Mainstreaming Slope Stability Management – Hazard and Risk Assessment – to Laos Practitioners

Theme 6

Engineering Geological Assessments

6.1 – Topographic survey

Scott Wilson

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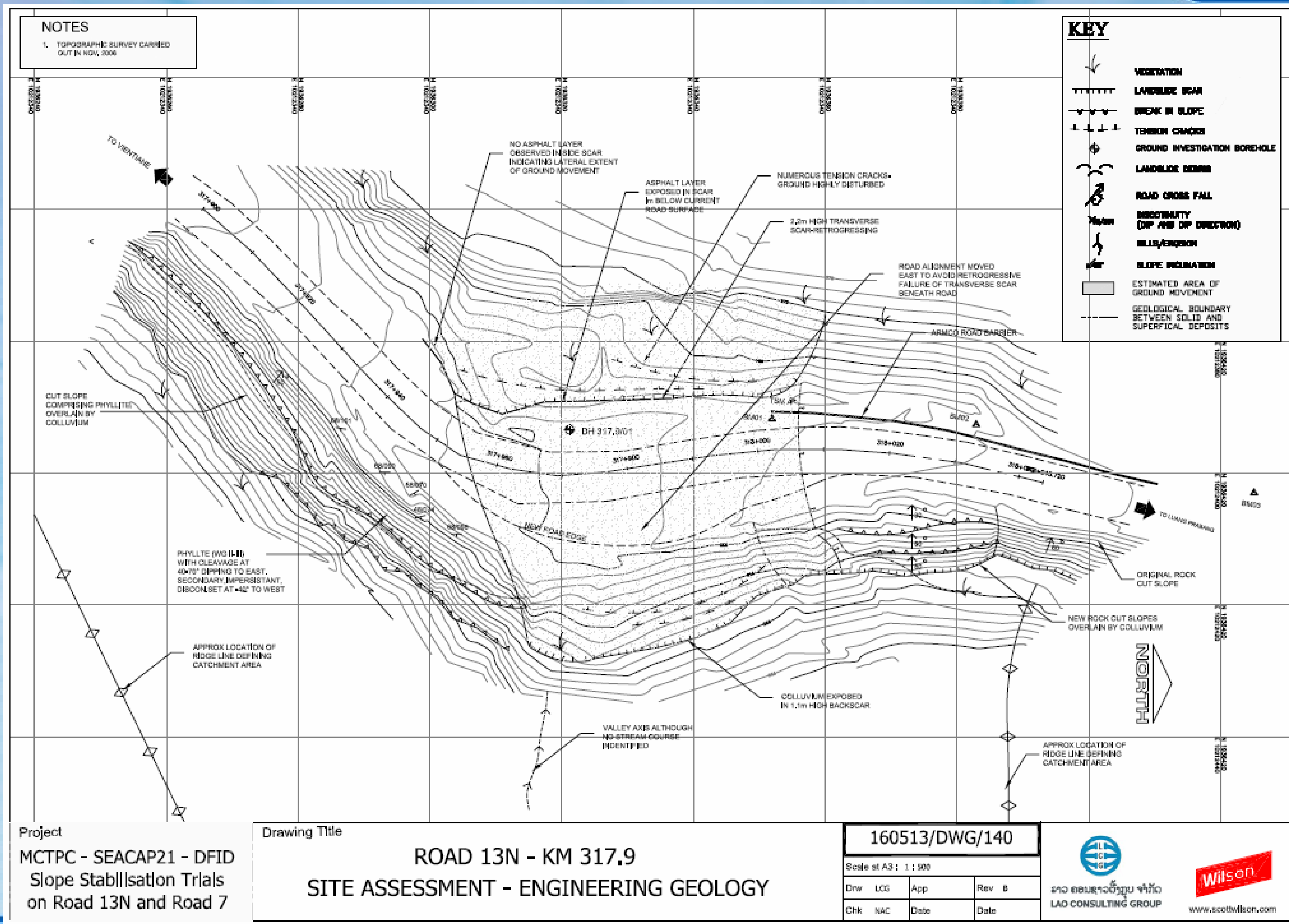
Topography and landforms

- Compass traverse – easy, quick, imprecise. Errors in this is normally of the orders of metres. Useful for rapid geological or geomorphological assessments.
- Theodolite / Levelling or EDM Survey – relatively easy to complete. Becomes time consuming in areas without good lines of sight. Precision is in the order of mm in X, Y and Z directions.
- Digital photogrammetry – expensive but can cover large areas in relatively short periods and provide good. Added benefit of having aerial photographs for interpretation.
- LiDAR / Laser scanning – laser distance measurement. A powerful survey method that can be employed on the ground or be airbourne. Normally will give precision in the order of mm, BUT can have large errors in heavily vegetated terrains.
- Airbourne / Satellite based remote sensing – good for large areas but generally scans vegetation surfaces and is of limited use for landslide investigations.

GPS

Engineering geological maps

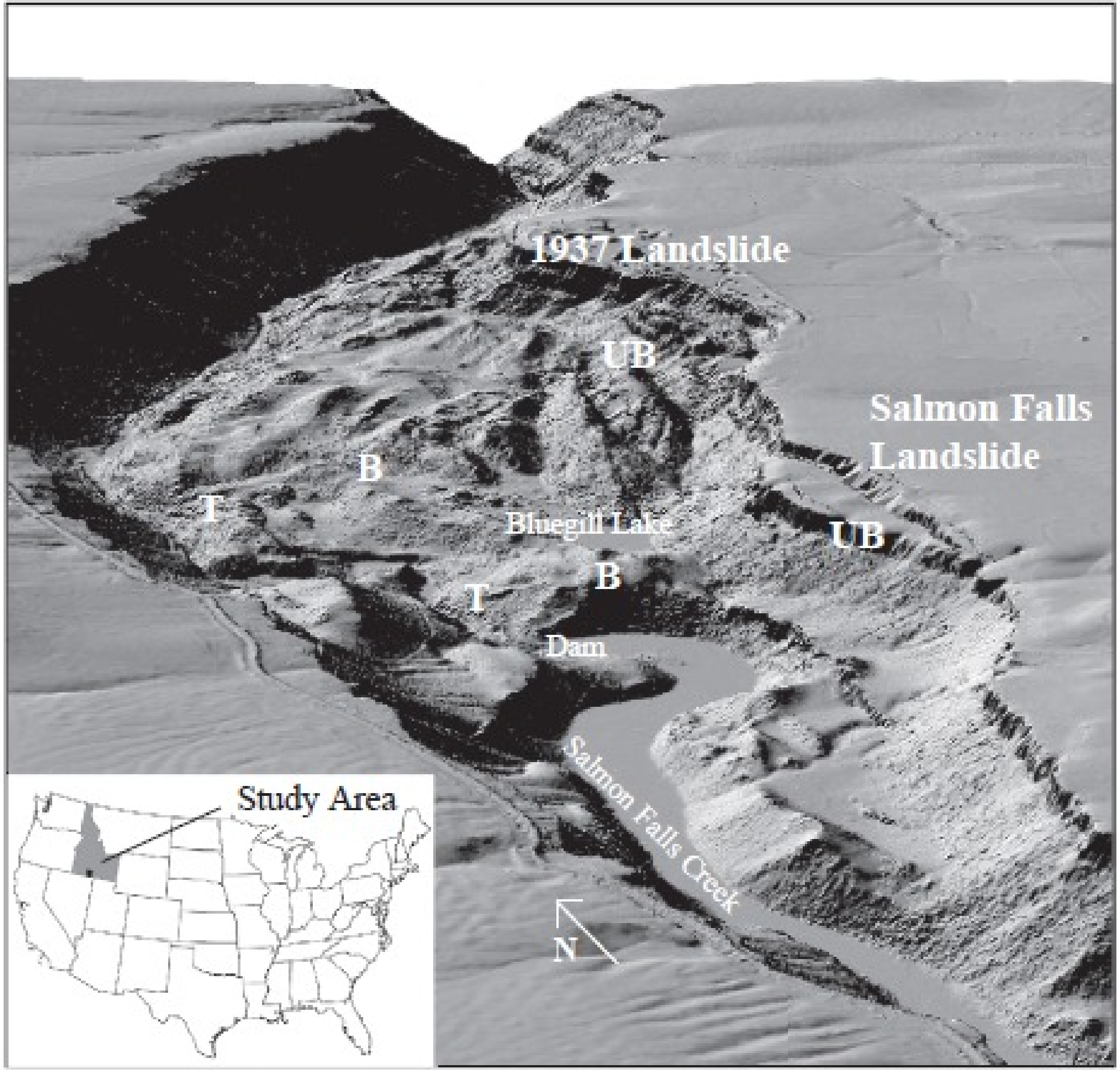


Use of laser scanning: Fathom Fault - Cullercoates

- Work undertaken as a partnership between Durham University and a major geotechnical contractor.
- Data used to map faults and fissures on the rock surface
- Digital camera linked to scanner allows colour to be applied to point cloud
- Scan time of 5-10 minutes
- 8000 observations per second

Image courtesy University of Durham and Halcrow Group.

