British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Physical properties of till deposits from Anglesey, north west Wales

Land Use Planning and Development - Geotechnical and Geophysical Properties and Processes Team (GGPP)

Open Report OR/14/052

BRITISH GEOLOGICAL SURVEY

Land Use Planning and Development - Geotechnical and Geophysical Properties and Processes Team

Physical properties of till deposits from Anglesey, north west Wales

D Boon, M Kirkham, A Scheib

Contributors

L Hughes, A Naylor

Keywords

Till, Glacial, Anglesey, Wales, Geotechnical, Physical Properties

Front cover

Coastal exposure of till at Cemlyn Bay, north Anglesey.

Bibliographical reference

BOON, D., KIRKHAM, M., SCHEIB, A. 2014. Physical properties of till deposits from Anglesey, north west Wales. *British Geological Survey Open Report*, OR/14/052. 72pp.

Keyworth, Nottingham British Geological Survey 2014

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report is the published product of a study by the British Geological Survey (BGS) to characterise the physical properties of rocks and soils occurring in the United Kingdom landmass. This report details a study of the geotechnical properties of till deposits occurring on Anglesey in North Wales. The study included a trial of handheld XRFS for geochemical mapping of till deposits.

Acknowledgements

Several individuals have contributed to the project and we would particularly like to thank the following: Emrys Phillips, James Riding, David Schofield, Jon Lee, Helen Burke and Helen Reeves.

Contents

FIGURES

TABLES

Summary

This report describes a study of geotechnical properties of till deposits that occur on Anglesey as part of the BGS Geotechnical and Geophysical Properties and Processes Team under Land Use and Development Programme. The first part of the report describes the sampling methods and the later the results. In the final section the engineering significance of the findings is discussed. The appendix includes the results of a trial to use rapid geochemical mapping techniques (handheld XRFS) to map the geochemical properties, and spatial extent of till units.

The till deposits on Anglesey are a mix of fine and coarse grained soils and this textural variability affects their geotechnical and hydrogeological properties. In engineering terms the tills on Anglesey are typically very stiff/hard, with very high stiffness and low permeability.

1 Introduction

Deposits of glacial lodgement till are found across much of Anglesey in North Wales and as a consequence they are of particular importance to onshore and offshore development on the island. The existing geotechnical data originates from the A55 extension through the west of the island, but little data is available for large parts of the island. New data will eventually become available from ground investigations for an extension of the Wylfa Head power station. To address a knowledge gap in the physical properties of till deposits on the island a targeted field-based geotechnical study was undertaken in 2011. The study also aims to complement a current resurvey of the geology of Anglesey. This report describes the methods and results of the study and includes details of a trial of inorganic geochemistry approach to mapping till deposits using XRFS.

The work was funded by NERC National Capability (project NEE2116 S83, Task 1, Engineering Properties of UK Rocks and Soils). The data reported within this report has been entered into the BGS Geotechnical Properties Database (Self et al 2012).

1.1 QUATERNARY GEOLOGY

During Late Devensian times Anglesey was glaciated from the north-east by ice moving down the Irish Sea (Greenly 1919). Between major glaciations this ice interacted with ice from Snowdonia and the Conwy Valley and meltwater carved out the Menai Straites (Lewis and Richards, 2005). These events led to deposition of a complex sequence of glacigenic sediments, the Lleyn Till Member of the St Asaph Glacigenic Formation (McMillan and Merritt 2012, McMillan et al 2011; Bowen et al 1999). The surface of Anglesey represents a subglacial landsystem, with widespread erosion and transport of local bedrock and formations of drumlins (Lewis and Richards 2005; Phillips et al 2011).

The recent geological resurvey of the island (see Anglesey iMap) identified two distinct till units, distinguished principally by colour and to a lesser extent composition. Tills are either ‘brown/red’ or ‘grey’ diamictons (Anglesey iMap; Hughes 2011 unpublished MSc Thesis). Sub-glacial processes have introduced hydro-fracture systems, modified bedrock properties at the bedrock sediment interface, locally introduced sand bodies into the till deposits (Phillips and Hughes, in prep) and deposited glaciofluvial sediments that interdigitate with the till.

1.2 FIELD WORK

Project field work was carried out at 6 coastal sites (Figure 1) where weathered and fresh till is exposed by coastal erosion. The work was undertaken in two phases: Phase 1 (16 to 18 February 2011) involved reconnaissance of potential sites (guided by the Anglesey Mapping Team) with samples taken for geotechnical testing from Cemlyn Bay. Phase 2 (7- 11 November 2011) involved taking samples for geotechnical testing from Hen Borth, Penrhos, Porth Nobla, Sea Zoo, Beaumaris and Cemlyn Bay.

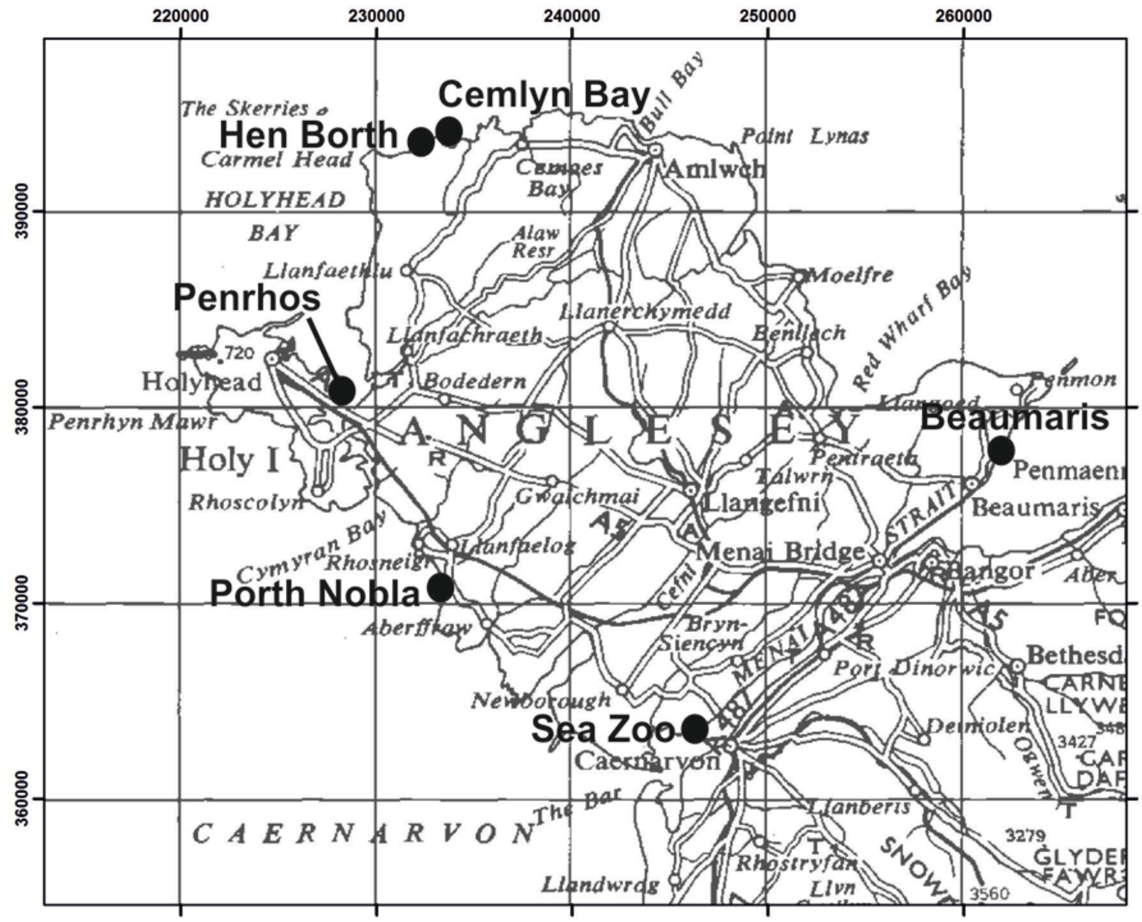


Figure 1 Location map of the study area and sample sites

2 Sample collection

Various samples were taken for determination of physical properties including: grading, bulk density, natural moisture content, shear strength. Sample types included 'disturbed' bulk samples, and 'undisturbed' samples including block samples and density rings. Sample details are given in Table 1. Samples were collected in accordance with field sampling procedures described in BS1377 and Head (2008). Samples were labelled in the field and sealed to minimise moisture loss. All samples were stored in a cool box while in transit and transferred to a constant temperature (4 degrees) humidity controlled fridge prior to testing.

2.1 SAMPLING METHODS

2.1.1 Disturbed sample procedure

Bulk samples were collected by excavating till from the cliff face using combination of picks, geological hammers and a drill (tills were very stiff to hard). The loosened soil was collected on a tarpaulin to retain the fine fraction content. The size of the sample was dependent on the largest size fraction, following EN guidance, to ensure adequate sample quantity for sieving results to be representative of the Clay to Gravel components. Samples containing cobbles (diamicts) were greater than 30kg and the minimum sample size was 15kg, in accordance with BS1377:1990.

2.1.2 Undisturbed density rings

Density rings were used to collect undisturbed samples for determination of bulk density and natural moisture content (NMC). It was not possible to obtain intact samples of till at several sites (e.g. Cemlyn Bay and Hen Borth) because the high abundance of gravel and hardness of the till makes undisturbed sampling by hand difficult. This factor results in data bias as only the 'softer' tills were sampled.

2.1.3 Undisturbed block sampling

The drumlin at Cemlyn Bay contains a horizontal sand body interpreted as a hydrofracture fill (Phillips and Hughes, in prep). An undisturbed block sample of the sand was gently carved by hand top down using a sharp knife (Fig 2) with a metal tin gradually lowered onto and around the column of soil to contain the sample. Great care was taken to avoid introducing discontinuities/fractures during the excavation process. The box was capped with lids on either end and was then marked with sample orientation, wrapped with cling film and taped up to minimise moisture loss.

Figure 2 Preparation of an undisturbed block sample of cemented sand (hydrofracture dyke) from a drumlin at Cemlyn Bay, Anglesey. A stable intact plinth is excavated by hand and box gradually lowered down encapsulating the soil sample.

Table 1 Geotechnical sample details.

Name of sample site	Sample Number	Type (D=disturbed, UD=Undisturbed, DR=Density Ring, PP=Panda Penetrometer)	Description	BNG Easting (m) (+/-5m)	BNG Northing (m) (+/-5m)	Elevation (m amsl) (+/- 2m)	Sample Mass (field) (kg +/- 0.01kg)
Cemlyn Bay	CB1 1/1	D	Red/Brown Till (landslide mass)	232743	393750	6	~30
		D	Weakly-cemented Sand	232815	393750	4	-
		UD	Weakly-cemented Sand	232815	393750	4	-
	CB2 1/1	D	Grey Till	232815	393750	2	~30
Hen Borth	HB1 1/2	D	Red/brown Till	232065	392984	6	23.20
	HB1 2/2	D	Red/brown Till	232065	392984	6	30.50
	HB2 1/2	D	Grey Till	232065	392984	3	23.68
	HB2 2/2	D	Grey Till	232065	392984	3	23.61
Beaumaris	B1 1/2	D	Grey Till	261309	377694	1	18.35
	B1 2/2	D	Grey Till	261309	377694	1	18.46
		DR x3	Grey Till	261309	377694	1	-
	B2 1/2	D	Red Till	261350	377722	6	18.00
	B2 2/2	D	Red Till	261350	377722	6	18.69
		DR x3	Red Till	261350	377722	6	-
Penrhos	PR1 1/2	D	Upper Grey Till/Red Till?	227734	381424	4	14.60
	PR1 2/2	D	Grey	227734	381424	4	18.90
	PR2 1/2	D	Lower Grey Till	227734	381424	2	15.00
	PR2 2/2	D	Lower Grey	227734	381424	2	15.00
Porth Nobla – Red Till	PN1 1/2	D	Red Till	233050	371119	2	18.67
	PN2 2/2	D	Red Till	233050	371119	2	16.40
Sea Zoo – Red Till	SZ1 1/2	D	Red Till	247048	364257	4	13.57
	SZ2 2/2	D	Red Till	247048	364257	4	18.73
	SZ3	D	Red Mudstone	247077	364258	2	-
		DR x3	Red Mudstone	247077	364258	2	-

2.1.4 Till Provenance: Palynology Samples

Additional samples were collected for Palynological analysis and the results are presented in Riding (2012).

Table 2 List of Palynology Samples

Name of sample site	Sample Bag Number	Type	BNG Easting (m)	BNG Northing (m)	Elevation (m amsl) +/- 2m error
Sea Zoo	1	Red Till	247048	364257	4
Beaumaris	2	Grey Till	261309	377694	1
Sea Zoo	3	Red Mudstone	247077	364258	2
Cemlyn Bay	4	Weakly- cemented Sand	232830	393741	4
Beaumaris	5	Red Till	261350	377722	6
Cemlyn Bay	6	Red/Brown Till (slipped)	232743	393750	6
Cemlyn Bay	7	Grey Till	232815	393750	2
Hen Borth	8	Red/brown Till	232065	392984	6
Hen Borth	9	Grey Till	232065	392984	3
Penrhos	10	Lower Grey Till	227734	381424	2
Porth Nobla – Red Till	11	sandy Red Till	233050	371119	2

3 Laboratory testing

Samples were tested following the methods described in the British Standard for Soil Classification (BS1377:1999) and Head (2008).

3.1 SOIL DENSITY

Soil density analysis was undertaken using Procedure 3 of the linear measurement method described in British Standard BS 1377: Part 2: 1990, test 7.2. The ring is inserted into the soil, (see Figure 16), the sample is excavated and the top and base surface trimmed flush with the ring and wrapped in cling film to retain moisture. In the Lab the ring and soil are weighed wet, and then oven dried to 110^{o} overnight, left to cool in a desiccator, and weighed again dry. The ring is then weighed and mass (g) of the soil sample is calculated. The volume of the sample is calculated by the average radius and length, determined from the average of six calliper measurements of the internal diameter, D, and three of the Length, L. The Bulk Density and Dry Density (Mg/m^3) are then calculated by dividing the soil mass by the interior volume of the ring, calculated by measuring.

3.2 SHEAR STRENGTH

The drained shear strength of poorly cemented sand from Cemlyn Bay was determined by a set of three direct shear box tests. The ‘undisturbed’ block sample was carefully excavated from the cliff by hand, as shown in Figure 2, and contained in a tin to maintain the integrity of the sample so as to not introduce artificial fractures or other disturbance. Three samples were prepared from one block in the BGS labs with care taken not to create new fractures. Tests were performed over a range of effective normal stresses 50, 100 and 200 kPa. Test procedure described by Head (2008) was followed. The same test procedure was then repeated with reworked sand (same sand compacted to similar density) in order to determine the effective shear strength without the cement.

4 Field tests

4.1 LIGHTWEIGHT DYNAMIC CONE PENETROMETER

The undrained shear strength (Cu) of the soils was investigated by performing in situ strength tests using a variable energy dynamic penetrometer, Panda2 lightweight penetrometer.

The Panda2 dynamic cone penetrometer measures the *in situ* dynamic cone resistance (in MPa) of the soil through which it is passing and can be used for indirect estimation of in situ relative density and undrained shear strength (Cu) and for stratigraphic mapping of soils in the shallow subsurface. The test is undertaken by driving a $4cm^2$ sacrificial steel cone on the end of a set of 0.5m long threaded steel rods using a fixed weight (hand held) hammer through the target deposit. The Panda2 measures the velocity of the hammer impact on the head of the rods and the depth of cone penetration in order to determine the dynamic cone resistance (q_d) using a modified form of the Dutch Formula (Langton, 1999). The Panda2 is capable of reaching depths of up to 6 m in soils with a resistance up to 20 MPa. It is relatively lightweight (20 kg) and readily portable thereby making it ideal for testing soils *in situ*, particularly where access is restricted, such as on coastal, river, landslide scarp and quarry exposures.

A more detailed explanation of the Panda Penetrometer testing methodology and correlations with other dynamic and static cone penetration tests can be found in Langton (1999) and Amor et al (1999). One limitation of the technique in coarse-gravel and cobble/boulder rich tills is that the cone can become obstructed by coarse grained stronger particles (cobbles & boulders) and this can limit penetration depth, and effect interpretation of results.

4.1.1 Details of in situ strength testing (Panda2 soundings)

Full raw Panda2 data and cone resistance plots are proved in Appendix 2.

Table 3 Details of Panda penetrometer testing

Site Name	Profile name	Termination Depth (m)	Unit	Orientation
Cemlyn Bay	P001	0.109	Sand lens – NB Invalid test due to brittle soil fracture	Vertical
	P002	0.122	Sand lens	Vertical
	P003	0.292	Sand lens	Horizontal
	P004	0.234	Sand lens	Vertical
	P005	0.049	Grey till	Vertical
	P006	0.330	Sand lens, grey till at base	Vertical
	P007	0.333	Grey till	Vertical
Beaumaris	P008	0.592	Grey till	Vertical
	P009	1.306	Grey till	Vertical
				Start height 5cm lower than P008
	P010	0.299	Red till	Vertical
	P011	0.321	Red till	Vertical
	P012	0.204	Red till	Vertical
Port Nobla	P014	0.294	Red till	Vertical
	P015	0.479	Red till	Vertical

5 Results

The results of the laboratory analyses and in-situ penetrometer tests are summarised in the following section, with further details in the Appendix 2.

5.1 PARTICLE SIZE DISTRIBUTION

No. 16 particle size distribution (PSD) tests were carried out on samples collected from coastal exposures. Sample location and weights are provided in Table 1. The particle size distribution results are summarised in Table 4, grading curves are given in Figure 3 and the spatial distribution of data is summarised in Figure 4.

The till deposits on Anglesey are predominantly well-graded FINE matrix dominated soils but 4 out of the 18 tills contained less than 35% fines and are therefore COARSE soils. Variability in the proportion of the fine fraction will influence the geotechnical and hydrological properties of the till. For example, the shape of the grading curve for the upper brown till and grey till from Cemlyn Bay is almost identical however the red till contains 10% more fines making the red till a 'coarse' soil and the grey till a 'fine' soil in terms of classification for engineering purposes.

The tills from nearby Hen Borth have a similar shaped grading curve to those at Cemlyn Bay but the red till is similar in composition to the grey till. On the south coast the tills at Sea Zoo and Penrhos have similar shaped grading curves but the Penrhos tills have a slightly higher proportion of fines. The red and grey tills from Beaumaris in the east of the island are distinctly sandy and the upper red till is particularly enriched in fine to medium-grained sand.

The till at Porth Nobla is by far the coarsest, contains 19 to 25% fines, 25 – 33% sand, 45-47% gravel and 3% cobbles and is classified as a 'COARSE' soil for engineering purposes. The wide grading of the tills means their particles can become extremely tightly packed achieving high relative densities when compacted under an ice sheet. The effects of weathering include reduction in bulk density and an increase in natural moisture content and compressibility.

The 'sand' body found between the grey and red tills in a drumlin at Cemlyn Bay is composed of around 17% clay, 26% silt, and 50% sand (silty SAND) with a small amount (5%) of medium to coarse gravel (Fig. 3 and Fig 4, Table 3) and is a FINE soil (after Anon, 1995).

