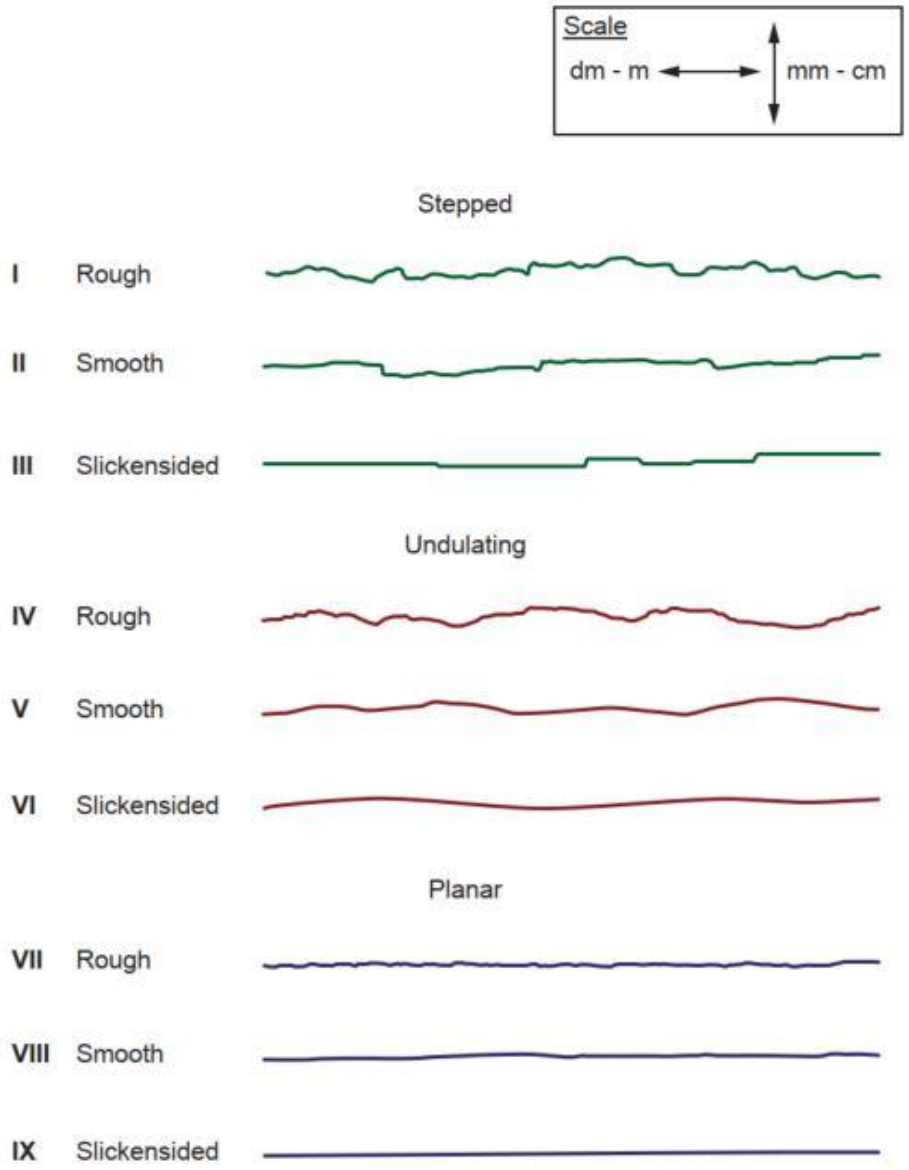
Discontinuity descriptions

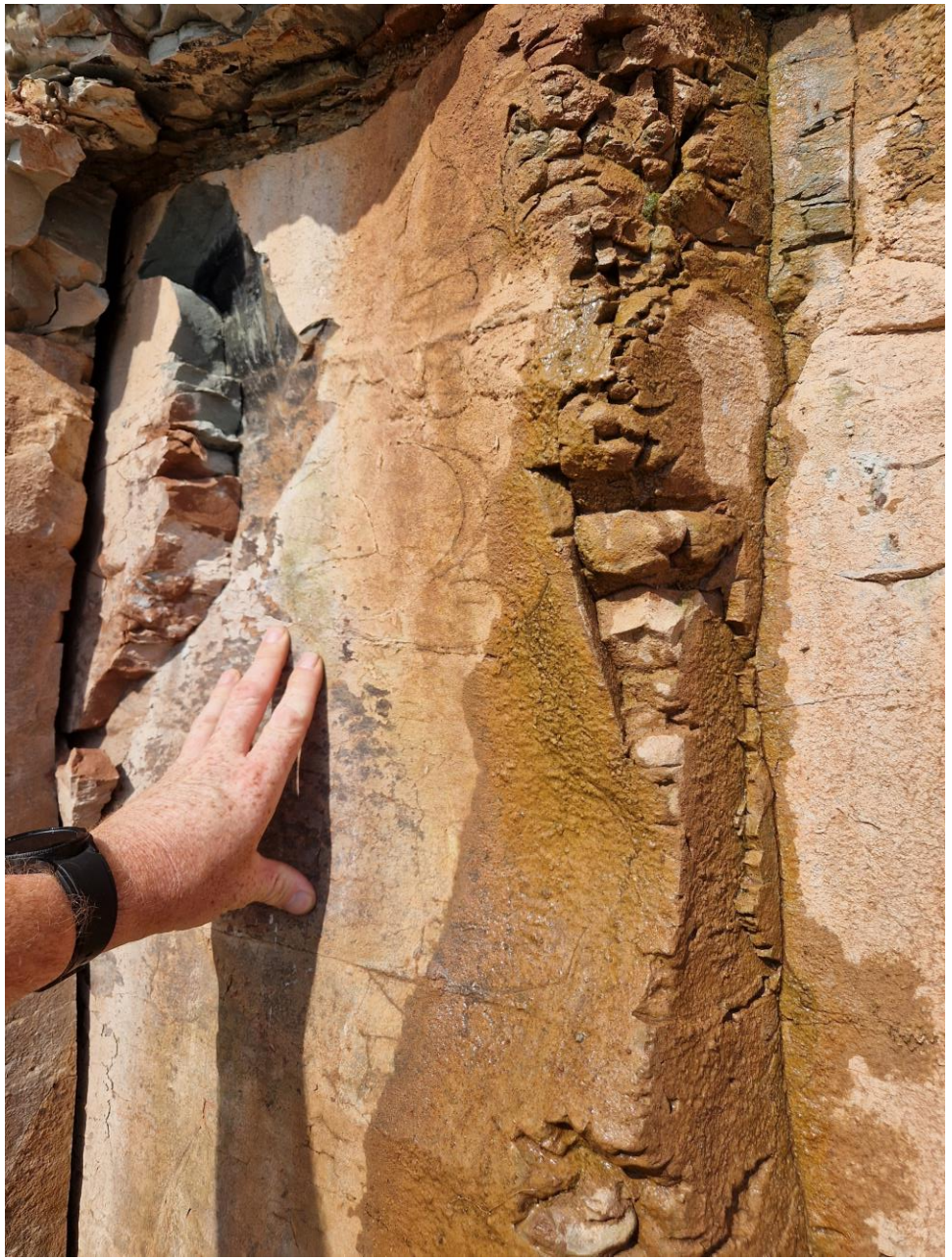
	Rough (irregular)	Smooth
Stepped	1	2
Undulating	3	4
Planar	5	6

Key

1 stepped rough surface
2 stepped smooth surface
3 undulating rough surface
4 undulating smooth surface
5 planar rough surface
6 planar smooth surface

