Attachment F Geotechnical Logging Procedures

LITHOLOGICAL AND GEOTECHNICAL ROCK DESCRIPTION TERMINOLOGY

WEATHERING STATE

Fresh: no visible sign of weathering.

Faintly weathered: weathering limited to the surface of major discontinuities.

Slightly weathered: penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material.

Moderately weathered: weathering extends throughout the rock mass but the rock material is not friable.

Highly weathered: weathering extends throughout rock mass and the rock material is partly friable.

Completely weathered: rock is wholly decomposed and in a friable condition but the rock texture and structure are preserved.

BEDDING THICKNESS

Description	Bedding Plane Spacing
Very thickly bedded	> 2 m
Thickly bedded	0.6 m to 2m
Medium bedded	0.2 m to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 mm to 60 mm
Laminated	6 mm to 20 mm
Thinly laminated	< 6 mm

JOINT OR FOLIATION SPACING

Description	Spacing
Very wide	> 3 m
Wide	1 - 3 m
Moderately close	0.3 - 1 m
Close	50 - 300 mm
Very close	< 50 mm

GRAIN SIZE

Term	Size*
Very Coarse Grained	> 60 mm
Coarse Grained	2 - 60 mm
Medium Grained	60 microns - 2 mm
Fine Grained	2 - 60 microns
Very Fine Grained	< 2 microns

Note: * Grains >60 microns diameter are visible to the naked eye.

CORE CONDITION

Total Core Recovery

The percentage of solid drill core recovered regardless of quality or length, measured relative to the length of the total core run.

Solid Core Recovery (SCR)

The percentage of solid drill core, regardless of length, recovered at full diameter, measured relative to the length of the total core run.

Rock Quality Designation (RQD)

The percentage of solid drill core, greater than 100 mm length, recovered at full diameter, measured relative to the length of the total core run. RQD varies from 0% for completely broken core to 100% for core in solid sticks.

DISCONTINUITY DATA

Fracture Index

A count of the number of discontinuities (physical separations) in the rock core, including both naturally occurring fractures and mechanically induced breaks caused by drilling.

Dip with Respect to (W.R.T.) Core Axis

The angle of the discontinuity relative to the axis (length) of the core. In a vertical borehole a discontinuity with a 90° angle is horizontal.

Description and Notes

An abbreviated description of the discontinuities, whether naturally occurring separations such as fractures, bedding planes and foliation planes or mechanically induced features caused by drilling such as ground or shattered core and mechanically separated bedding or foliation surfaces. Additional information concerning the nature of fracture surfaces and infillings are also noted.

Abbreviations

B - Bedding	P - Polished
FO - Foliation/Schistosity	S - Slickensided
CL - Cleavage	SM - Smooth
SH - Shear Plane/Zone	R - Ridged/Rough
VN - Vein	ST - Stepped
F - Fault	PL - Planar
CO - Contact	FL - Flexured
J - Joint	UE - Uneven
FR - Fracture	W - Wavy
MF - Mechanical Fracture	C - Curved
$\parallel$ - Parallel To	
$\perp$ - Perpendicular To	

MODIFIED UNIFIED SOIL CLASSIFICATION

Golder Associates
CONSULTING ENGINEERS

MAJOR DIVISION			GROUP SYMBOL	TYPICAL DESCRIPTION	CLASSIFICATION CRITERIA		
COARSE-GRAINED SOILS more than 50% retained on No. 200 (75 um) sieve	GRAVELS More than 50% of coarse fraction retained on No. 4 (4.75mm) sieve	CLEAN GRAVELS (less than 5% fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Classify on basis of percentage of fines: Less than 5% pass No. 200 (75um) sieve - GW, GP, SW, SP More than 12% pass No. 200 (75um) sieve - GM, GC, SM, SC 5% to 12% pass No. 200 (75um) sieve - Borderline Classification requiring use of dual symbols.	$Cu = \frac{D_{60}}{D_{10}} \geq 4$ $Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			GP	Poorly-graded gravels, and gravel-sand mixtures, little or no fines		Not meeting both criteria for GW	
		GRAVELS WITH FINES (more than 12% fines)	GM	Silty gravels, gravel-sand-silt mixtures,		Atterberg Limits plot below A-Line or $I_p < 4$	Atterberg Limits plotting in hatched area are borderline classifications requiring use of dual symbols
			GC	Clayey gravels, gravel-sand-silt-clay mixtures		Atterberg Limits plot above A-Line and $I_p > 7$	
	SANDS 50% or more of coarse fraction passes No. 4 (4.75mm) sieve	CLEAN SANDS (less than 5% fines)	SW	Well-graded sands, gravelly sands, little or no fines		$Cu = \frac{D_{60}}{D_{10}} \geq 6$ $Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}} = 1$ to 3	
			SP	Poorly-graded sands, and gravelly sands, little or no fines		Not meeting both criteria for SW	
		SANDS WITH FINES (more than 12% fines)	SM	Silty sands, sand-silt mixtures		Atterberg Limits plot below A-Line or $I_p < 4$	Atterberg Limits plotting in hatched area are borderline classifications requiring use of dual symbols
			SC	Clayey sands, sand-silt-clay mixtures		Atterberg Limits plot above A-Line and $I_p > 7$	
FINE-GRAINED SOILS 50% or more passes No. 200 (75um) sieve	SILTS	SILTS Little or no organic content	ML	Inorganic silts and fine sands, rock flour, silty or clayey fine sands of slight plasticity	Atterberg Limits plot below A-Line and $W_L < 50$		USE PLASTICITY CHART
			MH	Inorganic silts, micaceous or diatomaceous, fine sands or silts, elastic silts	Atterberg Limits plot below A-Line and $W_L > 50$		
	CLAYS	CLAYS Little or no organic content	CL	Inorganic clays of low plasticity, gravelly, sandy or silty clays, lean clays	Atterberg Limits plot above A-Line and hatched zone and $W_L < 30$		
			CI	Inorganic clays of medium plasticity, silty clays	Atterberg Limits plot above A-Line and $W_L > 30, < 50$		Atterberg Limits plotting in hatched area are borderline classifications requiring use of dual symbols
			CH	Inorganic clays of high plasticity, fat clays	Atterberg Limits plot above A-Line and $W_L > 50$		
	ORGANIC SILTS & CLAYS	ORGANIC SILTS & ORGANIC CLAYS	OL	Organic silts and organic silty clays of low plasticity	Atterberg Limits plot below A-Line and $W_L < 50$		
			OH	Organic clays of high plasticity	Atterberg Limits plot below A-Line and $W_L > 50$		
HIGHLY ORGANIC SOILS			Pt	Peat and other highly organic soils	Organic odor, dark brown to black color, spongy consistency, fibrous to amorphous texture		

REFERENCE:
Modified Unified Soil Classification System is the Unified Soil Classification System (ASTM D2487 and D2488) as modified by Soil Mechanics Laboratory, Prairie Farm Rehabilitation Administration (PFRA), Saskatoon, Sask. The modification identifies inorganic clays of medium plasticity and silty clays with liquid limits between 30 and 50, and which plot above the A-Line on the Plasticity Chart (CI)

GRAIN SIZE DISTRIBUTION:
The following adjectives are used to describe the percent by weight of components in the soil sample:

and	40% to 50%	some	10% to 25%
--y	25% to 40%	trace	less than 10%

Symbols and Definitions for Grain Size Distribution:

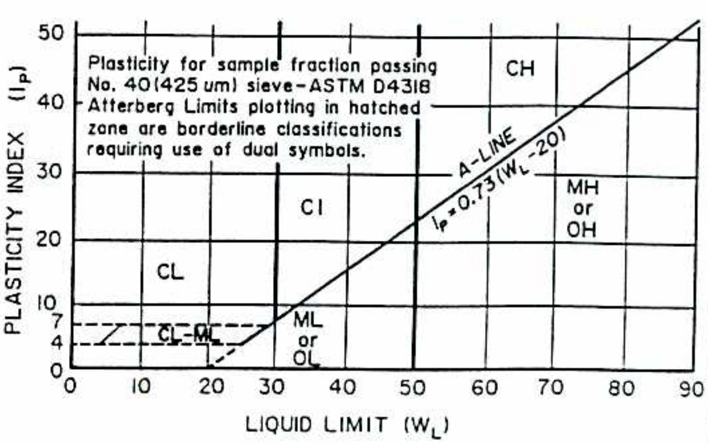
Cu = Coefficient of Uniformity = D_{60}/D_{10}

Cc = Coefficient of Curvature = $(D_{30})^2 / D_{10} \times D_{60}$

D_{10}, D_{30} and D_{60} = Grain sizes corresponding to 10%, 30% and 60% passing respectively from the grain size distribution curve

NOTE:
Soil Classification System is for the sample fraction passing the 3 in. (75mm) sieve and therefore excludes oversize material which may also be present. Oversize materials are identified separately as Cobbles and/or Boulders within the following sizes:
Cobbles-Rock particles which will not pass a 12in. (300mm) square opening but are retained on a 3in. (75mm) sieve,
Boulders-Rock particles which will not pass a 12in. (300mm) square opening.

PLASTICITY CHART
(Atterberg Limits)



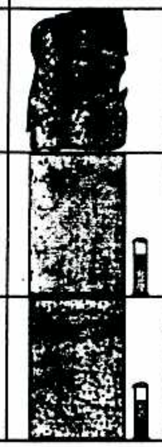
GROUND ICE DESCRIPTION

Golder Associates
CONSULTING ENGINEERS

The descriptive system for the ice phase in frozen soil is based on the *form* of ice found in frozen materials.

For descriptive purposes frozen materials are divided into three major groups in which the ice is:
not visible by eye,
visible by eye with individual ice layers *less* than 1 inch in thickness,
visible by eye with individual ice layers *greater* than 1 inch in thickness.

ICE NOT VISIBLE

GROUP SYMBOL	SUBGROUP DESCRIPTION	SUBGROUP SYMBOL	FIELD IDENTIFICATION
N	Poorly bonded or friable	Nf	 Identify by visual examination
	Well bonded No excess ice	Nbn	
	Well bonded Excess ice	Nbe	

VISIBLE ICE - LESS THAN 1in. (25mm) THICK

GROUP SYMBOL	SUBGROUP DESCRIPTION	SUBGROUP SYMBOL	FIELD IDENTIFICATION
V	Individual ice crystals or inclusions	Vx	 For ice phase, record the following when applicable: Location, Orientation, Thickness, Length, Spacing, Hardness, Structure, Colour, Size, Shape, Pattern of arrangement. Estimate volume of visible segregated ice present as percentage of total sample volume
	Ice coatings on particles	Vc	
	Random or irregularly oriented ice formations	Vr	
	Stratified or distinctly oriented ice formations	Vs	

VISIBLE ICE - MORE THAN 1in. (25mm) THICK

GROUP SYMBOL	SUBGROUP DESCRIPTION	SUBGROUP SYMBOL	FIELD IDENTIFICATION
ICE	Ice with soil inclusions	ICE + Soil Type	 Designate material as ICE and use descriptive terms as follows, usually one item from each group, when applicable: <u>Hardness</u>: HARD, SOFT (of mass, not individ. crystals); <u>Colour</u> (Examples): COLOURLESS, GRAY, BLUE; <u>Structure</u>: CLEAR, CLOUDY, POROUS, CANDLED, GRANULAR, STRATIFIED; <u>Admixtures</u> (Examples): CONTAINS FEW THIN SILT INCLUSIONS
	Ice without soil inclusions	ICE	

LEGEND: SOIL ▪ ICE ■

REFERENCE: "Guide to a Field Description of Permafrost for Engineering Purposes", by J.A. Pihlainen and G.H. Johnston, Associate Committee on Soil and Snow Mechanics, National Research Council, Ottawa, Ontario, Technical Memorandum 79, October 1963.

Geotechnical Core Logging Manual

2010

Table of Contents

Appendices

1 BASIC GEOTECHNICAL DATA GATHERING

1.1 Logging Depth Interval and Parameters

The logging depth interval over which the geotechnical parameters of the core are recorded may be project specific or dependant on the level of detail required or the scale of the features being logged. In general, the geotechnical parameters will be gathered over a single core run (approximately 3 m in length for the Kiggavik project); however, if there is a ‘zone of interest’ within the core run resulting the possible change in lithology or geotechnical property/character (such as strength, fracture frequency, and/or recovery), the feature should be measured and documented on the core logging sheet, either by breaking it out as a separate geotechnical logging interval (new domain), or writing a description in the comments column.

If the zone consists of broken or lost core, it should be recorded in logging sheet as a broken core or lost core. Depth should be referenced to ground surface, not the drill floor, top of casing (TOC) or top of drill head. Hence, it should be confirmed with the drillers in both day and night shift to avoid any discrepancies. Depth (meter marks) at any discontinuity, broken core, lost core, any zones tested or sampled and other ‘information of interest’ should be recorded on the core and/or core box using a permanent marker in appropriate way to facilitate photo interpretation at a later time.

Geotechnical parameters recorded during logging should be specific to the end use of the data. There are several rock mass classification systems which may be used in calculating the quality of the rock such as the RMR system, Q-System, RSR System, etc. Not all parameters are applicable to all rock mass classification systems.

1.2 Total Core Recovery (TCR)

Total Core Recovery is the sum of all measurable core recovered over one drill run length (obtained from the driller using the rod measurements and confirmed with him/her if you are in doubt). The length of broken core or gouge must be estimated as its true length in the ground (not as it appears spread out in the core box) and is included in the total recovery length. Percentage TCR is calculates as below.

$$\text{Recovery (\%)} = \frac{\text{Measurable core recovered length (m)}}{\text{Drill run length (m) based on core blocks}} \times 100$$

If the drill run length is 3.00m and the sum of the measurable core recovered is 2.40m.

TCR=2.40m/3.00mX100=80%

Please note that TCR does not tell a lot about the quality of the rock and its likely behaviour during the engineering construction.

Core Loss/Low Core Recovery/High Core Recovery:

Core loss or low (poor) core recovery may be indicative of a weak zone (possible presence of a fault), highly fractured zone (occurrence of open joints), and hence potentially poor geotechnical conditions in rock mass, which may be essential for determining rock mass properties.

It is important and sometimes requires your best judgement to find the reason for having a low recovery or high recovery (>100%) or core loss in the drill core.

It is possible to notice two cases: sometimes the entire retrieved core does not make it into the core box (low core recovery) and sometimes it cannot be accommodated in the assigned core box (high core recovery). Low core recovery may artificially occur if there is a piece of core missing that was present when the core is drilled. Low core recovery can also be due to a drill run not being completed to the whole length of the drill barrel. Drillers usually prepare their core blocks in advance, and do not always correct for these instances. The true depth is usually corrected within the next core run, with a longer drill run following. This same situation can arise when the core breaks above the end of the core barrel as the drill rods are pulled out to retrieve the core (the core is similarly recovered in the next run). High core recovery of greater than 100% is also possible, usually resulting from one of the above scenarios, or by a misplaced core block or piece of core. In strongly jointed rocks, where the core consists of only small pieces, it can be very difficult to measure the length of each piece of core (and each joint). In such intervals of core, the highly fractured rock may take up more space in the core box than the real core length it corresponds to, and resulting in a higher percent recovery (which is actually false recovery). The length of a crushed interval should be estimated by comparing it to the total length of intact core in the interval being logged.

It should be further noted that rubble or piece of core which has dropped into the drillhole and is retrieved at the top of a core lifter is not recommended to count as recovered core and should be discarded or clearly labelled to avoid a possible error on rock mass classification. However, core lifter should be checked and replaced if such problem exists. Core which was drilled in a previous run needs to be identified by marks from the drilling or the core lifter and it may require some interpretation. Since there is a potential for such error, if in doubt, it is worth to talk to a driller. Field methodology for the determination of TCR is given below.

- Fit the core together as best as possible (use a V-shaped angle-iron for this purpose)
- For the broken zones, push the core materials so that it approximately resembles a core volume
- Measure the total length of core recovered. This includes the solid and broken zones.
- In Figure 1.1, the TCR (yellow shaded core portion) of interval B is approximately 2.40m while the indicated drill run length is 3.00m (TCR=2.4/3.0*100=80%).

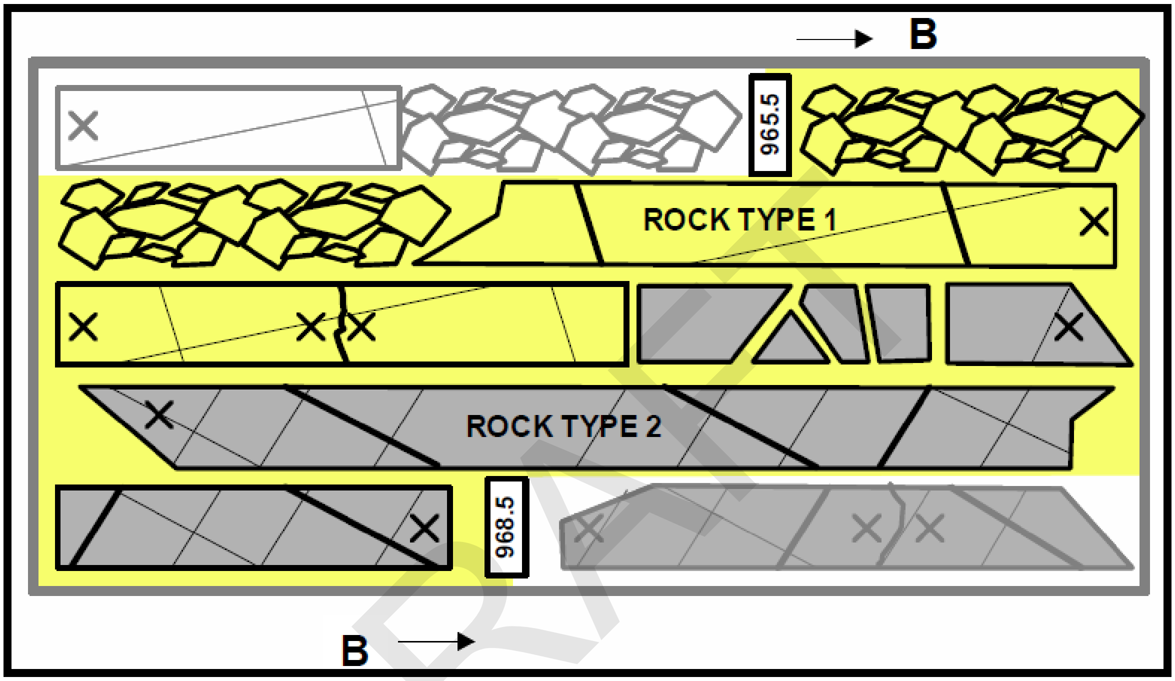


Figure 1.1: Example TCR Computation Procedure

1.3 Rock Quality Designation (RQD)

The engineering behaviour of the rock mass can be estimated from a simple parameter obtained from geotechnical core logging. RQD was defined by Deere in 1963 and was intended as a simple classification of rock masses. RQD is an improved method of logging rock core to calculate a modified core recovery percentage. It is essentially a simple measurement of the percentage of "good" rock in the rock core run (intact pieces 10cm or more in length) and has been found to have a much better correlation to the actual behaviour of the rock than the standard percentage of core recovery. Actually, RQD did not replace the traditional core recovery percentage; both are usually reported for each core run. The two percentages simply tell a lot about the quality of the rock and its likely behaviour during engineering construction. RQD is the basic parameter used in the two most widely used comprehensive rock mass classification systems i.e. Rock Mass Rating (RMR) System and Q- System.

RQD was originally defined from drill cores as follows:

The sum of the length (between natural joints) of all core pieces more than 10cm long as a percentage of the total core length.

$$\text{RQD (\%)} = \frac{\text{Length (m) of core pieces} \geq 10\text{ cm}}{\text{Total length (m) core run}} \times 100$$

As simple as RQD is, it still requires a full understanding of how to drill and how to measure and count the pieces in the core run. The minimum standards for RQD are

- Good drilling techniques
- Minimum NX (54.7mm) or NQ (47.6mm) size core
- Drilled with double-tube core barrel, generally no greater than 1.5m long for the better quality of data
- Count only pieces of core that are at least 10cm long
- Count only pieces of core that are "hard and sound"
- Consider mechanical breaks (drilling induced) as solid core (see Figure 1.7)
- Exclude Natural Rubble Zone (NRZ) such as joints (see Figure 1.4)
- Take Rubble Zone as Natural Rubble Zone if in doubt
- Consider joints along or sub-parallel to the core axis as solid core (see in Figure 1.3)
- Count only natural joints and fractures
- Log RQD in the field immediately after recovery before any deterioration

An example of an RQD core logging procedure is illustrated in Figure 1.2. Core length should be measured along the centerline of the core. Core breakage caused by drilling or handling (as evidenced by fresh rough surface) should be considered, with the pieces fitted together and counted as one piece. If in doubt, Deere recommends considering the break as natural. RQD is recorded as a measured length over the geotechnical interval (e.g. 2.4m/3.0m), and it is always be less than or equal to Total Core Recovery (TCR) i.e. RQD≤ TCR.

Fracture sub-parallel to the core axis (within approximately 10 degrees) is assigned to RQD if the core is sound and intact. It is a special case that might be encountered in measuring RQD and this method avoids biasing the RQD measurement with a single fracture parallel to the drillhole.

