FINAL REPORT

'Irish Ground Thermal Properties Project'

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SUSTAINABLE ENERGY AUTHORITY OF IRELAND

ENERGY RESEARCH, DEVELOPMENT & DEMONSTRATION PROGRAMME 2014

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1. INTRODUCTION

The objective of the Irish Ground Thermal Properties (IGTP) project is to profile the geothermal properties of Irish ground conditions and their suitability for deployment of closed loop collectors. This is done by carrying out site specific field tests on installed geothermal collectors to obtain data specific to Irish ground conditions relevant in the design and sizing of geothermal collectors. This data will be distributed to installers and professionals through a public database.

The data obtained through this project will facilitate the understanding of the potential of shallow geothermal resources in a given areas and will be used to help inform policy makers as to the potential for deployment of ground collector systems in different parts of Ireland, facilitating energy planning and the calculation of energy saving from shallow geothermal systems that are currently poorly understood.

The project is designed in four separate phases that include:

- the development of project website for dissemination
- sampling and laboratory testing of key bedrock samples to obtain thermal conductivity values from Irish rock formations
- testing of newly installed ground loop collectors using a thermal response test and compare this data the operating system installed in Ballyroan Library
- development of a reference dataset for Irish ground conditions to size ground source collectors

This report presents the results of the tasks undertaken as part of the project to date, outlines the work remaining to be completed along with some of the problems that have been encountered.

2. PROGRESS TO DATE

This section briefly presents the work undertaken to date by the project team as part of the IGTP project in the context of the expected deliverables.

3. PROJECT WEBSITE

A project website (http://www.irishgroundtherm.com) has been set up. The website presents the objectives of the project and proposed methodologies used for determining thermal properties through core samples and closed loop collectors.

The website has been used as a public dissemination tool to present the project to industry stakeholders including drillers and installers of ground source collectors, members of the public local authorities and the Geological Survey of Ireland.

The website is being used for dissemination of the final project results and for additional test data that may be made available to future testing.

4. COLLECTOR MONITORING

Collector monitoring data has been obtained in order to assess the performance of operating closed loop ground source collectors.

4.1. BALLYROAN LIBRARY COLLECTOR

The ground source system at Ballyroan library in South Dublin is equipped with a 30kW brine to water heat pump and a collector comprising 6 No. 150m boreholes below the car park of the recently constructed library (figure 1).

Figure 1: Ballyroan Library, South Dublin

The geothermal system is equipped with a data logger that monitors the performance of the heat pump, the transfer fluid flow levels and temperatures to and from the collector.

The library building was completed in 2012 and in equipped with a building management system (BMS) that monitors outdoor temperature and internal temperature changes in three different areas of the library. The BMS activates the operation of the heat pump, solar tubes and backup gas boiler to top up the 2,000l water cylinder that supplies both the underfloor heating in the building and the sanitary hot water of the building.

The project team has worked closely with South Dublin library staff to gain access to both the data from the BMS and the logger from the heat pump. This work has required that the heat pump logger be connected to the internet such that both the BMS and heat pump data are available at short time intervals over any 24hr period.

The data from the BMS and the heat pump logger are analysed together to understand the building heating requirements and both the response time of the heat pump and ground collector temperatures.

The BMS data in **Error! Reference source not found.** demonstrates the change in outside emperature and the change in the internal building temperature. The BMS utilises a series of ambient temperature sensors to ensure that the internal temperature in three different zones of the library building is kept constant as the external temperature fluctuates and the solar gains to the building vary.

The BMS controls the building's heating system that includes solar thermal heating, a geothermal heat pump and a gas fired boiler, in combination with the ventilation system.

A 2,000 litre buffer vessel in the plant room of the library stores all the produced hot water at a temperature between 55^{o}C and 65^{o}C and delivers this the underfloor heating system throughout the library. The temperature is controlled by the BMS system which activates the heat pump when the temperature drops below 48^{o}C as is shown in figure 2 below

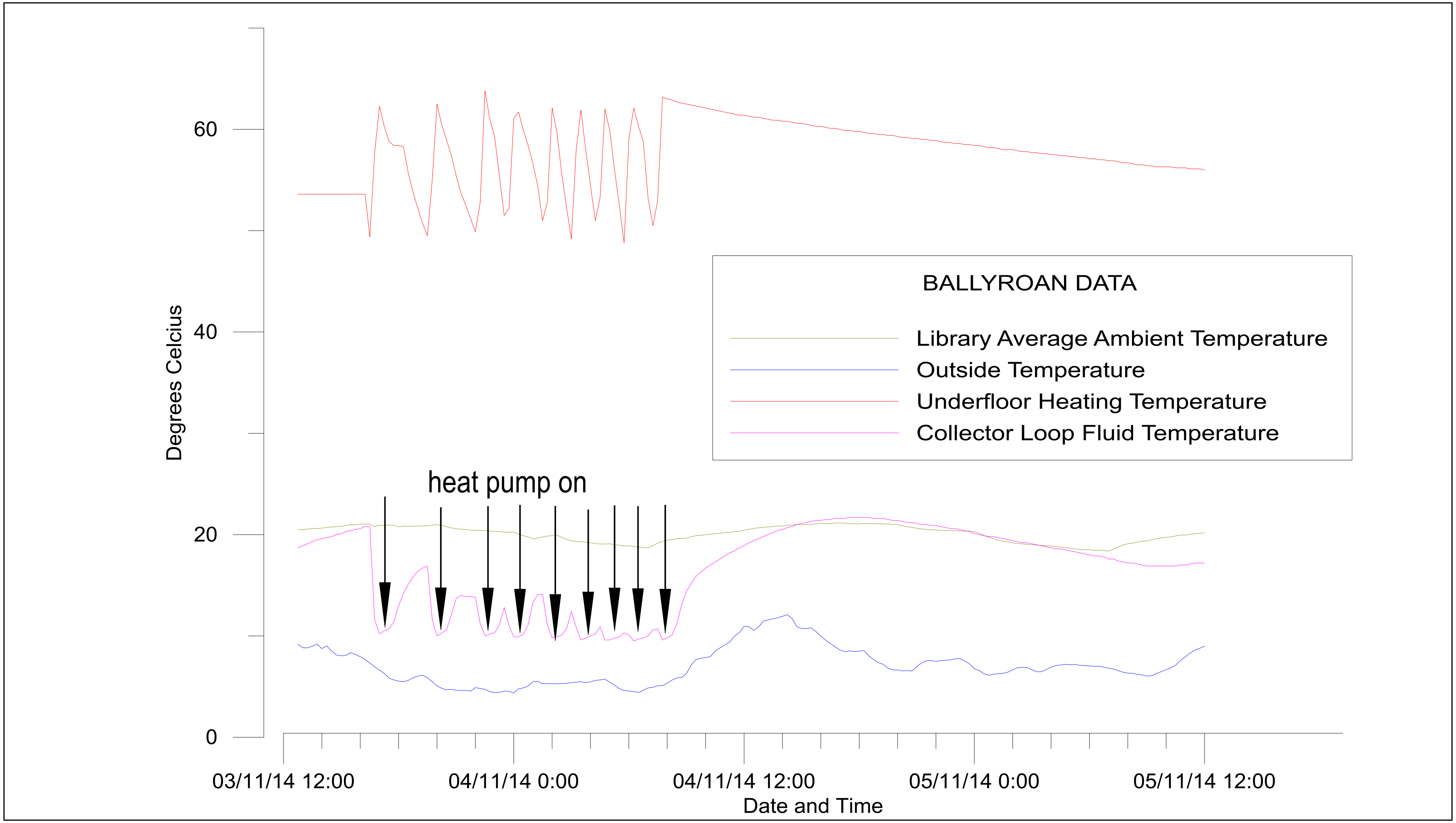

Figure 2: Ballyroan Library BMS and heat pump data for from 3 –5 November 2014

Figure 2 shows the change in the collector fluid temperature when the heat pump is in operation plotted against outside temperature.

The average ground and collector temperature recorded is 12°C when the heat pump is switched on and fluid is circulated from the vertical closed loop collectors under the library car park.

During the course of the collector performance observed throughout the project, the average temperature differential between the start and end of each 3 hour heat pump operation cycle is approximately 2°C, with lowest temperatures recorded of 10°C.

Once the heat pump is switched off, the working fluid is no longer pumped in the ground loop circuit and equilibrates to the ambient temperature in the plant room, hence showing a temperature of 22°C to 23°C when the heat pump is not in operation.

This working fluid gives its heat to the heat pump which through the use of compressors concentrates the heat into a heating fluid which is then circulated beneath the floors of the library in a heating circuit. This is the red line in **Error! Reference source not found.**, and is maintained t around 55 degrees constantly, which creates an internal air temperature of about 23 degrees.

5. BEDROCK LITHOLOGY SAMPLES

The GSI shallow geothermal energy project vertical collector suitability maps are based on a Lithological compilation of the 1:500,000 scale bedrock geological map of Ireland. During the completion of these maps 26 Lithological categories were identified and some of the thermal conductivity data from previous research projects on rock thermal properties were included.

A total of 6 thermal conductivity values for Ireland were available with an additional 20 lithological categories requiring to be measured.

5.1. LABORATORY THERMAL CONDUCTIVITY TESTS

The second phase of the IGTP project has focused on obtaining thermal conductivity measurements from Irish bedrock lithologies. Data from previous research from UCD has been reviewed as part of an initial literature review and consideration has been given to Irish rock formation previously tested with a view to identifying those lithologies that required further investigation into complete an initial database of Irish ground thermal properties.

A consultation with the Geological Survey of Ireland (GSI) was undertaken to negotiate access to core samples from the GSI core store from those lithologies that were of interest, focussing on those that have not previously been tested. Figures below show the logging and attention to detail undertaken in at this point in the project.

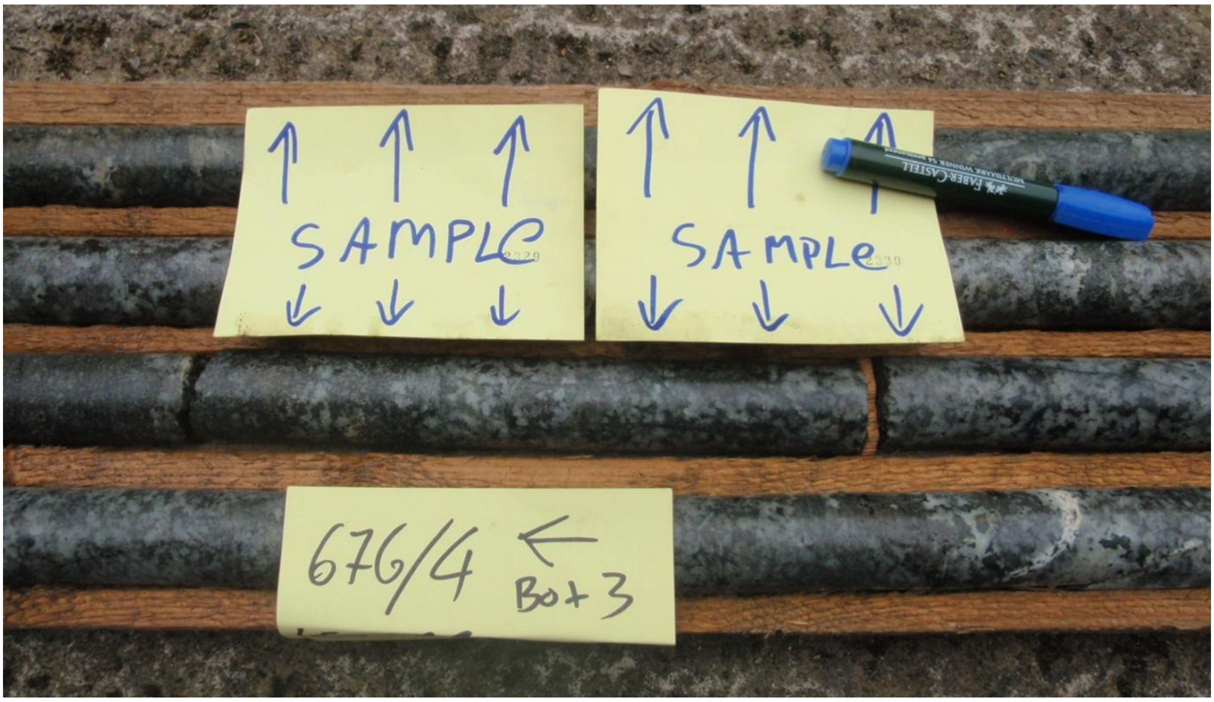

Figure 3: Example of the detailed recording and logging performed in the Core Store prior to sampling.