Discontinuity descriptions





Rock Quality Designation

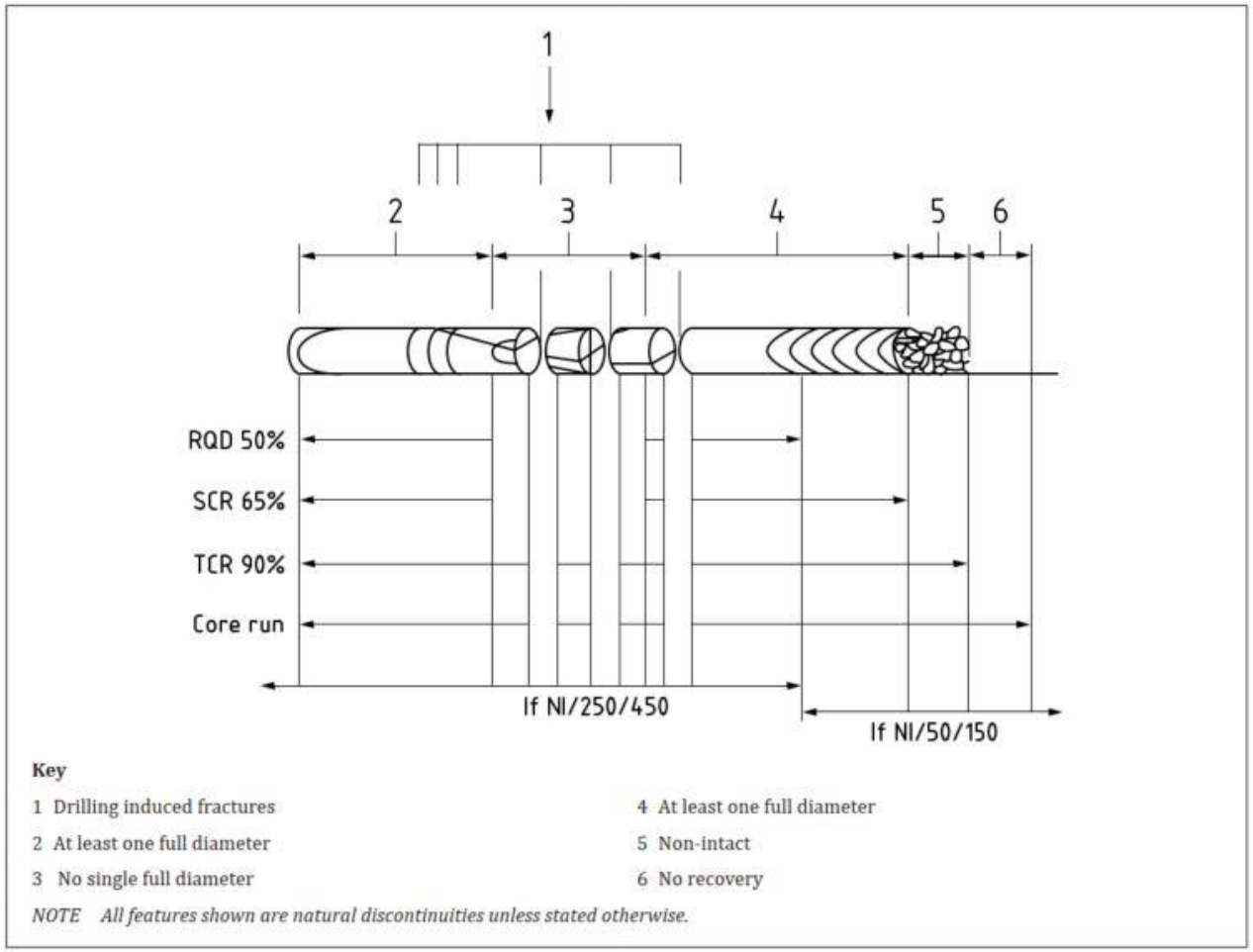
Table 31 — *Terms for classification of discontinuity state (see Figure 10)*

TCR (%)	Length of core recovered (solid and non-intact) expressed as a ratio of the length of core run.
SCR (%)	Length of solid core recovered expressed as a ratio of the length of core run. Solid core has a full diameter, uninterrupted by natural discontinuities, but not necessarily a full circumference and is commonly measured along the core axis or other scan line.
RQD (%)	Length of solid core pieces, each longer than 100 mm, expressed as a ratio of the length of core run.
Fracture index	Count of the number or spacing of fractures over an arbitrary length of core of similar intensity of fracturing recorded as minimum/mode/maximum. Commonly reported as Fracture Spacing (If, mm) or as Fracture Index (FI, number of fractures per metre). Where core is non-intact in the ground, the abbreviation NI may be used.

NOTE The total core recovery (TCR) records the proportion of core recovered and is read with the description, solid core recovery (SCR) and rock quality designation (RQD). The TCR of itself gives little information on the character of the core or the rock from which it was recovered. This measurement is required to ensure that all depth related records such as boundaries, markers and samples are correct.

Rock Quality Designation

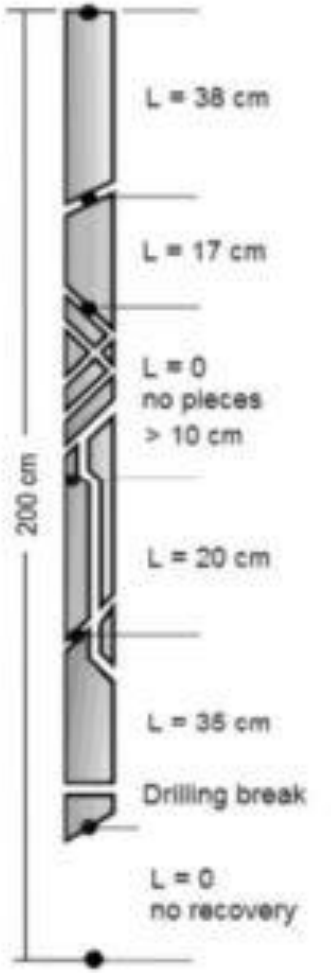
Figure 10 — *Application of fracture state terms for rock cores*



Key

1 Drilling induced fractures
2 At least one full diameter
3 No single full diameter
4 At least one full diameter
5 Non-intact
6 No recovery

NOTE All features shown are natural discontinuities unless stated otherwise.



$$RDQ = \frac{\Sigma \text{Core pieces} > 10\text{ cm}}{\text{Total length of core run}} \times 100$$

$$RDQ = \frac{38 + 17 + 20 + 35}{200} = 55\ \%$$

Weathering

Table 3.2 *Simplified weathering scheme for Mercia mudstone*

Weathering Grade		Description	Notes
Fully weathered	IVb	Matrix only	Can be confused with solifluction or drift deposits, but contains no pebbles. Plastic slightly silty clay. May be fissured.
Partially weathered	IVa	Matrix with occasional claystone pellets less than 30 mm dia, but more usually coarse sand size.	Little or no trace of original (Grade I) structure, through clay may be fissured. Lower permeability than underlying layers.
	III	Matrix with frequent lithorelicts up to 25 mm. As weathering progresses, lithorelicts become less angular.	Water content of matrix greater than that of lithorelicts.
	II	Angular blocks of unweathered marl with virtually no matirx.	Spheroidal weathering. Matrix starting to encroach along joints: first indications of chemical weathering
Unweathered	I	Mudstone (often jointed and fissured).	Water content varies due to depositional variations.