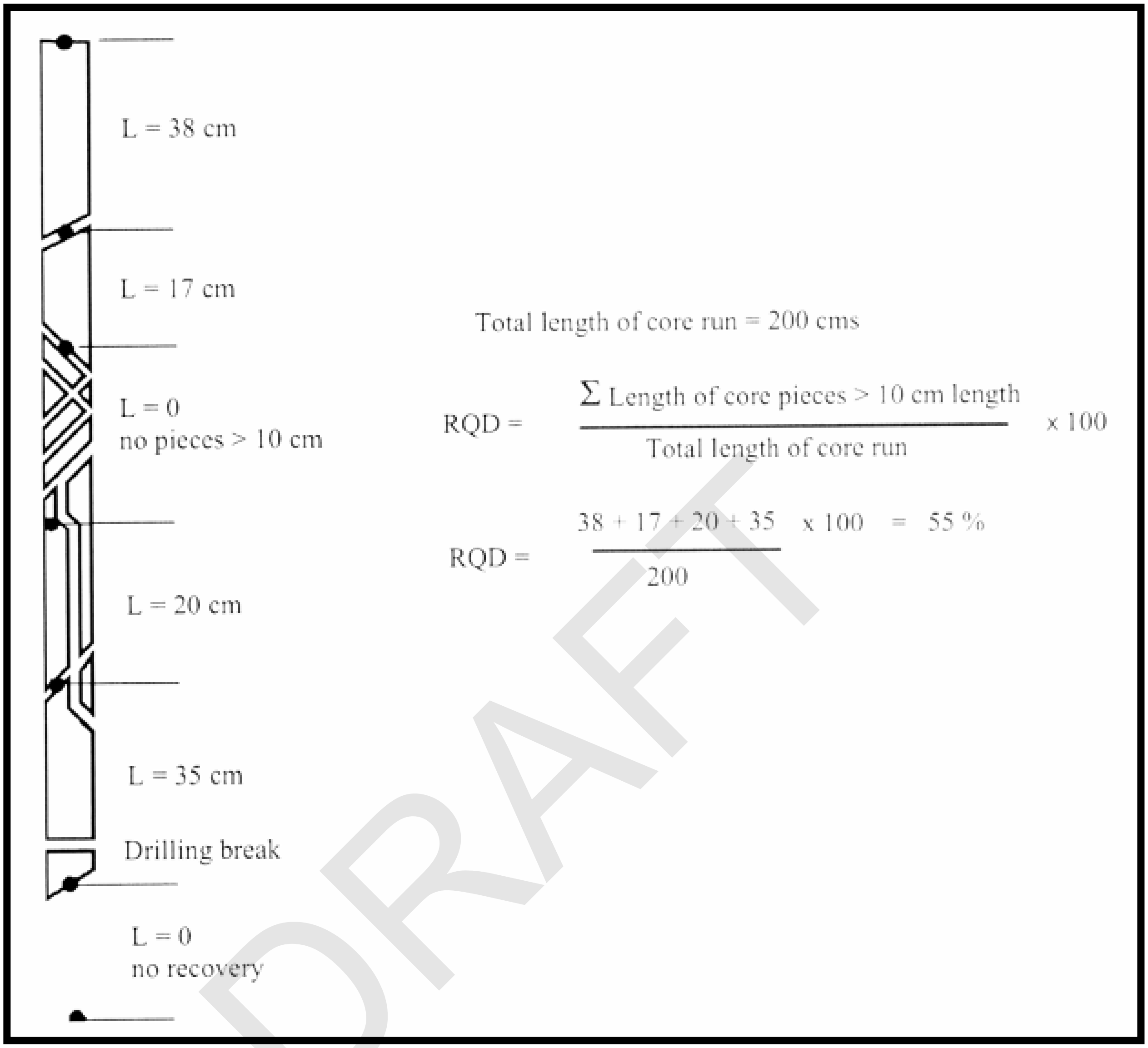


Figure 1.2: Example RQD core logging procedure (After Deere 1989)

The basic classification comparing RQD with a qualitative rock quality and description of the rock is given in Table 1.

Table 1: RQD classification system

Rock Quality	RQD (%)	Approximate Description of Rock
Excellent	90-100	Intact Rock
Good	75-90	Massive, moderately jointed
Fair	50-75	Blocky and seamy
Poor	25-50	Shattered, very blocky and seamy
Very poor	0-25	Crushed

Limitations of RQD:

- Does not account for joint orientation
- Does not account for joint continuity or persistence
- Ignores interlocking of joint blocks
- Ignores block size
- Ignores external forces like groundwater condition
- Ignores nature of joint surfaces and infilling
- Does not account for geology
- Ignores in-situ stress condition

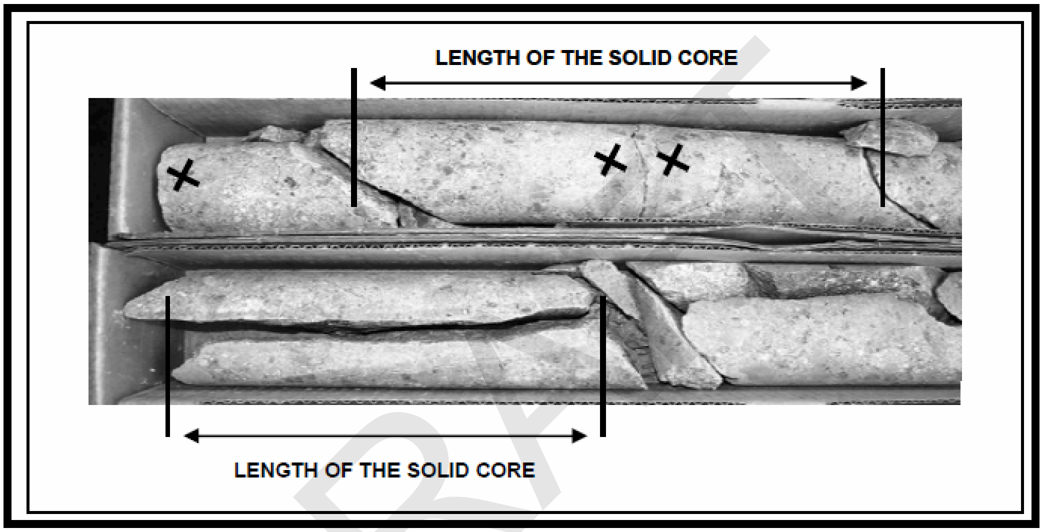


Figure 1.3: Example RQD core logging procedure with joints sub-parallel to the core axis

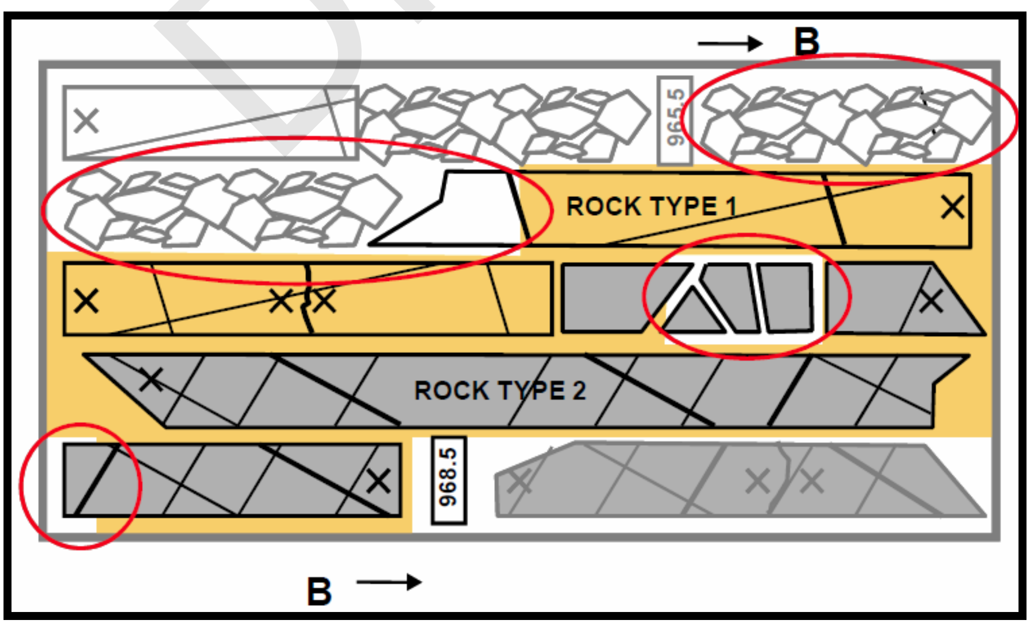


Figure 1.4: Example RQD core logging procedure in Natural Rubble Zone (circled in red excluded from RQD)

An example of core logging in poor rock with broken zones is illustrated in Figure 1.5. First of all, fragments in Domain B need to be pushed together to approximate a core volume. RQD and IRS of the domain B is zero. As it is obviously a poor zone in engineering design and construction, rock mass classification will need to be done anyway. In order to compute RMR value, the fracture frequency (FF/m) and Joint Conditions need to be estimated. As 40 FF/m generates a zero rating, this equates to 4 joints per 0.1m. So, a total of 12 “open joints’ can be considered for 1.2m core length. Joint conditions are also considered to be low.

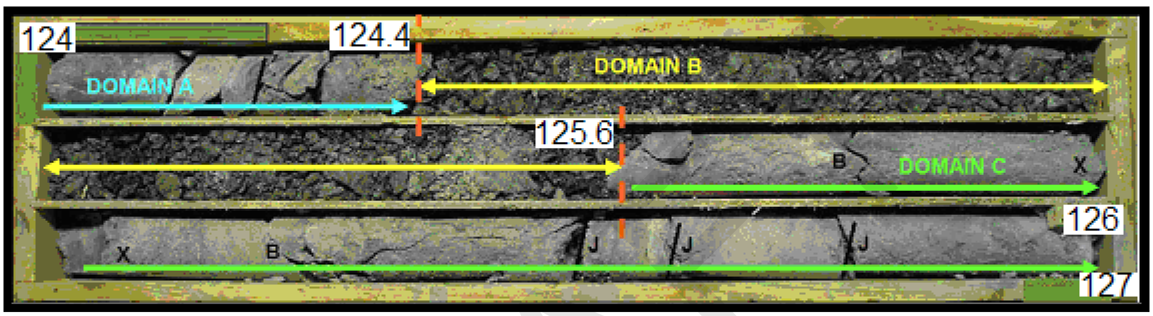
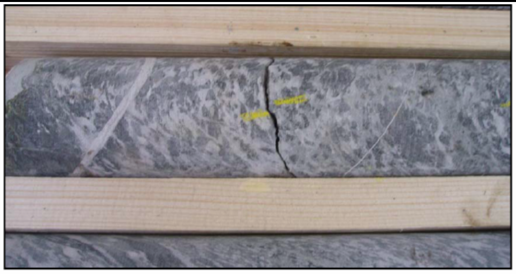


Figure 1.5: Illustration of Broken Zone

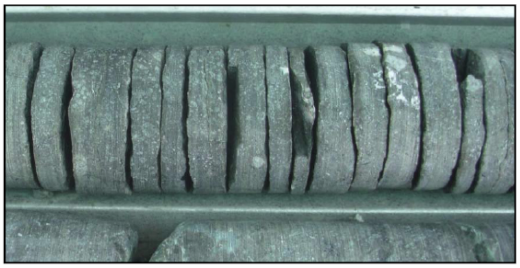
Figure 1.6 is a good example of Natural Rubble Zones (joints) experiencing in drilling program. It is suggested that all Natural Rubble Zones as well as those you are in doubt should be included. It is recommended that Rubble Zones must be noted in the geotechnical logging sheet as the major structures. 4 joints for every 10cm of Rubble Zone should be considered.


Figure 1.6: Illustration of Natural Rubble Zone (Broken Zone)

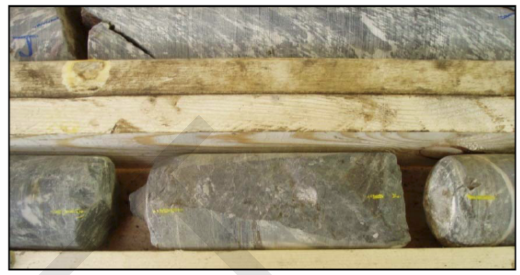


Note high angle, very fresh break indicating drill damage.

Cluster of foliation sub-parallel fractures; roughness and angularity indicate mechanical damage.



High angle “discing” is a strong indication of mechanical damage.



“Drill spin” is an obvious indication of mechanical damage.

Figure 1.7: Illustration of mechanical breaks in drill core

2 DETAIL GEOTECHNICAL DATA GATHERING

2.1 Lithology

Lithology should be simple, and general rock names should be based on field identification, existing literature, or detailed petrographic examination, as well as engineering properties. Over-classification may be distracting and unnecessary. For example, the term “granite” may be used as the rock name and conveys note to the designer than the petrographically correct term “nepheline-syenite porphyry”.

Variations in grain/particle size, texture (e.g. granular, well developed grains, dense, slaty, amorphous, vuggy, cavity, etc.), composition (detail mineralogy is normally not required), alteration, and colour are common in all rock types. As part of the lithological description of the drill cores, information and comments describing colour, weathering/alteration, grain/particle size, texture, structure such as foliation, micro defects, veining, etc. should be taken into consideration for all rock types. It is recommended to note unique features such as fossils, large crystals, inclusions, concretions, and nodules which may be used as markers for correlations and interpretations.

2.2 Fracture and Fracture Frequency

Fracture is a terminology used to describe any natural and/or artificial break in rock mass. Some of the examples of the most common fractures are joint, bedding plane separation, random fracture (which does not belong to a joint set), fault, shear, fault breccia, etc. Fracture assessment in drill core is crucial. It is also essential to understand that different types of open fractures may be encountered in the drill core. It is equally necessary to mark drill core with appropriate colour to distinguish the type of fractures. Figure 2.1 shows an example of marking drill core (it can be project or company specific).

- Artificial breaks induced by the core handling process should be marked with a yellow (**X**)
- Artificial breaks induced by the drilling process (mechanical breaks) should be marked with a yellow line (▬▬) across the break
- Cemented joints that are closed or broken open by drilling are marked with red (**CJ**).
- Natural joints that are present in the rock mass are marked with a red (**J**)

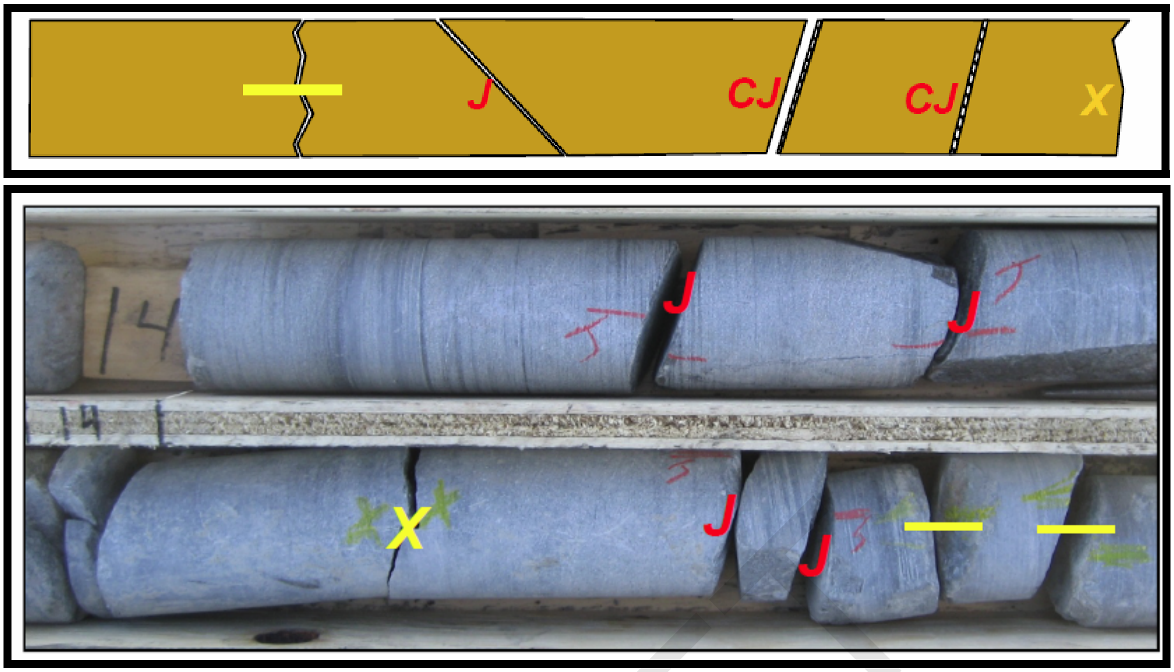


Figure 2.1: Illustration of marking drill core

<u>Cemented Joint</u>

It is often difficult to confirm whether the break is an open cemented joint or a joint. If you are in doubt, consider the break as a joint. Figure 2.2 shows an example of cemented joint in drill core. The following steps can be taken to distinguish the type of joint.

- Find a closed cemented joint in close proximity to a possible open cemented joint that was induced by drilling process
- Open the closed cemented joint with a rock pick to open the cemented joint
- Assess the appearance of the surface of this joint and compare it with the joint that was already open
- If the properties are the same, then the initial joint may be classified as a cemented joint

Cemented joint can be observed in drill core as open or closed. Each type should be considered no matter whether it is open or close. Strength of the filling (closed cemented joint only) may be determined by (hammer test) striking the drill core with a geological hammer or (drop test) dropping a section of the drill core containing a cemented joint, from waist height on the floor. Strength of filling by drop test may be categorized as below.

0- Strong (Never breaks)
1- Moderate (Sometimes breaks)
2- Weak (Always breaks)

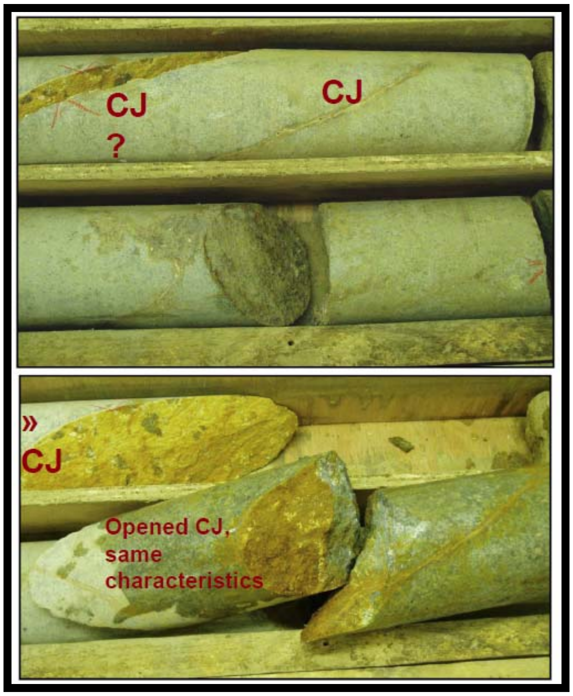


Figure 2.2: Illustration of cemented joint in drill core

Artificial Break

The following are the indications of the artificial break (see Figure 2.3).

- Freshness- surface on the break looks fresh
- Roughness- rough surface (highly foliated rock e.g. schist may cause difficulties on your judgement)
- Coating- no coating
- Alpha angle- a break perpendicular to the core axis

Figure 2.3: Illustration of artificial break in drill core

Fabric Break

It is difficult to assess between naturally open and mechanically induced breakage. If you are in doubt, mark as naturally open. Any evidence of staining (fluid flow) at surfaces may suggest the break as open prior to drilling. In this case, consider the break as a joint. In foliated or bedded rock types, it is relatively difficult to make a judgement and hence everything “in-between” these two types of breaks are suggested to mark as FABRIC.

Fracture Frequency (FF) is a count of the number of fractures (natural discontinuities as physical separations) in the drill core over a specified length (usually 1m). The number of natural fractures is divided by the length and is reported as fractures per metre.

2.3 Intact Rock Strength (IRS) - Field Strength Test

It is an empirical determination of the rock strength. The purpose of conducting this test and collecting intact rock strength is to have chance to correlate it with the laboratory testing results. The field strength of the intact drill core in the geotechnical interval can be estimated using Table 2.

- Start with the rock pick test
- Continue further tests to see whether the intact rock is weaker
- Make sure the sample size to be tested in field is approximately the same size as an average test sample to be sent to laboratory
- The rock is classified in the R0-R6 range according to Table 2
- S1 to S6 range is also used in the comments section to describe the weaker materials
- If a variation in rock strength is encountered in the logging interval (such as presence of thin fault gouge), the average rock strength of the interval is recommended to estimate taking into account the relative amounts of different material present within the interval

Estimation of strength of drill core in the field is illustrated in Figure 2.4-2.9.

