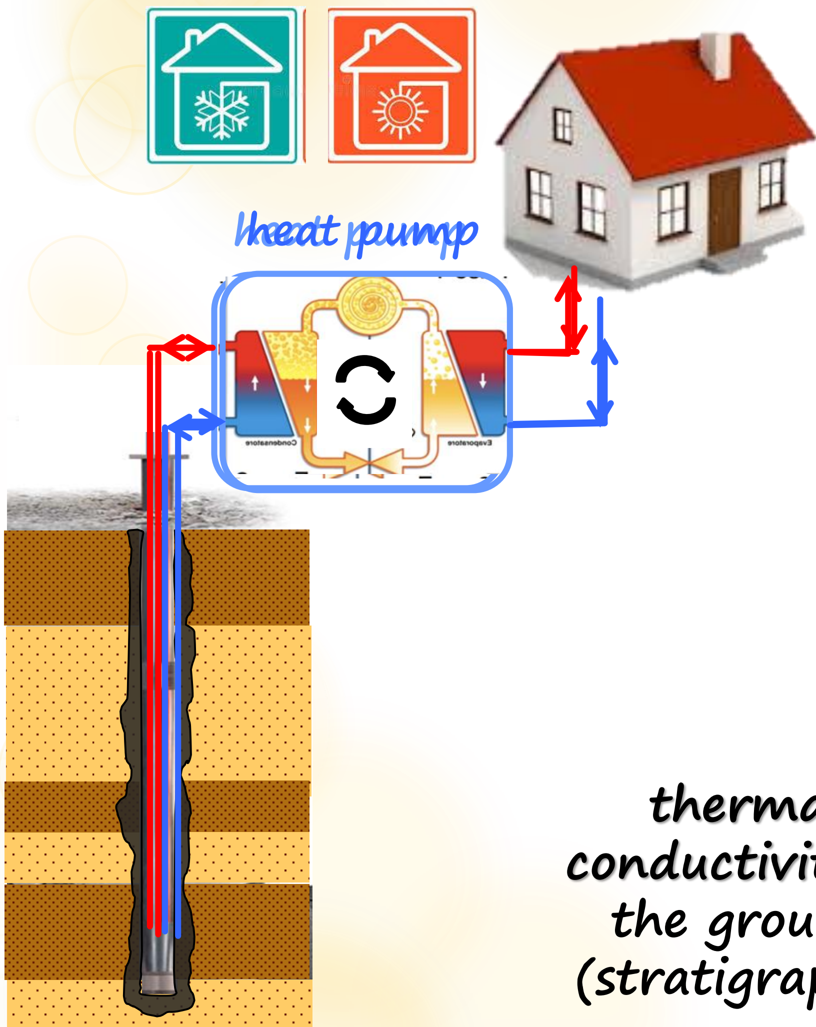
GROUND SOURCE HEAT PUMP SYSTEMS



building's function and typology

climate conditions (altitude and latitude)

building's thermal requests

thermal exchange capability probe-ground

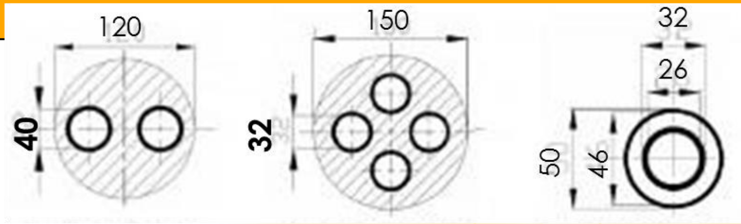
thermal conductivity of the ground (stratigraphy)

presence and velocity of aquifers

materials and technologies used for construction

1. total length of the probes
2. Q and T of the fluid

GSHP SYSTEMS DESIGN

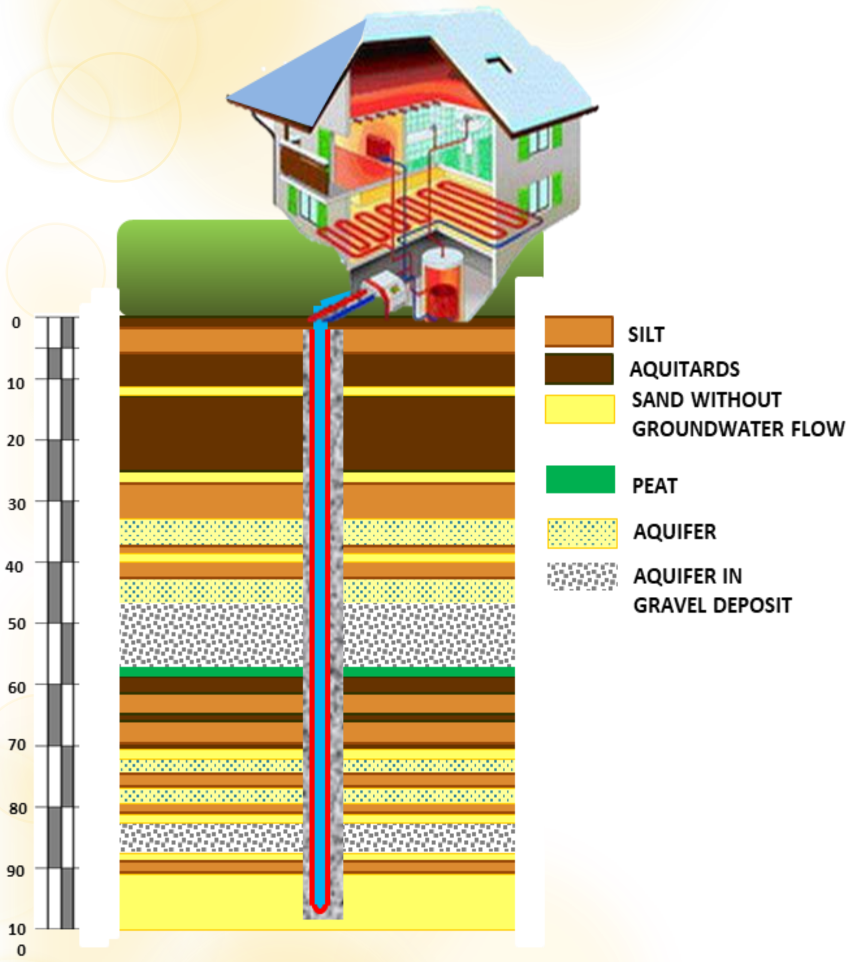


single U　　Double-U　　coaxial

- ✓ HEAT EXCHANGER TYPOLOGY (vertical/horizontal, section..)
- ✓ HEAT EXCHANGERS TOTAL LENGTH
- ✓ SINGLE BHE LENGTH, NUMBER, DISTANCE AND SPATIAL ARRANGMENT (by taking into account the underground characteristics, aquifer direction, other existing plants, available space..)
- ✓ HEAT-CARRIER FLUID TO BE USED INSIDE THE PROBE (water or brines?)
- ✓ HORIZONTAL COLLECTORS DESIGN

1. UNDERGROUND THERMAL PERFORMANCES

The GEOLOGICAL variables mainly affecting the GHE performance

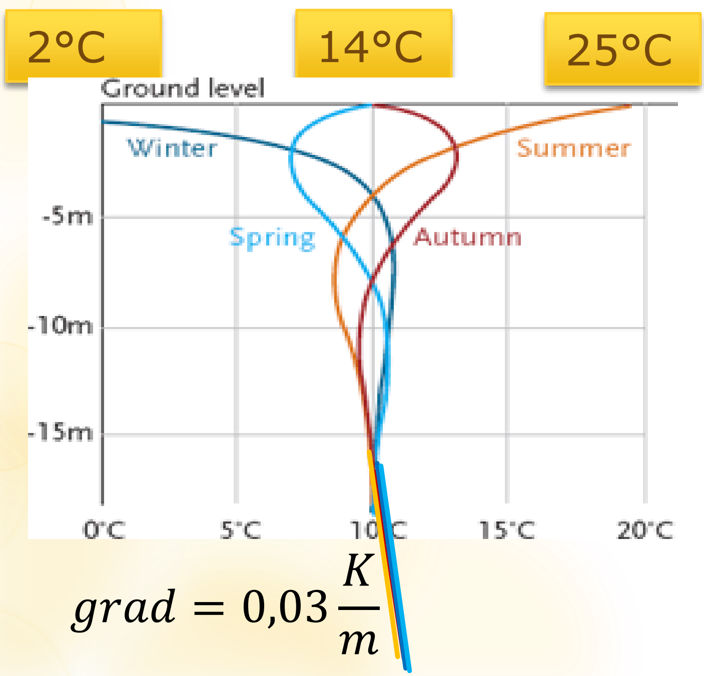


1. undisturbed ground temperature
2. local geothermal heat flux
3. thermal properties of the ground
4. Hydrogeological setting / water content within the ground
5. conduction / convection

1. UNDERGROUND THERMAL PERFORMANCES

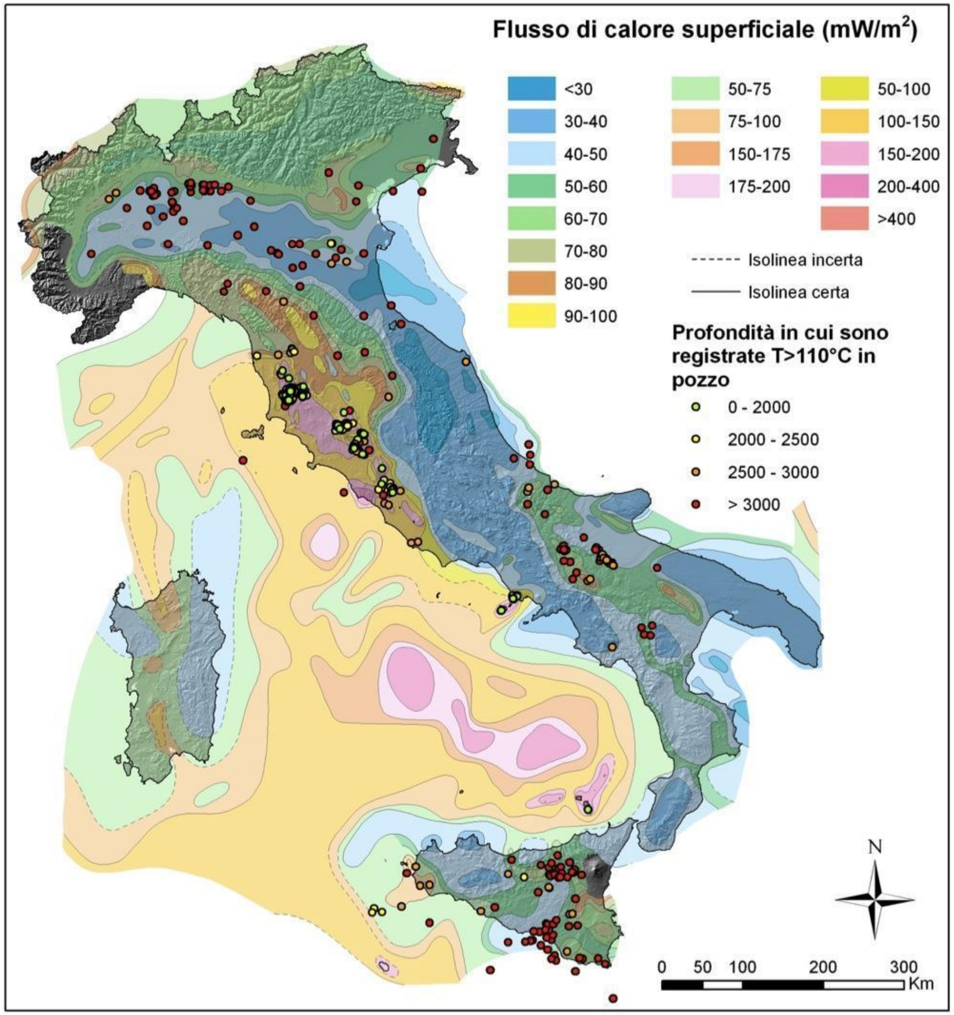
UNDISTURBED GROUND TEMPERATURE

- varies in the shallower layers as a function of the air temperature
- from about 10m, stable throughout the year + increases with depth (local geothermal heat flux)