Laser scanning and LiDAR are powerful tools for monitoring and mapping the ground. However, the difficulties encountered with these techniques due to vegetation are significant



From Glen et al. 2006. Analysis of LiDAR-derived topographic information for characterizing and differentiating landslide morphology and activity. *Geomorphology*. **73,** 131–148

Electromagnetic distance measurement

- Requires the establishment of a temporary bench mark which ideally should allow a view of the entire site.
- Requires a survey to operate the EDM equipment and a colleague to carry a staff with a reflector for the surveyor to sight onto.
- Requires post processing and mapping. Normally within a Geographic Information System or a Computer Aided Design (CAD) package.
- Data are recorded as a series of X, Y and Z points. Local coordinate systems must be linked clearly to National or International Grid systems.

Global Positioning Systems (GPS)

- Does not require a clear line of sight and therefore is valuable where terrain is difficult.
- However, it does require a clear view of the sky and precision is generally related to the number of satellites visible to the receiver.
- Precision is vastly improved by GPS in differential mode. This is where a GPS bases station is ‘fixed’ on a known location and a ‘rover’ or ‘ranger’ station is used to make observations. Baselines between stations should be of the order of 100s of metres.
- GPS precision is improved by post processing of data. Precision of GPS in kinetic mode (walking around making only brief measurement stops) is nominally +/- 1-2cm with a local station but this requires post survey processing.
- GPS is a powerful and practical tool for rapid landslide surveying.

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Engineering Geological Assessments

6.2 – Engineering Geological Mapping

Geology and ground models

- Most rock materials have sufficient strength for civil engineering purposes. HOWEVER this is less true of rock masses.
- The ROCK MASS is the combination of the material (rock) and the fractures and discontinuities in the mass.
- The ground is modified by recent and active GEOMORPHOLOGICAL processes.
- In tropical and sub tropical zones the most important geomorphological process is WEATHERING.
- Weathering results in the formation of RESIDUAL SOILS on slopes.
- Residual soils give rise to ground conditions that are extremely difficult to predict. This is known as geological HETEROGENEITY.
- The likely heterogeneity in the ground should be identified in the GEOLOGICAL MODEL and on ENGINEERING GEOLOGICAL MAPS.

Initial Assessment of Slope Failure / Landslide

↓

Topographic Survey

↓

Engineering Geological Mapping

↓

Ground Investigation & Monitoring – Yes/No?

↓

Design of Stabilisation Works

Hydrology (surface water, stream erosion, ground water)

Slope angle & shape

Geology - soil & rock properties and weathering

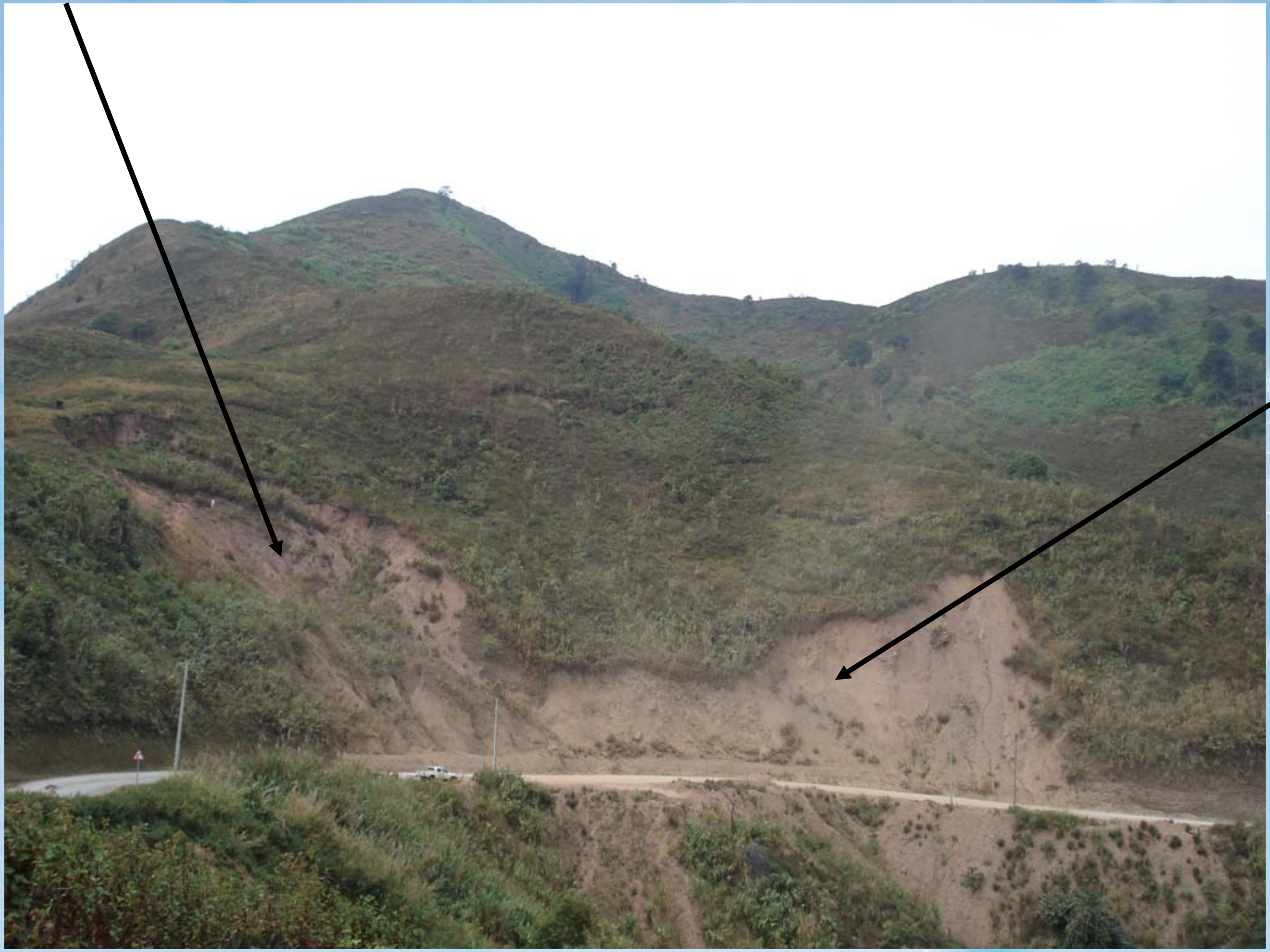
Engineering Geological Map

Vegetation & land Use

Man made Features

Previous landslides

Road 13N - Km 260.3



Rotational Failure

shallow (translational) failure

Road 13N - Km 260.3

Road 13N - Km 336.4

Shallow failures below and above road

Road 13N - Km 336.4

Road side-drain 'lifted'

Road surface deformed

Road 13N - Km 336.4

Back Scarp

Examples of Engineering Geological Maps

- Examples from Laos (SEACAP) Sites
  - Km 260.3
  - Km 242
  - Km 317.9

Road 13N - Km 242

Concrete surface protection

Road 13N - Km 317.9

Tension cracks hidden in trees

Back Scarp??