Figure 4: Example of how core is stored and made available for inspection. Box is approximately 1.5 meters long.

Table 1 below summarises these categories and the samples targeted by the IGTP project.

Table 1: Lithologies and GSI Core Samples taken for lab testing

Location	Sample No.	Rock Type	Lithology	IGTP class
Waterford	Ik-1	Rhyolite tuff	Clashabeema Formation (CB)	Volcanic acid
A vuggy pale brow/beige acid tuff ,with minor dolomite veining throughout. Minor stylolite and vug textures as evidence for later dissolution and recrystalisation by dolimitic fluids. Sampled from 60 to 60.26m.				
Maum, Galway	AM 16	Chlorite Schist	Ballynakill Formation (MRBKIL)	Schist
A fine grained medium grey rock, green in places due to presence of chlorite. Some small scale folding and crenulations visible, and graphitic in parts. Definitely schistose texture. 35 mm diameter sample.				
Carlingford, Louth	676/4	Gabbro	Early gabbro (ITGBRO)	Plutonic alkaline
A coarse grained igneous rock, mainly of mafic composition, with dark crystalline minerals composing up to 70% of rock, paler minerals (plagioclase) approx 30%. No alteration, no mineralization. Drilled in feet, and sampled from 53' to 53'10". 35mm diameter sample.				
Brownstown, wexford	1714/6	Tuff	Ballyneale member (Mnbniv)	Volcanic alkaline
pale grey to green rock with alternating pale/dark layering on mm scale. Chlorite rich, hard but fissile. Some disseminated Pyrite. A welded tuff. Sampled 309' to 310' 1", 35mm diameter sample.				
near Castleblaney, Monaghan	14/05 Almseed	Dolerite	Dolerite Dyke	Plutonic alkaline
Medium grained crystalline rock, dark green in colour. Non friable, no alteration, minor plagioclase, mainly mafic minerals. Dolerite. Sampled from 114m 20cm to 114m 40cm. 50mm sample.				
Knockroe, Limerick	14/07 Knockroe	Basaltic Lava flow	Knockroe Basalt Lava Flow Member (KRb)	Volcanic alkaline
Coarse (pebble supported). Fine grained matrix, dark purple colour, consisting of minor layers of clay sized particles up to 2cm thick. Clasts are rounded but no evidence of imbrication. Classified as a Volcanoclastic deposit due to multi modal clast size. Sampled from 11.8 to 12m. 50mm sample.				
Croagh Patrick	LYH 5	Quartzite	Cregganbaun Formation (Cb)	Quartzite
Fine grained sedimentary rock. Rough to touch, sugary texture on cut faces of core. Yellow colour, with brown flecks, between quartz grains. 50mm sample.				
Moycullen Galway	Moycullen 2	Granite	Errisbeg Townland Granite (GaEb)	Plutonic intermediate
Very coarse grained granite, rich in plagioclase. Core somewhat rotted in places along fractures. Some hornblende evident. 50mm sample.				
Maum, Galway	AM 15	Chlorite Schist	Ballynakill Formation (MRBKIL)	Schist
Rock is light grey/green colour, fine grained, foliated and quite fissile. Crenulated, creating sheath folds in some places. Possibly quartz rich lighter layers up to 2cm thick, a Chlorite Schist, sampled from 20'6" to 21'6". 35mm diameter sample.				

5.2. TEST RESULTS

The laboratory phase of this project involved testing of samples of 9 unique rock cores in the Divided Bar Apparatus (DBA). Each rock core is divided into three samples, so as to serve as a check against each other an. This gives a total of 29 samples to be tested. These were tested for thermal conductivity in addition to measurements of density and porosity. The thermal conductivity was measured in both oven dried and water saturated conditions. These were combined with previously assessed conductivity values from the work of McGuinness, T. (2012)

Table two below summarises the dry and saturated values measured from samples on the various IGTP classes.

Table 2: Thermal Conductivity Values of Irish formations and corresponding IGTP classes

Location	Rock type	IGTP Avg. Sat. Value (W/mK)	IGTP Avg. oven value (W/mK)	Avg. Porosity (%)	IGTP Class	Lithology
Kilronan Wexford	Rhyolite tuff	2.47	2.67	1.68	Volcanic acid	Clashabeema Formation (CB)
Maum, Galway	Chlorite Schist	2.53	2.60	0.19	Schist	Ballynakill Formation (MRBKIL)
Calingford, Louth	Gabbro	1.80	1.64	0.24	Plutonic alkaline	Early gabbro (ITGBRO)
Brownstown, new Ross	tuff	1.91	1.91	0.38	Volcanic alkaline	Ballyneale member (Mnbniv)
Castleblaney, Monaghan	Dolerite	1.40	1.30	2.01	Plutonic alkaline	Dolerite Dyke
Knockroe	Volcanoclastic	1.72	1.39	4.80	Volcanic alkaline	Knockroe Basalt Lava Flow Member (KRb)
Croagh Patrick	Quartzite	3.56	2.69	2.63	Quartzite	Cregganbaun Formation (Cb)
Moycullen Galway	Granite	2.19	2.15	0.93	Plutonic intermediate	Errisbeg Townland Granite (GaEb)
Maum, Galway	Chlorite Schist	2.35	2.11	1.54	Schist	Ballynakill Formation (MRBKIL)
ESB Dublin	Limestone	2.58	2.26	1.94	Limestone/ Mudstone (80/20)	65, Marine basinal facies (Tobercolleen & Lucan Fms - "Calp"); Dark-grey argillaceous & cherty limestone & shale
Ardnacrusha	Sandstone	3.21	3.10	0.48	Sandstone	36, Deep marine; Greywacke, shale, sandstone & conglomerate

References

McGuinness, T., Hemmingway, P. and Long, M. (2013) 'Design and development of a low-cost divided bar apparatus', Geotechnical Testing Journal, 37(2), 12. pp 230-241
McGuiness T. (2012)"Thermal Conductivity Measurements on Irish Rocks" Masters Thesis UCD

5.3. DIVIDED BAR DATA ANALYSIS.

The suite of data recorded was assessed and several conclusions can be drawn about thermal behaviour of Irish rock types.