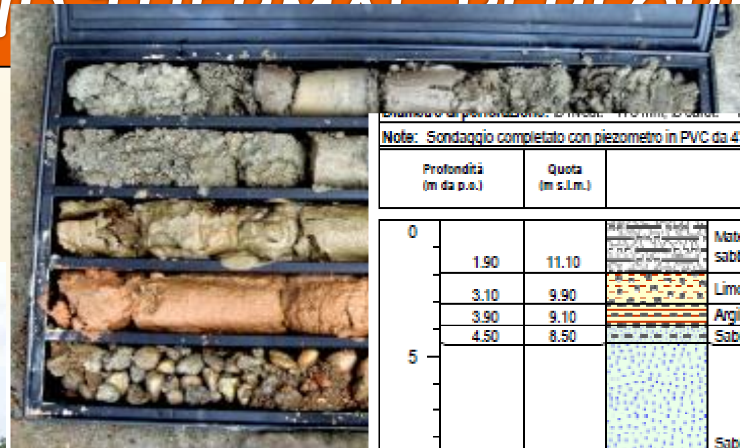
$$grad = 0{,}03\,\frac{K}{m}$$

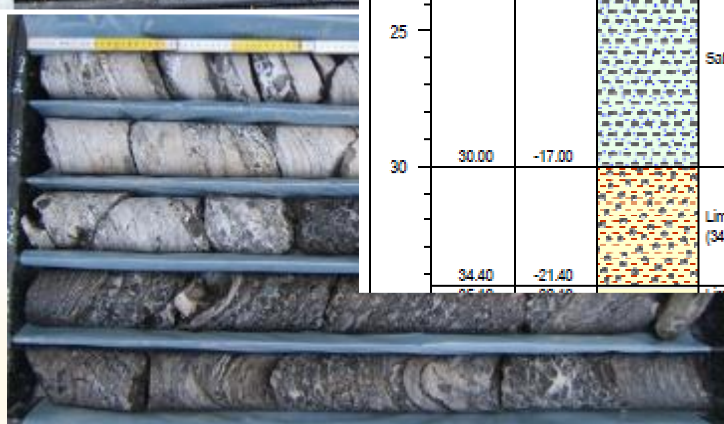
LOCAL GEOTHERMAL HEAT FLUX

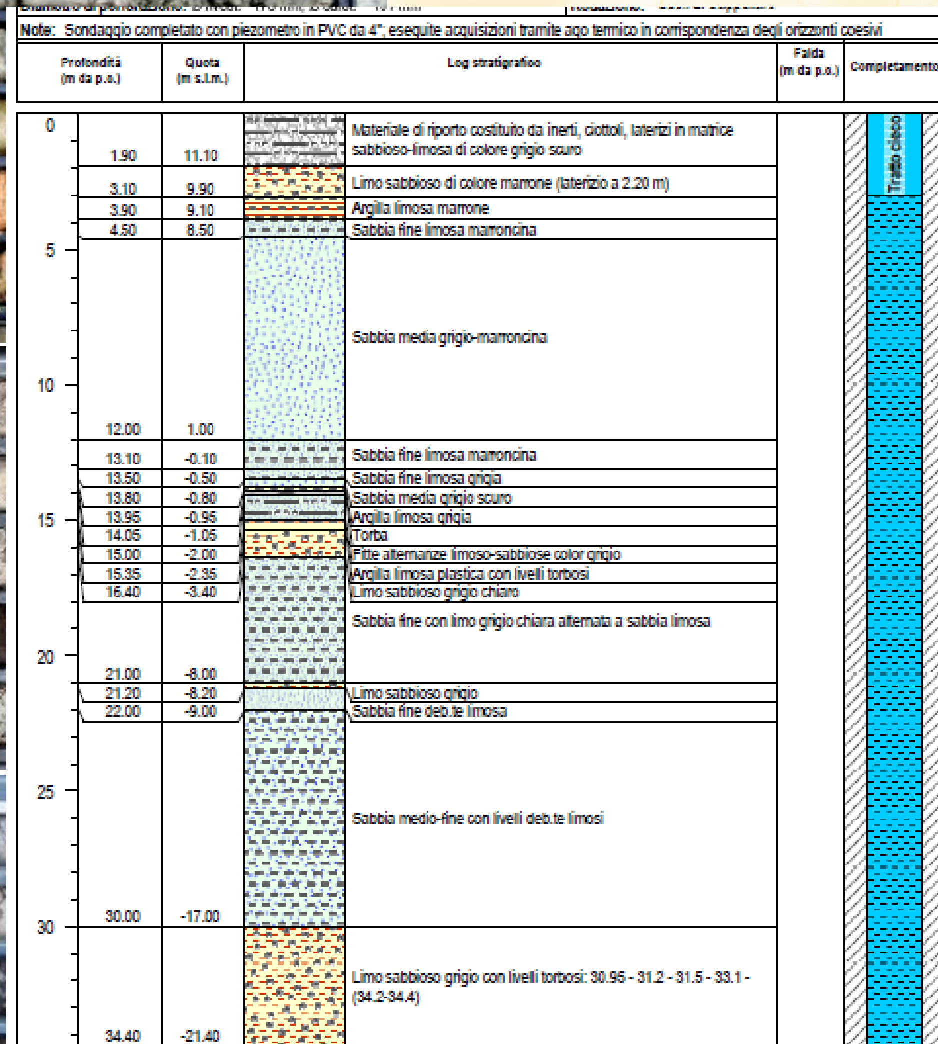


1. UNDERGROUND THERMAL PERFORMANCES

coring







Note: Sondaggio completato con piezometro in PVC da 4"; eseguite acquisizioni tramite ago termico in corrispondenza degli orizzonti coesivi

Profondità (m da p.o.)	Quota (m s.l.m.)	Log stratigrafico
1.90	11.10	Materiale di riporto costituito da inerti, ciottoli, laterizi in matrice sabbioso-limosa di colore grigio scuro
3.10	9.90	Limo sabbioso di colore marrone (laterizio a 2.20 m)
3.90	9.10	Argilla limosa marrone
4.50	8.50	Sabbia fine limosa marroncina
12.00	1.00	Sabbia media grigio-marroncina
13.10	-0.10	Sabbia fine limosa marroncina
13.50	-0.50	Sabbia fine limosa grigia
13.80	-0.80	Sabbia media grigio scuro
13.95	-0.95	Argilla limosa grigia
14.05	-1.05	Torba
15.00	-2.00	Fitte alternanze limoso-sabbiose color grigio
15.35	-2.35	Argilla limosa plastica con livelli torbosi
16.40	-3.40	Limo sabbioso grigio chiaro
21.00	-8.00	Sabbia fine con limo grigio chiara alternata a sabbia limosa
21.20	-8.20	Limo sabbioso grigio
22.00	-9.00	Sabbia fine deb.te limosa
30.00	-17.00	Sabbia medio-fine con livelli deb.te limosi
34.40	-21.40	Limo sabbioso grigio con livelli torbosi: 30.95 - 31.2 - 31.5 - 33.1 - (34.2-34.4)

Falda (m da p.o.) | Completamento: Tratto cieco

1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

b) direct measurements

→STEADY STATE METHODS:
a constant temperature difference is established and maintained across the sample. Requires:
(i) long time to reach the steady conditions,
(ii) an apparatus able to guarantee a stable thermal condition to perform the measurement,
(iii) an accurate control to create and maintain the stability of measurement conditions

→TRANSIENT STATE METHODS:
the time-dependent heat dissipation within a material is monitored, by applying a momentary and known heat IMPULSE to the sample

1. UNDERGROUND THERMAL PERFORMANCES

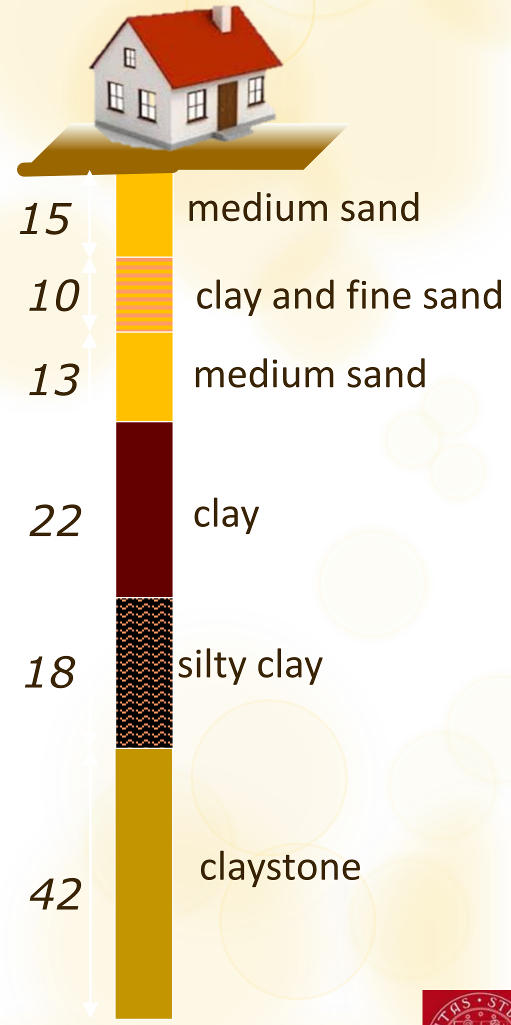
ROCK / SEDIMENTS THERMAL PROPERTIES
both a) and b) HOW DO YOU APPLY THEM?

WHEN THE STRATIGRAPHIC SEQUENCE IS AVAILABLE, the equivalent thermal conductivity can be evaluated:

- assigning a TC value (as indicated in the TABLES or directly measured) to each identified lithotype
- calculating a global TC value as a weighted average on the layer thickness

The TC values must be chosen within the range, by considering:

- the state of consolidation / density
- the state of saturation
- the texture / possible anisotropy



1. UNDERGROUND THERMAL PERFORMANCES

a) and b) PROS AND CONS

PROS | CONS

- By assuming the thermal parameters reported in literature for each sediment/rock type

	Type of rock	Thermal conductivity λ in W/(m·K)		Volume-related specific heat capacity $\rho \cdot c_p$ in MJ/(m³·K)	Density ρ in 10^3 kg/m³
			recommended value		
Unconsolidated	clay/silt, dry	0,4–1,0	0,5	1,5–1,6	1,8–2,0
	clay/silt, water-saturated	1,1–3,1	1,8	2,0–2,8	2,0–2,2
	sand, dry	0,3–0,9	0,4	1,3–1,6	1,8–2,2
	sand, moist	1,0–1,9	1,4	1,6–2,2	1,9–2,2
	sand, water-saturated	2,0–3,0	2,4	2,2–2,8	1,9–2,3
	gravel/stones, dry	0,4–0,9	0,4	1,3–1,6	1,8–2,2
	gravel/stones, water-saturated	1,6–2,5	1,8	2,2–2,6	1,9–2,3
	till/loam	1,1–2,9	2,4	1,5–2,5	1,8–2,3
	peat, soft lignite	0,2–0,7	0,4	0,5–3,8	0,5–1,1
Sedimentary rock	clay/silt stone	1,1–3,4	2,2	2,1–2,4	2,4–2,6
	sandstone	1,9–4,6	2,8	1,8–2,6	2,2–2,7
	conglomerate/breccia	1,3–5,1	2,3	1,8–2,6	2,2–2,7
	marlstone	1,8–2,9	2,3	2,2–2,3	2,3–2,6
	limestone	2,0–3,9	2,7	2,1–2,4	2,4–2,7
	dolomitic rock	3,0–5,0	3,5	2,1–2,4	2,4–2,7
	sulphate rock (anhydrite)	1,5–7,7	4,1	2,0	2,8–3,0
	sulphate rock (gypsum)	1,3–2,8	1,6	2,0	2,2–2,4
	chloride rock (rock salt, potash)	3,6–6,1	5,4	1,2	2,1–2,2
	anthracite	0,3–0,6	0,4	1,3–1,8	1,3–1,6

PROS: Very quick

CONS: Not so accurate:
- Need an accurate local stratigraphy
- Based on wide classes & present large ranges of values

BOTH: THE CONVECTIVE CONTRIBUTION IN AQUIFERS IS NOT TAKEN INTO ACCOUNT

- Direct measurements

PROS: Performed directly on purpose

CONS: Quite hard:
- Requires samples
- Time/cost consuming
- Prone to measurement errors

2. UNDERGROUND THERMAL PERFORMANCES

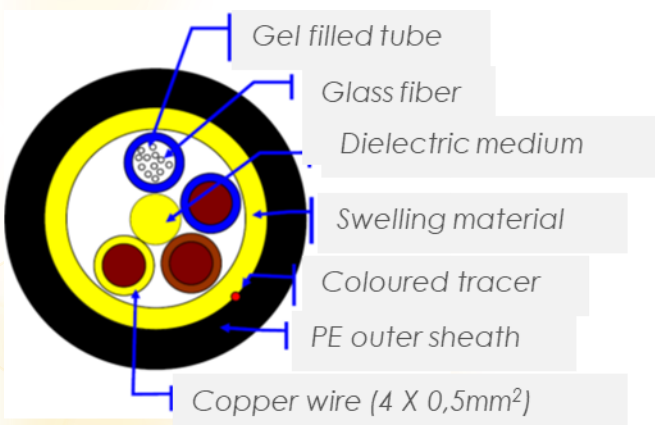
d) DISTRIBUTED THERMAL RESPONSE TEST

- *innovative method*
- ***D**istributed **T**hermal **R**esponse **T**ests (DTRT)*