Table 4 Results of particle size analysis

Site name	Sample ID	Particle Size % passing					
		Clay	Silt	Sand	Gravel	Cobbles	% Fine fraction (clay + silt)
Hen Borth	HB1 1/2	18.9	17.5	28.4	32.6	2.6	36.4
	HB1 2/2	16.7	15.7	26.0	34.9	6.7	32.4
	HB2 1/2	15.1	16.1	24.4	36.7	7.7	32.1
	HB2 2/2	18.2	18.7	29.0	34.2	0	36.9
Beaumaris	B2 1/2	8.5	10.6	44.8	36.1	0	19.1
	B2 2/2	18.3	23.0	23.2	35.5	0	41.3
	B1 1/2	19.6	22.8	38.8	18.8	0	42.4
	B2 2/2	19.0	21.6	36.2	23.2	0	40.6
Sea Zoo	SZ (mudstone)	19.0	18.0	45.8	17.2	0	37.0
	SZ 1/2	10.9	16.2	26.1	20.6	26.2	27.1
	SZ 2/2	14.1	21.5	32.4	32.0	0	35.6
Porth Nobla	PN 1/2	11.1	13.5	24.7	47.1	3.5	24.6
	PN 2/2	8.1	10.8	33.2	45.1	2.9	18.9
Cemlyn Bay	Grey till	15.0	15.7	25.4	41.9	4.1	30.7
	Red till	23.3	17.0	22.6	31.8	5.3	40.3
	Sand dyke	17.4	26.3	50.8	5.6	0	43.7
Penrhos	PR1 1/2	18.8	24.1	29.9	27.2	0	42.9
	PR1 2/2	24.2	31.3	15.8	28.8	0	55.5
	PR2 1/2	17.2	21.0	22.4	39.4	0	38.2
	PR2 2/2	18.3	23.0	23.2	35.5	0	41.3

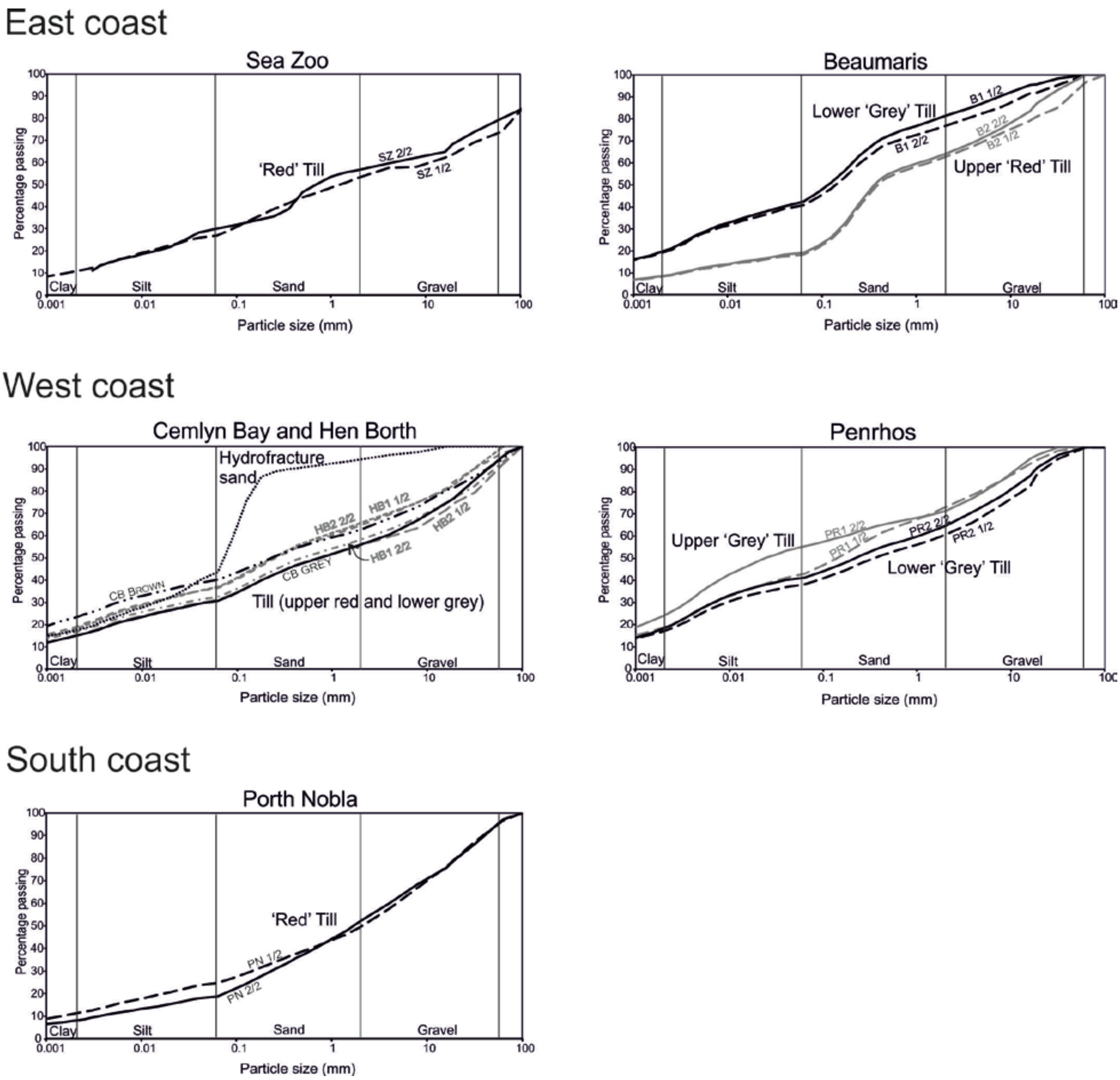


Figure 3 Particle size distribution curves.

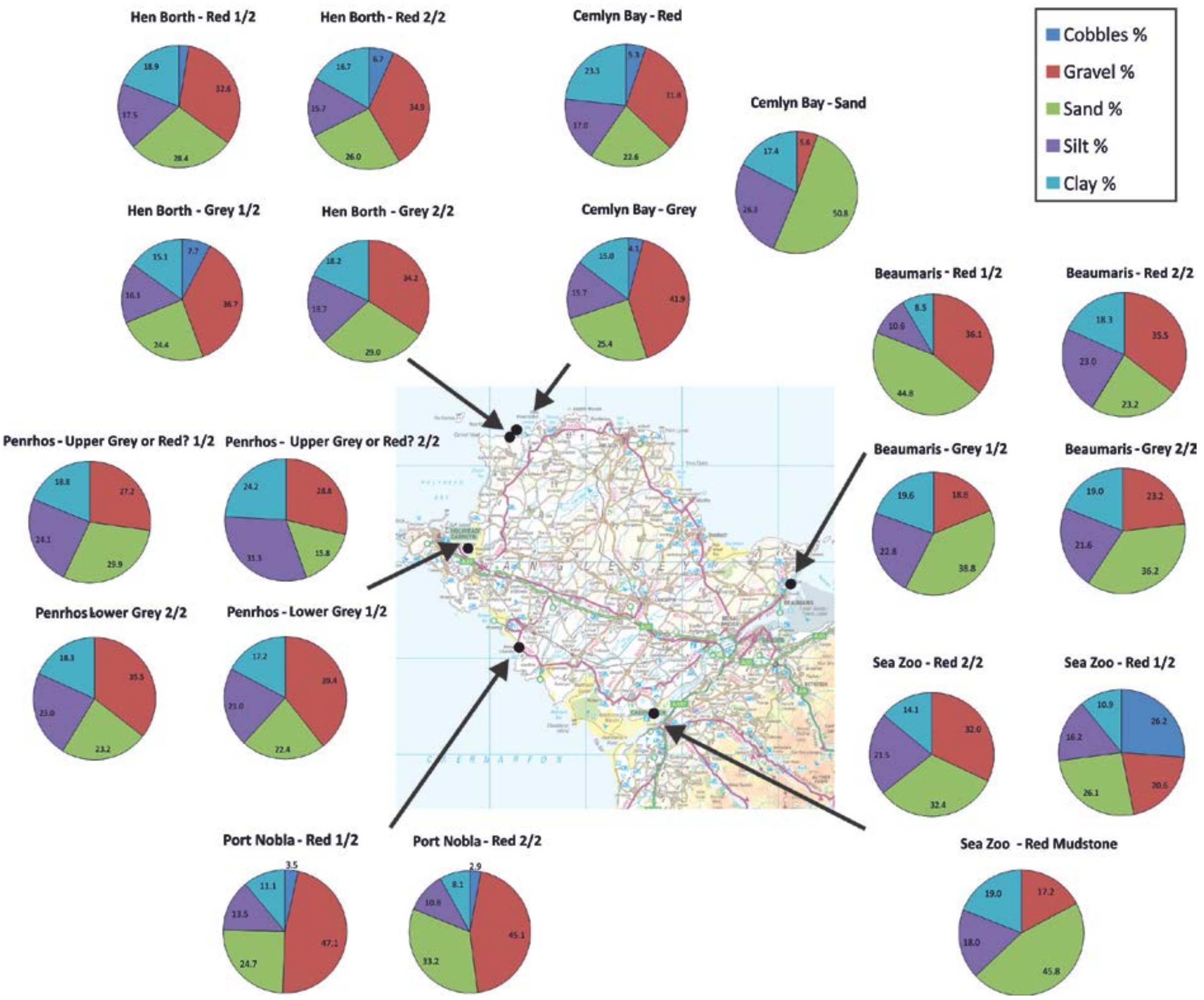


Figure 4 Particle size distribution of Anglesey tills

5.2 BULK DENSITY AND NATURAL MOISTURE CONTENT

The results are summarised in Table 4, and show that bulk density of red till range from between 2.02 to 2.26 Mg/m^3. Values of dry density for red till are on average 8 % lower than the bulk density. Natural Moisture Content ranges between 7.3 and 9.1 % for red till and 13.0 % for grey till, though the latter is a single test result and so may not be representative. Bulk density values will also of course vary depending on their degree of saturation. The bulk density of the hydrofracture sand is fairly uniform and ranges from 1.92 to 2.09 Mg/m^3 with a NMC of 15.3 %.

Table 5 Results of soil density and moisture content tests

Sample ID	Geology Unit	Sample Type	Bulk Density, ρ_{bulk} Mg/m^3	Dry Density, ρ_d Mg/m^3	NMC, %
Cemlyn Bay A	Brown/Red Till	Ring	-		8.5
Cemlyn Bay B	Grey Till	Ring	-		13.0
Cemlyn Bay 7	Weakly cemented Sand	Ring	2.09		
Cemlyn Bay 8	Weakly cemented Sand	Ring	2.02		
Cemlyn Bay 9	Weakly cemented Sand	Ring	1.99		
Cemlyn Bay (SB 50kPa)	Weakly cemented Sand	Tin	2.00		15.3
Cemlyn Bay (SB 100kPa)	Weakly cemented Sand	Tin	2.05		15.3
Cemlyn Bay (SB 200kPa)	Weakly cemented Sand	Tin	1.92		15.3
Beaumaris 1	Red Till	Ring	2.04		
Beaumaris 2	Red Till	Ring	*2.43**	2.22*	8.8
Beaumaris 3	Red Till	Ring	2.26	2.10	7.3
Sea Zoo 1	Red Till	Ring	2.16	1.98	8.3
Sea Zoo 2	Red Till	Ring	2.21	2.01	9.1
Sea Zoo 4	Red Mudstone	Ring	2.09		
Sea Zoo 5	Red Till	Ring	2.04		
Sea Zoo 6	Red Till	Ring	2.02		

*gravel protruding density ring – density overestimated. SB = Shear Box sample initial 'pre-test' values.

5.3 SHEAR STRENGTH OF CEMENTED SAND (CEMLYN BAY)

Peak values of Phi' and apparent cohesion, c', determined by direct shear tests, are summarised in Table 6, and give an effective angle of internal friction of 34 degrees. This is fairly typical of a fine sand deposit, however the sand does possess a small amount of apparent cohesion (13 kPa).

Table 6 Summary of effective shear stress strength parameters for cemented and remoulded sand from drumlin at Cemlyn Bay, Anglesey ('effective' stresses = 50, 100, 200 KPa)

	Undisturbed sand	Remoulded, recompacted sand
Apparent cohesion, c' (kPa)	13.3	0
Angle of internal friction, φ'	34.3	34.3

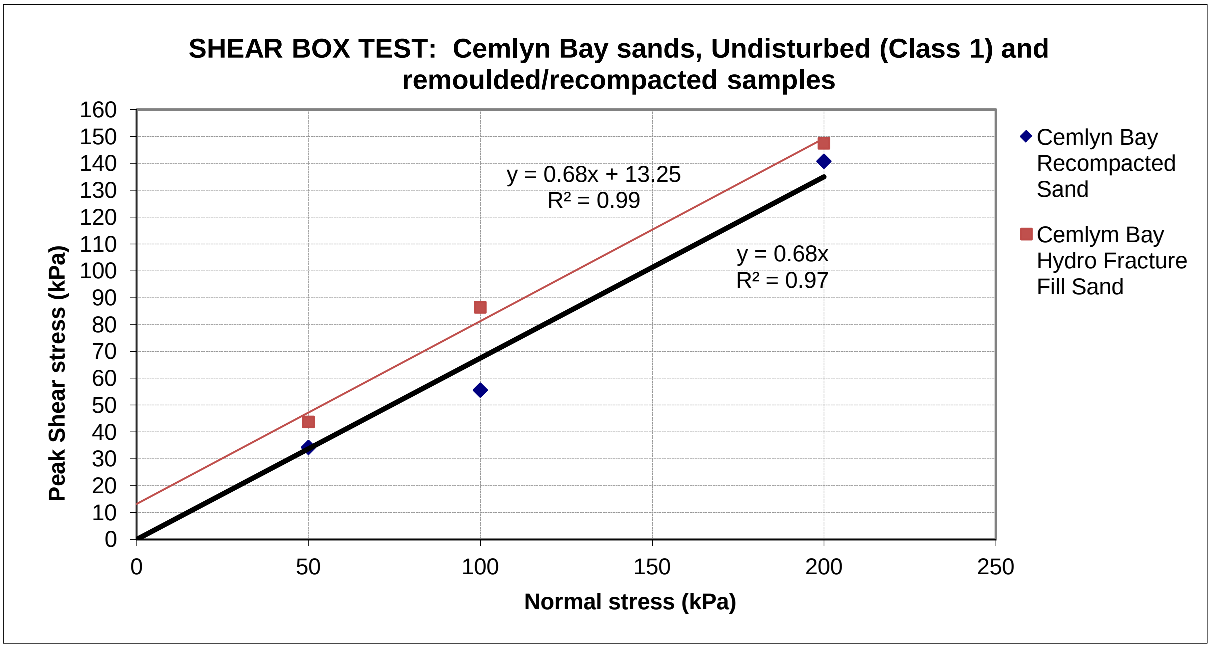


Figure 5 Plot of shear stress/normal stress for cemented and remoulded sand

5.4 PANDA PENETROMETER RESULTS

The Panda variable energy dynamic penetrometer (Panda) test results are summarised in Table 7. Full details are included in Appendix.

Table 7 Summary of 'Panda' penetrometer results

Site	Profile name	Unit	Cone resistance range (MPa)
Cemlyn Bay	P001	Sand lens – NB Invalid test due to brittle soil fracture	0.5 – 0.7
	P002	Sand lens	2.0 – 6.0
	P003	Sand lens	2.0 – 5.0
	P004	Sand lens	2.0 – 5.0
	P005	Grey till	5.0 – 10.0
	P006	Sand lens	2.0 – 6.0
		grey till at base	10.0
	P007	Grey till	10.0
Beaumaris	P008	Grey till	5.0 – 7.0
	P009	Grey till	3.0 – 6.0
	P010	Red till	6.0 – 10.0
	P011	Red till	4.0 – 10.0
	P012	Red till	3.0 – 6.0
Port Nobla	P014	Red till	7.0 – 10.0
	P015	Red till	2.0* – 10.0

6 Discussion

The results of the Particle Size Analysis tests on red and grey tills from Cemlyn Bay and Hen Borth suggest these tills are texturally similar. The matrix of the Cemlyn Bay Red till has a slightly higher fines (clay & silt) content than the lower Grey till. The red till from Beaumaris is slightly more gravelly than the underlying basal grey till.

Direct shear box tests on sand from the drumlin at Cemlyn Bay provide an effective cohesion value, c', of 13 kPa. This cohesion is likely provided by calcium carbonate cement, possibly derived from the carboniferous limestone content within the till. Similar cements have been described in sand and gravel soils in drumlins in the USA and attributed to precipitation due to reduction of hydrostatic pressure and CO_2 outgassing of subglacial meltwater (Menzies & Brand, 2006). This cement and the strength it provides may indeed become reduced over time, as acidic meteoric rainwater and soil water percolates through the slope, and this process may be a controlling factor in the development and style of slope failures in natural and cut soil slopes.

The silty fine sand grain-size of the hydrofracture sand material makes it potentially susceptible to liquefaction under cyclic loading conditions (e.g. under an ice sheet or during earthquake shaking), which may inform conceptual models for its mode of emplacement, although the clay content decreases the liquefaction potential slightly.

The XRFS analysis shows the lower grey tills from Cemlyn Bay contain very high levels of Ca and Sr. By comparison the brown till above contains low levels of Ca with around half the Sr. This is explained by incorporation of Carboniferous limestone into the Grey till. Alternatively this could also result from calcium carbonate leaching from the red till as a result of the near surface weathering processes.

The geotechnical properties of the bedrock material vary markedly across the island; with weak fissured mudstone, strong limestone and extremely strong metamorphic and igneous rocks (Greenley, 1919) present. It has been postulated that the shear strength and permeability of the bedrock may control sub-glacial landform distribution and processes (Phillips et al, 2010). The influence of bedrock physical properties on processes at the deforming bed is relevant for modern day ice sheet evolution. The finer grained tills of the west coast sit within Assemblage Zone 1 of (Phillips et al, 2010) whereas the sandy tills sit within Assemblage Zones 2 and 3 where the presence of elongated sub-glacial landforms indicate a faster ice stream down the Menai Strait. The composition of the matrix is likely controlled by local source material (bedrock and superficial deposits) and may influence ice stream velocity or even be a product of it. However, the quantity of data collected so far is insufficient in explore this relationship fully and further field and laboratory work is required.

Previous workers have assumed till deposits are dominated by local materials with erratic rich tills along the east coast (Lewis and Richards, 2005). This led Whittow and Ball (1970) to propose a late 'Liverpool Bay Phase' ice re-advance, but these erratic rich tills and underlying locally-sourced tills may well represent the same event. The tills at Beaumaris are more sand rich than elsewhere on the island and contain Carboniferous limestone boulders, and their presence supports Whittow and Ball's proposition. Harris (1991) inspected the till at Wylfa Head in northern Anglesey and showed locally-derived material interdigitates with erratic rich till, suggesting formation in a single event. The XRFS data produced from this study (Cemlyn Bay) supports the notion of two till compositions or a vertical gradation and further work using this technique could potentially contribute to an improved understanding, till unit distribution, ice steam flow paths in the region, and mixing processes in the deforming bed of a glacier (for a review see Evans et al 2006).