Integrating topography and engineering geology

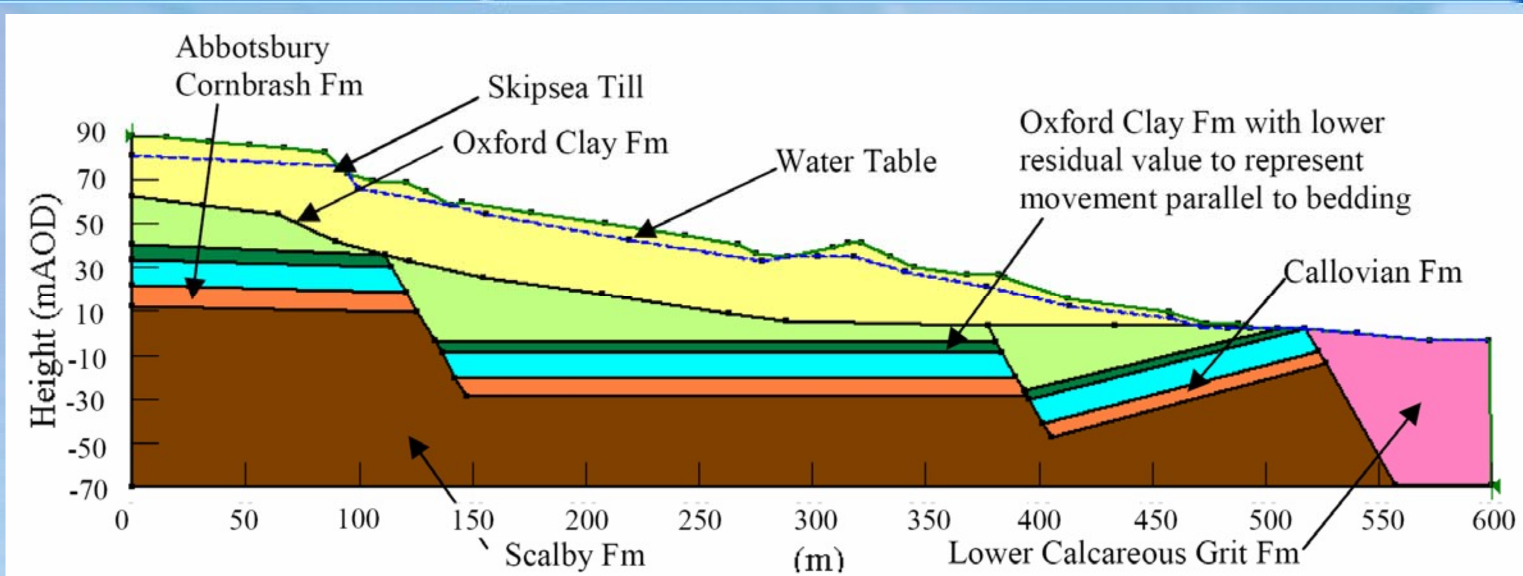
- The following slides show how geological features have been used to help to locate the boundaries of a large landslide at Knipe Point, Cayton Bay near Scarborough, England.
- Surface observations show that the landslide shear surface is located in the Oxford Clay formation because this is being thrust upwards through the current beach level.
- Further surface observations show that Oxford Clay is thrust against glacial deposits marking the lateral boundaries of the landslide.
- Simple topographic measurements combined with engineering geological mapping allowed the main shear planes to be identified in the landslide system for further analysis. These are shown on the cross section.

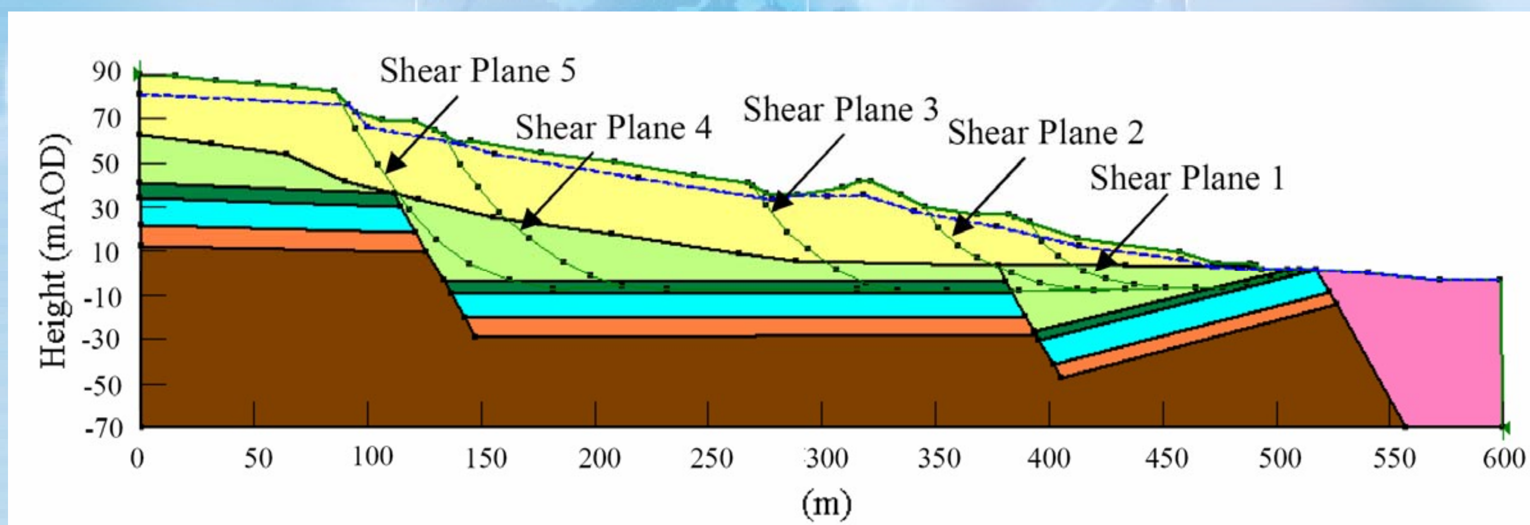

Looking WSW
3m


Looking WNW


Faint slickensides noted

From: Thompson, B. 2008. SLOPE STABILITY INVESTIGATION INTO A RE-ACTIVATED, COMPOUND LANDSLIDE, CAYTON BAY, NEAR SCARBOROUGH. Unpublished MSc Dissertation, University of Leeds.


Abbotsbury
Cornbrash Fm
Skipsea Till
Oxford Clay Fm
Water Table
Oxford Clay Fm with lower
residual value to represent
movement parallel to bedding
Callovian Fm
Height (mAOD)
90
70
50
30
10
-10
-30
-50
-70
0
50
100
150
200
250
300
350
400
450
500
550
600
(m)
Scalby Fm
Lower Calcareous Grit Fm


Shear Plane 5
Shear Plane 4
Shear Plane 3
Shear Plane 2
Shear Plane 1
Height (mAOD)
90
70
50
30
10
-10
-30
-50
-70
0
50
100
150
200
250
300
350
400
450
500
550
600
(m)

Bulk Density (kg/m^3)	c' (kPa)	ϕ' (^{o})	c_u (kPa)	ϕ_u(^{o})	c'_r (kPa)	ϕ'_r(^{o})	Source
2235	38	19	38	17.5	0	26.5	Mills (1981)
-	28	30	29	12	1	25	Bell (2002)
2150 - 2300	0 - 20	30 - 32	150 - 220	-	0	28 - 30	Russell and Eyles (1985)
2240	6	27	-	-	0	25	Powell and Butcher (2003)
2230	21	27	34	15	0	26	Representative values to be used

After defining the geometry of the landslide using the surface geology, geomorphology and borehole data, geotechnical parameters were applied to the cross section for analysis.

Ground models

- Conceptual Ground models seek to show the types of conditions that are expected to be encountered based on desk study data and field observations.
- Such models should show what types of variations should be expected based on the available data. Examples include:
  - In highly weathered terrains a ground model may suggest the presence of corestones in the soil mass
  - In areas with geological faults they may indicate that there may be a higher fracture density in the immediate vicinity of the fault.
- Ground models may at some point have quantitative data applied such as fracture spacing or shear strength data.
- Ground models should therefore evolve as you get more data
- Ground models can include a 4th dimension – TIME! A good example would be how slopes over-steepen in response to erosion (see theme 2.3)

From Fookes, P. G. 1997. Geology for Engineers: the Geological Model, Prediction and Performance. Quarterly Journal of Engineering Geology, 30, 293–424.