*Monitoring well equipped with an **hybrid fiber optic cable**:*

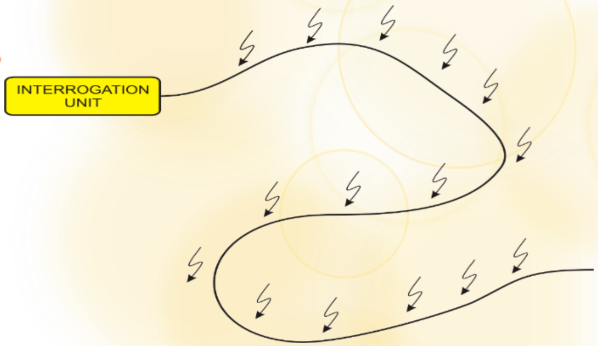
- *several copper wires* → *to **inject heat** by means of electric input (Joule effect) to perform the TRT*
- *bundle of optic fibers* → ✓ ***Measure temperature over time** both when the wires are heating or not (active/passive mode)*

✓ *with **high temporal** and **spatial resolution (Distributed Thermal Sensing)***

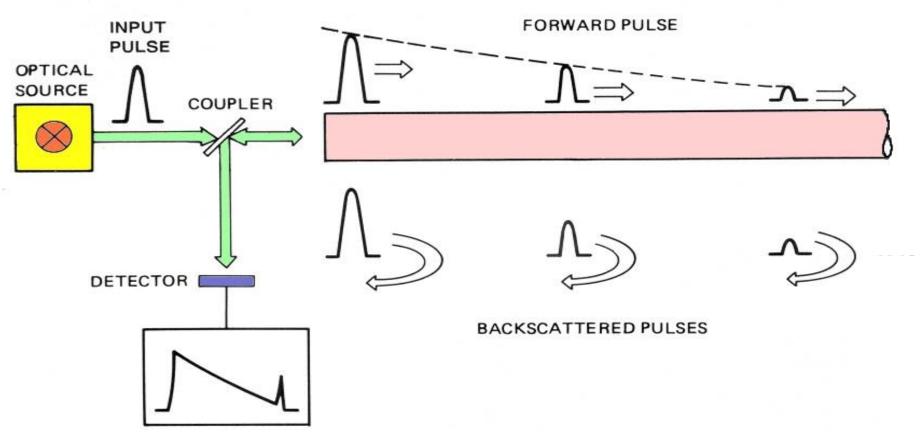


Aim: Distinguish the thermal behaviour of single geological layers

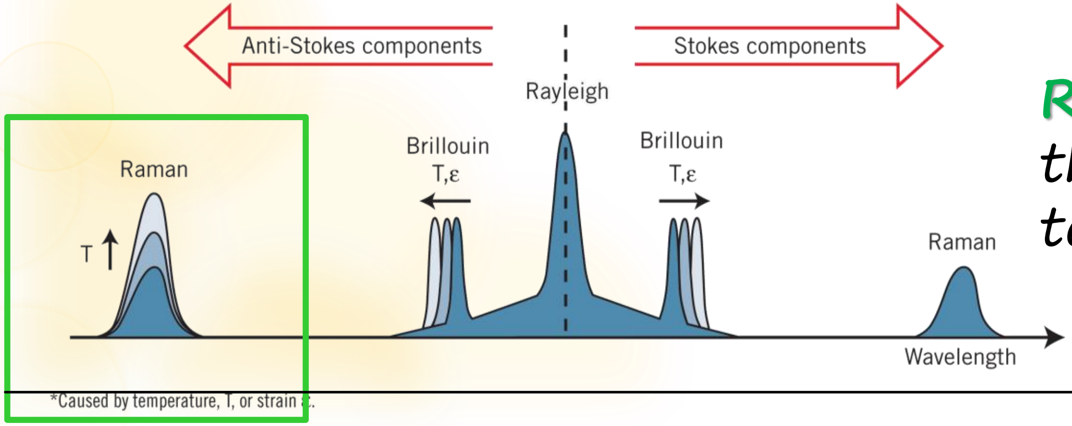
d) DISTRIBUTED THERMAL RESPONSE TEST



Sub-meter scale sections of the fiber correspond to an individual probe → a single fiber concatenates thousands of sensors



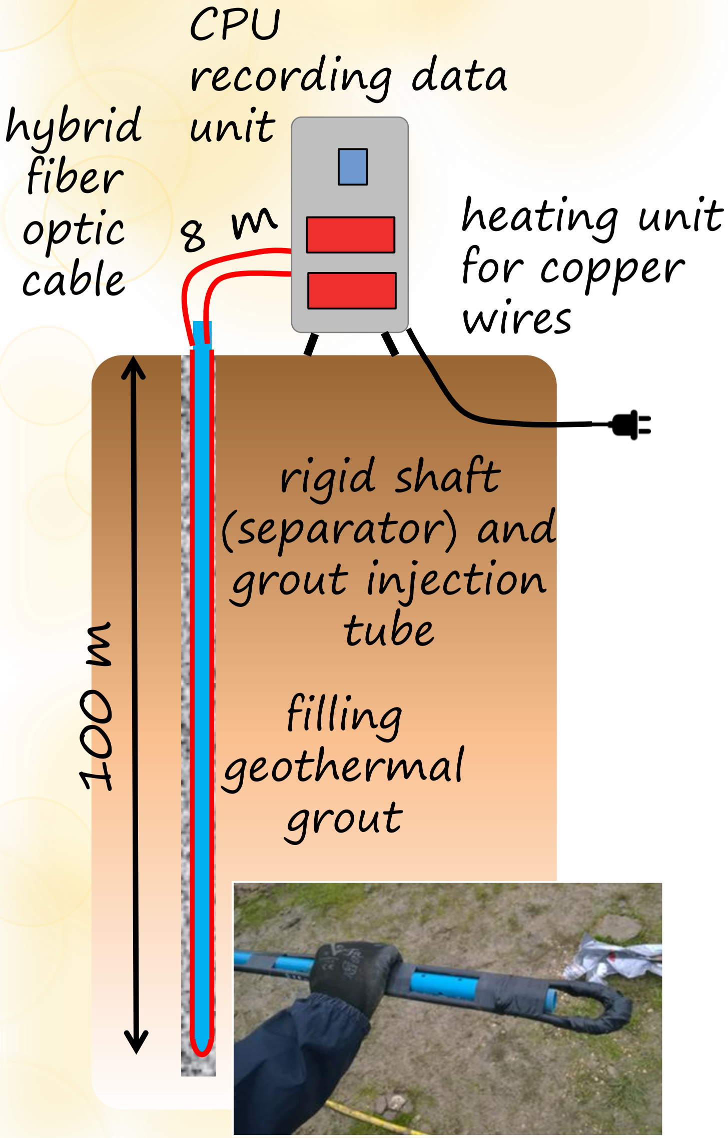
During the propagation a faint echo is generated → by **analyzing the echo, it is possible to map the local properties of the environment where the fiber is deployed**



RAMAN (anti-stokes): the intensity is temperature-dependent

1. UNDERGROUND THERMAL PERFORMANCES

d) DISTRIBUTED THERMAL RESPONSE TEST

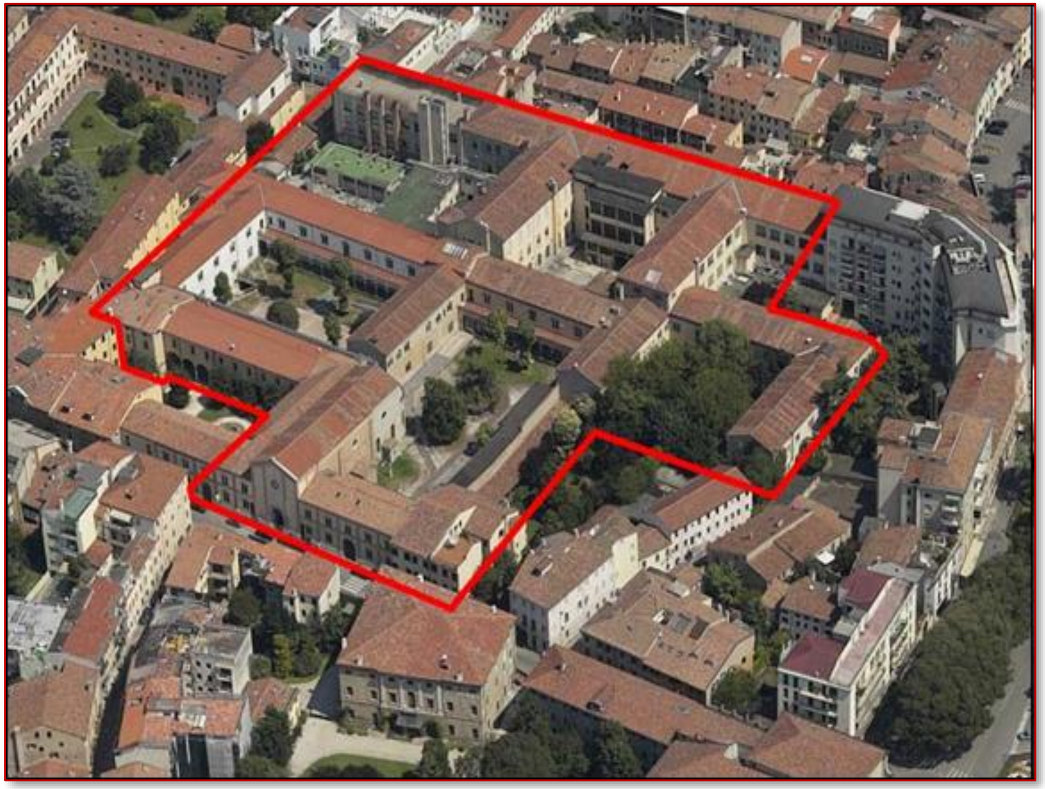


Specifications (AP Sensing):

- Sampling interval: 0.5 m
- **Spatial resolution: 1 m**
- Repeatibility: ~ 0.2 °C (for acquisition time of a few minutes)

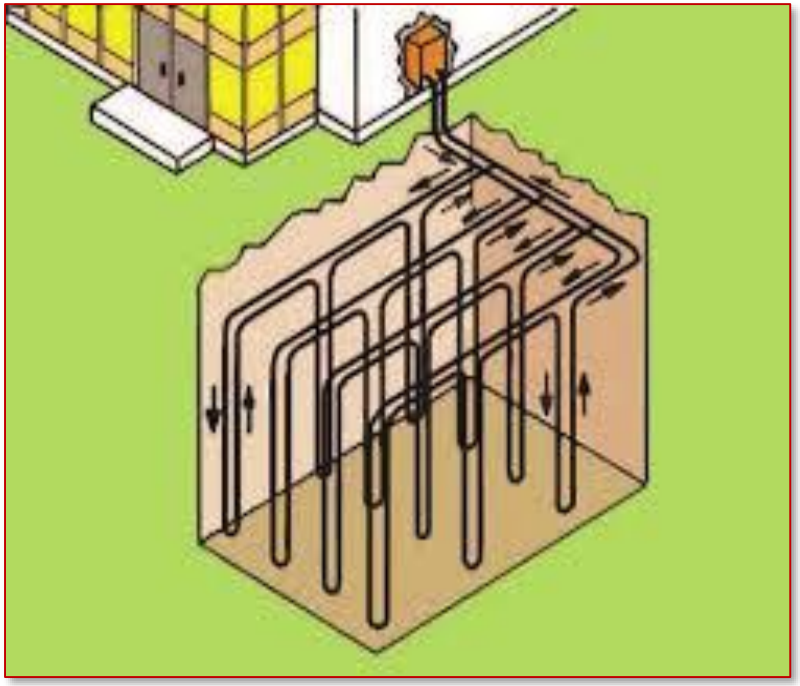
Ex-Geriatrico area geoexchange system

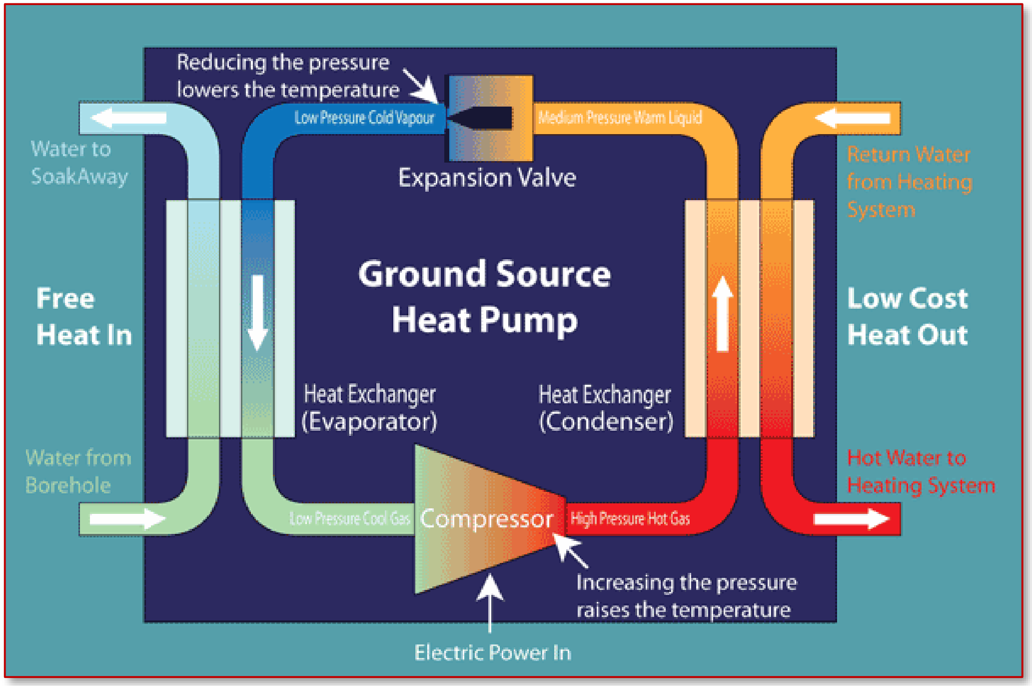
The new humanistic campus of the Padua University has been chose as pilot site where perform the ground thermal tests