Table 3.3 *Ranges of index and other properties of Mercia mudstone with weathering grade (Chandler 1969, with additions)*

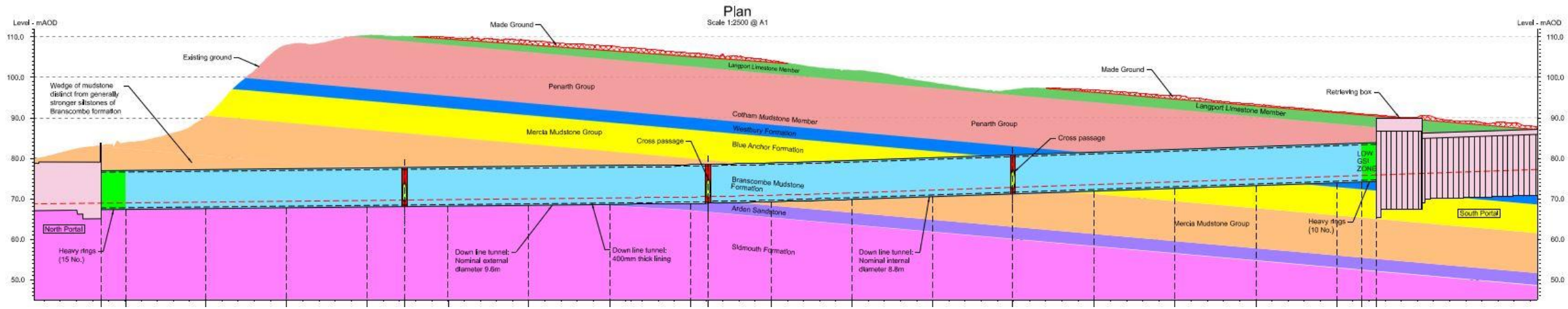
Index property		Grades I and II	Grade III	Grade IV
Bulk weight unit	kN/m³	24.5–22.0	23.0–20.5	21.0–18.0
w_{nat}	%	5–15	12–20	18–35
w_L	%	25–35	25–40	35–60
w_P	%	17–25	17–27	17–23
I_P	%	10–15	10–18	17–33
clay size *	%	10–35	10–35	30–50
Aggregation ratio A_r	–	10–2.5	10–2.5	32.5
Typical SPT N values	blows	>80	30–80	<30

Table 10.9 Weathering classification for Mercia Mudstone

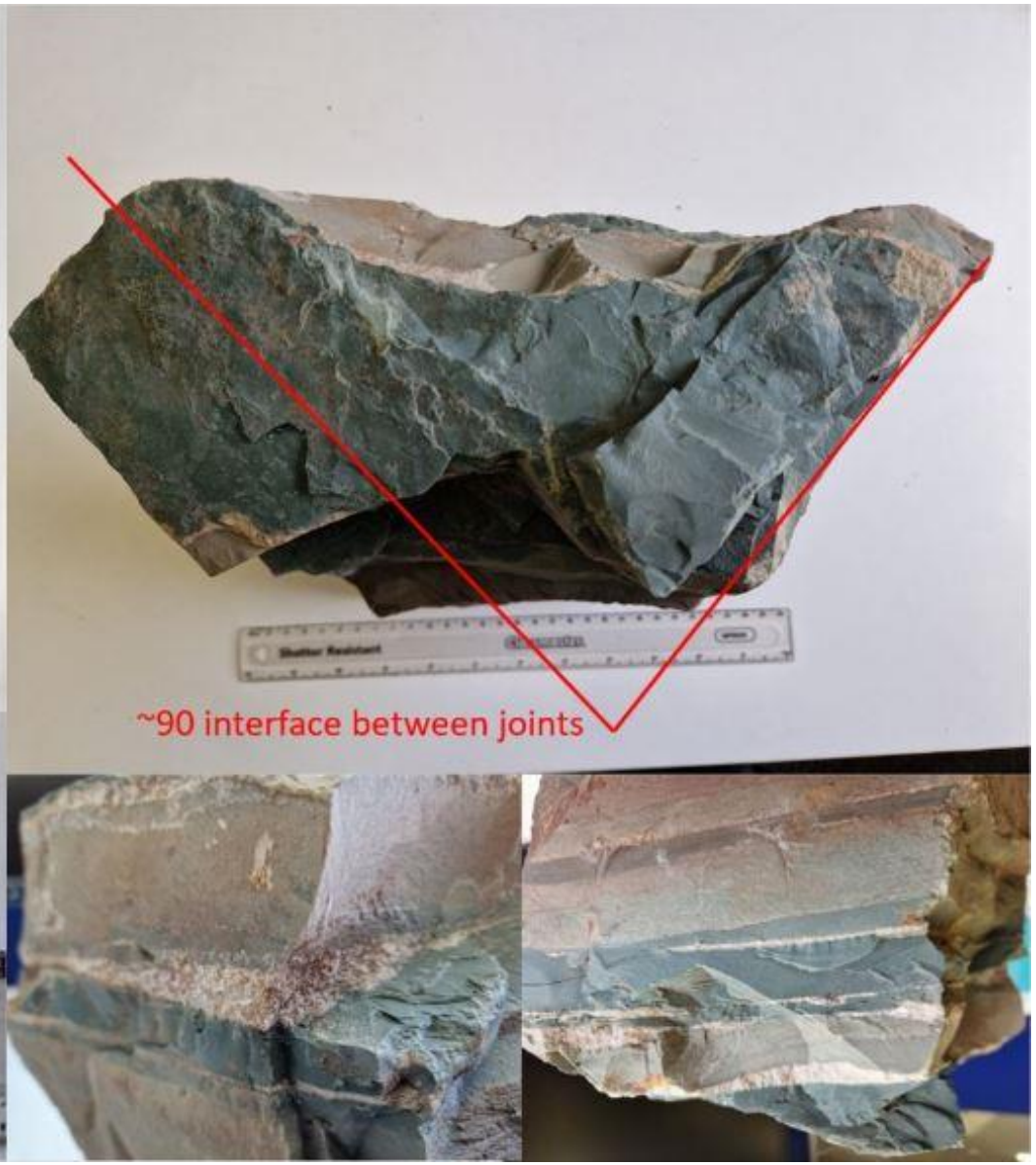
Class (after Spink & Norbury, 1993)		Example descriptions Note – Classes and Example descriptions as BS5930:1999 *Colloquial descriptions from Chandler are not to be used*	Zone (Chandler, 1969)[1]
Reworked	E	Firm fissured reddish brown slightly gravelly CLAY. Gravel is fine to medium of subangular grey and yellow moderately weak sandstone. Rare rounded quartzite gravel. Fissures are near vertical extremely closely to closely spaced. *(Solifluction deposit with foreign pebbles.)*	V
Destructured	Dc	Firm to stiff fissured reddish brown CLAY with rare subangular fine to medium gravel of grey moderately weak sandstone. Fissures are near vertical closely to medium spaced. *(Clay matrix with no lithorelicts, but no pebbles.)*	IVb
	Db	Firm to stiff fissured reddish brown slightly coarse sandy slightly fine gravelly CLAY. Sand and gravel are of randomly oriented subangular to rounded lithorelicts of reddish brown very stiff clay to extremely weak mudstone. Fissures are near vertical generally medium spaced. *(Clay matrix with <3 mm lithorelicts.)*	IVa
	Da	Firm to stiff reddish brown coarse sandy fine to medium gravelly CLAY. Sand and gravel are of randomly orientated subangular to subrounded lithorelicts of reddish brown very stiff clay to extremely weak mudstone. Occasional relict structure of randomly orientated discontinuities extremely closely spaced. *(Clay matrix with frequent lithorelicts up to 25 mm.)*	III
Distinctly weathered	C	Firm to very stiff fissured reddish brown gravelly to very gravelly CLAY. Horizontal subangular to subrounded lithorelicts of extremely weak reddish brown mudstone. Fissures are generally near horizontal and near vertical extremely to very closely spaced orange and black stained with up to 3 mm of clay or silt infill. *(Lithorelicts of MUDSTONE in silt matrix.)*	III
Partially weathered	B	Extremely weak to very weak laminated to very thinly bedded reddish brown locally calcareous MUDSTONE. Near horizontal and near vertical generally very closely spaced occasionally black stained discontinuities with a trace of silt or clay infill. *(Angular blocks of unweathered MUDSTONE)*	II
Unweathered	A	Weak to medium strong laminated to very thinly bedded reddish brown calcareous MUDSTONE. Near horizontal and near vertical very closely to closely spaced discontinuities. *(Unweathered MUDSTONE)*	I

[1] Extended by Chandler and Davis (1973)

