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Falling head permeability tests on Till deposits from the Vale of Eden, England

Geotechnical and Geophysical Properties and Processes Team:

UK Rocks and Soils

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BRITISH GEOLOGICAL SURVEY

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INTERNAL REPORT IR/13/034

Falling head permeability tests on Till deposits from the Vale of Eden, England

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Preparation of till sample for hydraulic conductivity testing

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Foreword

This report is the published product of a study by the British Geological Survey (BGS) to investigate the physical properties of till deposits that occur in the United Kingdom. This report is a factual account of a laboratory assessment of permeability on till deposits from the Vale of Eden. The work was done as part of the BGS research programme into physical properties of UK rocks and soils project under the Geotechnical and Geophysical Properties and Processes Team.

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Summary

This report describes permeability tests carried out on sixteen samples of glacial till obtained from boreholes drilled in the Vale of Eden area in Cumbria, England. The report outlines the testing procedure and presents the results of the permeability tests. Measured permeability values were variable and ranged from 10^{-5} to 10^{-10} m/s, Medium Low to Impermeable.

1 Introduction

Permeability tests carried out on 16 samples of Till from the Eden Valley area of Cumbria. Samples were obtained from boreholes drilled by DEFRA from two catchments 'Pow' and 'Dedra Banks'. The tests were carried out according to the procedure in Section 10.7 of Head (1994), with only minor modifications to specimen dimensions. The test is neither a British nor an American standard, but is generally accepted. The BH locations are listed in Table 1 below.

Table 1 Sample locations

Site name	BH Name	NGR_East	NGR_North
Pow Catchment	BH1	339544	550161
	BH2	339534	550135
	BH3	339312	550188
	BH6	338854	550028
	BH7	338703	550091
Dedra Banks (Moorland Catchment)	BH1	357903	519550

The samples were cut from core material that was acquired the previous year, and kept, sealed, in cold storage prior to the permeability testing. The original core was from industry-standard U100 samples – approximately 100mm diameter. The cores lengths were logged and photographed prior to sample preparation and care was taken not to disturb the specimens during logging.

Following completion of the permeability tests, the samples were handed over to researchers at the University of Lancaster (Professor Andrew Binley) for further analysis of geophysical properties.

2 Test Apparatus

The apparatus configuration is shown in Figure 1. The test apparatus was originally supplied by Wykeham Farrance Eng. Ltd of Slough, Buckinghamshire. However, parts of the equipment proved to be inadequate for a variety of reasons, and as a result the pipe network connecting the cells to the header tank and standpipe tubes was rebuilt using Swagelok fittings and the test cells themselves were modified. These were arranged in such a way as to discourage the entrapment of air bubbles emanating from the test specimen. The central component of the cell is the tightness of fit of the specimen inside the cutter tube. The tube supplied by the manufacturer has an internal diameter of 100mm. This resulted in an immediate problem in that the samples provided were also 100mm in diameter and the normal process of trimming to produce a tight fit in the tube was not possible. Therefore, a plastic liner was fitted to each cell to reduce the internal diameter to a nominal 90mm.

Rubber connecting tubes were replaced with nylon and neoprene tubes and pinch valves replaced with Legris taps. The cell was primed from a header tank supplied with de-ionized, de-aired water. Three capillary standpipes were included in the apparatus, of internal diameter 6mm, 7mm and 10mm. These were supplied in plastic, instead of the traditional glass, and sealed at each end with O-rings. In the past, problems have been experienced in dislodging air bubbles (emanating from the test specimen) from the walls of the capillary standpipes, as these adhere more than they would with glass tubes. In this series of tests, no such problems were encountered.