Shallow geothermal system:

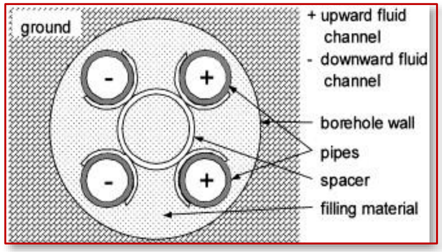
- Exploit the thermal energy of the Earth
- Composed by a heat pump and ground heat exchangers

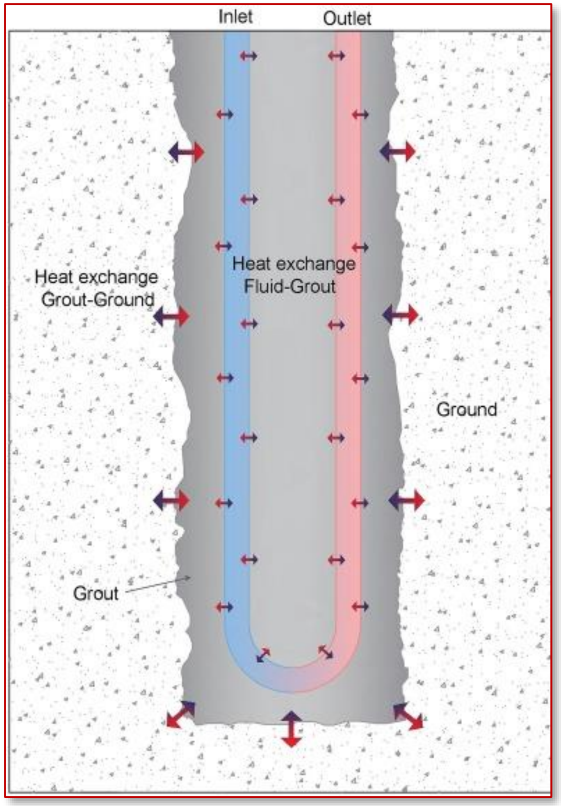


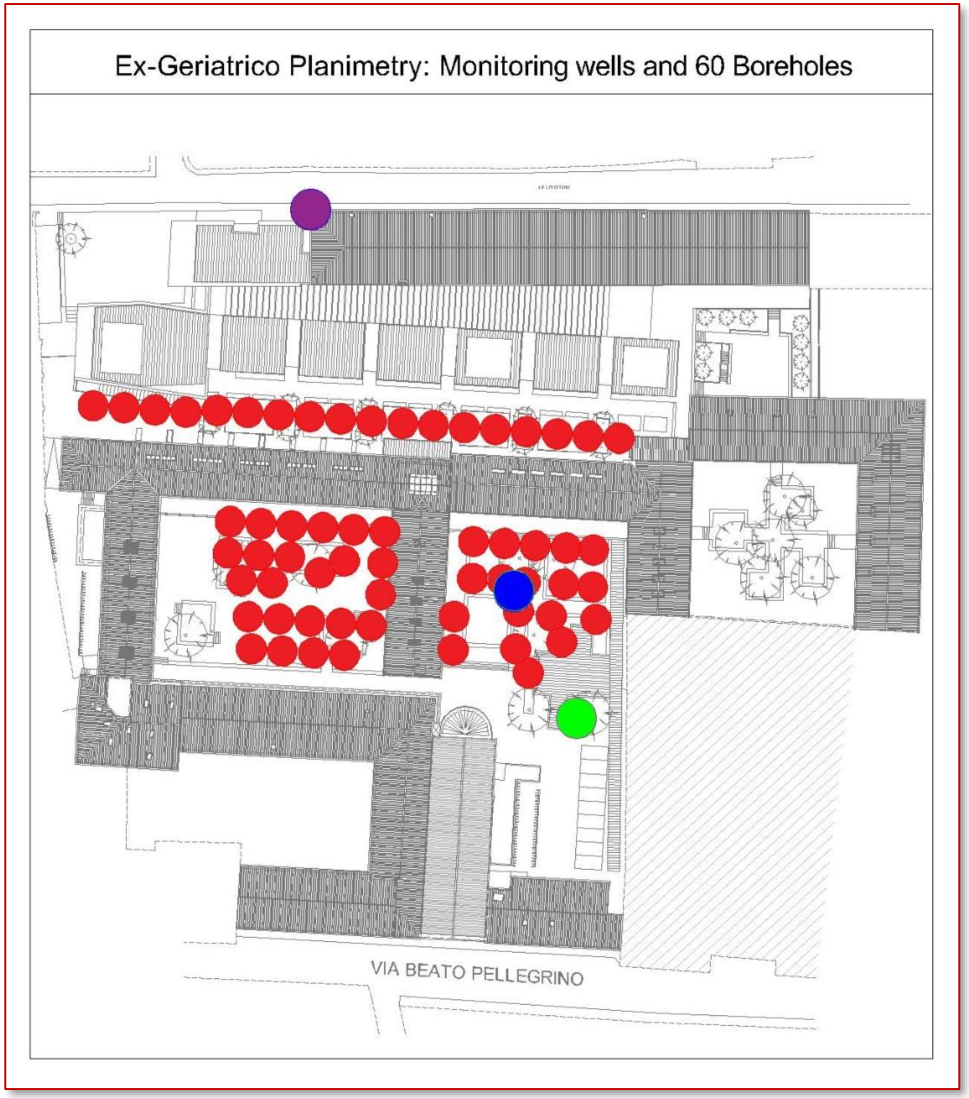


Ex-Geriatrico geothermal system plant includes:

- 2 multisource ground heat pumps
- 60 borehole heat exchangers
- double-U borehole heat exchangers
- 3 monitoring wells







Ground Thermal Response Test

Aims of the study:

- Detect the equivalent thermal conductivity λ_{eff} of the ground
- Compare different thermal response tests methods and devices (TRTs)

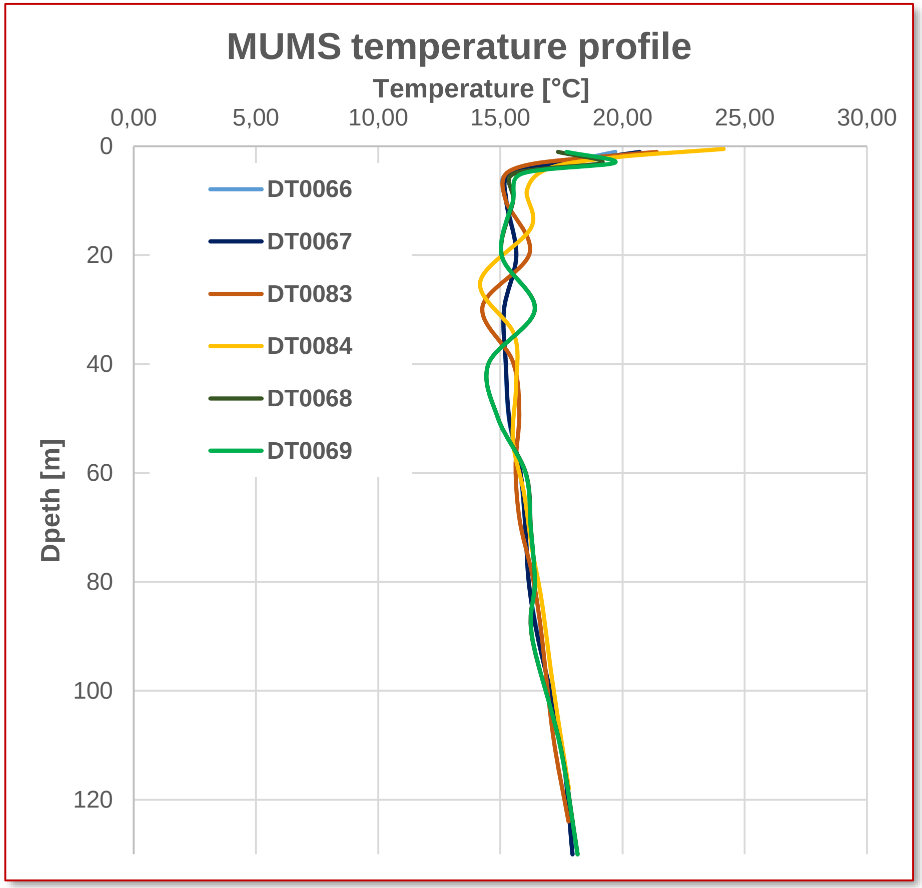
Traditional TRT

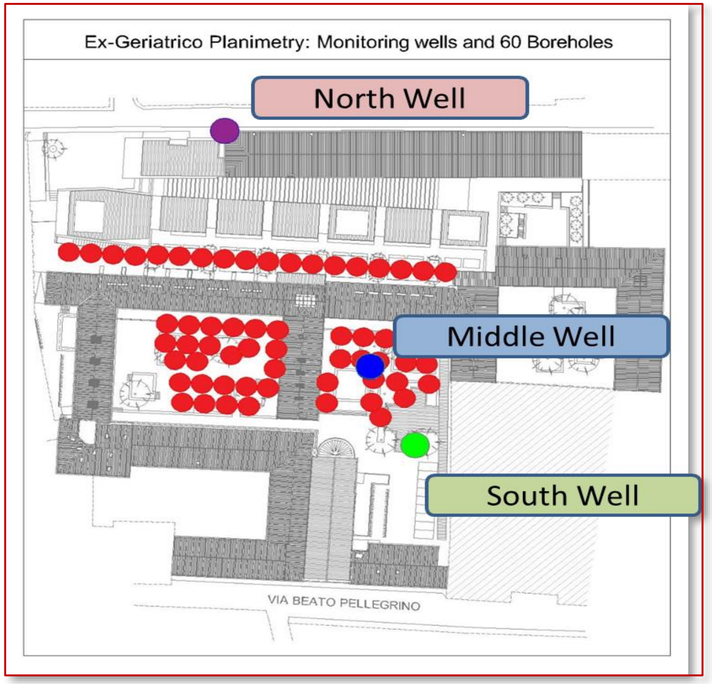
Distributed TRT

Enhanced TRT

Modular underground monitoring systems MUMS:

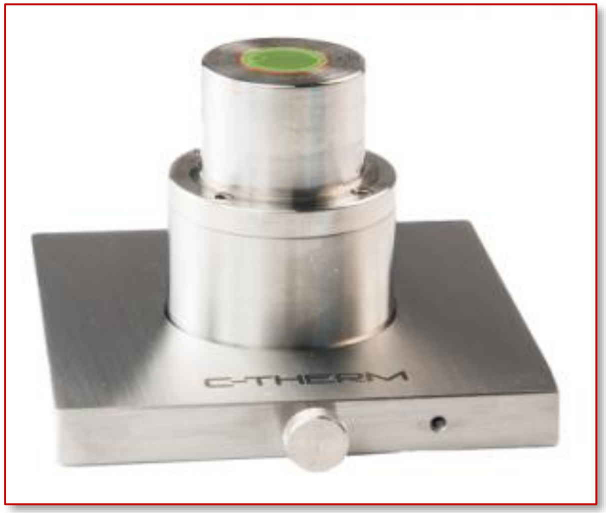
- Continuous detection of ground temperature
- 2 chains each well
- 14 temperature sensors each chain