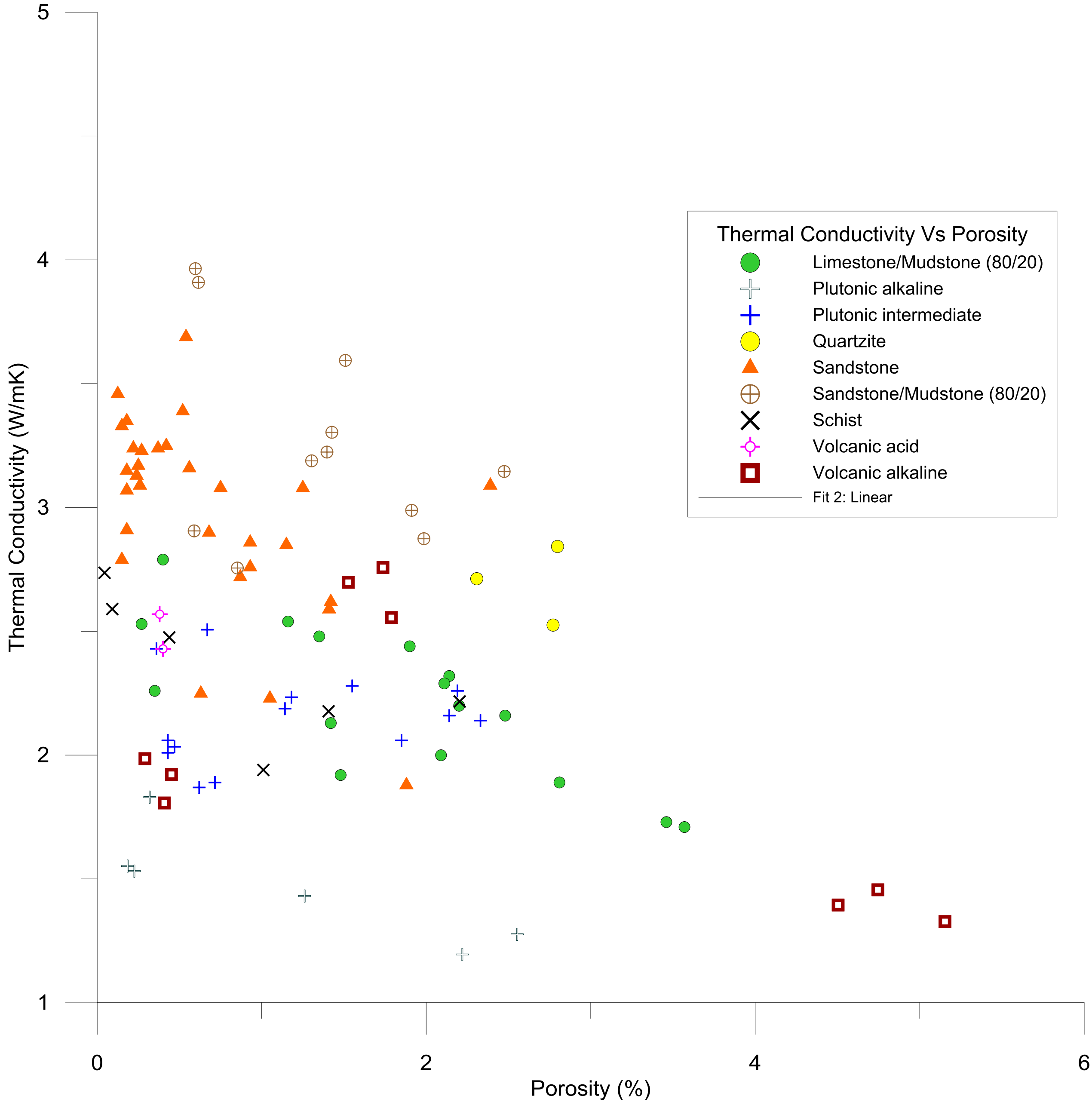

Figure 5: Thermal Conductivity vs. Porosity

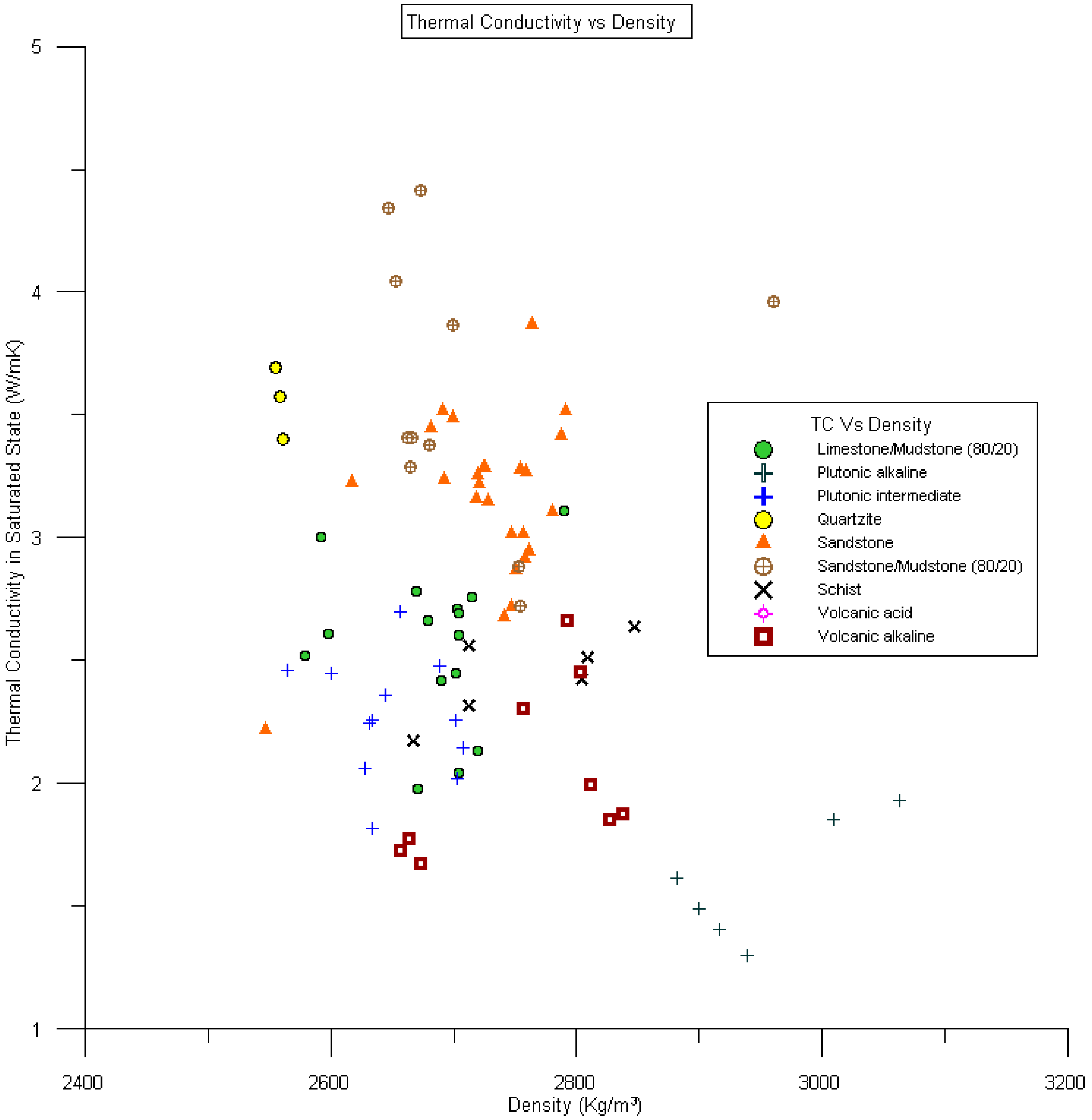

Figure 6: Thermal Conductivity vs. Density

Figures 5 and 6 show the relationships identified for the tested samples between thermal conductivity, porosity and density. The results demonstrate that whilst there is no relationship between thermal conductivity and dry density, increased porosity in samples of similar lithology results in a decrease in thermal conductivity due to poorer connectivity of the mineral crystals.

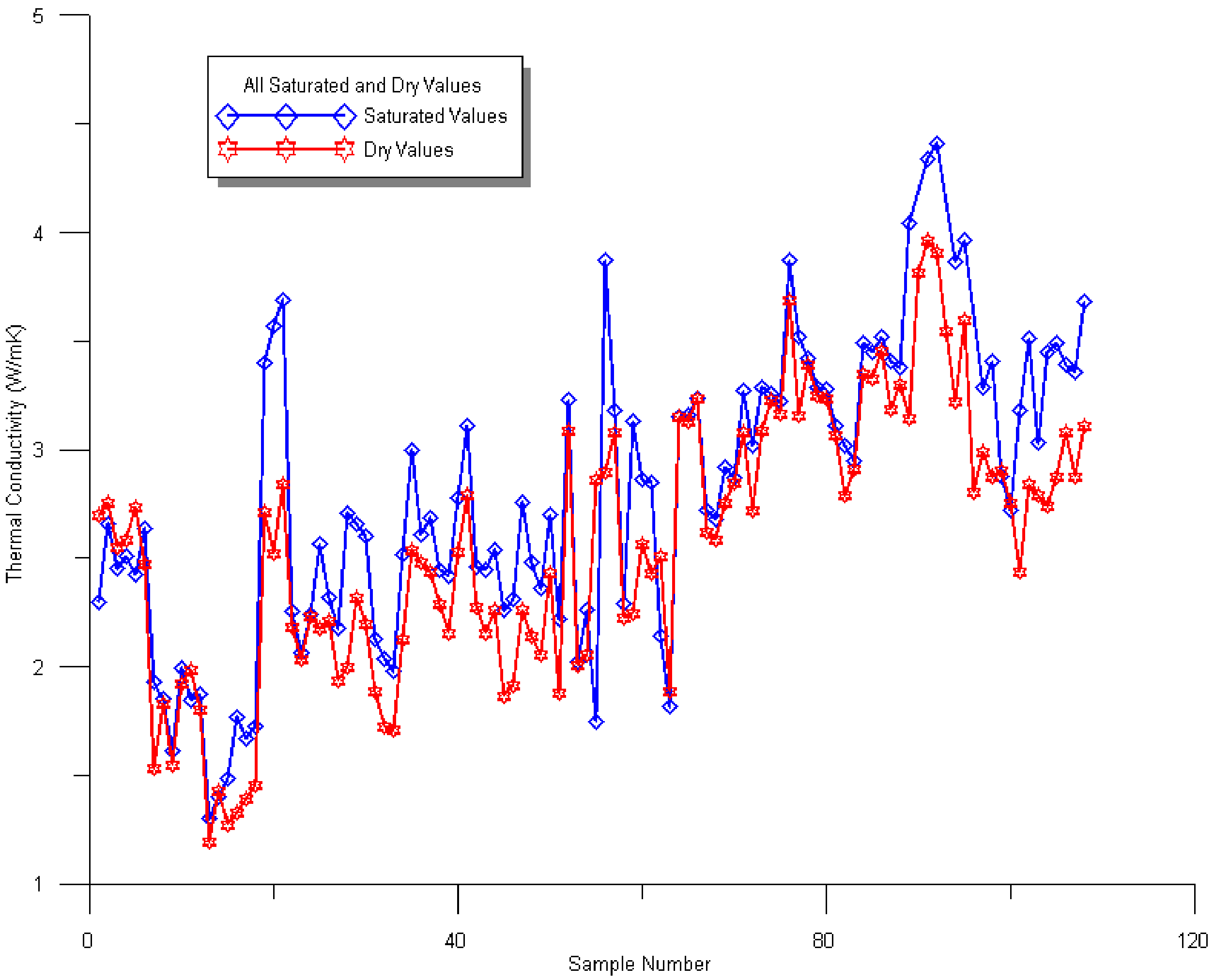

Figure 7: Saturated and Dry values.

Figure 7 shows there is a strong correlation between the saturated and dry values, with the saturated values always higher.

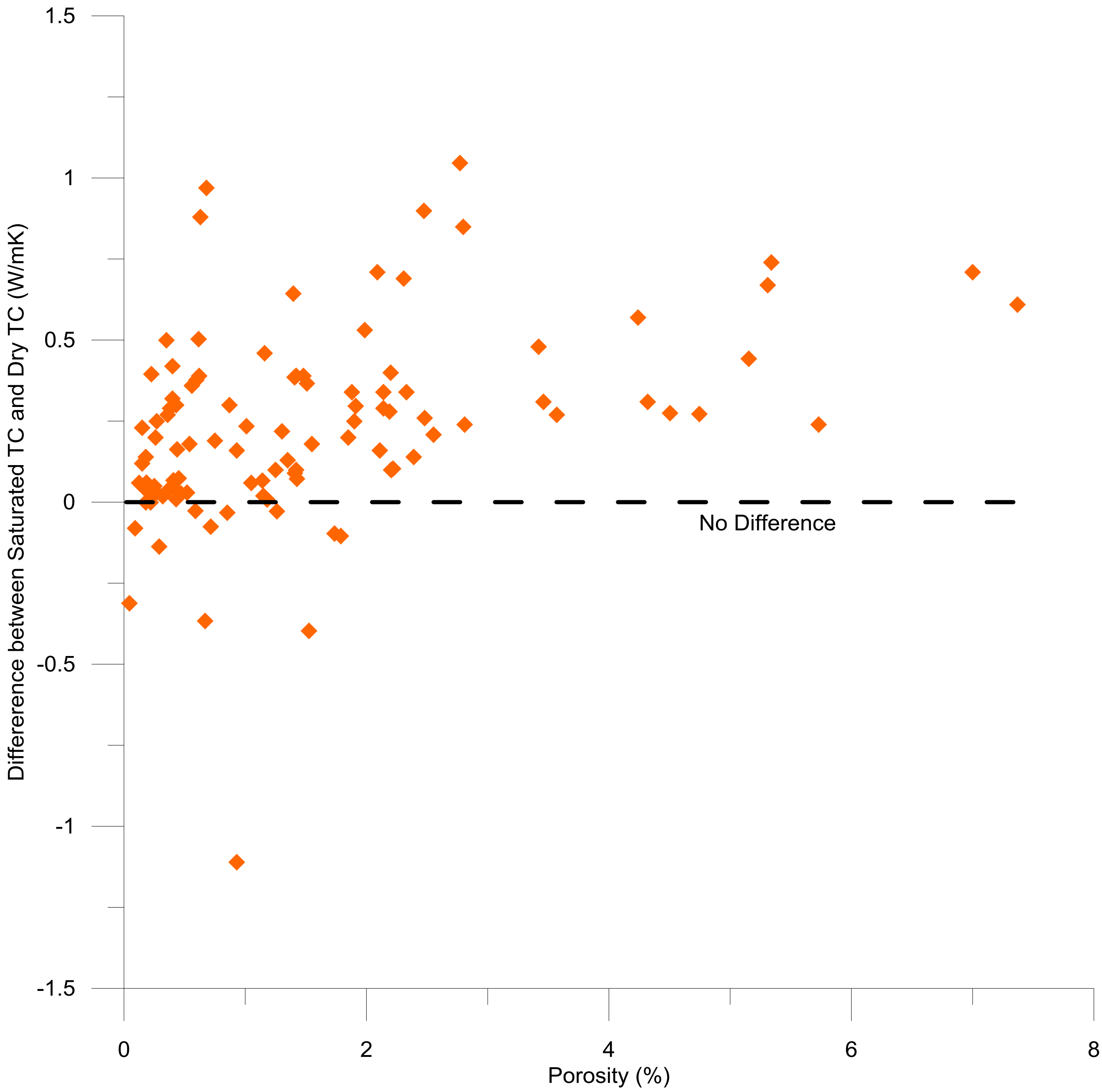

Figure 8: Difference in Dry and saturated conductivity vs. porosity.

The saturated and dry thermal conductivity values measured for low porosity rock types are generally close (Figure 8).

The thermal conductivity values observed begin to deviate more strongly as porosity increases, with the saturated values being higher than the dry values. This can be explained as a water filled pore is more conductive/ convective to heat flow than an air filled pore.