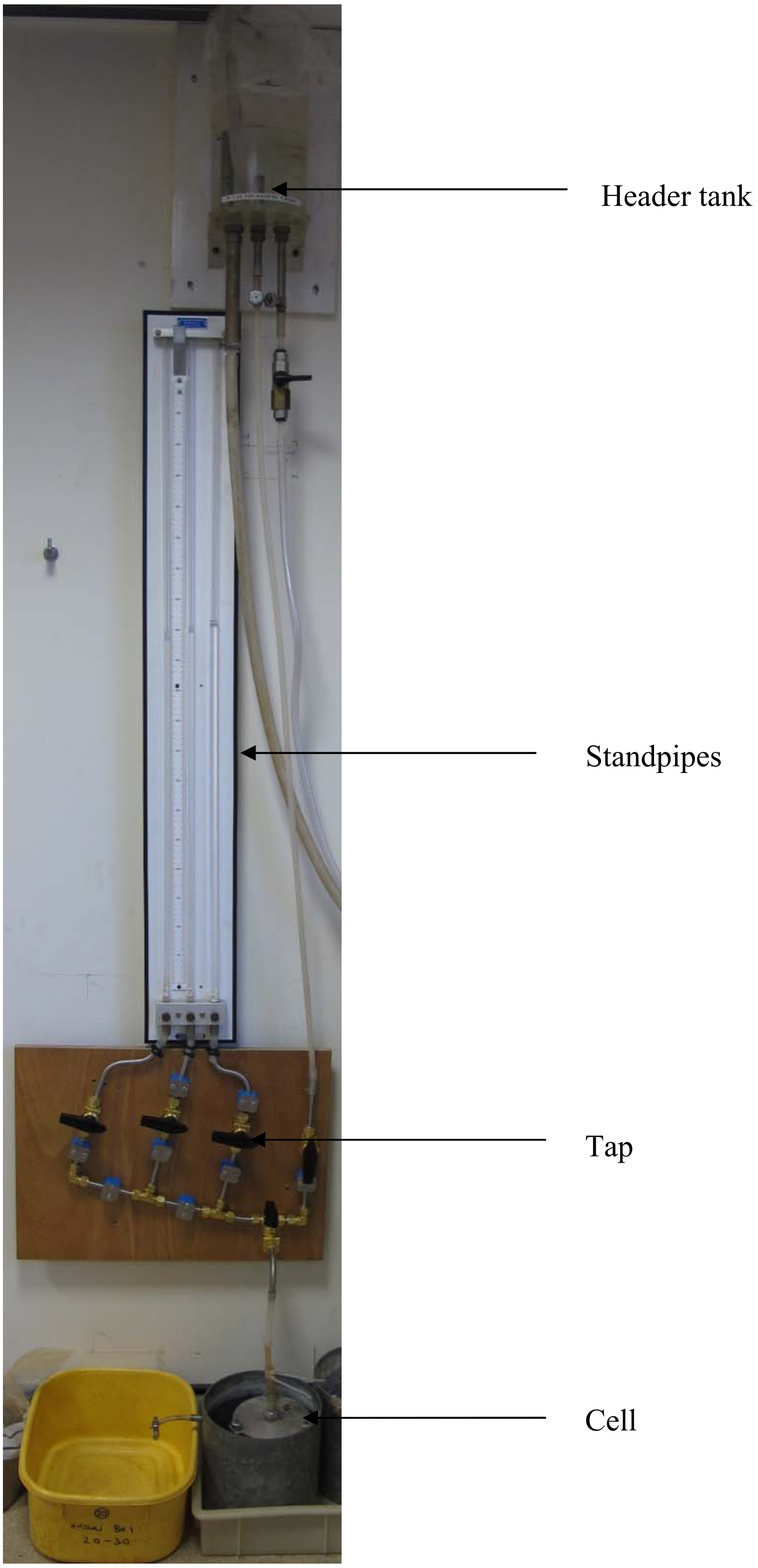

Figure 1: Falling Head Permeability Apparatus

3 Sample Preparation

The plastic sample liner was cut from the sample using a vibrating saw rig at the BGS Core Store labs. This produced less sample disturbance than extrusion of the sample by piston. The plastic (UPVC) sample tube was then greased on the inside with silicone grease, in order to fill any voids between the sample and the inside of the tube, and weighed. The tube was made from UPVC as this material is non-conductive and could be later retrofitted with electrodes for geophysical work on the sample. A chamfered metal cutting shoe (produced in the BGS workshops) was fitted to the tube to help with the cutting as shown in Figure 2. The sample was trimmed down with a sharp blade as the tube was pushed down over the sample in small increments, using a block of wood to keep the pressure more evenly distributed, to produce a specimen that fitted tightly in the tube (Fig 2). It was essential to produce a tight fit in order to prevent leakage of water between the specimen and the tube.

Figure 2: Trimming the sample to fit the UPVC tube.