7 Conclusions

1. The till deposits from Anglesey are variable in texture and composition ranging from widely-graded ‘fine’ soils to ‘coarse’ soils. Some tills are fissured. These characteristics result in slight variability in geotechnical properties across island and are partly a function of the underlying bedrock geology and pre-existing quaternary deposits prior to the last ice advance. Even slight variability in geotechnical properties may have affected subglacial processes within the deforming bed and may have influenced the formation of glacial landforms and ice stream dynamics.
2. The tills are typically ‘very dense’ or ‘hard’ soils and generally require ‘hard digging’ with a pick axe to hand excavate. Their relatively high strength (hard) makes them difficult to sample and prepare for geotechnical testing and in-situ field tests or large samples are recommended to assess field scale geotechnical parameters for design purposes.
3. The tills are mostly traction tills and contain very strong cobbles and occasionally boulders which may present a ground engineering risk, particularly in excavations and for reuse of material for earthworks.
4. Drumlinoid landforms are widely distributed across Anglesey and are predominantly composed of very stiff to hard traction till or high strength (strong to extremely strong) bedrock that may require blasting to excavate. Soil drumlins may contain irregular shaped sand bodies, which will affect their mass geotechnical and hydrogeological characteristics.
5. Coastal slopes in till can maintain steep angles, probably due to development of large pore suctions and high compaction efforts from the overriding ice sheet. Stability of slopes in excavations and tunnels in till may be affected by sand bodies and boulders present within the till sequence and sediment bedrock interface may be irregular. Dissolution of carbonate cements, particularly in the sand units in drumlins, may reduce strength over time and may lead to progressive slope failure.
6. The thickness of till at the coast is typically around 4-6m, but locally may vary, and will be thinner in low ground between drumlins (onshore).
7. The local bedrock material partly influences the mineralogy and engineering behaviour of tills.
8. The trial use of handheld XRFS analysis of tills offers a rapid, cost effective, method for geochemical mapping of tills and this method could be deployed in the field with a trained operator. Geochemical analysis may offer a means to discriminate till deposits for provenance studies, provided a representative number of samples is available.
9. The Palynological analysis of grey tills at Cemlyn Bay provides new evidence that this till type is derived from Irish Sea bedrock sources. Differentiation of red till from grey till using Palynoflora has been attempted but the results were inconclusive.

Other engineering geological considerations:

10. The presence of low-strength ‘normally consolidated’ Holocene sediments and peats in depressions between drumlins creates locally poor ground conditions, including compressible ground, poor drainage, and may impact on ground engineering.

11. Sub-glacial deformation processes and periglacial activity may have altered the geotechnical rock mass properties of bedrock materials at rockhead in places, particularly on the south west (downstream) side of drumlins.

Appendix 1: Photographic record of sample sites

Figure 6 Sea cliff cut into drumlinoid landform at Cemlyn Bay, Wilfa Head Nuclear Power Station can be seen on the horizon. Photo taken February 2011.

Figure 7 Sample site at northern end of Cemlyn Bay (17 February 2011). Notice the sequence of red till (top of section) overlying a yellow sand body, and a grey till at the base of the section.

Figure 8 The red till at the top of the sequence at Cemlyn Bay is prone to slumping over the grey till and on to the beach. Photo taken 17 February 2011.

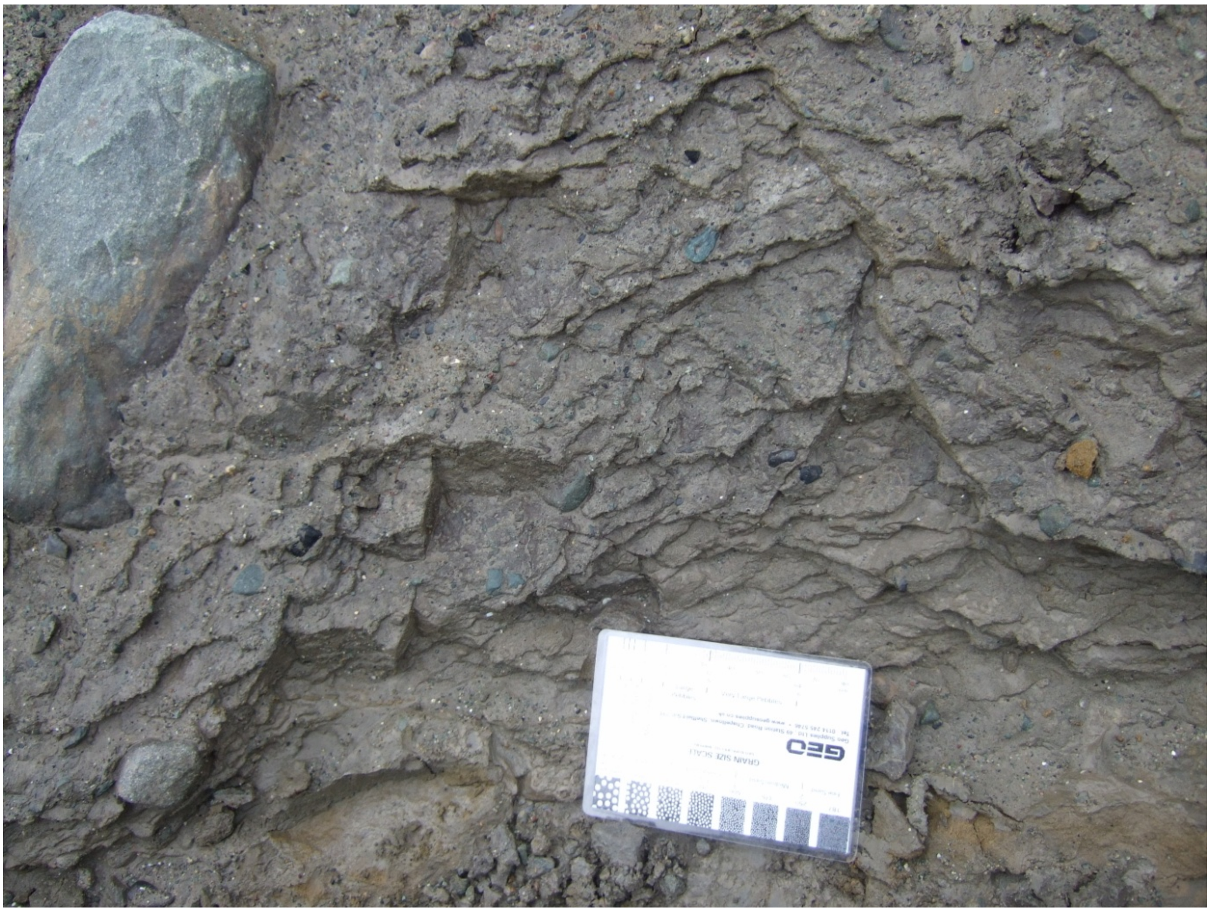


Figure 9 Tight fissures in grey till exposed on the foreshore of Cemlyn Bay. These mechanical discontinuities affect soil mass strength and permeability properties, and assist the coastal erosion process by providing release surfaces. Scale: 10cm-long grain size card.

Figure 10 Coastal cliff section at Hen Borth, North West Anglesey, exposes internal structure of a drumlinoid landform. The section exposes a basal grey till overlain by an upper red till divided in places by a horizontal body of sand rich material. Slumping of the upper red till onto the beach protects the foot of the slope from wave action, and provides lateral support, until the mass is removed by erosion. Differential weathering exposes cobbles in the till.

Figure 11 Coastal cliff exposure of Grey Till at Hen Borth. The sample site (centre) is marked with 30cm long hammer.

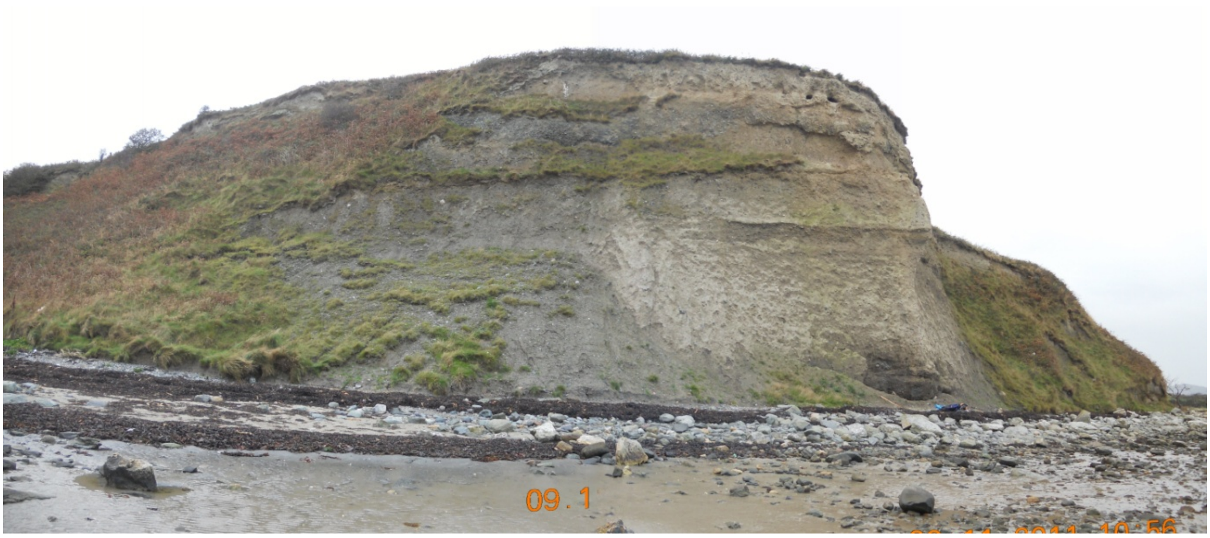


Figure 12 Coastal cliff slope at Penrhos site. Note slumping of sands and gravels and red till over grey till. Cliff is subject to wave action and coastal erosion.

Figure 13 Penrhos sampling site (sample PR1 1-2). Excavation in hard till using electric hammer drill with tarpaulin to catch fine fraction. Note how differential erosion has picked out more resistant beds composed of coarse gravel in the upper part of the cliff and the presence of sand lenses (possibly dykes) within grey till approx 1m above base of cliff.

Figure 14 Exposure of Red till at the Sea Zoo site

Figure 15 Low coastal cliff exposure at Sea Zoo. Very stiff sheared bright-red mudstone (bedrock) underlies red till. The upper boundary of the mudstone is sharp and planar. The mudstone contains closely spaced wavy veins of hard/extremely weak, mineral filled sub-horizontal spary calcite that display polished surfaces, micro faults, folds the veins are truncate at the mudstone/ till interface. Pick axe for scale.

Figure 16 Example of a density ring prior to extraction at the Beaumaris site

Figure 17 Example of a Panda Penetrometer test set up. Lower Grey Till on the foreshore at Beaumaris test site.

Figure 18 Red till exposed in a low sea cliff near Beaumaris. Notice how the beach is strewn with light-grey sub-rounded, strong, Carboniferous limestone cobbles and boulders probably derived from the red till.

Figure 19 Low coastal cliffs expose Red Till along the Menai Straits passage north of Beaumaris. The red till is rich in limestone cobbles and boulders.

Figure 20 Close up of the Red till at Beaumaris sampling site. Hammer for scale.

Figure 21 Low coastal cliff exposure of Red till at Port Nobla. Bulk sample was taken from 300mm below boulder. Panda penetrometer test started from hammer location. Note this erratic boulder is approx 2.5m long composed of weathered granite.

Figure 22 Detail of Red Till sampling site at Port Nobla. Panda test started on cut ledge below hammer tip. Note the deeply weathered smooth/striated granite erratic top left with 'wrinkled' surface texture. 30 cm long hammer for scale.

Appendix 2: Dynamic Penetrometer Data

File site and sounding catalog

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPan

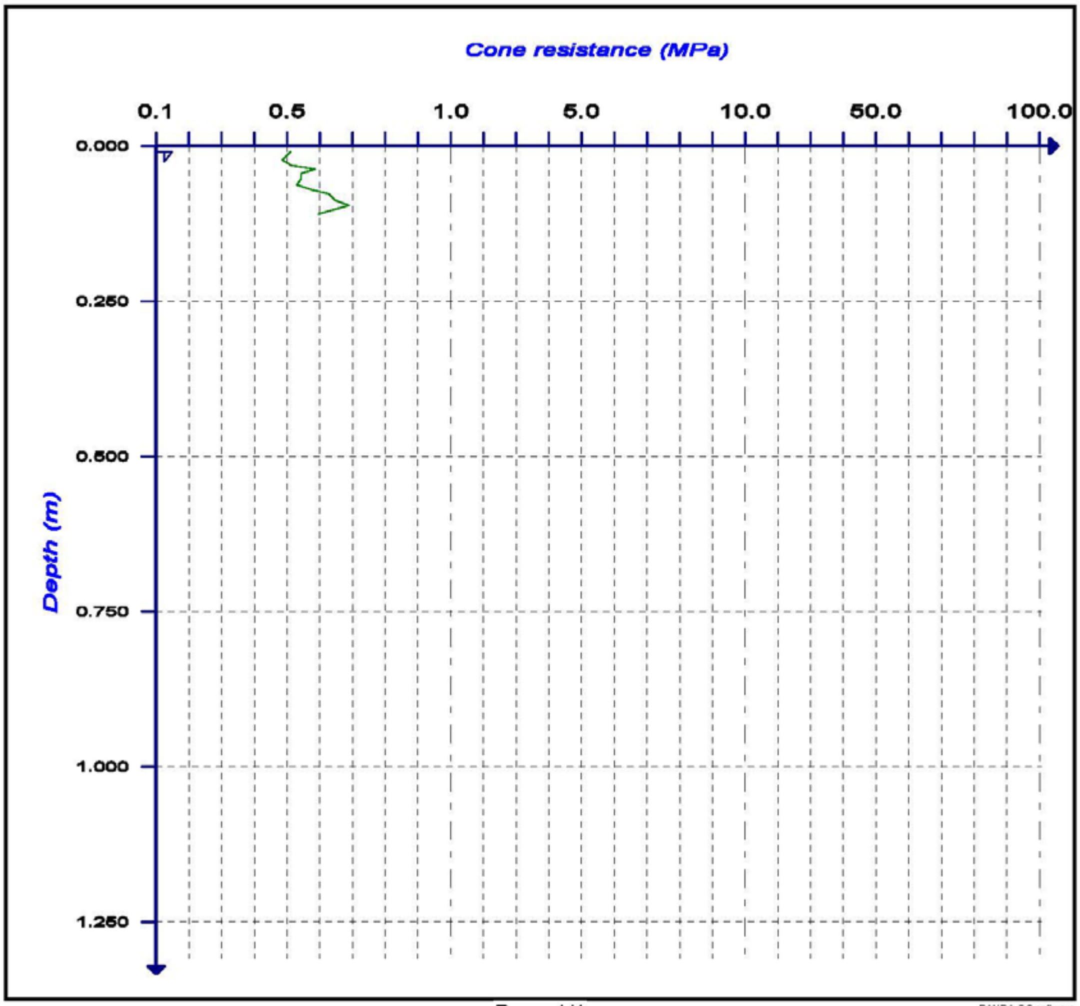
Site	Sounding	Date	Study
cemlyn bay anglesey	001	08/11/2011	Ground investigation
cemlyn bay anglesey	P002	08/11/2011	Ground investigation
cemlyn bay anglesey	P003	08/11/2011	Ground investigation
cemlyn bay anglesey	P004	08/11/2011	Ground investigation
cemlyn bay anglesey	P005	08/11/2011	Ground investigation
cemlyn bay anglesey	P006	08/11/2011	Ground investigation
cemlyn bay anglesey	P007	08/11/2011	Ground investigation
baumaris	P008	10/11/2011	Ground investigation
baumaris	P009	10/11/2011	Ground investigation
baumaris	P010	10/11/2011	Ground investigation
baumaris	P011	10/11/2011	Ground investigation
baumaris	P012	10/11/2011	Ground investigation
PORT NOBLA	P014	10/11/2011	Ground investigation
PORT NOBLA	P015	10/11/2011	Ground investigation

Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : 001			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 15:56:00
Operator : dpb		Company :	
Comments :			

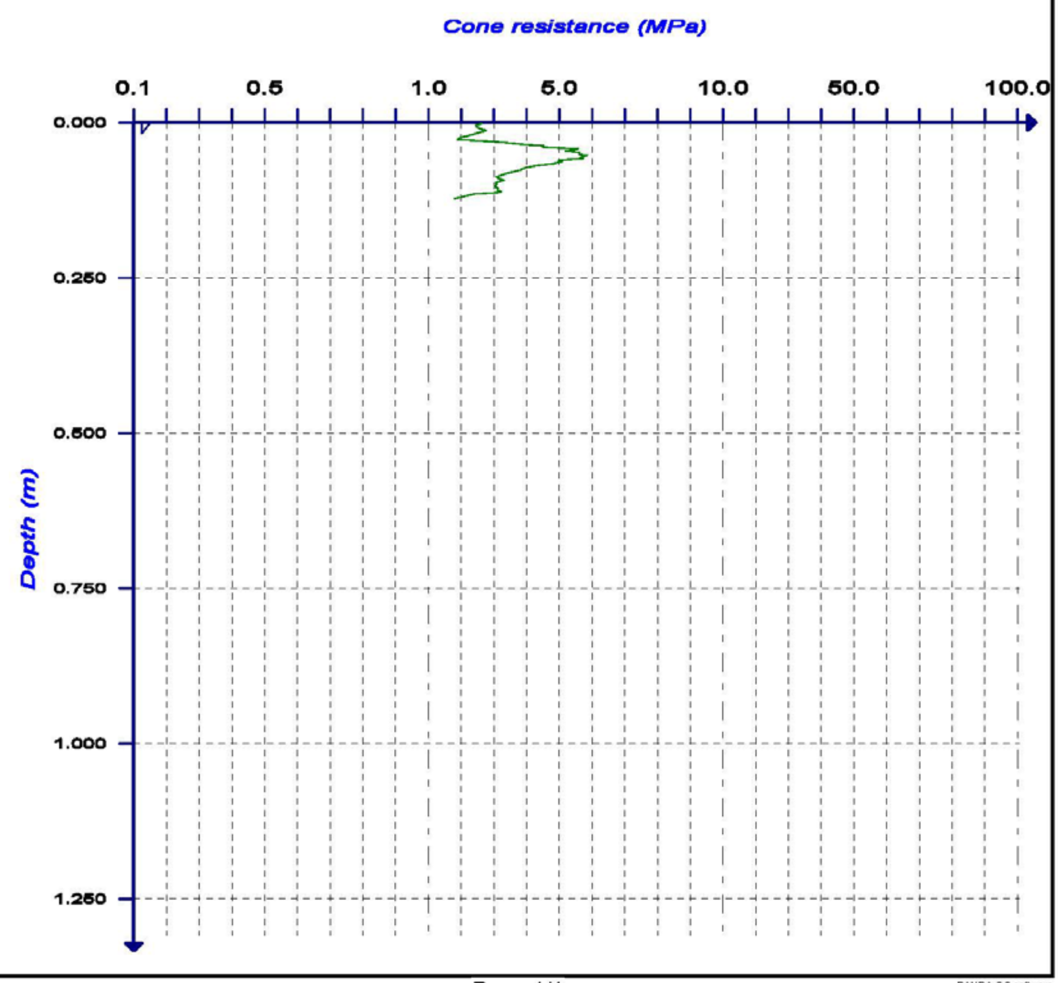


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : P002			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:01:00
Operator : dpb		Company :	
Comments :			