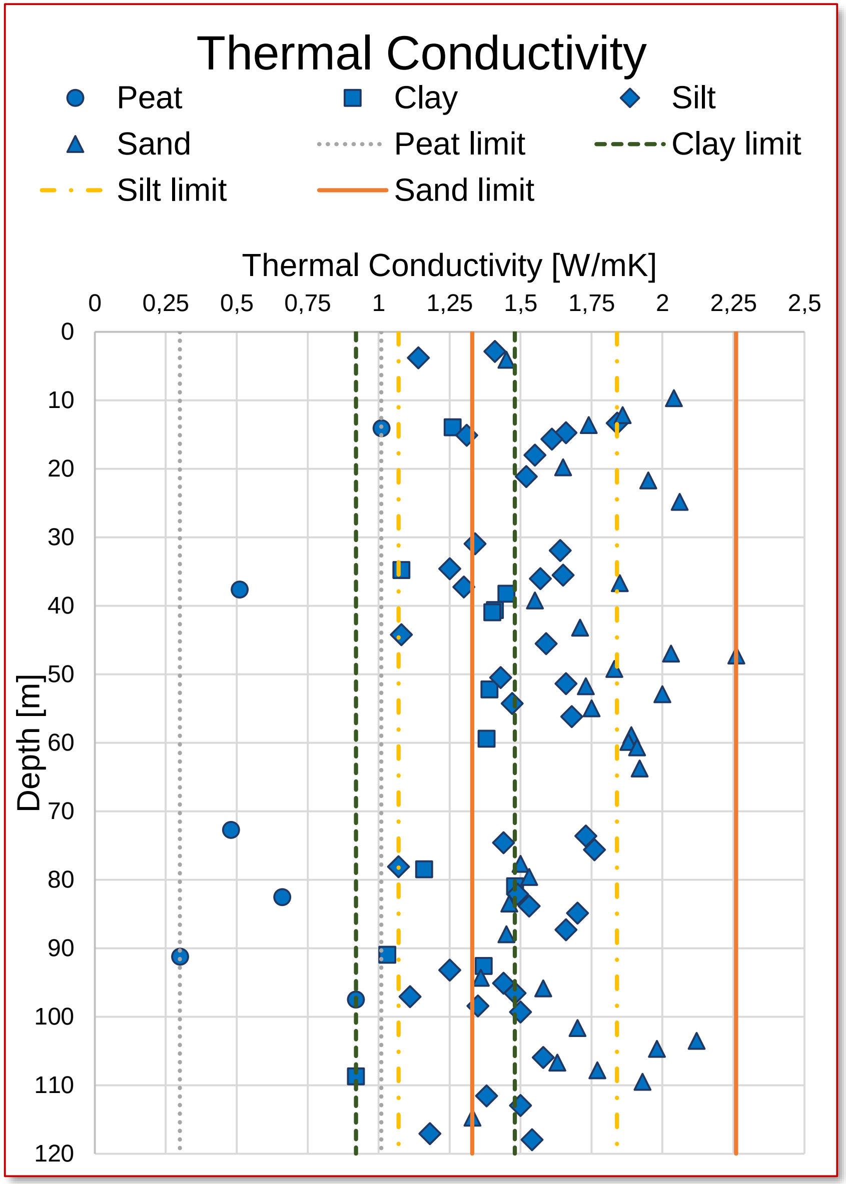




South well	*Middle well*	*North well*
DT0066	DT0083	DT0068
DT0067	DT0084	DT0069

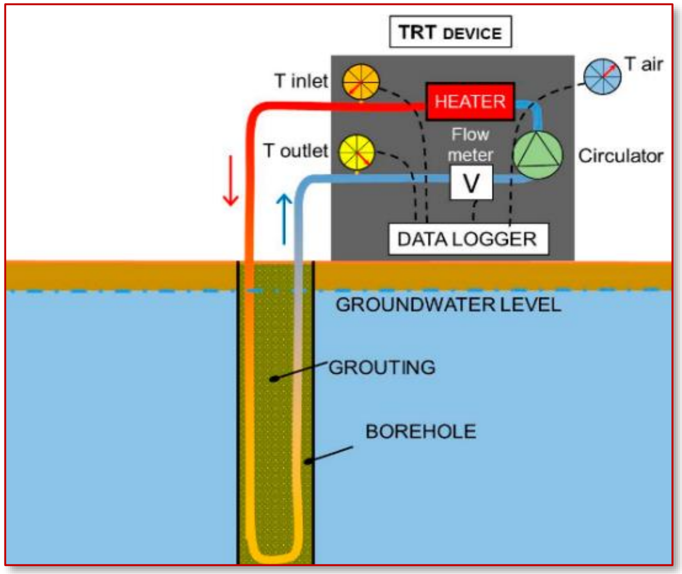
Modified Transient Plane Source MTPS:





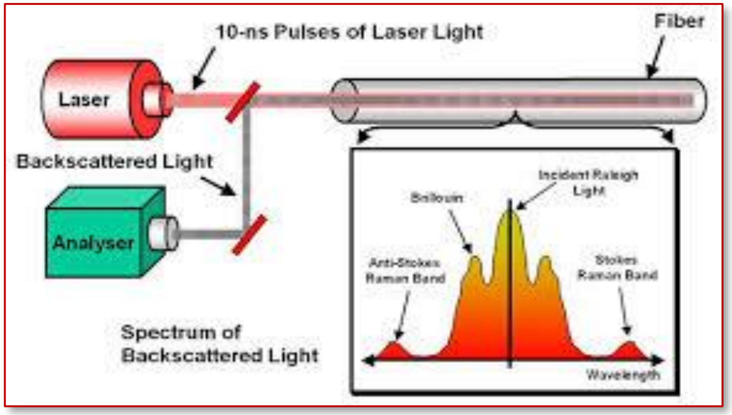
Traditional TRT

- Agiva International device
- Continuous temperature measurements over time
- Direct temperature measurements
- Averaged temperature value over depth



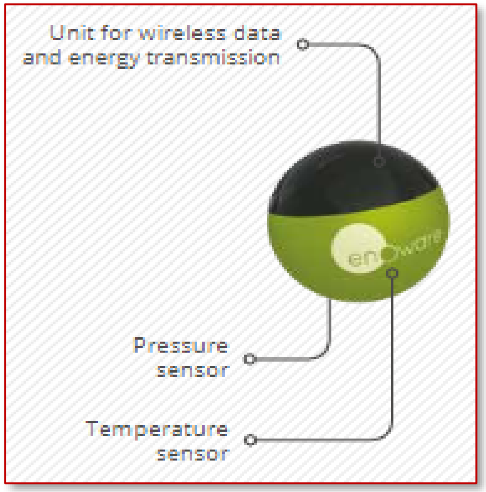
Distributed TRT

- AP Sensing device
- Continuous temperature measurements over time along depth
- Temperature value every 50 cm
- Indirect temperature and depth measurements
- Based on Raman scattering effect



Enhanced TRT

- enOware device
- Discrete temperature measurements over time
- Direct temperature measurements
- Indirect depth measurements
- Temperature value every 10 cm



Infinite Line Source (ILS) theory

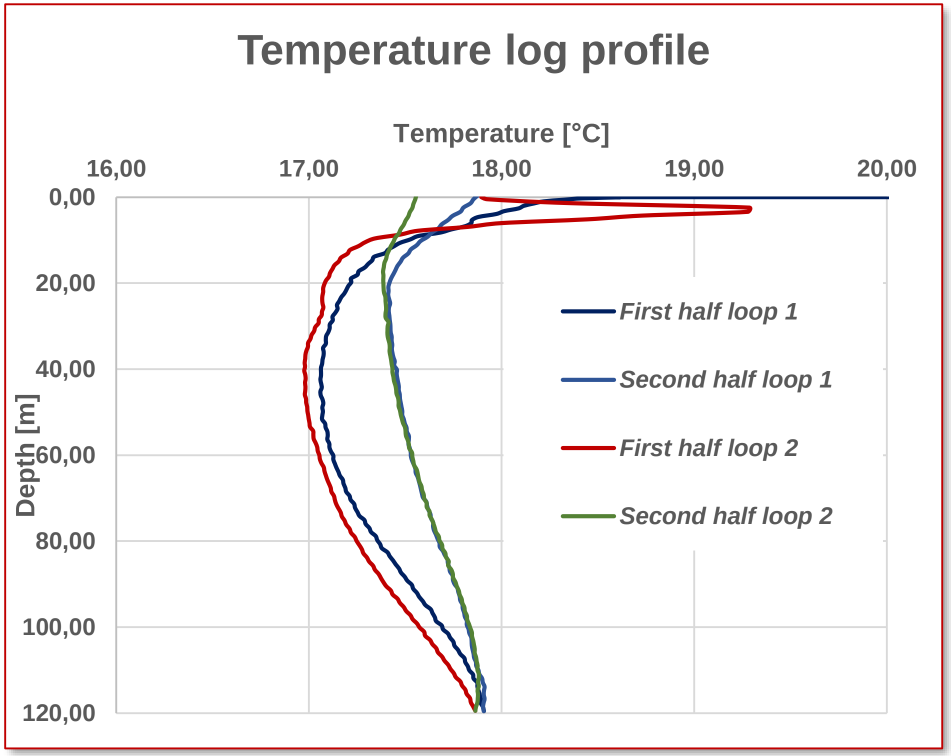
$$T_f(t) - T_g = \frac{q}{4\pi\lambda}\ln(t) + q\left[R_b^* + \frac{1}{4\pi\lambda}ln\left(\frac{4\alpha}{r_b^2}\right) - \gamma\right]$$

$$T_f(t) = k * \ln(t) + \mathrm{p}$$

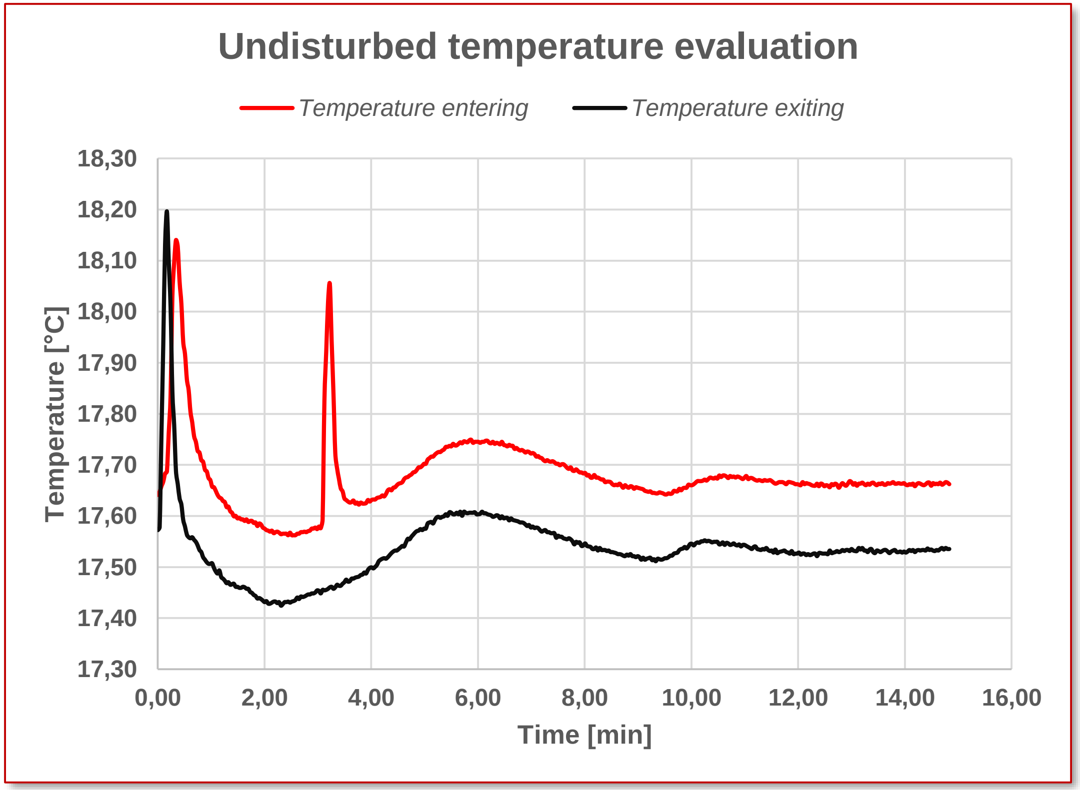
Thermal conductivity $\boldsymbol{\lambda = \frac{q}{4\pi k}}$

$$t_{ss} > \frac{5r_b^2}{\alpha}$$

TRT RESULTS



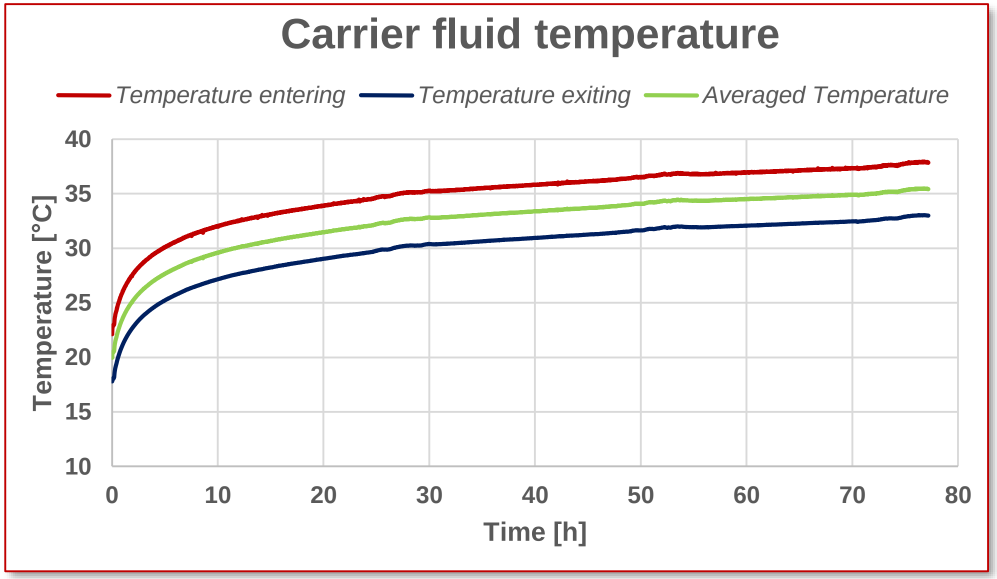
Approches 1	Temperature (°C)
Loop 1	17,56
Loop 2	17,46