In order to fit the tube, a number of gravel-sized clasts had to be removed from most of the samples. The resulting voids were filled with fine-grained material from the sample. The cutting shoe was removed and the ends of the specimen trimmed flat with a straight-edged blade. The specimen and tube were weighed, as well as the excess grease extruded in the process. The specimen was then inserted in a greased metal 100mm diameter cutter tube (from the original test apparatus), and placed in the permeameter cell, as shown in Figure 10.36 in Head (1994). A water tight seal was formed between the cutter tube and UPVC tube by applying silicone (bathroom) sealant to the surfaces and allowing to ‘go off’ for several hours. The soil sample was immersed in de-ionized, de-aired water and left overnight or longer to saturate and to allow the clay fraction to swell. The cell was placed in a constant level tray with outlet to waste. The height difference between the zero reading on the scale and the overflow level of the tray was measured.

4 Test Method

The hyrdraulic connections were made to the cell, and the standpipe tube, interconnecting tubes, and tap primed and de-aired from the header tank. The constant level tray was filled with de-ionized, de-aired water to its overflow level. Water was allowed to flow through the cell and flush out any air remaining in the specimen. When a constant flow had been established the standpipe was primed, the level in the standpipe recorded, and the timer started. The falling levels in the standpipe were recorded at intervals appropriate to each specimen. This varied from seconds to hours, according to the permeability. The temperature of the laboratory was monitored throughout, and remained constant at 20°C.

The method outlined by Head (1994) suggests a single run on the permeameter, with three measurements of Height as the water level falls. But due to the variability of the permeability results, it was decided that a series of measurements would be taken, sometimes over a single run, and in some instances the test was stopped, the standpipes refilled, and another run recorded. The results were recorded as a series of numbered tests, and are displayed as graphs in Figure 3. Minimum value of permeability used, for reasons described below, in section 7.1.

Errors in the falling head permeability test may arise from the following:

a) Leakage between the test specimen and the sample tube due to leaks in the seal between sample and tube, or between test vessel and tube. Leaks will tend to increase the measured permeability.
b) Incomplete saturation of the test specimen and/or air in the tubing and standpipes. This will tend to decrease the permeability result.
c) The development of fissures in, or swelling of, the specimen, or other changes in the structure of the specimen. This may increase or decrease the measured permeability.
d) Darcy's Law, used to determine the permeability, only applies to laminar flow in a saturated soil and not turbulent flow. However, turbulent flow is unlikely in soils with permeabilities in the region of 10^{-10} to 10^{-9} m/s. Flow in cohesive soils may also be influenced by the nature and content of clay minerals present. This may be strongly time dependent, and influenced by the relative chemistry of the natural pore water and the de-ionized, de-aired water used in the test.
e) Variations in temperature. An increase in temperature will reduce the viscosity of the water and increase the measured permeability.
f) Variation in the diameter of the standpipe.
g) Evaporation of water from the standpipe. This will tend to increase the measured permeability.

5 Calculations

The fundamental equation governing the laminar flow of water through soil is Darcy's Law:

$$Q = A.k.i$$

Where: Q = rate of discharge through a soil of cross-sectional area, A
k = coefficient of permeability
i = hydraulic gradient

This equation only applies to laminar flow through a saturated soil.

The working equation using test data is as follows:

$$K=[a.L / (A.\Delta t)].Log_{10}(h_U / h_L)10^{-5}$$

in which we have:
L: the height of the soil sample column
A: the sample cross section
a: the cross section of the standpipe
Δt: the recorded time for the water column to flow though the sample
h_U and h_L : the upper and lower water level in the standpipe measured using the same water head reference)

6 Test Results

Sixteen falling head permeability tests have been carried out. The results for each test are summarised in Table 2 and full test data is saved in W:\Teams\GPP\GeoengPropProcProjMgmt\Data\Geotechnical_Labs\Lab_Jobs\201-210\LJ_203 Eden_Valley_Tills, and are summarised in Appendix 1. Temperature corrections to the results were not required due to steady laboratory temperatures (20^o Celsius) throughout. The range of minimum permeability values is from 1.5 x 10^{-10} m/s to 5.7 x 10^{-5} m/s (Table 2). The permeability values measured can be classified as 'impermeable' to 'medium low' and are typical of 'intact clays' to 'fissured and weathered clays' and silts (Head, 1994). Permeability values from samples from the Pow catchment ranged from 10^{-10} to 10^{-5} m/s, whilst values from Dedra Banks site (Moorland Catchment) ranged from 10^{-10} to 10^{-7} m/s. The results show a slight tendency for permeability to increase with depth, although there is no overall relationship between permeability and depth.