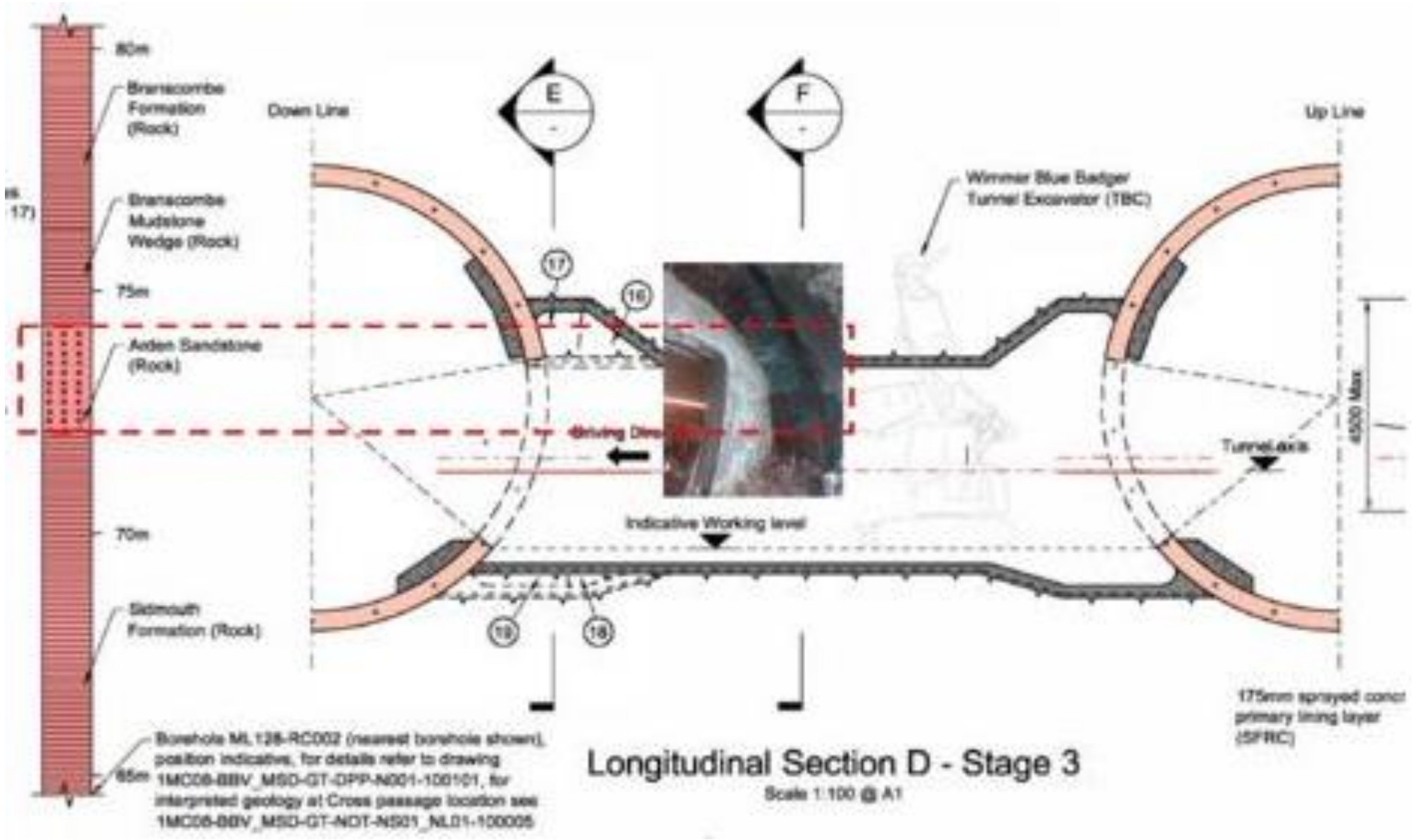
Applications – ground model



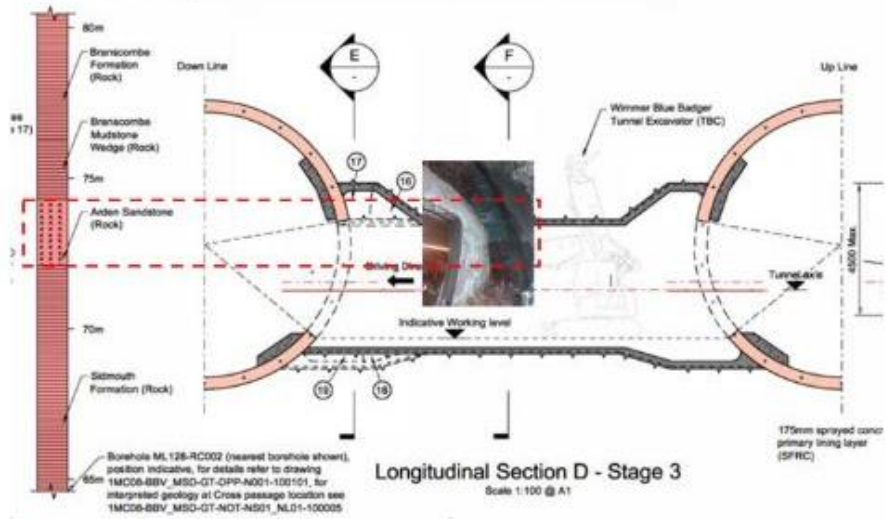
Applications – rock strength and stratigraphy observations



Applications – ground model



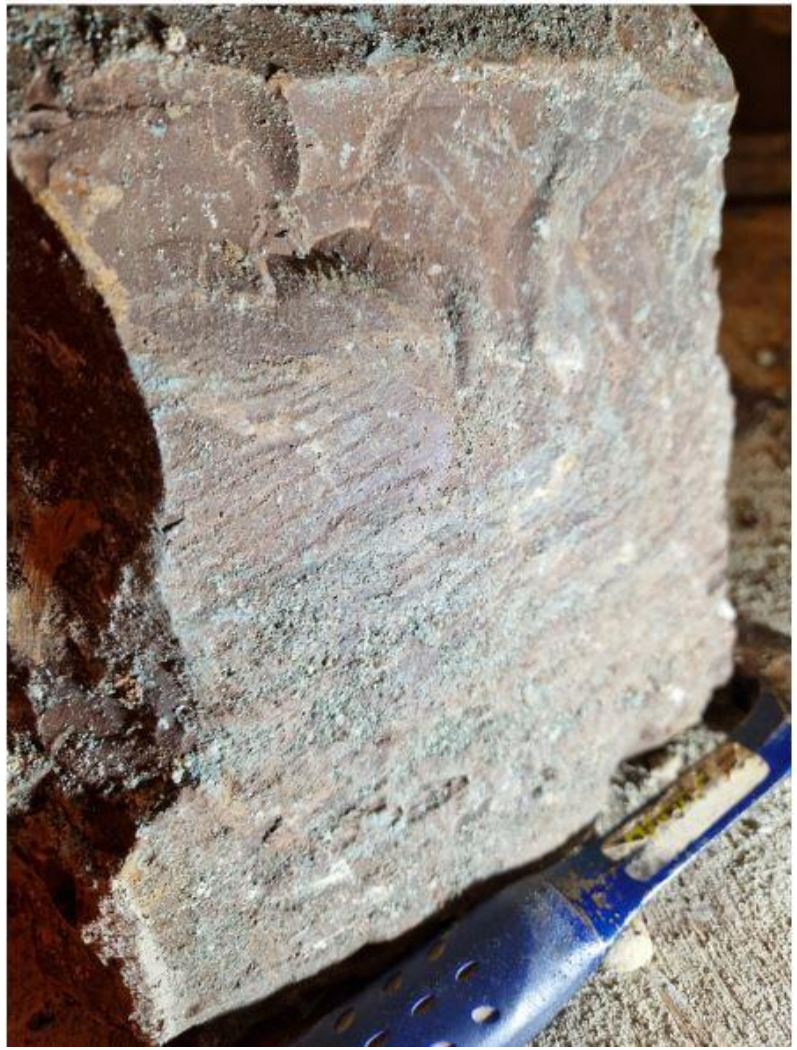
Applications – ground model



Mott MacDonald Restricted

Mott MacDonald Restricted

Applications – discontinuity observations



Undulating smooth

Very tight and clean

Applications – Rock Mass Rating$_{89}$ (RMR$_{89}$)

Table 1: RMR classification of rock masses (Bieniawski, 1989).