Table 2: ISRM Standard- Field Strength of Rock Strength

Index Abrv.	Description	Field Test	Approximate Range Uniaxial Compressive Strength (MPa)
S1	Very Soft Clay	Easily penetrated several inches by fist	< 0.025
S2	Soft Clay	Easily penetrated several inches by thumb	0.025 - 0.05
S3	Firm Clay	Penetrated several inches by thumb with mod. effort	0.05 - 0.10
S4	Stiff Clay	Indented with thumb, but penetrated with great effort	0.10 - 0.25
S5	Very Stiff Clay	Readily indented with thumbnail	0.25 - 0.50
S6	Hard Clay	Indented with difficulty with thumbnail	> 0.50
R0	Extremely Weak	Indented by Thumbnail	0.25 - 1.0
R1	Very Weak	Crumbles under firm blow of geologic hammer pick, peeled by pocket knife	1.0 - 5.0
R2	Weak	Shallow indentation under firm blow of pick end of geologic hammer	5.0 - 25
R3	Medium Strong	Fractured with single firm blow of geologic hammer	25-50
R4	Strong	Requires more than one blow of hammer to fracture	50 - 100
R5	Very Strong	Requires many blows of hammer to fracture	100 - 250
R6	Extremely Strong	Can only be chipped with strong blows of hammer	> 250

Source: Brown, 1981, "Rock Characterization Testing and Monitoring: ISRM Suggested Methods", International Society of Rock Mechanics

Figure 2.4: Rock pick test in drill core

Figure 2.5: Estimation of Field Strength of drill core

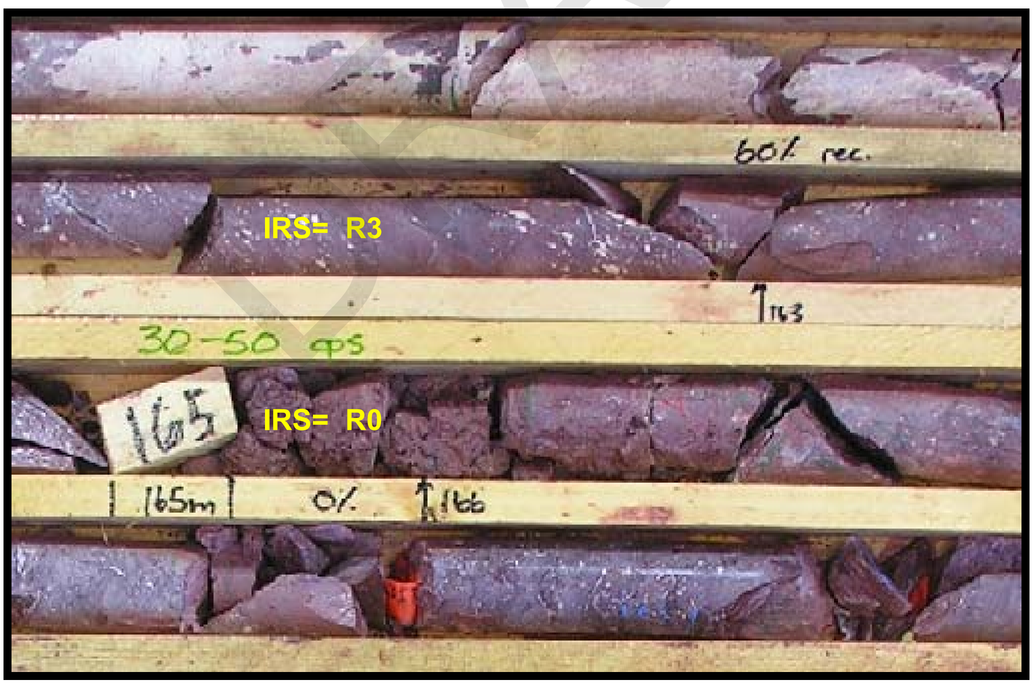


Figure 2.6: Estimation of Field Strength of drill core

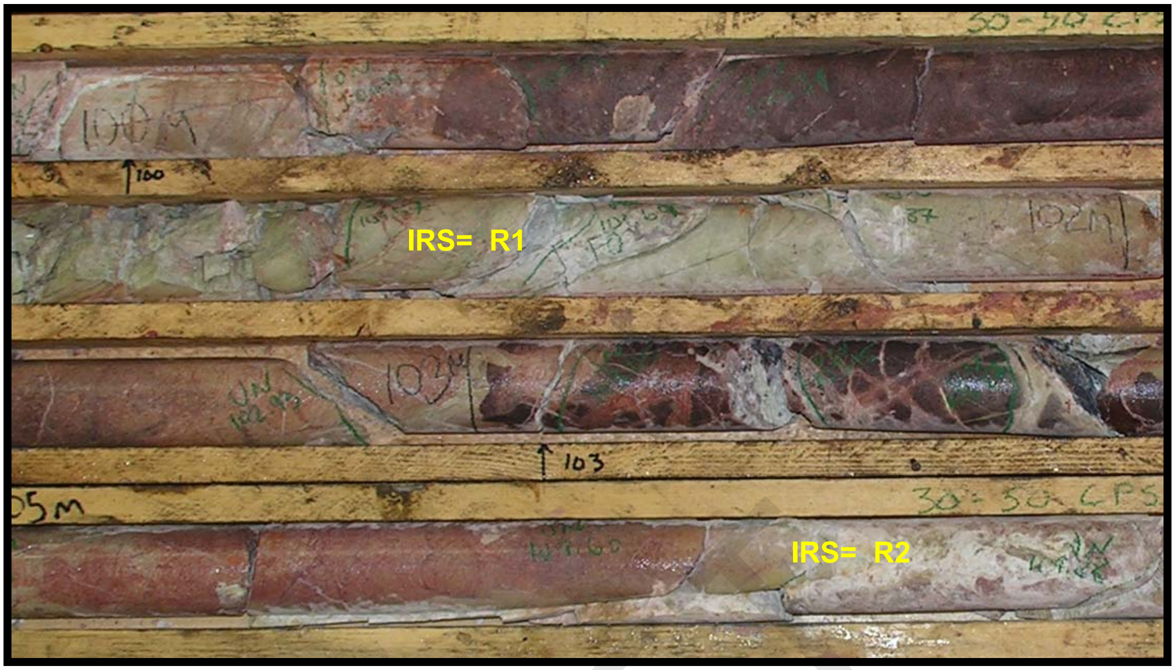


Figure 2.7: Estimation of Field Strength of drill core

Figure 2.8: Estimation of Field Strength of drill core

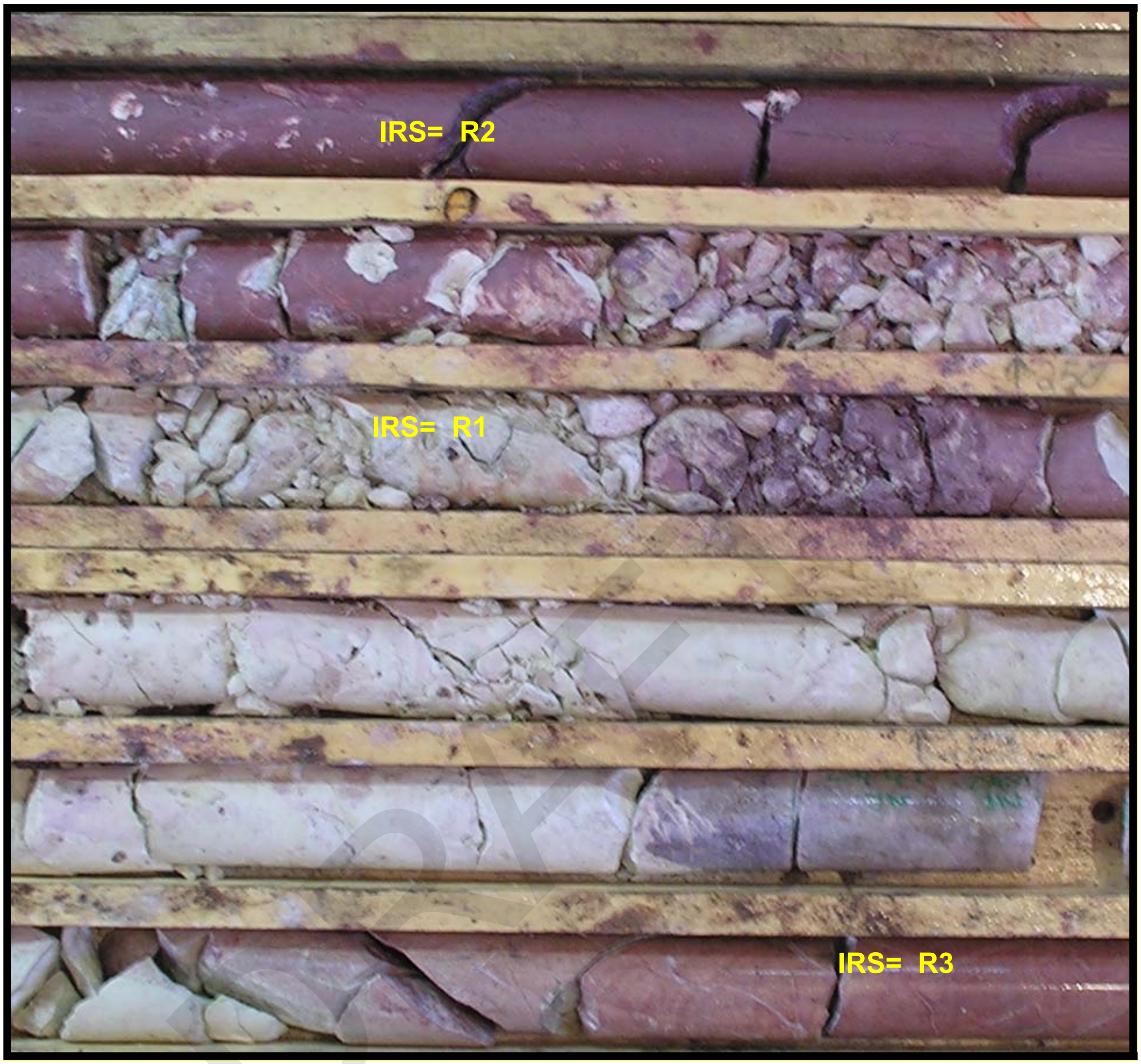


Figure 2.9: Estimation of Field Strength of drill core

2.4 Weathering

Weathering does not correlate directly with specific geotechnical properties used for many rock mass classifications. However, weathering is important because it may be the primary criterion for determining depth of excavation, cut slope design, method and ease of excavation, and use of excavated materials. Weathering influences the major engineering parameters such as porosity, compressibility, shear and compressive strengths, density, absorption, etc.

In general, weathering is indicated visually by changes in colour and texture of the body of the rock, colour and condition of the fracture filings and surfaces as well as physical properties such as hardness.

Weathering is to be reported using descriptors presented in Table 3. This table simply

Table 3: Weathering Classification Chart

Term	Symbol	Description	Discoloration Extent	Fracture Condition	Surface Characteristics
Fresh	W1	No visible sign of rock material weathering.	None	Closed or Discoloured	Unchanged
Slightly Weathered	W2	Discoloration indicates weathering of rock material on discontinuity surfaces. Less than 5% of rock mass altered.	<20% of fracture spacing on both sides of fracture	Discoloured, may contain thin filling	Partial discoloration
Moderately Weathered	W3	Less than 50% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones.	>20% of fracture spacing on both sides of fracture	Discoloured, may contain thick filling	Partial to complete discoloration, not friable except poorly cemented rocks
Highly Weathered	W4	More than 50% of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones.	Throughout	Filled with alteration minerals	Friable and possibly pitted
Completely Weathered	W5	100% of rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	Throughout	Filled with alteration minerals	Resembles soil
Residual Soil	W6	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	Throughout	N/A	Resembles soil

Source: Brown, 1981, "Rock Characterization Testing and Monitoring: ISRM Suggested Methods", International Society of Rock Mechanics attempts to classify degradation of the rock material instead of differentiating chemical disintegration (decomposition) and mechanical desegregation as agents of alteration. This is crucial, as degradation of the rock mass generally impacts the strength and geotechnical character of the rock. It is also recommended that site-specific conditions such as fracture openness, infill, and degree and depth of penetration of oxidation from fracture surfaces should be identified and described.

2.5 Alteration

Rock alteration simply means changing the mineralogy of the rock. The old minerals are replaced by new ones due to a change in the conditions. These could be changes in temperature, pressure, or chemical conditions or any combination of these. Chemical alteration effects are distinct from chemical decomposition and mechanical degradation (weathering), such as hydrothermal alteration, may not fit into the horizontal suite of weathering categories presented in Table 3. Oxides may or may not be present. Many of the general characteristics may not change, but the degree of discolouration and oxidation in the body of the rock and on fracture surfaces could be very different. Appropriate degree of alteration may be assigned such as none, low, medium or strong alteration. Alteration products, depths of alteration, and minerals should also be described.

Alteration is site-specific, may be either deleterious or beneficial, and may affect some rock units and not others at a particular site. For those situations where the alteration does not relate well to the weathering categories, Table 3 should be disregarded. At Kiggavik site, hydrothermal alteration is believed to be common, which is a change in the mineralogy as a result of interaction of the rock with hot water fluids, called "hydrothermal fluids". Hydrothermal fluids cause hydrothermal alteration of rocks by passing hot water fluids through the rocks and changing their composition by adding or removing or redistributing components.

Hydrothermal fluids may also circulate along fractures and faults. A well-developed fracture system may serve as an excellent host rock. Veins form where the fluids flow through larger, open space fractures and precipitate mineralization along the walls of the fracture, eventually filling it completely. Fault zones are excellent places for fluids to circulate and precipitate mineralization. Faulting may develop breccia and gouge, which is often a good candidate for replacement style mineralization. The form of mineralization and alteration associated with faults is highly variable, and may include massive to fine-grained, networks of vein-lets, and occasionally vuggy textures in some breccias.

The most common type of alteration at Kiggavik site includes, but not limited to the following.

- Hematization
- Chloritization
- Silicification
- Limonitization
- Argillization
- Sericitic alteration

Hematization

Red Rock Alteration is known as hematization. It occurs due to oxidation process i.e. simply the formation of any type of oxide mineral. The most common ones to form are hematite and limonite (iron oxides), but many different types can form, depending on the metals which are present. Sulphide minerals often weather easily because they are susceptible to oxidation and replacement by iron oxides. Oxides form most easily in the surface or near surface environment, where oxygen from the atmosphere is more readily available. The temperature range for oxidation is variable. It can occur at surface or atmospheric conditions, or it can occur as a result of having low to moderate fluid temperatures.

Chloritization

Chloritic alteration turns rocks green, because the new minerals formed are green. These minerals include chlorite, actinolite and epidote. They usually form from the decomposition of Fe-Mg-bearing minerals, such as biotite, amphibole or pyroxene, although they can also replace feldspar. Propylitic alteration occurs at relatively low temperatures. Propylitic alteration will generally form in a distal setting relative to other alteration types.

Silicification

Silicification is the addition of secondary silica (SiO_2). Silicification is one of the most common types of alteration, and it occurs in many different styles. One of the most common styles is called “silica flooding”, which results from replacement of the rock with micro-crystalline quartz (chalcedony). Greater porosity of a rock will facilitate this process. Another common style of silicification is the formation of close-spaced fractures in a network, or “stockworks”, which are filled with quartz. Silica flooding and/or stockworks are sometimes present in the wall rock along the margins of quartz veins. Silicification can occur over a wide range of temperatures.

Limonitization

Limonitization is alteration, which occurs due to the formation of limonite (hydrated iron oxides). Colour of the alteration usually yellow or orange, but may also vary from reddish brown to brownish black. Fracture is crumbly or earthy. Most of limonite is made up of geothite. Massive goethite and Limonite can be indistinguishable.

Argillization

Argillic alteration is that which introduces any one of a wide variety of clay minerals, including kaolinite, smectite and illite. Argillic alteration is generally a low temperature event, and some may occur in atmospheric conditions. The earliest signs of argillic alteration include the bleaching out of feldspars. A special subcategory of argillic alteration is "advanced argillic". This consists of kaolinite + quartz + hematite + limonite. feldspars leached and altered to sericite. The presence of this assemblage suggests low pH (highly acidic) conditions. At higher temperatures, the mineral pyrophyllite (white mica) forms in place of kaolinite.

Sericitization

Sericitic alteration alters the rock to the mineral sericite, which is a very fine-grained white mica. It typically forms by the decomposition of feldspars, so it replaces feldspar. In the field, its presence in a rock can be detected by the softness of the rock, as it is easily scratchable. It also has a rather greasy feel (when present in abundance), and its colour is white, yellowish, golden brown or greenish. Sericitic alteration implies low pH (acidic) conditions. Alteration consisting of sericite + quartz is called "phyllic" alteration.

2.6 Discontinuity

Discontinuity (D) is a collective term used for all structural breaks in geologic materials which usually have zero to low tensile strength. In most rock masses the discontinuities form planes of weakness or surfaces of separation, including foliations and bedding joints, joints, fractures, and zones of crushing or shearing. These discontinuities most commonly control the strength, deformation, and permeability of rock masses. Discontinuities may be healed.

Discontinuities comprise, but are not limited to the following.

- Joint
- Foliation
- Shear/fault
- Shear/Fault zone
- Planes of weakness

- Fracture
- Fault gouge
- Fault breccia

Identifying and recording the physical characteristics of discontinuity during core logging is the least expensive part of most geological and geotechnical investigations. An accurate and concise description of these characteristics permits interpretation in geotechnical terms directly applicable to design and construction. A general format for recording discontinuity descriptions may include, but not limited to the following.

- Type
- Orientation
- Spacing
- Continuity
- Openness (width or aperture)
- Infillings
    - Type (composition)
    - Width (thickness)
    - Alteration (weathering)
    - hardness (strength)
    - Character
- Healing
- Surfaces
    - Roughness (discontinuous, undulating/rough, undulating/smooth, undulating/slickensided, planar/rough, planar/smooth, planar/slickensided)
    - Shape (planar, curved, undulating, stepped, irregular)
    - Alteration (healed, staining/oxidation, altered, decomposed silty/sandy, disintegrating clay)
    - Strength (hardness)
- Intact field strength
- Moisture

2.6.1 Joint

Joint (J) is a fracture which is relatively planar along which there has been little or no obvious displacement parallel to the plane. In many cases, a slight amount of separation normal to the joint surface has occurred. A series of joints with similar orientation form a joint set. Joints may be open, healed, or filled; and surfaces may be striated due to minor movement. Fractures which are parallel to bedding are termed bedding joints or bedding plane joints. Those fractures parallel to metamorphic foliation are called foliation joints (FJ).

Joint set number (Jn)

The shape and size of the blocks in a rock mass depend on the joint geometry. In a given location, there will, as a rule, be a few joint directions occurring systematically, usually 2-4. Most of the joints will be more or less parallel to one of these main directions and such parallel joints are called a joint set. In order to get an impression of the joint pattern, the orientation of a number of joints can be measured and plotted onto a stereonet (see Figure 2.10). The different joint directions will then occur as concentrations in the stereonet diagram.

A joint set is defined as parallel joints occurring systematically with a characteristic spacing. Random joints are joints that do not occur systematically and do not generally take part in forming blocks. When the joint is several metres, systematically occurring joints may also be considered as random if they are rather unimportant for the stability. Joint set number is one of the important parameters in the rock mass classification system (Q-System) and gives the degree of jointing or block size when coupled with RQD.

RQD/Jn= Degree of Jointing (or block size)

For example, one joint set corresponds to one distinct fracture orientation (such as bedding or foliation), which would have a Jn of 2, and two joint sets indicate that two distinct fracture orientations are present, which would have a Jn of 4. Jn value for rubble zone and gouge intervals should be recorded as 20. Table 4 presents the parameter values for Jn according to the different number of joint sets.

Table 4: Ratings for Joint Set Number (Jn)

	Joint Set Number	J_n
A	Massive, no or few joints	0.5-1.0
B	One joint set	2
C	One joint set plus random joints	3
D	Two joint sets	4
E	Two joint sets plus random joints	6
F	Three joint sets	9
G	Three joint sets plus random joints	12
H	Four or more joint sets, random heavily jointed "sugar cube", *etc.*	15
J	Crushed rock, earthlike	20

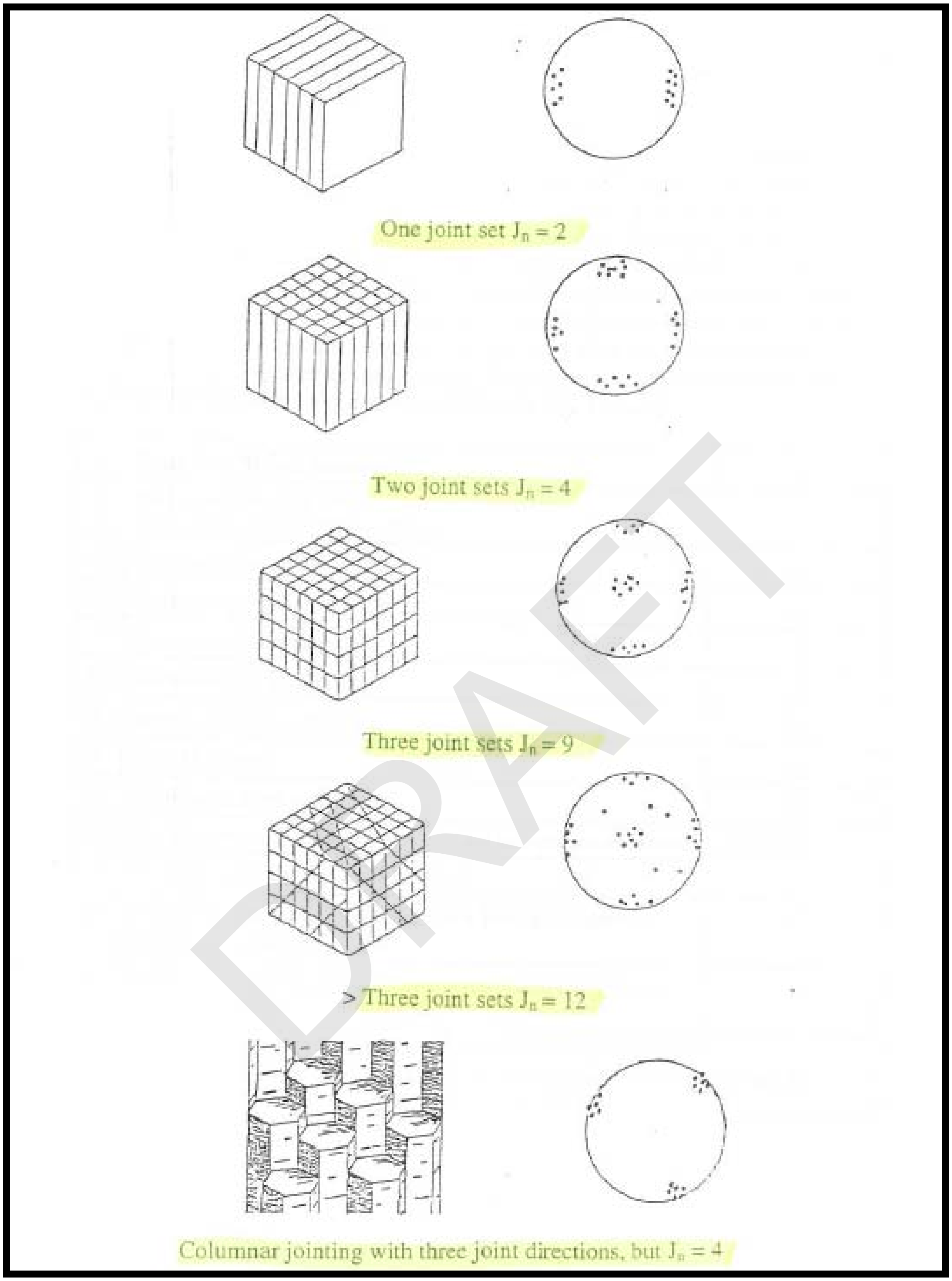


Figure 2.10: Different joint patterns shown as block diagrams and stereonet diagrams

Joint Roughness number (Jr)

Joint friction is dependent on the character of the joint walls, if they are undulating, planar, rough or smooth. The joint roughness number describes these conditions. The description is based on the roughness in two scales: small scale roughness and large scale roughness. The term "rough-smooth" refer to small structures in a scale of centimetres or millimetres. Such small scale roughness can be felt and evaluated by running a finger along the joint walls. Large scale roughness in the decimetre to metre scale is termed "planar-undulating (eventually stepped)", which can be evaluated by placing a ruler along the joint wall; undulations and their amplitudes will then easily be observed. By means of such considerations the Jr value can be estimated from the Table 5. Shape and roughness of joint walls are presented in Figure 2.11a, Figure 2.11b, and Figure 2.11c.

