Borehole Description

At the start of this investigation, two new shallow boreholes were drilled in 2008 in the south coast of Cyprus; one in the Ariel region and the other in the Ayia Phyla region, in the town of Limassol. The locations are shown in Figure 1. They were selected mainly because of the specific ground formation in the area. Drill chipping samples were collected during the drilling of the boreholes to characterise the soil types. Hardcore material like marl, chalk and gravel are prevalent in these areas. The findings are listed in Table 1.

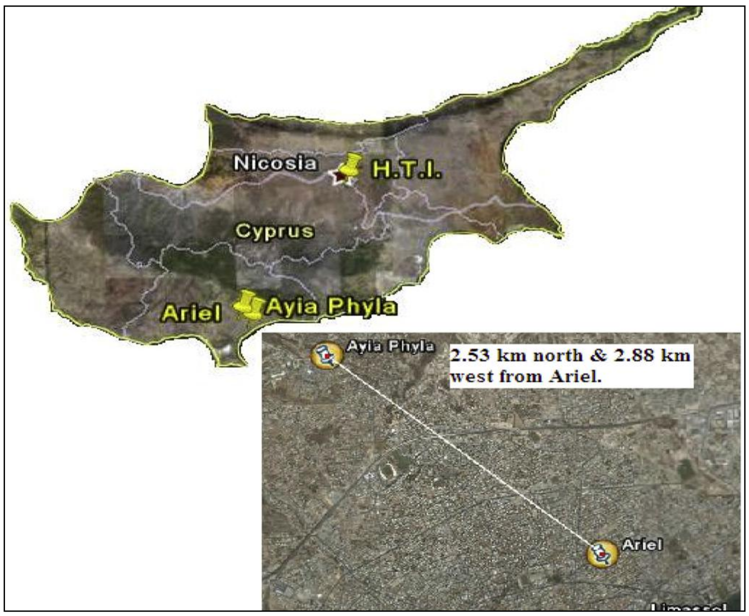

Figure 1: Google earth map showing the positions of the two boreholes in respect to the one drilled in the Athalassa region in Nicosia, Pouloupatis *et al.* (2011)

Table 1: Geological data for the boreholes in Ayia Phyla and Ariel regions in Limassol, Pouloupatis *et al.* (2011)

Location	Type of material
Ayia Phyla	Hardcore material (marl, chalk and gravel)
Ariel	Hardcore material (marl, chalk and gravel)

In the Ayia Phyla region a borehole 10 cm in diameter and 7.7 m in depth was drilled. A U-tube GHE made of polyethylene pipe with 32 mm external diameter was installed to the depth of 7 m in order to gain the required experience. The borehole was backfilled with the soil extracted during drilling. Thermocouples were placed at various depths on the borehole's wall on the undisturbed ground. In the Ariel region the borehole was 10 cm in diameter and 7 m in depth and it was drilled only for measuring the temperature of the ground at various depths. The thermocouples were placed on the central axis of the borehole which was backfilled with the soil taken out during the drilling operation. No heat exchanger was placed in this borehole, Pouloupatis *et al.* (2011). These boreholes proved to be very shallow and obviously could not be used to extract useful information about the thermal conductivity of the ground.

Because of the high cost of drilling and the necessity to perform in situ TRT to determine the thermal conductivity of full depth boreholes, funding was sought to support the work. In 2008 the Energy Service of the Ministry of Commerce, Industry and Tourism of the Republic of Cyprus in collaboration with the Cyprus Institute of Energy and the Cyprus University of Technology funded a project for the determination of the thermal parameters of the ground in two locations in Cyprus, in the Agios Georgios region of Limassol and in Saittas. The Agios Georgios region was selected because of its interesting geological formation. Also it was close to the two previous boreholes drilled in Ayia Phyla and Ariel which were not deep enough and could not be used for measurements. Unconsolidated clay and silt are the main soil types in the area. Saittas, is a mountainous region and the ground is mainly formed by diabase. Details of the borehole lithology in Agios Georgios, Limassol and Saittas regions are shown in Table 2.