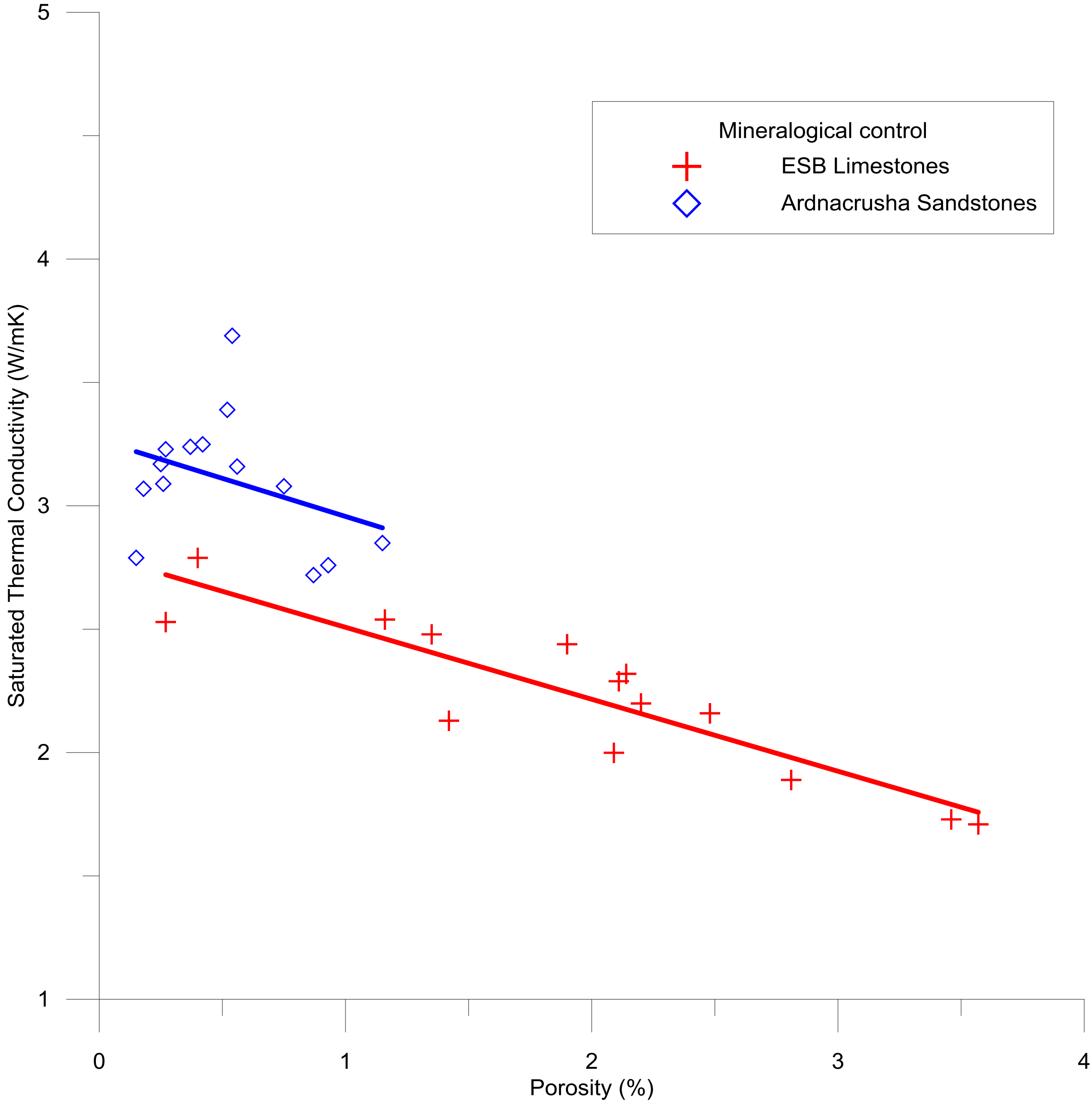

Figure 9: Variation of conductivity with lithology.

Figure 9 shows the trends of thermal conductivity values verses porosity in the shale rich Calp Limestone in the Dublin area and the quartz rich Ardnacrusha Sandstone. Both formations show similar thermal conductivity and porosity trends. However the elevated thermal conductivity values of the Ardnacrusha sandstone in the 0.25% to 1.25 % porosity range reflect the quartz rich nature of this formation which is more conductive than the muddy limestone.

These results demonstrate that although porosity is the main control on thermal conductivity a, mineralogy and in particular quartz content has some effect, in the order of 0.4W/mK in the case of the formations compared above.

6. THIN SECTION ANALYSIS.

To further our understanding of the rocks, particularly as related to mineralogy and porosity, it was decided to have samples of 14/07 Knockroe Basalt Flow and LYH5 Quartzite cut into thin sections for microscope analysis. A thin section is a very thin (about 30µm thick) sliver of core cut on a diamond saw. They are thin enough to allow light to pass through and use their optical properties to determine mineralogical composition.

As can be seen in

Table 2, both the Knockroe and Quartzite had high porosities, but only the quartzite had an above average conductivity. This interesting relationship is why these two samples were sectioned.

6.1. 14/07 KNOCKROE BASALT LAVA FLOW

- Average saturated conductivity:1.72W/mK
- Average dry conductivity:1.39 W/mK
- Average porosity: 4.8%

This consists of many feldspar crystals with larger clasts of surrounding rock which were entrained or "caught up" in the flow when it was a mobile lava. Metal oxides are present, which should aid in the conductivity of heat in the specimen.

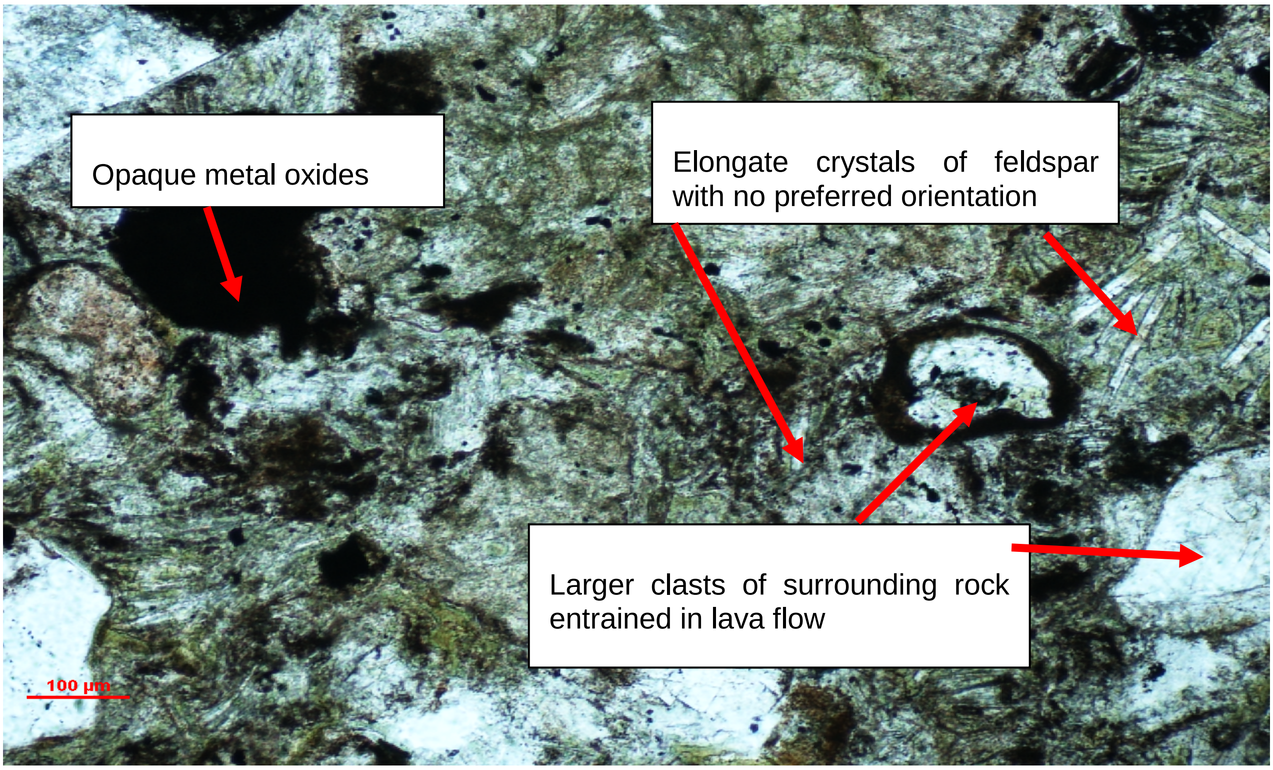

Figure 10: Image of mineralogy of Knockroe basalt. Scale bar is 100µm

The once flowing nature of this rock type is key to understanding its porosity. Escaping gases from the lava leave voids in the rock; these voids can remain once the lava cools into solid rock. Figure 11 shows an example of this.

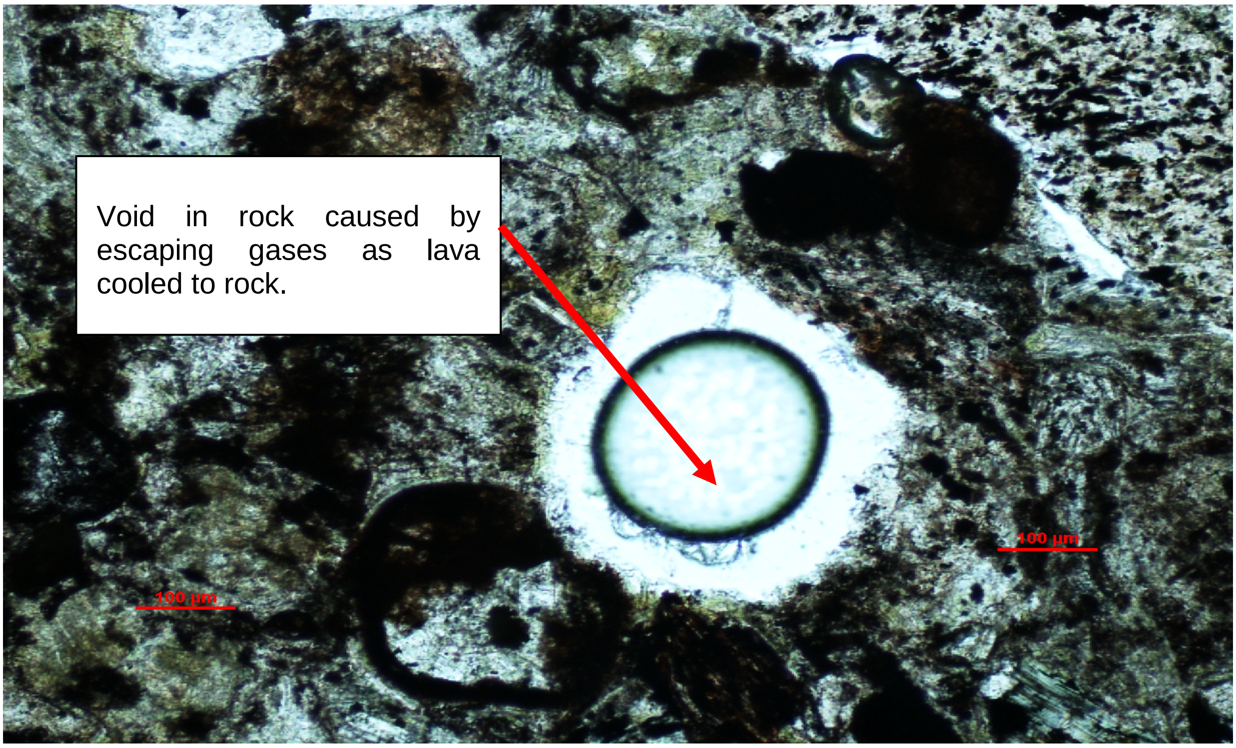

Figure 11: Image of void in Knockroe basalt. Scale bar is 100µm

Additional to void porosity, the chemical nature of minerals in the basalt can be susceptible to chemical weathering, especially in near surface samples such as this. Figure 12 shows a thin section stained with a blue dye. This dye highlights areas which have been weathered and degraded by chemical alteration.