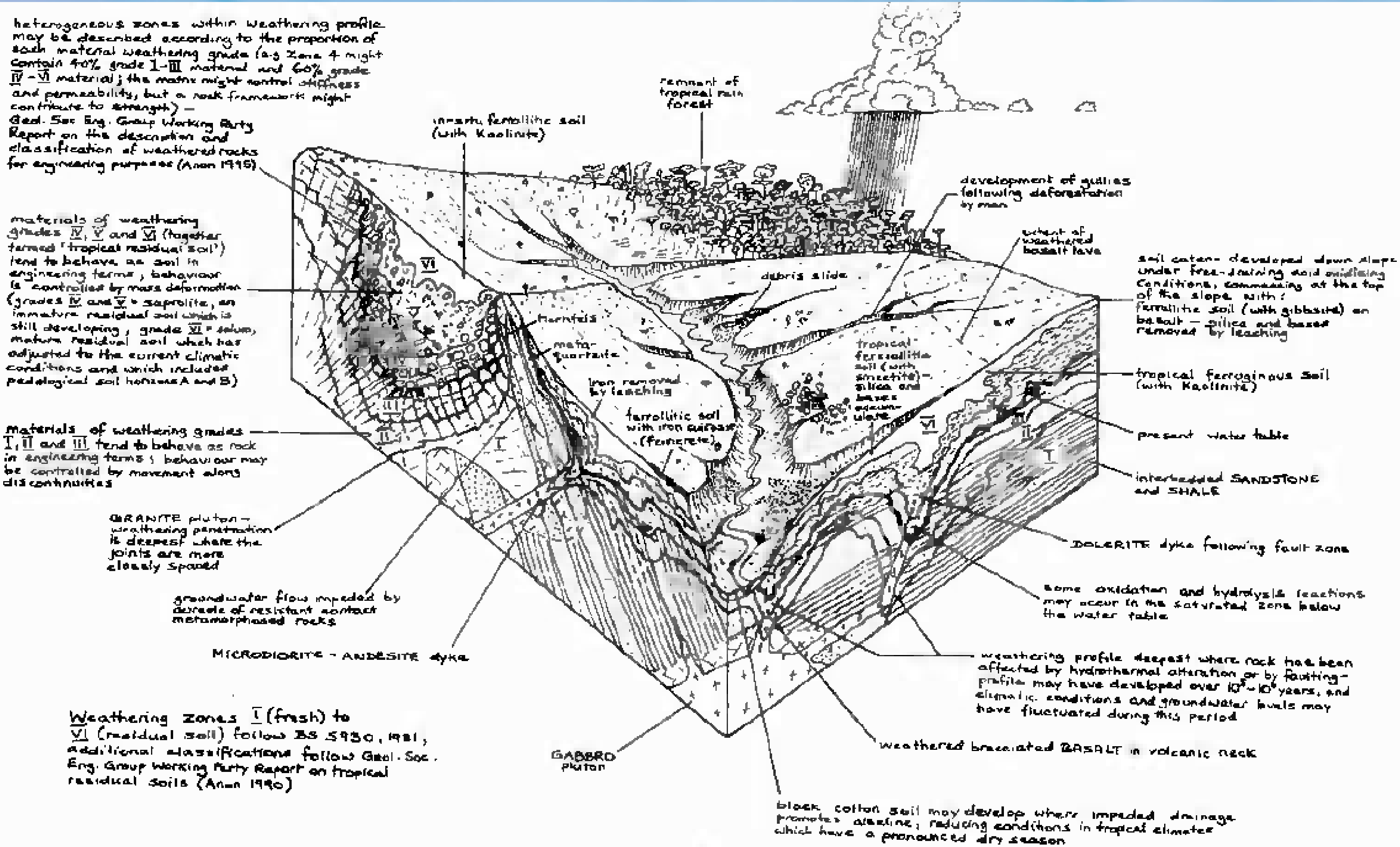


Fig. 33. Wet tropical weathering (superimposed on geology shown in Fig. 19).

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Theme 6

Engineering Geological Assessments

6.3 – Field description of soils and rocks

Description of Rock

1. Material characteristics
   1. Strength – unconfined compressive (MN/m^2)
   2. Structure – inter-relationship of texture & lithology
   3. Texture & fabric – arrangement & relationship of rock components
   4. Colour
   5. Grain size – averaged dimensions of rock fragments
   6. Name
2. General Information
   1. Additional info & minor constituents
   2. Geological Formation
3. Mass characteristics
   1. State of weathering
   2. Discontinuities

Description of rock in cores

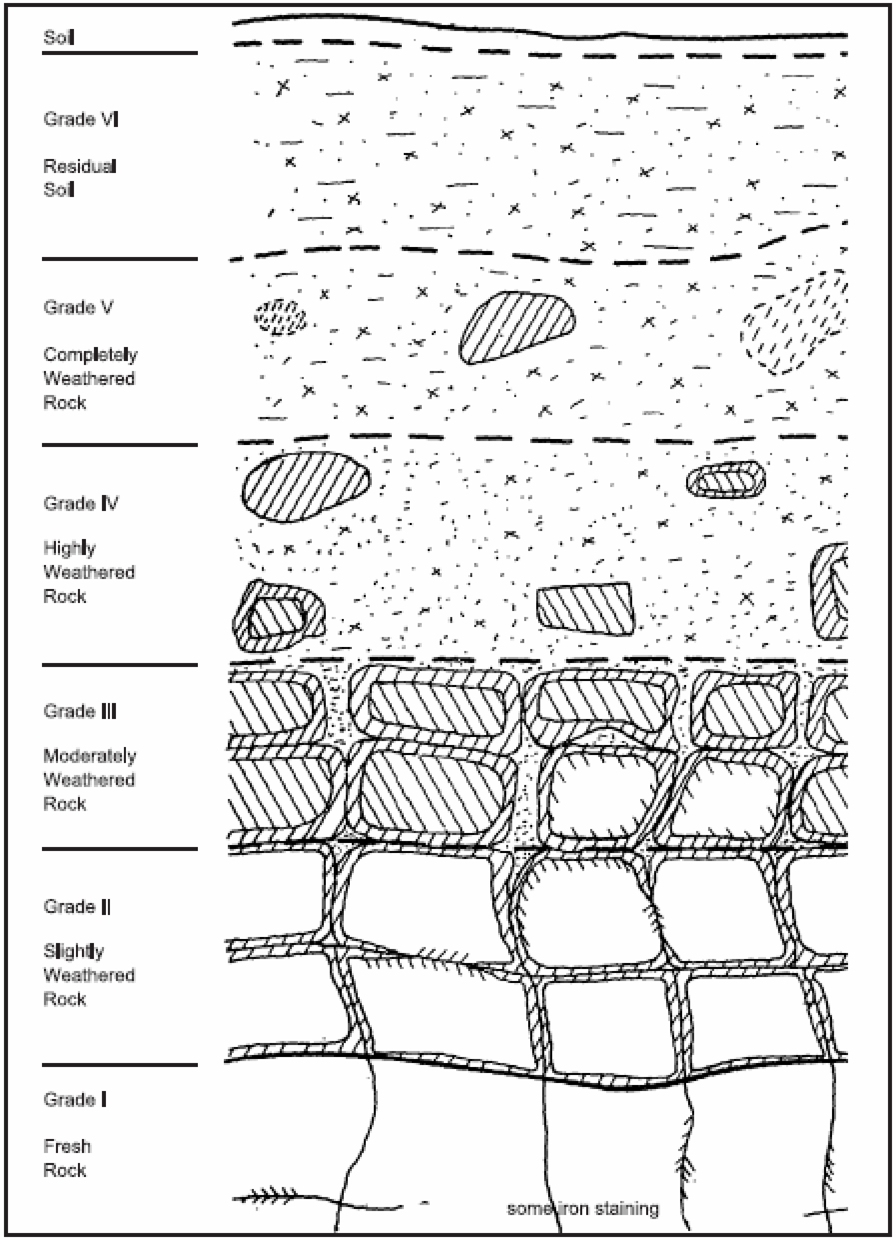
1. Rock material characteristics
- Colour
  - Grain size – averaged dimensions of rock fragments
  - Structure – inter-relationship of texture & lithology
  - Texture & fabric – arrangement & relationship of rock components
  - Strength – unconfined compressive (MN/m^2)
1. General Information
  - Minor constituents and additional information
  - Geological Formation
2. Rock mass characteristics
  - State of weathering
  - Discontinuities
  - Fracture state

(After BS EN ISO 14689-1:2003; BS5930, 1999)

Field description of strength

Field description of rock strength (from BS EN ISO 14689-1:2003)		
Descriptor	*Strength* (MPa)	*Typical characteristics*
Extremely weak*	< 1	Indented by thumbnail
Very weak	1-5	Crumbles under firm blows with point of geology hammer, can be peeled by pocket knife
Weak	5-25	Can be peeled by pocket knife with difficulty, shallow indentations made by firm blow with point of geology hammer
Medium strong	25-50	Cannot be peeled or scrapped with a pocket knife, specimen can be fractured with a single firm blow of geology hammer
Strong	50-100	Specimen requires more than one blow of geology hammer to fracture.
Very strong	100-250	Specimen needs many blows of geology hammer to fracture.
Extremely strong	>250	Specimen can only be chipped with geology hammer
* some extremely weak rocks behave as soils and should be described as soils see BS ISO 14688-1		

Weathering



Whole mass is decomposed to a residual soil and relict structure is no longer evident. Describe as an engineering soil