Table 2: Borehole lithology in Agios Georgios, Limassol and Saittas regions

Agios Georgios - Limassol		Saittas	
Type of material	Depth m	Type of material	Depth m
Red soil	0-4	Top soil	0-8
Silty sand with some gravels	4-16		
Yellow marl	16-38	Diabase	8-178
Green marl	38-120		

The borehole in Agios Georgios was about 15 cm in diameter and 120 m in depth. A double U-tube GHE made of polyethylene pipe with 40 mm external diameter (3.7 mm thickness) was installed down to the entire depth of the borehole. Thermocouples attached to the GHE were also placed in the borehole before it was backfilled with thermo-cement.

The borehole drilled in Saittas was also 15 cm in diameter but with a depth of 178 m. In both boreholes the thermal conductivity of the drill chipping samples collected during drilling were determined by Geoliving Energy the Swiss company that was responsible for the drilling and the determination of the thermal properties of the ground.

Finally, a Project funded by the Research Promotion Foundation of Cyprus that was undertaken by the Cyprus University of Technology and other collaborators provided the opportunity to gather and publish similar information for six new-drilled boreholes. The sites were selected based on geologic conditions, prevailing weather conditions and population density in order to include seaside, inland, semi-mountain and mountainous locations. For this study the drilling sites were located in the regions of Lakatamia in Nicosia, Kivides in Limassol, Meneou in Larnaca, Agia Napa in Famagusta, Geroskipou and Prodromi in Paphos. Figure 2 depicts the geological map of Cyprus with the locations of the 6 new-drilled boreholes and the 2 boreholes drilled in Agios Georgios in Limassol and in Saittas region.

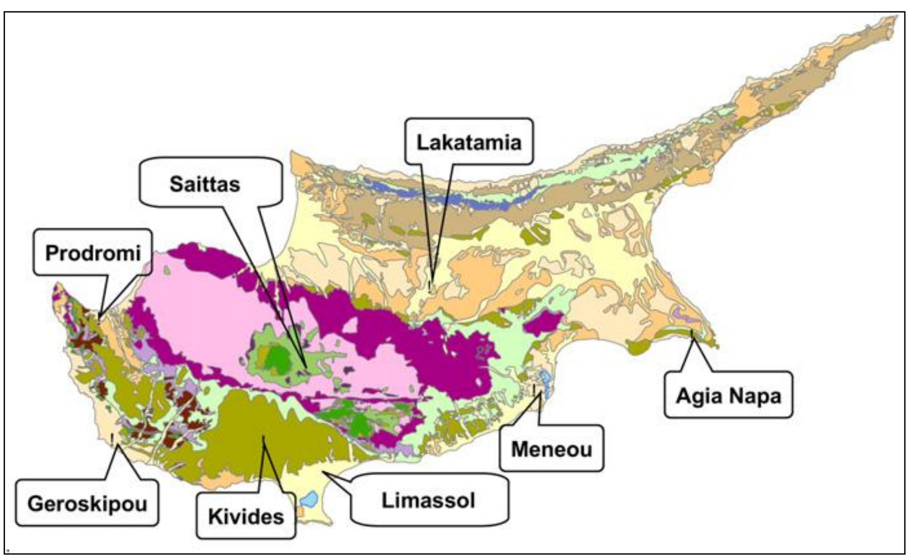

Figure 2: Geological map of Cyprus with the 8 borehole locations, Florides *et al.* (2011)

Table 3 presents all relevant information for the boreholes. In most of the boreholes more than one GHE were installed. This would allow the examination of the effect of the GHE length, diameter or type on the result of the thermal conductivity tests.