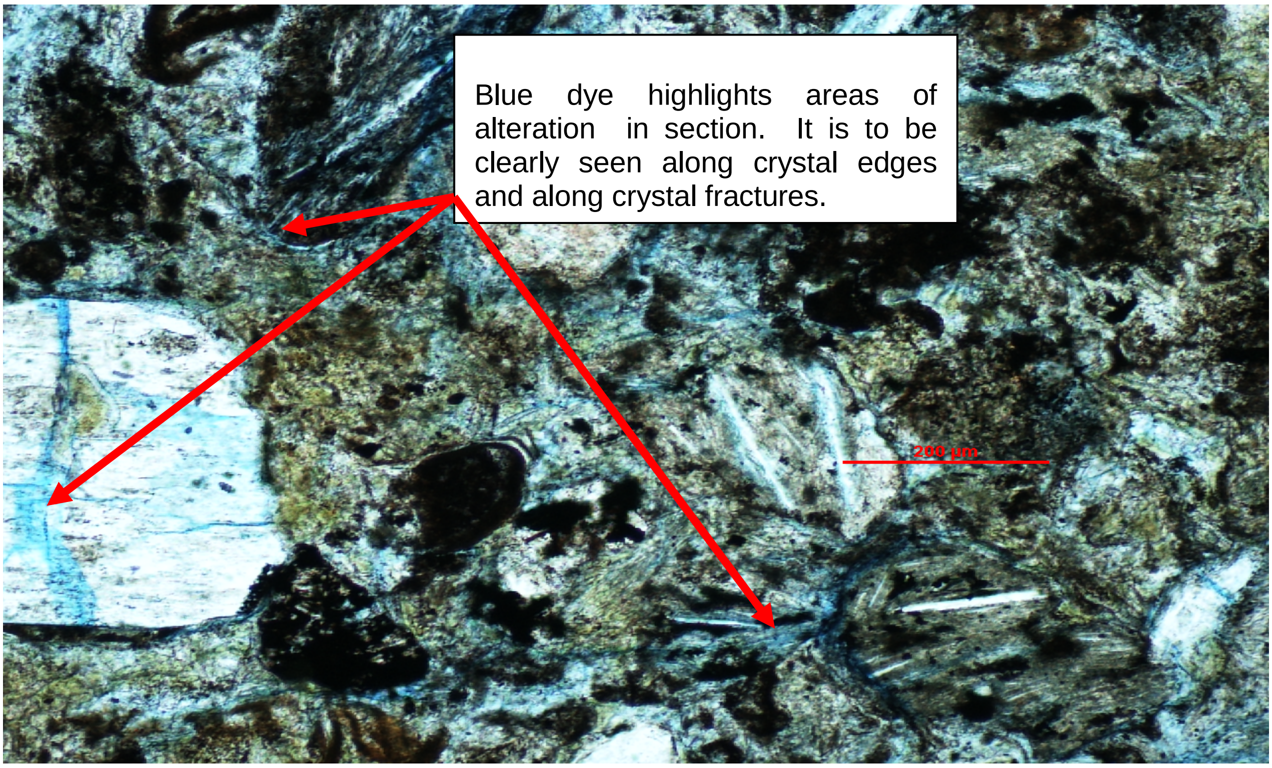

Figure 12: Image of porosity in Knockroe basalt. Scale bar is 200μm

This pervasive alteration along crystal boundaries and the large irregular voids (giving porosity of up to 5%) precludes good crystal face contacts and prevents heat being readily conducted across the sample, despite the presence of minor amounts of highly conductive metal oxides. Additionally, the presence of water in the pores does not increase the conductivity substantially as the volume of pores is unevenly distributed throughout the sample in the form of large voids.

6.2. LYH 5 CROAGH PATRICK QUARTZITE

Average saturated conductivity:3.56W/mK

Average dry conductivity:2.69 W/mK

Average porosity: 2.63%

The LYH5 quartzite is as the name suggests, a quartz rich rock, with some mud.

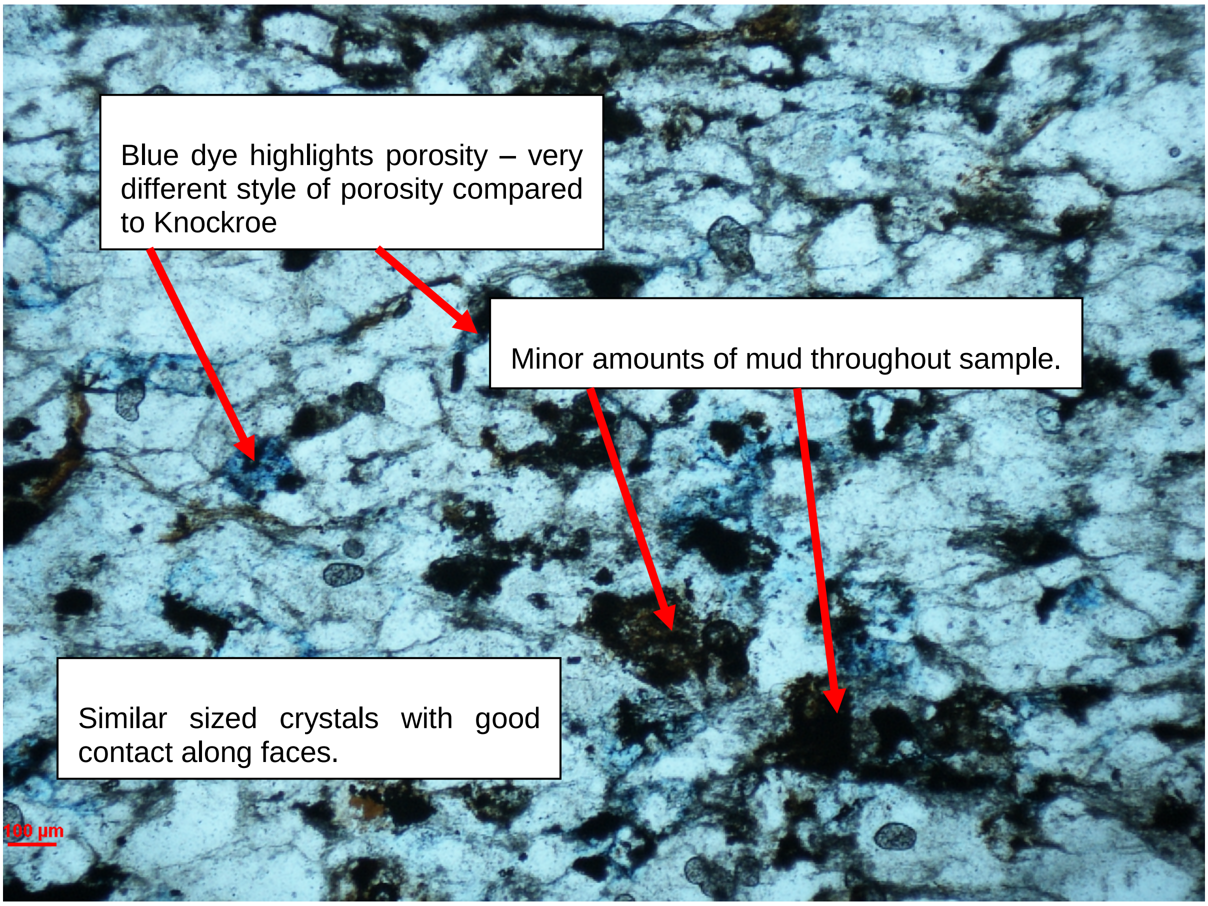

Figure 13: Image of mineralogy and porosity in LYH Quartzite. Scale bar is 100µm

The angular nature and similar size of all the quartz crystals allows for regular pore spaces. Unlike Knockroe there is no alteration between crystal faces and so will not impede heat flow through the rock. Quartz is a moderately good conductor and the crystals here show good connectivity and face contact.

Therefore it is plausible therefore that the quartz mineralogy is the main control on the conductivity of this rock, but the presence of water in the pores has a very noticeable effect. This can be explained as a water filled pore is more conductive/convective to heat flow than an air filled pore and the evenly distributed nature of the pores.

7. THERMAL RESPONSE TESTS

Extensive consultation has been undertaken to identify sites where closed loop collectors are being installed. These sites are suitable for thermal response testing to characterise different lithological units.

Stakeholders including drillers and installers nationwide have been contacted. The project and the objectives of the TRT tests were presented and a request for collaboration making installed collectors available for testing was undertaken.

Table 3 presents the sites where new collectors have been installed and where a TRT test has been carried out. The sections below present the results of the TRT tests undertaken. Further details of the tests are included in the appendix.

Table 3: Proposed TRT tests to be undertaken by IGTP

	Location	Building Type	Test Date
1	UCD Campus, Dublin	Standalone Collector	9th October 2014
2	Ring, Co. Waterford	Residential	4th November 2014
3	Westport Co. Mayo	Residential	3rd December 2014
4	Arva Co. Cavan	Residential	27th November
5	Glencree, Co. Wicklow	Residential	21st November 2014

7.1. UCD CAMPUS

The UCD TRT test was planned on a 20m, single U collector installed in borehole drilled in Calp Limestone in the car par near the water tower at the UCD building. The objective of this test was to provide a reference thermal conductivity value for the Calp Limestone which is the same formation in which the Ballyoran library collector is installed.

Upon arrival on site the collector pipe was found to be blocked by a stone resulting in one of the U bend pipes to be nearly entirely obstructed.

As it was not possible to undertake the test on the obstructed collector, a test on a 9m, single U shallow collector in the overburden outside the Newstead Building. Upon completion of the 6 hour test, the logger unit in the TRT rig was found to be malfunctioning and no data was acquired.

The overburden nature of this collector was no the prime focus of this project as TRT tests aim to provide data for consolidated, deeper rock formations, hence a repeat test was not undertaken.

7.2. RING, CO. WATERFORD.

The test was carried out on a residential collector at Ring, Co. Waterford. The 40mm pipe single U collector is installed in a 150m deep borehole drilled in the Ballytrasna Formation. The Ballytrasna is described as a purple mudstone and pale red, fine to medium grained sandstone.

The cuttings observed on site suggested that the collector borehole intersected a quartz rich sandstone dominated section of the formation with some purple mudstones (figure 14).

Figure 14: Thermal Response Test Rig at Ring, Co. Waterford

The collector will supply a heat pump installed in a 420m^2 house which is being partly renovated with a new extension.

The test was undertaken over a 24hr period using a 6kW heater for a period of 12hrs. The minimum recorded air temperature on the 4th of November was 4^{o}C and the maximum 11.4^{o}C. Figure 11 below demonstrates the temperature variation observed throughout the course of the heating phase in the first 12 hours of the test and in the recovery phase once the heaters have been switched off.

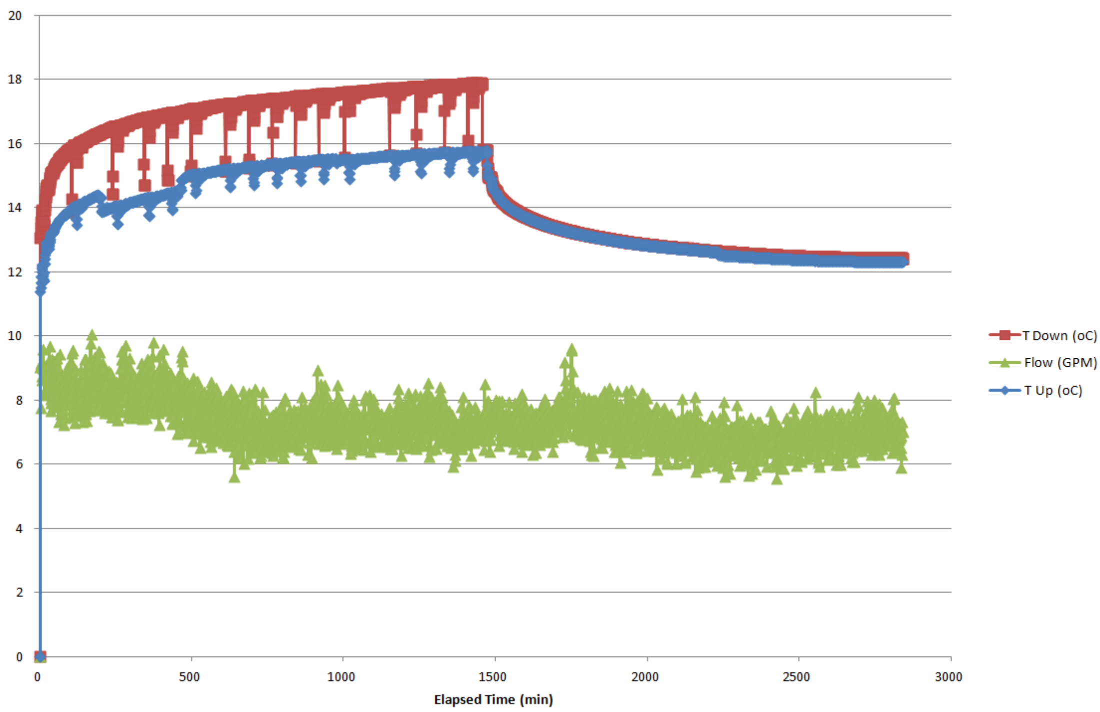

Figure 15: Temperature Records from Thermal Response Test Rig at Ring, Co. Waterford

The line source approximation method was used to calculate the thermal conductivity of the formation tested where the collector is installed based on the slope of the temperature values and the log of time.

An average thermal conductivity value of 4.49 W/m/K was calculated. The results demonstrate that whist a lower value may have been expected as a result of the muddy nature of this formation, the quartz rich sandstone section intersected by the collector results in higher values.

8. METHOD STATEMENTS

This section briefly outlines the generic method statement used for completing both the thermal response tests in the field and the thermal conductivity measurements using the divided bar apparatus.

8.1. THERMAL RESPONSE TESTING

The objectives of the Thermal Response Testing the individual borehole collectors test will include the determination of:

- the thermal conductivity of the ground
- average undisturbed formation temperature
- volumetric heat capacity
- thermal diffusivity
- thermal resistance
- effects of groundwater flow upon borehole exchange rates based on the subsurface geological and hydrogeological conditions known at the site

Detailed borehole logs for the individual boreholes to confirm the geological conditions and the configuration of the collector are reviewed in advance of the test.

In the absence of detailed information, assumptions on the subsurface conditions are made based on the geotechnical information available from the Geological Survey of Ireland. This information is used to consider the potential impacts of groundwater flow across the collector.

In the case of multiple collectors, at least two areas including the upstream and downstream sections of the collector be tested in order to ensure that representative results of the thermal performance of the collector be achieved. This should include the testing of between 2 and 4 boreholes.

A minimum test duration of between 24 to 36hrs will be performed. However, a review of the subsurface information available is required and a calculation of the adequate testing period based on the grout material to be used in the borehole and confirmation of the subsurface geological conditions. This will be also subject to the borehole construction verification as part of phase 2.

Individual borehole collectors selected for TRT tests shall be pressure tested in advance of the TRT taking place and the content of the double U collectors will to ensure these are filled with water.

In advance of the TRT tests taking place, the borehole construction will be surveyed and, as far as reasonably possible, the nature of the grouting of the boreholes will be confirmed.

The following test procedure will be applied:

- ensure that the distance between the TRT unit and the individual boreholes to be tested shall be as short as possible, and no longer than 1.5m in order to minimise any temperature loss between the TRT unit and the collector.
- pipe connections from the TRT rig to the individual borehole shall be heavily and separately insulated to minimise the influence of ambient conditions and solar radiation on the test. To minimise this influence, reflective insulation material will be used.
- the TRT rig will also be insulated to minimise the influence of ambient conditions on the test.
- the test the TRT rig will deliver a maximum return temperature variation of ±0.3°C from a straight line trend of a log (time) versus average loop temperature.
- Measurement accuracy during will include fluid temperature of <0.3°C, the power input measurable to an accuracy of <2%, and the fluid flow rate measurable to <5% accuracy.
- an appropriate heat rate will be applied to the u-bend loop (generally between 40 – 80 W per metre of borehole) with lower rates corresponding to lower thermal conductivity formations., and that flow rates shall be sufficient enough to provide a differential loop temperature of 3.7 - 7.0°C achieved with turbulent flow.
- a detailed record of the ambient air temperatures for the duration of the test so that ambient climatic interference on the measurements effects can be detected.
- Upon completion of the collector survey phase and more detailed review of the subsurface geological conditions, a minimum duration for the individual TRT tests shall be estimated by calculation based upon anticipated properties of the heat exchanger.
- the TRT test shall be started without the heating elements switched on and the temperature of the fluid exiting the loop shall be measured and recorded immediately after start-up and for up to 30 minutes thereafter.
- testing shall comprise the application of controlled heat to the closed-loop for the duration of the test. Specific requirements for the monitoring and provision of heat and power to the circulated fluid are that:
- the TRT data collected shall be analysed using the line source method. Other methods, may be given consideration should if deemed appropriate.
- In the event that a TRT will be interrupted during the heating period or that an individual borehole will need to be re-tested, a re-stabilisation period will be required before another test can be conducted. Typically this could be up to 10-14 days to allow for the u-bend loop temperature to return to within 0.28°C of the natural average temperature.
- Factual Report and data outlining thermal conductivity, resistance and ground temperatures recorded.

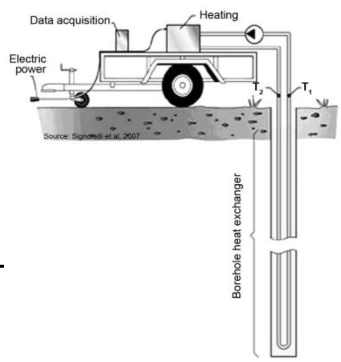

Figure 16: (a) Thermal Response Test Rig (b) TRT Components

8.2. DIVIDED BAR APPARATUS

The UCD divided bar apparatus is capable of testing samples 50mm in diameter or smaller. However the core samples received from the ESB site borehole were 86 mm diameter and had to be cut down to 50 mm diameter prior to testing.

1. Core and face a cylinder of rock of appropriate thickness and diameter (within 10% of the standard length and diameter and stack diameter of 50 mm). Each sample should be of sufficient length to provide three test specimens.

2. The samples are then cut with a diamond saw perpendicular to the core axis to the required lengths ensuring that the two faces of the sample produced are parallel.

3. Samples are flattened by use of a flat grinding wheel, with every effort being made to ensure the faces remain parallel and not causing excessive wear to part of the face, thus promoting good thermal contacts on the divided bar equipment by avoiding wedge shapes and concave/convex surfaces.

4. Sample faces are then polished with Grit 400 or finer silicon carbide or diamond powder on a lap wheel to minimise thermal contact resistance, and should be flat to within ±0.1 mm (no wedge shape) and parallel to within 0.01 mm throughout (no dome or concavity on the sample surface).

5. Following grinding and polishing the samples is oven dried at 105°C for one week and the weight determined with an electronic balance accurate to 0.1g for porosity calculations.

6. Subsequently the samples are placed in a beaker full of water in a desiccator attached to a vacuum pump for 12 hours and then left to rest for another 12 hours under atmospheric pressure to allow the water to saturate the rock.

7. The diameter of the specimens are measured across two perpendicular diameters at mid height of the sample to the nearest 0.1 mm with a dial micrometer, whilst the height is measured at three equally spaced locations to the nearest 0.1 mm and these readings recorded with the average values reported.

8. The porosity of the sample is calculated based on Ulusay and Hudson,2007.

9. All contacting surfaces are lubricated with glycerine gel prior to assembly in the divided bar apparatus to reduce any contact resistance.

10. The sample is then carefully placed in the stack and insulated with great care being taken so as to ensure it does not hit any of the copper discs (Figure 17: (a) Divided Bar Components (b) Divided Bar)

11. A thermal gradient is applied across the sample.

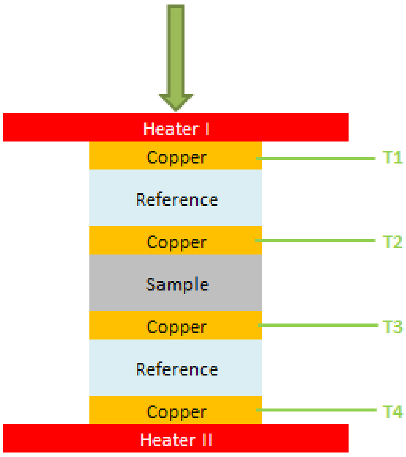

Figure 17: (a) Divided Bar Components (b) Divided Bar

12. Thermal conductivity is subsequently calculated using Fourier's Law:

$$Q = \lambda A \frac{\Delta T}{\Delta Z}$$

where Q = heat flow, λ = thermal conductivity, A = cross sectional area, ΔT = temperature difference and ΔZ = thickness

9. CONCLUSIONS

The results of this study show that common thermal conductivity values for Irish rock types range from approximately 2-4 W/mK. Combined with Ireland's temperate climate year round, it makes the Irish subsurface a viable thermal reservoir for the purpose of ground source heat pumps. This can be seen in the case of Ballyroan Library where sufficient heat is extracted from six 150 meter boreholes to heat the entire building.

The geological controls on conductivity are mainly based on porosity, with lithology having a smaller influence. It is not observed that rock density has any effect on porosity, so areas with histories of tectonic burial or stress do not need special attention. The presence of pore fluid will consistently elevate thermal conductivity. This only applies if the water is allowed to equilibrate with the rock; flowing water instead will tend to bleed heat away from the rock.

Therefore, a good knowledge of the hydrogeological and lithological properties of any potential shallow geothermal site should be obtained in order to optimise the collector length. The IGTP project attaches a thermal conductivity value to some of the lithology types in Ireland, so that a sound estimate of heat energy available per drilled metre can be made.

However, further work in joint collaboration with the Geological Survey of Ireland and the heat pump installers and drillers is required to increase the database of Irish thermal properties and help better understand the potential for heat delivery through ground source systems from Irish rock formations.

10. REFERENCES

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McGuinness, T., Hemmingway, P. and Long, M. (2013) 'Design and development of a low-cost divided bar apparatus',ASTM Geotechnical Testing Journal, 37(2), 12. p230-241