Jr describes the small scale geometry of the joint surfaces, and is a function of joint shape and roughness. An exception to the shape/roughness correlation to Jr is when the joint is considered to be infilled. In these cases, Jr has an assigned value of 1.

Table 5: Rating for Joint Roughness Number (Jr)

	Joint Roughness Number	J_r
a) *b)*	*Rock-wall contact, and* *Rock-wall contact before 10 cm*	
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating,	2
D	Slickensided, undulating	1.5
E	Rough, irregular, planar	1.5
F	Smooth, planar	1
G	Slickensided, planar	0.5
Note:	Description refers to small scale features and intermediate scale features, in that order.	
c)	*No rock-wall contact when sheared*	
H	Zone containing clay minerals thick enough to prevent rock-wall contact	1
J	Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1

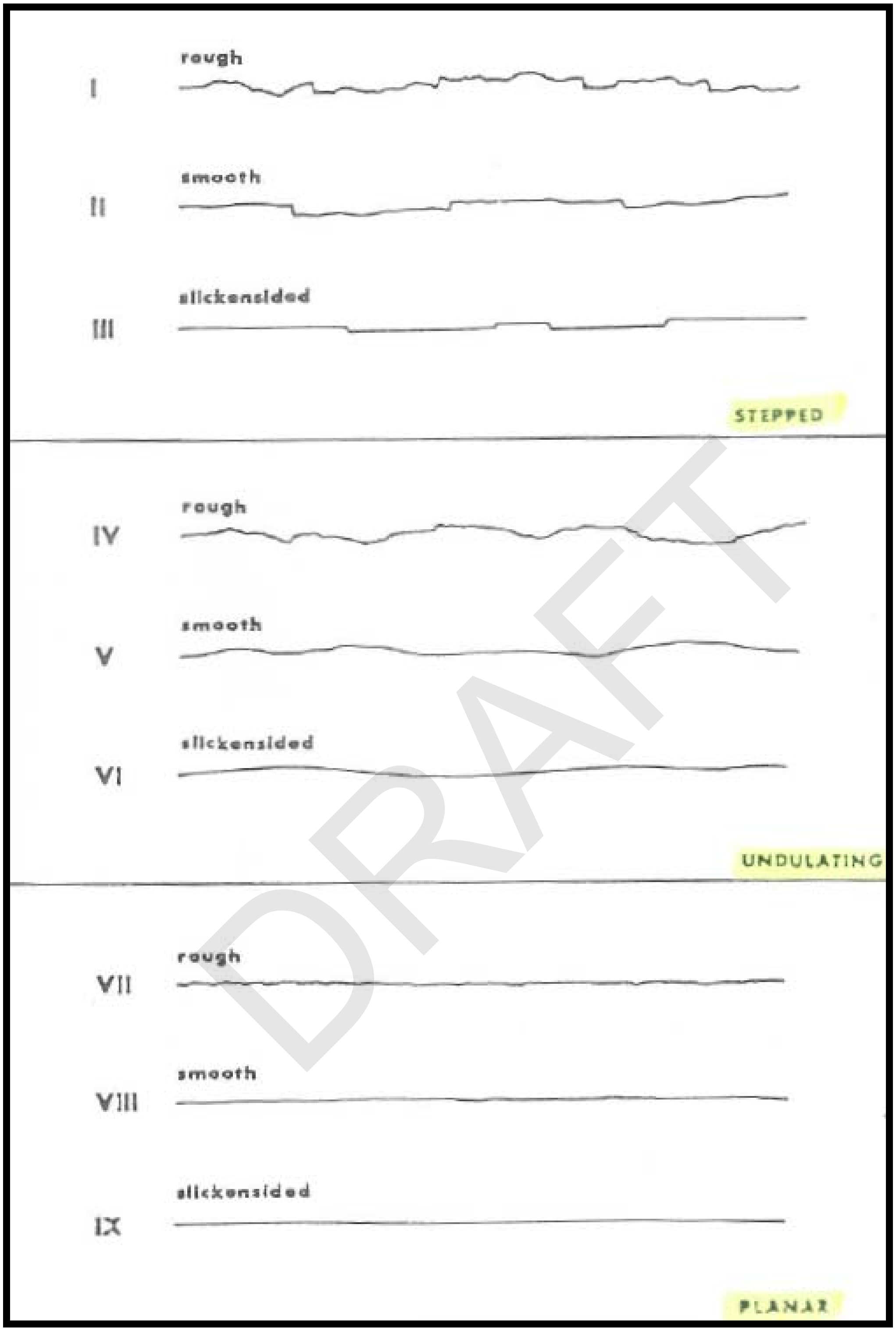


Figure 2.11a: Shape and roughness of the joint walls

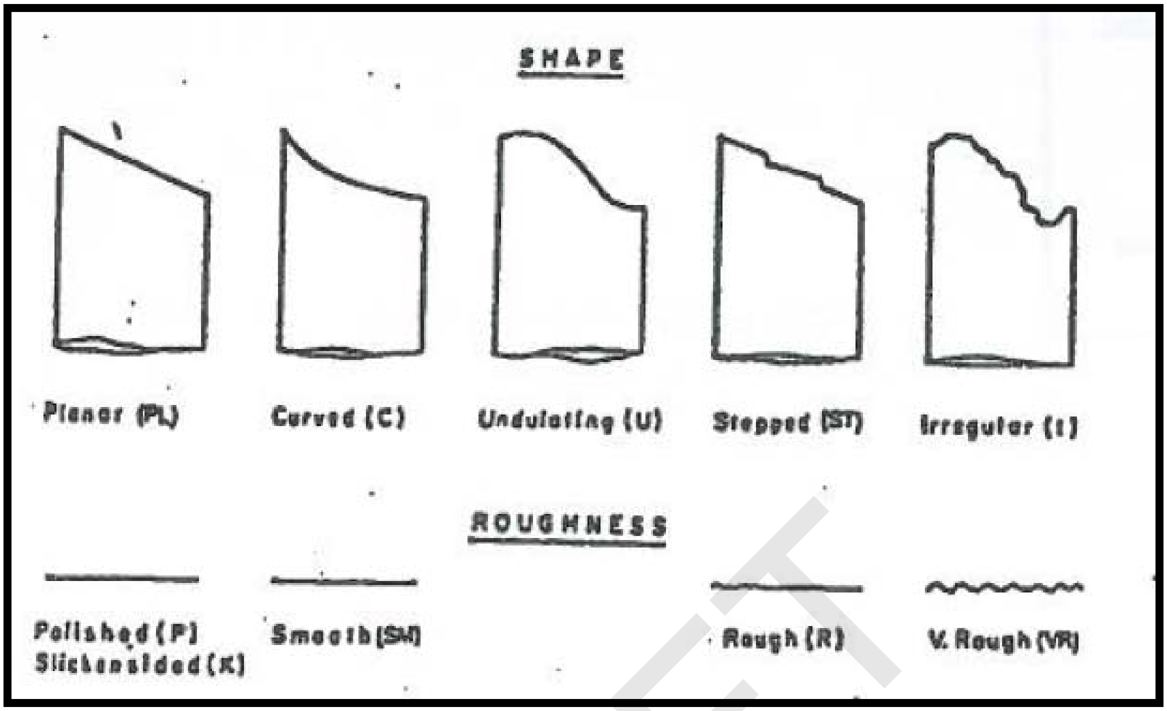


Figure 2.11b: Shape and roughness of the joint walls

Figure 2.11c: Roughness of the joint walls

Joint Alteration number (Ja)

In addition to the joint roughness the joint infill will be significant for joint friction. When considering infill, two things are important: its mineral composition and its thickness. Joint Alteration Number describes the alteration and infill along the fracture surface. Ja value are divided into two categories based on whether the fracture is infilled or not, and they also distinguish between fractures which are filled with alteration minerals such as clay, and those which are not. Within each of the two categories the Ja are evaluated based on the mineral content of the infill according to the Table 6. For example, fractures which are stained only would have a Ja value of 1, but fractures with a clay coating would have a Ja of 4. Filled fractures lower the rock mass strength, thus reducing stability of engineering construction and mining excavations.

As Ja value is depended on the type of mineral contents, a laboratory analysis of the mineral infill may there be necessary. For example, swelling clay will be most unfavourable for stability of any engineering structures and mining excavations.

Ja value may be closely associated with the groundwater condition, because water may play a significant role when swelling clay is abundant. Since only small quantity of water is sufficient to cause swelling of the clay minerals a high Ja value is usually assigned independent of the water situation where swelling clay is abundant.

Joint Infilling

Describing the presence of absence of coatings or fillings and distinguishing between types, alteration, weathering, and strength and hardness of the infilling material may be as significant as joint spatial relationships or planarity. Strength and permeability of the joints may be affected by infillings. Description of the joint coatings and infillings are site specific, but must address the following considerations.

- Infilling type (composition)
- Infilling width (thickness)
- Infilling hardness (strength)
- Infilling/coating character
- Healing (?)
- Weathering or alteration (?)

Infilling composition can be, but not limited to chlorite, clay, sericite, biotite, calcite, gypsum, hematite, quartz, talc, silt, sand, and gravel. Infilling thickness may range from clean (no film coating) to thick (> 30mm). Infilling strength may be described from very soft to extremely hard. Infilling/coating character may be described as clean, staining only, slightly altered, continuous coating, discontinuous coating and continuous infill >2mm.

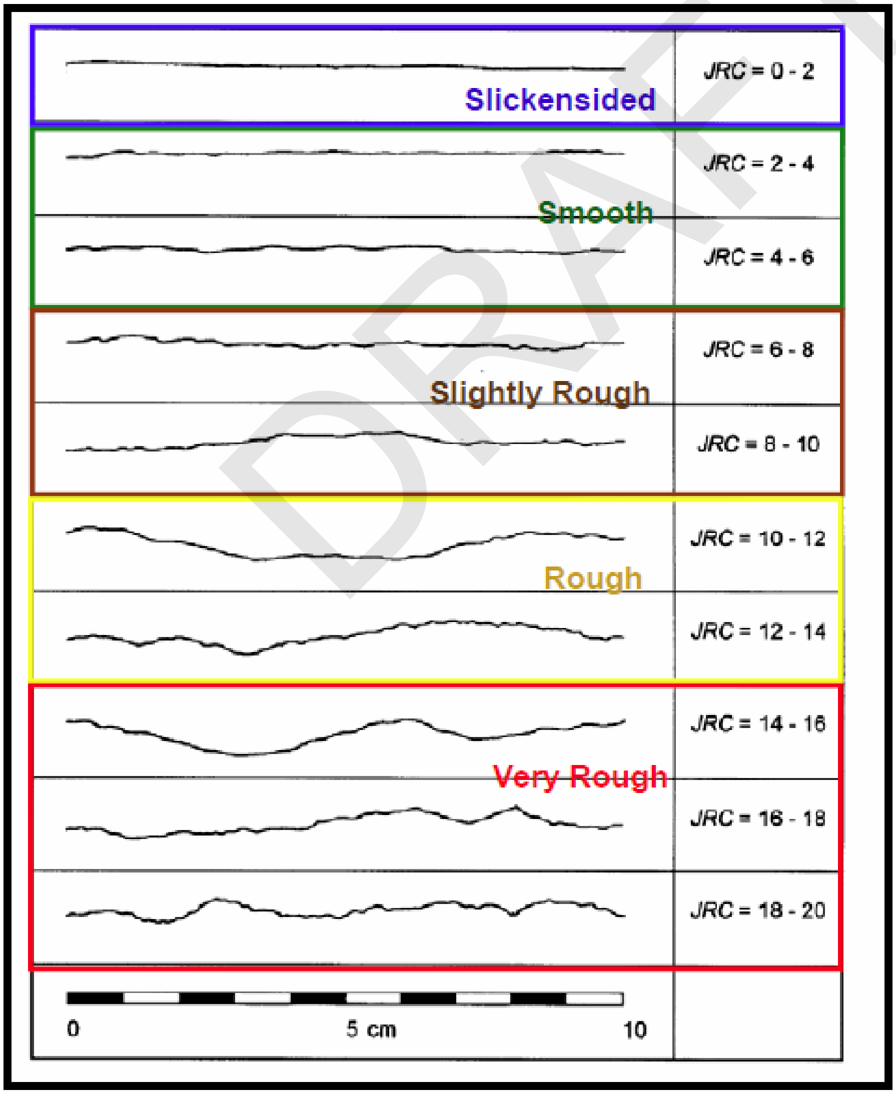
Table 6: Joint Alteration Number (Ja) Determination

	Joint Alteration Number	ϕ_r approx	J_a
a)	*Rock-wall contact (no mineral fillings, only coatings)*		
A	Tightly healed, hard, non-softening, impermeable filling, *i.e.*, quartz or epidote.		0.75
B	Unaltered joint walls, surface staining only.	25-35°	1
C	Slightly altered joint walls. Non-softening mineral coatings; sandy particles, clay-free disintegrated rock, *etc.*	25-30°	2
D	Silty or sandy clay coatings, small clay fraction (non-softening).	20-25°	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.	8-16°	4
b)	*Rock-wall contact before 10 cm shear (thin mineral fillings)*		
F	Sandy particles, clay-free disintegrated rock, *etc.*	25-30°	4
G	Strongly over-consolidated, non-softening, clay mineral fillings (continuous, but <5mm thickness).	16-24°	6
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, but <5mm thickness).	12-16°	8
J	Swelling-clay fillings, *i.e.*, montmorillonite (continuous, but <5mm thickness). Value of J_a depends on percent of swelling clay-size particles.	6-12°	8-12
c)	*No rock-wall contact when sheared (thick mineral fillings)*		
K	Zones or bands of disintegrated or crushed rock. Strongly over-consolidated.	6-24°	6
L	Zones or bands of clay, disintegrated or crushed rock. Medium or low over-consolidation or softening fillings.	12-16°	8
M	Zones or bands of clay, disintegrated or crushed rock. Swelling clay. J_a depends on percent of swelling clay-size particles.	6-12°	8-12
N	Thick continuous zones or bands of clay. Strongly over-consolidated.	6-122°	10
O	Thick, continuous zones or bands of clay. Medium to low over-consolidation.	16-24°	13
P	Thick, continuous zones or bands with clay. Swelling clay. J_a depends on percent of swelling clay-size particles.	12-16°	13-20

Joint Condition (Jcon)

It is one of the major parameters of RMR system. The rating ranges from 0 to 30 depending on the roughness, weathering, infill thickness and strength, and continuity. Rating for different parameters and Jcon is presented below.

Joint Condition (Jcon)	Rating
Very rough surfaces, not continuous, no separation, unweathered wall rock	30
Slightly rough surfaces, separation<1mm, slightly weathered	25
Slightly rough surfaces, separation<1mm, highly weathered	20
Slickensided surfaces OR gouge<5mm, separation 1-5mm, continuous	10
Soft gouge>5mm thick OR separation>5mm, continuous	0



2.6.2 Bedding/Foliation

These features give the rock anisotropic properties or represent potential failure surfaces. Continuity and thickness of these features influence rock mass properties and cannot always be tested in the laboratory. The descriptions of these features by identifying their thickness are presented below.

Bedding and foliation descriptors:

Description	Bedding Plane Spacing
Very thickly bedded	> 2 m
Thickly bedded	0.6 m to 2 m
Medium bedded	0.2 m to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 mm to 60 mm
Laminated	6 mm to 20 mm
Thinly laminated	< 6mm

2.6.3 Shear/Fault

Shear is a structural break where differential movements has occurred along a surface or zone of failure; characterized by polished surfaces, striations, slickensides, gouge, breccia, mylonite, or any combination of these.

Fault may be defined as a shear with significant continuity, which can be correlated between observation locations or regions. The designation of fault or fault zone is a site specific determination.

2.6.4 Shear/Fault Zone

It may be defined as a band of parallel or sub-parallel fault or shear planes. The zone may consist of gouge, breccia, or many fault or shear planes with fractured and crushed rock units between the shears or faults or any combination. In the literature, many fault zones may be simply referred to as faults.

2.6.5 Fracture

Fracture is a terminology that is used to describe any natural breaks in geologic material, excluding shear or shear zones. Joint (bedding or foliation joints), bedding plane separation due to stress relief or slaking, random fracture (not belonging to a joint set, often with rough, highly irregular, and non-planar surfaces along which there has been no obvious displacement) are a few examples of fracture.

2.6.6 Fault Gouge

Fault gouge is observed as pulverized material derived from crushing or grinding of rock by shearing, or the subsequent decomposition or alteration. Gouge may be soft, uncemented, cemented, indurated (hard), or mineralized. Breccia may range from sand-size to large boulder-size fragments, usually within a matrix of fault gouge. Breccia may also consist exclusively of mineral grains.

2.6.7 Fault Breccia

Fault breccia may be observed as cemented or uncemented, predominantly angular (may be platy, rounded, or contorted) and commonly slickenslided rock fragments resulting from the crushing or shattering of rock materials during shear displacement.

2.6.8 Vein

A discontinuity infilled by another mineral is known as vein and it should be recorded. For example, if a vein is infilled by quartz or druzy quartz, it should be noted in the log.

2.6.9 Core Loss and Broken Core Zone

Significant core loss and broken core interval may indicate the possible presence of discontinuity. First of all, it is essential to make sure the reason of core loss and broken core zone and necessary comments are recommended to include in the logs. It is also recommended to record with depth from/to on the core box to assist in photo logging. Then it should be verified with other available information if any. Please see section 1.2 for further detail.

Core loss with depth interval and percentage should be recorded in the geotechnical logs. Broken core zone should be logged and recorded as separate geotechnical domain when exceeding 10% of the run length. When broken core zone is less than 10% of the drill run length, these should be recorded and measured as a distinct fracture in the log, and given an infill thickness (width). However, these criteria may be site or project specific.

When any difficulty encountered to identify measurable features within broken zone, this should not prevent recording the additional geotechnical properties in the log. This can be performed observing and assessing the surfaces of rock fragments within the broken zone.

2.7 Core Orientation

Alpha angle and Beta angle should be measured for each logged discontinuity. Figures 2.14a-c illustrates core orientation measurement in drill core.

2.7.1 Alpha angle (α)

Alpha angle is the apparent acute angle between the core axis and the long axis of the ellipse (apparent dip of the discontinuity). It ranges from 0 to 90º. The carpenter angle is used to measure the maximum dip (α) of the discontinuity relative to the core axis.

2.7.2 Beta Angle (β)

Beta angle is the angle between a reference (orientation) line along the core (marked by the driller at the bottom of the core with the help of Reflex ACE Tool) and the bottom of the ellipse in a clockwise direction on the down dip end of the discontinuity (0-360º). The plastic graduated strip is place with the "0" on the 'orientation line' of the same piece of drill core and the tape is wrapped clockwise around the core so that the 360º point returns to the orientation line.

Reflex ACE Tool is used to mark the core orientation reference point i.e. the lowermost point on the top face of a run of core (see Figure 2.12). The 'orientation mark' along with the knowledge allows the core to be uniquely oriented in space. Figure 2.13 shows the 'orientation line' drawn by a geologist in drill core. This fully electronic core orientation system will only work for inclined drillholes, and is advertised as being accurate for drillholes with a dip as steep as 88 degrees.

Additional information on drill core orientation measurement is presented in Appendix A (source:http://www.holcombecoughlin.com/downloads/HCA_oriented_core_procedures.pdf). Please refer to Appendix B for specific details on ACT orientation tool operation. A video of Reflex ACE Training Guide (*Reflex_ACE Tool Operation.mpg*) is also available and gives an overview of ACE orientation tool operation.