Fluctuations in permeability with time are conspicuous in most cases, sometimes varying by as much as an order of magnitude. The majority of these showed a steady decrease in permeability over time, with the notable exception of Sample 5 (from Pow BH3, 3.62-3.75m), which appears to have an exponential-like increase in permeability. This may be due to flushing out of fines during the test or the development of secondary permeability through a fissure. There seems to be no obvious relationship between the permeability of the specimens and the fluctuations in the measured values, although the samples with permeability of more than 10^{-7} m/s do not seem to exhibit this to the same degree as the specimens of very low permeability.

Most of the samples tested are at the lower end of the permeability range recommended for this test (Head, 1994). Permeability testing in the oedometer rather than the falling head cell is recommended for permeabilities of 10^{-9} m/s and less (Head, 1994). However, the oedometer test only accepts a small specimen and is unsuitable for testing tills that contain gravel. For such materials a large specimen is essential in order to allow as much of the particle size range to be represented as possible.

Table 2 Summary of permeability test results

Sample Number	Site and BH	Sample Depth m	Average Coefficient of Permeability, k (m/s) to 1 decimal	Minimum value, k m/s	Standard Deviation m/s
1	Pow BH1	0.75-0.93	1.5 x 10^{-9}	2.8 x 10^{-10}	1.3 x 10^{-9}
2	Pow BH1	1.97-2.10	5.2 x 10^{-9}	3.7 x 10^{-9}	1.0 x 10^{-9}
3	Pow BH1	4.84-4.97	9.9 x 10^{-9}	5.7 x 10^{-9}	5.0 x 10^{-9}
4	Pow BH1	7.12-7.25	6.5 x 10^{-07}	5.7 x 10^{-7}	6.0 x 10^{-8}
5	Pow BH3	3.62-3.75	1.1 x 10^{-09}	3.6 x 10^{-10}	1.0 x 10^{-9}
6	Pow BH6	2.80-2.93	3.7 x 10^{-09}	1.5 x 10^{-10}	3.3 x 10^{-10}
7	Pow BH6	1.47-1.60	1.6 x 10^{-09}	1.2 x 10^{-9}	3.9 x 10^{-10}
8	Pow BH1	5.82-5.95	5.0 x 10^{-08}	1.8 x 10^{-8}	2.2 x 10^{-8}
9	Dedra Bank BH1	1.47-1.60	1.4 x 10^{-09}	8.7 x 10^{-10}	5.6 x10^{-10}
10	Dedra Bank BH1	1.97-2.10	5.1 x 10^{-07}	4.2 x 10^{-7}	4.4 x 10^{-8}
11	Pow BH2	0.78-0.91	4.9 x 10^{-06}	2.0 x 10^{-09}	1.2 x 10^{-06}
12	Pow BH2	2.03-2.16	2.9 x 10^{-09}	3.9 x 10^{-06}	1.5 x 10^{-09}
13	Pow BH6	0.96-1.09	2.4 x 10^{-06}	2.3x 10^{-06}	1.2 x 10^{-07}
14	Pow BH7	0.82-0.95	1.1 x 10^{-05}	1.1 x 10^{-05}	2.2 x 10^{-07}
15	Pow BH1	1.20-1.65	1.6 x 10^{-07}	9.5x 10^{-08}	1.0 x 10^{-07}
16	Pow BH2	1.41-1.54	5.6 x 10^{-07}	*8.0 x 10^{-07}	3.5 x 10^{-07}

*Value used from later tests, which gave higher values of k

7 Conclusions

Minimum permeabilities for the till samples range from 8.7 x 10^{-10} m/s to 1.1 x 10^{-5} m/s. The test results appear to be satisfactory.

Several tests gave a consistent incremental permeability with time over periods of hours, whilst some were rather variable with time. The reason for this is not clear, as the tests were all subject to the same conditions. One reason could be that the samples did not have time to reach equilibrium; and the clay may still have been expanding (swelling) during the tests, thereby producing a steady decrease in permeability over time. One sample (Pow BH3, 3.62-3.75m) showed an increase in incremental permeability with time.

Due to the very small amounts of water passing through the test specimens, it is usually easy to detect artificial permeability due to leaks. This was observed in some earlier tests, whilst the preparation technique was being developed.

The test method is not ideal, but is a reasonable and cost-effective alternative to permeability testing in the triaxial apparatus. Other methods, such as permeability testing in an oedometer, do not suit the particle size range of this till. All permeability tests involving water stand the risk of air entrapment, both within the test specimen and the tubing, taps, and connectors. One advantage of the triaxial test method is that the test can be conducted at elevated stresses sufficient to enable entrapped air to be taken into solution, and thus not affect permeability.

7.1 NOTES

The bulk density values are subject to error because estimates had to be used for mass of mould + internal grease, due to grease being extruded when sample obtained. In most cases the excess grease was collected and weighed, but it was mixed with some of the till sample. Therefore bulk density values have not been reported here.

As noted above, many of the tests show a steady decrease in permeability over time. This suggests that either the clay was still expanding, or there is some error in the parameters used in the calculation of permeability. Assuming that the cause is the expansion (swelling) of the clay, the **minimum** value of permeability should be taken as the most representative value (under fully saturated conditions) for each test.

Taken from Coastal And Engineering Geology and Geophysics Laboratory Report CEGLR99/1C: “It was noted that the hydraulic conductivity reduced as the test proceeded. This was probably due to the sample absorbing water and swelling and to the very low hydraulic conductivity of the material, less than 1x10^{-10} m/s for which the falling head method is not suitable.”

Appendix 1

NB. The graphs below do not have a linear scale for time, the x axis indicates the number of tests taken over various time intervals

