Dr. GM Reeves

For

The Stonehenge Alliance

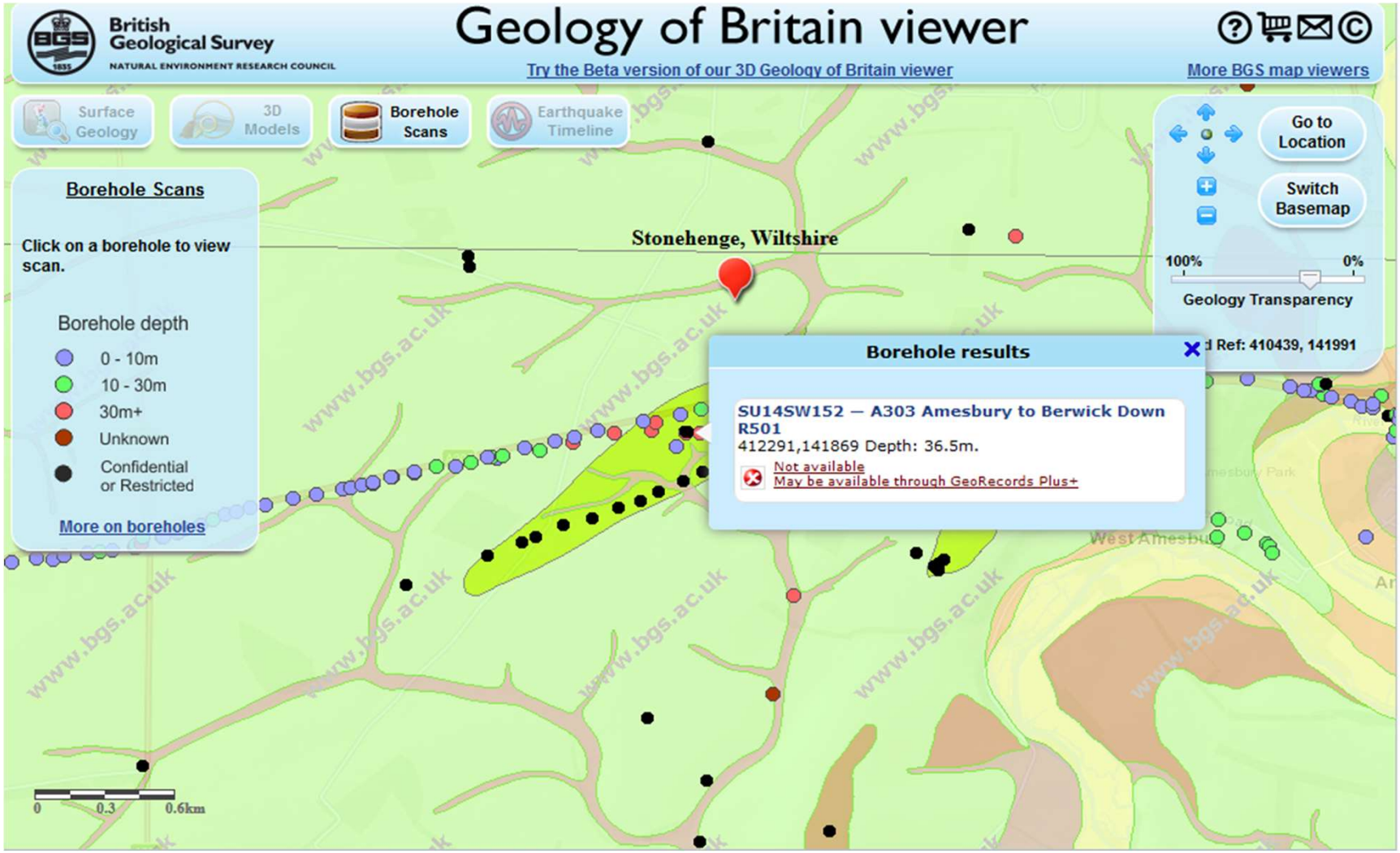
On

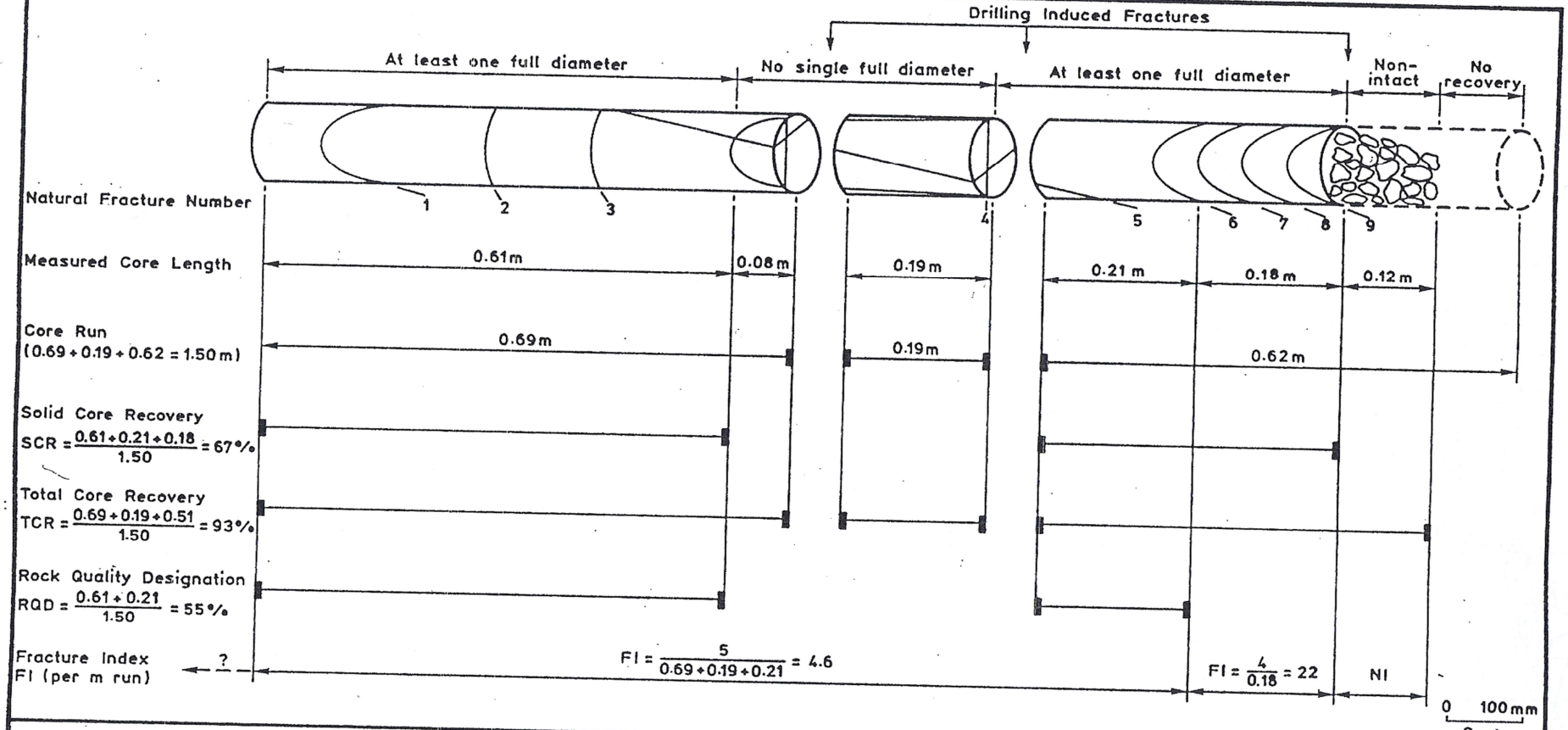
Geology, Hydrogeology, Geotechnics &

Effects of Tunnelling on Groundwater

Core Drilling, Core Logging & RQD: Wireline Logging

- Core Drilling & Recovery Methods
    - Wireline Recovery
    - Triple Tube core barrels
- Core Logging
- Rock Mass Classification
- TCR; SCR & RQD
    - Rock Quality Designation:
    - Rock Strength Classification Systems (CIRIA etc).
- Geophysical Logging Techniques:-
    - Caliper Logging
    - Natural Gamma
    - Optical & Acoustic Televiewers


British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
Geology of Britain viewer
Try the Beta version of our 3D Geology of Britain viewer
More BGS map viewers
Surface Geology
3D Models
Borehole Scans
Earthquake Timeline
Go to Location
Switch Basemap
100%
0%
Geology Transparency
Borehole Scans
Click on a borehole to view scan.
Borehole depth
0 - 10m
10 - 30m
30m+
Unknown
Confidential or Restricted
More on boreholes
Stonehenge, Wiltshire
Borehole results
SU14SW152 – A303 Amesbury to Berwick Down R501
412291,141869 Depth: 36.5m.
Not available
May be available through GeoRecords Plus+
0
0.3
0.6km

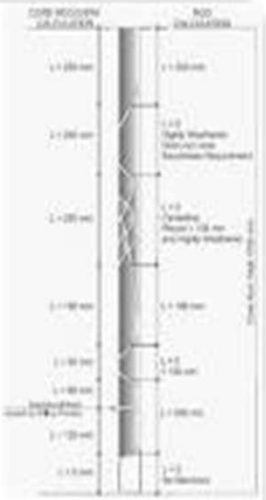


Notes : (1) All fractures shown on the core are natural unless otherwise stated.
(2) Table adapted from Norbury et al (1984).