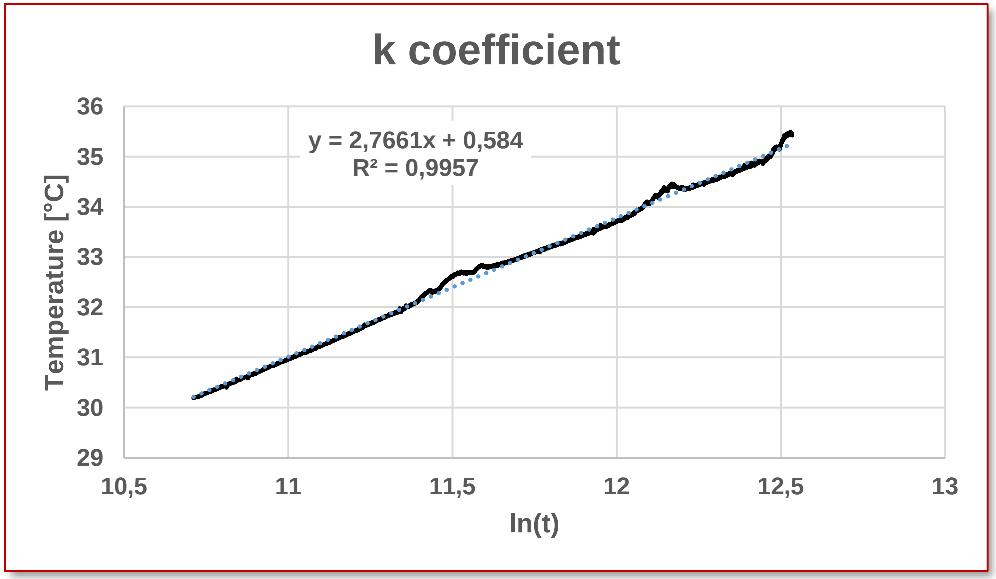


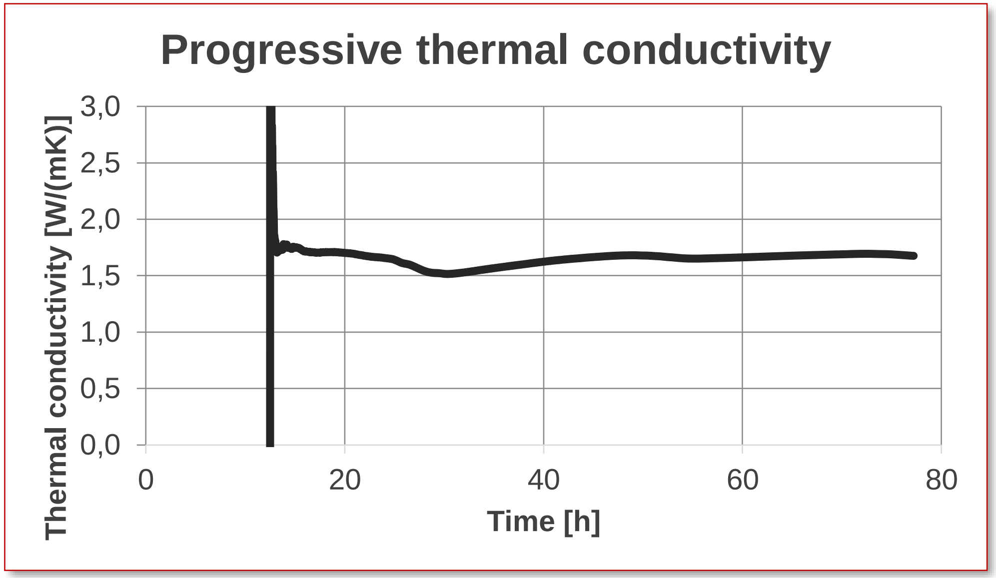
Approches 2	Temperature (°C)
Single loop	17,61

TRT RESULTS

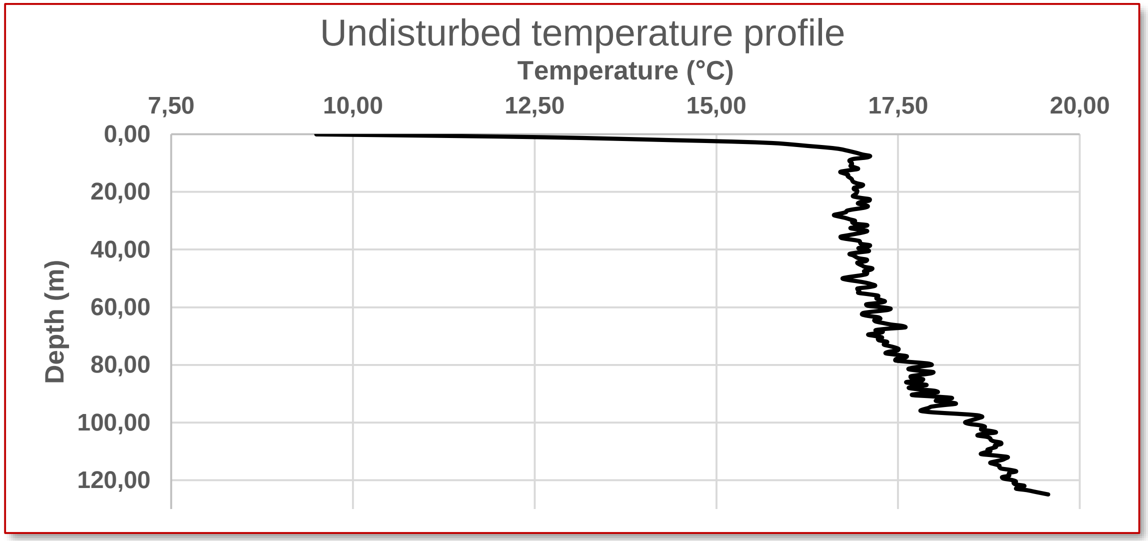
L investigated	120	m
q	58,0	W/m
r_b	0,076	m
Testing time	77,2	h
Steady state time	12,5	h
# time point considered	3880	n°
λ	1,68	W/mK