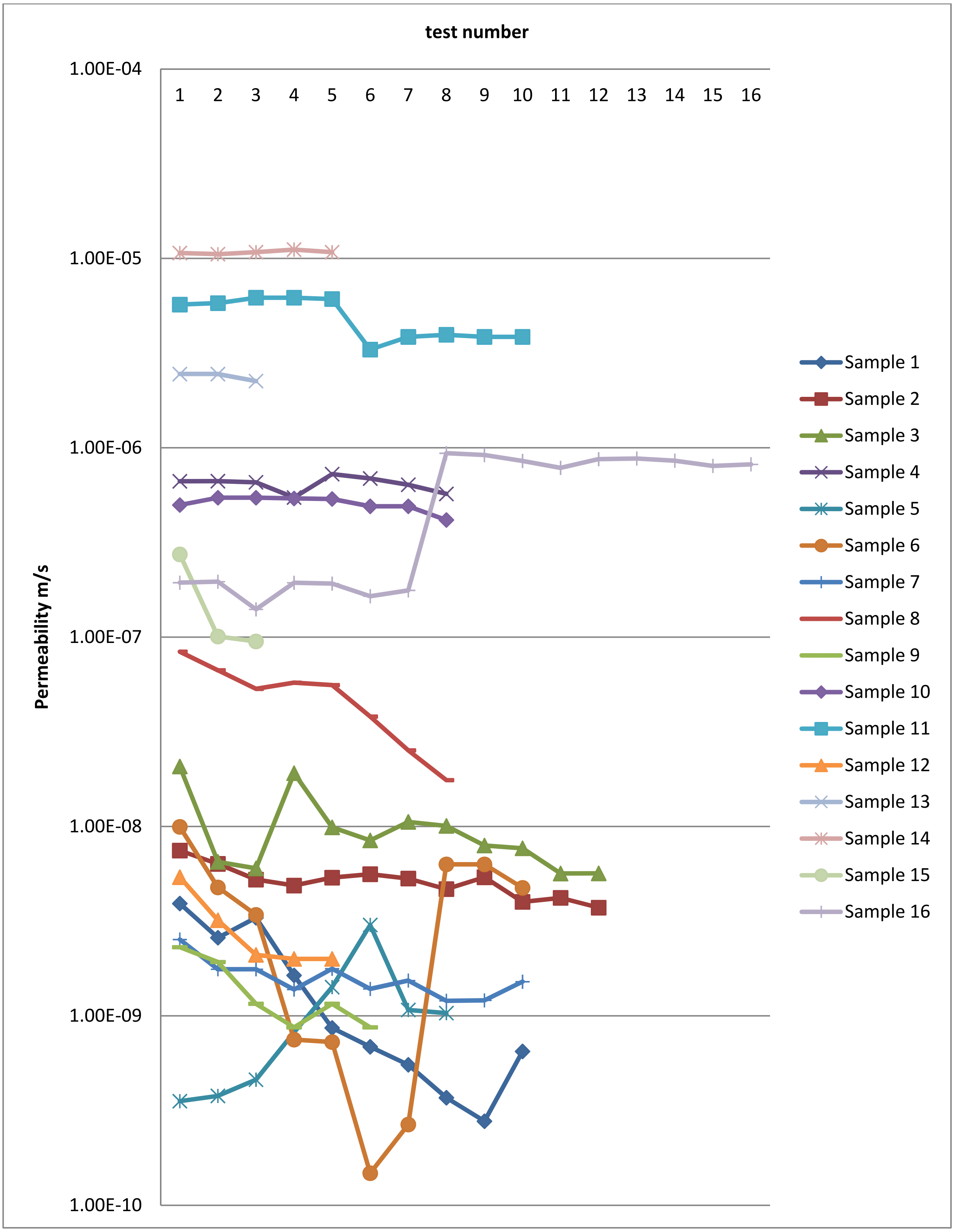

Figure 3: Graph of permeability values for each test carried out on the samples, using data shown in Table 2.

Table 3: Results of permeability tests. Units are m/s.

Test no.	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample10	Sample11	Sample12	Sample 13	Sample 14	Sample 15	Sample 16
1	3.92E-09	7.46E-09	2.07E-08	6.65E-07	3.55E-10	9.96E-09	2.53E-09	8.38E-08	2.31E-09	4.98E-07	5.70E-06	5.40E-09	2.45E-06	1.07E-05	2.73E-07	1.94E-07
2	2.59E-09	6.35E-09	6.51E-09	6.66E-07	3.78E-10	4.77E-09	1.76E-09	6.68E-08	1.93E-09	5.45E-07	5.80E-06	3.20E-09	2.45E-06	1.05E-05	1.01E-07	1.96E-07
3	3.30E-09	5.25E-09	6.01E-09	6.57E-07	4.60E-10	3.42E-09	1.76E-09	5.33E-08	1.16E-09	5.45E-07	6.20E-06	2.10E-09	2.25E-06	1.08E-05	9.49E-08	1.40E-07
4	1.64E-09	4.88E-09	1.91E-08	5.46E-07	8.19E-10	7.49E-10	1.38E-09	5.75E-08	8.70E-10	5.40E-07	6.20E-06	2.00E-09		1.11E-05		1.94E-07
5	8.64E-10	5.37E-09	9.90E-09	7.26E-07	1.42E-09	7.28E-10	1.78E-09	5.58E-08	1.16E-09	5.36E-07	6.10E-06	2.00E-09		1.08E-05		1.92E-07
6	6.87E-10	5.60E-09	8.45E-09	6.88E-07	3.02E-09	1.48E-10	1.39E-09	3.81E-08	8.70E-10	4.91E-07	3.30E-06					1.65E-07
7	5.52E-10	5.31E-09	1.06E-08	6.38E-07	1.08E-09	2.67E-10	1.54E-09	2.53E-08		4.91E-07	3.85E-06					1.77E-07
8	3.70E-10	4.67E-09	1.01E-08	5.70E-07	1.03E-09	6.31E-09	1.20E-09	1.76E-08		4.15E-07	3.95E-06					9.36E-07
9	2.78E-10	5.40E-09	7.94E-09			6.31E-09	1.21E-09				3.85E-06					9.15E-07
10	6.49E-10	4.00E-09	7.67E-09			4.74E-09	1.52E-09				3.85E-06					8.52E-07
11		4.20E-09	5.65E-09													7.83E-07
12		3.73E-09	5.66E-09													8.71E-07
13																8.77E-07
14																8.55E-07
15																8.02E-07
16																8.17E-07
Mean	1.48E-09	5.18E-09	9.86E-09	6.45E-07	1.08E-09	3.74E-09	1.61E-09	4.98E-08	1.38E-09	5.08E-07	4.88E-06	2.94E-09	2.38E-06	1.08E-05	1.56E-07	5.60E-07
Std dev	1.32E-09	1.03E-09	5.02E-09	5.96E-08	1.03E-09	3.28E-09	3.90E-10	2.18E-08	5.95E-10	4.43E-08	1.20E-06	1.47E-09	1.15E-07	2.22E-07	1.01E-07	3.49E-07
Min value	**2.78E-10**	**3.73E-09**	**5.65E-09**	**5.70E-07**	**3.55E-10**	**1.48E-10**	**1.20E-09**	**1.76E-08**	**8.70E-10**	**4.15E-07**	**3.30E-06**	**2.00E-09**	**2.25E-06**	**1.05E-05**	**9.49E-08**	**7.83E-07**

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.

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