Schematic Illustration of Fracture Logging Terms

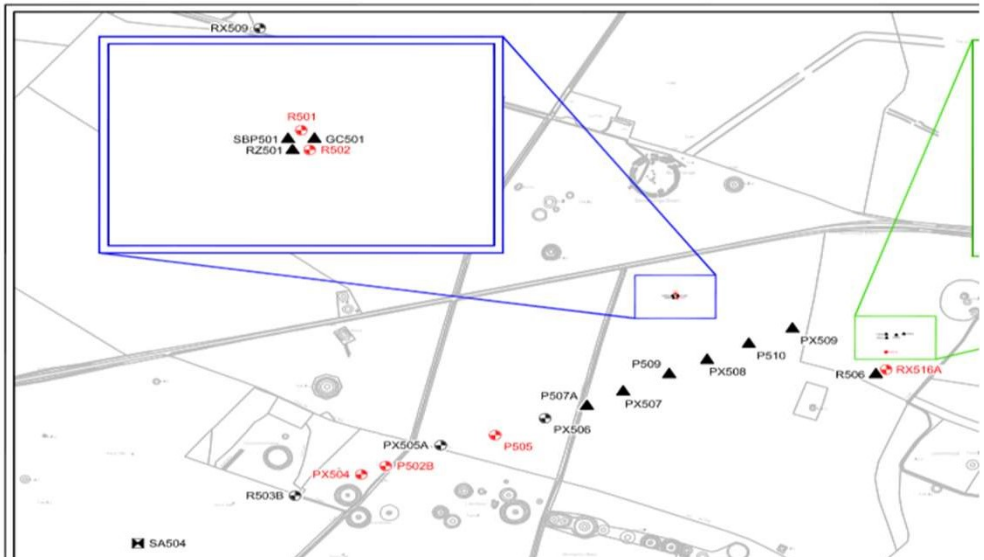
RQD

Rock Quality Designation (**RQD**) is a measure of quality of rock core taken from a borehole. **RQD** signifies the degree of jointing or fracture in a rock mass measured in percentage, where **RQD** of 75% or more shows good quality hard rock and less than 50% show low quality weathered rocks.



What is RQD (Rock Quality Designation) and How to Calculate it?

https://theconstructor.org/geotechnical/rqd-rock-quality-designation.../20536/



STRUCTURAL SOILS — FINAL

BOREHOLE LOG

Contract:	Client:	Borehole:
A303 Amesbury to Berwick Down	Highways England	R501

Contract Ref:	Start / End	Ground Level (m AOD):	National Grid Co-ordinate:	Sheet:
731823	Start: 22.02.17 End: 01.03.17	93.16	E:412291.0 N:141868.9	8 of 33

Depth (m)	No	Type	Results	TCR (%)	SCR (%)	RQD (%)	If (mm)	Flush Returns & Details
				80	56	56		0% return Air+Mist
17.80	14	C						
18.00-18.75 (0:05)				85	53	53	NI 100 220	0% return Air+Mist
18.50	PS7	ES						
18.75-20.25 (0:09)				100	0	0	NI	0% return Air+Mist
19.00	15	C						
19.50	PS8	ES						

Description of Strata:
brown chalk.
. . . at 14.30m chalk fragments are extremely weak.
. . . at 14.35m to 14.65m joint is 85° undulating rough open brown communted chalk.
. . . at 14.50m to 14.70m joint is 75° undulating rough open infilled with communted chalk.
. . . at 14.75m phosphatic chalk becomes very weak.

between 14.75m and 16.00m chalk fragments weak.
. . . at 14.85m to 15.00m heavily phosphatic.
. . . at 15.20m joint is 45° undulating rough open communted chalk.
. . . at 16.00m phosphatic chalk becomes very weak.
. . . at 16.00m to 16.75m joint is 85° undulating rough open black specks and lower fracture surface between 16.20m and 16.60m.
. . . from 16.00m to 18.75m becomes very weak as per nail test and fragment test.
. . . between 16.55m and 16.73m joint is 75° planar rough with black specks and brown staining upper fracture surface fragmented.
. . . at 17.90m to 18.00m nail test (17/18/18) hard surface very weak.
. . . at 18.35m to 18.55m joint is 70° planar rough infilled with communted chalk (<2mm).
. . . at 18.35m and 18.70m joints are closely spaced.
. . . at 18.58m to 18.68m joint is 70° planar rough communted chalk.

Fracture Log: 26[i], 27[i]

Reduced Level: 74.41 — Depth (Thickness): 18.75, (1.50)

Boring Progress and Water Observations

Date	Time	Borehole Depth	Casing Depth	Borehole Diameter (mm)	Water Depth

General Remarks

All dimensions in metres — Scale: 1:14

Method Used:	Plant Used:	Drilled By:	Logged By:	Checked By:
Inspection pit + Rotary Cored	Comacchio Geo 602	Ryan Pincher	RHunt + BSalmen	AGS

STRUCTURAL SOILS — FINAL

BOREHOLE LOG

Contract:	Client:	Borehole:
A303 Amesbury to Berwick Down	Highways England	R501

Contract Ref:	Start / End	Ground Level (m AOD):	National Grid Co-ordinate:	Sheet:
731823	Start: 22.02.17 End: 01.03.17	93.16	E:412291.0 N:141868.9	9 of 33

Depth (m)	No	Type	Results	TCR (%)	SCR (%)	RQD (%)	If (mm)	Flush Returns & Details
20.10	16	C		100	0	0	NI	
20.25-21.00 (0:02)								0% return Air+Mist
20.60	PS9	ES		100	20	20		
20.82-20.95	17	C						
21.00-22.50 (0:02) 21.00-21.30	18	C					10 100 150	0% return Air+Mist
21.50	PS10	ES		50	36	36		

Description of Strata:
Extremely weak and very weak brown CHALK (crumbles into multistepped fine to coarse angular fragments of chalk up to 30mm on inspection). There are weaker zones probably formed by the weathering of chalk (fragments at the centre of the core are very weak) (possible weakening/disturbance of chalk from use of multistep drilling tools). (PHOSPHATIC CHALK)

Very weak to weak medium density brown phosphatic CHALK. Fractures are subhorizontal to subvertical extremely closely to closely spaced (10/100/150) undulating rough open black specks subhorizontal closely spaced subvertical to extremely to very closely spaced. (PHOSPHATIC CHALK Grade A5)
. . . between 20.25m and 20.50m non intact recovered as fine to coarse angular gravel size fragments of phorphitic (brown chalk). Chalk is very weak medium density.
. . . at 20.55m and 20.75m subvertical (85°) joint undulating rough black specks.
. . . at 20.75m and 20.90m non intact recovered as fine to coarse angular fragments of chalk. Chalk is very weak to weak.
. . . at 20.80m to 21.00m nail test (6/11mm) probably weak high density.

Very weak high density brown phosphatic CHALK with occasional lenticular

Fracture Log: 28[i], 29[i], 30[i], 31

Reduced Level	Depth (Thickness)
72.91	20.25
	(0.75)
72.16	21.00
	(0.75)
71.41	21.75
	(1.45)

Material Graphic Legend: AZCL

Boring Progress and Water Observations

Date	Time	Borehole Depth	Casing Depth	Borehole Diameter (mm)	Water Depth

General Remarks

All dimensions in metres — Scale: 1:14

Method Used:	Plant Used:	Drilled By:	Logged By:	Checked By:
Inspection pit + Rotary Cored	Comacchio Geo 602	Ryan Pincher	RHunt + BSalmen	AGS

STRUCTURAL SOILS — FINAL

BOREHOLE LOG

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A303 Amesbury to Berwick Down	Highways England	R501

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731823	Start: 22.02.17 End: 01.03.17	93.16	E:412291.0 N:141868.9	32 of 33

R501 box 20, 18.75m - 20.25m depth (Rigside)

R501 boxes 20 - 21, 18.70m - 21.00m depth (Compound)

R501 boxes 20 - 21, 18.70m - 21.00m depth (logging area)

STRUCTURAL SOILS

FINAL

BOREHOLE LOG

Contract:		Client:		Borehole:
A303 Amesbury to Berwick Down		Highways England		R501
Contract Ref:	Start: 22.02.17	Ground Level (m AOD):	National Grid Co-ordinate:	Sheet:
731823	End: 01.03.17	93.16	E:412291.0 N:141868.9	10 of 33

Depth (m)	Samples & Testing: No	Type	Results	Mechanical Log: TCR (%)	SCR (%)	RQD (%)	If (mm)	Flush Returns & Details	Sacrifi	Water	Description of Strata	Frac Freq	Reduced Level	Depth (Thickness)	Material Graphic Legend
22.50-23.20 (0:01)								0% return 2nd shift			or patches of chalk and brown phosphatic sandy matrix. Fractures are subvertical very closely spaced undulating rough to planar rough open/closed infilled with cemented chalk and black specks. (PHOSPHATIC CHALK Grade B4)				AZCL
											. . . at 21.00m to 21.75m percentage of phosphate content comparatively less.				
											. . . at 21.30m to 21.40m joint is 85° undulating rough open black specks and another joint 85° cuts across previous one (conjugate joints).	3(0)	69.96	23.20	
23.20-24.00 (0:01)											. . . at 21.43m to 21.52m joint is 50° undulating rough open with black specks.				
23.30	19	C									. . . at 21.50m to 21.68m incipient joint (85°) planar rough closed.			(0.80)	
23.70	PS11	ES		100	77	41	70 100 250	0% return 2nd shift			Assumed zone of core loss.				
											Very weak medium density brown phosphatic CHALK containing patches/lenticular sheped chalk and brown phosphatic irregular randomly disturbed brown sandy matrix. Fractures are subhorizontal to subvertical very closely to medium spaced undulating rough planar rough infilled with brown sandy chalk upto 4mm. (PHOSPHATIC CHALK Grade C3)	3(0)	69.16	24.00	
24.00-25.00 (0:01)											. . between 23.20m and 24.00m chalk dark brown and highly polished.				
											. . . at 23.30m to 23.42m joint is 75° undulating rough open black specks.				
											. . . at 23.80m fracture is subhorizontal open undulating rough brown sand upto 2mm.		68.16	25.00	
24.50	PS12	ES		55	44	39	80 190	0% return 2nd shift						(1.00)	

Boring Progress and Water Observations					
Date	Time	Borehole Depth	Casing Depth	Borehole Diameter (mm)	Water Depth

General Remarks

All dimensions in metres — Scale: 1:14

Method Used:	Plant Used:	Drilled By:	Logged By:	Checked By:
Inspection pit + Rotary Cored	Comacchio Geo 602	Ryan Pincher	RHunt + BSalmon	AP

STRUCTURAL SOILS

FINAL

BOREHOLE LOG

Contract:		Client:		Borehole:
A303 Amesbury to Berwick Down		Highways England		R501
Contract Ref:	Start: 22.02.17	Ground Level (m AOD):	National Grid Co-ordinate:	Sheet:
731823	End: 01.03.17	93.16	E:412291.0 N:141868.9	11 of 33