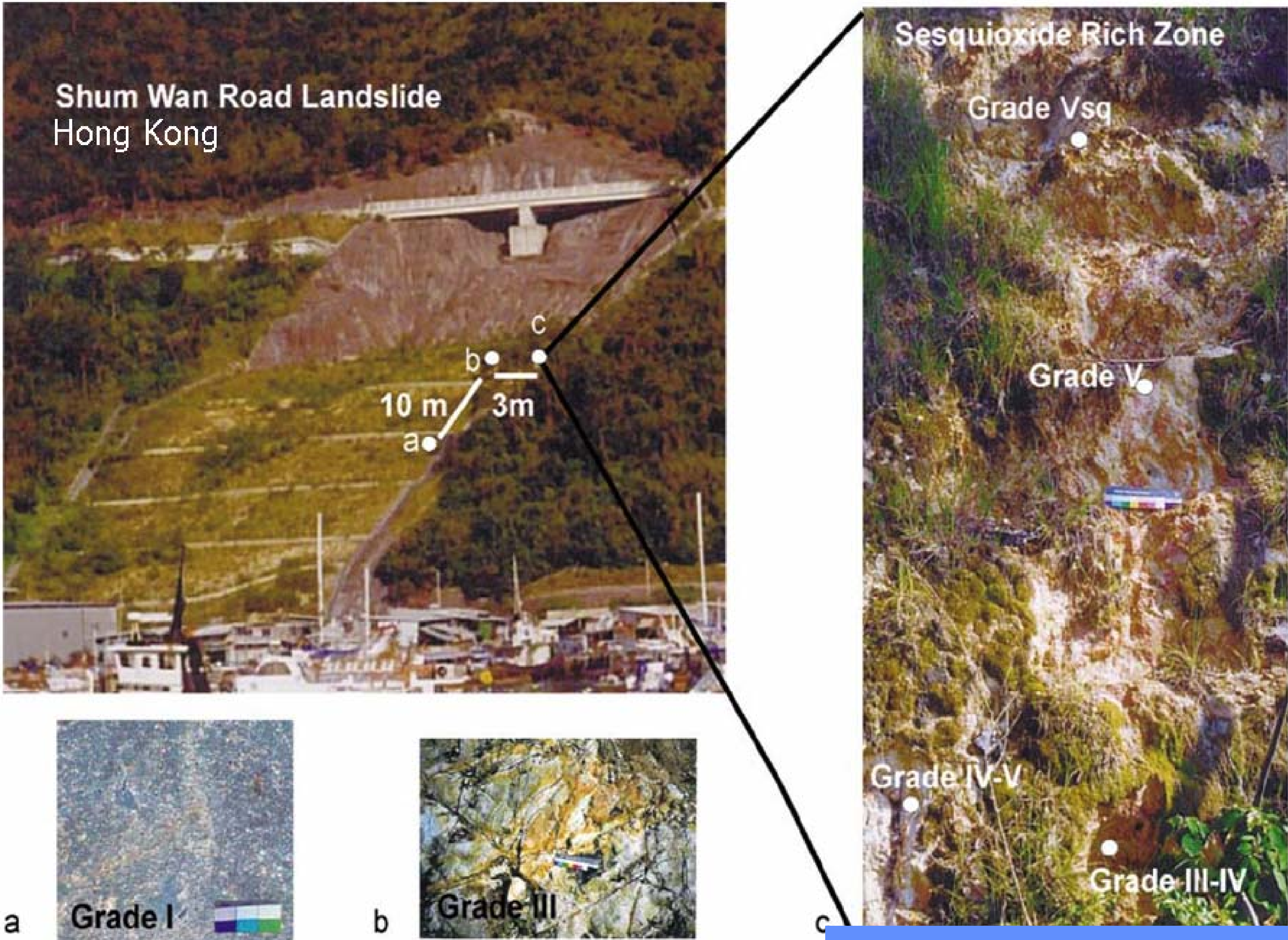
Describe rock as completely weathered (weathering grade V). All of the rock mass is a soil material although some relict structure remains.

Describe rock as severely weathered (weathering grade IV). More than 50% of the rock mass is decomposed to a soil material.

Describe rock as moderately weathered (weathering grade III). The rock is discoloured throughout with significant weakening

Describe rock as discoloured or slightly weathered (weathering grade IIa-c depending on degree of discolouration.)

Bedrock geology – describe rock material as FRESH weathering grade I)



From Duzgoren-Aydin *et al.* (2002)

Rock type	Density dry t/m^3	Porosity %	Dry UCS range MPa	Dry UCS mean MPa	UCS saturated MPa	Modulus of elasticity GPa	Tensile strength MPa	Shear strength MPa	Friction angle
Granite	2.7	1	50-350	200		75	15	35	55
Basalt	2.9	2	100-350	250		90	15	40	50
Greywacke	2.6	3	100-200	180	160	60	15	30	45
Sandstone-Carboniferous	2.2	12	30-100	70	50	30	5	15	45
Sandstone-Triassic	1.9	25	5-40	20	10	4	1	4	40
Limestone-Carboniferous	2.6	3	50-150	100	90	60	10	30	35
Limestone–Jurassic	2.3	15	15-70	25	15	15	2	5	35
Chalk	1.8	30	5-30	15	5	6	0.3	3	29
Mudstone-Carboniferous	1.4	10	10-50	40	20	10	1		30
Shale-Carboniferous	2.2	15	5-30	20	5	2	0.5		25
Clay-Cretaceous	2.1	30	1-4	2		0.2	0.2	0.7	20
Coal	1.4	10	2-100	30		10	2		
Gypsum	2.2	5	20-30	25		20	1		30
Salt	2.1	5	5-20	12		5			
Hornfels	2.7	1	200-350	250		80			40
Marble	2.6	1	60-200	100		60	10	32	35
Gneiss	2.7	1	50-200	150		45	10	30	30
Schist	2.7	3	20-100	60		20	2		25
Slate	2.7	1	20-250	90		30	10		25

What is a discontinuity ?

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

Discontinuity terminology

Information described in a scanline survey –

- **spacing**
- **orientation (dip/strike or just dip in cores)**
- **persistence**
- **termination**
- **block size**
- **roughness (wavelength/amplitude, stepped/undulating/planar, rough/smooth)**
- **wall strength, weathering,**
- **aperture & infill**
- **seepage**
- **no. of joint sets**

(After BS EN ISO 14689-1:2003; BS5930, 1999)

Discontinuity terminology

- Joints, faults, bedding fractures and cleavage fractures
- Incipient fracture – retaining some tensile strength, not fully developed, may contain cement
- Induced fractures – discontinuity of non-geological origin (e.g. coring/blasting)

(After BS EN ISO 14689-1:2003; BS5930, 1999)

Fracture/joint spacing From: BS EN ISO 14689-1:2003	
Measurement	**Discontinuity spacing**
>2 m	**very wide**
2 m - 0.6 m	**wide**
0.6 - 0.2 m	**medium**
200 - 60 mm	**close**
60 -20 mm	**very close**
< 20 mm	**extremely close**

Field testing

- SPT : Standard Penetration Test
  - no. of blows/300mm penetration
- Permeability Test
- Vane tests
- Cone Penetration Tests
- In-Situ Density Test
- Index testing
- Point load tests – *important to evaluate the strength of discontinuities.*
- Schmidt Hammer – *important to evaluate the strength of discontinuities.*

Bedding thickness	
Measurement	Bedding thickness
>2 m	very thick
2 m - 0.6 m	thick
0.6 - 0.2 m	medium
200 - 60 mm	thin
60 -20 mm	very thin
20 - 6 mm	thickly laminated
6 - 2 mm	thinly laminated

Joint aperture (From: BS EN ISO 14689-1:2003)

Discontinuity aperture	
Aperture	**Term**
< 0.1 mm	very tight
0.1 – 0.25 mm	tight
0.25 – 0.5 mm	partly open
0.5 - 2.5 mm	open
2.5-10 mm	moderately wide
1-10 cm	wide
10-100 cm	very wide
> 1 m	extremely wide

LEFT: MSc Hydrogeology students logging rock core during a field course. BELOW: Core from a ground investigation (photographs courtesy of Drs N. Odling and J. Lawrence)

Describing soils

Material type	Strength	Compressibility	Permeability
Rock	Very high	Very low	Medium to high
Granular soil	High	Low	High
Cohesive soil	Low	High	Very low
Organic soil	Very low	Very high	High
Made ground	Medium to very low	Medium to very high	Low to high

Soil type	Description
CLAY	Cohesive soil
BOULDERS	Granular soils
COBBLES	Granular soils
GRAVEL	Granular soils
SAND	Granular soils
SILT	Granular soils
PEAT	Organic soil
MADE GROUND	Man-made soils and other materials

Consistency	Undrained shear strength
Very soft	< 20 kPa
Soft	20-40 kPa
Firm	40 -75 kPa
Stiff	75 – 150 kPa
Very Stiff	150 – 300 kPa
Hard	> 300 kPa

Correlation between consistency and C_u

In addition to shear strength you should also record plastic limit, liquid limits and plasticity index. These are generally termed the Atterberg limits.

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Theme 6

Engineering Geological Assessments

6.4 – Ground Investigation

Ground investigations

- The most likely methods you will employ to investigate landslides are:
  - Trial Pitting – MUST be used with caution on landslides and the risk to the engineering geologist logging the face MUST be carefully assessed.
  - Cable percussive drilling – sometimes known as shell and augur. A good method of advancing a hole and sampling soft ground
  - Rotary coring. A good method of sampling in firm soils and rocks. Has limitations related to the use of fluid flushes.

Trial pitting

Advantages:

- allows for undisturbed sampling;

- allows easy identification of slip planes

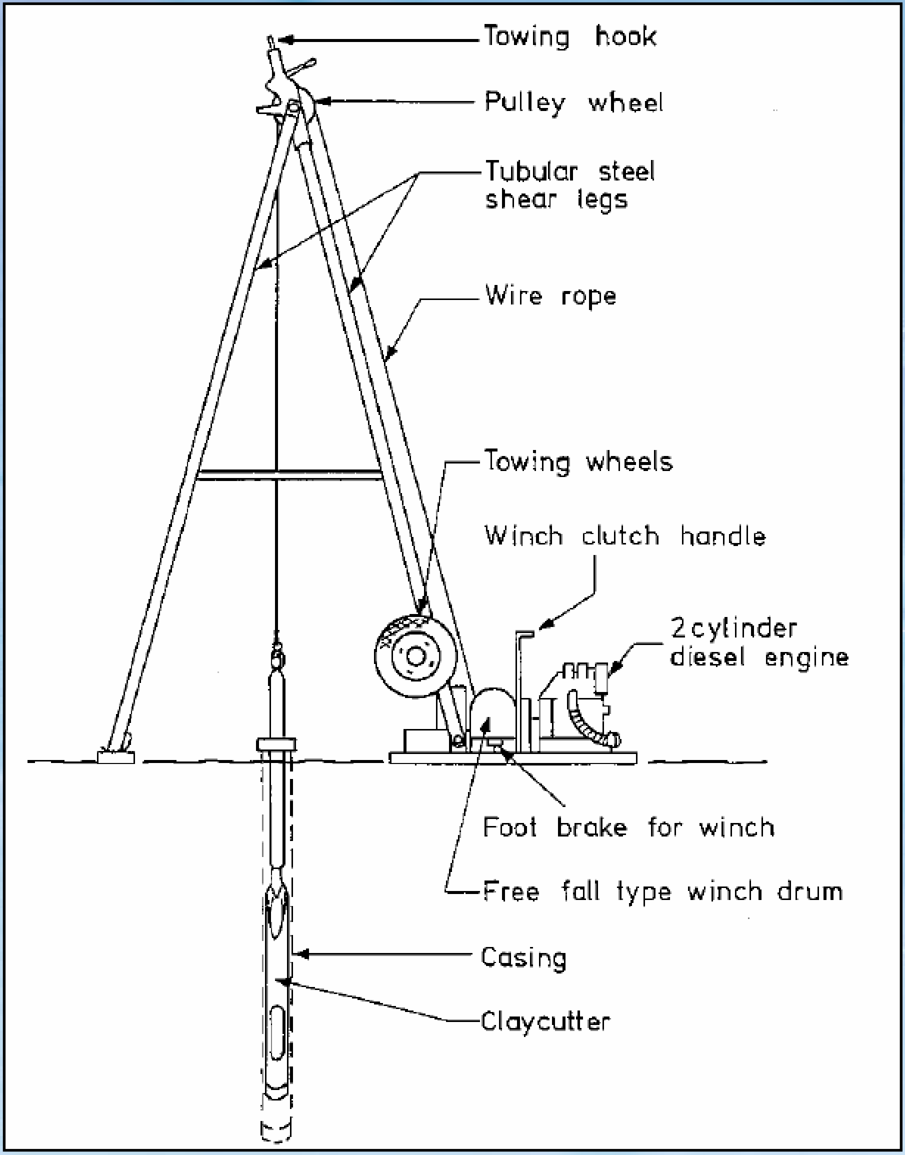
- cheap

Disadvantages:

- Must be supported for safety reasons.

Photographs courtesy of Dr J. A. Lawrence, University of Leeds.

Cable percussive drilling



- Mobile A Frame with power winch 1-2 tonne, towed behind 4x4
- Sand shell/clay cutter driven into ground by weight repeatedly dropped 1-2m
- Used in soils and weak/soft rock and sediments –clays, silts, sands
- Disturbed samples retrieved in U100s (100mm sampler in 150mm casing) for description and classification
- Chisel head used for harder rock
- 15m to 40m depth

Photographs courtesy of Dr J. A. Lawrence, University of Leeds.

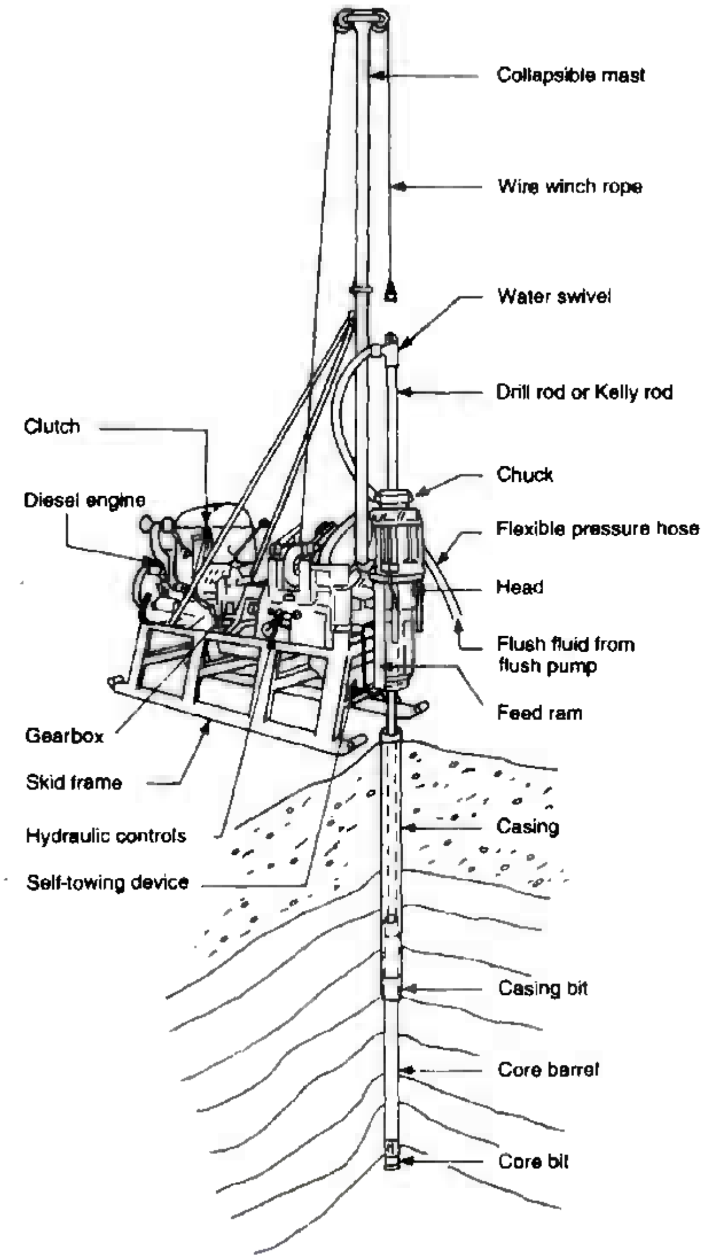
Cable Percussion drill Log

Depth (m)	Sample / Tests	Casing Depth (m)	Water Depth (m)	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water	Instr
0.00-0.50	B1					(0.50)	TOPSOIL. Greyish brown CLAY / SILT			
0.50-1.00	B2				19.72	0.50 (1.40)	Very stiff yellowish brown and light yellowish brown slightly gravelly sandy SILT. Gravel is angular fine to coarse weak siltstone.			
1.50 1.50	D1 U1			40 blows						
1.95 2.00	D2 D3				18.32	1.90	Very stiff yellowish brown and light yellowish grey thinly laminated and closely fissured friable CLAY.			
2.50-2.95 2.50-2.95 2.50-3.00	SPT N=28 D4 B3	2.50		3,4/4,6,9,9		(1.60)				
3.50 3.50	D5 U2			100 blows	16.72	3.50	Very stiff yellowish brown very sandy SILT.			
4.00	D6					(1.10)				
4.50-4.95 4.50-4.95 4.50-5.00 4.60	SPT N=28 D7 B4 D8	4.50		1,4/4,7,8,9	15.62	4.60	...from 4.50m slightly sandy Very stiff to hard brown and light grey laminated closely fissured CLAY with some iron staining.			
5.50 5.50	D9 U3			50 blows		(1.40)				
6.00	D10				14.22	6.00	Very stiff yellowish brown sandy CLAY becoming hard silt / very weak siltstone.			
6.50-6.95 6.50-6.95 6.50-7.00	SPT N=28 D11 B5	6.00		2,7/11,9,5,3						
7.00	W1									
7.50 7.50	D12 U4			100 blows		(3.20)				
8.50-8.87 8.50-8.95 8.50-9.00	SPT 50/220 D13 B6	8.00		8,9/12,16,22					1 1	
9.20	D14			SLOW (1) at 9.20m, rose to 9.00m in 20 mins.	11.02	9.20	Hard brown greyish brown and yellowish brown thinly laminated friable SILT.			
9.50	U5			100 blows						

Remarks	Scale (approx)	Logged by
Hand excavated pit to 1.20m 50mm diameter standpipe installed with raised cover protected by fence PID reading adjacent to BH at 0.30m bgl = 0.3ppm	1:50	AE/EM
	Figure No.	SI1085.BH19

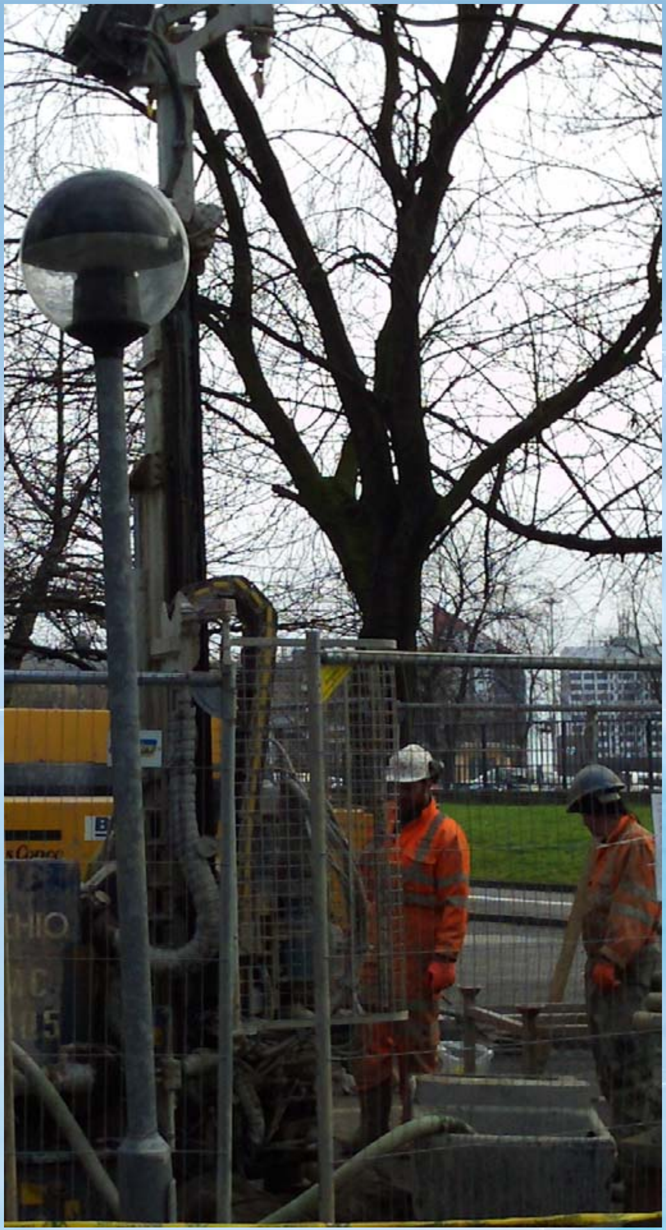
(0.50)		
0.50		
	Very stiff yellowish brown and light yellowish brown slightly gravelly sandy SILT. Gravel is angular fine to coarse weak siltstone.	
(1.40)		

Rotary coring



Layout for small-scale rotary core drilling

- Good method for advancing a hole in rock.
- Good method for obtaining samples.
- Orientation of discontinuities cannot be measured from core due to rotation of core in barrel
- Can induce fractures in weaker rock materials
- Generally requires some form of fluid flush to lubricate and cool drill bit
- Diagram from Clayton et al 1997.



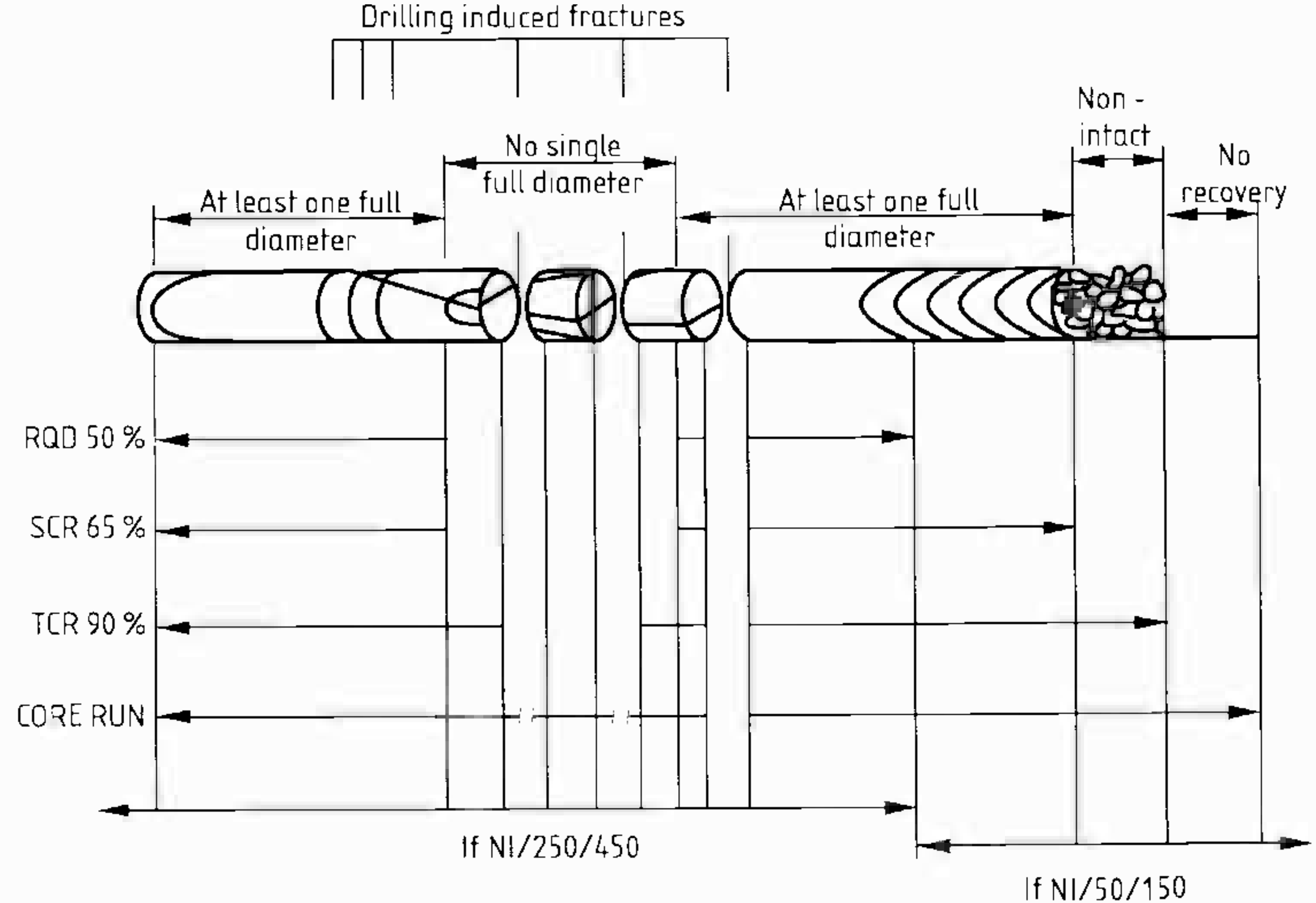
Rotary Log

Depth (m)	TCR	SCR	RQD	FI	Field Records	Level (mOD)	Depth (m) (Thickness)	Description	Legend	Water	Instr
20.00	100	59	27		D29			Very weak to moderately weak thickly bedded orange brown and grey MUDSTONE. Potentially weathered. Discontinuities subhorizontal to subvertical fracture, closely to widely spaced, rough to smooth planar, generally open, heavy orange brown stain penetrating up to 22.20m, silt infill.			
21.00	90	70	30				(2.20)				
22.10	100	98	81			-1.98	22.20	Weak to moderately weak very thickly bedded light grey MUDSTONE interbedded with moderately weak thinly bedded light grey fine grained SANDSTONE. Distinctly weathered. Discontinuities are subhorizontal bedding fracture 20 - 60 degree dip, close to widely spaced tight to open light brown stain penetrating from 24.50m - 28.00m, locally silt and sand infill. ...at 23.50 - 24.40m recovered as moderately weak thinly bedded light grey fine grained SANDSTONE			
23.70	97	75	64				(3.30)				
25.10	100	88	88			-5.28	25.50	Moderately weak to moderately strong very thickly bedded dark and light grey MUDSTONE. Distinctly weathered. Discontinuities are closely spaced, horizontal to subvertical bedding fracture, dipping 30 - 70 degrees, smooth planar, light brown stain, aperture tight and locally clay and silt infill.			
26.00	95	95	81								
27.65	96	91	85				(5.00)				
29.20	90	80	53								

Remarks	Scale (approx)	Logged By
	1:50	AE/EM
	Figure No. S1085.BH19	

Photographs and logs courtesy of Dr J. A. Lawrence, University of Leeds.