Table 3: Borehole and equipment installation details, Florides *et al.* (2011)

Location	Depth /Diam m	Ground heat exchangers	Filling material
Agia Napa Famagusta	100.5/0.2	PE100, PN16, 32x3 mm, 2Ux100 m	bentonitic clay
Meneou Larnaca	97/0.2	PE100, PN16, 32x3 mm, 1Ux97 m PE100, PN16, 40x3 mm, 1Ux97 m PE80, PN16, 40x3 mm, 1Ux97 m	bentonitic clay
Lakatamia Nicosia	160/0.23	PE100, PN16, 32x3 mm, 1Ux160 m 1Ux100 m	bentonitic clay and cement
Kivides Limassol	196/0.15	PE100, PN16, 32x3 mm, 1Ux196 m 1Ux96 m	bentonitic clay
Geroskipou Pafos	100/0.2	PE100, PN16, 32x3 mm, 1Ux100 m PE100, PN16, 25x3 mm, 1Ux100 m	bentonitic clay
Prodromi Paphos	100/0.2	PE100, PN16, 32x3 mm, 1Ux100 m	bentonitic clay
Agios Georgios Limassol	120/0.152	PE100, PN16, 40x3.7 mm, 2Ux120 m	bentonitic clay
Saittas Limassol	178/0.152	PE100, PN16, 40x3.7 mm, 1Ux178 m	bentonitic clay

As in the previous cases, drill chipping samples were collected during drilling (Figure 3). The drill chipping samples were used by the Geological Survey Department of the Ministry of Agriculture and Natural Resources of the Republic of Cyprus (GSDC) to identify the geological layers. The ground layers mostly include sandy marls, chalk, limestones and sandstones. Figure 4 depicts the borehole lithology at the six selected locations based on the GSDC findings.