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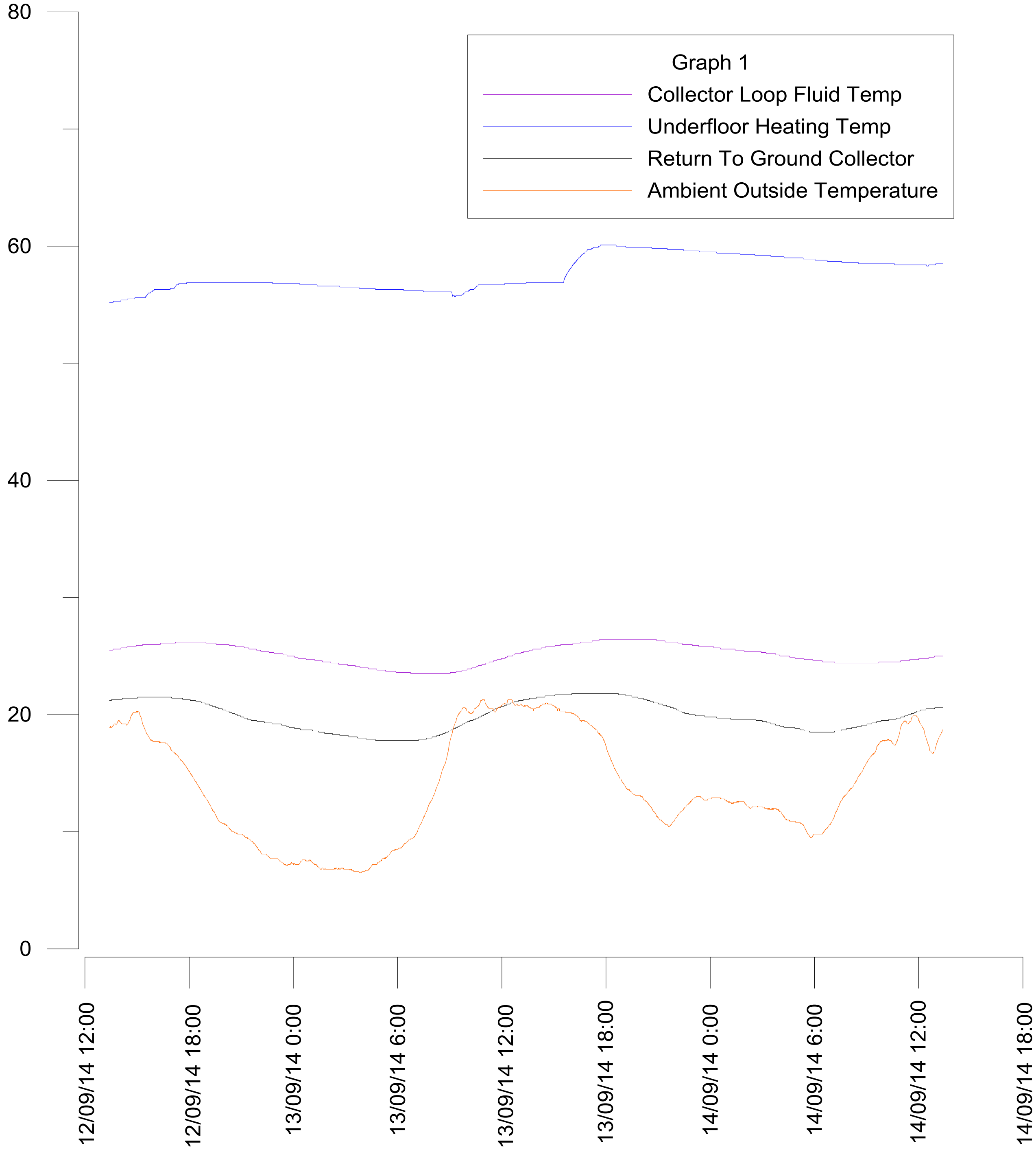
APPENDIX 1

Sample Collector Data

The following graph shows the normal temperatures during a warm period (September 2014) where there is no extraction from ground collectors. The from ground and return to ground loops merely sit at the ambient room temperature of the plant room (where the sensors are located) which lags slightly behind the outside temperature. This was common over the period of the project; it was not until November that the heat pump was regularly operational.

During this warm period any heating needs are met by the gas boiler or the solar panels.


80
60
40
20
0
Graph 1
Collector Loop Fluid Temp
Underfloor Heating Temp
Return To Ground Collector
Ambient Outside Temperature
12/09/14 12:00
12/09/14 18:00
13/09/14 0:00
13/09/14 6:00
13/09/14 12:00
13/09/14 18:00
14/09/14 0:00
14/09/14 6:00
14/09/14 12:00
14/09/14 18:00

APPENDIX 2

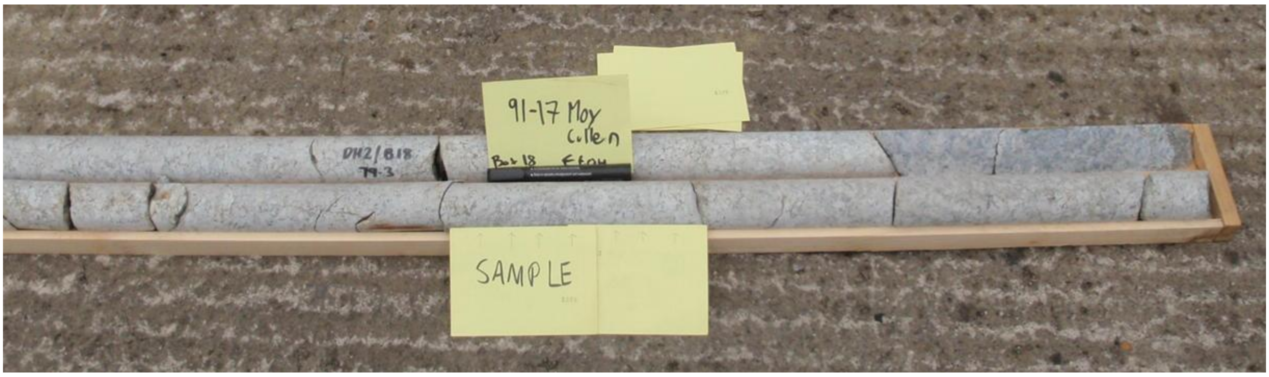
Core Store Samples Photos

LK1

Porters Gate Formation (PG)

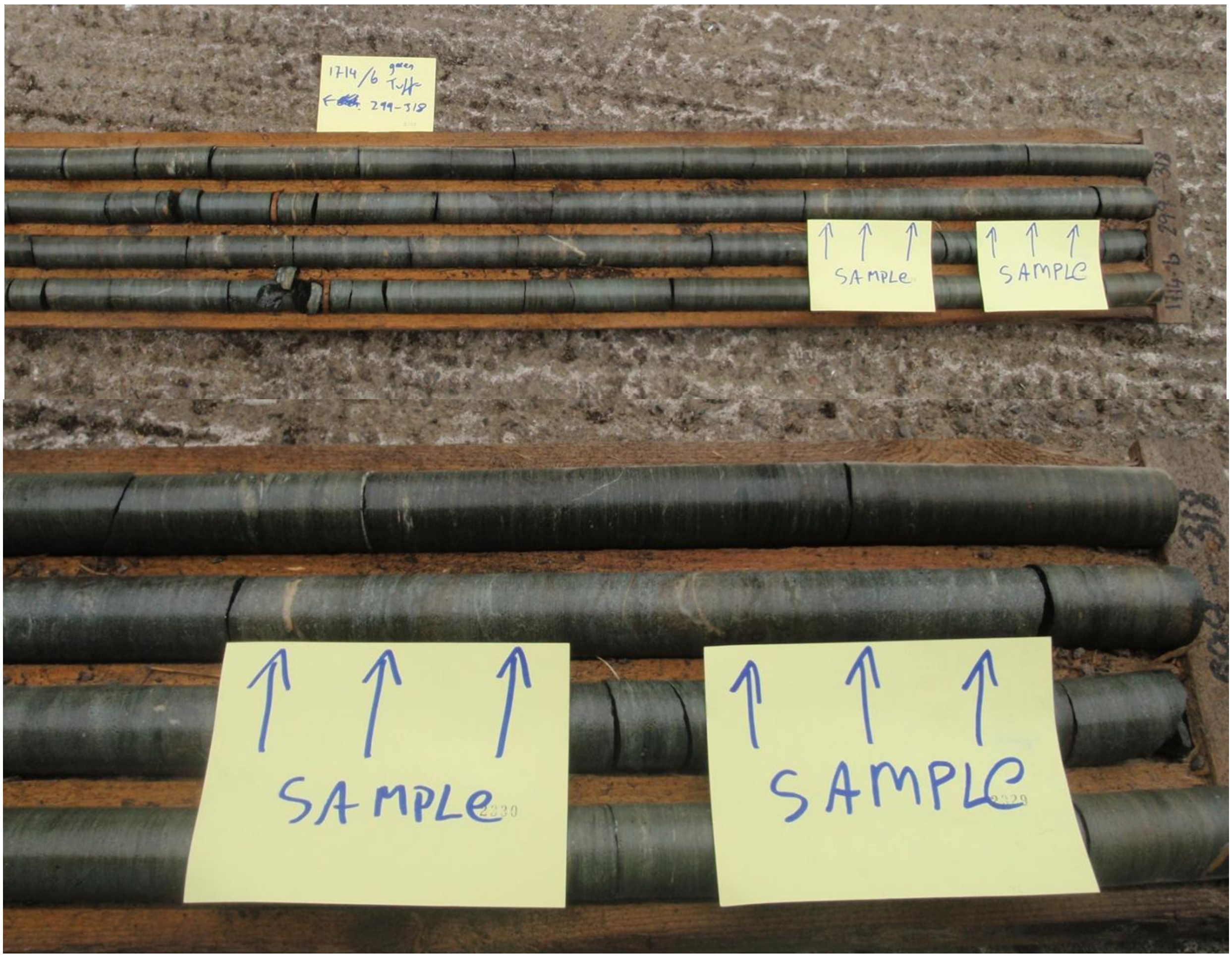
91-17 Moycullen 2 Granite

Formation: Errisbeg Townland Granite



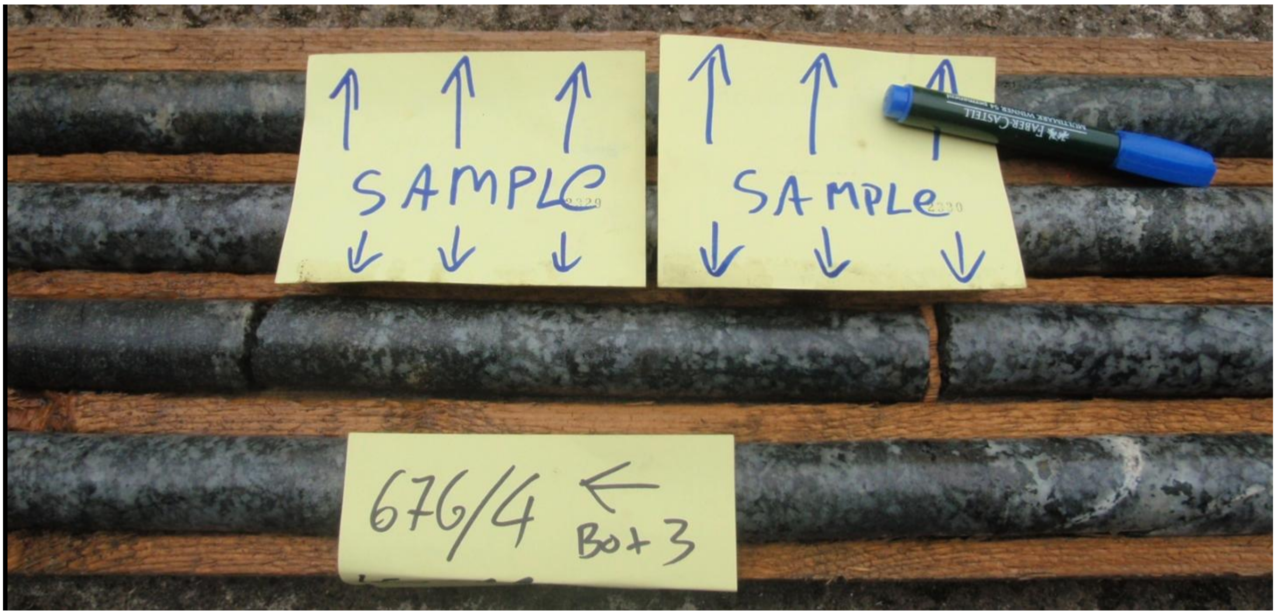
1714/6 Green tuff

Formation: Ballyneale Member



676/4 Gabbro

Formation: Early Gabbros (ITGBRO)



AM 16 Chlorite Schist

Formation: Ballynakill Formation

14/07 Knockroe

Formation: Knockroe Basalt Lava Flow Member (KRb)