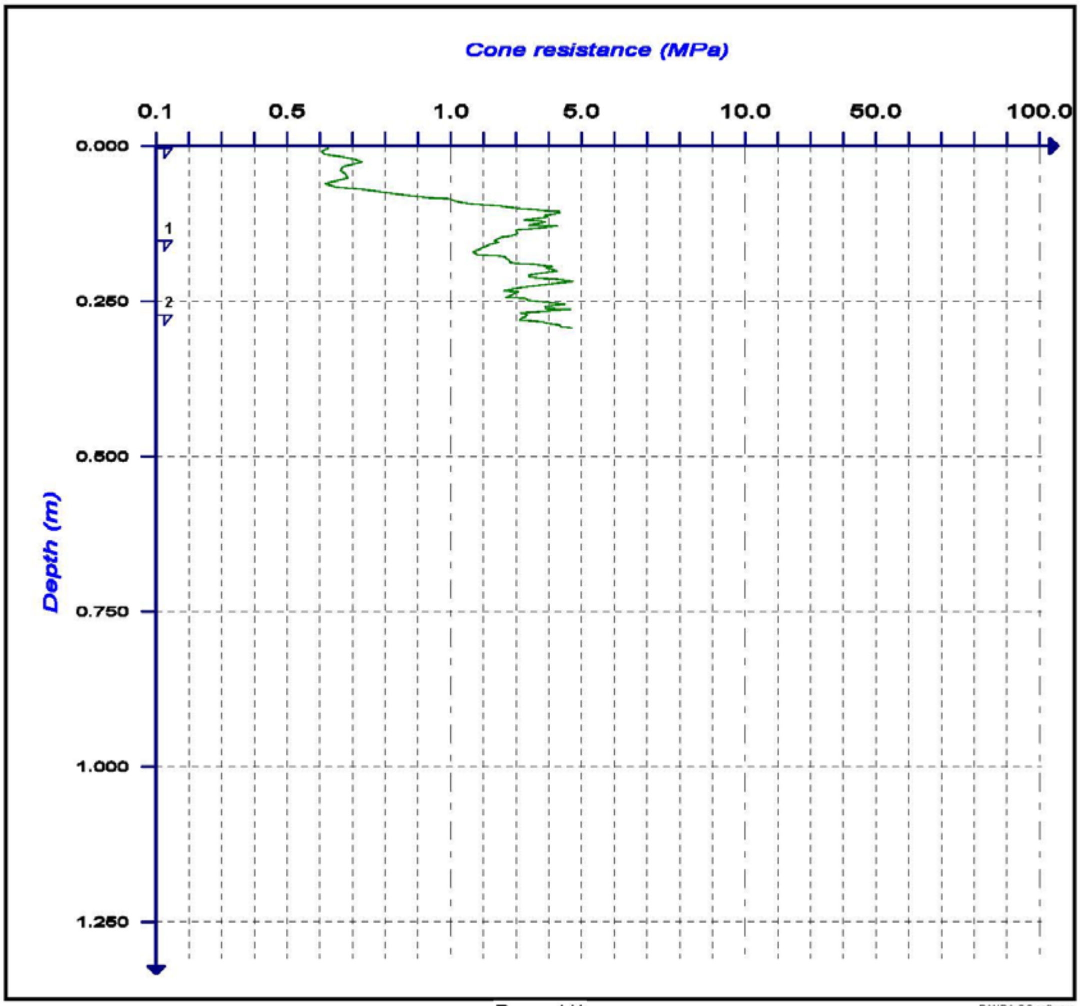


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : P003			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:09:00
Operator : dpb		Company :	
Comments : SAND HORZ			

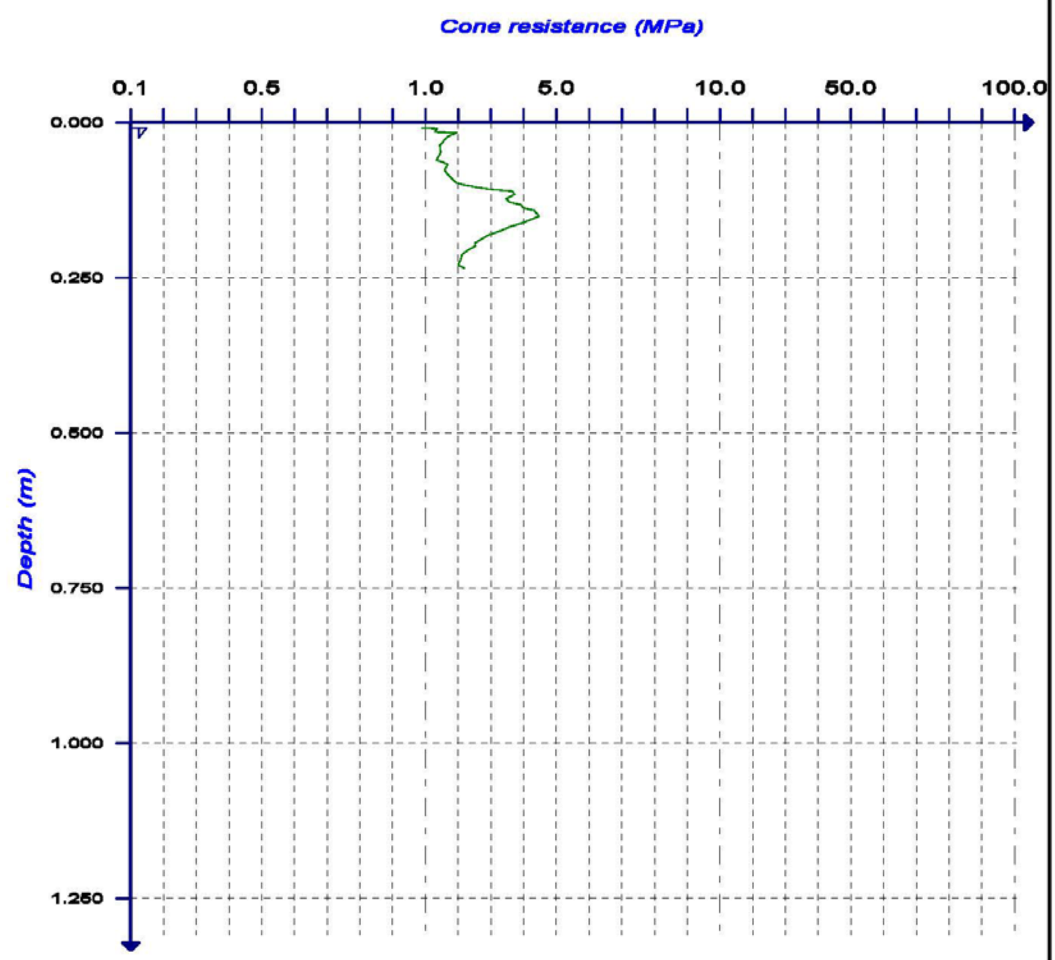


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.|			
Site : cemlyn bay anglesey			
Sounding : P004			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:18:00
Operator : dpb		Company :	
Comments :			

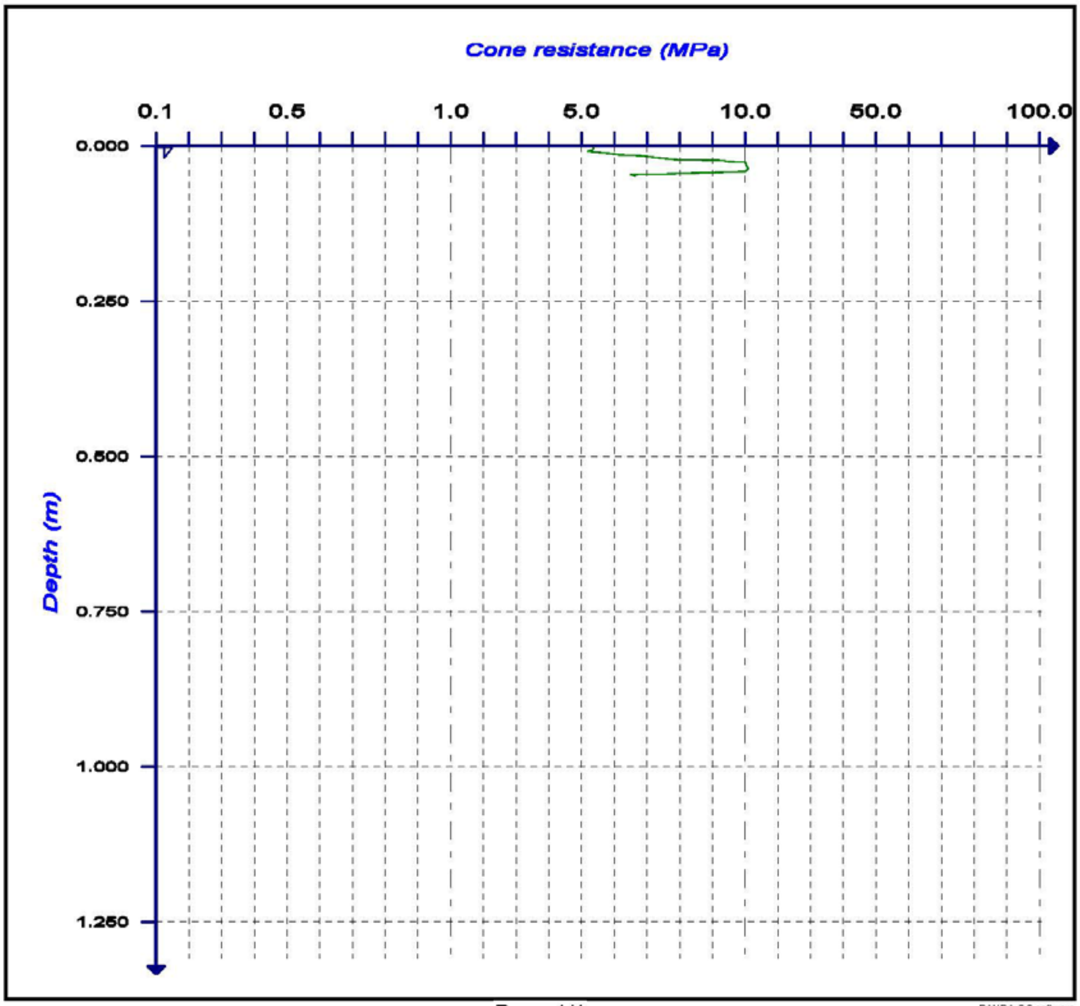


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : P005			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:29:00
Operator : dpb		Company :	
Comments :			

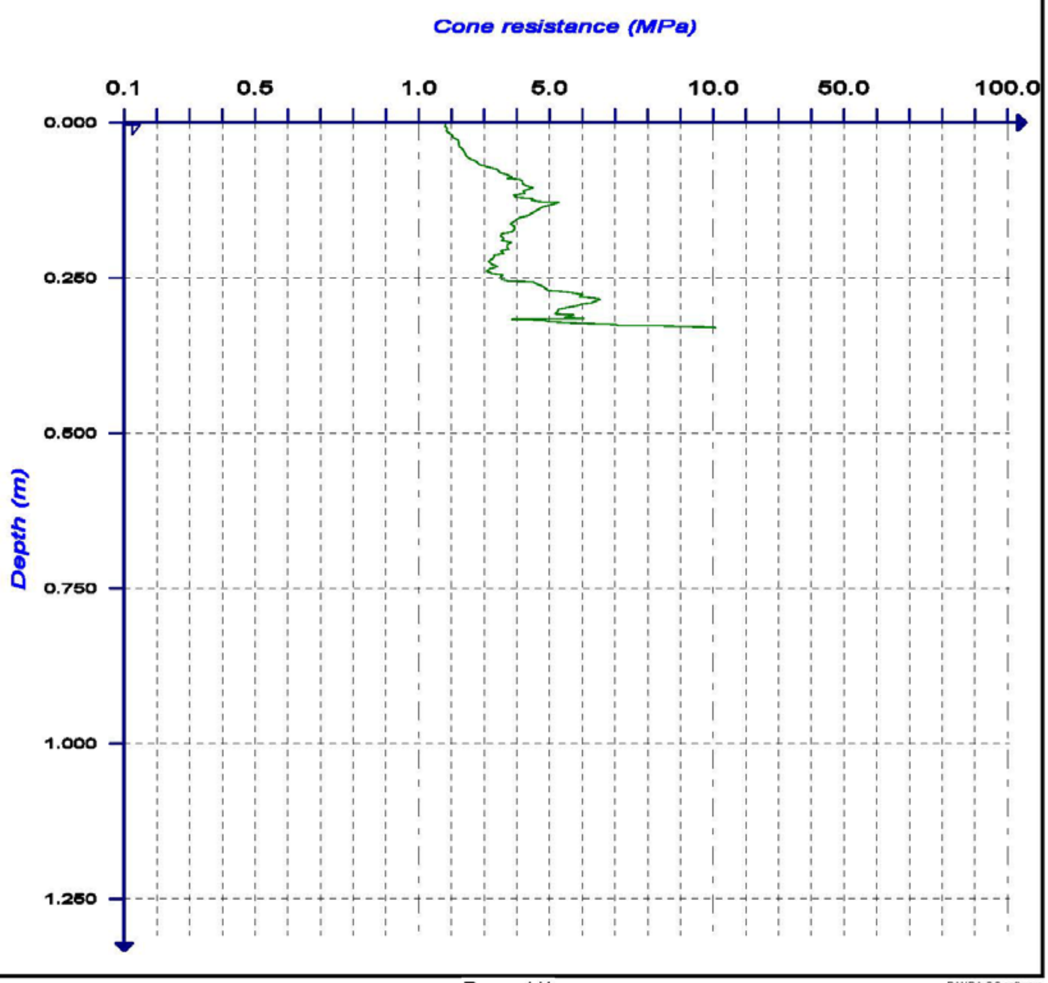


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : P006			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:33:00
Operator : dpb		Company :	
Comments :			

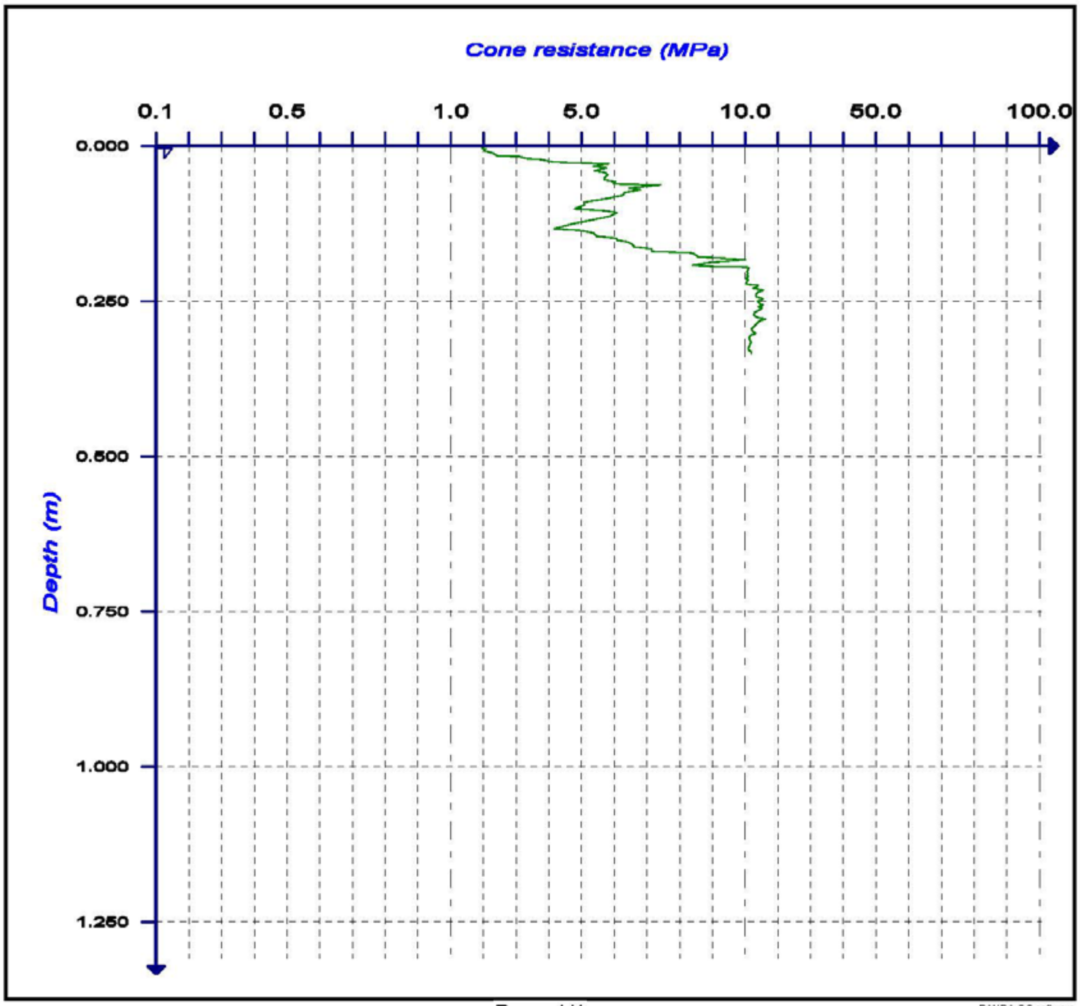


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : P007			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:45:00
Operator : dpb		Company :	
Comments : GREY TILL			

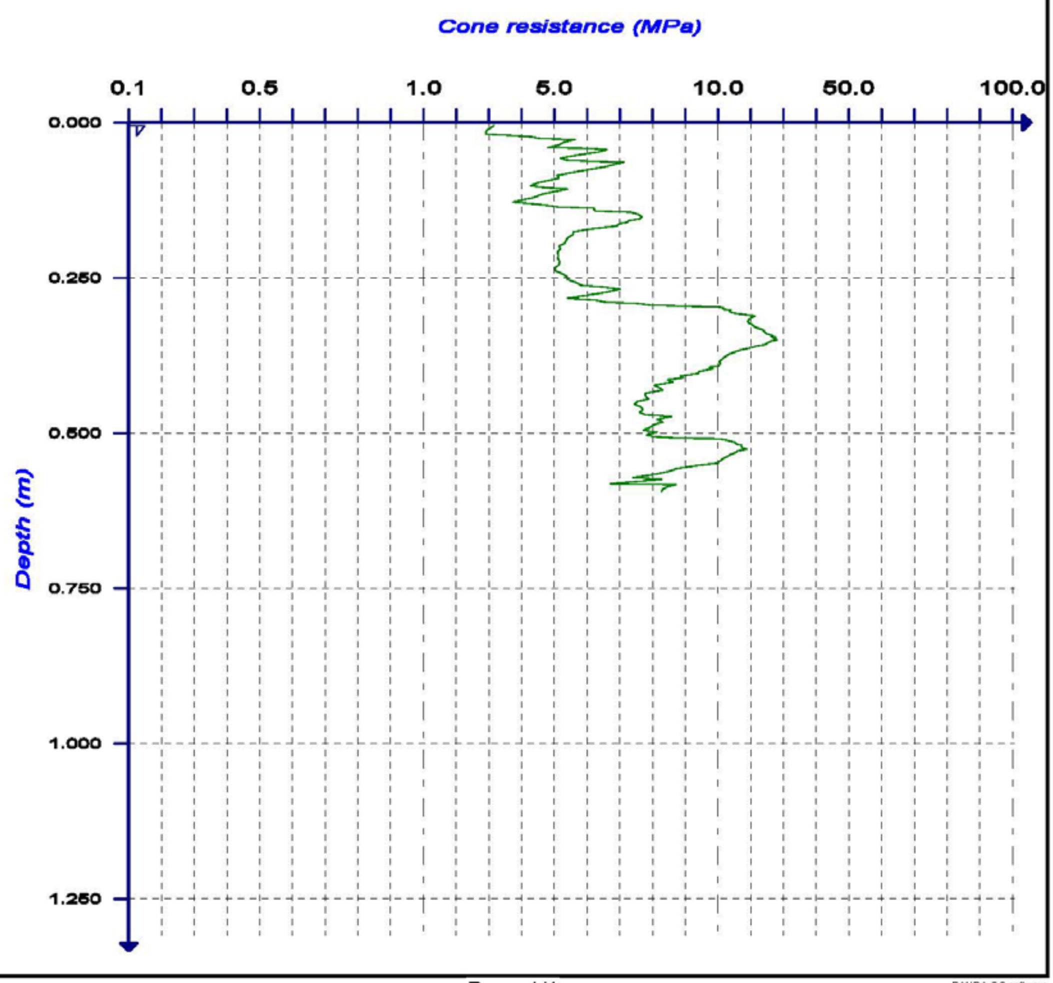


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : baumaris			
Sounding : P008			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 10:53:00
Operator : dpb		Company :	
Comments : greytill			