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

PARAMETER			Range of values // ratings						
1	Strength of intact rock material	Point-load strength index	> 10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range uniaxial compr. strength is preferred		
		Uniaxial com-pressive strength	> 250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
		RATING	**15**	**12**	**7**	**4**	**2**	**1**	**0**
2	Drill core quality RQD		90 - 100%	75 - 90%	50 - 75%	25 - 50%	< 25%		
		RATING	**20**	**17**	**13**	**8**	**5**		
3	Spacing of discontinuities		> 2 m	0.6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm		
		RATING	**20**	**15**	**10**	**8**	**5**		
4	Condition of discon-tinuities	Length, persistence	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m		
		Rating	**6**	**4**	**2**	**1**	**0**		
		Separation	none	< 0.1 mm	0.1 - 1 mm	1 - 5 mm	> 5 mm		
		Rating	**6**	**5**	**4**	**1**	**0**		
		Roughness	very rough	rough	slightly rough	smooth	slickensided		
		Rating	**6**	**5**	**3**	**1**	**0**		
		Infilling (gouge)	none	Hard filling		Soft filling			
			-	< 5 mm	> 5 mm	< 5 mm	> 5 mm		
		Rating	**6**	**4**	**2**	**2**	**0**		
		Weathering	unweathered	slightly w.	moderately w.	highly w.	decomposed		
		Rating	**6**	**5**	**3**	**1**	**0**		
5	Ground water	Inflow per 10 m tunnel length	none	< 10 litres/min	10 - 25 litres/min	25 - 125 litres/min	> 125 litres /min		
		p_w / $\sigma 1$	0	0 - 0.1	0.1 - 0.2	0.2 - 0.5	> 0.5		
		General conditions	completely dry	damp	wet	dripping	flowing		
		RATING	**15**	**10**	**7**	**4**	**0**		

p_w = joint water pressure; $\sigma 1$ = major principal stress

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS

		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
RATINGS	Tunnels	**0**	**-2**	**-5**	**-10**	**-12**
	Foundations	**0**	**-2**	**-7**	**-15**	**-25**
	Slopes	**0**	**-5**	**-25**	**-50**	**-60**

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 - 81	80 - 61	60 - 41	40 - 21	< 20
Class No.	I	II	III	IV	V
Description	VERY GOOD	GOOD	FAIR	POOR	VERY POOR

D. MEANING OF ROCK MASS CLASSES

Class No.	I	II	III	IV	V
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 1 m span
Cohesion of the rock mass	> 400 kPa	300 - 400 kPa	200 - 300 kPa	100 - 200 kPa	< 100 kPa
Friction angle of the rock mass	< 45°	35 - 45°	25 - 35°	15 - 25°	< 15°

Applications – Rock Mass Rating$_{89}$ (RMR$_{89}$)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

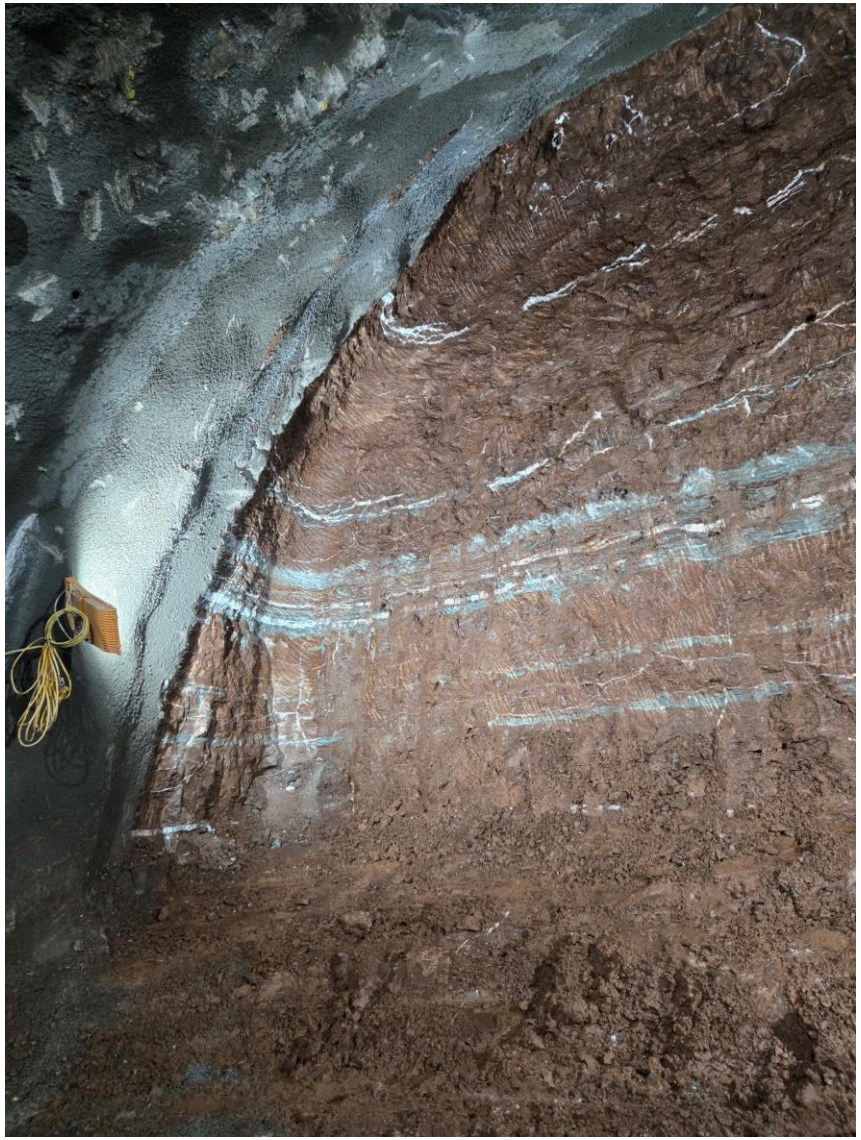
PARAMETER			Range of values // ratings						
1	Strength of intact rock material	Point-load strength index	> 10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range uniaxial compr. strength is preferred		
		Uniaxial com-pressive strength	> 250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
		RATING	**15**	**12**	**7**	**4**	**2**	**1**	**0**
2	Drill core quality RQD		90 - 100%	75 - 90%	50 - 75%	25 - 50%	< 25%		
		RATING	**20**	**17**	**13**	**8**	**5**		
3	Spacing of discontinuities		> 2 m	0.6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm		
		RATING	**20**	**15**	**10**	**8**	**5**		
4	Condition of discon-tinuities	Length, persistence	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m		
		Rating	**6**	**4**	**2**	**1**	**0**		
		Separation	none	< 0.1 mm	0.1 - 1 mm	1 - 5 mm	> 5 mm		
		Rating	**6**	**5**	**4**	**1**	**0**		
		Roughness	very rough	rough	slightly rough	smooth	slickensided		
		Rating	**6**	**5**	**3**	**1**	**0**		
		Infilling (gouge)	none	Hard filling		Soft filling			
			-	< 5 mm	> 5 mm	< 5 mm	> 5 mm		
		Rating	**6**	**4**	**2**	**2**	**0**		
		Weathering	unweathered	slightly w.	moderately w.	highly w.	decomposed		
		Rating	**6**	**5**	**3**	**1**	**0**		
5	Ground water	Inflow per 10 m tunnel length	none	< 10 litres/min	10 - 25 litres/min	25 - 125 litres/min	> 125 litres /min		
		p_w / $\sigma 1$	0	0 - 0.1	0.1 - 0.2	0.2 - 0.5	> 0.5		
		General conditions	completely dry	damp	wet	dripping	flowing		
		RATING	**15**	**10**	**7**	**4**	**0**		

p_w = joint water pressure; $\sigma 1$ = major principal stress

= 51

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS

		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
RATINGS	Tunnels	**0**	**-2**	**-5**	**-10**	**-12**
	Foundations	**0**	**-2**	**-7**	**-15**	**-25**
	Slopes	**0**	**-5**	**-25**	**-50**	**-60**