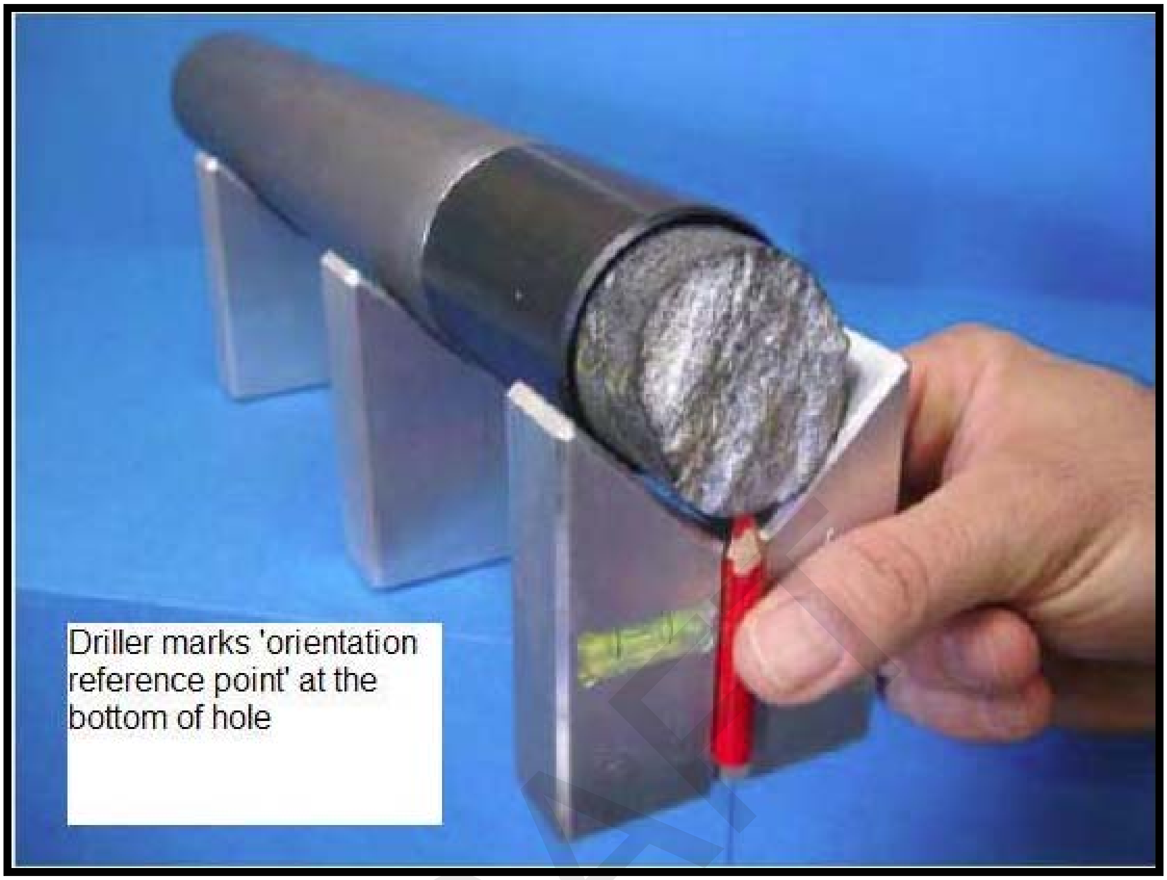


Figure 2.12: Demonstration of marking 'orientation reference point'

Figure 2.13: Core orientation line in drill core

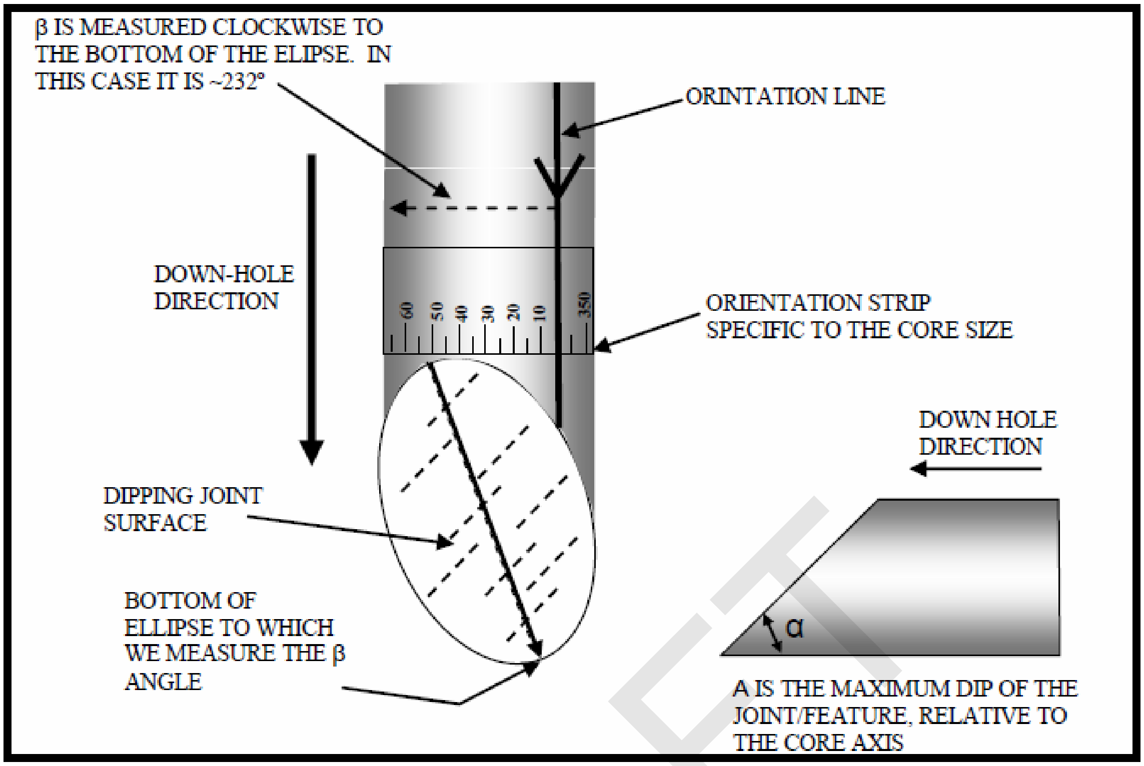


Figure 2.14a: Example core orientation measurement in drill core

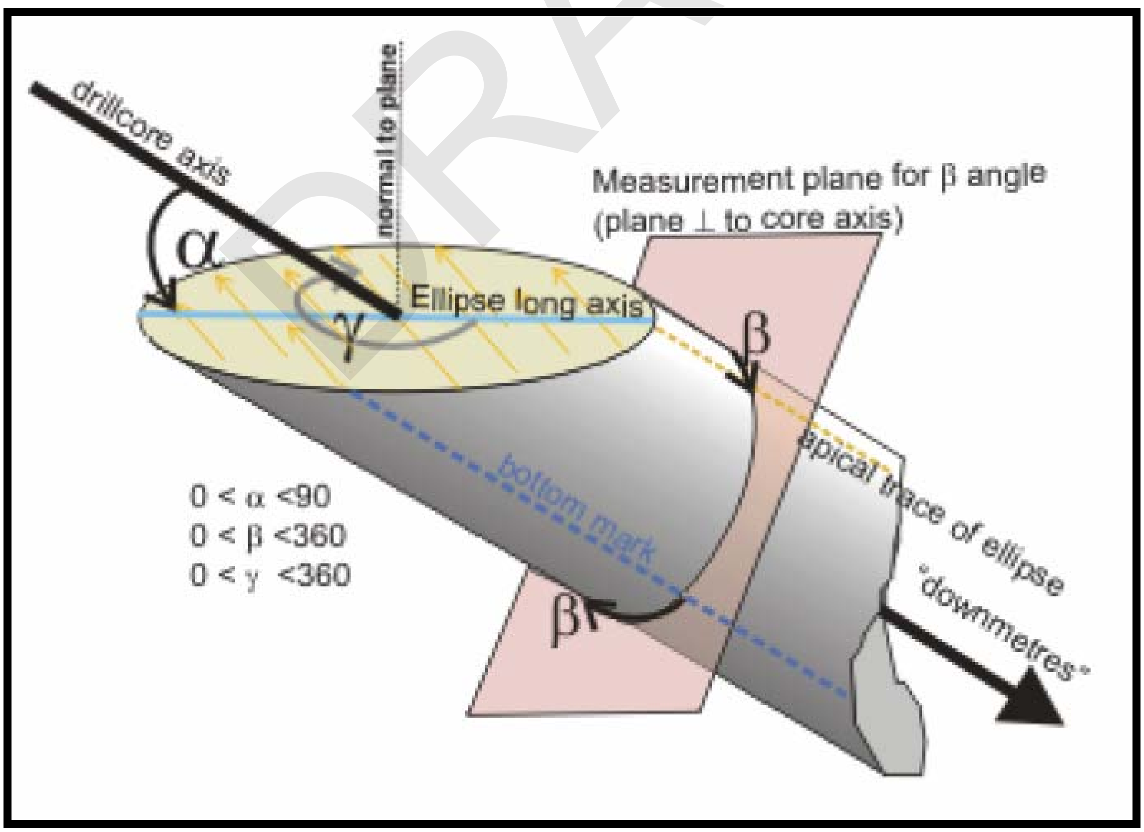


Figure 2.14b: Example core orientation measurement in drill core

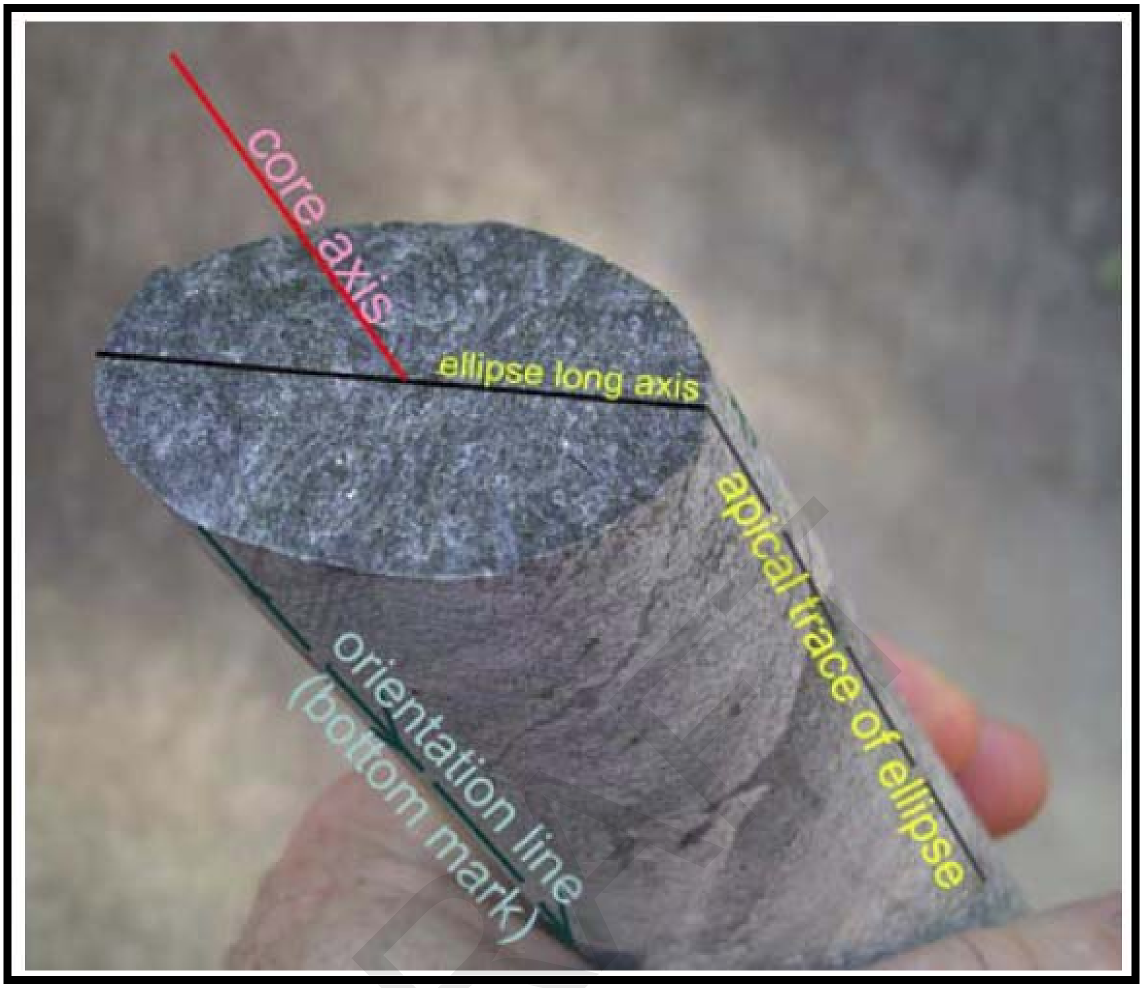


Figure 2.14c: Example core orientation measurement in drill core

2.8 Drill Core Photo

After core has been measured and labelled, photos should be taken as perpendicular to the core as possible. Make sure core is wet, depth labels and other necessary information are visible, and include a scale and colour chart. An example of core photo is shown in Figure 2.15.

Figure 2.15: Example drill core photo

3 REFERENCES

Barton N. et al., 1974. Engineering Classification of Rock Masses for the Design of Tunnel Support.

Bickel J., Kuesel T., and King E. 1997. *Tunnel Engineering Handbook*. 2nd edition.

Bieniawski, Z. T., 1989. *Engineering Rock Mass Classifications*.

Hoek, E., 2007. *Practical Rock Engineering*. 2007 edition.

HOLCOMBE COUGHLIN & Associates, 2008. *Oriented Drillcore: Measurement and Calculation Procedures for Structural and Exploration Geologists.*

Johnson, R. and De Graff J., 1994. *Engineering Geology.*

Kirkaldie, L. (editor), 1987. *Rock Classification Systems for Engineering Purposes-Special Technical Publication (STP) 984, pp. 17-34, 59-101.*

Norwegian Geotechnical Institute (NGI), 1997. *Engineering Geology: Practical Use of the Q-Method.*

Singh, A., 1992. *Modern Geotechnical Engineering*. 3rd edition

U.S. Department of the Interior Bureau of Reclamation, 1998. *Engineering Geology Field Manual.* 2nd edition, vol. I and II.

http://reflexinstruments.com. Reflex ACT Tool Operation

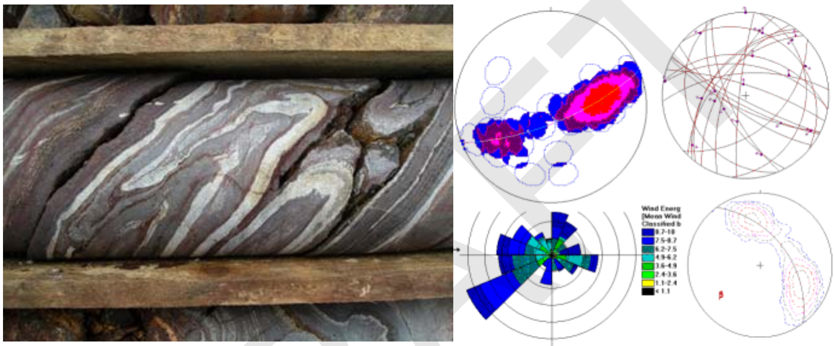
Appendix A
Additional Information on Drill Core Orientation Measurement

HOLCOMBE COUGHLIN & ASSOCIATES

CONSULTANTS IN STRUCTURAL GEOLOGY & EXPLORATION

HTTP://www.holcombecoughlin.com/

ORIENTED DRILLCORE: MEASUREMENT AND CALCULATION PROCEDURES FOR STRUCTURAL AND EXPLORATION GEOLOGISTS



CONTENTS

RodHolcombe

DRILLCORE ORIENTATION TYPES

Unoriented drillcore

During core drilling, runs of core (commonly ~ 3 metres long) are extracted from a core barrel at a time. The extraction process rotates the core randomly, so that once the core is laid out in core boxes its original orientation is lost, although the orientation of the core axis is generally known. Various down-hole surveying techniques are available for this, and the common usage of 3-D modelling software has lead to holes being generally very well surveyed.

Oriented drillcore

Various mechanical methods are available during drilling to mark the lowermost point on the top face of a run of core. As the process generally uses gravity to find the lowermost point, the process is generally only feasible in holes with an appreciable plunge. The orientation mark, along with knowledge allows the core to be uniquely oriented in space.

Orientation line on core. The barbs point 'down-hole' – that is away from the collar, even if the hole is directed upwards from underground.

'**Oriented**' core has an 'orientation mark' ('OM') along the core marking either the lowermost or topmost line along an inclined drillhole (called the 'bottom mark ('BM') or 'top mark', respectively).
The orientation of structures in oriented core can be determined in two ways:

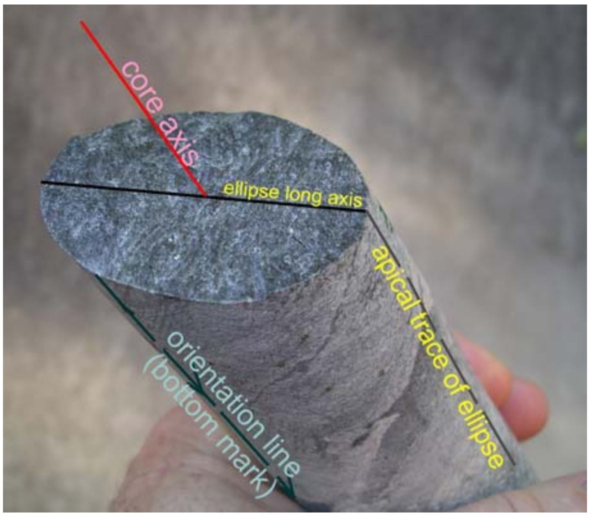
1. by reorienting the core using either a bucket of sand or a mechanical jig and measuring the structures as you would in outcrop;
2. by measuring several critical angles on the core and then using either software or stereographic projection to calculate the true geological orientation. The bulk of this document concerns these measurement and plotting procedures.

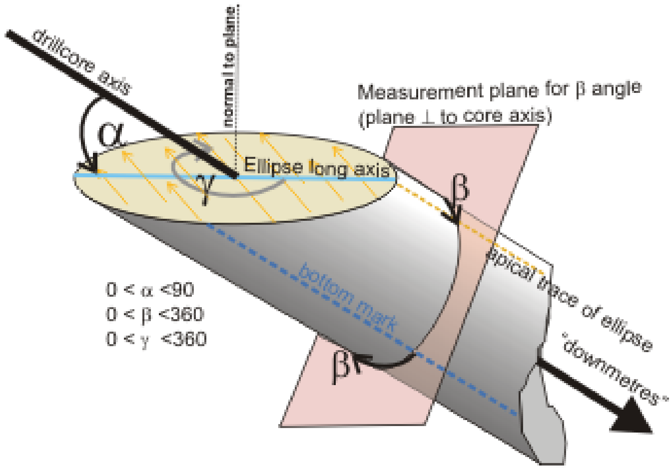
Partially oriented drillcore

In nothing else was known about the orientation of a planar bedding surface (for example) visible in unoriented core, it would require three differently oriented drill holes to solve the geometrical problem to determine the orientation of the bedding planes. However, if we know something else about the plane, such as its **general** dip, or **general** strike direction then we would only need two drill holes. If, however, we can be specific about one or other of these directions then we may only need a single drill hole to solve the orientation problem.
'**Partially oriented**' core is core in which a local reference plane whose orientation is well known (such as bedding, cleavage, etc) can be recognised. Only partial knowledge of the orientation of this reference plane need be known (e.g. dip direction/strike, or even just the local fold axis) in order to solve the orientation of the unknown plane.

Drillcore angle conventions

Various conventions are used to reference angles in oriented or partially oriented drill core.





Software, such as **GeoCalculator** (http://www.holcombe.net.au/software/) can be used to convert angles measured from such core into geographical structural readings.

All planes intersecting drill core have an elliptical cross-section in the core. The '**apical trace**' of this ellipse is the line subtended along the core from one end of the long axis, formed by the intersection of the plane that contains the ellipse long axis, the ellipse normal, and the core axis. Similarly, the 'apical trace' of a Line, is defined by the intersection with the core of a plane containing the core axis and parallel to the line (i.e., passing through the central axis of the core).

Measurement conventions used in the discussion and protractor templates here are:

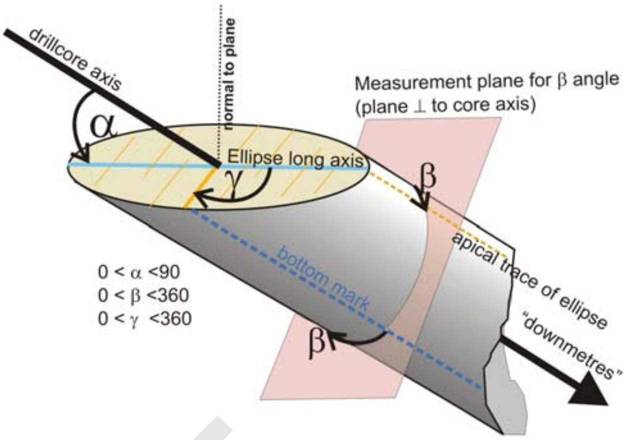
- **alpha angle:** the acute angle between the core axis and the long axis of the ellipse (0-90°).
  (Alpha angle can also refer to the angle between the core axis and a **line** that passes through the centre of the core).
- **beta angle:** the angle between a reference line along the core and the ellipse apical trace measured in a clockwise sense (0-360°). In 'oriented core', the reference line is the 'orientation mark' or 'bottom mark' and the beta angle of the apical trace of the ellipse is measured clockwise from this line.
  In 'partially oriented' core the reference line is the apical trace of the reference plane ellipse, and the beta angle is the angle between this apical trace and the apical trace of an unknown plane or line.
- **gamma angle** of a line lying within a plane: angle, measured within the plane, between the long axis of the ellipse and the line. Different conventions are in use (360° clockwise, ±180).

> While Greek letter naming conventions are universal for drillhole data, there has been inconsistency in the actual letters and usage. The alpha-beta letter conventions defined here are those currently in common usage (although an equivalent delta, alpha convention has precedence in the literature).