14/05 Almseed

Formation: Dolerite dyke

AM 15

Formation: Chlorite schist

APPENDIX 3

Divided Bar Data

Dry data

Corrected Thermal Conductivity of	Sample No.	lith	Date	T1	T2	T3	T4	ΔT_1	ΔT_2	ΔT_3	sample Weight (g)	Sample dianeter ø (m)	Sample Δz - 1 (m)	Sample Δz - 2 (m)	Sample Δz - 3 (m)
2.70	lk-1 A (dry)	lomitized limeston	08/10/2014	42.3	38.43	32.98	29.66	3.870	5.4500	3.3200	57.49	0.0363	0.0200	0.0202	0.0206
2.76	lk-1 B (dry)	lomitized limeston	08/10/2014	41.8757	37.7414	31.8043	28.4443	4.134	5.937143	3.36	62.3	0.0363	0.0218	0.0216	0.0217
2.56	lk-1 C (dry)	lomitized limeston	08/10/2014	42.3950	38.1867	32.1317	28.8467	4.208	6.055	3.285	59.17	0.0363	0.0205	0.0206	0.0205
2.59	AM 16 A (dry)	Chlorite Schist	14/10/2014	42.32727	38.03455	31.84091	28.47	4.293	6.193636	3.370909	61.2	0.0364	0.0210	0.0211	0.0207
2.74	AM 16 B (dry)	Chlorite Schist	14/10/2014	42.46667	38.14	32.02	28.52167	4.327	6.12	3.498333	62.34	0.0364	0.0214	0.0214	0.0213
2.48	AM 16 C (dry)	Chlorite Schist	14/10/2014	42.2600	38.8200	32.6000	28.9900	3.440	6.22	3.61	64.87	0.0364	0.0220	0.0220	0.0218
1.55	676/4 A	Gabbro	16/10/2014	42.2400	39.0000	30.8200	28.1800	3.240	8.18	2.64	67.75	0.0361	0.0216	0.0217	0.0216
1.85	676/4 B	Gabbro	16/10/2014	42.4520	38.8040	31.2900	28.4500	3.648	7.514	2.84	65.84	0.0361	0.0214	0.0215	0.0213
1.57	676/4 C	Gabbro	16/10/2014	42.4600	38.9900	30.9600	28.4400	3.470	8.03	2.52	62.19	0.0361	0.0211	0.0210	0.0212
1.92	1714/6 A	tuff	20/10/2014	42.3400	38.8500	32.5100	29.6500	3.490	6.34	2.86	55.96	0.0363	0.0189	0.0192	0.0197
1.99	1714/6 B	tuff	21/10/2014	42.4500	38.9300	32.3200	29.2400	3.520	6.61	3.08	58.35	0.0363	0.0198	0.0201	0.0200
1.81	1714/6 C	tuff	21/10/2014	42.6200	38.9800	31.8000	28.5500	3.640	7.18	3.25	55.51	0.0363	0.0190	0.0191	0.0187

Corrected Thermal Conductivity of	Sample No.		Date	T1	T2	T3	T4	ΔT₁	ΔT₂	ΔT₃	sample Weight (g)	Sample dianeter ø (m)
1.20	14/05 Almseed A	Dolerite	28/10/2014	42.24	38.54	31.65	28.53	3.700	6.8900	3.1200	109.05	0.0475
1.43	14/05 Almseed B	Dolerite	28/10/2014	42.2400	38.1900	31.8200	28.4800	4.050	6.37	3.34	110.52	0.0475
1.28	14/05 Almseed C	Dolerite	28/10/2014	42.0800	38.3000	31.4200	28.4000	3.780	6.88	3.02	115.94	0.0476
1.33	14/07 Knockroe A	Volcanoclastic	24/10/2014	42.3400	38.3100	31.6800	28.5600	4.030	6.63	3.12	99.85	0.04755
1.40	14/07 Knockroe B	Volcanoclastic	28/10/2014	42.2400	37.9600	31.6100	28.4900	4.280	6.35	3.12	97.46	0.04755
1.46	14/07 Knockroe C	Volcanoclastic	24/10/2014	41.9800	38.0400	32.3200	29.0300	3.940	5.72	3.29	92.91	0.04755
2.71	LYH 5A	Quartzite	22/10/2014	42.16	37.76	33.88	30.2	4.400	3.88	3.68	99	0.0474
2.53	LYH 5B	Quartzite	22.10.2014	42.42	37.84	33.59	29.9	4.580	4.25	3.69	98.62	0.0474
2.84	LHY 5C	Quartzite	22/10/2014	42.41571	38.02429	34.34286	30.64143	4.391	3.681429	3.701429	97.54	0.0474
2.19	Moycullen 2 A	Granite	20/10/2014	42.12	37.47	32.66	28.87	4.650	4.81	3.79	98.79	0.04742
2.03	Moycullen 2 B	Granite	20/10/2014	42.12	37.591	32.509	28.855	4.529	5.082	3.654	100.46	0.04742
2.23	Moycullen 2 C	Granite	20/10/2014	42.36	38.12667	33.72833	30.175	4.233	4.398333	3.553333	99.83	0.04742
2.18	AM 15 A	Chlorite Schist	28/10/2014	42.2100	38.2100	31.2200	28.3300	4.000	6.99	2.89	61.39	0.03622
2.22	AM 15 B	Chlorite Schist	28/10/2014	42.1700	38.1400	31.4000	28.3900	4.030	6.74	3.01	58.6	0.03621
1.94	AM 15 C	Chlorite Schist	28/10/2014	42.2267	38.2300	31.0600	28.3800	3.997	7.17	2.68	57.87	0.03633

Saturated datasheets

Corrected Thermal Conductivity of	Sample No.		Date	T1	T2	T3	T4	sample Weight (g)	Sample dianeter ø (m)	Sample Δz - 1 (m)	Sample Δz - 2 (m)	Sample Δz - 3 (m)
2.30	lk-1 A (sat)	dolomitized limestone.	14/10/2014	42.33	38.28	31.93	28.78	57.81	0.0363	0.0200	0.0202	0.0206
2.66	lk-1 B (sat)	dolomitized limestone.	14/10/2014	42.4500	38.1900	31.9700	28.6400	62.69	0.0363	0.0218	0.0216	0.0217
2.45	lk-1 C (sat)	dolomitized limestone.	14/10/2014	42.0200	38.0300	31.9100	28.6200	59.55	0.0363	0.0205	0.0206	0.0205
2.51	AM 16 A (sat)	Chlorite Schist	16/10/2014	42.45	38.33	32.11	28.76	61.17	0.0364	0.0210	0.0211	0.0207
2.43	AM 16 B (sat)	Chlorite Schist	20/10/2014	42.39	38.41	32.1	28.89	62.35	0.0364	0.0214	0.0214	0.0213
2.64	AM 16 C (sat)	Chlorite Schist	23/10/2014	42.1400	37.9100	31.7100	28.4700	64.97	0.0364	0.0220	0.0220	0.0218
1.93	676/4 A (sat)	Gabbro	24/10/2014	42.4400	38.7000	31.2800	28.4300	67.8	0.0361	0.0216	0.0217	0.0216
1.85	676/4 B(sat)	Gabbro	24/10/2014	42.4275	38.6500	31.1375	28.4350	65.91	0.0361	0.0214	0.0215	0.0213
1.61	676/4 C (sat)	Gabbro	24/10/2014	42.4700	39.0000	31.0600	28.4500	62.23	0.0361	0.0211	0.0210	0.0212
2.00	1714/6 A (sat)	tuff	22/10/2014	42.29714	38.34286	31.54286	28.43429	56.05	0.0363	0.0189	0.0192	0.0197
1.85	1714/6 B (sat)	tuff	21/10/2014	42.29714	38.34286	31.54286	28.43429	58.41	0.0363	0.0198	0.0201	0.0200
1.88	1714/6 C (sat)	tuff	22/10/2014	42.3900	38.8200	31.8200	28.4300	55.59	0.0363	0.0190	0.0191	0.0187

1.30	14/05 Almseed A	Dolerite	29/10/2014	42.36	38.33	31.69	28.59	4.030	6.6400	3.1000	109.88	0.0475	0.0211	0.0210	0.0212
1.40	14/05 Almseed B	Dolerite	29/10/2014	42.3700	38.46	32.1000	28.7700	3.910	6.36	3.33	111	0.0475	0.0214	0.0215	0.0215
1.49	14/05 Almseed C	Dolerite	29/10/2014	42.2500	38.14	31.9000	28.8600	4.110	6.24	3.04	116.97	0.0476	0.0226	0.0227	0.0227
1.77	14/07 Knockroe A	Volcanoclastic	28/10/2014	42.09	37.64	32.13	28.72	4.450	5.51	3.41	101.82	0.04755	0.0214	0.0218	0.0214
1.67	14/07 Knockroe B	Volcanoclastic	29/10/2014	42.24	37.64	31.92	28.58	4.600	5.72	3.34	99.13	0.04755	0.0208	0.0210	0.0209
1.73	14/07 Knockroe C	Volcanoclastic	29/10/2014	42.2400	37.3875	31.8600	28.4625	4.852	5.5275	3.3975	94.6	0.04755	0.0200	0.0201	0.0201
3.40	LYH 5A	Quartzite	23/10/2014	42.0900	37.21	33.7800	29.8100	4.880	3.43	3.97	99.9	0.0474	0.0221	0.0221	0.0221
3.57	LYH 5B	Quartzite	23/10/2014	42.3050	36.965	33.5600	29.6967	5.340	3.405	3.863333	99.7	0.0474	0.0221	0.0221	0.0221
3.69	LYH 5C	Quartzite	23/10/2014	42.1600	36.74	33.4100	29.4600	5.420	3.33	3.95	98.62	0.0474	0.0218	0.0220	0.0218
2.26	Moycullen 2 A	Granite	21/10/2014	42.2600	37.79	33.2500	29.5200	4.470	4.54	3.73	99.22	0.04742	0.0213	0.0214	0.0213
2.06	Moycullen 2 B	Granite	21/10/2014	41.8767	37.56111	32.7822	29.3022	4.316	4.778889	3.48	100.64	0.04742	0.0217	0.0217	0.0217
2.24	Moycullen 2 C	Granite	21/10/2014	42.1700	37.71	33.1800	29.5900	4.460	4.53	3.59	100.28	0.04742	0.0215	0.0218	0.0215
2.56	AM 15 A	Chlorite Schist	29/10/2014	42.24	38.08	31.79	28.7	4.160	6.29	3.09	61.71	0.03622	0.0221	0.0221	0.0221
2.32	AM 15 B	Chlorite Schist	29/10/2014	42.3200	38.06167	31.3850	28.3683	4.258	6.676667	3.016667	59.08	0.03621	0.0211	0.0212	0.0212
2.18	AM 15 C	Chlorite Schist	29/10/2014	42.3400	38.18	31.3300	28.3700	4.160	6.85	2.96	58.09	0.03633	0.0210	0.0209	0.0211

APPENDIX 4

Thermal Response Test Data

Geoserv

Client: UCD - SEAI	Date: 04/11/2014

Location:	Ring, Co. Waterford		
Easting:		**Northing:**	
Weather:			
Elevation (m. a. G. L.)		**Field Crew**	C. Lavelle J. McAteer

Test Information		Comments
Test Duration	24 hours	
Power Source	Generator 30 kVa	
Heat Applied (W)	6000	

Borehole Information			
Depth ((m. b. G . L.))	150	Collector Heitght (m. a. G . L.)	1.23
Casing Height (m. a. G . L.)	0.58	Collector Type	Single U
Grouting	None	Pipe Diameter (mm)	40

Test Log				
	Time	Flow (l/m)	Pressure (bar)	Comments:
Start (Open Loop)	15:48:00	12.9	1.0	On 03/11/2014
Closed Loop	12:40:00	9.02	0.8	
Loop Pressurised	16:02:00	12.9	1.0	On 03/11/2014
Data Acquisition	12:40:00	9.02	0.8	
Heater Switched On	12:40:00	9.02	0.8	
Heater Switched Off	00:48:00	7.30	0.8	
Test End	13:00:00	7.01	0.8	

Daily Progress Log			
Time	Flow (l/m)	Pressure (bar)	Comments

Test Results	
Thermal Conductivity Average (W/m/k)	4.49