Depth (m)	Samples & Testing: No	Type	Results	Mechanical Log: TCR (%)	SCR (%)	RQD (%)	If (mm)	Flush Returns & Details	Sacrifi	Water	Description of Strata	Frac Freq	Reduced Level	Depth (Thickness)	Material Graphic Legend
25.00-26.00 (0:01)											. . . between 23.87m and 23.97m joint is 50° planar rough infilled with brown sand.				
25.12-25.12	20	C									Extremely weak low density brown phosphatic CHALK with patches/lense of white chalk and disturbed in brown phosphatic sandy matrix. Fractures are randomly orientated extremely closely to very closely spaced undulating rough open to moderately wide infilled with brown sandy phosphatic and fine gravel sized fragments more than 4cm. (PHOSPHATIC CHALK Grade C4)			(1.00)	
				90	82	79	88 190	0% return 2nd shift			. . . at 24.00m end 25.00m chalk becomes lower end of very weak.				
25.80	PS13	ES									at 24.00m to 25.00m only 55mm recovery loss of recovery due to possible intense fracturing.				
25.93	21	C									. . . between 24.90m to 26.00m highly phosphatic.		67.16	26.00	
26.00-27.50 (0:02)											. . . at 24.90m and 25.00m nail test grains 27mm of penetration (extremely weak low density) at rig site.				
26.13-26.40	22	C									Very weak medium density brown phosphatic CHALK with patches/lenses of white chalk disturbed in brown phosphatic sandy matrix (possible burrow infilled). Fractures are subhorizontal closely spaced undulating rough open infilled brown sand up to 2mm. (PHOSPHATIC CHALK Grade B4)	3(0) 3(0)			
26.48-26.70	23	C									. . . at 25.00m and 26.00m phosphatic chalk becomes very weak medium density.				
				100	98	87	70 308 620	0% return 2nd shift			. . . at 25.33m, 25.56m and 25.92m fractures are				
26.80	PS14	ES													

Boring Progress and Water Observations					
Date	Time	Borehole Depth	Casing Depth	Borehole Diameter (mm)	Water Depth

General Remarks

All dimensions in metres — Scale: 1:14

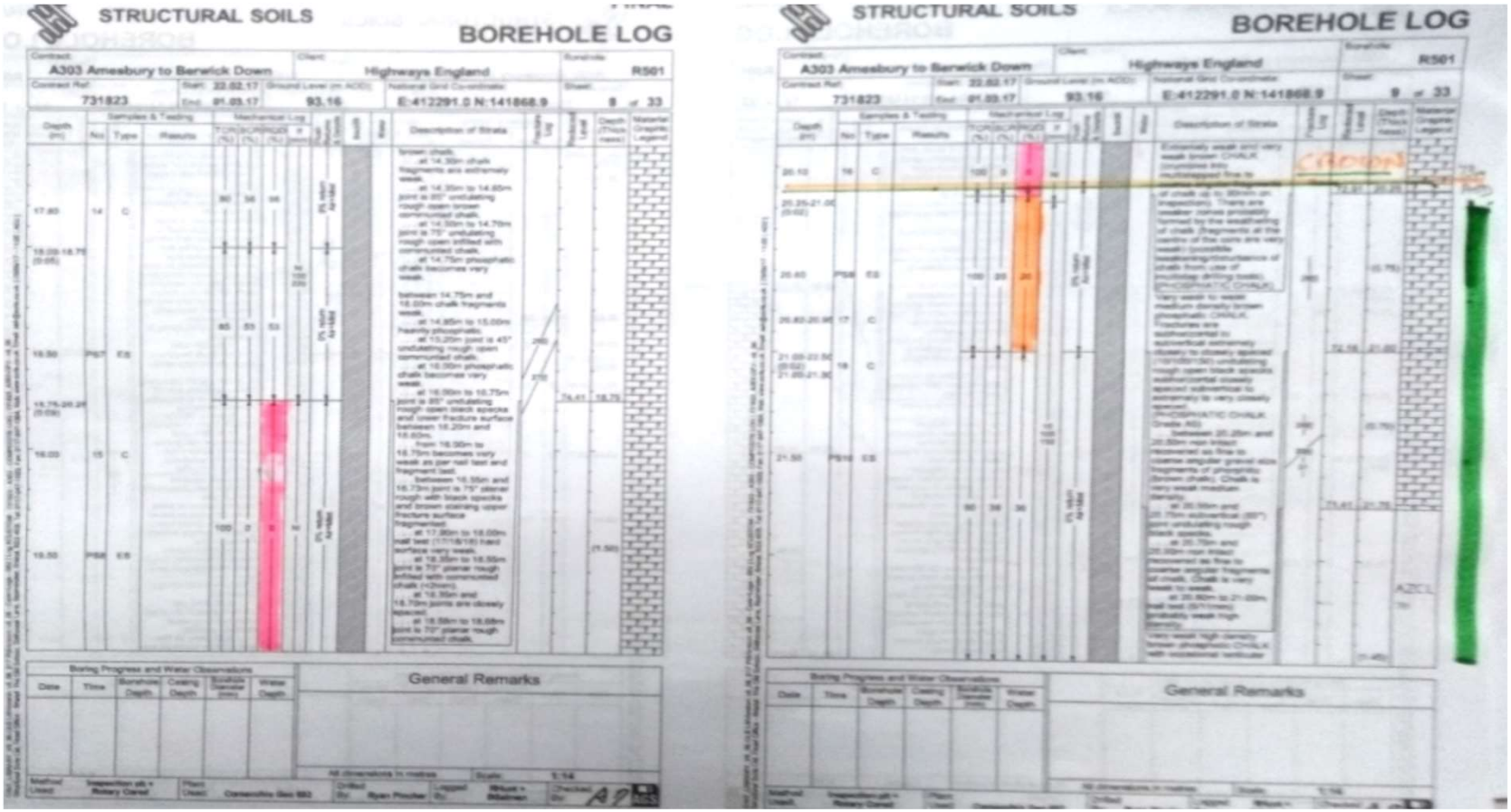
Method Used:	Plant Used:	Drilled By:	Logged By:	Checked By:
Inspection pit + Rotary Cored	Comacchio Geo 602	Ryan Pincher	RHunt + BSalmon	AP

R501 boxes 25 - 27, 24.00m - 27.50m depth (Logging area)

R501 boxes 25 - 27, 24.00m - 27.50m depth (Compound)

R501 boxes 25 - 26, 24.00m - 26.00m depth (Riqside)

Tunnel Crown Level- Chn. 8700: BH. No. R501



From Mortimore -11th Glossop Lecture 2012 (QJEGH

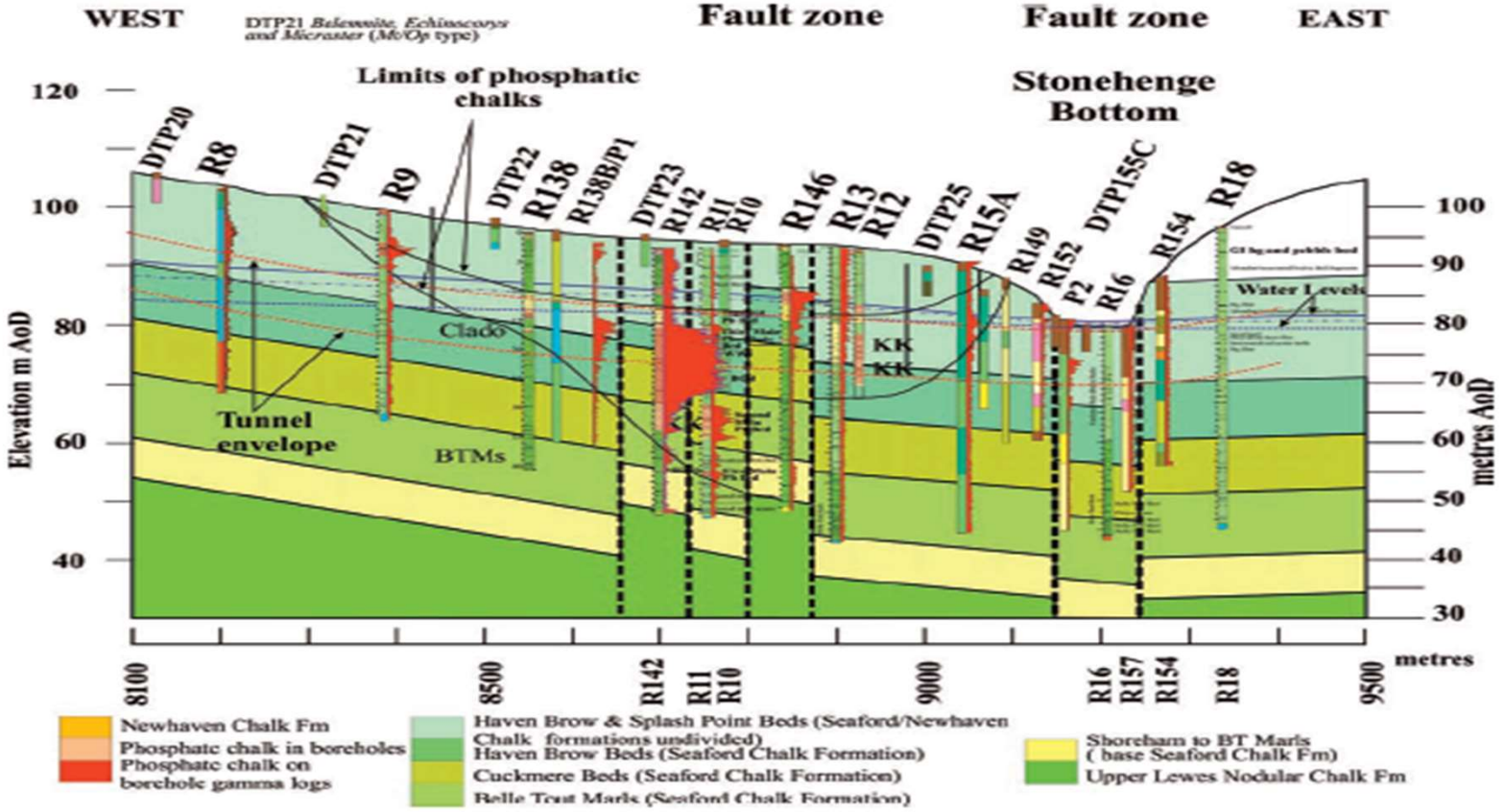


Fig. 120. Simplified geological section of the Chalk and the phosphatic chalk deposits at Stonehenge showing the fault-controlled Stonehenge Bottom and the fault zone containing the thickest phosphatic chalks identified in cored boreholes and on the natural gamma borehole logs.