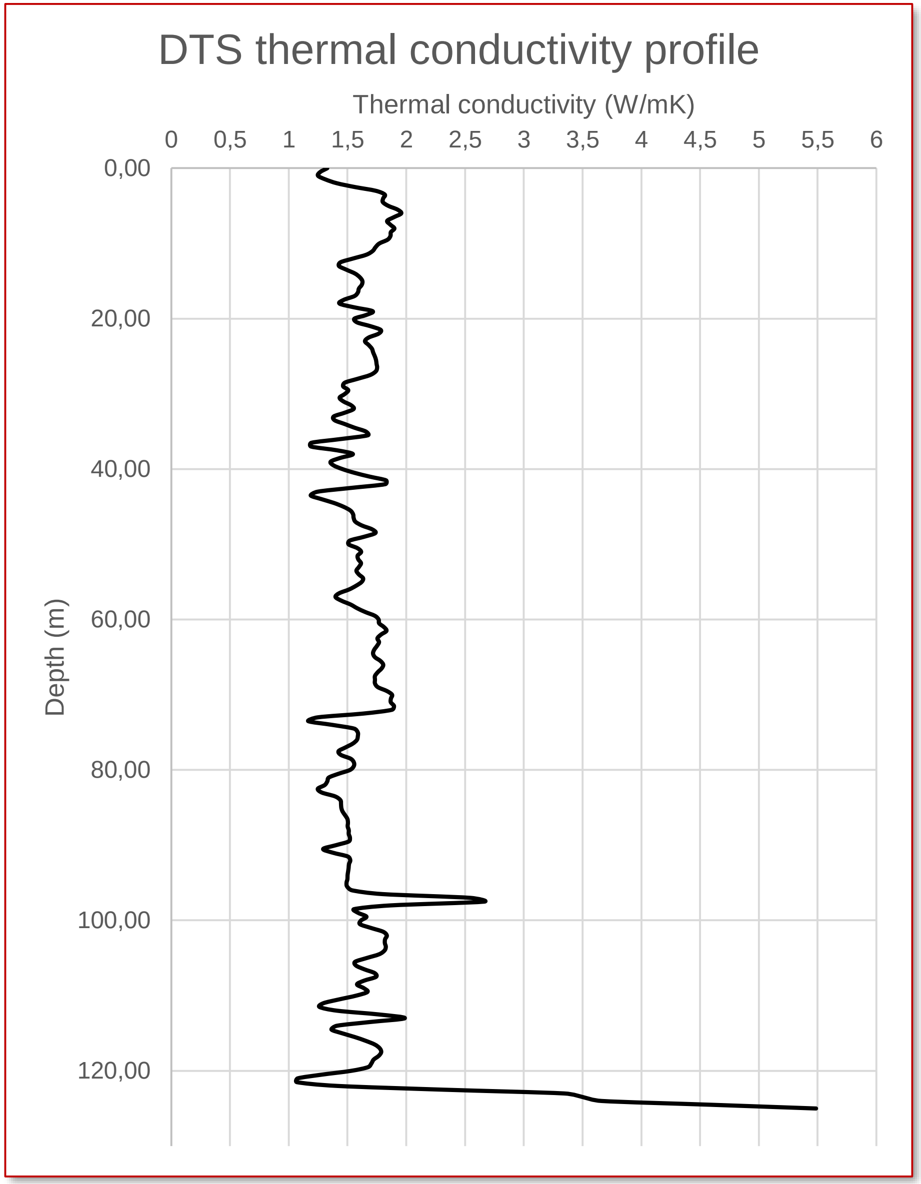




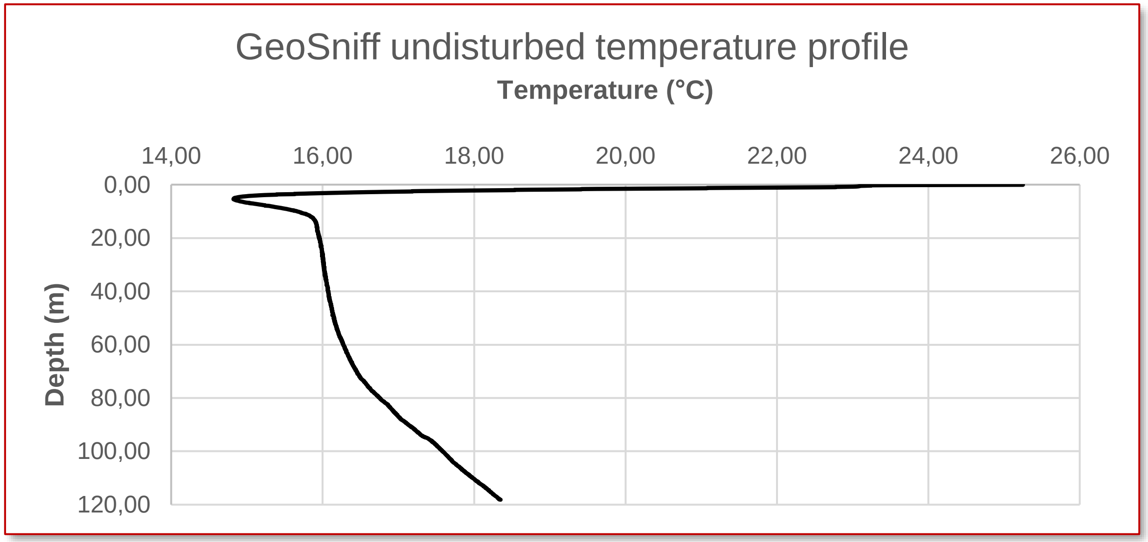
DTRT RESULTS



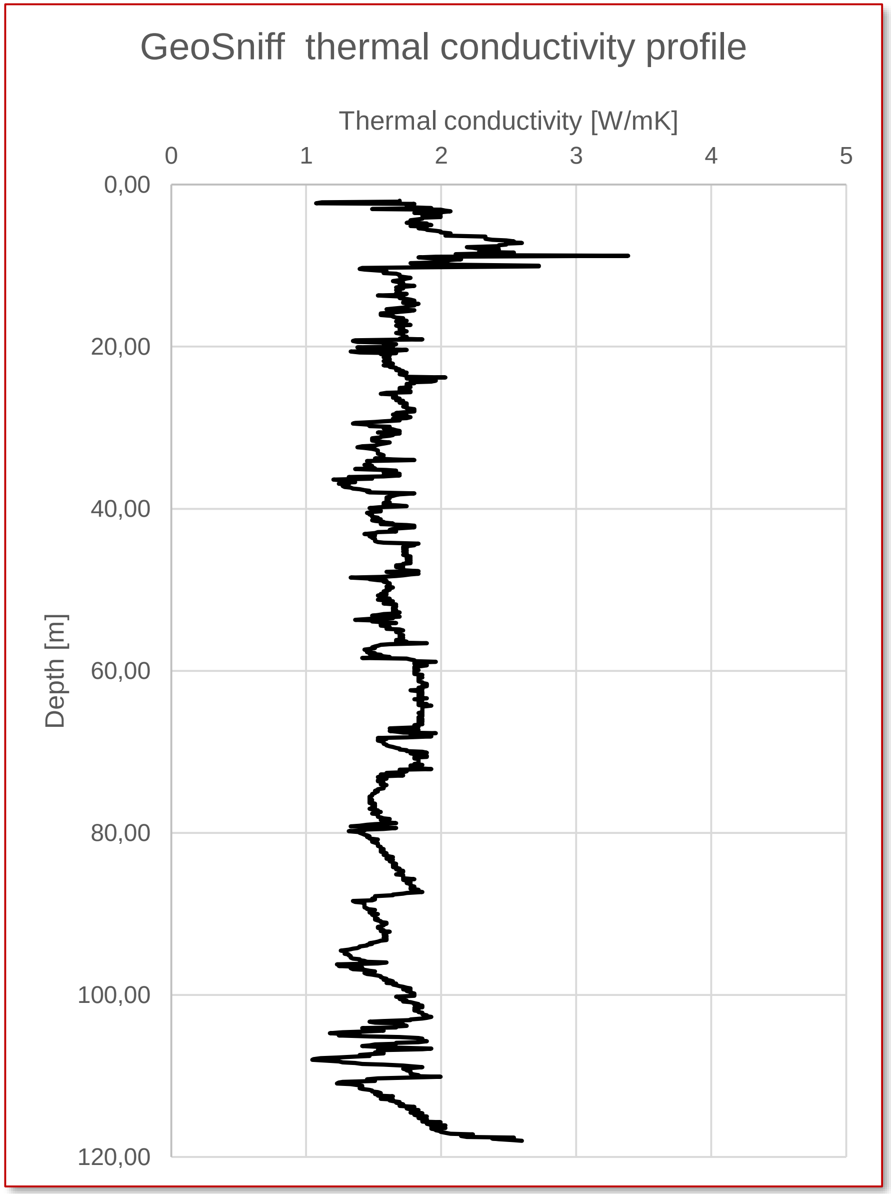
T undisturbed	17,46	°C
L investigated	125	m
q	22,4	W/m
r_b	0,0515	m
Testing time	73,7	h
Steady state time	5,5	h
# time point considered	2047	n°
λ	1,60	W/mK



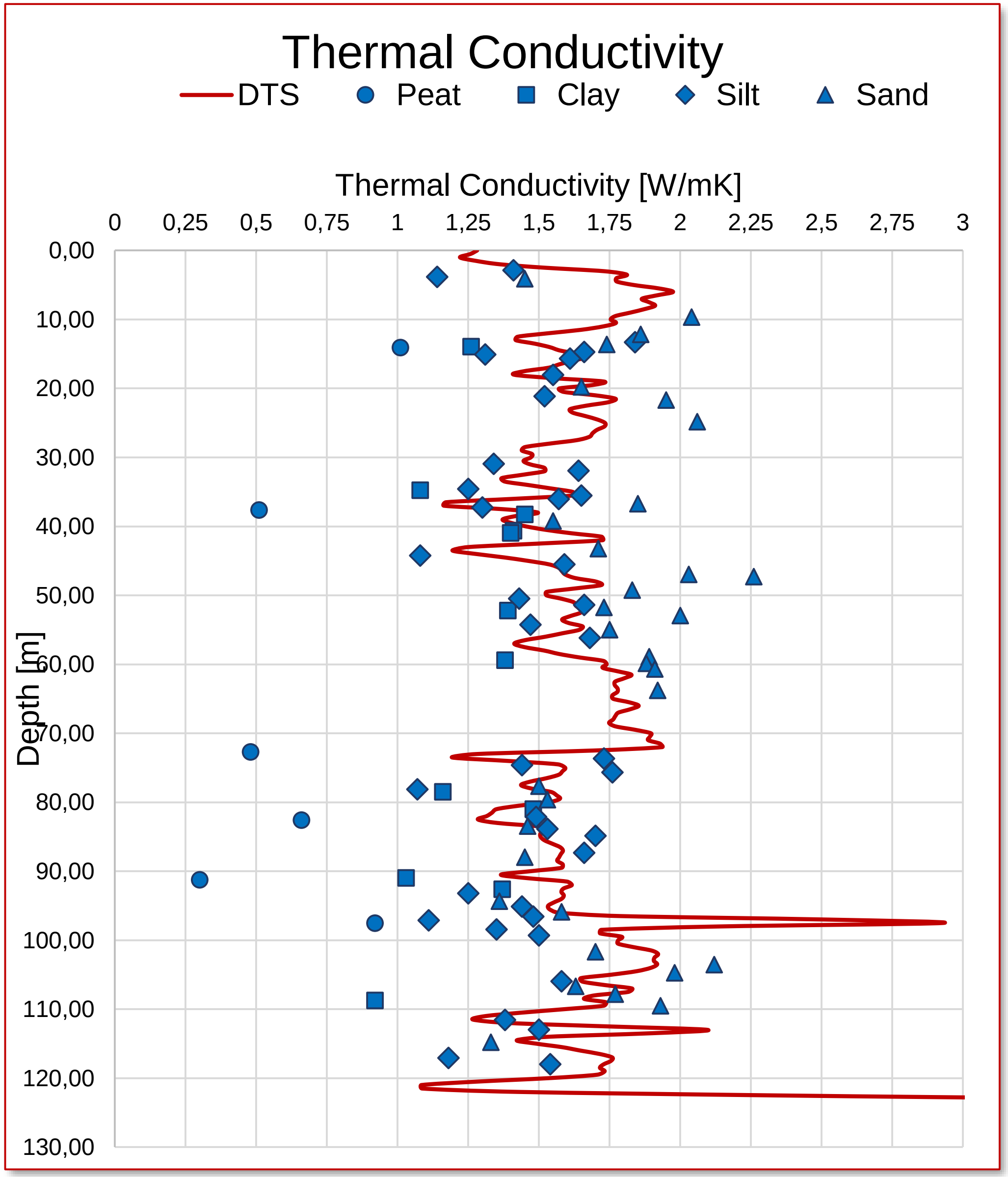
ETRT RESULTS

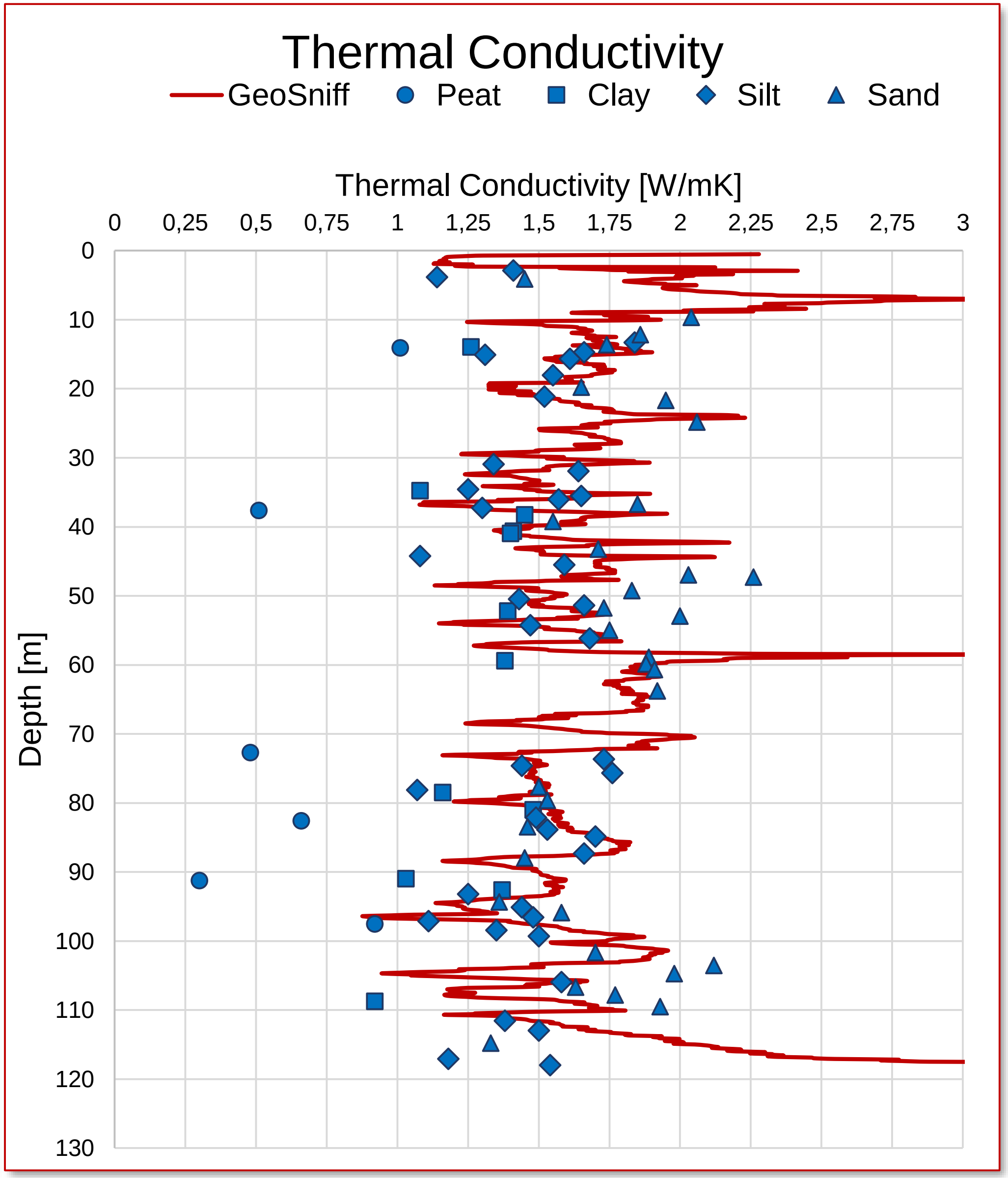


T undisturbed	16,66	°C
L investigated	118	m
q	17,8	W/m
$\mathbf{r_b}$	0,076	m
Testing time	72,6	h
Steady state time	11,4	h
# time point considered	2	n°
λ	1,68	W/mK



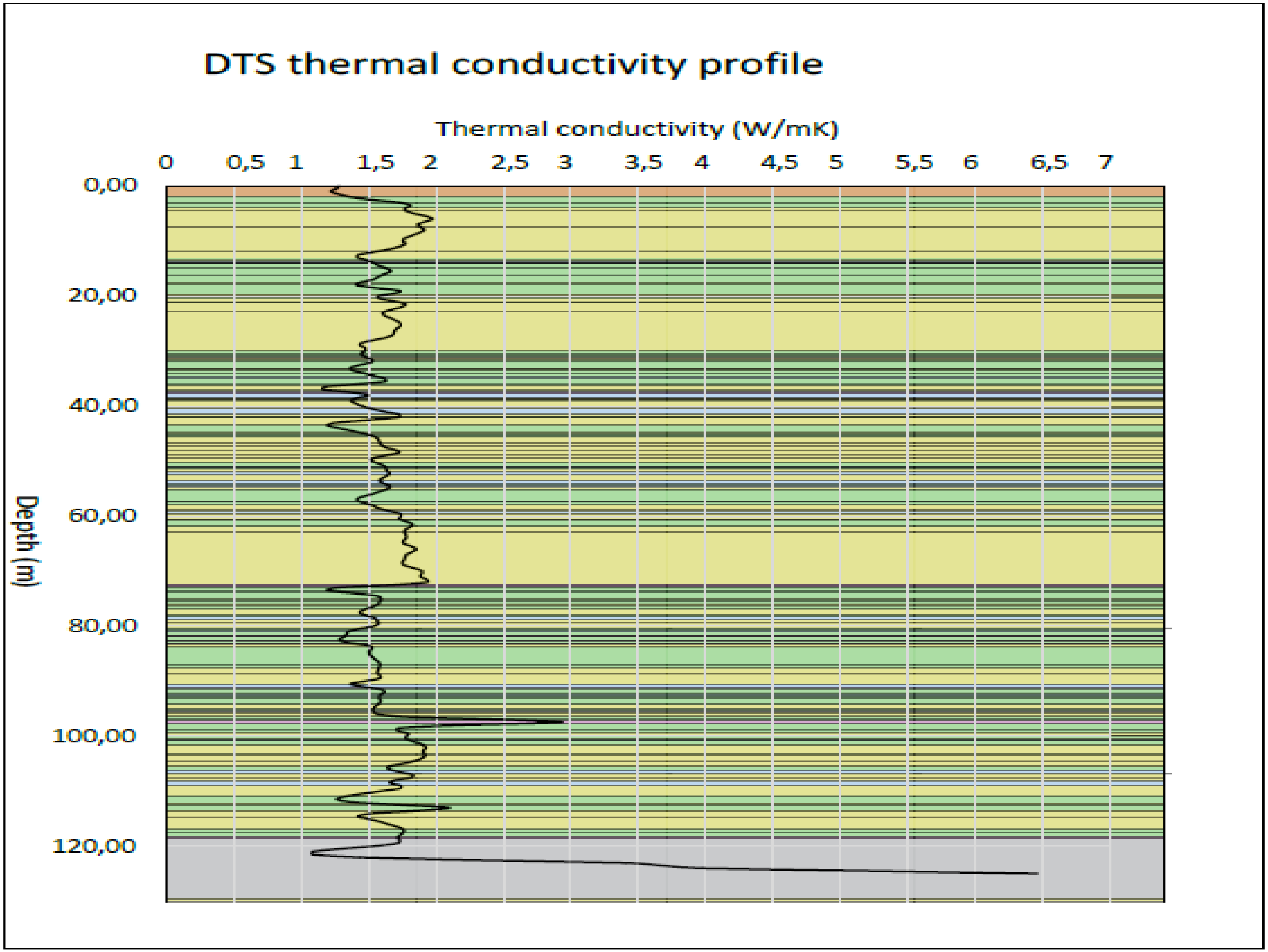
LABORATORY-IN SITU TESTS COMPARISON





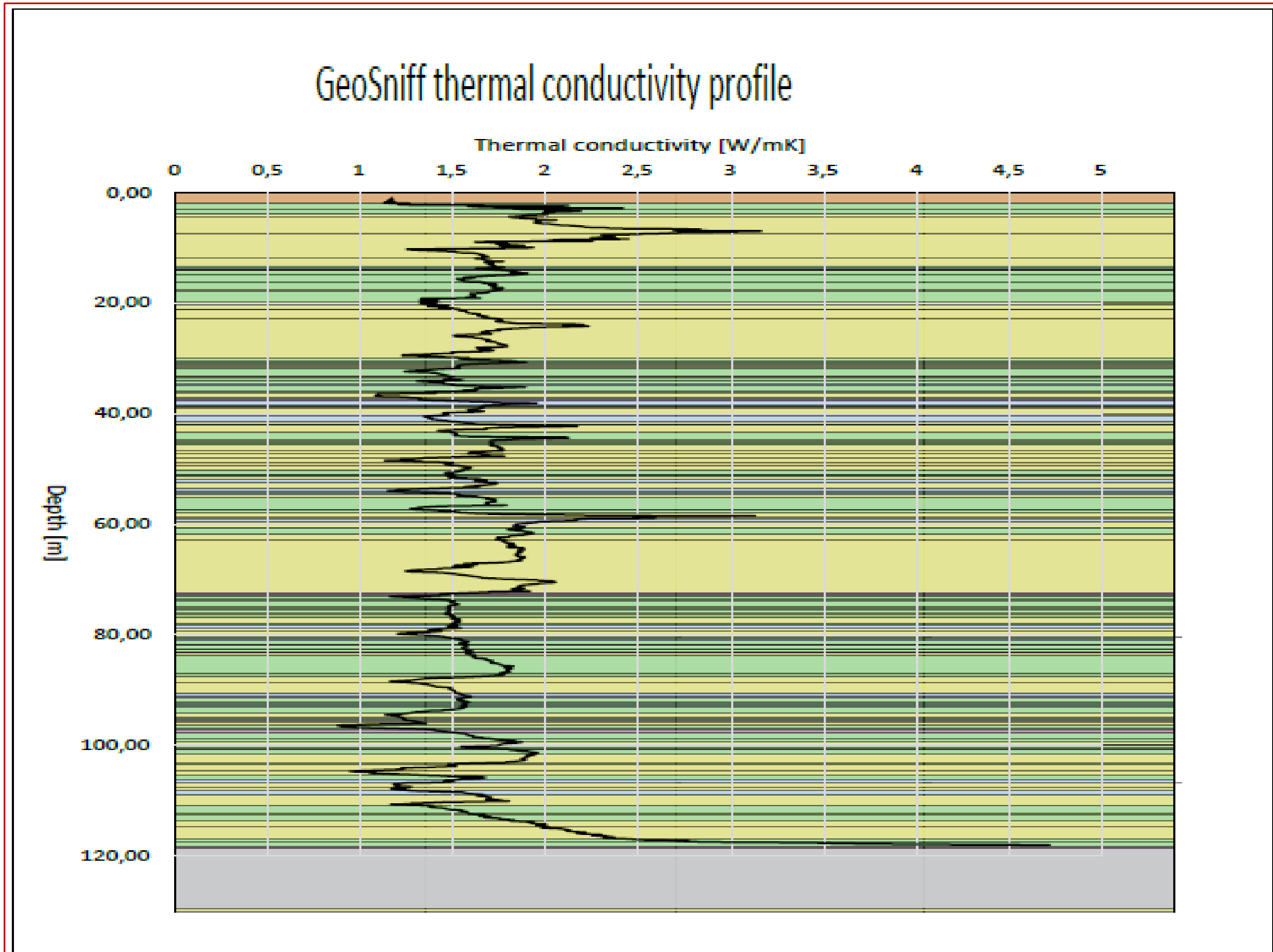
STRATIGRAPHY COMPARISON

Overlapping of DTS thermal conductivity profile on the stratigraphy

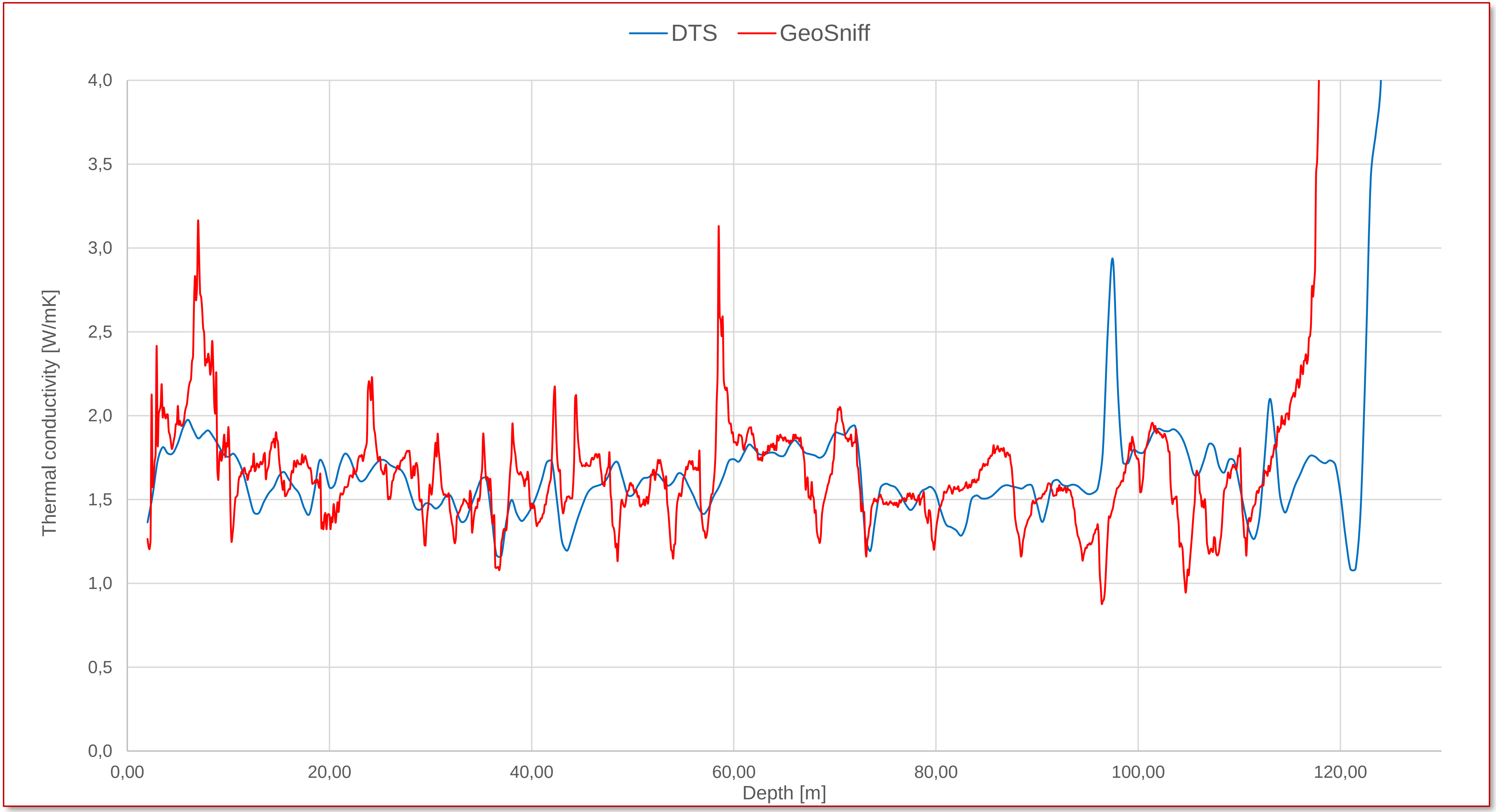


STRATIGRAPHY COMPARISON

Overlapping of GeoSniff® thermal conductivity profile on the stratigraphy



Comparison of DTS and GeoSniff® thermal conductivity profile



CONCLUSION

	Time from heating start	λ	depth	Time sample	Spatial sample	# time point considered	# depth point considered	q	Test duration
	[h]	*[W/mK]*	*[m]*	*[s]*	*[m]*	*[n°]*	*[n°]*	*[W/m]*	*[h]*
Laboratory	/	1,56	130	/	/	/	/	/	/
TRT	12,5	1,68	120	2	/	3880	/	58,0	77,2
DTS	5,5	1,60	125	120	0,5	2047	250	22,4	73,7
DTS	17,2	1,57	125	120	0,5	1696	250	22,4	73,7
DTS	23,0	1,62	125	120	0,5	1522	250	22,4	73,7
DTS	33,0	1,82	125	120	0,5	1222	250	22,4	73,7
GeoSniff®	17,2	1,35	118	/	0,1	4	1180	17,8	72,6
GeoSniff®	23,0	1,66	118	/	0,1	3	1180	17,8	72,6
GeoSniff®	33,0	1,68	118	/	0,1	2	1180	17,8	72,6

CONCLUSION

TRT	*Suitable for homogeneous soil*
	High linear thermal power supplied
DTRT	*High number of measurement series*
	Usable also in cemented monitoring wells
ETRT	*Simple distributed thermal test method*
	Thin layer deep investigation

Suggestion for further studies:

- Carry out the tests in the same period of the year
- Provide the same linear thermal power
- Use numerical models to takes into account groundwater flow