Figure 3: Drill chipping samples collected during drilling

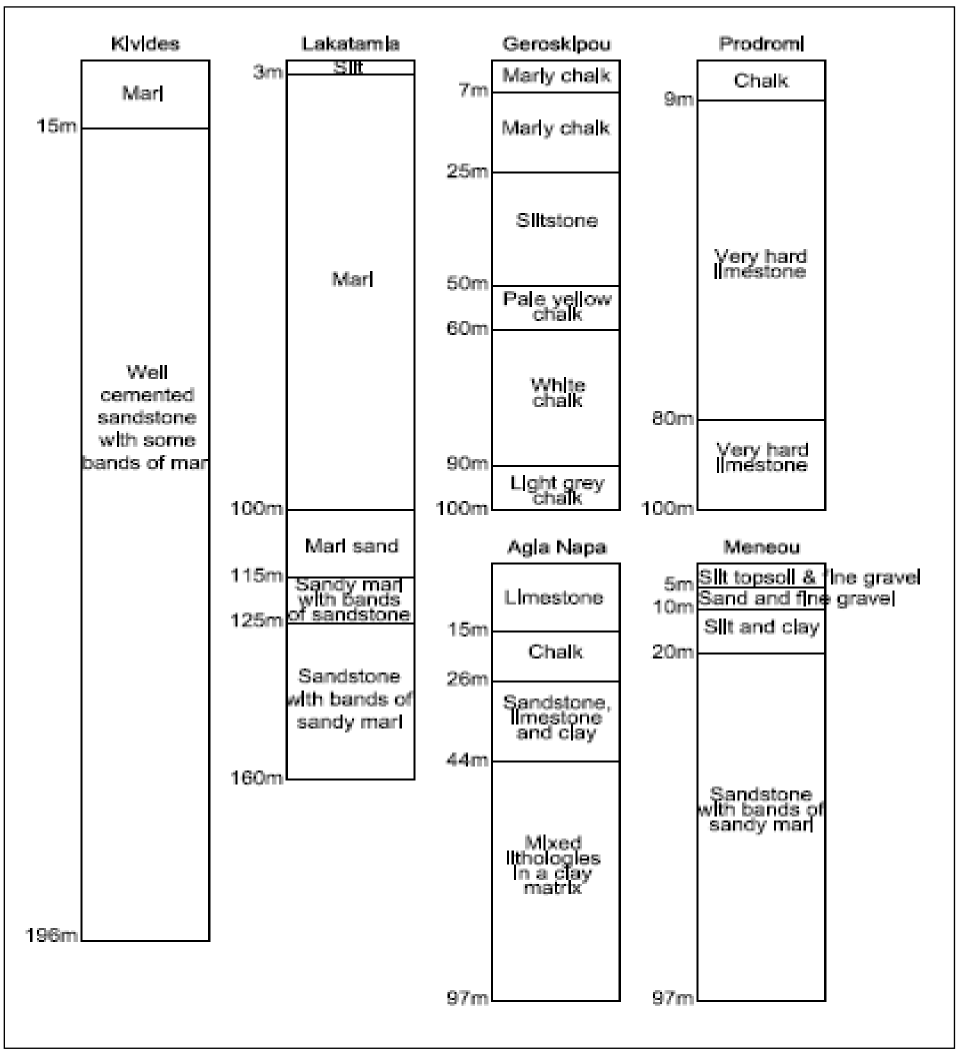

Figure 4: Borehole lithology at the six selected locations

Additionally, samples from areas lithologically identical or similar to those of the boreholes were collected from nearby areas for analysis. For every sample, a number of thermal conductivity measurements were made using the Hukseflux TPSYS02 thermal sensor device. The device could measure the thermal conductivity of soils, thermal backfill materials, sediments, etc with the aid of needle probes. The measurement principle is that of a non-steady state probe or transient line source where the thermal conductivity of the sample is determined by the temperature response to heating. After an initial transition period, the temperature rise close to the heater depends only on the thermal conductivity of the surrounding medium, and no longer on heat capacity. The Measurement and Control Unit (MCU) controls the process while a software installed on a PC analyses the data and presents the results (see Figure 5). The needle probes used were designed for measure thermal conductivities in the range 0.1 to 6 W/mK while the accuracy of the system is ±(3% + 0.02) W/mK. This method of measurement is fast and independent of sample size, (www.hukseflux.com).

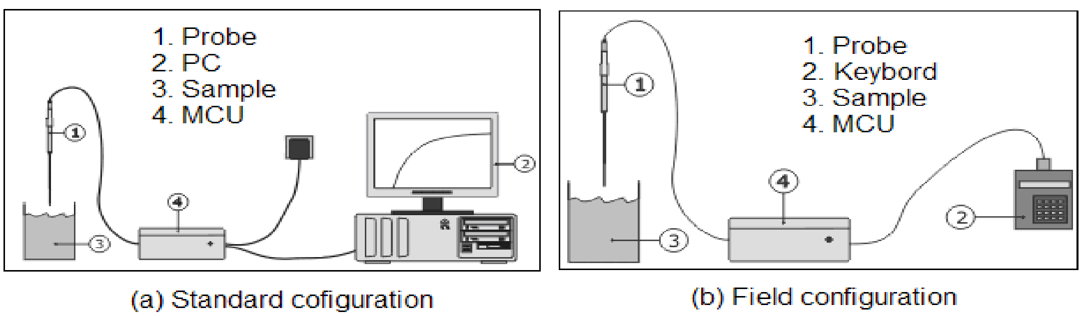

Figure 5: The Hukseflux TPSYS02 device in (a) standard and (b) field configurations (www.hukseflux.com).

To measure the thermal conductivity of a rock sample a hole 3 mm in diameter and 150 mm in depth should be drilled in the sample. With this method, in order to prevent convective heat flow between the needle probe and the hole wall, the hole diameter should match the probe diameter and the hole should be sealed at both ends. Since the needle probe diameter was very thin and it was difficult to drill such a hole in hard samples, the larger diameter hole drilled (5 mm) was filled with conductive materials such as heat conducting paste. The measured values using the Hukseflux TPSYS02 thermal sensor are presented in Table 4.

Table 4: Measured values using the Hukseflux TPSYS02 thermal sensor device

Specimen	Type of material	Absorption %, WA24	λ	ρ	Condition
			W/mK	kg/m^3	
1	Chalk	15.9	0.73	2030	dry
					100% saturated
2	Chalk	10.3	0.77	2160	dry
					100% saturated
3	Chalk	4.7	0.87	2420	dry
			1.54		100% saturated
4	Chalk	3.0	0.9	2580	dry
					100% saturated
5	Chalk	8.2	0.7	2270	dry
			1.33		100% saturated
6	Chalk	5.1	0.83	2440	dry
			1.05		100% saturated
7	Chalk	5.6	1.07	2070	dry
			1.45		100% saturated
8	Marl	34.7	0.51	1720	dry
			1.45		100% saturated

All values of Table 4 are lower than those expected. This is because hard rock specimens present problems in drilling and as experienced thin needle probes cannot give accurate results due to the difference between needle and hole diameter. Needle probes on the other hand can be used reliably for the determination of the thermal conductivity of soft materials like moist clay, sands, polystyrene and powders.

For more accurate and consistent results, the Isomet 2104 portable heat transfer analyzer was bought (Figure 6) and used to repeat the tests performed with the Hukseflux thermal device. The Isomet 2104 analyzer is a device that uses surface probes for direct measurement of thermophysical properties, thermal conductivity and volumetric heat capacity of a wide range of materials. The measurement principle is based on the temperature response of the sample to heat flow impulses. The heat flow is induced by electrical heating using a resistor heater. The surface probe assures a direct thermal contact with the surface of the sample. The accuracy of the instrument when measuring thermal conductivity in the range 0.015 to 0.7 W/mK is 5% of the reading +0.001

W/mK, while in the range 0.7 to 6.0 W/mK it is 10% of the reading. The instrument has a repeatability of 3% of the reading +0.001 W/mK, Applied Precision Ltd.

Figure 6: Isomet 2104 portable heat transfer analyzer with surface probe, Applied Precision Ltd.

The measurements were performed on various samples in their dry and water saturated state. All results measured with the Isomet 2104 portable heat transfer analyzer with a surface probe are shown in Table 5.

Table 5: Isomet 2104 portable heat transfer analyzer results

Specimen	Type of material	λ	Cp	ρ	Condition
		W/mK	W/kgK	kg/m^3	
1	Reef limestone	1.22	654	2232	dry
		1.74	906	2347	100% saturated
2	Reef limestone	1.51	718	2125	dry
		1.94	962	2234	100% saturated
3	Chalk	1.58	729	2304	dry
		1.70	733	2402	100% saturated
4	Marly chalk	0.75	1020	1591	dry
		1.22	961	1862	100% saturated
5	Marl	0.50	806	1832	dry
		0.99	767	2155	100% saturated
6	Calcarenite	0.78	784	2075	dry
		1.19	757	2461	100% saturated

7	Calcarenite	0.36	296	1359	dry
		0.80	527	1777	100% saturated
8	Gypsum	1.23	717	2301	dry
		1.19	753	2301	100% saturated
9	Ochre	0.72	690	2174	dry
10	Lava (lower horizon)	0.80	751	1997	dry
		0.97	805	2020	100% saturated
11	Lava (upper horizon)	0.82	749	2119	dry
		0.98	756	2225	100% saturated
12	Lava (basal group)	1.45	596	2728	dry
13	Gabbro	1.97	675	2749	dry
14	Werlite	2.65	630	2941	dry
15	Hartzbourgite	2.34	645	2708	dry
16	Plagiogranite	2.81	586	2893	dry
		3.16	703	2893	100% saturated
17	Diabase	3.76	522	3264	dry
		3.73	603	3264	100% saturated
18	Iron pyrite	9.06	392	4093	dry
19	Umber (silisified)	2.97	642	2773	dry
		3.14	690	2773	100% saturated
20	Pyroxenite	2.02	660	2718	dry
21	Serpentinite	2.29	641	2588	dry

The thermal conductivity of each type of sample is not constant. Due to the fact that the specific weight of the samples also varies. Samples collected from the surface appear to be less dense than the ones collected from deeper in the ground. Also it must be stated that, as expected, materials which absorb water attain a higher conductivity than when they are dry since water with higher conductivity replaces the air. Materials like gypsum in a crystalline form or diabase do not absorb water therefore their conductivity remains the same. Small differences observed in the table are due to the accuracy of the measurement and the uniformity of the material.

References

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