2.20	Weak to moderately weak very thickly bedded light grey MUDSTONE interbedded with moderately weak thinly bedded light grey fine grained SANDSTONE. Distinctly weathered. Discontinuities are subhorizontal bedding fracture 20 - 60 degree dip, close to widely spaced tight to open light brown stain penetrating from 24.50m - 28.00m, locally silt and sand infill.
.30)	...at 23.50 - 24.40m recovered as moderately weak thinly bedded light grey fine grained SANDSTONE



NOTE All features shown are natural discontinuities unless stated otherwise.

(After, BS5930, 1999)

Rock Quality Designation

- **Rock Quality Designation index *(RQ*D) was developed by Deere (Deere et al 1967)**
- **defined as the percentage of intact core pieces longer than 100 mm**
- **Core diameter must be at least NX (i.e. 54 mm and upwards)**

Rock Quality Designation

$$RQD = \frac{\sum \text{Length of core} > 10\text{ cm}}{\text{Total length of core run}} \times 100\ \%$$

disadvantages:

it is difficult for the engineering geologists to assess why core has been lost - is it though a high discontinuity density or a weak layer in the stratigraphy

Advantages:

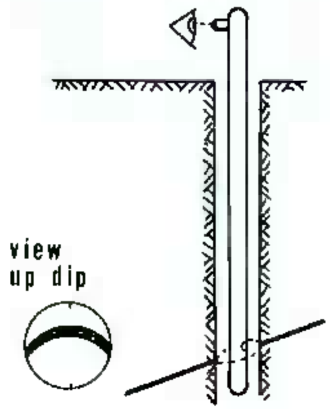
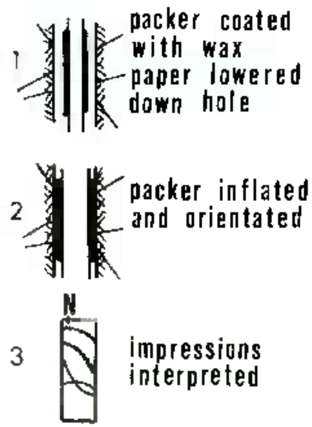
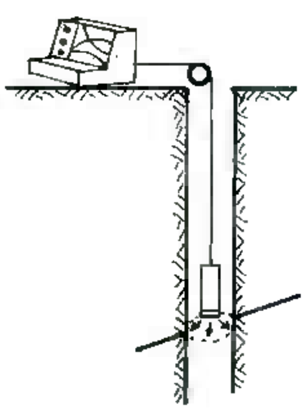
implicitly accounts for discontinuities and weak materials by using core loss as an analogue for fractures and weak layers

Guidelines for sampling

- **Clays:**
  - Normally need undisturbed samples
  - U100 every 1.5m or change of stratum. Blow count and penetration should be noted.
  - If unable to obtain a U100 then bulk samples as above.
  - If U100 does not full penetrate SPT test is required.

- **Silts:**
  - Alternate SPT and U100 samples at 0.75m intervals

- **Sands & Gravels:**
  - Undisturbed samples are not practical due to the lack of cohesion.
  - SPT every 1m or change of stratum.
  - Bulk samples to be taken between SPT.

Methods		Comments
Borehole Periscope		• Simple device that works successfully to about 30 m • Orientation dip and depth can be measured. • Aperture/infill can be observed/photographed. • Water ingress seen if hole pumped dry.
Impression Packer		• Excellent impressions achieved. • Joint characteristics other than orientation are unknown unless reference is made to core. • Care must be taken that compass is fully set before withdrawal.
Television Camera		• Video record can be made of hole • Some systems only suitable for general viewing of quality rather than detailed measurement of joint data.

Methods of downhole discontinuity survey (above - compression packer impression both from Clayton et al 1997)

Guidelines for sampling

- **Rock**
  - SPT on penetrating rock, every 1m and change of stratum where possible
  - In softer rocks (Chalks, Marls) U100 may be possible
  - Rock must be penetrated at least 1.5m to ensure it isn't a large cobble
  - If SPT refusal (>50 blows) record number of blows and penetration

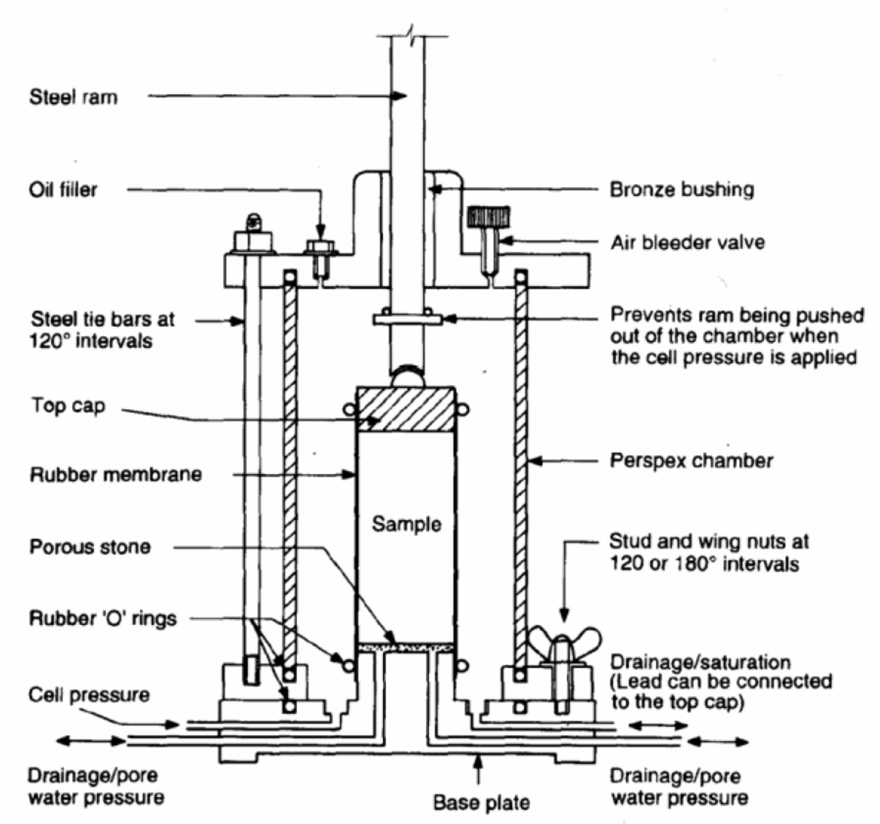
Look at Chris Clayton’s book “Site Investigation” online at:

http://www.geotechnique.info/

Field testing

- SPT : Standard Penetration Test
  - no. of blows/300mm penetration
- Permeability Test
- Vane tests
- Cone Penetration Tests
- In-Situ Density Test
- Index testing
- Point load tests – *important to evaluate the strength of discontinuities.*
- Schmidt Hammer – *important to evaluate the strength of discontinuities.*

Laboratory tests



- Laboratory tests are often considered as an essential part of the ground investigation process.
- Tests should seek to replicate the state of stress in the ground as most failure criteria are actually non-linear in fact.
- Structured soils – such as residual soils – often show strongly non-linear Mohr-Coulomb envelopes.

- Most strength tests require non-disturbed samples.
- Index tests can normally be done on disturbed samples.
- The tests you wish to carry out may dictate what equipment you deploy to site.

Rock Tests

- Direct shear (rock material – intact shear cohesion)
- Direct shear – discontinuities
- Unconfined Compression Test
- Tensile tests (direct and indirect)
- Hoek Cell (triaxial)
- Density

Soil Tests

- UCS – soils (of limited value in slope engineering)
- Triaxial test (UU to CD)
- Direct shear – shear box / ring shear
- Plasticity indices / Atterberg limits
- Moisture content
- Density
- Void ratio

Mainstreaming Slope Stability Management – Hazard and Risk Assessment – to Laos Practitioners

Theme 6

Engineering Geological Assessments

6.4 – Geological sections and monitoring movement see practical exercise