MEASUREMENT PROCEDURES IN ORIENTED CORE

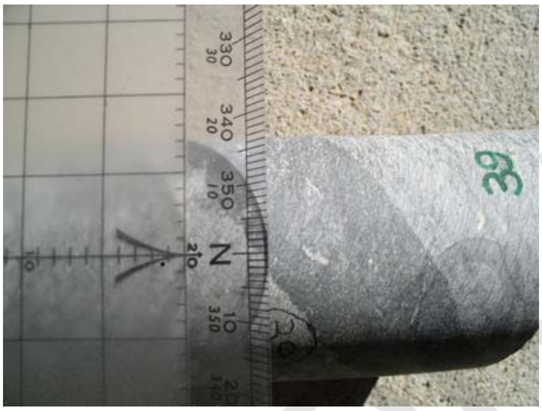
Two techniques are common for obtaining the geological orientation of structures in core:

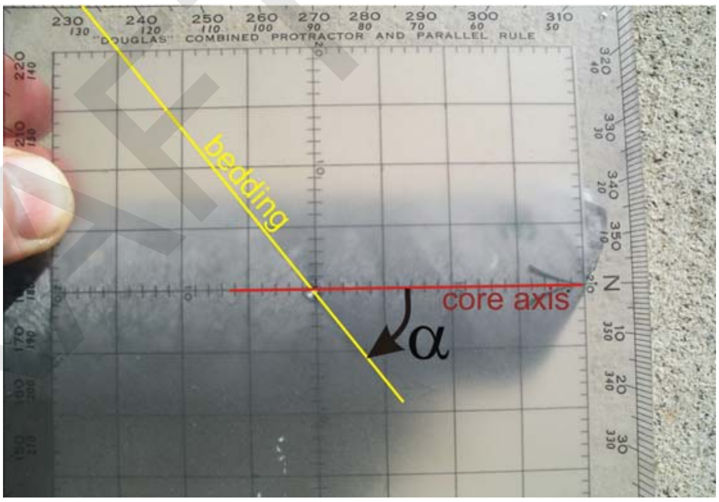
- Reorienting the core in sand or a mechanical jig and directly measuring the structures using normal field outcrop techniques. This procedure is straightforward and will not be described further;
- Alpha-beta-gamma measurement of: (i) α – angle between plane and core axis; (ii) β - angle from orientation line measured in a clockwise sense around the core; and (iii) γ - angle from ellipse long axis to a line lying in the ellipse plane.



Measurement of alpha angle

1. Direct measurement by rotating the core until the surface to be measured appears to make a maximum angle with the core axis. This procedure is the easiest method

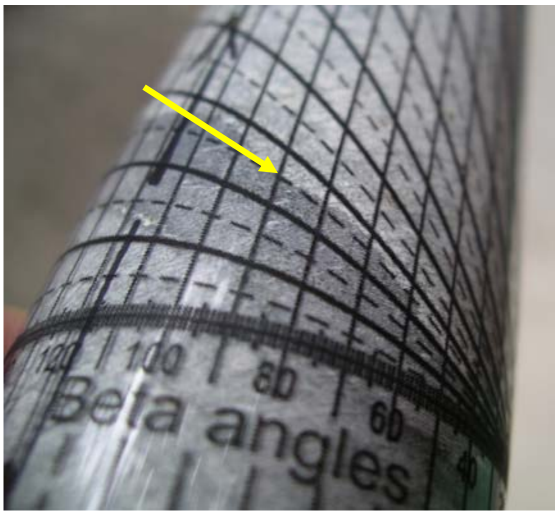




2. Using the alpha angle lines on the wrap around protractor template included with this manual printed onto transparent film.

Base of the protractor alpha angle curves aligned with the base of a bedding ellipse.

Alpha angle of 65º read from trace of bedding parallel to alpha curve.

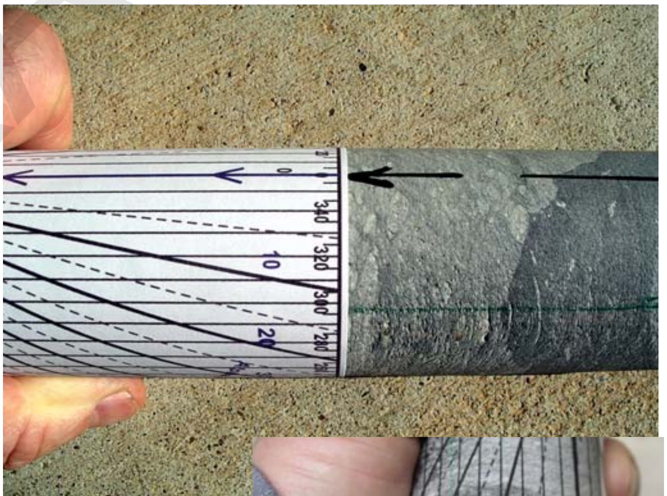


Measurement of beta angle

1. Mark the apical trace of the plane ellipse along the core.
   Two possible conventions are in use: to use the down-hole* end of the ellipse, or (less commonly) to use the up-hole end of the ellipse. If the convention used is to take the bottom of the ellipse then ensure that this line joins the lowest point of curvature of the plane in the core.

   If the surface to be measured is a fine cleavage then it is easiest to mark cleavage traces around the core in order to determine the points where the fabric is perpendicular to the core axis.

2. Hold the core such that you are looking toward the base of the hole. The beta angle is the angle measured clockwise between the orientation mark and the apical trace of the plane.
   Accurate measurement of the beta angle can be made using either specially constructed circular protractors or, more simply a flexible wrap-around protractor printed on paper or heavy transparent film such as the ones supplied with this document. (Transparent film is best). Orient the wrap-around protractor with the 0 degree line on the orientation mark and the arrows on this zero line pointing down-hole*.



   In the example the beta angle between the black orientation line (with down-hole arrows) and the apical line of bedding (green) is 295º.

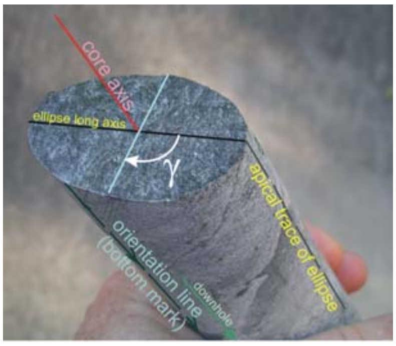
   *'***Down-hole***' means in the direction away from the start (collar) of the core, irrespective as to whether that is geographically oriented upward or downward. This is sometimes called the 'down-metres' direction.

Using a protractor printed on transparent film it is easier to see the lines drawn on the core.

Measurement of lines in core

Two procedures can be used to measure lines in oriented core:

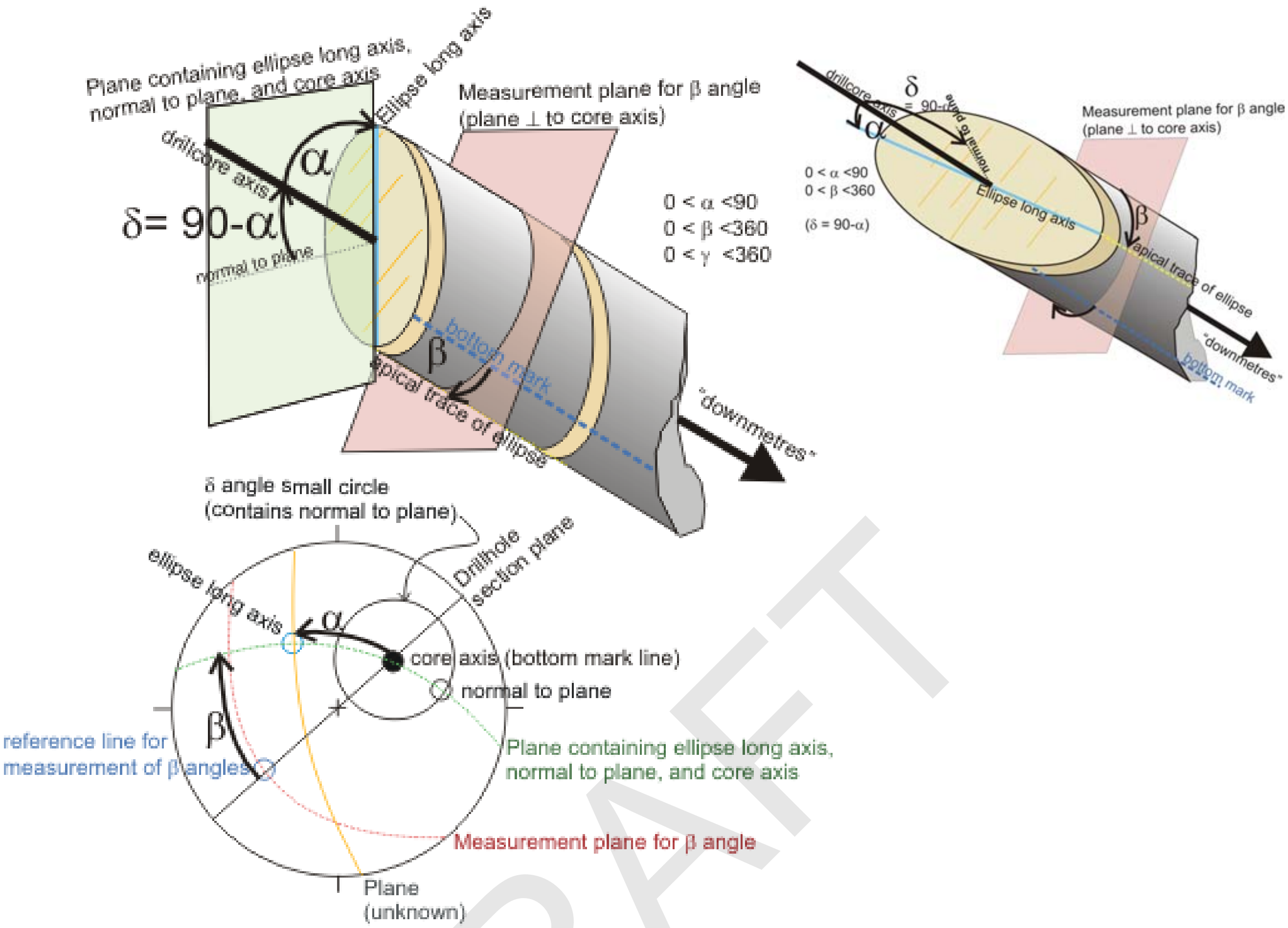
1. Treat the line as if it were the long axis of an ellipse and measure its alpha and beta angles. To do this you must subtend the line through the centre of the core and mark the apical line along the core from where the end of the subtended line. Proceed to measure the alpha and beta angles in the same way as for a plane.
2. Measure the gamma (γ) angle of the line within a plane that has already been measured. Ensure that the same conventions used to identify the ends of the ellipse long axis are used. That is, if the convention in use is to measure beta angles to the down-hole end of the ellipse, then use the down-hole end of the ellipse to measure the gamma angle.
   Two conventions are in use for the gamma angle:
   1. +ve (clockwise) or –ve angle (0-180) from the ellipse long axis;
   2. 360 clockwise angle (preferred as it is a single unambiguous number)



Measurement in partially oriented core
In partially oriented core the orientation mark is the apical trace of a reference plane whose orientation is known or partly known. The only difference to the procedures described for oriented core is that of using this reference plane apical trace from which to measure beta angles of other planes.

Although the calculations can be performed using a precise reference plane orientation, a more robust procedure is to record the alpha angle of the reference plane ellipse, and use only its dip direction to define it. The calculations then use the dip direction to calculate the most likely dip angle, and from there calculate the orientation of the other unknown planes and lines.

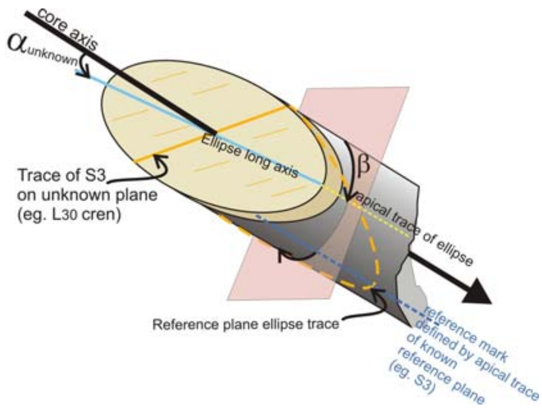
GEOMETRICAL RELATIONSHIPS IN ORIENTED CORE



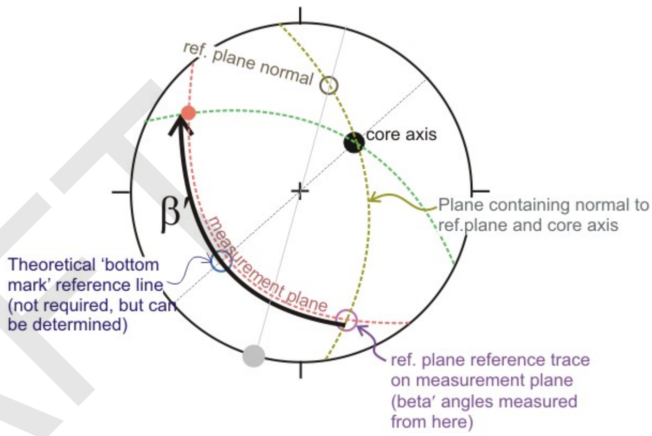
The stereo diagram shows the geometrical relationships used to solve oriented core problems. Note that the normal to the plane forming the ellipse lies somewhere along a small circle with an opening angle of 90-α (= the angle δ, in the figure above). The critical relationship is that the plane containing the long axis of the ellipse and the core axis also contains the normal to the ellipse plane. Finding this normal is the principal solution of most oriented core calculations. The stereographic projection procedure is outlined later in this manual, but in general the solutions are obtained by spreadsheets or computer packages such as our GeoCalculator (http//www.holcombe.net.au/software/).

An important construction plane is the **measurement plane**, normal to the core axis. Because beta and gamma angles commonly use 360-degree clockwise conventions, care must be taken during manual calculation to preserve the upward or downward sense of the line or ellipse axis. Although the direct stereographic solution is shown later, a visually unambiguous way to preserve these line senses, is to construct the planes relative to a vertical axis, and then rotate the axis, and the solution, into its true orientation.

GEOMETRICAL RELATIONSHIPS IN PARTIALLY ORIENTED CORE



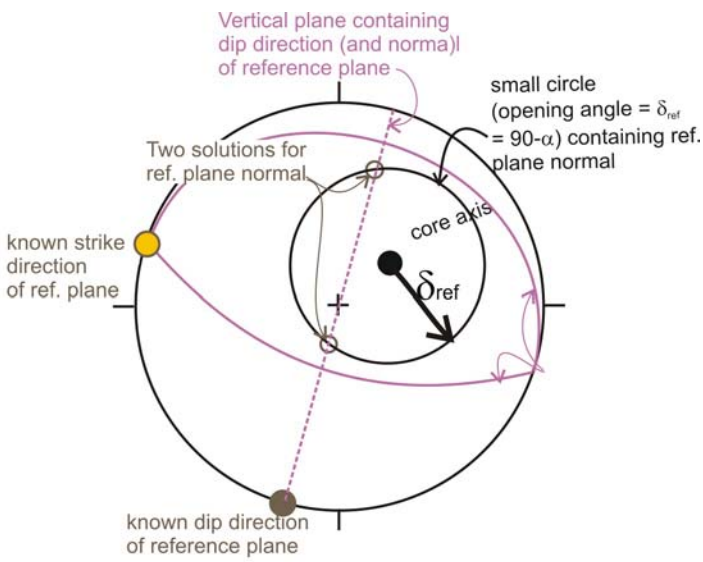
Techniques using **partially oriented** core are not generally described in the structural literature, yet they provide a powerful tool to unravel structure from old, unoriented, core, or to extract structural information from the unoriented parts of oriented core, using the orientations found in the oriented parts. The critical factor is that a specific, relatively planar, structural fabric can be recognised throughout the core. This is called the **reference plane**, and the apical trace of its ellipse is used as the 'orientation mark' for all core beta angle measurements.



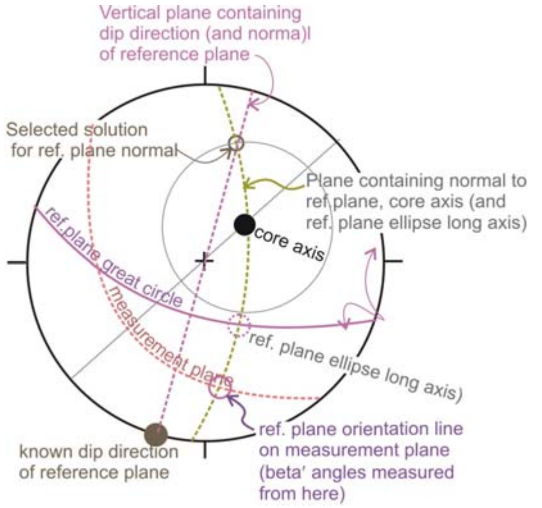
The algorithms for solving **partially oriented** core are equivalent to using the known orientation of the reference plane to back-calculate where the theoretical 'bottom mark' would have been on the core, relative to the apical trace of the reference plane ellipse long axis. Thus, the orientation of any other unknown plane can be calculated as for the 'oriented core' procedures above.

The accuracy and confidence of results using the **partially oriented** core technique relies strongly on how well the reference plane orientation is known. Precision is best when the reference plane normal is at a high angle to the core axis (i.e the alpha angle of the reference plane ellipse is large), but at very high alpha angles it is difficult to define the ellipse long axis.

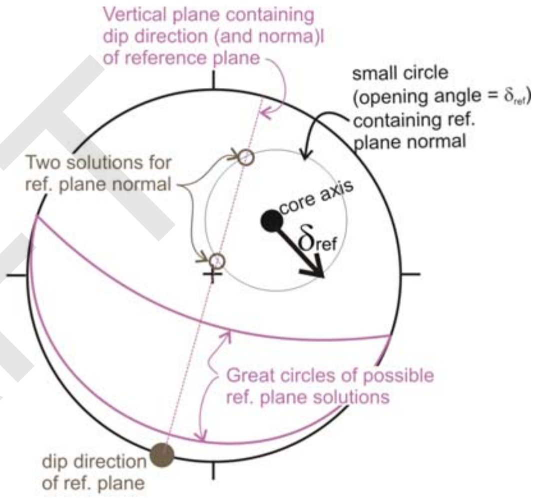
Commonly the strike or dip direction is better constrained than the actual dip of the reference plane. Or the orientation of a cylindrical (straight) fold axis might be well-constrained, although the orientation of the reference plane is quite variable. In most instances, the full orientation of the reference plane can be calculated provide that the alpha angle of the reference plane is also measured. The drawback is that, in some instances, there are two solutions for the full orientation of the reference plane and a decision must be made as to which is most likely.



The figure summarises the geometrical relationships used to determine the full orientation of a reference plane given only its dip direction. We know that the normal to the reference plane lies in the small circle with opening angle of 90-alpha (the delta angle). The critical point is to find another line in the plot that also contains the normal. One is the vertical plane containing the dip direction (i.e the plane normal to the strike). Another, not shown here, is the pi-girdle plane normal to a cylindrical fold axis. Note that, except in the tangential case, there will always be two solutions for the normal and we need to know something else about the orientation of the reference plane in order to choose the correct one. The simplest situation is to use the dip direction. For example, in the diagram above the only correct solution is the great circle with a southerly dip direction (Figure right), and from that the remainder of the geometry can be calculated as described for oriented core in a later section.



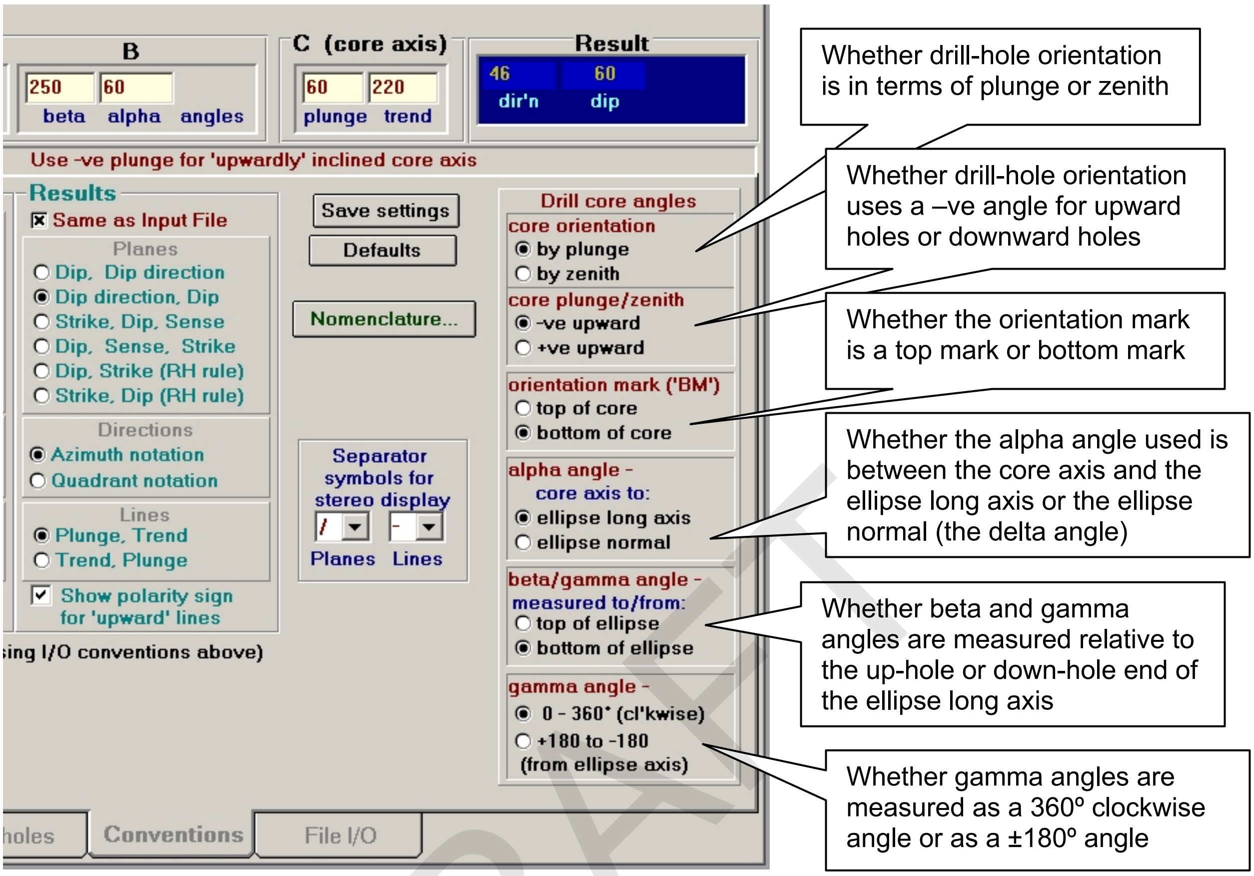
Two ambiguous solutions can occur (Fig. right); particularly when the small circle is small (the alpha angle is large). When this occurs something more needs to be known about the reference plane (such as does it have a steep or a shallow dip)? In some situations the two answers can become close enough that it is impossible to choose the correct solution. For this reason, care must be taken to examine such ambiguous solutions when using software to perform the calculations. Our package, GeoCalculator, will produce the 'best-fit' solution as the primary solution, but then set out the ambiguous alternatives for the reference plane solution, which you need to check manually.