From Mortimore et al 2017

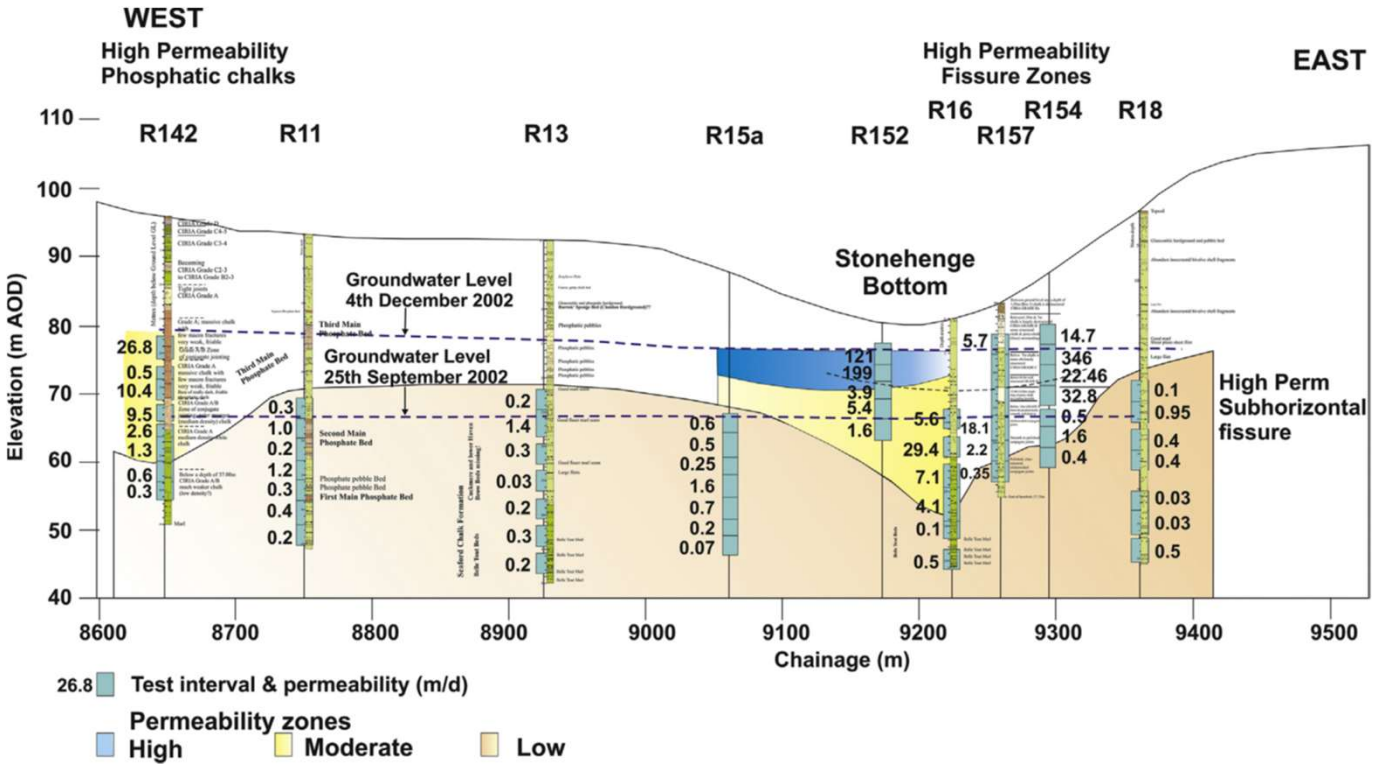
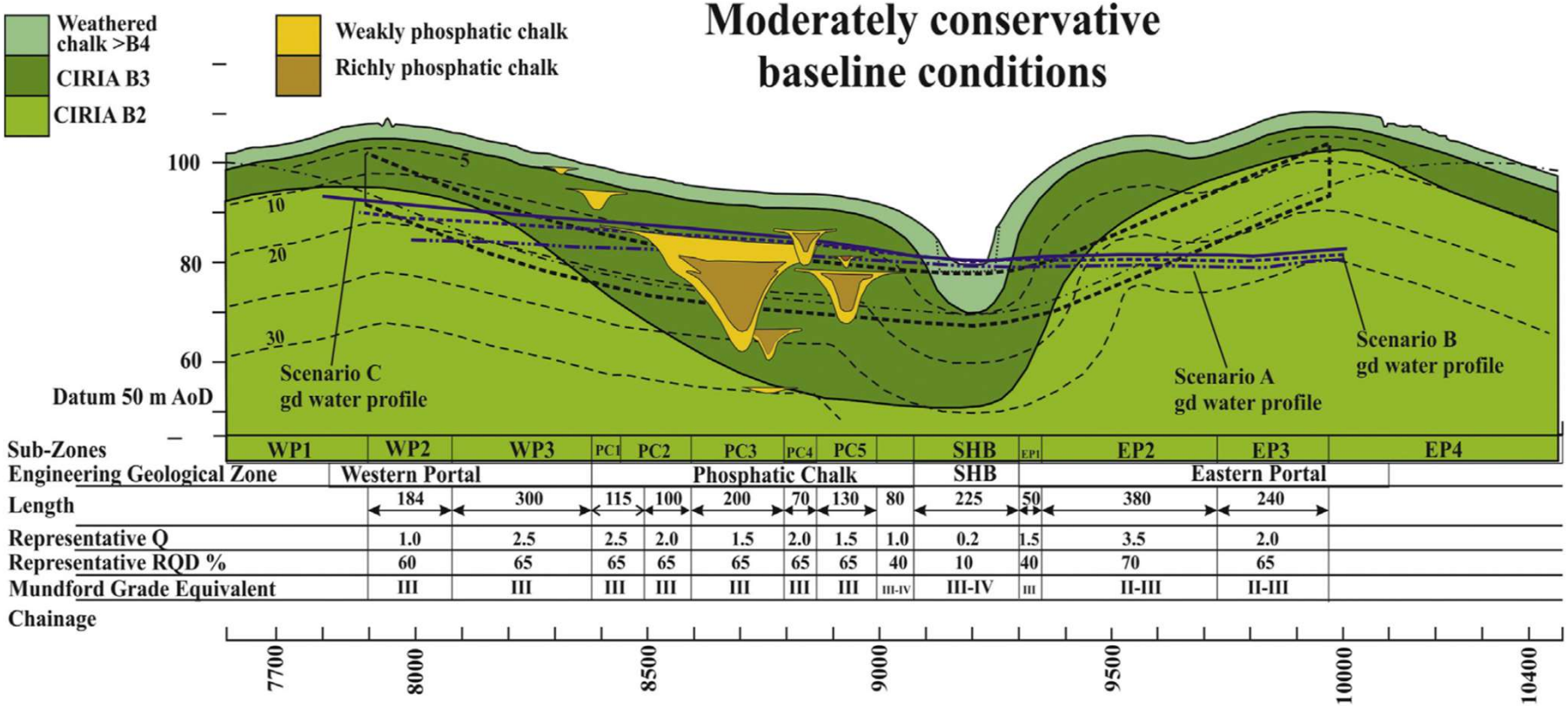


Fig. 26. A303 Stonehenge Tunnel section Packer Test permeability profile showing increased permeability (metres per day) in the thicker phosphatic-chalks (Borehole R142) and in fracture zones associated with the dry valley, Stonehenge Bottom. In the tighter rock towards the interfluve on the east side of Stonehenge Bottom groundwater permeability is focussed along a subhorizontal fissure (Borehole R18). Note the rapid rise in groundwater (watertable) between September and December 2002.

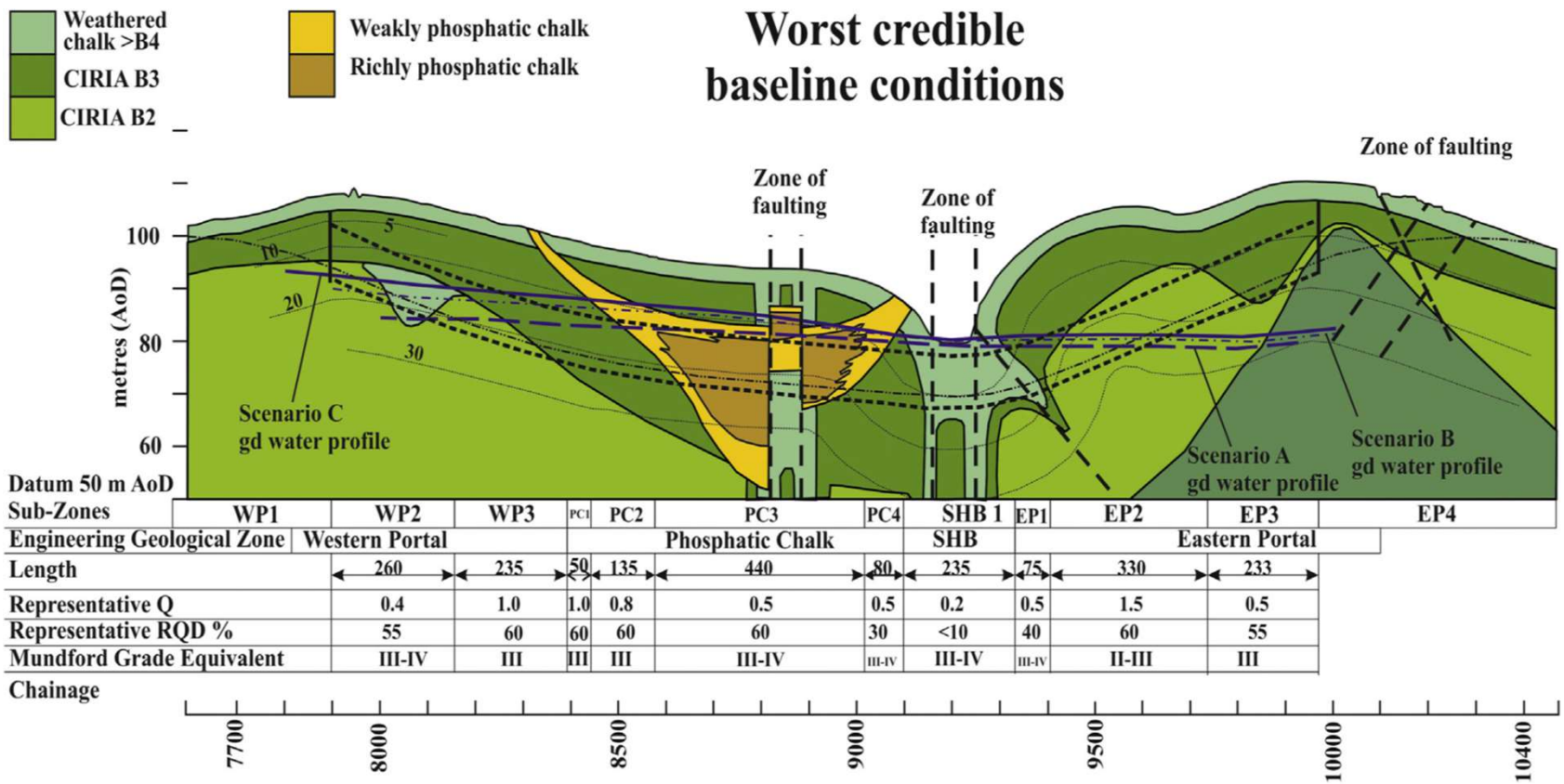
Groundwater Data, Modelling and Groundwater Barriers