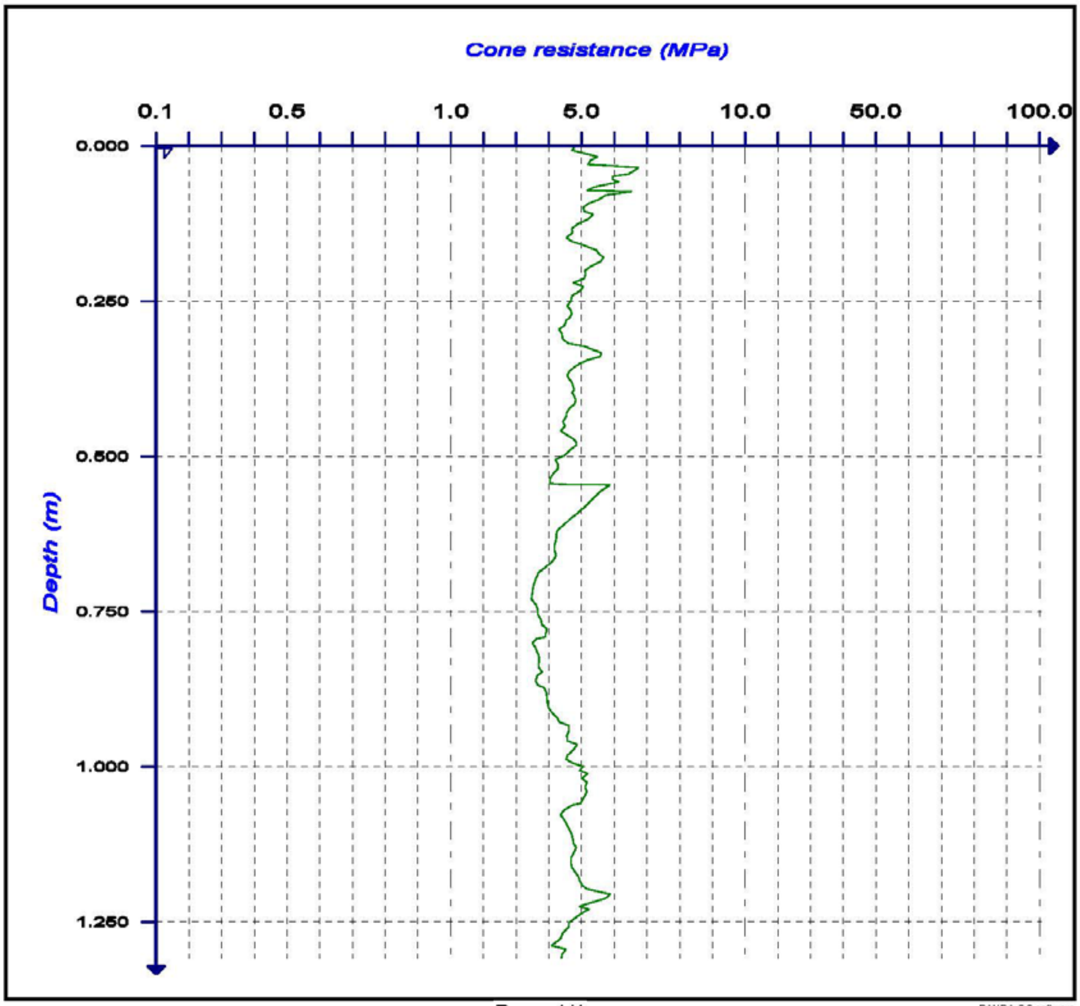


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : baumaris			
Sounding : P009			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 11:11:00
Operator : dpb		Company :	
Comments : greytill			

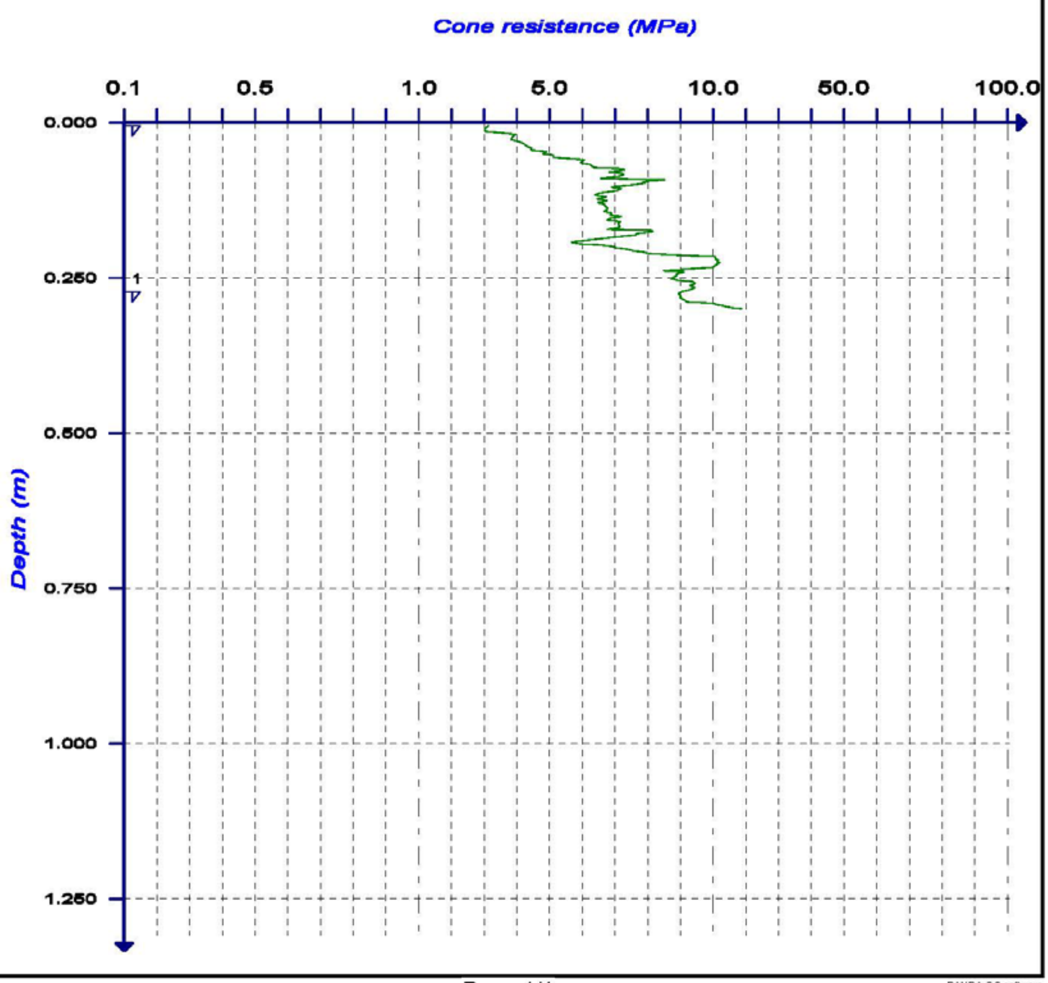


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : baumaris			
Sounding : P010			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 12:10:00
Operator : dpb		Company :	
Comments : RED TILL BAUMARIS			



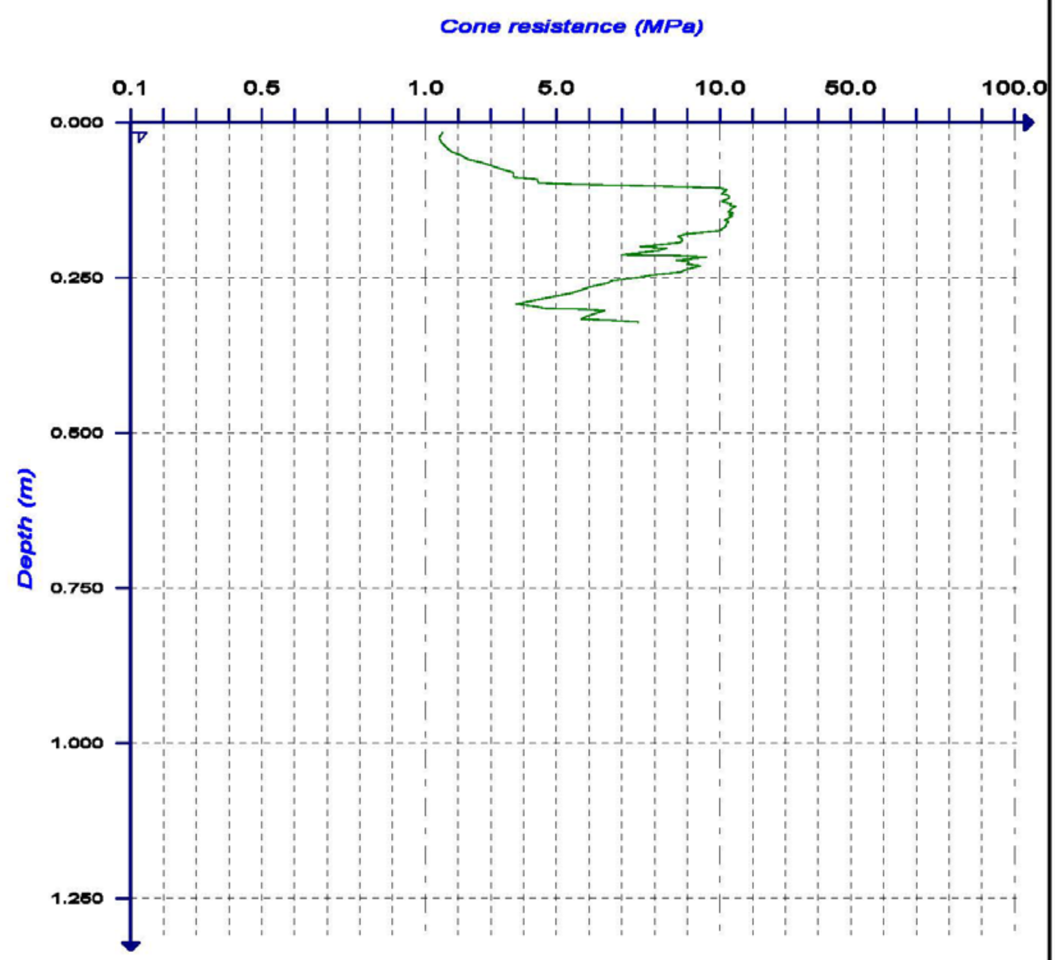
Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : baumaris			
Sounding : P011			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 12:16:00
Operator : dpb		Company :	

Comments :
RED TILL

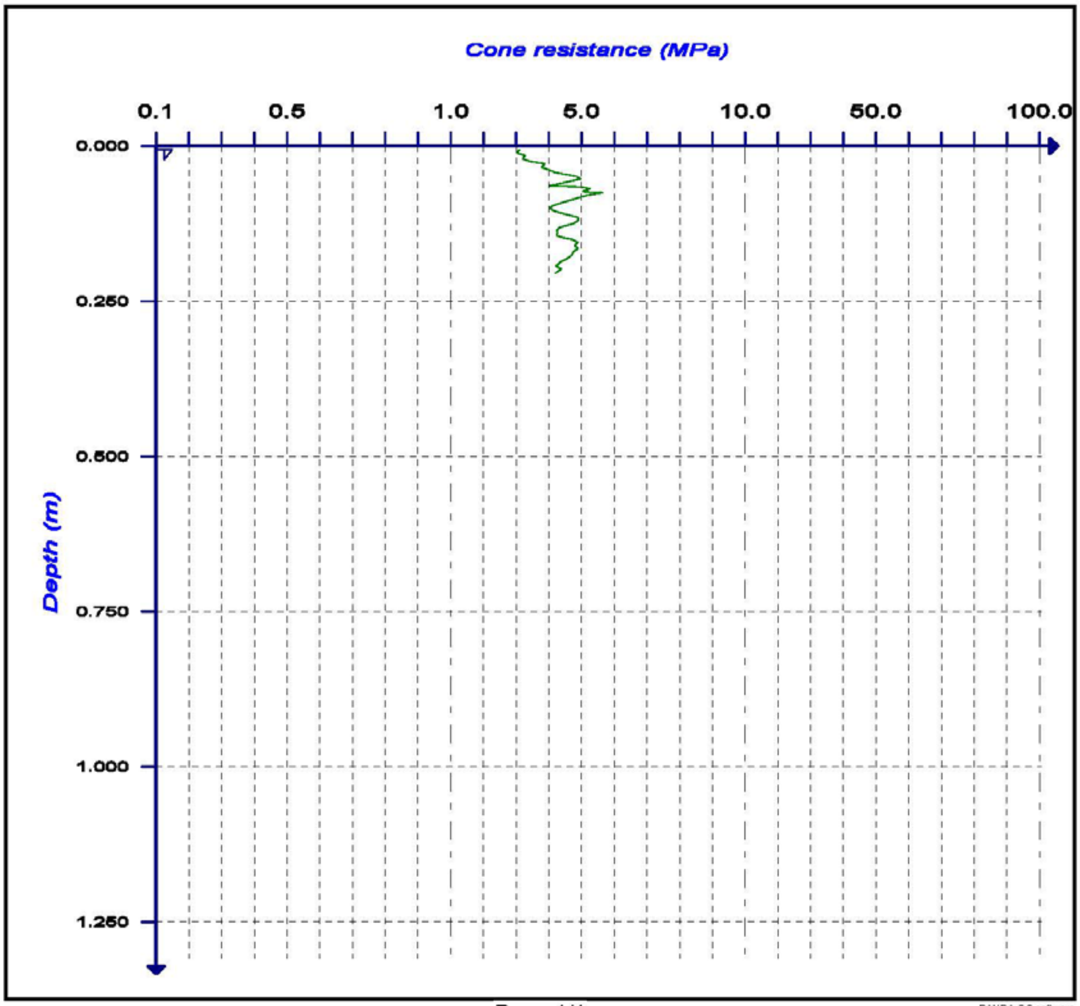


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.p			
Site : baumaris			
Sounding : P012			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 12:23:00
Operator : dpb		Company :	
Comments : RED TILL			



Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

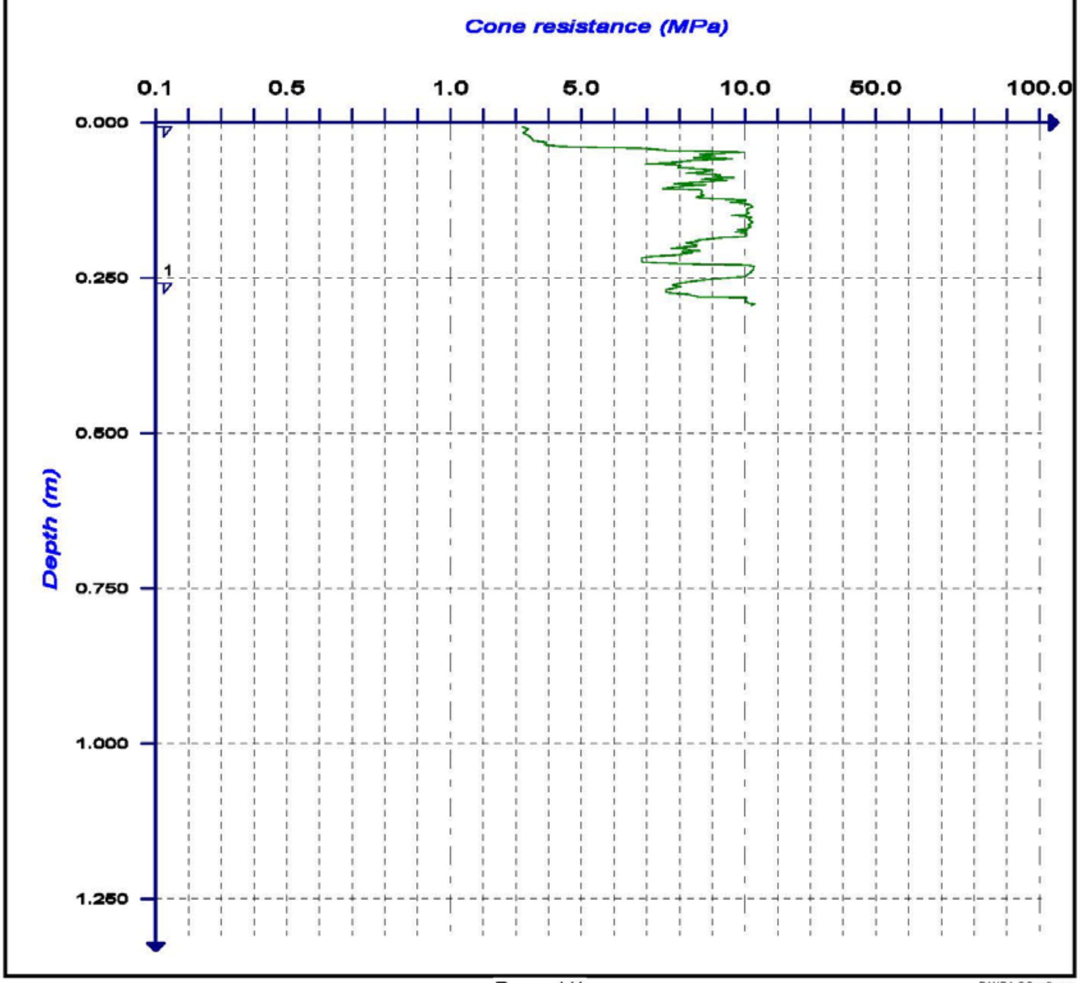
Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.p

Site : PORT NOBLA

Sounding : P014

Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 16:16:00
Operator : dpb		Company :	

Comments :
RED TILL

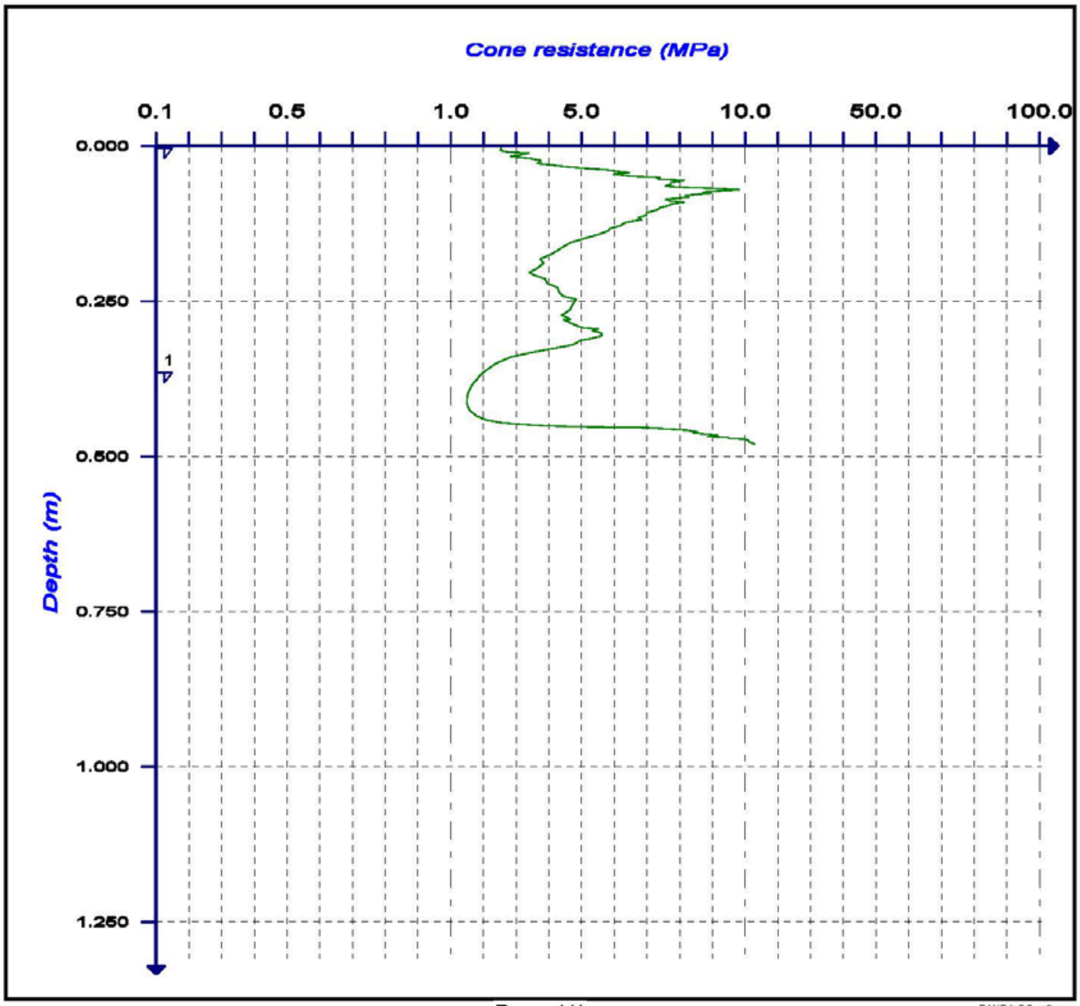


Page 1/1

PANDA 2.2 software

Ground investigation with variable energy dynamic penetrometer

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : PORT NOBLA			
Sounding : P015			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 16:22:00
Operator : dpb		Company :	
Comments : RED TILL			



Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : cemlyn bay anglesey

Sounding : 001			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 15:56:00
Operator : dpb		Company :	

Comments :

Index Measure	*Depth (m)*	*Resist. (MPa)*
1	0.009	0.46
2	0.022	0.41
3	0.031	0.62
4	0.037	0.94
5	0.044	0.41
6	0.053	0.55
7	0.062	0.48
8	0.071	0.77
9	0.077	0.86
10	0.087	0.72
11	0.095	0.86
12	0.109	0.36

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : P002			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:01:00
Operator : dpb		Company :	
Comments :			

Index Measure	Depth (m)	Resist. (MPa)
1	0.002	2.58
2	0.005	1.89
3	0.008	2.62
4	0.010	3.12
5	0.013	3.40
6	0.021	0.97
7	0.025	1.27
8	0.028	1.72
9	0.029	5.23
10	0.030	5.35
11	0.032	5.87
12	0.034	5.17
13	0.036	5.61
14	0.037	6.91
15	0.040	4.42
16	0.041	7.17
17	0.042	8.30
18	0.044	5.02
19	0.046	4.34
20	0.048	7.47
21	0.050	5.56
22	0.051	5.60
23	0.053	6.89
24	0.055	5.35
25	0.056	5.28
26	0.058	6.03
27	0.060	3.02
28	0.061	5.58
29	0.063	4.99
30	0.065	4.32
31	0.066	4.54
32	0.069	3.00
33	0.072	2.99
34	0.074	3.46
35	0.076	3.56
36	0.079	2.83
37	0.082	2.82
38	0.085	2.68
39	0.087	2.61
40	0.090	3.43
41	0.092	3.94
42	0.097	2.29
43	0.099	3.29
44	0.103	2.73
45	0.105	3.54
46	0.109	3.04
47	0.111	3.65
48	0.112	3.00
49	0.115	0.89
50	0.122	0.64

Index Measure	Depth (m)	Resist. (MPa)

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : cemlyn bay anglesey

Sounding : P003

Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:09:00
Operator : mrd		Company :	

Comments :

SAND HORZ

Index Measure	Depth (m)	Resist. (MPa)	Index Measure	Depth (m)	Resist. (MPa)
1	0.004	0.40	51	0.189	3.61
2	0.008	0.54	52	0.190	6.55
3	0.013	0.65	53	0.192	4.90
4	0.017	0.88	54	0.194	5.44
5	0.021	0.88	55	0.197	3.33
6	0.026	0.82	56	0.199	4.99
7	0.033	0.50	57	0.201	4.72
8	0.039	0.63	58	0.204	2.51
9	0.045	0.74	59	0.208	2.25
10	0.052	0.71	60	0.211	3.51
11	0.061	0.42	61	0.212	5.21
12	0.066	0.79	62	0.214	6.32
13	0.070	1.13	63	0.217	7.30
14	0.075	1.11	64	0.227	0.74
15	0.079	1.09	65	0.233	1.36
16	0.083	1.27	66	0.234	5.22
17	0.088	1.86	67	0.241	2.11
18	0.090	2.62	68	0.243	2.26
19	0.093	3.30	69	0.245	6.74
20	0.095	5.08	70	0.248	3.64
21	0.096	4.87	71	0.250	5.56
22	0.100	6.06	72	0.252	5.56
23	0.102	5.79	73	0.254	6.24
24	0.104	5.22	74	0.258	2.34
25	0.105	6.69	75	0.261	3.92
26	0.108	4.39	76	0.262	8.83
27	0.111	2.59	77	0.266	1.54
28	0.114	4.36	78	0.268	1.84
29	0.119	1.58	79	0.270	3.92
30	0.120	6.05	80	0.272	3.47
31	0.122	4.59	81	0.275	3.08
32	0.127	2.07	82	0.277	2.76
33	0.128	9.59	83	0.280	2.92
34	0.132	2.07	84	0.281	5.22
35	0.135	1.48	85	0.283	5.49
36	0.137	3.09	86	0.285	4.50
37	0.141	3.14	87	0.288	5.87
38	0.144	2.38	88	0.291	4.53
39	0.147	1.61	89	0.292	6.03
40	0.149	2.16			
41	0.153	2.00			
42	0.155	2.92			
43	0.158	1.48			
44	0.171	0.65			
45	0.175	2.44			
46	0.177	7.32			
47	0.178	3.53			
48	0.181	2.83			
49	0.183	3.10			
50	0.187	2.88			

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : cemlyn bay anglesey

Sounding : P004			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:18:00
Operator : DPB		Company :	

Comments :

Index Measure	*Depth (m)*	*Resist. (MPa)*
1	0.008	0.33
2	0.010	4.13
3	0.015	1.09
4	0.016	8.65
5	0.023	0.92
6	0.033	1.09
7	0.037	1.19
8	0.048	1.59
9	0.060	0.98
10	0.064	2.48
11	0.067	2.36
12	0.076	1.27
13	0.082	1.99
14	0.090	2.49
15	0.097	2.44
16	0.101	3.58
17	0.104	4.66
18	0.108	5.20
19	0.110	7.08
20	0.115	4.00
21	0.123	2.65
22	0.128	4.06
23	0.132	5.44
24	0.137	4.19
25	0.141	5.79
26	0.146	4.69
27	0.151	4.71
28	0.155	3.63
29	0.161	3.09
30	0.167	2.50
31	0.174	2.44
32	0.180	1.92
33	0.194	1.43
34	0.198	2.57
35	0.204	1.80
36	0.212	1.48
37	0.218	1.98
38	0.230	1.72
39	0.234	2.99

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.p			
Site : cemlyn bay anglesey			
Sounding : P005			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:29:00
Operator : mrd		Company :	
Comments :			

Index Measure	*Depth (m)*	*Resist. (MPa)*
1	0.003	4.31
2	0.006	5.19
3	0.009	4.68
4	0.011	6.94
5	0.012	7.40
6	0.014	7.09
7	0.016	9.81
8	0.018	8.42
9	0.020	8.87
10	0.022	10.10
11	0.023	15.93
12	0.025	10.28
13	0.026	12.64
14	0.028	10.61
15	0.029	10.74
16	0.031	10.18
17	0.032	11.05
18	0.033	11.16
19	0.035	11.63
20	0.036	11.75
21	0.041	7.67
22	0.045	2.13
23	0.046	4.45
24	0.049	7.16

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : cemlyn bay anglesey			
Sounding : P006			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:33:00
Operator : mrd		Company :	
Comments :			

Index Measure	Depth (m)	Resist. (MPa)	Index Measure	Depth (m)	Resist. (MPa)	Index Measure	Depth (m)	Resist. (MPa)
1	0.004	1.36	51	0.192	5.09	101	0.330	15.91
2	0.007	1.77	52	0.196	3.32			
3	0.010	2.11	53	0.200	3.68			
4	0.013	1.78	54	0.204	3.89			
5	0.017	2.25	55	0.206	2.79			
6	0.020	2.39	56	0.210	3.90			
7	0.024	2.18	57	0.213	2.48			
8	0.028	2.81	58	0.217	3.22			
9	0.032	2.30	59	0.223	2.61			
10	0.038	2.26	60	0.228	3.61			
11	0.042	2.79	61	0.231	4.15			
12	0.048	2.61	62	0.235	2.43			
13	0.053	2.62	63	0.239	2.79			
14	0.058	2.92	64	0.240	3.48			
15	0.062	3.62	65	0.243	3.60			
16	0.068	3.29	66	0.245	4.91			
17	0.072	4.40	67	0.248	3.33			
18	0.075	4.50	68	0.252	3.63			
19	0.080	3.78	69	0.255	4.63			
20	0.083	4.49	70	0.256	8.61			
21	0.087	4.57	71	0.260	5.17			
22	0.090	3.22	72	0.263	5.45			
23	0.091	5.75	73	0.266	5.11			
24	0.094	4.53	74	0.270	5.36			
25	0.098	4.14	75	0.272	7.64			
26	0.102	4.71	76	0.274	6.88			
27	0.105	5.33	77	0.277	7.09			
28	0.110	3.29	78	0.280	5.57			
29	0.114	4.40	79	0.282	8.14			
30	0.116	2.85	80	0.284	7.30			
31	0.120	4.34	81	0.287	5.81			
32	0.122	6.95	82	0.289	6.06			
33	0.124	4.28	83	0.291	4.98			
34	0.127	5.48	84	0.294	5.55			
35	0.128	8.28	85	0.297	4.67			
36	0.132	4.47	86	0.300	4.25			
37	0.135	3.85	87	0.304	5.17			
38	0.141	4.08	88	0.307	4.84			
39	0.145	3.97	89	0.309	8.42			
40	0.150	3.83	90	0.313	4.58			
41	0.153	3.24	91	0.315	8.75			
42	0.158	3.60	92	0.316	0.76			
43	0.163	3.30	93	0.317	10.90			
44	0.167	4.42	94	0.320	5.50			
45	0.172	3.96	95	0.322	8.49			
46	0.175	3.59	96	0.323	9.58			
47	0.178	2.57	97	0.325	10.54			
48	0.183	3.42	98	0.326	7.23			
49	0.186	3.95	99	0.327	15.41			
50	0.190	3.34	100	0.328	15.30			

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : cemlyn bay anglesey

Sounding : P007

Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 08/11/2011	Hour : 16:45:00
Operator : dpb		Company :	

Comments :
GREY TILL

Index Measure	Depth (m)	Resist. (MPa)
1	0.004	0.50
2	0.006	2.45
3	0.008	1.83
4	0.011	3.54
5	0.016	3.17
6	0.017	7.18
7	0.020	4.12
8	0.021	5.93
9	0.026	5.98
10	0.027	10.02
11	0.029	9.89
12	0.032	3.97
13	0.035	7.43
14	0.040	4.27
15	0.043	7.09
16	0.046	6.12
17	0.050	5.37
18	0.055	5.62
19	0.058	7.44
20	0.061	5.73
21	0.062	16.18
22	0.068	3.91
23	0.070	8.21
24	0.075	4.79
25	0.079	6.19
26	0.084	4.32
27	0.090	3.15
28	0.095	5.18
29	0.101	3.83
30	0.104	10.35
31	0.107	7.91
32	0.113	5.00
33	0.126	2.10
34	0.133	2.77
35	0.136	9.24
36	0.140	7.11
37	0.145	5.78
38	0.148	8.93
39	0.151	6.16
40	0.154	7.75
41	0.158	7.03
42	0.162	6.79
43	0.165	9.46
44	0.169	7.17
45	0.172	14.55
46	0.175	9.04
47	0.178	8.83
48	0.180	13.26
49	0.183	12.55
50	0.187	5.96
51	0.192	6.65
52	0.194	12.19
53	0.195	23.76
54	0.199	9.52
55	0.202	9.79
56	0.205	11.73
57	0.208	9.82
58	0.210	12.30
59	0.213	8.27
60	0.215	13.87
61	0.218	9.23
62	0.221	8.92
63	0.223	18.14
64	0.224	26.89
65	0.226	13.07
66	0.229	8.95
67	0.230	24.45
68	0.232	20.40
69	0.235	8.74
70	0.238	12.37
71	0.240	12.69
72	0.242	14.88
73	0.244	19.38
74	0.246	18.42
75	0.249	9.39
76	0.252	15.27
77	0.254	15.69
78	0.256	19.81
79	0.259	9.84
80	0.260	20.04
81	0.263	12.11
82	0.267	8.58
83	0.270	12.12
84	0.273	12.70
85	0.274	16.24
86	0.277	16.58
87	0.278	27.78
88	0.281	9.53
89	0.284	11.43
90	0.287	11.55
91	0.290	10.60
92	0.294	9.91
93	0.297	12.80
94	0.299	13.55
95	0.301	16.67
96	0.305	6.78
97	0.310	10.26
98	0.312	12.90
99	0.315	12.69
100	0.319	10.12
101	0.322	10.79
102	0.326	9.67
103	0.328	12.78
104	0.331	14.17
105	0.333	11.77

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : baumaris			
Sounding : P008			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 10:53:00
Operator : dpb		Company :	
Comments : greytill			

Index Measure	Depth (m)	Resist. (MPa)	Index Measure	Depth (m)	Resist. (MPa)	Index Measure	Depth (m)	Resist. (MPa)	Index Measure	Depth (m)	Resist. (MPa)
1	0.005	2.50	51	0.198	4.58	101	0.349	31.66	151	0.513	21.81
2	0.013	2.27	52	0.203	5.32	102	0.350	21.97	152	0.515	17.10
3	0.018	2.82	53	0.208	4.76	103	0.352	22.97	153	0.517	16.86
4	0.020	8.13	54	0.213	5.26	104	0.357	19.41	154	0.518	23.00
5	0.023	7.93	55	0.218	5.02	105	0.359	14.32	155	0.520	17.21
6	0.026	5.61	56	0.223	5.40	106	0.361	17.22	156	0.522	17.29
7	0.027	11.90	57	0.228	5.05	107	0.363	13.37	157	0.523	21.55
8	0.032	4.22	58	0.234	4.61	108	0.366	10.91	158	0.524	21.51
9	0.036	4.69	59	0.238	5.06	109	0.369	10.88	159	0.528	8.89
10	0.040	3.75	60	0.242	6.01	110	0.372	7.95	160	0.531	12.68
11	0.041	14.52	61	0.247	5.97	111	0.374	10.89	161	0.533	10.55
12	0.044	8.66	62	0.252	5.48	112	0.377	9.30	162	0.537	8.76
13	0.048	5.36	63	0.257	6.61	113	0.380	9.68	163	0.541	7.54
14	0.053	3.80	64	0.262	6.49	114	0.384	7.39	164	0.545	7.44
15	0.057	3.85	65	0.264	9.35	115	0.386	12.76	165	0.550	6.87
16	0.060	6.05	66	0.268	9.37	116	0.389	9.75	166	0.555	6.66
17	0.062	9.48	67	0.273	5.19	117	0.393	7.28	167	0.560	7.77
18	0.064	12.49	68	0.282	2.71	118	0.395	10.27	168	0.564	6.88
19	0.068	5.86	69	0.285	10.45	119	0.397	9.13	169	0.570	5.27
20	0.071	5.60	70	0.289	8.01	120	0.400	8.50	170	0.573	12.36
21	0.078	3.62	71	0.290	11.86	121	0.403	9.28	171	0.580	3.19
22	0.085	3.26	72	0.293	9.69	122	0.407	7.19	172	0.581	22.16
23	0.089	5.42	73	0.295	14.16	123	0.410	9.29	173	0.585	7.57
24	0.097	2.79	74	0.296	13.15	124	0.413	6.93	174	0.589	7.76
25	0.102	3.55	75	0.297	21.28	125	0.417	9.23	175	0.592	8.21
26	0.105	7.00	76	0.300	10.93	126	0.422	6.31			
27	0.107	8.49	77	0.301	27.37	127	0.426	8.82			
28	0.114	2.78	78	0.303	12.04	128	0.430	8.65			
29	0.121	3.33	79	0.305	16.93	129	0.435	6.12			
30	0.128	2.18	80	0.307	23.47	130	0.439	7.86			
31	0.131	7.54	81	0.308	27.33	131	0.444	8.19			
32	0.133	6.98	82	0.309	25.49	132	0.448	6.49			
33	0.136	6.38	83	0.310	30.19	133	0.453	7.13			
34	0.138	12.29	84	0.313	17.95	134	0.457	8.44			
35	0.140	6.20	85	0.315	17.10	135	0.461	7.88			
36	0.142	6.44	86	0.319	17.89	136	0.465	7.26			
37	0.144	12.97	87	0.320	18.07	137	0.469	8.44			
38	0.147	8.38	88	0.325	26.35	138	0.472	12.11			
39	0.151	8.10	89	0.329	26.03	139	0.477	6.76			
40	0.155	7.48	90	0.333	32.42	140	0.481	8.97			
41	0.158	6.10	91	0.334	26.42	141	0.485	7.27			
42	0.160	7.15	92	0.335	23.50	142	0.489	7.43			
43	0.163	6.20	93	0.338	27.52	143	0.494	7.03			
44	0.166	6.55	94	0.340	25.70	144	0.498	9.75			
45	0.171	3.77	95	0.342	32.44	145	0.502	6.77			
46	0.176	4.21	96	0.343	28.06	146	0.504	8.92			
47	0.180	5.55	97	0.343	23.94	147	0.507	11.94			
48	0.185	4.92	98	0.344	30.22	148	0.508	23.64			
49	0.189	5.11	99	0.346	30.78	149	0.510	20.58			
50	0.194	5.18	100	0.347	24.36	150	0.512	18.99			

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : baumaris

Sounding : P009			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 11:11:00
Operator : dpb		Company :	