USING GEOCALCULATOR TO PROCESS DRILLCORE DATA

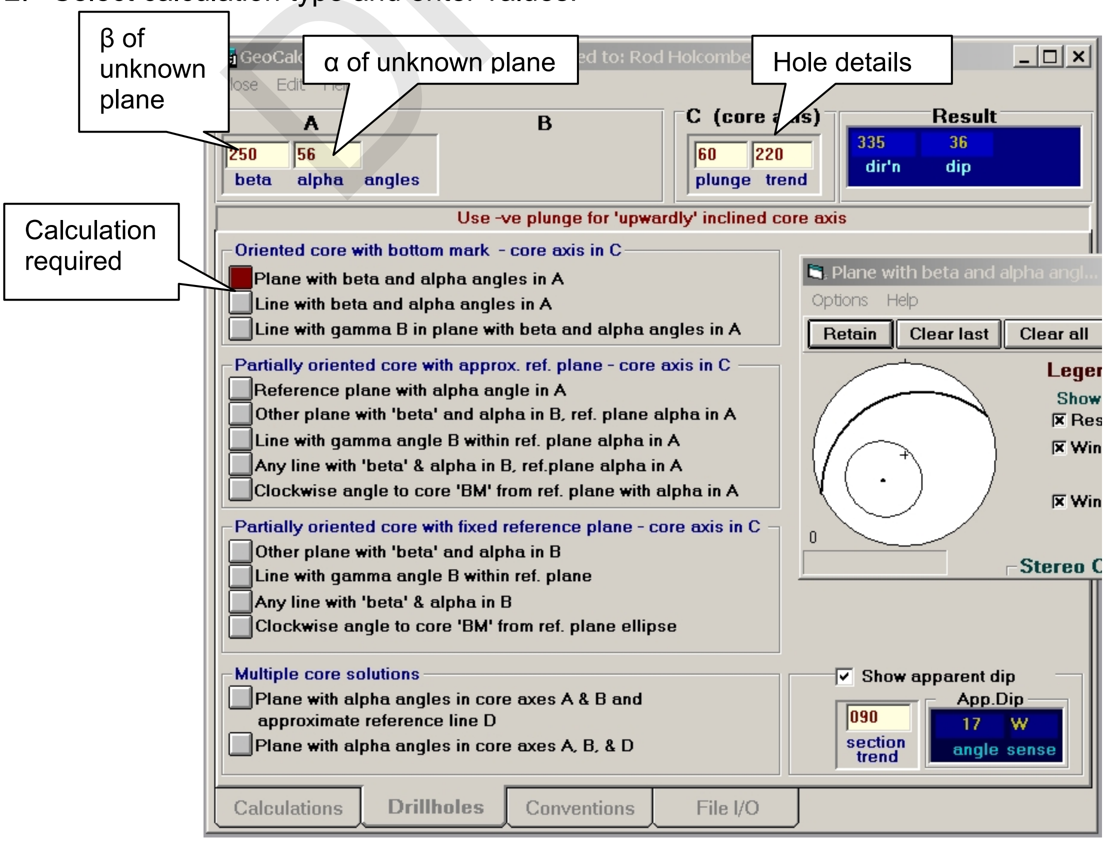
(GeoCalculator can be downloaded from: http://www.holcombe.net.au/software/)

1. Set the measurement conventions:



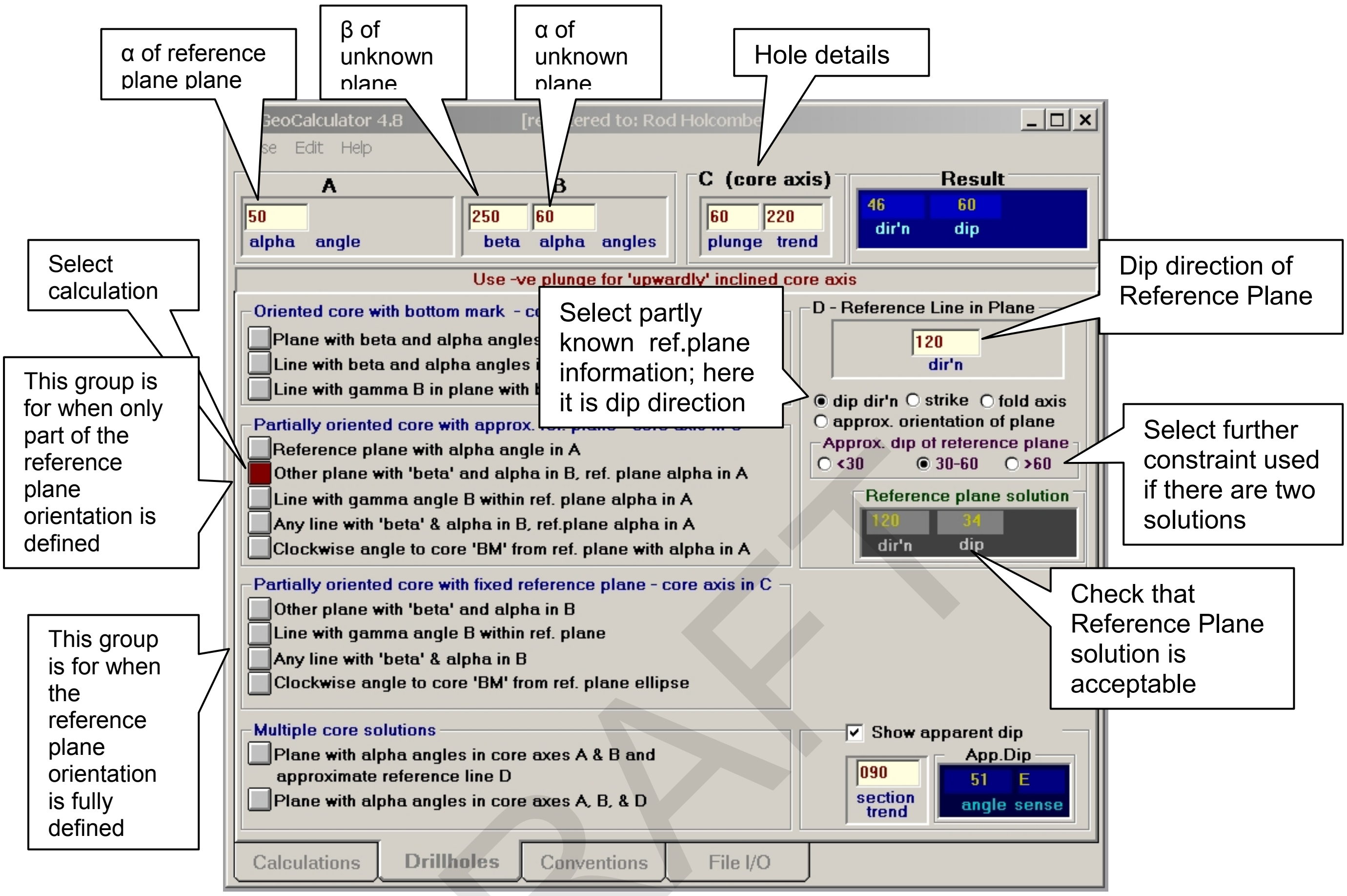
Using GeoCalculator with oriented core

2. Select calculation type and enter values:

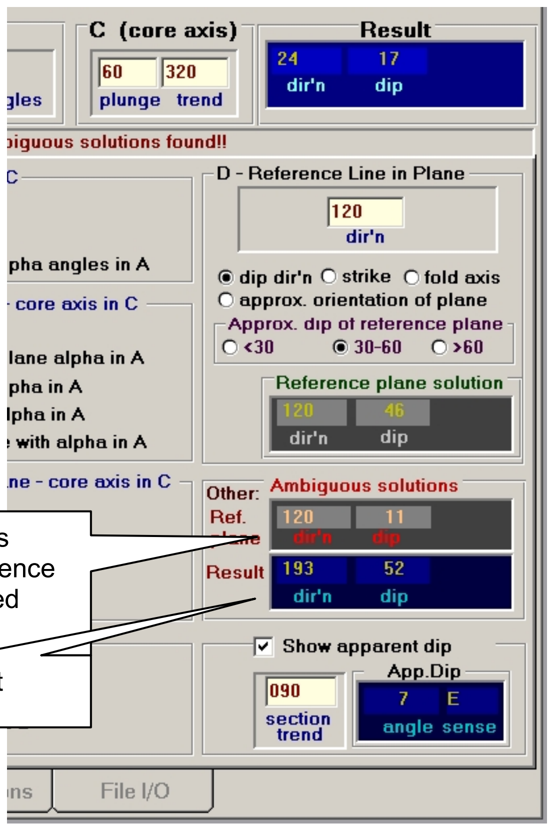


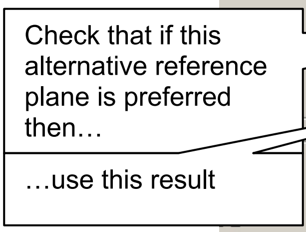
Using GeoCalculator with partially oriented core

Example: Calculating the orientation of an unknown plane given the dip direction of a known reference fabric plane and its alpha angle in the core:

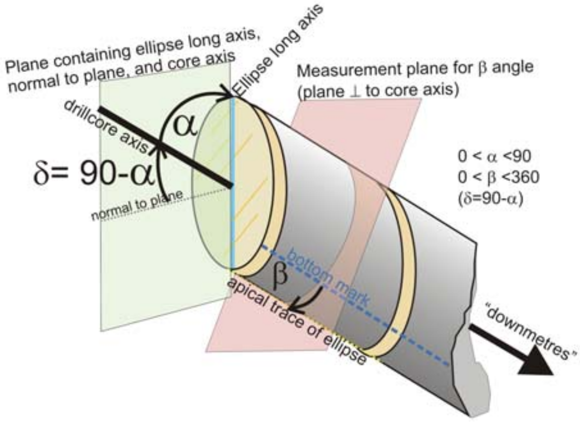


If a second ambiguous solution exists then you may need to check that the second reference plane might not have been a better solution than the one chosen.





MANUAL STEREOGRAPHIC PLOTTING OF ORIENTED CORE



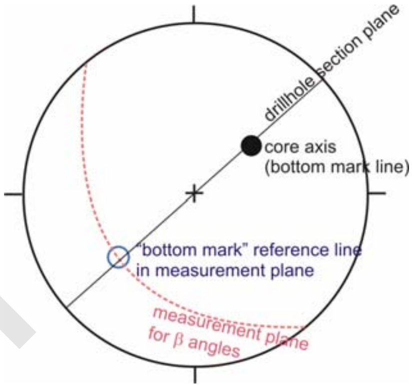
The conventions assumed for the following description are:

- Alpha – acute angle between core axis and ellipse long axis
- Beta – angle clockwise from 'bottom mark' to **bottom** of ellipse of unknown plane (looking 'downmetres').

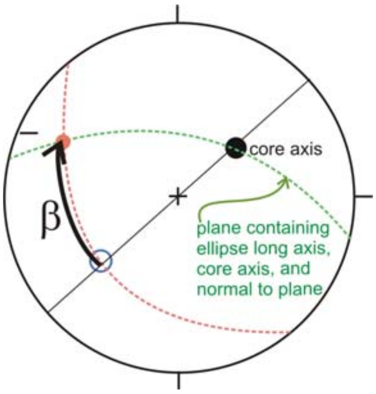
The diagram and description on this page applies specifically to a plane with a small (<90°) beta angle. See the following page for how to handle large beta angles.

Procedures

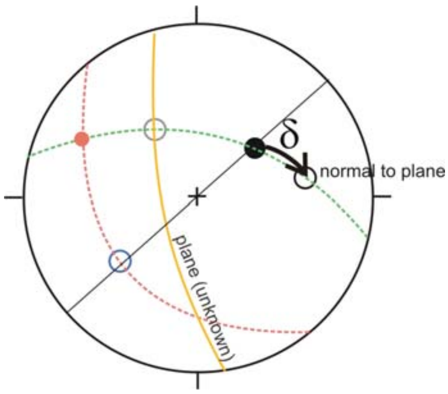
Step 1: Plot the core axis (parallel to the bottom mark). This axis is the pole (normal) to the measurement plane great circle. Draw the measurement plane great circle and mark its dip line. This is the reference line for measuring the beta angle.



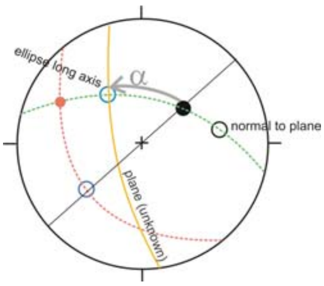
Step 2: Count the beta angle along the measurement plane great circle, clockwise from the 'bottom mark' reference line.
Draw the great circle through this point and the core axis. This is the plane that contains the normal to the ellipse (the unknown plane).
(Be careful here to preserve the sense of direction of the beta angle line – see next page)



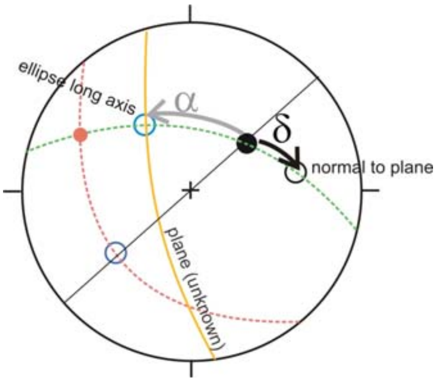
Step 3: Calculate the delta angle (90-α). Using the rules developed on the next page, find the **normal** to the ellipse (the unknown plane) by counting the delta angle along the calculated great circle. (Use the rules developed on the next page to determine whether to count the delta angle away from, or toward, the beta line).
Plot the unknown plane. (The normal is the pole to this plane).

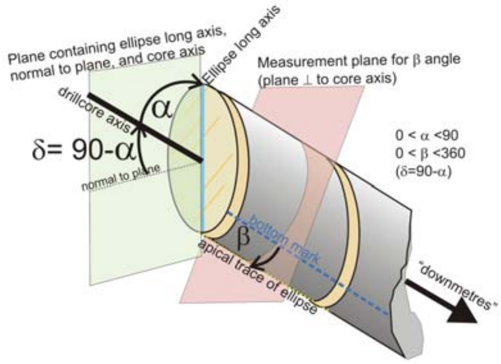


Note that we have not used the alpha angle directly. Although we can find the ellipse long axis using the alpha angle – this is not sufficient to determine the unique solution for the plane.



Details of step 2 and 3: preservation of sense of beta direction and sense of counting of delta angle



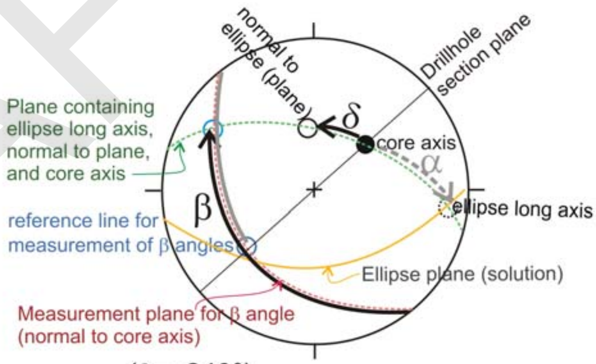


In our assumed conventions, the beta angle references the angle to the bottom of the ellipse long axis in the core. Care must be taken when finding this beta line in the measurement plane to remember whether it plunges downwards or upwards in the measurement plane, as this affects the sense in which the delta angle is counted.

In the calculation described on the previous page, the beta angle is less than 90 (~70), so the sense of plunge of the beta line is downwards (to the NW in the stereo) so we plot it with a filled circle. This means that the long axis of the ellipse must also plunge toward the same quadrant. Hence the delta angle is counted from the core axis **away** from the beta line in order to find the normal.

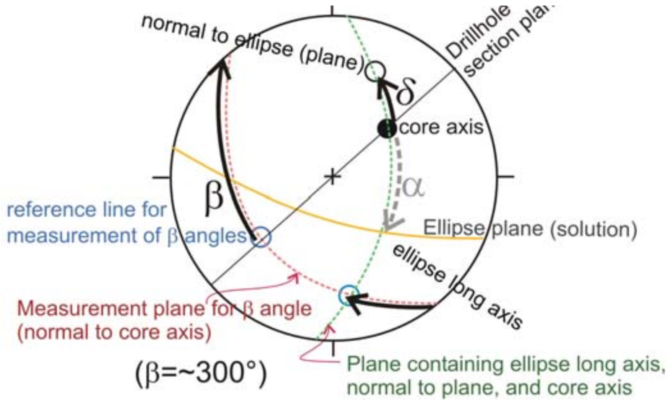
Now consider the case of a beta angle >90 and <270 (the example shown is ~240):

In this instance the point representing the beta line is in the same location in the stereo as our β=70 example. That is, it still plunges to the NW, but its sense is upward in the measurement plane (so we plot it with an open circle). What this means is that the ellipse long axis is plunging away from the bottom mark, hence the normal will be found by counting the delta angle from the core axis **toward** the beta line.



(β=~240°)

The 'rule' for a beta angle >270 is the same as for the <90 case (e.g. the figure shows a beta angle of ~300). That is, the delta angle is counted from the core axis **away** from the beta line



(β=~300°)

Put simply the 'rule' is:

for beta angles from >90 and <270 measure the delta angle from the core axis **away** from the calculated beta intersection line in the measurement plane;

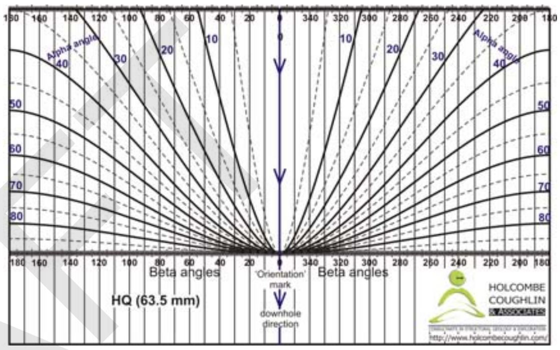
for all other beta angles measure the delta angle from the core axis **toward** the calculated beta intersection line in the measurement plane.