- Drill Log Data
- Groundwater Observations & Monitoring.
- Multi-Seasonal Records
- Fracture Flow
- Chalk Hydrogeology

Mortimore et al: PGA 2017- Figure 27



Mortimore et al: PGA 2017- Figure 27



Simplified Conceptual Groundwater Flow Regime

: 1.- From Mortimore et al; 2017.

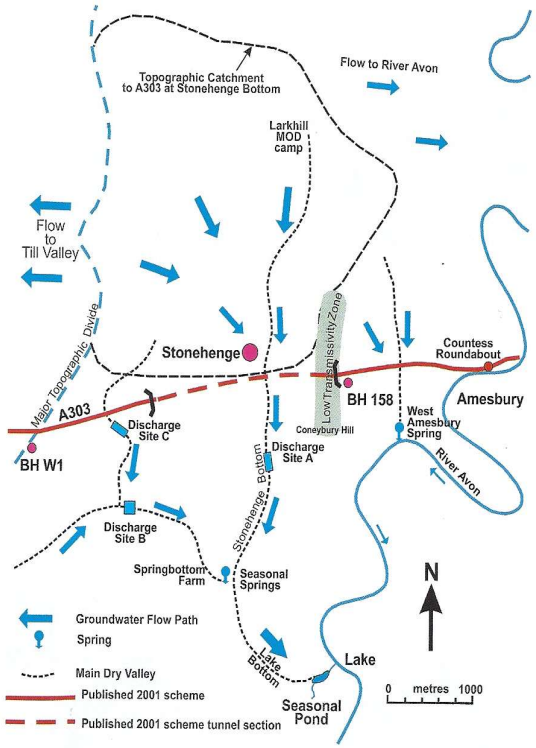
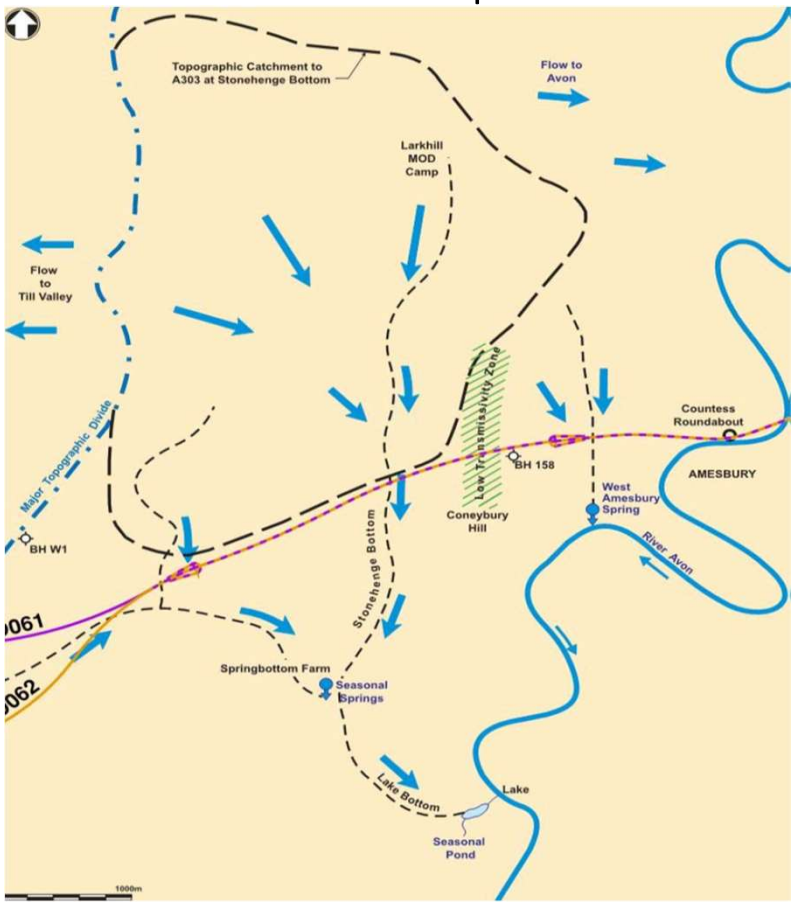
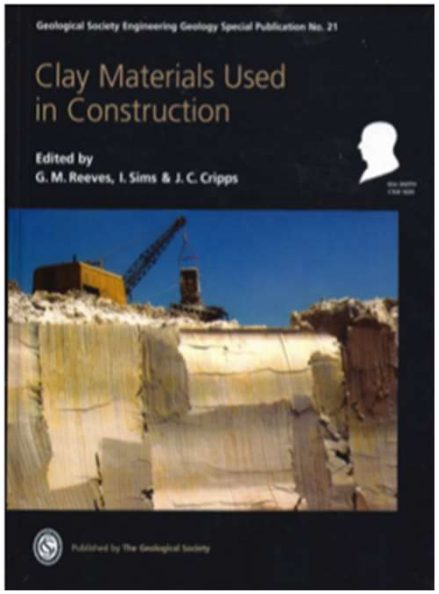


Fig. 28. A303 Stonehenge tunnel area conceptual groundwater flow regime. Stonehenge Bottom acts as a drain to the area with a spring located downstream at Springbottom Farm and a seasonal pond in Lake Bottom close to the River Avon. During the rapid rise in groundwater levels in 2002 the floor of Stonehenge bottom became flooded up to the A303 crossing and Trial Pits on the west side partly filled with water.

2. From Halcrow-Gifford 2006 & Arup-Atkins 2016.



Bentonite Shield Tunnelling Methods, Grouting, :Poor Quality Rock and Grout Invasion.



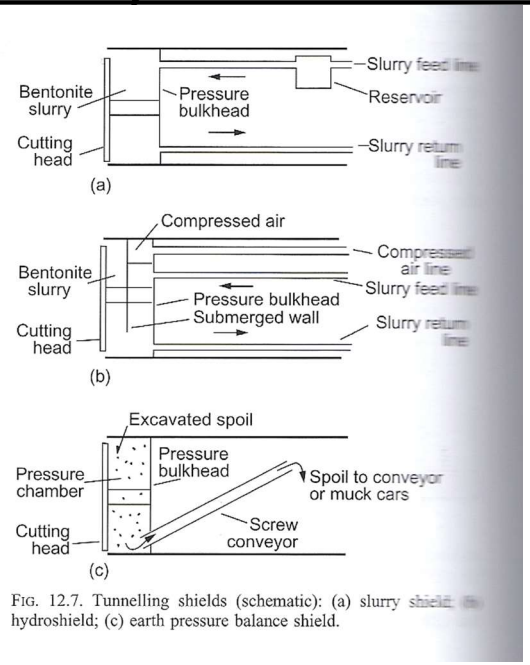
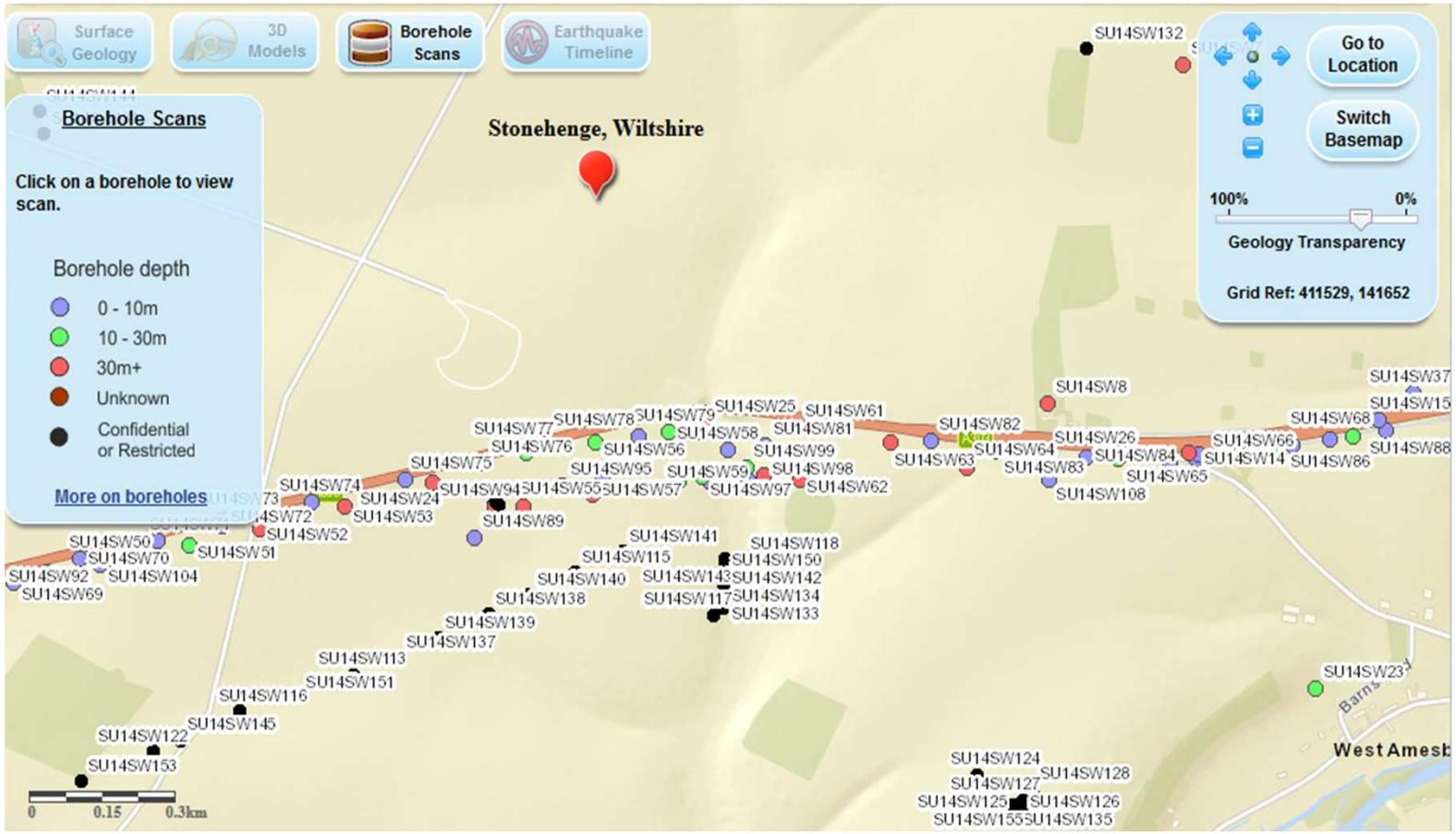