Applications – Joint Condition$_{89}$ (JCond$_{89}$)

Condition of discontinuities	Strengthening intrablock structure Strong infill minerals welded to wall rock	Very rough or healed surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces or weak veins Separation <1mm Slightly weathered walls	Slightly rough surfaces Separation <1mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge > 5 mm thick or Separation > 5 mm Continuous
Overall rating	37.5	30	25	20	10	0
Guidelines for classification of discontinuity conditions						
Discontinuity length (persistence)	< 0.5 m	< 1 m	1 to 3 m	3 to 10 m	10 to 20 m	> 20 m
Rating	7.5	6	4	2	1	0
Separation (aperture)	Welded	None	< 0.1 mm	0.1 to 1.0 mm	1 to 5 mm	> 5mm
Rating	7.5	6	5	4	1	0
Roughness	Rough, undulating, irregular	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	7.5	6	5	3	1	0
Infilling (gouge)	Strong bonded vein (quartz)	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating	7	6	4	2	2	0
Weathering	Strengthening by alteration	Unweathered	Slightly weathered	Moderate weathering	Highly weathered	Decomposed
Rating	7	6	5	3	1	0

Applications – Geological Strength Index

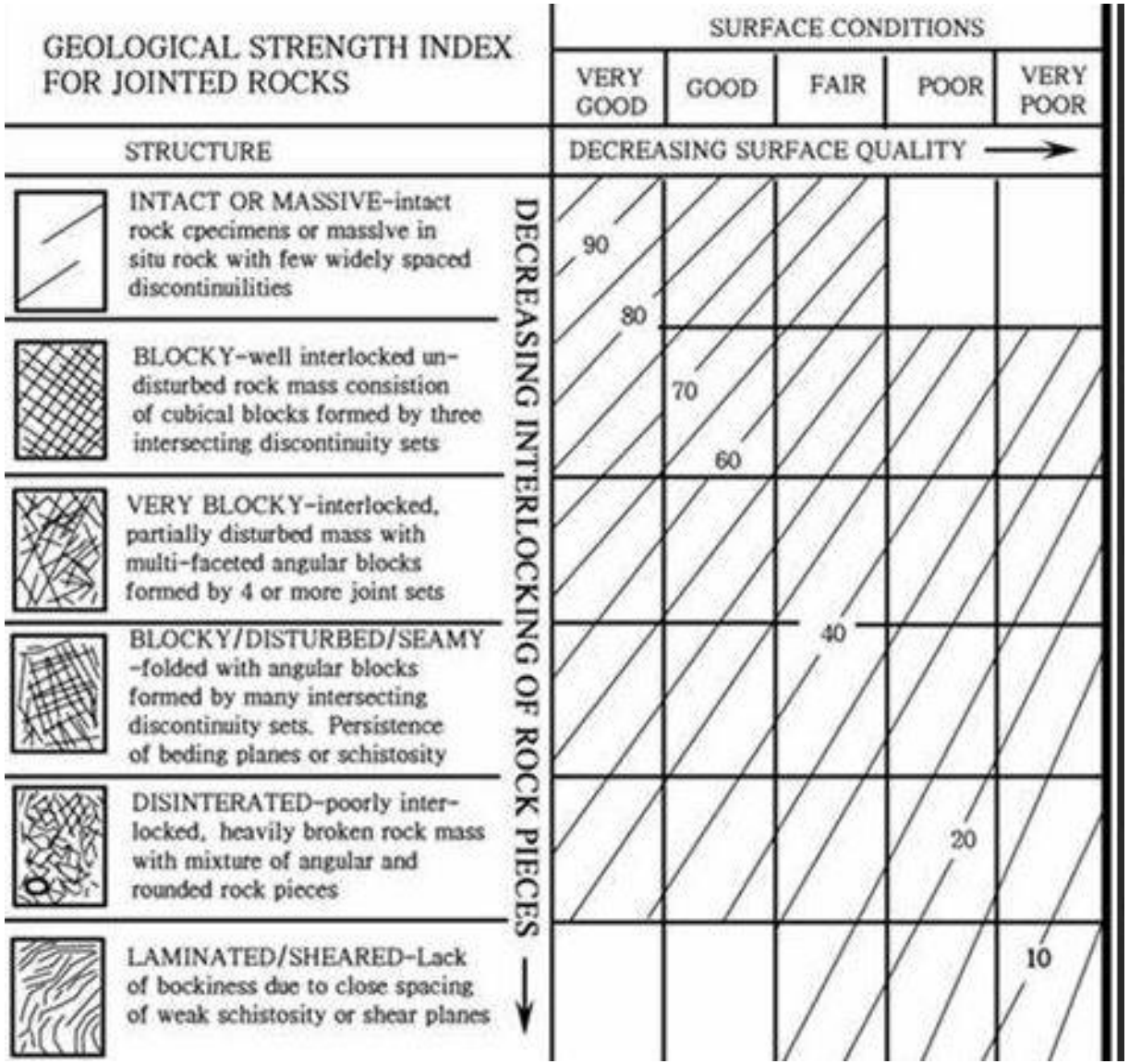
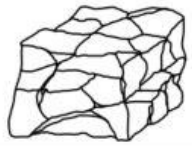
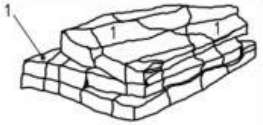
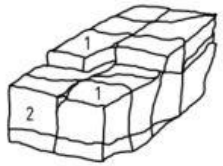
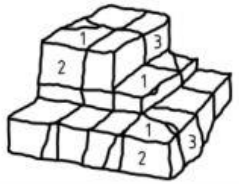
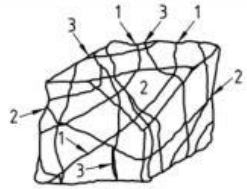
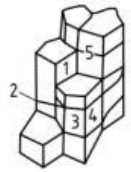


Table 10 — Terms to describe the main rock mass structures and block shapes

Term	Figure	Description
a) Polyhedral blocks		Irregular discontinuities without arrangement into distinct sets, and of small persistence.
b) Tabular blocks		One dominant set of parallel discontinuities (1), for example bedding planes, with other non-continuous joints; thickness of blocks much less than length or width.
c) Prismatic blocks		Two dominant sets of discontinuities (1 and 2), approximately orthogonal and parallel, with a third irregular set; thickness of blocks much less than length or width.
d) Equidimensional blocks		Three dominant sets of discontinuities (1, 2 and 3), approximately orthogonal, with occasional irregular joints, giving equidimensional blocks.
e) Rhomboidal blocks		Three (ore more) dominant, mutually oblique, sets of joints (1, 2 and 3), giving oblique-shaped, equidimensional blocks.
f) Columnar blocks		Several, usually more than three, sets of continuous, parallel joints (1, 2, 3, 4, 5) usually crossed by irregular joints; length much greater than other dimensions.

Applications – Geological Strength Index

Condition of discontinuities	Strengthening intrablock structure Strong infill minerals welded to wall rock	Very rough or healed surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces or weak veins Separation <1mm Slightly weathered walls	Slightly rough surfaces Separation <1mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge > 5 mm thick or Separation > 5 mm Continuous
Overall rating	37.5	30	25	20	10	0
Guidelines for classification of discontinuity conditions						
Discontinuity length (persistence)	< 0.5 m	< 1 m	1 to 3 m	3 to 10 m	10 to 20 m	> 20 m
Rating	7.5	(6)	4	2	1	0
Separation (aperture)	Welded	None	< 0.1 mm	0.1 to 1.0 mm	1 to 5 mm	> 5mm
Rating	7.5	(6)	5	4	1	0
Roughness	Rough, undulating, irregular	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	7.5	6	5	3	(1)	0
Infilling (gouge)	Strong bonded vein (quartz)	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating	7	(6)	4	2	2	0
Weathering	Strengthening by alteration	Unweathered	Slightly weathered	Moderate weathering	Highly weathered	Decomposed
Rating	7	6	(5)	3	1	0

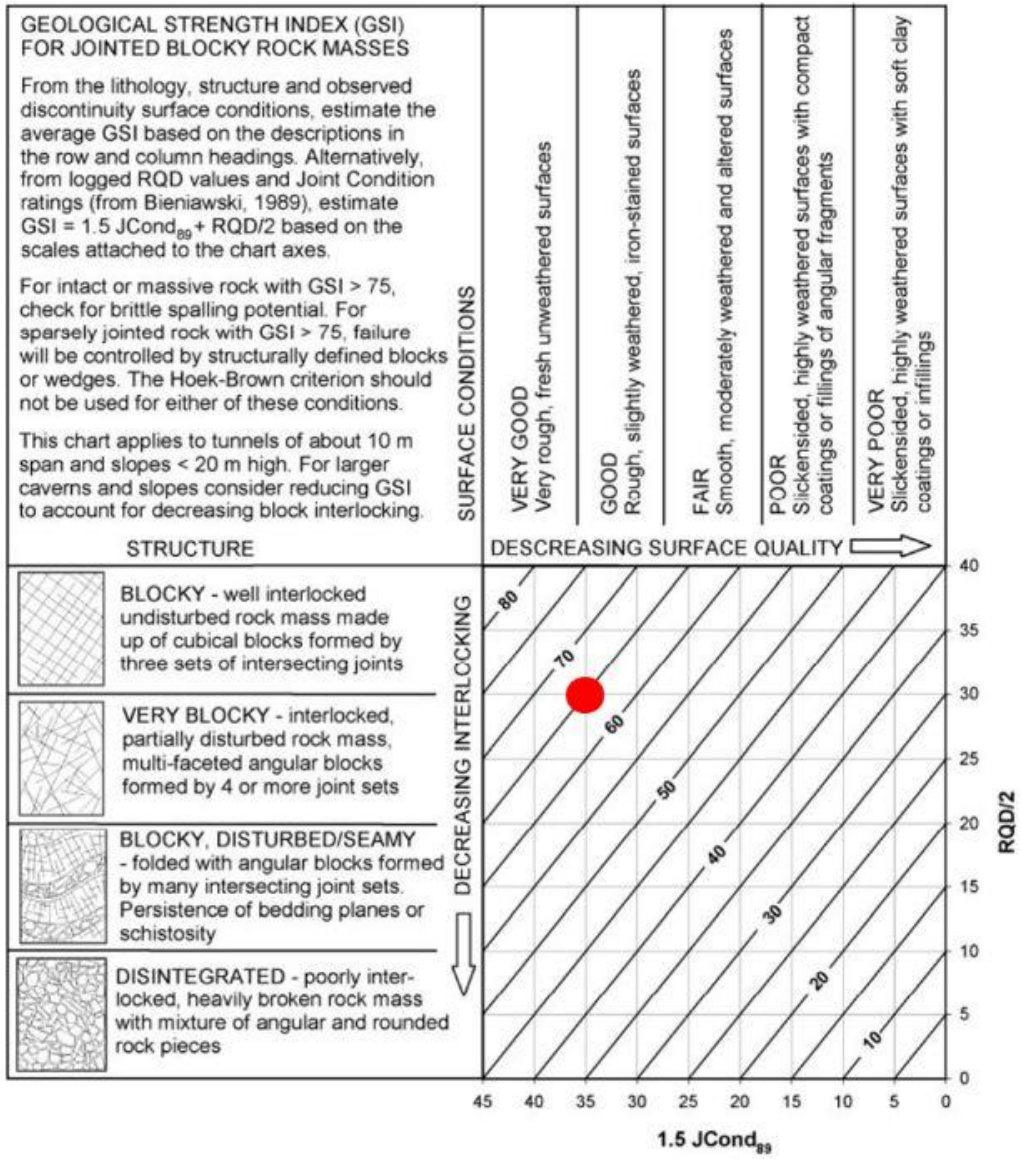
RQD ~ 60

Jcond89 = 24

1.5Jcond89 = 36

RQD/2 = 30

GSI = 65



Applications – Rock Mass Quality (RMQ)

The Q-value gives a description of the rock mass stability of an underground opening in jointed rock masses. High Q-values indicates good stability and low values means poor stability. Based on 6 parameters the Q-value is calculated using the following equation:

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

The six parameters are:

RQD = Degree of jointing (Rock Quality Designation)

J_n = Joint set number

J_r = Joint roughness number

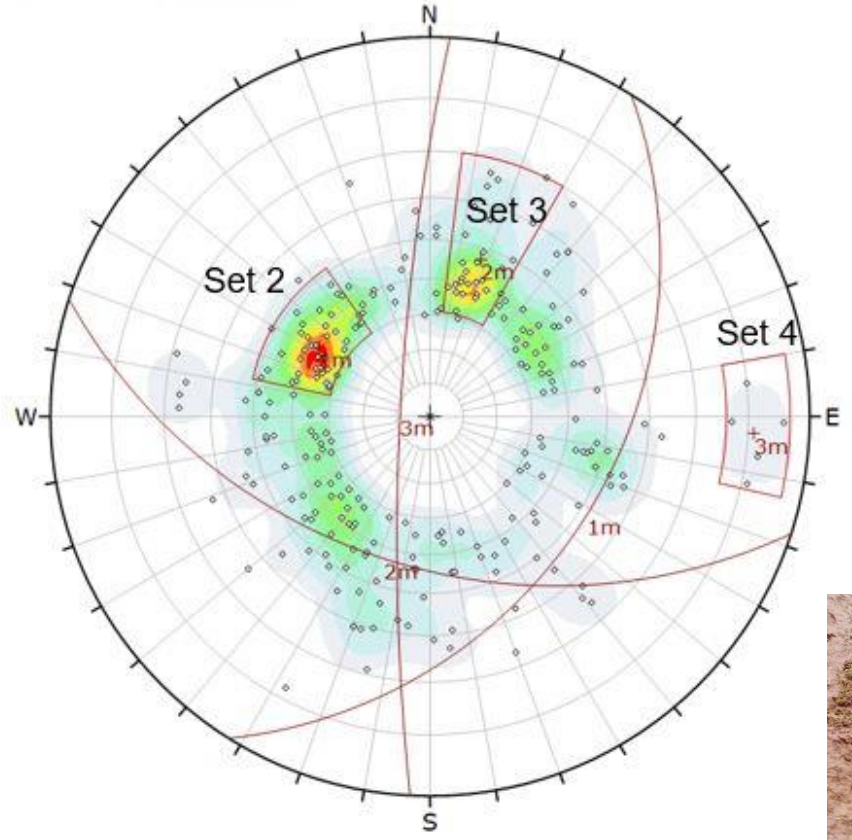
J_a = Joint alteration number

J_w = Joint water reduction factor

SRF = Stress Reduction Factor

Applications – Wedge Failure Assessment

Figure 7-2: Stereonet Geophysical Data – Discontinuity Sets 2,3,4 (Rock Joints)

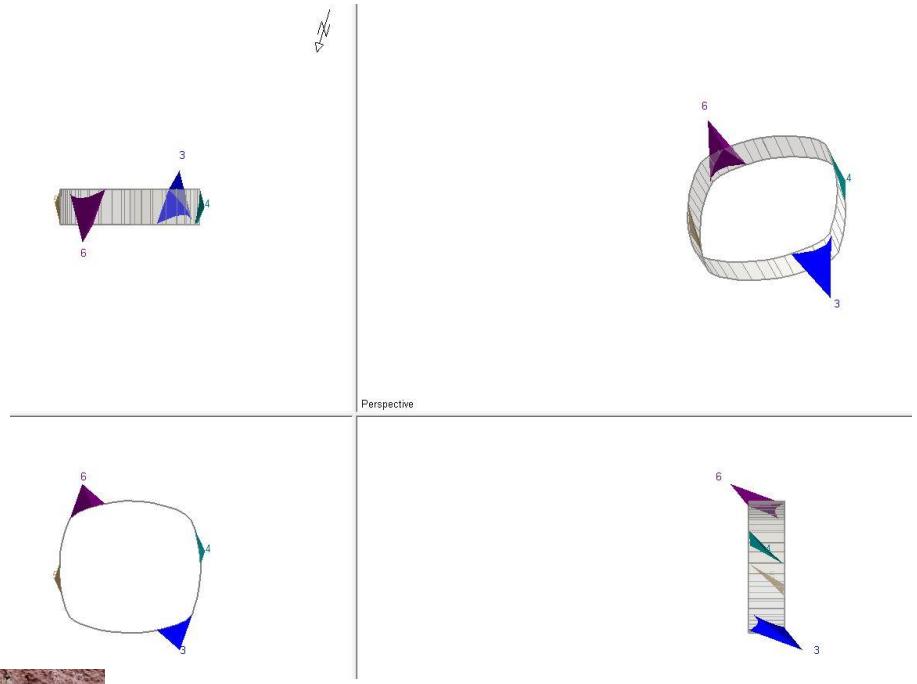


Symbol	Feature
○	Pole Vectors

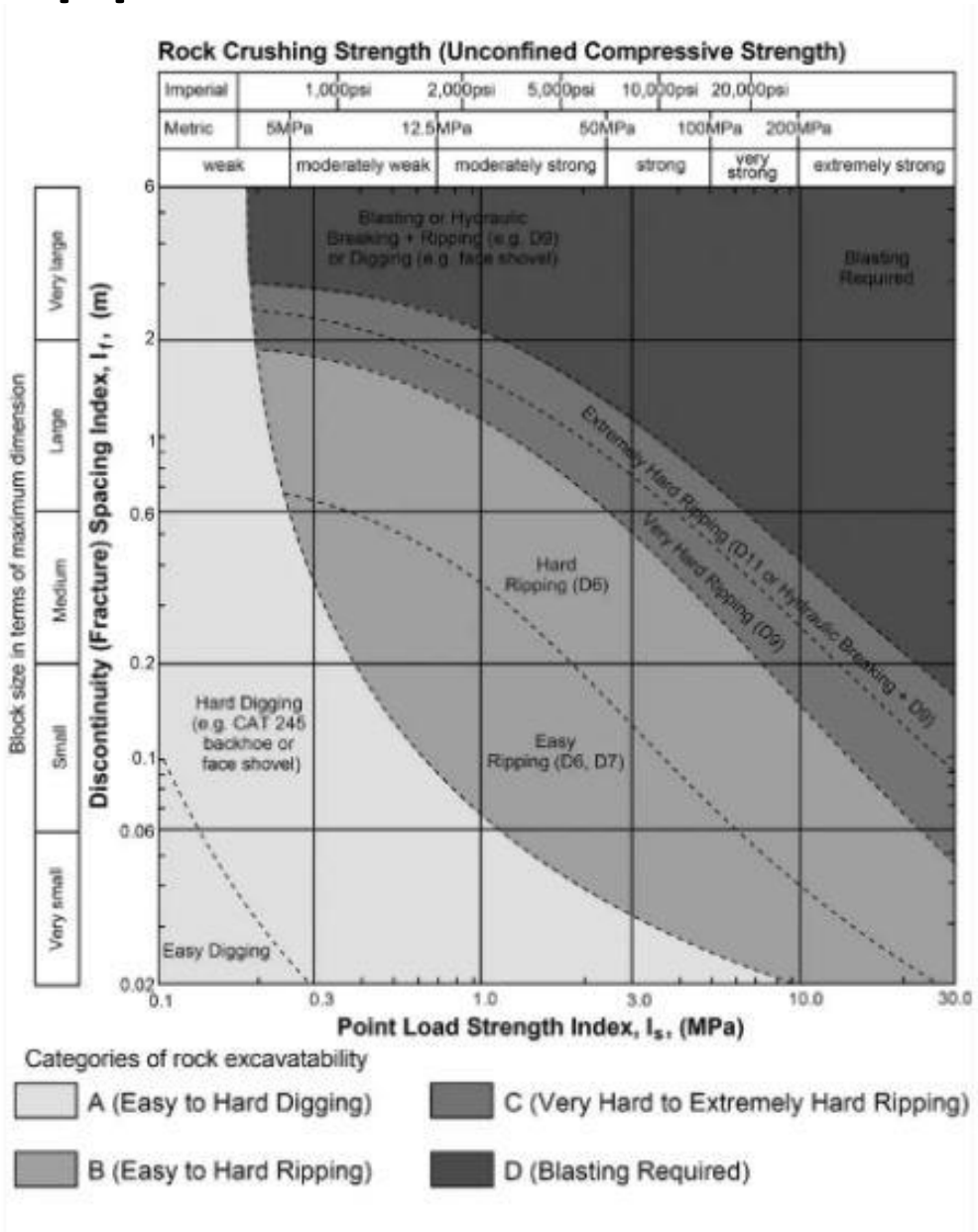
Color	Density Concentrations
	0.00 - 0.80
	0.80 - 1.60
	1.60 - 2.40
	2.40 - 3.20
	3.20 - 4.00
	4.00 - 4.80
	4.80 - 5.60
	5.60 - 6.40
	6.40 - 7.20
	7.20 - 8.00

Contour Data	Pole Vectors
Maximum Density	7.65%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	253 (253 Entries)
Hemisphere	Lower
Projection	Equal Angle



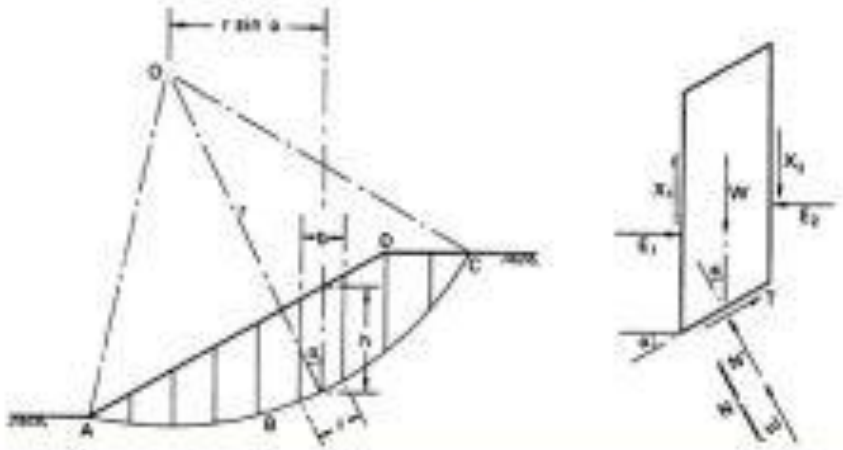
Applications – Excavatability/Rippability



Applications – Slope Stability

Soil Continuum

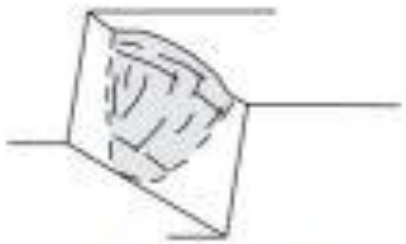
Stability governed by strength at soil particle contacts



Rock Continuum

Stability governed by strength of block contacts or particle/mineral contacts

Closely fractured rock



Weak, massive rock

Applications – Earthworks

Thank you – any questions?