Comments :

greytill

Index Measure	Depth (m)	Resist. (MPa)
1	0.004	2.43
2	0.007	4.48
3	0.010	5.98
4	0.014	6.26
5	0.017	6.52
6	0.023	4.59
7	0.030	4.95
8	0.032	10.28
9	0.035	9.96
10	0.039	6.22
11	0.045	5.81
12	0.049	4.55
13	0.054	5.88
14	0.058	6.81
15	0.066	3.40
16	0.071	4.49
17	0.074	14.89
18	0.079	3.62
19	0.086	4.93
20	0.092	4.14
21	0.099	4.55
22	0.105	5.18
23	0.110	6.47
24	0.117	4.71
25	0.125	3.85
26	0.133	4.11
27	0.139	4.86
28	0.147	3.90
29	0.153	5.40
30	0.159	6.27
31	0.162	5.88
32	0.167	6.48
33	0.173	5.78
34	0.179	6.22
35	0.186	5.30
36	0.194	4.29
37	0.200	4.55
38	0.207	5.16
39	0.213	4.95
40	0.220	3.71
41	0.225	6.30
42	0.233	4.66
43	0.241	3.91
44	0.249	4.51
45	0.258	4.22
46	0.264	5.06
47	0.270	4.79
48	0.275	4.50
49	0.281	4.10
50	0.288	4.37

Index Measure	Depth (m)	Resist. (MPa)
51	0.295	3.72
52	0.302	4.76
53	0.310	4.50
54	0.317	5.23
55	0.322	7.48
56	0.327	6.14
57	0.332	6.75
58	0.338	5.45
59	0.344	4.05
60	0.349	4.18
61	0.356	4.18
62	0.363	4.13
63	0.368	4.38
64	0.374	4.74
65	0.379	5.04
66	0.386	4.86
67	0.391	4.95
68	0.396	4.49
69	0.403	5.05
70	0.409	4.96
71	0.415	4.65
72	0.421	4.12
73	0.428	4.30
74	0.435	4.45
75	0.443	4.11
76	0.450	4.73
77	0.458	3.93
78	0.464	5.26
79	0.469	5.27
80	0.475	5.32
81	0.481	4.92
82	0.489	3.95
83	0.497	4.03
84	0.504	3.29
85	0.512	4.54
86	0.519	4.30
87	0.525	3.73
88	0.534	3.67
89	0.542	3.97
90	0.544	5.80
91	0.545	16.85
92	0.551	5.13
93	0.556	5.04
94	0.562	5.04
95	0.570	4.82
96	0.578	4.65
97	0.585	4.46
98	0.591	4.46
99	0.598	4.04
100	0.607	3.91

Index Measure	Depth (m)	Resist. (MPa)
101	0.617	3.53
102	0.623	4.12
103	0.632	4.21
104	0.641	4.00
105	0.651	4.18
106	0.658	4.40
107	0.667	3.74
108	0.676	3.28
109	0.685	2.97
110	0.697	3.30
111	0.706	3.31
112	0.718	3.36
113	0.728	3.38
114	0.737	4.13
115	0.745	3.88
116	0.753	3.69
117	0.761	4.08
118	0.770	3.96
119	0.776	4.52
120	0.784	3.75
121	0.789	3.88
122	0.792	2.75
123	0.799	3.11
124	0.806	3.95
125	0.812	3.80
126	0.820	3.93
127	0.829	3.70
128	0.838	3.64
129	0.845	4.24
130	0.850	3.19
131	0.859	3.38
132	0.866	3.84
133	0.871	4.71
134	0.878	4.16
135	0.886	4.01
136	0.895	4.01
137	0.903	4.17
138	0.911	4.50
139	0.918	4.76
140	0.926	4.59
141	0.932	5.81
142	0.940	4.65
143	0.948	4.35
144	0.956	4.64
145	0.962	6.07
146	0.970	4.42
147	0.979	3.94
148	0.986	4.37
149	0.992	5.49
150	0.997	6.41

Index Measure	Depth (m)	Resist. (MPa)
151	1.003	4.60
152	1.009	6.09
153	1.016	4.45
154	1.023	5.75
155	1.030	4.94
156	1.038	5.34
157	1.048	4.72
158	1.056	4.68
159	1.059	4.00
160	1.062	4.28
161	1.066	4.00
162	1.069	4.25
163	1.075	4.07
164	1.082	4.86
165	1.089	4.82
166	1.097	4.86
167	1.105	4.97
168	1.112	4.90
169	1.120	4.85
170	1.128	5.10
171	1.135	4.57
172	1.143	4.39
173	1.151	4.64
174	1.159	4.79
175	1.166	5.12
176	1.174	5.33
177	1.181	5.14
178	1.187	5.21
179	1.194	5.66
180	1.198	7.08
181	1.202	7.35
182	1.209	5.17
183	1.222	2.92
184	1.227	6.40
185	1.234	4.18
186	1.241	4.23
187	1.248	3.97
188	1.256	4.63
189	1.264	3.83
190	1.274	4.12
191	1.285	3.23
192	1.291	6.54
193	1.298	4.04
194	1.306	4.26

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : baumaris			
Sounding : P010			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 12:10:00
Operator : dpb		Company :	

Comments :
RED TILL
BAUMARIS

Index Measure	*Depth (m)*	*Resist. (MPa)*
1	0.005	1.78
2	0.010	2.64
3	0.014	3.03
4	0.016	6.05
5	0.019	6.01
6	0.023	3.53
7	0.027	3.68
8	0.031	5.08
9	0.034	4.80
10	0.038	4.57
11	0.041	5.04
12	0.044	4.34
13	0.047	7.21
14	0.050	4.36
15	0.053	6.49
16	0.056	5.08
17	0.058	7.29
18	0.060	8.40
19	0.062	5.83
20	0.065	5.74
21	0.067	7.33
22	0.070	6.54
23	0.073	6.65
24	0.074	11.64
25	0.077	7.33
26	0.080	5.42
27	0.081	8.66
28	0.083	7.51
29	0.086	6.76
30	0.089	4.84
31	0.091	11.59
32	0.092	13.93
33	0.095	5.92
34	0.097	8.12
35	0.100	6.63
36	0.103	4.79
37	0.106	8.40
38	0.109	6.65
39	0.113	4.85
40	0.117	5.99
41	0.119	8.03
42	0.123	5.58
43	0.126	7.95
44	0.129	5.56
45	0.131	7.46
46	0.134	6.79
47	0.137	7.02
48	0.140	6.69
49	0.143	6.35
50	0.145	7.81

Index Measure	*Depth (m)*	*Resist. (MPa)*
51	0.148	6.71
52	0.151	8.44
53	0.154	5.64
54	0.157	6.61
55	0.159	8.77
56	0.162	6.89
57	0.165	7.20
58	0.168	7.26
59	0.171	5.55
60	0.173	15.34
61	0.175	8.35
62	0.178	6.25
63	0.180	7.35
64	0.184	5.22
65	0.192	2.66
66	0.195	7.07
67	0.196	9.03
68	0.199	8.51
69	0.201	7.58
70	0.203	8.65
71	0.206	8.29
72	0.208	9.29
73	0.211	8.56
74	0.213	11.82
75	0.214	12.27
76	0.216	15.78
77	0.218	11.34
78	0.219	11.42
79	0.221	14.23
80	0.224	9.83
81	0.225	15.53
82	0.229	7.64
83	0.232	8.13
84	0.234	7.52
85	0.238	5.59
86	0.240	11.71
87	0.243	8.17
88	0.245	8.95
89	0.248	8.55
90	0.251	8.34
91	0.253	9.73
92	0.256	11.27
93	0.259	9.63
94	0.262	8.81
95	0.265	9.93
96	0.268	8.86
97	0.272	8.07
98	0.275	8.66
99	0.278	9.26
100	0.282	8.93

Index Measure	*Depth (m)*	*Resist. (MPa)*
101	0.285	9.57
102	0.288	9.54
103	0.290	14.19
104	0.293	15.55
105	0.294	22.38
106	0.296	20.79
107	0.298	22.99
108	0.299	33.18

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : baumaris

Sounding : P011

Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 12:16:00
Operator : dpb		Company :	

Comments :
RED TILL

Index Measure	Depth (m)	Resist. (MPa)	Index Measure	Depth (m)	Resist. (MPa)
1	0.016	0.82	51	0.214	18.58
2	0.024	1.09	52	0.216	13.83
3	0.032	1.78	53	0.222	6.04
4	0.040	2.26	54	0.224	10.63
5	0.047	2.65	55	0.228	8.76
6	0.053	3.54	56	0.230	10.98
7	0.060	3.32	57	0.233	8.42
8	0.064	4.88	58	0.237	8.12
9	0.070	4.46	59	0.241	8.30
10	0.075	4.58	60	0.245	5.44
11	0.080	5.33	61	0.249	6.05
12	0.088	3.72	62	0.254	4.50
13	0.091	8.32	63	0.258	6.22
14	0.097	4.61	64	0.263	4.55
15	0.100	13.28	65	0.268	4.92
16	0.101	21.01	66	0.274	4.44
17	0.104	18.98	67	0.282	2.62
18	0.106	15.86	68	0.292	1.77
19	0.108	20.77	69	0.295	6.67
20	0.115	6.17	70	0.299	6.42
21	0.116	21.89	71	0.300	13.53
22	0.119	15.14	72	0.302	9.05
23	0.122	11.98	73	0.307	5.31
24	0.127	5.56	74	0.311	5.09
25	0.129	16.84	75	0.316	5.15
26	0.130	21.66	76	0.318	11.77
27	0.133	11.66	77	0.321	11.06
28	0.135	24.52			
29	0.138	9.52			
30	0.141	11.52			
31	0.144	10.63			
32	0.145	20.72			
33	0.148	9.46			
34	0.150	18.42			
35	0.153	9.48			
36	0.157	7.69			
37	0.159	18.20			
38	0.163	9.31			
39	0.166	12.39			
40	0.169	9.14			
41	0.174	6.54			
42	0.179	6.05			
43	0.183	7.87			
44	0.186	9.22			
45	0.190	8.98			
46	0.193	8.50			
47	0.200	4.45			
48	0.202	12.03			
49	0.206	7.28			
50	0.213	4.11			

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : baumaris

Sounding : P012			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 12:23:00
Operator : dpb		Company :	

Comments :
RED TILL

Index Measure	Depth (m)	Resist. (MPa)
1	0.006	2.11
2	0.011	2.75
3	0.015	4.33
4	0.021	2.96
5	0.025	4.56
6	0.028	5.84
7	0.034	3.44
8	0.038	4.96
9	0.043	4.94
10	0.046	6.01
11	0.049	6.09
12	0.053	5.47
13	0.064	1.92
14	0.066	10.45
15	0.069	6.40
16	0.073	4.34
17	0.075	8.45
18	0.080	3.71
19	0.084	3.96
20	0.089	3.58
21	0.095	3.03
22	0.100	3.53
23	0.104	4.68
24	0.108	5.32
25	0.111	5.78
26	0.115	5.83
27	0.119	4.97
28	0.124	4.28
29	0.131	3.12
30	0.135	3.93
31	0.139	4.31
32	0.144	4.18
33	0.147	5.08
34	0.150	6.05
35	0.155	5.49
36	0.160	4.45
37	0.165	5.27
38	0.170	4.28
39	0.176	4.52
40	0.181	4.05
41	0.187	3.71
42	0.193	3.79
43	0.198	5.00
44	0.204	3.62

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.			
Site : PORT NOBLA			
Sounding : P014			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 16:16:00
Operator : dpb		Company :	
Comments : RED TILL			

Index Measure	Depth (m)	Resist. (MPa)
1	0.007	2.23
2	0.011	4.09
3	0.017	2.77
4	0.021	3.99
5	0.025	3.84
6	0.029	3.67
7	0.032	5.84
8	0.036	3.70
9	0.038	6.36
10	0.040	13.12
11	0.041	15.45
12	0.043	9.17
13	0.045	8.84
14	0.046	19.71
15	0.048	12.31
16	0.051	5.13
17	0.053	10.87
18	0.056	6.51
19	0.058	15.36
20	0.062	4.75
21	0.064	6.70
22	0.067	4.49
23	0.068	12.60
24	0.070	8.44
25	0.073	7.65
26	0.074	11.50
27	0.076	10.62
28	0.078	8.27
29	0.081	6.25
30	0.083	12.68
31	0.085	10.11
32	0.086	8.19
33	0.088	12.39
34	0.091	5.93
35	0.093	12.82
36	0.095	6.32
37	0.098	5.50
38	0.100	13.37
39	0.104	5.15
40	0.106	6.36
41	0.108	14.53
42	0.111	8.81
43	0.114	8.49
44	0.117	9.14
45	0.120	7.67
46	0.123	11.89
47	0.124	15.88
48	0.128	7.25
49	0.130	12.00
50	0.132	14.82

Index Measure	Depth (m)	Resist. (MPa)
51	0.133	17.48
52	0.135	13.31
53	0.140	5.98
54	0.143	10.35
55	0.145	14.21
56	0.149	5.45
57	0.151	13.97
58	0.152	20.02
59	0.155	8.40
60	0.157	11.95
61	0.159	13.95
62	0.160	14.42
63	0.162	9.21
64	0.165	8.83
65	0.167	15.23
66	0.168	10.81
67	0.172	5.41
68	0.173	14.27
69	0.176	7.02
70	0.177	13.44
71	0.179	10.23
72	0.180	11.23
73	0.182	9.86
74	0.183	8.63
75	0.185	6.86
76	0.187	7.99
77	0.189	7.08
78	0.191	8.85
79	0.193	7.10
80	0.195	8.96
81	0.197	9.05
82	0.198	8.52
83	0.201	6.25
84	0.202	6.99
85	0.203	10.14
86	0.205	8.61
87	0.206	9.92
88	0.208	6.41
89	0.209	9.55
90	0.211	7.47
91	0.213	6.69
92	0.216	4.99
93	0.218	6.05
94	0.220	6.83
95	0.224	6.93
96	0.226	10.15
97	0.228	16.73
98	0.230	24.24
99	0.231	21.76
100	0.233	11.78

Index Measure	Depth (m)	Resist. (MPa)
101	0.238	11.84
102	0.242	8.15
103	0.246	7.54
104	0.250	6.83
105	0.254	6.03
106	0.258	6.24
107	0.261	7.09
108	0.264	9.01
109	0.269	6.13
110	0.273	7.66
111	0.276	11.22
112	0.280	9.75
113	0.281	21.84
114	0.284	9.51
115	0.287	9.95
116	0.289	13.28
117	0.291	24.75
118	0.294	8.91

Page 1/1

PANDA 2.2 software

Sounding cone resistance data table

Document : W:\Teams\GPP\PhysPropBehaviourUKRockSoils\Data\TILLS\Fieldwork_Data\Anglesey\AngleseyPandaNov2011.

Site : PORT NOBLA

Sounding : P015			
Elevation : 0.00 m	Pre-sounding depth : 0.000 m	Area : 0.0004 m²	Water table : Non-existent
Weight : Panda 2 hammer	Breaking cond. : Temporary	Date : 10/11/2011	Hour : 16:22:00
Operator : dpb		Company :	

Comments :
RED TILL

Index Measure	Depth (m)	Resist. (MPa)
1	0.004	1.06
2	0.008	2.41
3	0.010	4.02
4	0.011	6.83
5	0.014	2.66
6	0.017	1.81
7	0.020	6.79
8	0.023	5.23
9	0.028	3.28
10	0.031	6.16
11	0.034	7.37
12	0.036	7.92
13	0.038	8.28
14	0.041	7.25
15	0.043	8.03
16	0.045	4.51
17	0.047	7.53
18	0.049	7.58
19	0.051	11.44
20	0.053	7.16
21	0.055	11.75
22	0.059	6.44
23	0.062	7.66
24	0.065	7.04
25	0.067	11.43
26	0.068	13.60
27	0.070	12.26
28	0.074	5.69
29	0.076	9.89
30	0.080	5.88
31	0.082	8.69
32	0.086	5.48
33	0.088	8.25
34	0.090	9.80
35	0.093	6.61
36	0.096	7.37
37	0.099	6.50
38	0.103	6.97
39	0.107	5.93
40	0.111	6.97
41	0.115	5.91
42	0.118	7.22
43	0.123	4.84
44	0.128	5.71
45	0.133	4.82
46	0.137	5.60
47	0.143	4.52
48	0.148	3.88
49	0.155	3.42
50	0.163	3.56
51	0.172	3.29
52	0.182	2.60
53	0.189	4.23
54	0.196	3.03
55	0.203	2.65
56	0.208	4.15
57	0.213	5.31
58	0.221	4.23
59	0.228	5.59
60	0.235	4.49
61	0.241	4.92
62	0.246	6.56
63	0.255	4.35
64	0.263	4.39
65	0.272	3.58
66	0.278	5.77
67	0.280	3.77
68	0.282	5.07
69	0.285	5.08
70	0.288	5.40
71	0.292	5.65
72	0.294	7.79
73	0.297	4.70
74	0.300	6.34
75	0.302	6.01
76	0.306	5.50
77	0.310	4.19
78	0.313	4.00
79	0.316	4.60
80	0.319	4.22
81	0.325	2.87
82	0.331	1.88
83	0.339	1.26
84	0.349	1.28
85	0.364	1.03
86	0.382	0.94
87	0.398	1.05
88	0.413	1.40
89	0.425	1.90
90	0.433	2.72
91	0.440	3.56
92	0.445	5.46
93	0.447	6.93
94	0.450	8.74
95	0.452	14.08
96	0.453	19.13
97	0.455	11.76
98	0.457	10.05
99	0.460	9.73
100	0.461	7.98
101	0.464	10.84
102	0.465	10.10
103	0.467	7.92
104	0.468	11.92
105	0.470	9.75
106	0.472	12.58
107	0.473	14.26
108	0.476	13.01
109	0.477	16.91
110	0.479	14.85

Page 1/1

PANDA 2.2 software

Appendix 3: Geochemistry of the Brown and Grey Till deposits of Anglesey, Wales – preliminary results

(A. Scheib)

Background

Soil geochemical baseline data have successfully been applied as proxy in the reconstruction of the flowpaths of the Middle Pleistocene British Ice Sheet in central-eastern England. In this study Scheib et al. (2011) used total element concentrations from XRFS analysis to firstly establish element associations in soils over known till deposits and secondly provenance these geochemical signatures, enabling the reconstruction of ice flow paths associated with two different Middle Pleistocene till sheets.

Analysis

Samples from the Grey Till and Brown Till units from Cemlyn Bay, North Anglesey, were analysed using a hand-held (HH) portable X-ray fluorescence spectrometry (XRFS) element analyser; a method that is an inexpensive, quick and easy way to obtain semi-quantitative results.

The analyses with the HH XRFS were carried out on two samples from each till deposit; one sample containing material below 63 µm (clay and silt fraction) and the other containing material above 63 µm (sand fraction to 2 mm). All samples were air dried and retained in a small re-sealable plastic bag.

These sample bags were laid out on a clean work bench and measured using the NITON XLt Analyser in test mode "Standard Bulk Mode". Latter mode gives result in mg/kg for elements K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Ag, Cd, Sn, Sb, Hg and Pb. Individual samples were measured three times at 30 seconds each.

To assess the precision and accuracy of the HH XRFS results, the G-BASE internal secondary reference material (SRM) S22B was measured at the start and end of analysis. Tables 1 and 2 list results of those measurements. Results for some elements (Ni, Co, Cr, Hg, Cd, and Se) were excluded because concentrations were either below detectable limits or inconsistent with the lab-based XRFS results.

Tables 1 and 2 also display a column for each element that gives two standard deviations (2SD) for each of the 30 second measurement; and informs on the distribution of the concentrations. Results for the six measurements of S22B are consistent throughout, except the third measurement which seems to give lower concentrations for all determinants. Results for V should also be handled with care as measurements are not as consistent.

The average (mean) concentration of the six individual measurements (total HH) is listed with the lab-based XRFS results for SRM S22B below. The error (difference), displayed in %, between those two results is calculated as follows:

error = [(Lab - HH mean)/Lab]*100

Except for results for Ca, K, V and Sr, HH results are within 20% of the lab-based XRFS results. Positive percentages throughout the analysis indicate an underreporting by the HH XRFS method. A modification factor (Tables 1 and 2) was calculated for each element, and applied to the results obtained for the four till samples.

Table 8 Concentrations (mg/kg) for SRM S22B following analysis by handheld XRFS NITON XLt Analyser; 2SD = two standard deviations for each 30 second measurement.

SAMPLE	No	As	As 2SD	Pb	Pb 2SD	Zn	Zn 2SD	Cu	Cu 2SD	V	V 2SD	Sr	Sr 2SD	Rb	Rb 2SD
S22B	1	2864	79.78	428	40.63	1134	81.93	253	66.42	142.0	145.48	27.8	6.35	171	12.59
S22B	2	2973	82.17	422	41.13	1136	83.23	251	68.08	27.3	155.19	32.8	6.73	164	12.53
S22B	3	1870	54.00	253	27.09	700	55.13	183	46.86	58.9	123.68	21.5	4.78	120	8.93
Mean HH		**2569**	**71.98**	**368**	**36.28**	**990**	**73.43**	**229**	**60.45**	**76.1**	**141.45**	**27.3**	**5.95**	**152**	**11.35**
S22B	4	2774	76.28	378	37.85	1062	77.53	206	61.59	159.7	160.79	29.3	6.23	174	12.36
S22B	5	2821	78.12	387	38.79	1084	79.63	293	67.62	85.9	146.12	24.0	6.09	160	12.09
S22B	6	2503	69.63	336	34.41	981	71.62	174	55.79	156.7	144.65	27.8	5.84	151	11.13
Mean HH		**2699**	**74.68**	**367**	**37.02**	**1042**	**76.26**	**224**	**61.67**	**134.1**	**150.52**	**27.0**	**6.05**	**162**	**11.86**
Total HH		**2634**	**73.33**	**367**	**36.65**	**1016**	**74.85**	**227**	**61.06**	**105.1**	**145.99**	**27.2**	**6.00**	**157**	**11.61**
Lab		**3405**		**440**		**1098**		**271**		**148.4**		**47.4**		**196**	
Difference %		**22.6**		**16.5**		**7.5**		**16.3**		**29.2**		**42.7**		**20.0**	
Mod Factor		**1.29**		**1.20**		**1.08**		**1.19**		**1.41**		**1.74**		**1.25**	

Table 9 Concentrations (mg/kg) for SRM S22B following analysis by handheld XRFS NITON XLt Analyser; 2SD = two standard deviations for each 30 second measurement, continued.

SAMPLE	Fe	Fe 2SD	Mn	Mn 2SD	Ti	Ti 2SD	Ca	Ca 2SD	K	K 2SD
S22B	68309	1087	7486	482	6332	722	5767	1009	14290	1647
S22B	68663	1105	7663	493	5371	768	5771	971	13636	1582
S22B	38507	687	3556	286	3077	593	2547	771	4972	1124
Mean HH	**58493**	**959**	**6235**	**420**	**4926**	**694**	**4695**	**917**	**10966**	**1451**
S22B	64557	1031	6719	448	6062	782	6282	1018	14459	1648
S22B	65774	1057	6926	461	6535	737	4733	967	14743	1650
S22B	54375	910	5472	390	4822	695	3842	891	9243	1396
Mean HH	**61569**	**999**	**6372**	**433**	**5806**	**738**	**4953**	**959**	**12815**	**1565**
Total HH	**60031**	**979**	**6304**	**427**	**5366**	**716**	**4824**	**938**	**11890**	**1508**
Lab	**71049**		**7498**		**6534**		**7505**		**20581**	
Difference %	**15.5**		**15.9**		**17.9**		**35.7**		**42.2**	
Mod Factor	**1.18**		**1.19**		**1.22**		**1.56**		**1.73**	

Results

Following on from the analysis of SRM S22B, tables 8 and 9 list the results for elements As, Pb, Zn, Cu, Rb, Sr, V and majors Ca, K, Fe, Mn and Ti (as percentage), respectively. The concentrations are the average (mean) of the three measurements and have each been multiplied by the modification factor (Tables 8 and 9); hence the Mod prefix in the header of both tables. Additional to the results for both the fine and sand fraction, tables also list the concentration of the bulk sample; simply the sum of former two results.

Table 10. Modified concentrations (mg/kg) of As, Pb, Zn, Cu, Rb, Sr and V measured in the fine and coarse fraction of the Grey Till and Brown Till samples; concentration difference between the fine and coarse fraction in %.

SAMPLE	Fraction	Mod As	Mod Pb	Mod Zn	Mod Cu	Mod Rb	Mod Sr	Mod V
Grey Till fine	<63 µm	19.57	25.79	148.60	131.26	110.90	272.36	140.05
Grey Till coarse	>63 µm	8.58	6.65	52.34	21.33	57.96	182.10	104.26
difference	%	*56.1*	*74.2*	*64.8*	*83.7*	*47.7*	*33.1*	*25.6*
Grey Till bulk	<2mm	28.15	32.44	200.94	152.59	168.86	454.46	244.31
Brown Till fine	<63 µm	23.92	34.76	100.42	96.20	116.73	136.62	273.46
Brown Till coarse	>63 µm	6.31	20.12	45.04	22.12	69.71	77.32	78.45
difference	%	*73.6*	*42.1*	*55.2*	*77.0*	*40.3*	*43.4*	*71.3*
Brown Till bulk	<2mm	30.23	54.88	145.45	118.32	186.44	213.94	351.92
Brown Till	cobble	9.07	15.15	66.72	-18.20	11.40	2213.05	57.26

Table 11. Modified concentrations (%) of Ca, K, Fe, Mn and Ti measured in the fine and coarse fraction of the Grey Till and Brown Till samples; concentration difference between the fine and coarse fraction in %.

SAMPLE	Fraction	Mod Ca	Mod K	Mod Fe	Mod Mn	Mod Ti
Grey Till fine	<63 µm	6.24	2.68	4.44	0.16	0.59
Grey Till coarse	>63 µm	4.85	1.27	2.13	0.12	0.31
difference	%	*22.3*	*52.5*	*52.0*	*22.8*	*46.8*
Grey Till bulk	<2mm	11.08	3.95	6.58	0.28	0.91
Brown Till fine	<63 µm	0.42	2.43	5.04	0.17	0.77
Brown Till coarse	>63 µm	0.19	1.52	2.65	0.15	0.34
difference	%	*53.6*	*37.3*	*47.4*	*14.3*	*56.3*
Brown Till bulk	<2mm	0.61	3.95	7.69	0.32	1.11
Brown Till	cobble	31.61	0.65	0.89	0.03	0.07

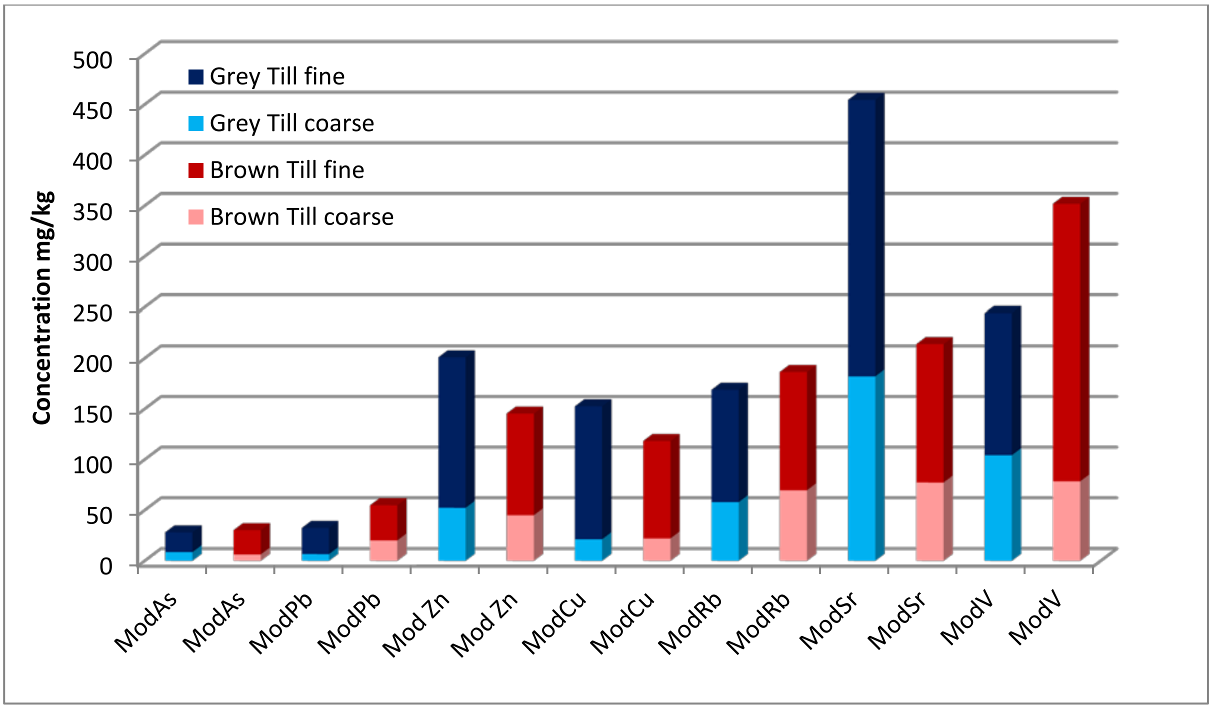


Figure 23. Bar chart of concentrations (mg/kg) of As, Pb, Zn, Cu, Rb, Sr and V measured in the fine and coarse fraction of the Grey Till and Brown Till samples.

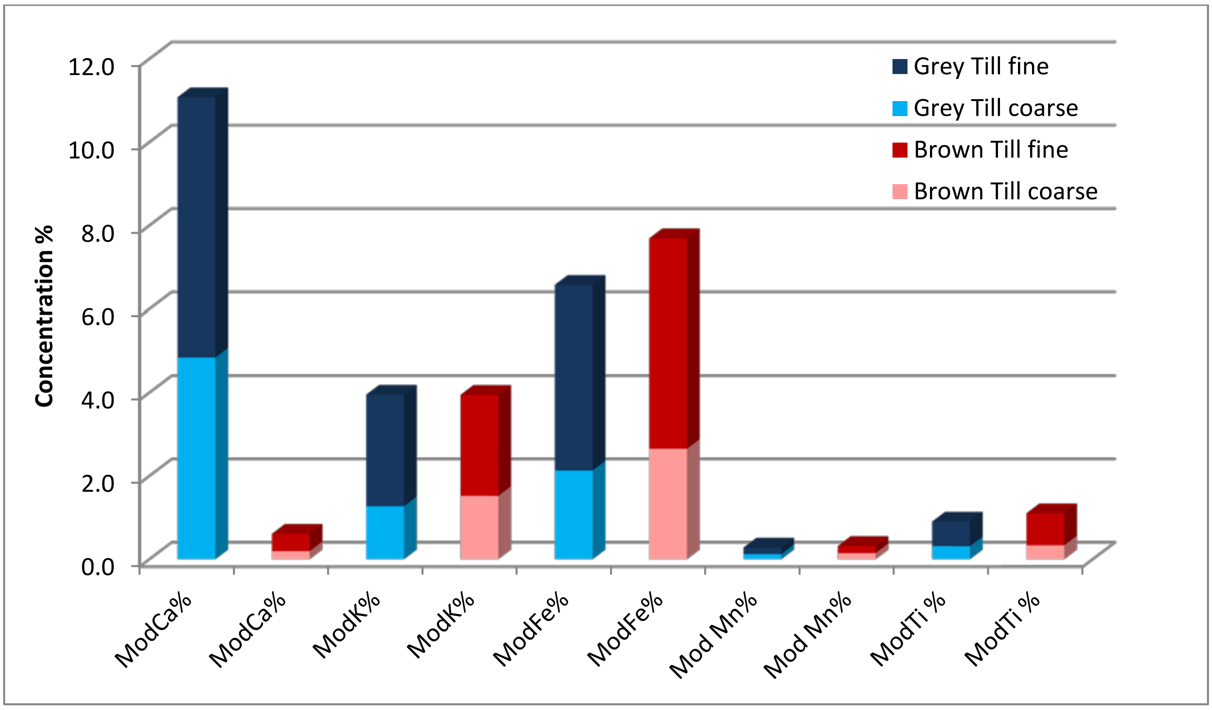


Figure 24. Bar chart of concentrations (%) of Ca, K, Fe, Mn and Ti measured in the fine and coarse fraction of the Grey Till and Brown Till samples.

Figures 23 and 24 display the concentrations of the coarse and fine fractions, for both the Grey and Brown Till as a stacked column chart. Throughout both charts, concentrations measured in the fine fraction of both till types are higher than in the sand fraction, which largely comprises quartz grains. The difference between concentrations between the fine and coarse fraction, expressed as %, are listed in Tables 8 and 9.

For the major elements, lowest concentration differences are calculated for Mn of 22.8 and 14.3 % for Brown Till and Grey Till respectively (Table 24). Highest differences occur for Fe and Ti (approximately 50%) For the trace elements and base metals, concentration differences are much higher and range from 40 to 84 %, with differences below 33% only calculated for Sr and V in Grey Till samples.

The most significant differences in concentration levels between the two till types can be seen for Ca and Sr (Figure 23 and 24). Whilst Sr concentrations in the Grey Till are approximately twice as high, Ca concentrations are 15 times higher in the fine fraction and 25 times higher in the coarse fraction; for the bulk sample, Ca concentrations in the Grey Till are 19 times higher. The sample from the Brown Till was obtained from a near surface, and decalcification may have occurred. Other elements that are slightly higher in the Grey Till are Cu and Zn. Concentrations of the other major elements are fairly similar across both till types.

For the Brown Till samples, results for V stand out. In particular, concentrations for the fine fraction are almost twice as high. Other elements that are slightly higher in the Brown Till are Rb and Pb.

Conclusions

- The handheld XRFS is very easy and quick to use. Results for SRM S22B showed that this method can provide consistent and statistically sound data for, in this case, 12 elements.
- Results showed that Sr and Ca are significantly higher in Grey Till samples, suggesting a calcareous signature. Most of the natural Ca relates to minerals, such as calcite and gypsum, and are subsequently particularly enriched in carbonate rocks, such as limestone, dolomite and chalk. Strontium is also often found in host minerals such as gypsum, calcite and dolomite.
- Ca and Sr levels measured in Grey Till samples are very high (bulk = 11.1% Ca and 455 mg/kg Sr) and are comparable to Ca and Sr levels measured in stream sediments from areas over Cretaceous Chalk or Jurassic Limestone of central and eastern England.
- Potential source rocks for the Grey Till are Carboniferous limestone and dolomite of the Red Wharf Bay area or/and calcareous Triassic strata of the Liverpool Bay (offshore), particularly Mercia Mudstone.
- The Brown Till is completely lacking in a calcareous signature and suggests that the Grey Till has derived (in parts) from different source material, though the sample may be decalcified.
- Results show that V is nearly twice as high in the Brown Till compared with the Grey Till samples. Vanadium is mainly associated with and enriched in basalt or gabbro with host mineral such as pyroxenes and amphiboles. The higher concentrations in Brown Till samples could maybe relate to a mafic igneous signature?

Recommendations

Geochemical data from the analysis using the handheld XRFS could be a useful additional method to help discriminate between different till deposits. Obtaining these semi-quantative results is very quick and cheap - compared with Lab XRF, and can be performed in the field.

The separate analysis of the sand and clay-silt fractions showed the same consistent trend of either elevated or low concentrations in both fractions. It is therefore appropriate and sufficient to use the dried <2 mm sample fraction. This would on the one hand reduce cost and time for sample preparation, and residual PSD material could be used, but is also in line with the size fraction used by the G-BASE project for soil samples.

Handheld XRFS should certainly be considered in future studies of tills or any other superficial deposit that may vary in its composition.

To investigate the tills of Anglesey, more samples need to be collected, prepared and analysed to firm up some of the above results and derived conclusions.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

Amor SJ, MH Burtwell and AS Turner (1999). Panda dynamic cone penetrometer assessment. Transport Research Laboratory, Crowthorne.

Bowen, D. Q. (Ed). 1999. A revised correlation of Quaternary deposits in the British Isles. Special Report of the Geological Society of London No. 23, p. 174.

BS 1377:Part 9:1990 Methods of testing soils for civil engineering purposes. British Standards Institution. London.

Evans, D.J.A., Phillips, E.R., Hiemstra, J.F. Auton, C.A. 2006. Subglacial till: Formation, sedimentary characteristics and classification. Earth Science Reviews 78, p115-176.

Greenly, E., 1919. The geology of Anglesey. Memoir (District) Geological Survey of Great

Britain. HMSO, London. 980 pp.

Harris, C. 1991. Glacial deposits at Wylfa Head, Anglesey, North Wales: evidence for Late Devensian deposition in a non-marine environment. *Journal of Quaternary Science* 6, 67-77.

HEAD, K H. 2008. Manual of Soil Laboratory Testing volume 1: Soil classification and compaction tests, 3rd edition. Whittles Publishing Ltd. 416pp.

Langton, D.D. 1999. The Panda lightweight penetrometer for soil investigation and monitoring material compaction. Ground Engineering, p33-37.

Lewis, C.A., Richards, A.E. (Eds). 2005. The glaciations of Wales and adjacent areas. Logaston Press. ISBN 1 904396 36 4.

McMillan, A.A., Hamblin, R.J.O., Merritt, J.W., 2011. A lithostratigraphical framework for onshore Quaternary and Neogene (Tertiary) superficial deposits of Great Britain and the Isle of Man. British Geological Survey Research Report RR/10/03.

McMillan, A.A., Merritt, J.W., 2012. A new Quaternary and Neogene Lithostratigraphical Framework for Great Britain and the Isle of Man. *Proceedings of the Geologists' Association*. 123, 679-691.

Menzies, J., Brand, U. 2006. The internal sediment architecture of a drumlin, Port Byron, New York State, USA. Quaternary Science Reviews 26, 322-335.

Phillips, E., Everest, J., Diaz-Doce, D. 2010. Bedrock controls on subglacial landform distribution and geomorphologic processes: Evidence from the Late Devensian Irish Sea Ice Stream. Sedimentary Geology 232, 98-118.

Riding, J. B. 2012. A palynological report on the Quaternary tills of Anglesey, North Wales. British Geological Survey Research Report Internal Report IR/12/024.

Scheib, Andreas J.; Lee, Jonathan R.; Breward, Neil; Riding, James B. 2011 Reconstructing flowpaths of the Middle Pleistocene British Ice Sheet in central-eastern England : the application of regional soil geochemical data. *Proceedings of the Geologists' Association*, 122 (3). 432-444. 10.1016/j.pgeola.2011.01.008

Self, S., Entwisle, D., Northmore, K. 2012. The structure and operation of the BGS National Geotechnical Properties Database Version 2. *British Geological Survey Internal Report IR/12/056.* British Geological Survey. 61pp.