FIG. 12.7. Tunnelling shields (schematic): (a) slurry shield; (b) hydroshield; (c) earth pressure balance shield.

Slurry (Bentonite Based) Tunnelling:

- **Up to 12 to 15% Bentonite**
- **Additives to aid filter cake formation (eg. Long Chain Polymers such as …**
  - **Sodium carboxy methyl cellulose,**
  - **Polyanionic cellulose (PAC),**
  - **Polyacrylamides & derivitives.**
- **High degree of Penetration into formation in:-**
  - **Fracture Zones**
  - **Poor quality fractured rock**
  - **High Permeability rock.**
- **Maximum Penetration of Latents into high K zones.**

BGS GeoIndex Database:



Durrington Down
DURRINGTON
Dismantled Railway
Durrington Walls
Undercliff
Fargo Road
Tumuli
Tumulus
Cursus
Fargo Plantation
Durrington Down Farm
Sewage Works
Strangways
Married Quarters
Woodhenge
Totterdown Clump
The Cursus
Long Barrow
A 344
MS
Memorial
Old King Barrows
Stonehenge Avenue (course of)
Countess
Countess Farm
Motel
New King Barrows
Stonehenge
Stonehenge Cottages
Long Barrow
Tumuli (Winterbourne Stoke Group)
King Barrow
Winterbourne Stoke Clump
Normanton Gorse
Henge (site of)
West Amesbury
Luxenborough
Coneybury Hill
Coneybury House
Amesbury Park
Amesbury Abbey
Queensberry Falls (Weir)
Fort
Bush Barrow
Normanton Down
The Diamond
Wilsford Down
Moor Hatches
New Barn
Ham Hatches
Sewage Works
Aqueduct
Pit (dis)
Chalk Pit
Southmill Hill Plantation
AMESBURY CP
Springbottom Farm
Normanton Down House
Normanton
Lake Group
Long Barrow
43
42
41
10
13
14
15
WILSFORD CUM LAKE CP
SAL 2000
*1:10,000 'RESCALED'.

Modern Methods of Ground Data Presentation: 3-D Ground Modelling

- 2 Dimensional :-
  - Maps
  - Sections
  - Fence Diagrams

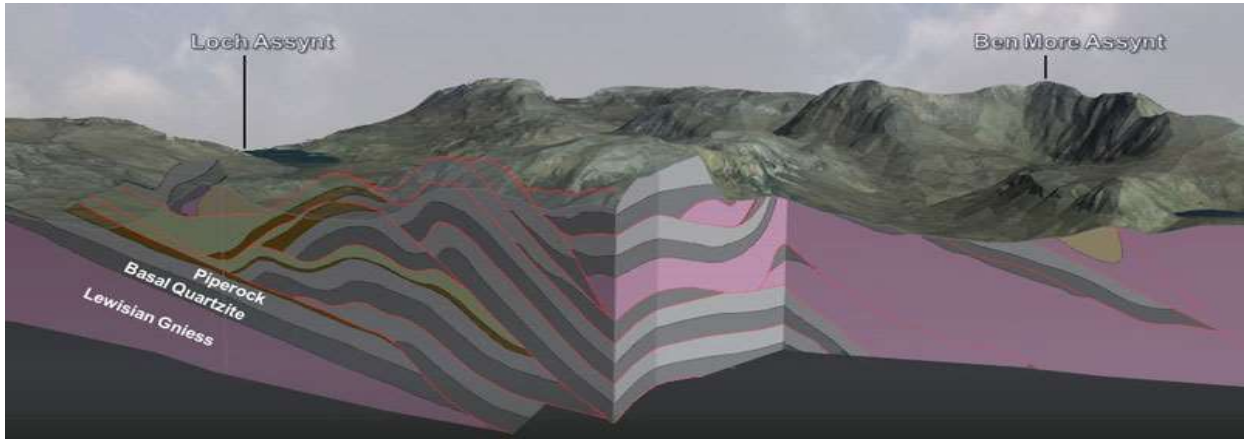
- 3-D Modelling:-
  - Borehole Logs and Data
  - Rock Properties- Strength/Lithology/Degree of Fracturing/Fault Zones
  - Alteration Zones (e.g. Phosphatic Chalk)
  - Groundwater Levels, Zones; Aquifers; Aquicludes; Recharge & Discharge
  - 3-D Geophysics- Methods; Combined Interpretations; Exponential Data Gains.

3-D Geological Ground Modelling

- **Summary Paper: Entwistle et al; January 2019 BCA Singapore, ...**http://nora.nerc.ac.uk/id/eprint/522402/1/3D%20geological%20modelling%20at%20the%20British%20Geological%20Survey_pdf_Final.pdf
- Lithoframe Examples (See.... https://www.bgs.ac.uk/services/3Dgeology/lithoframe.html)
  - Assynt Culmination Geological 3D Model (©BGS)

Assynt Culmination 3D geological model | UK geology .bgs.ac.uk 800 × 342 jpeg Image may be subject to copyright.

  - https://youtu.be/WkOWUzvAxq4

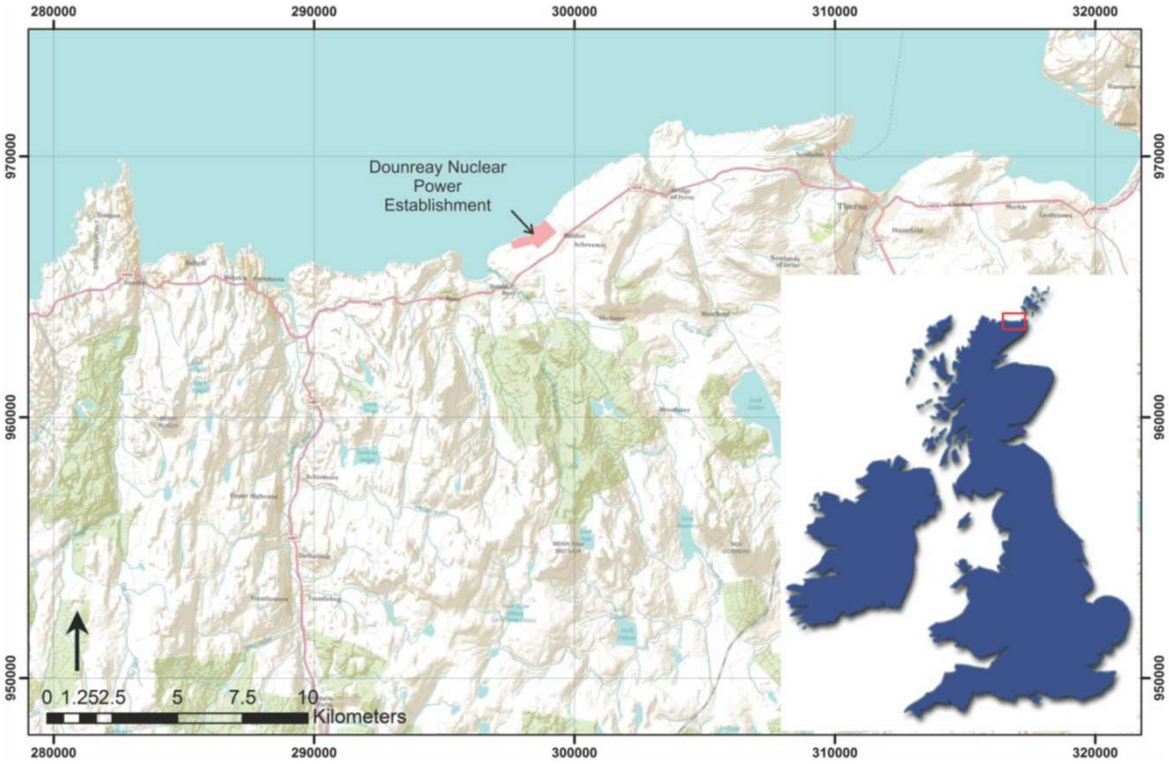


Conclusions:

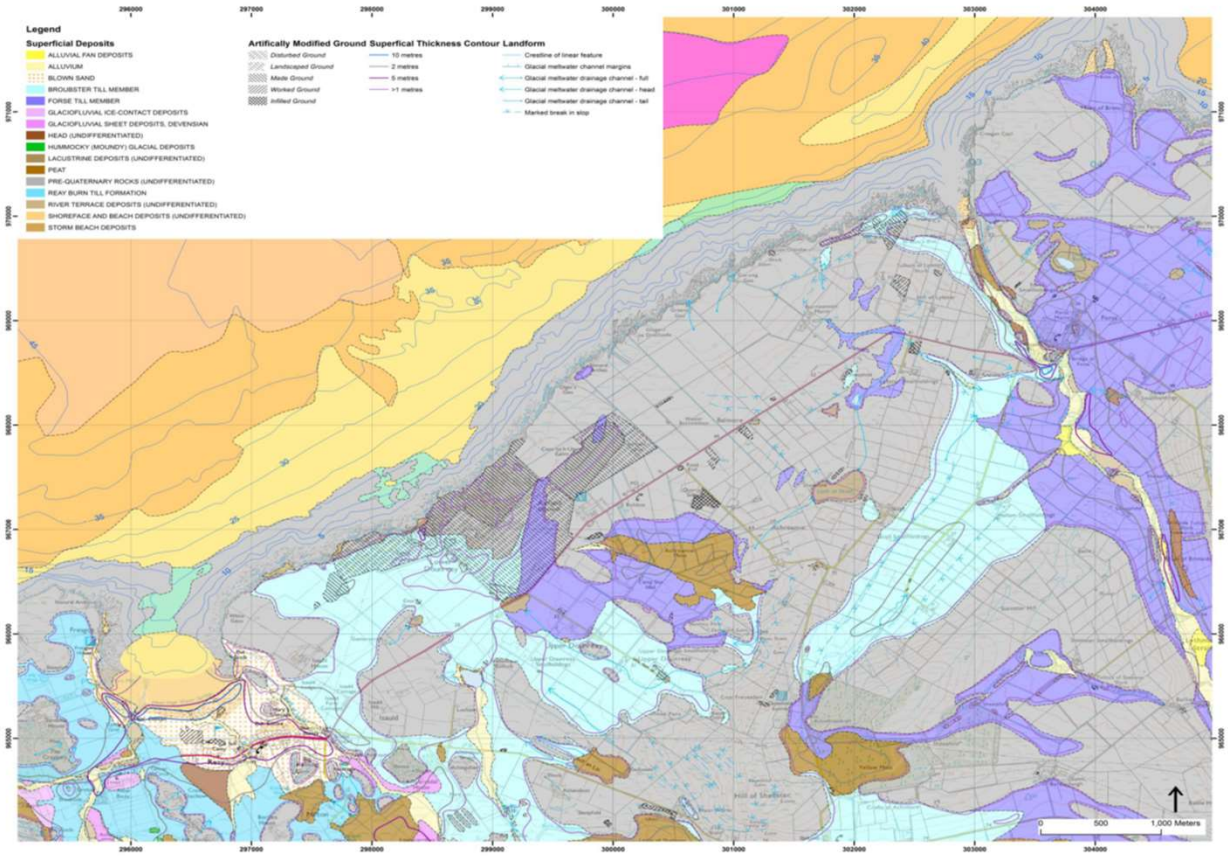
- **Potential Creation of massive, deep & penetrative (to up to 50m BGL)**
  GROUNDWATER CUT-OFF/"Groundwater Dam"- 3.3km+long.
- **Significant long-term changes in :- Groundwater Flow, G/W recharge,**
  G/W discharges, G/W chemistry and quality, Well yields and
  Chalk Rock solution (especially in Phosphatic zones).
- **Potential for short-term contamination from grouting (ex-TBM) and possible need for back-up surface dewatering and grouting, with associated effects**
- **Inadequate (inc. interpretation of existing)- Site Investigation Data (Drill & Well-logs)**
  - **Groundwater Data and consequent G/W Modelling**
  - **Data presentation (3-D Ground Modelling)**
  - **Rock Permeability values,changes across site and effects.**

gmr 01.06.19

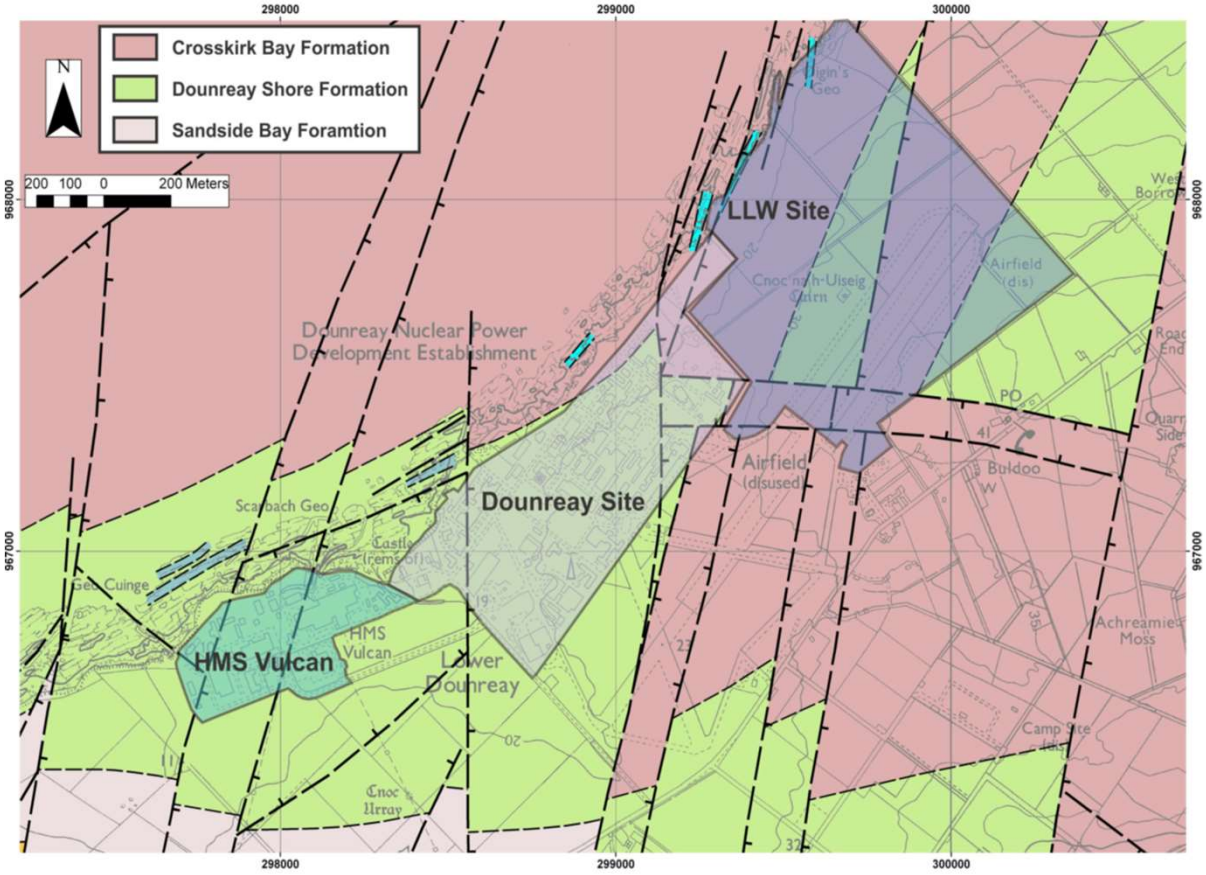
Location of the Dounreay Site



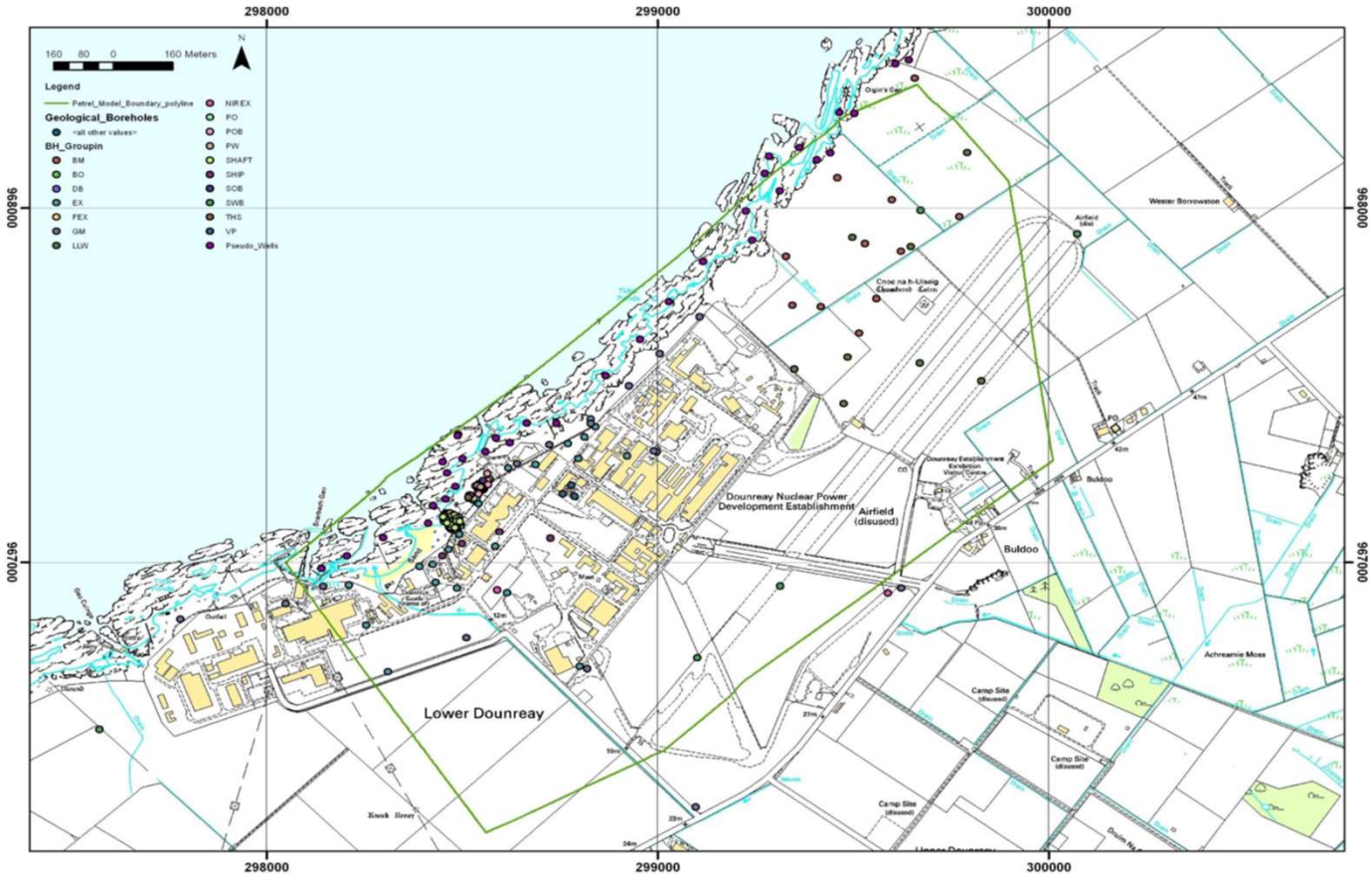
Superficial Deposits (1:25,000 map:- BGS 2006)



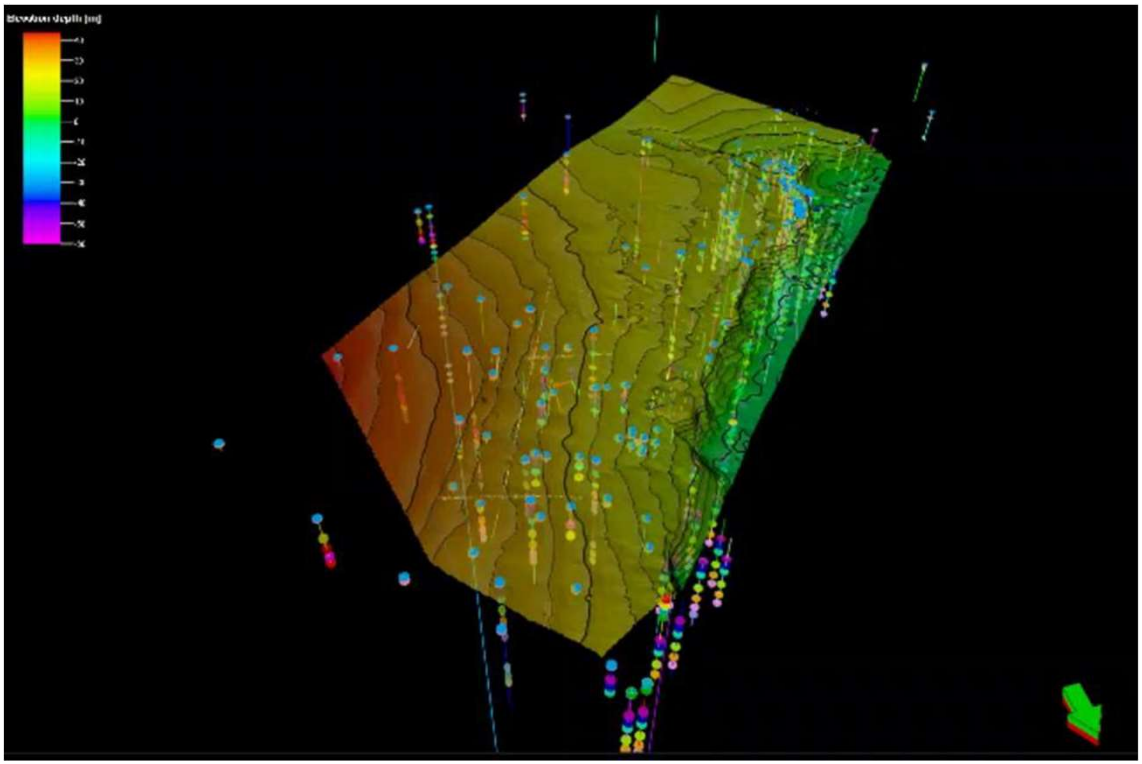
Dounreay Site- Solid Geology (afterBGS 2005)



Dounreay Site- Boreholes selected for 3-D Models

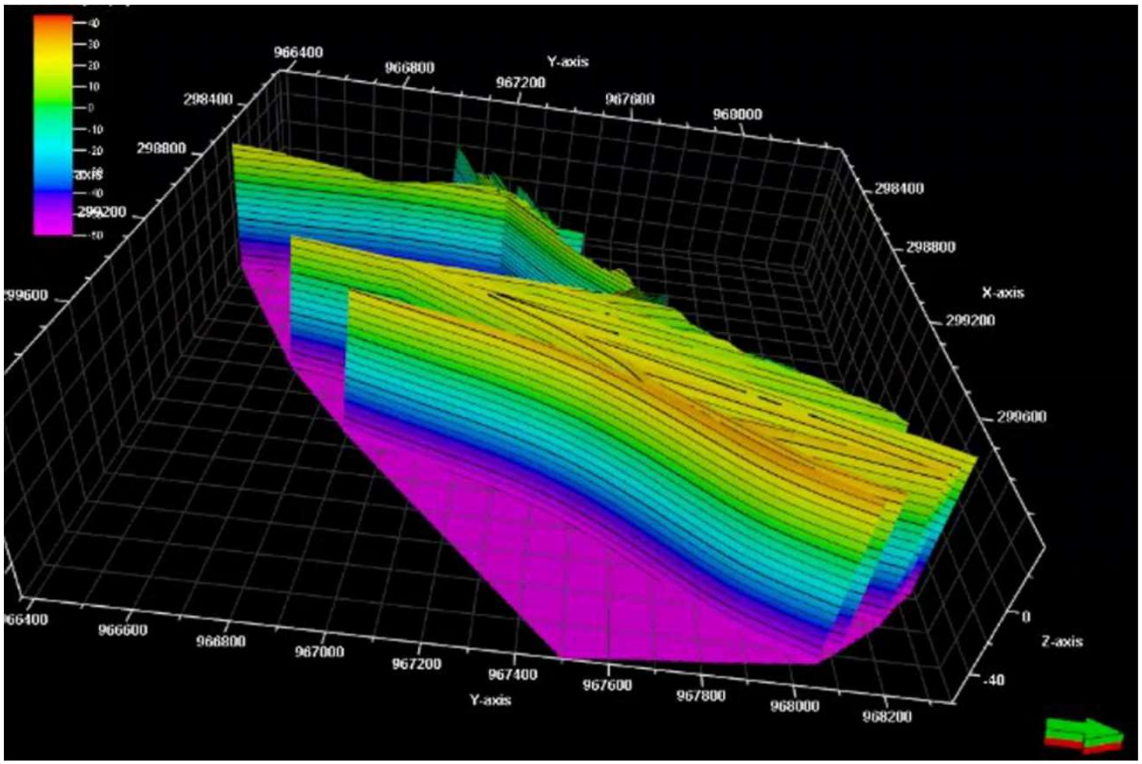


3-D Geological Ground Modelling-1
:Borehole Logs



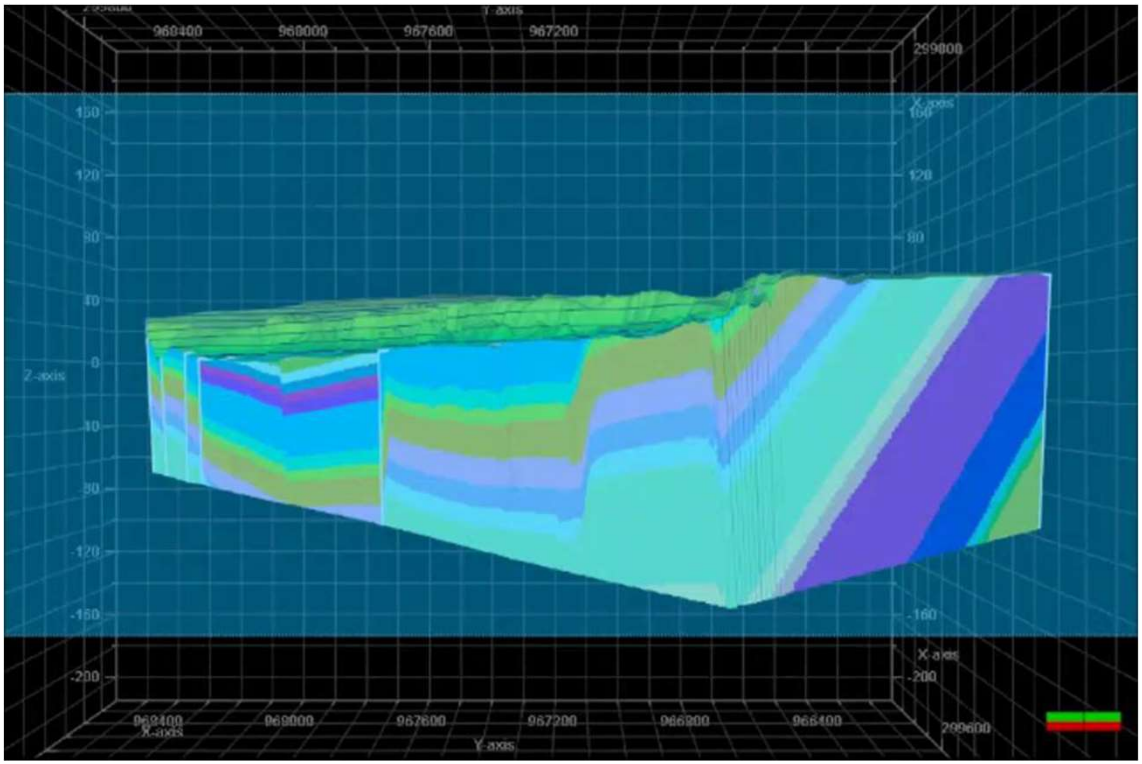
3-D Geological Ground Modelling-2

:Major Faulting



3-D Geological Ground Modelling-3

:Solid Geology Model



3-D Geological Ground Modelling-4

:Fracture Networks