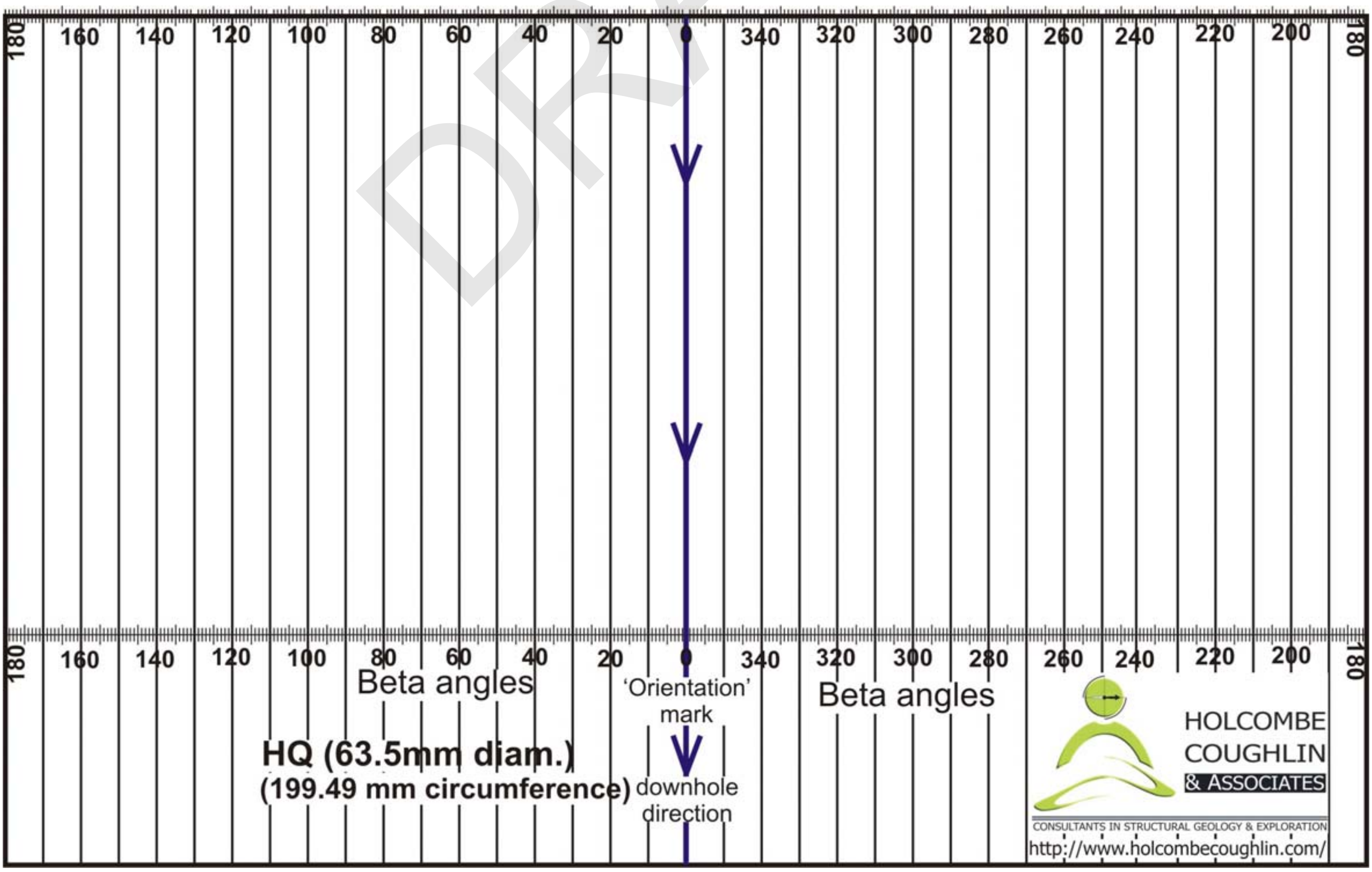
WRAP-AROUND PROTRACTORS FOR ORIENTED DRILLCORE MEASUREMENTS

It is a relatively simple matter to construct a wrap-around protractor to measure beta angles in oriented core using a software drawing package. The procedure is to measure the circumference of the core and divide it by 360 to calculate the spacing of a 1-degree beta angle. A set of parallel lines is then drawn, using a convenient spacing (eg. 10 degrees).
Shown below is one such protractor constructed for 63.5mm HQ core. (Note that with multiple core barrels core such as HQ can have slightly different diameters). Once constructed the protractor is printed onto stiff plastic film using a laser projector. (Laser printers give a finer, more durable line than most ink-jet printers).

An accompanying downloadable brochure: ‘HCA Oriented Core Templates’ can be downloaded from our website at: http://www.holcombecoughlin.com/HCA_downloads.htm and contains printable protractors for common core sizes. Ensure that the printer does not rescale the pages (set the page scaling to NONE in Print manager).
Two types of protractor are available:

- a simple wrap around beta angle protractor as shown at full-scale below). Use an ordinary protractor as shown in this manual to measure the alpha angle;
- Combined alpha-beta wrap around protractor. Although this template can be useful for larger core, the lines tend to be a little too busy for easy visibility, and the larger width of the protractor, necessary to show the alpha angle curves, makes it a little awkward to use.





ABOUT US:

Holcombe Coughlin and Associates is a consortium of two independent European and Australian-based consultancies specialising in the application of modern structural techniques to the global resource industry. We operate globally from both Australian and European bases.

HOLCOMBE COUGHLIN & ASSOCIATES

CONSULTANTS IN STRUCTURAL GEOLOGY & EXPLORATION

http://www.holcombecoughlin.com/
email: info@holcombecoughlin.com

Tim Coughlin (MSc, PhD) is a specialist in structural geology and exploration applied to Phanerozoic orogenic systems. Tim has some 18 years of applied research and mineral and petroleum exploration experience. He has worked on target-generation and deposit-scale problems in the central and northern Andes, the western Tethyan, the Papuan fold belt, northern China the Russian Far East, and eastern Australia. Tim has consulted to a wide range of resource industry clients and has held senior staff positions with well-known medium and large-scale companies.

email: tcoughlin@attglobal.net

RodHolcombe

Rod Holcombe (PhD) is a specialist in structural analysis, particularly in multiply deformed, and sheared metamorphic rocks. He has over 40 years of structural geology experience, including 31 years in academia engaged in contract research and consulting to the minerals exploration industry. He has serviced exploration and geotechnical projects in Australia (Mt Isa, Yilgarn, Tasman FB; NEFB); South America (Brazil, Uruguay, Argentina, Peru); Europe (Finland, Balkans); Asia (Siberia, Thailand, Laos) and Africa (Mali, Guinea, Congo, Tanzania).

Computer applications and other products developed by Rod for use by structural and exploration geologists can be found at: http://www.holcombe.net.au/software/

email: rod@holcombe.net.au

Holcombe Coughlin & Associates Australia:
ABN: 29863107460
PO Box 593, Kenmore, Qld 4069, Australia: Ph +61 7 33786326

Appendix B
Additional Information on ACT Orientation Tool Operation

Reflex ACT

Electronic core orientation

Reflex ACT is a fully electronic orientation device, designed to provide highly accurate and consistent core orientations in broken formations. The unit is easy to operate and its robust design ensures long and trouble-free operation.

Accurate Orientations in broken ground

The Reflex ACT instrument is a precision tool and is accurate to 0.5 of a degree. Unlike conventional mechanical orientation devices, which begin to lose accuracy at a dip of approximately 75 degrees, the Reflex ACT provides full accuracy up to 88 degrees. The high accuracy is achieved by three accelerometers which electronically measure the Earth's gravitational field. This superior technology ensures that geological anomalies and magnetic disturbances have no effect on the accuracy of the Reflex ACT.

The Reflex ACT has been designed for geotechnical and mine planning applications where highly accurate and consistent data streams are required.

Broken ground is overcome by the use of triple tube. On retrieval of the sample, the core is marked using the standard Reflex ACT orientation method. The splits are then pumped out and one of the tubes is removed. The orientation mark can then be scribed up the core sample, carefully placed in a core tray, and examined with confidence in the accuracy of the orientation marks.

Ease of assembly

The Reflex ACT is available in sizes to suit LTK60, NQ, NQ2, NQ3, NTW, HQ, HQ3, PQ, PQ3, as well as the new generation QPQ back ends. Assembly of the equipment is straightforward; the tool is simply inserted between the core tube and the backend assembly. The only other addition to the drill string is the inclusion of a barrel extension to account for the increased length of the inner tube.

Water proof and durable

The Reflex ACT was designed with the realities of harsh drilling environments in mind. The tool is fully sealed and has a rugged design. When installed into the drill string and secured by the driller's normal tightening practice, the Reflex ACT is rated to 3,500m water resistance. The unit is shock resistant and can handle the forces created during the lowering of the inner tube and seating in the barrel. Resilience up to 500 G's of force is achievable due to clever internal shock absorption techniques.

On-site calibration test

A quick function test on the surface allows any questions regarding the performance of the Reflex ACT to be answered in less than two minutes. The calibration of the tool does not fluctuate and is not subject to intermittent lapses in accuracy. Therefore, if the unit passes the function test, other factors would be the cause of any discrepancies.

More metres drilled

Every Reflex ACT kit contains two orientation tools, allowing orientation of every core sample from every run. While one of the tools is down the hole locating the orientation of the drilled sample, the other unit is on the surface being orientated.

No consumable costs

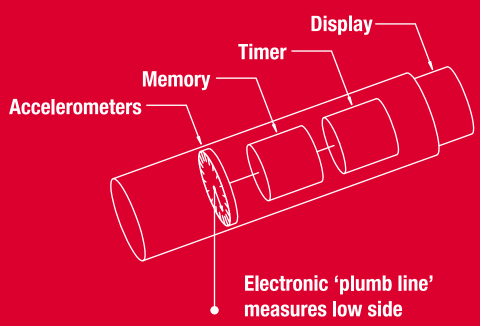
The Reflex ACT requires no consumables and has no moving mechanical parts to wear and fail during use. Contamination and clogging of moving parts by the drilling mud is also not possible. A non-rechargeable lithium battery pack ensures long and trouble-free operation.

Proven concept

The Reflex ACT has been in service all over the world since the beginning of 2005. The units orientate accurately and consistently in all types of extreme environments, including Canada's frozen Northern Territories, the humidity of New Guinea and the hot exploration holes encountered in Indonesia.

WORKING PRINCIPLE

Every minute during the drilling process, the accelerometers sense the 'low side' of the core tube and records the position in the memory. On completion of the drilling run, the tool is returned to the surface and the driller enters the time at which the core was broken. The tool uses the associated accelerometer information stored in its memory and guides the user to position the tool so that the same 'low side' position is reproduced on the surface. In layman's terms, the tool is acting as an electronic plumb line.



On site calibration check procedure

The Reflex ACT does not suffer from intermittent calibration errors, it is either calibrated correctly or requires maintenance. Being a digital item it is important that the accuracy of each Reflex ACT can be determined on site quickly and easily.

The calibration check procedure requires the operator to use the tools in the same manner as they would when in the field. This calibration check mimics the tool operation whilst drilling and merely recreates the activity in sight of the person performing the test. The tool records the orientation of the tool in memory at the end of every minute after the tool is armed.

1) Reset the Reflex ACT as for normal use by pressing and holding the N button until 888 appears on the screen. When 888 appears start the stop watch.
2) Lay the tool at an inclined angle in a stationary position and make a single mark at the base of the bezel indicating bottom of hole. When 888 flashes on the screen of the tool it indicates that an orientation has been taken, this will coincide with approximately 1 minute on the stopwatch.
3) After the first orientation has been taken, roll the Reflex ACT approximately 90 degrees and repeat the procedure above. In this case mark the bezel with 2 marks.
4) Continue steps 2 and 3 until you have recorded 4 minute readings each approximately 90 degrees apart. Stop the stop watch at the end of the fourth minute.
5) Press the R button and then + to enter 1 minute, press R again and roll the tool as per normal operating procedure until the full box appears in the LCD screen. With the formation of a full box, the 1st mark should be at the bottom indicating that the tool has successfully reorientated the first mark (figure A).
6) Press the R button again and then the + button once more to scroll to the second minute. By recalling the 2nd minute, the tool is being asked to show the orientation it took at minute number 2.

   Press R again and roll the tool until a full box is formed. With the formation of a full box the 2nd mark on the bezel should be at the bottom, indicating that the tool has successfully reorientated the second mark (figure B).
7) Repeat step 6 for the remaining 3rd and 4th minutes.

Figure A

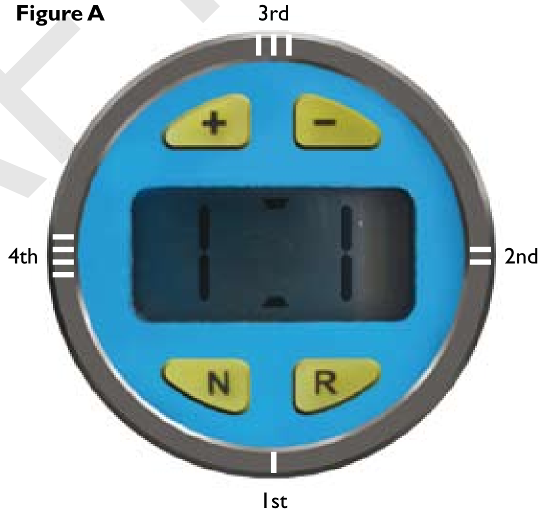
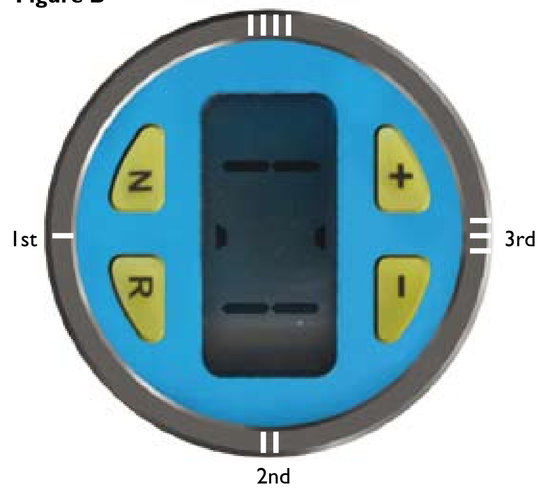


Figure B



If the tool passes this test it is operating correctly. Please contact Reflex for training assistance because incorrect use of the tool is the most likely cause of core misalignment.

Key features of Reflex ACT

- Highly accurate
- Easy to use and maintain
- Water resistant and rugged
- Available for all drilling sizes
- No battery charging
- No consumables and hidden costs
- Not affected by geological anomalies

Technical Specifications

Reflex ACT

Dimensions	
Outer diameter	To suit all Q series applications
Length	Average tool length 300mm
Weight	Average weight per kit is 24kg
Accuracy	
Range	0 to ±88° dip
Accuracy	±0.5°
Depth rating	
Housing pressure	3,500 m vertical in fresh water 6,000psi, >4000m.
Temperature rating	Operating: -20c to +70c
Battery	
Non-rechargeable lithium battery pack	
Approximate battery life:	
Infrequent use	3 years +
Normal use	2 years

Measurement every 60 seconds.

The core orientation device is protected by Australian Innovation Patent Number 2006100113 *(and other patents in other parts of the world).*

Telephone: +61 (0) 8 9445 4000

Reflex is a leading manufacturer world wide of survey instruments for drill holes. Its product portfolio includes a complete programme of borehole surveying instruments for mining, tunnelling, construction, oil operations, and other geotechnical applications. Reflex is established in all major markets, the Americas, Africa, Europe and Asia Pacific. The success of Reflex is based on its leading innovative technology, customer focus and a network of local service centres world wide.

REFLEX ASIA PACIFIC
T +61 (0) 8 9445 4020

REFLEX NORTH AMERICA
T +1 (705) 235 2169

REFLEX SOUTH AMERICA
T +56 (2) 247 9504

REFLEX SOUTH AFRICA
T +27 (0) 11 792 0452

REFLEX EUROPE
T +44 (0) 1273 475 928

an imdex limited company

REFLEX™

For further information, or to contact your nearest distributor, please visit

www.reflexinstruments.com

REFLEX ACT

Each Reflex ACT is a fully sealed digital survey instrument comprising of a triaxial accelerometer pod, operating software and battery. Each Reflex ACT unit is calibrated prior to dispatch, and bottom of hole orientation is correct to 0.5 degree.

The Reflex ACT does not suffer from intermittent calibration errors, it is either calibrated correctly or requires maintenance. Being a digital item it is important that the accuracy of each Reflex ACT can be determined on site quickly and easily.

Calibration Check Procedure

The calibration check procedure requires the operator to use the tool in the same manner as they would when using the tool in the field. This calibration check mimics the tools operation whilst drilling and merely recreates the activity in plain site of the person performing the test. When performing this test please remember that the tool records the orientation of the tool in memory at the end of every minute after the tool is armed.

1) Reset the Reflex ACT as per normal use by pressing and holding the ”N” button until ”888” appears on the screen. When ”888” appears start the stop watch.
2) Lay the tool at an inclined angle in a stationary position and make a single mark at the base of the bezel indicating bottom of hole. When ”888” flashes on the screen of the tool it indicates that an orientation has been taken, this will coincide with approximately 1 minute on the stopwatch.
3) After the first orientation has been taken roll the Reflex ACT approximately 90 degrees and repeat the procedure above. In this case mark the bezel with 2 marks.
4) Continue steps 2 and 3 until you have recorded 4 minute readings each approximately 90 degrees apart. Stop the stop watch at the end of the fourth minute.
5) Press the ”R” button and then ”+” to enter 1 minute, press ”R” again and roll the tool as per normal operating procedure until the full box appears in the LCD screen. With the formation of a full box the 1st mark should be at the bottom indicating that the tool has successfully reorientated the first mark (figure A).
6) Press the ”R” button again and then ”+” button once more to scroll to the second minute. By recalling the 2nd minute we are asking the tool to show the orientation it took at minute number 2. Press ”R” again and roll the tool until a full box is formed. With the formation of a full box the 2nd mark on the bezel should be at the bottom, indicating that the tool has successfully reorientated the second mark (figure B).
7) Repeat step 6 for the remaining 3rd and 4th minutes.

Figure A

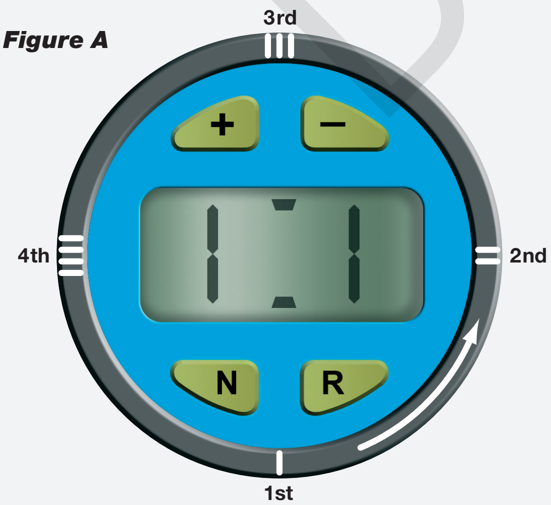
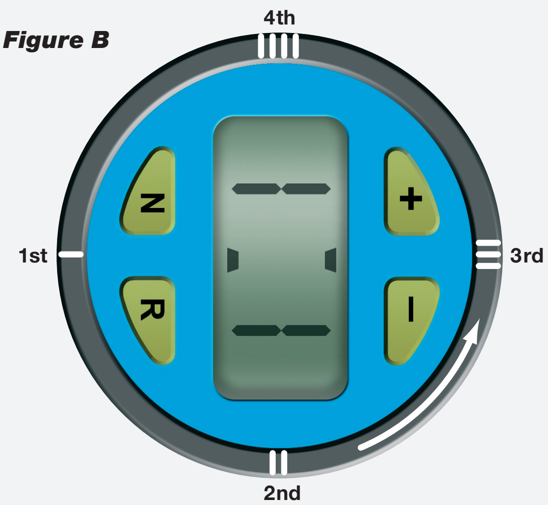


Figure B



If the tool passes this test it is operating correctly. Please contact Reflex for training assistance because incorrect use of the tool is the most likely cause of core misalignment.

Technical Support for Reflex ACT

Phone: +61 (0)8 9445 4020
Fax: +61 (0)8 9445 4040

E-mail: technicalsupport@reflex.se
www.reflex.se

DRAFT

Appendix C
Geotechnical Logging Data Sheet

GEOTECHNICAL LOGGING DATA SHEET

Project:	Drillhole ID.:	Elevation:	Drilling Contractor:	Core Size:
Site:	Northing:	Dip:	Drilling Method:	Logger:
Date:	Easting:	Azimuth:	Driller:	Checked By:

DH	Rock Type	Core Recovery Data								Fracture Data	Strength Data		Joint Data													Broken Zone		Others
Depth (m)	Description	Run #	Depth_From (m)	Depth_To (m)	Run Length (m)	TCR (m)	TCR (%)	RQD m)	RQD (%)	Frequency per metre (F/m)	Strength Index	Weatheing Index	Type	Depth (m)	Dip	Dip Direction	Surface Shape	Surface Roughness	Infill/coating Type	Infill/Coating Character	Infill/Coating Thickness	Condition (Jcon)	Roughness # (Jr)	Alteration # (Ja)	Set # (Jn)	Broken Core	Lost Core	Fault Breccia/Gouge

Joint Condition (Jcon)	Rating
Very rough surfaces, not continuous, no separation, unweathered wall rock	30
Slightly rough surfaces, separation<1mm, slightly weathered	25
Slightly rough surfaces, separation<1mm, highly weathered	20
Slickensided surfaces OR gouge<5mm, separation 1-5mm, continuous	10
Soft gouge>5mm thick OR separation>5mm, continuous	0

Joint Set Number (Jn)	Rating
Massive, no or few joints	0.5-1.0
One joint set	2
One joint set plus random joints	3
Two joint sets	4
Two joint sets plus random joints	6
Three joint sets	9
Three joint sets plus random joints	12
Four or more joint sets	15
Crushed rock, earthlike	20

Joint Roughness # (Jr)	Rating
Discontinuous joints	4
Undulating, rough or irregular	3
Undulating, smooth	2
Undulating, slickensided	1.5
Planar, rough, irregular	1.5
Planar, smooth	1
Planar, slickensided	0.5

Joint Alteration Number (Ja)		Rating
No mineral fillings, only coating		
Healed, hard, impermeable filling		0.75
Unaltered, staining only		1
Slightly altered		2
Silty or sandy clay coatings		3
Clay mineral coating		4
Thin mineral fillings		
Sandy particles	Clay free	4
strongly over-consolidated/non-softening	clay filling<5mm	6
Med or low over-consolidated/softening		8
Swelling clay filling		8-12
Thick mineral fillings		
strongly over-consolidated/non-softening	clay filling>5mm	10
Med or low over-consolidated/softening		13
Swelling clay filling		13-20

D-Type	Rating
Joint	JN
Fault	FLT
Shear	SH
Vein	VN
Fracture	FR

J-shape	Rating
Planar	PL
Curve	CU
Undulating	UN
Stepped	ST
Irregular	IR

J-roughness	Rating
Slickensided	SL
Polished	PO
Smooth	SM
Rough	RO
Very Rough	VRO

Infill Type	Rating
Biotite	Bi
Chlorite	Ch
Clay	Cl
Sericite	Se
Calcite	Ca
Epidote	Ep
Iron	Fe
Manganese	Mn
Gypsum	Gy
Graphite	Gr
Sulphide	Su
Hematite	He
Quartz	Qz
Talc	Tc
Silt	M
Sand	S
Gravel	G
Gouge	Go

Remarks: