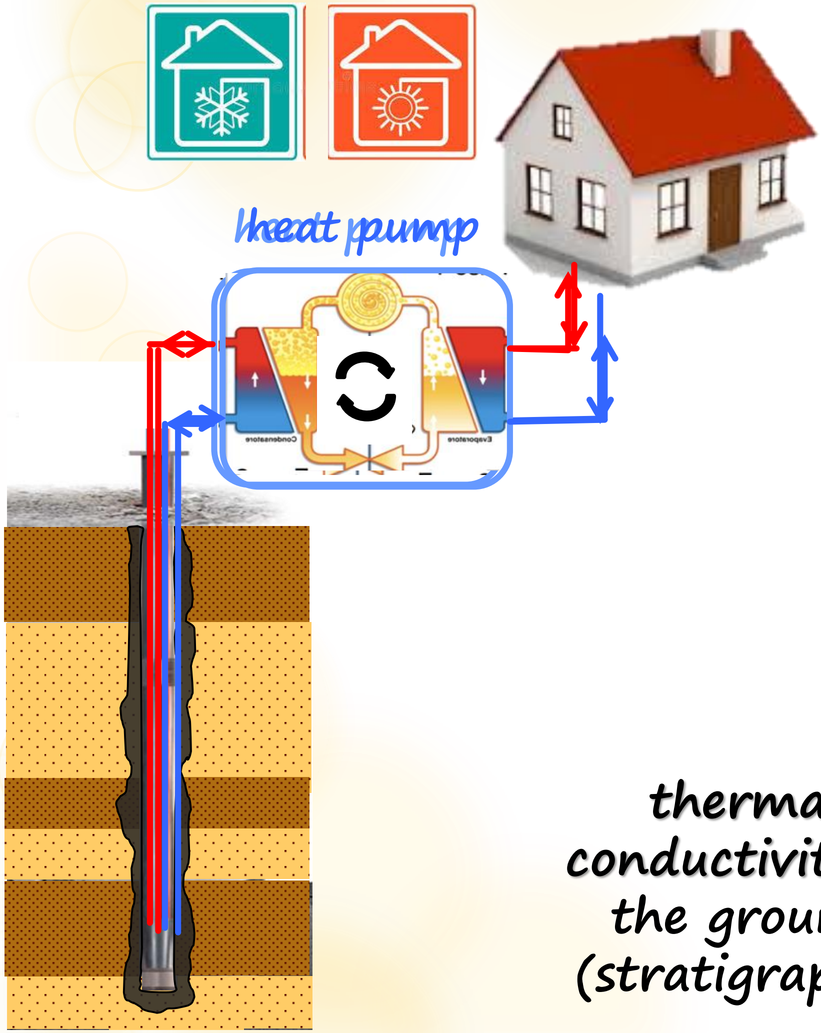
GROUND SOURCE HEAT PUMP SYSTEMS



building's function
and typology

climate conditions
(altitude and
latitude)

building's
thermal requests

thermal
exchange
capability
probe-ground

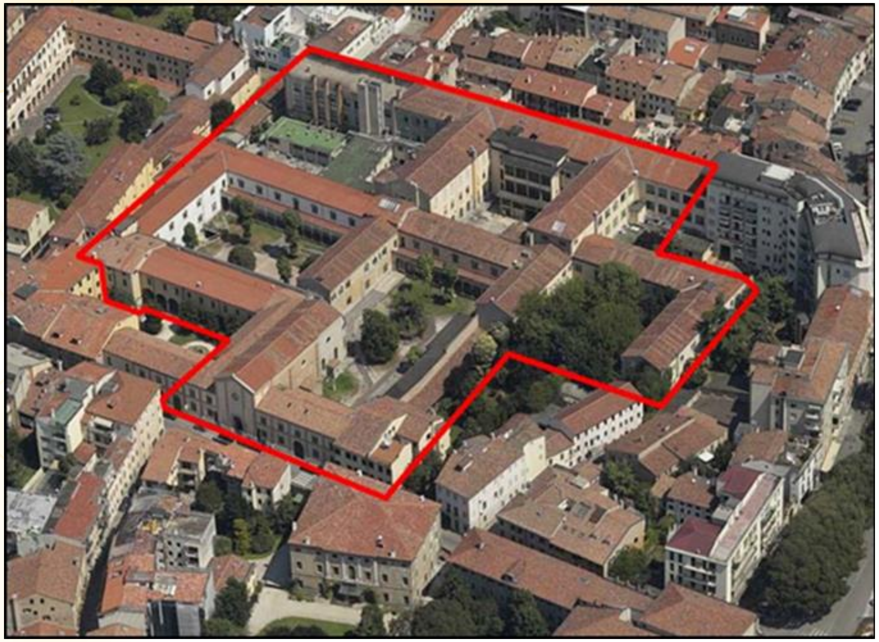
thermal
conductivity of
the ground
(stratigraphy)

presence and
velocity
of aquifers

materials and
technologies used
for construction

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

GROUND SOURCE HEAT PUMP SYSTEMS



4 courts: 60 X 30m; 40 x 30m, 30 x 30m and 20 x 100m

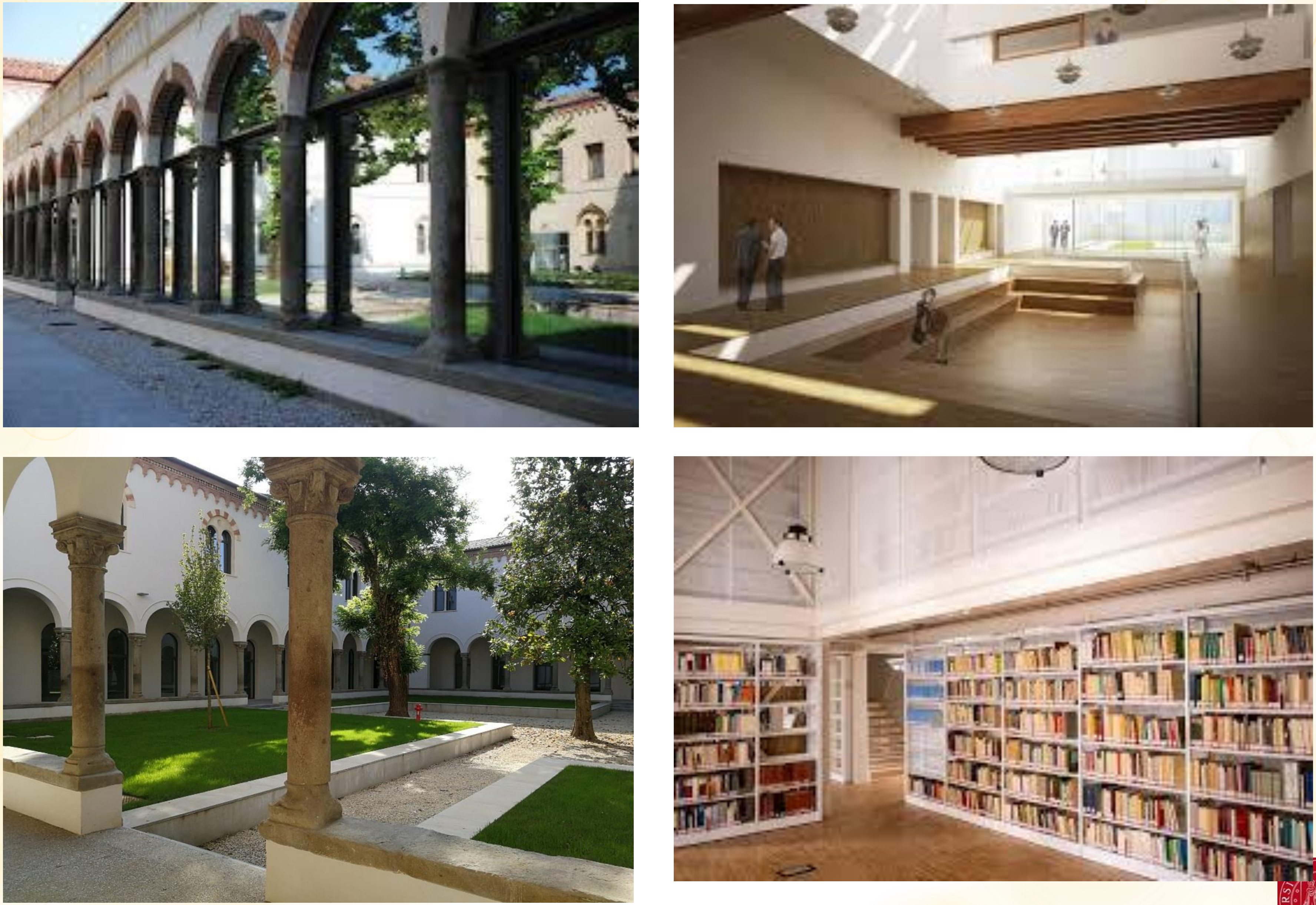
60 vertical boreholes 120 deep
2 double-U probes,
Outsider Ø103mm
4 tubes Ø32mm (thic.2.9) PE-Xa
PN 15

perforation Ø152mm down to 121 m
destry core method - drilling fluid only water

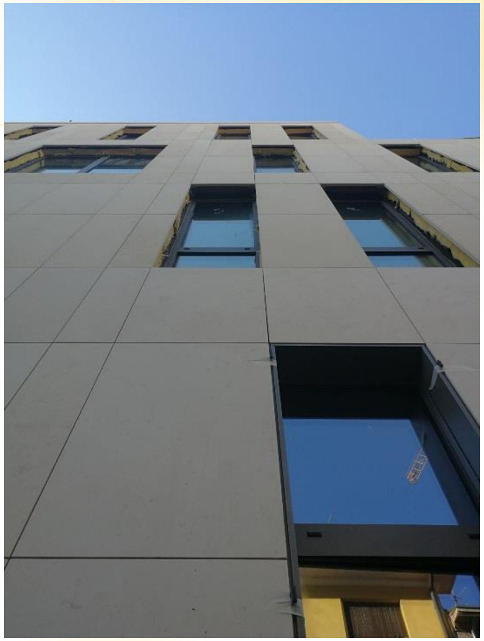
Total Length of horizontal connections 3280m

2 reversible water/water geothermal heat pump:
- ✓ refrigerant: r410a
- ✓ heating capacity 177 kwt each, COP = 4.1
- ✓ cooling capacity 168 kWt each, EER= 4.7

GROUND SOURCE HEAT PUMP SYSTEMS



GROUND SOURCE HEAT PUMP SYSTEMS



1. Good thermal insulation of the envelope (windows and facàdes)
2. Radiant cooling and heating terminals
3. Heating/cooling system:
   - ✓ heat pumps
   - ✓ main distribution ring and substations
   - ✓ plate heat exchangers
   - ✓ expansion vessels
   - ✓ circulation pumps and valves

GROUND SOURCE HEAT PUMP SYSTEMS

A heat pump is a device that takes heat from one place and transfers that heat to another destination. In that respect, it works much like a refrigerator. Both heat pumps and refrigerators are considered to be “heat engines”—they operate to move heat from a cooler area (the heat source) to a warmer area (the heat “sink”). This transfer of energy from a cooler place to a warmer place runs counter to the second Law of Thermodynamics, which basically says that heat ALWAYS flows from a warmer location to a cooler location—spontaneous heat flow from warmer to cooler. So, in order to run the system “backwards”, both heat pumps and refrigerators must do work (in the physics sense) and expend energy. If they are running efficiently, they will extract more energy than they expend.

The Carnot cycle

The Carnot cycle provides an absolute upper limit on the efficiency of any thermodynamic cycle. If a cycle proceeds clockwise around the Carnot cycle shown below, it is acting as a heat engine that produces useful work, removing heat from a warmer source, doing useful work, and delivering waste heat to a cooler heat sink.

This is sometimes referred to as a *power cycle*.

If, on the other hand, the cycle operates with the addition of energy from an outside source, it will cycle counterclockwise around the cycle below.

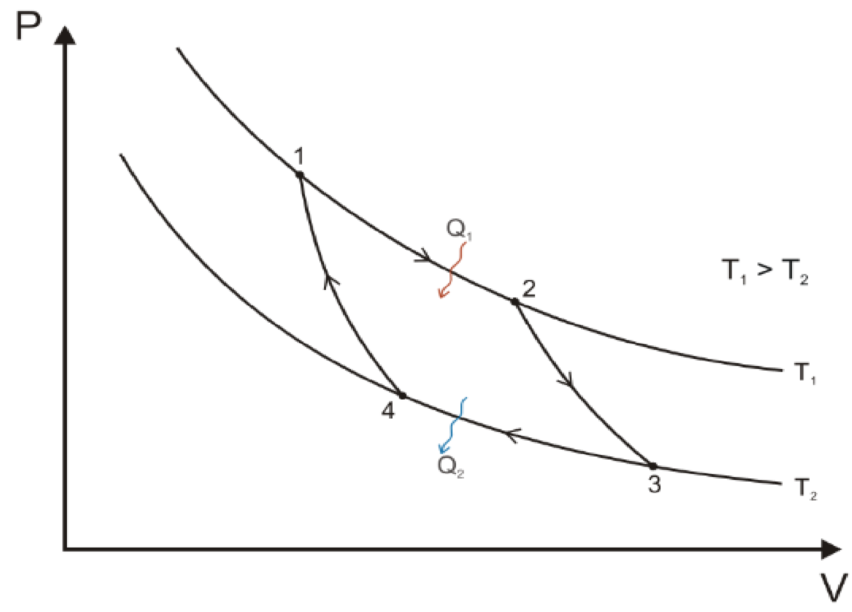
This reversed Carnot cycle is sometimes referred to as a *heat pump and refrigerator cycle*.

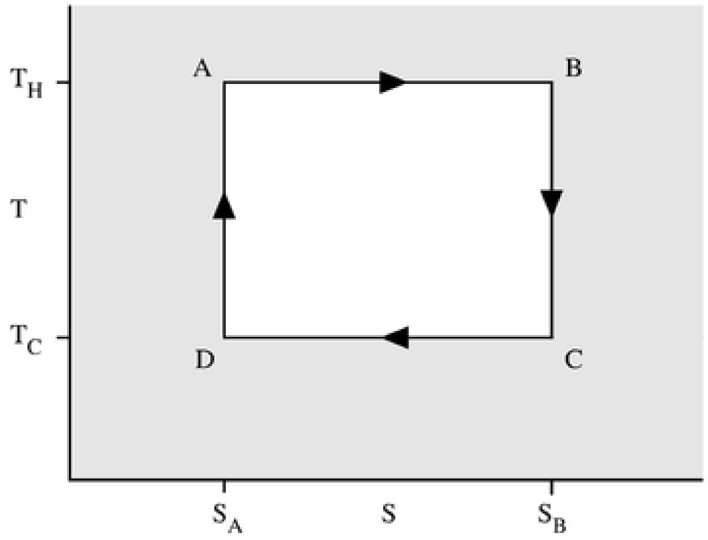
The heat pump represents one such reversed-Carnot cycle, where outside energy is used to do work on the system, allowing the system (the heat pump) to take heat from the lower temperature heat source and transfer it to the higher temperature heat sink.

The Carnot cycle when acting as a heat engine consists of the following steps:

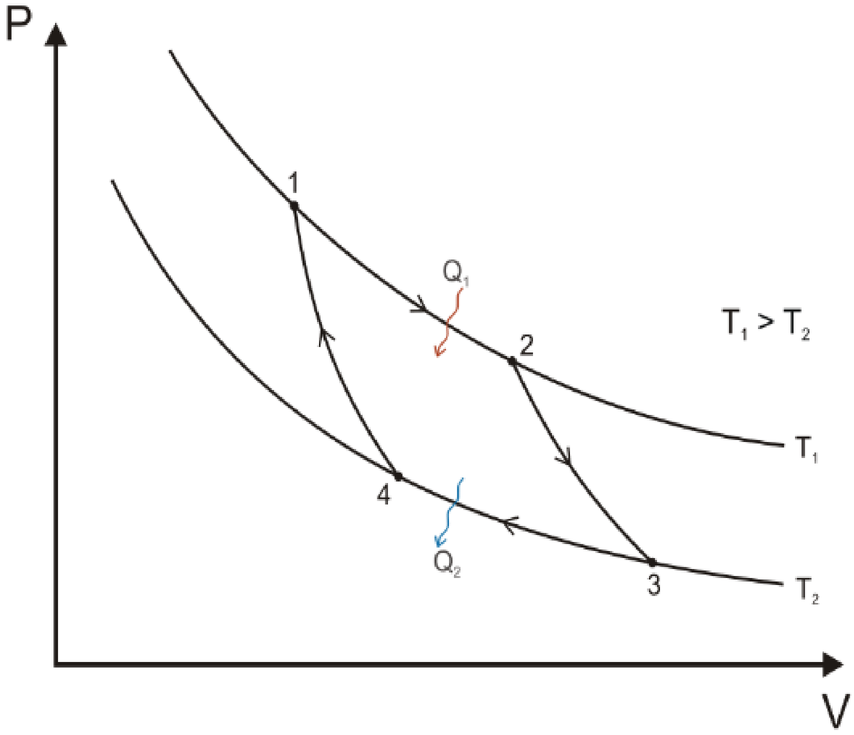
Reversible isothermal expansion of the gas at the "hot" temperature, T_1 (isothermal heat addition or absorption). During this step (1 to 2 on Figure 1, A to B in Figure 2)
the gas is allowed to expand and it does work on the surroundings. The temperature of the gas does not change during the process, and thus the expansion is isothermal. The gas expansion is propelled by absorption of heat energy Q_1 and of entropy from the high temperature reservoir.

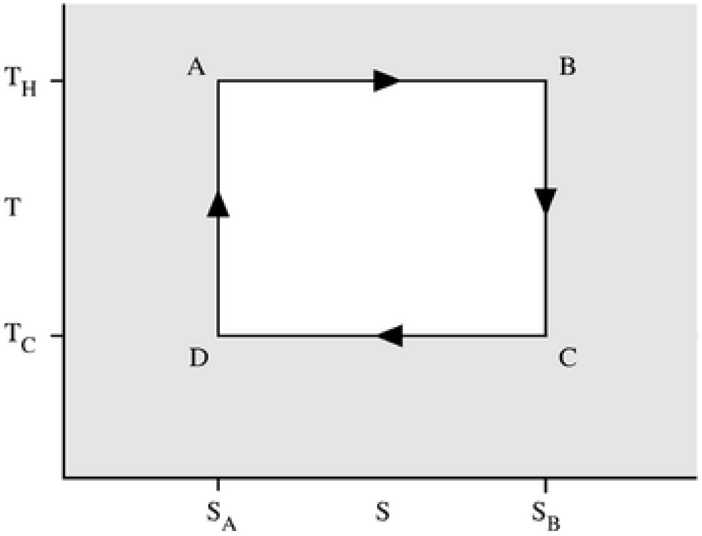
$$\Delta S = Q_1/T_1$$





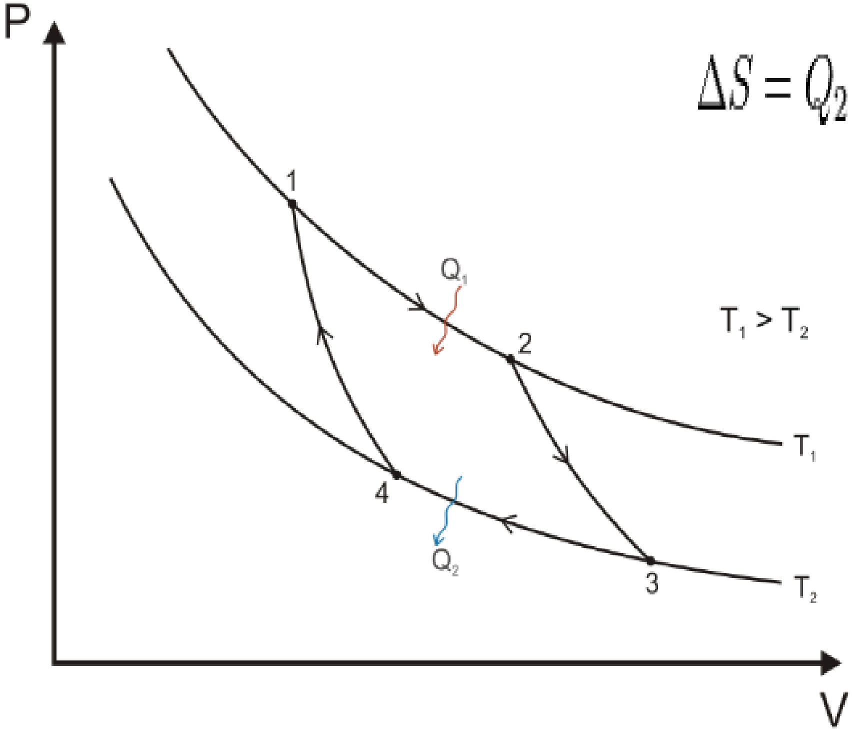
Isentropic (reversible adiabatic) **expansion of the gas (isentropic work output).** For this step (2 to 3 on Figure 1, B to C in Figure 2) the mechanisms of the engine are assumed to be thermally insulated, thus they neither gain nor lose heat. The gas continues to expand, doing work on the surroundings, and losing an equivalent amount of internal energy. The gas expansion causes it to cool to the "cold" temperature, T_2. The entropy remains unchanged.



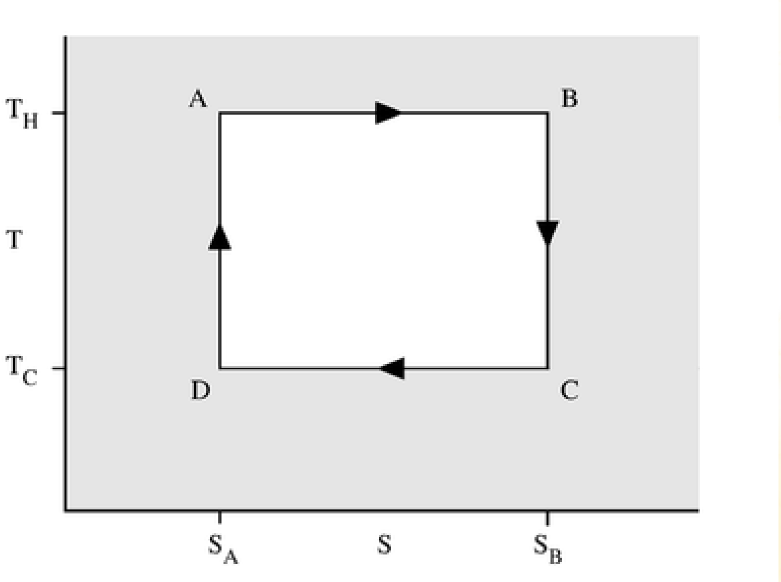


Reversible isothermal compression of the gas at the "cold" temperature, T_2. (isothermal heat rejection) (3 to 4 on Figure 1, C to D on Figure 2) Now the surroundings do work on the gas, causing an amount of heat energy Q_2 and of entropy to flow out of the gas to the low temperature reservoir. (This is the same amount of entropy absorbed in step 1, as can be seen from the Clausius inequality.)

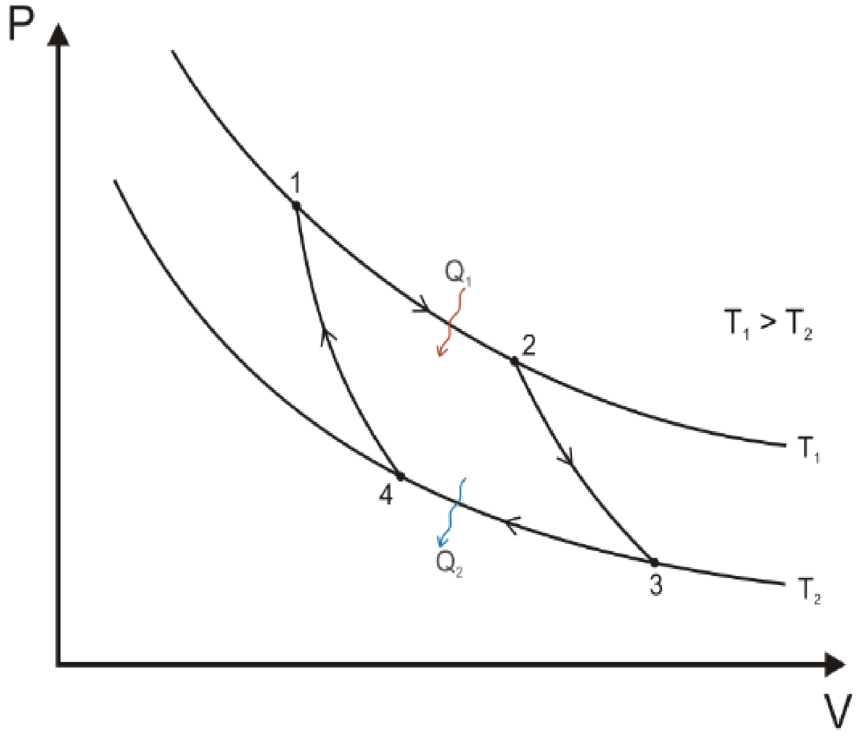
When one compresses a gas, one does work on the system containing the gas molecules. That means that energy is transferred from the surroundings to the system, which will increase the kinetic energy of the molecules, resulting in their faster motion. Temperature represents the average kinetic energy of the molecules, so temperature will rise.

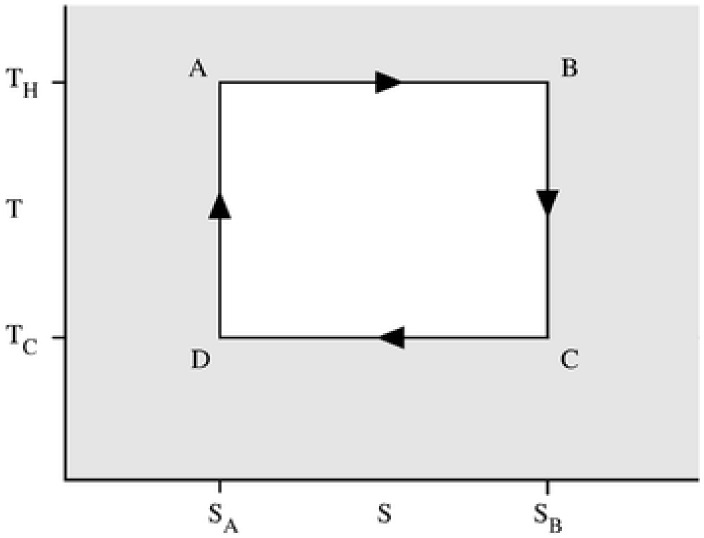


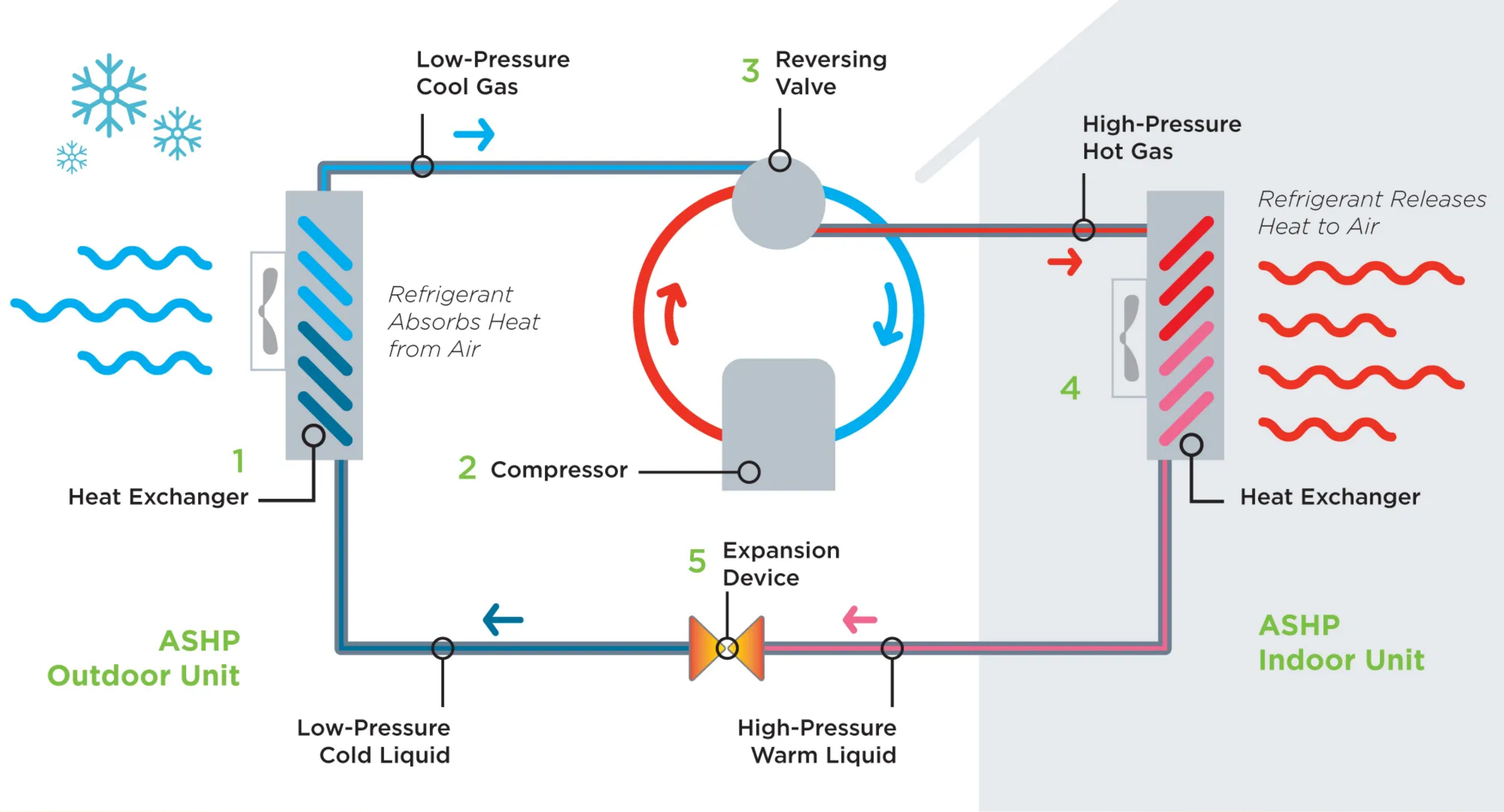
$$\Delta S = Q_2/T_2$$

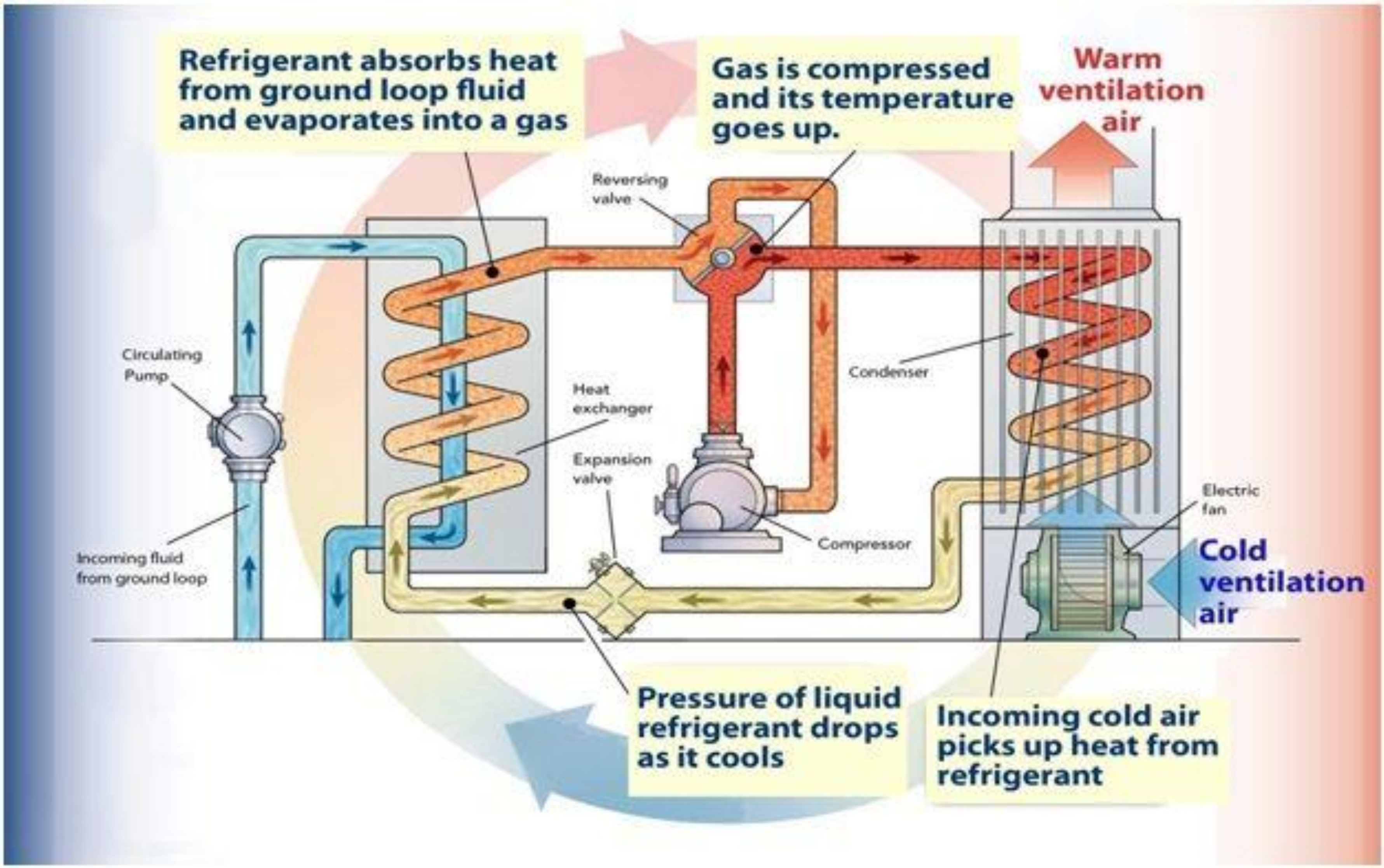


Isentropic compression of the gas (isentropic work input). (4 to 1 on Figure 1, D to A on Figure 2) Once again the mechanisms of the engine are assumed to be thermally insulated. During this step, the surroundings do work on the gas, increasing its internal energy and compressing it, causing the temperature to rise to T_1. The entropy remains unchanged. At this point the gas is in the same state as at the start of step 1.






Low-Pressure Cool Gas
3 Reversing Valve
High-Pressure Hot Gas
Refrigerant Releases Heat to Air
Refrigerant Absorbs Heat from Air
4
1
Heat Exchanger
2 Compressor
Heat Exchanger
5 Expansion Device
ASHP Outdoor Unit
ASHP Indoor Unit
Low-Pressure Cold Liquid
High-Pressure Warm Liquid



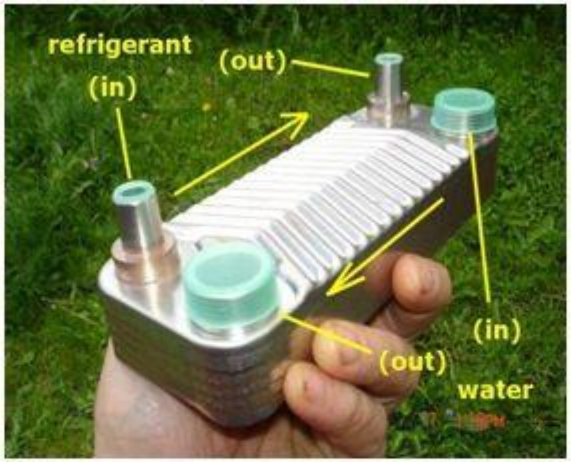
Refrigerant absorbs heat from ground loop fluid and evaporates into a gas

Gas is compressed and its temperature goes up.

Pressure of liquid refrigerant drops as it cools

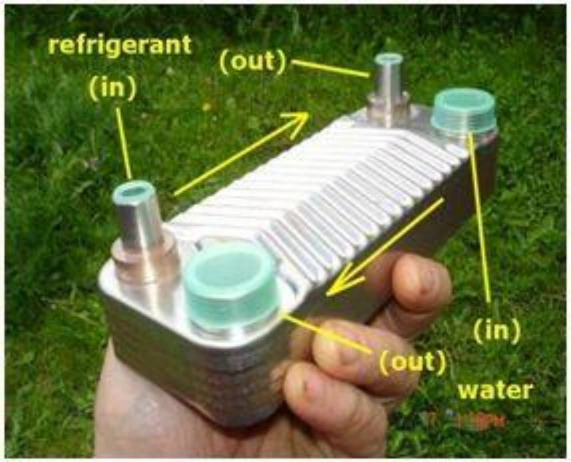
Incoming cold air picks up heat from refrigerant

Heat Exchangers



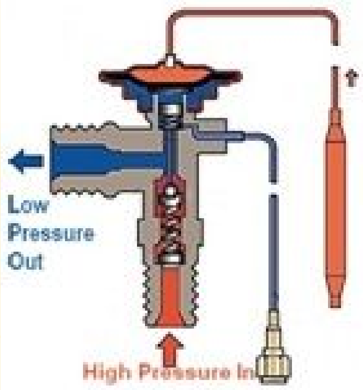
The Evaporator Heat Exchanger

The first place the energy from the geothermal loop meets the heat pump loop is the evaporator. The evaporator is a heat exchanger that works on the same principles as a car radiator. The warmed ground loop water enters the evaporator and transfers its energy to the refrigerant by warming up metal plates that separate the refrigerant and the water. Remember that each loop is a closed system. In figure 3 it might appear that the water and refrigerant mix, but they are completely separated by metal plates in the exchanger. Although the ground loop water is not very hot, the low boiling temperature of the refrigerant means that even the relatively low temperature of the ground loop is enough to turn the liquid refrigerant into a gas state (hence the name evaporator). Like water, which boils at 100 C, Freon’s properties are such that it boils at as low as zero degrees C.



The Condenser Heat exchanger

The condensing heat exchanger works in the exact opposite way as the evaporator. The hot gas from the compressor enters this heat exchanger and interacts with the load baring loop. The air in the house is circulated across this heat exchanger and absorbs the thermal energy of the refrigerant (again the two systems never physically touch and are separated by layers of metal plates). Since the energy is absorbed from the refrigerant, the refrigerant cools down as it continues through the heat pump loop. The condenser and the evaporator do opposite things but are mechanically identical.



Expansion valve

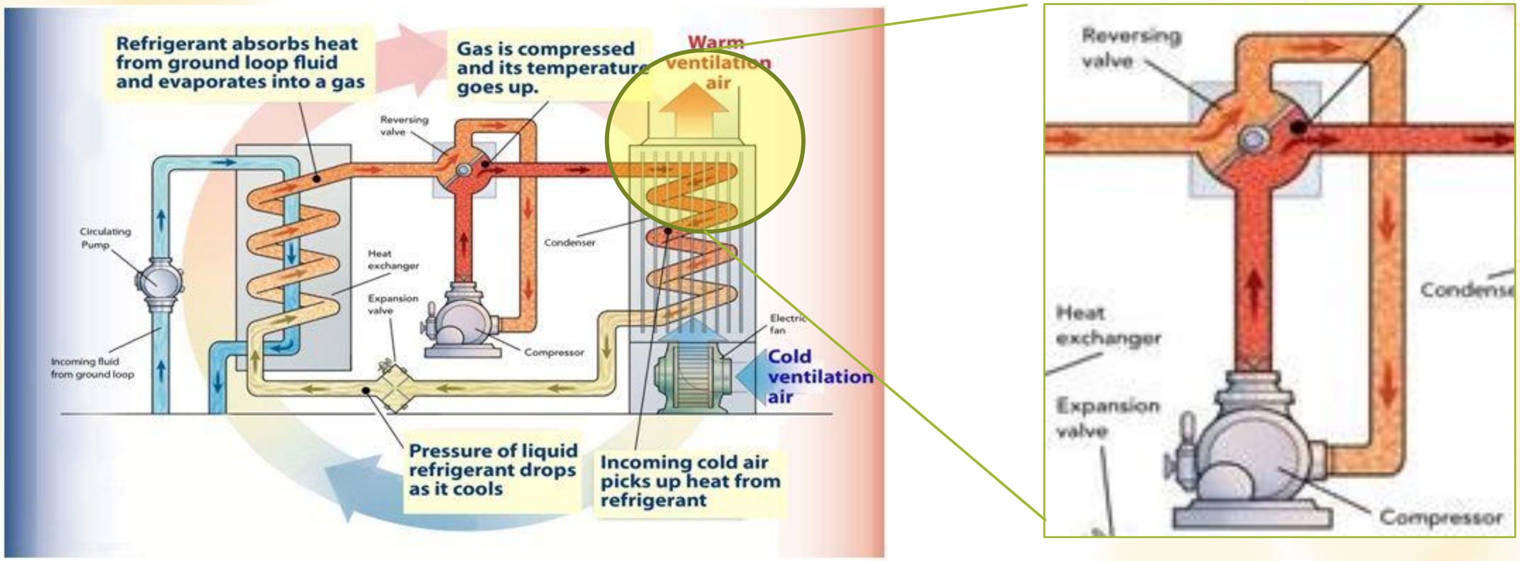
The Expansion Valve

The last component the refrigerant passes through before it repeats the cycle is the expansion valve. Basically, this valve depressurizes the refrigerant, turning it back into a liquid state so it can re-enter the evaporator and be warmed up by the energy absorbed through the ground loop again.

Scroll compressor

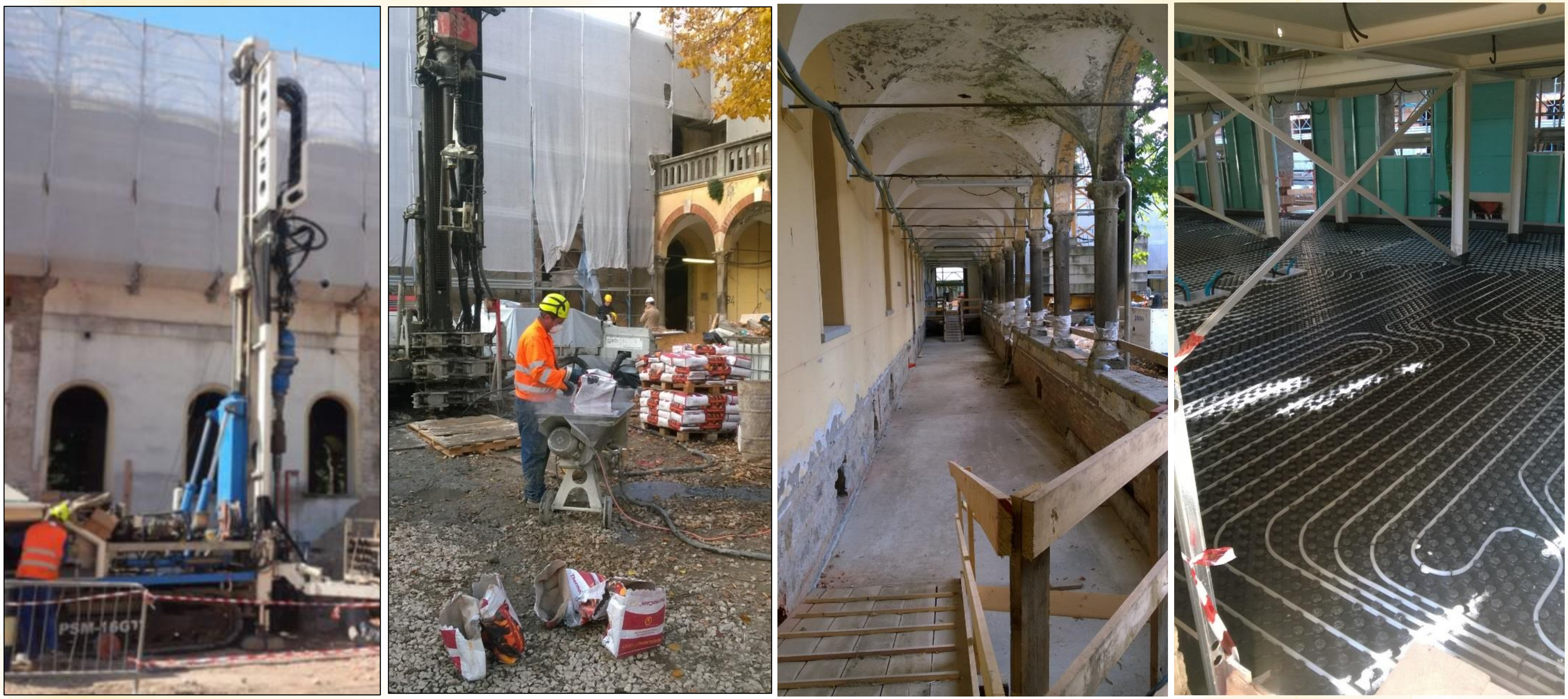
The Compressor

The compressor is one of the fundamental components of the heat pump. It is comprised of two parts, the motor that turns the compressor, and the scroll compressor that compresses the refrigerant (see figure 4). The refrigerant enters the compressor in a gaseous state after being warmed by the ground water at around 2-3 degrees C at 50 PSI and leaves the compressor at around 60-70 degrees C at 250 PSI. You might be wondering how the compressor was able to heat the refrigerant so drastically, but in reality, the compressor doesn’t heat anything at all. The gas that exits the compressor has the exact same amount of energy as the gas that entered, what changed is the volume. By reducing the volume, the temperature rises as the same amount of energy is found in a smaller space causing its temperature increases. Physics explains that this temperature increases is the result of the molecules being denser thus more collisions.



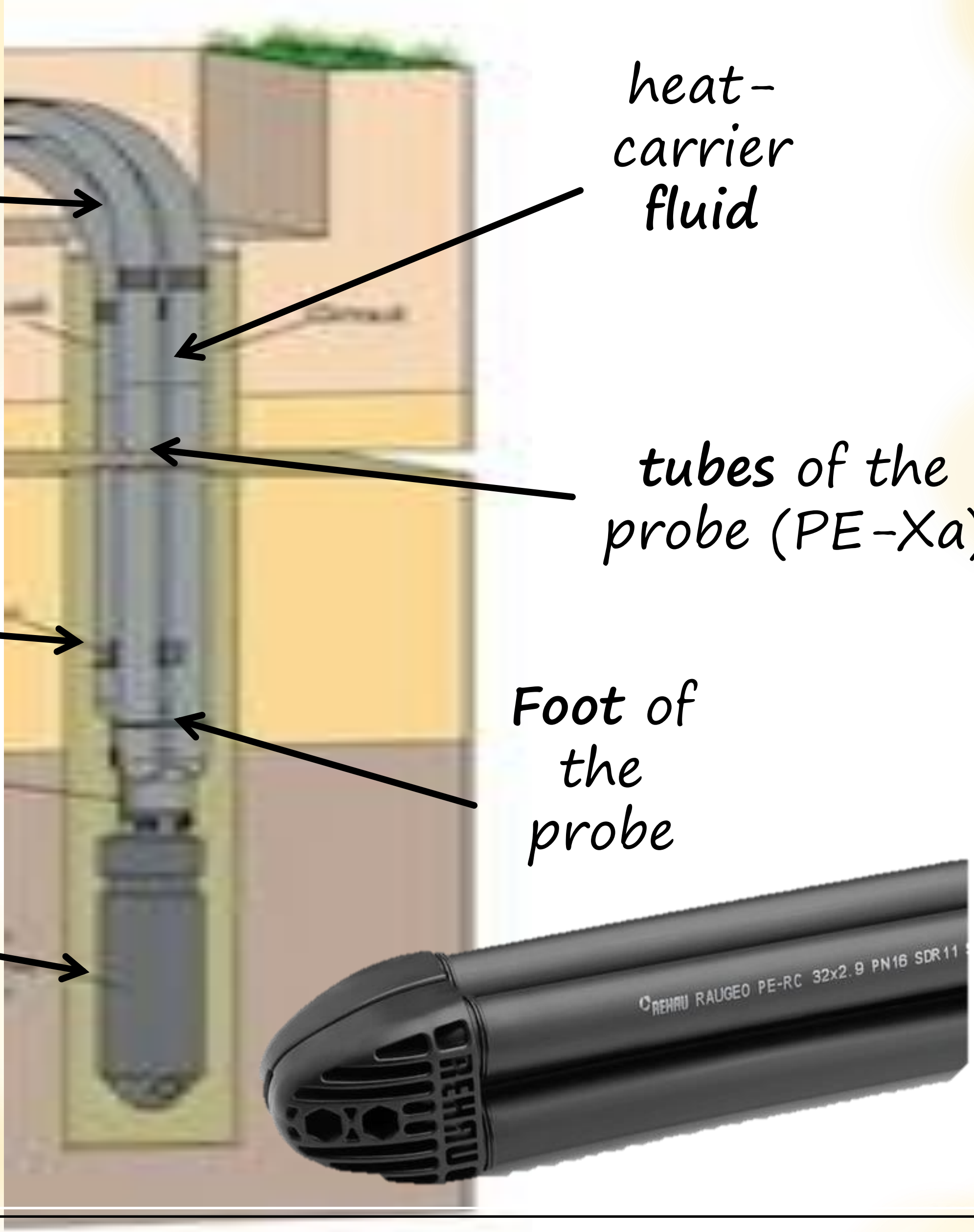
The Reversing Valve (used when both Heating and Cooling)
The last component making up the heat pump that we will discuss is the reversing valve. If you look at figure of heat pump carefully you will notice that when the reversing valve is closed the warmed gas that usually enters the compressor at the entrance port would enter through the exit port. What activating the reversing valve does is decompress the refrigerant and reverse the condenser and evaporator’s functionality. You would do this in the summer months to use the heat pump as a substitute for air conditioning. Instead of carrying hot gas to the condenser which would warm your home when a fan blows air over the coil the compressor would decompress the gas and send cold refrigerant to a coil located in an air duct thus cooling down your house when air is blown over coil. This is possible because the ground maintains a temperature around 15 degrees C during the summer and winter, so in the winter the ground is warmer than the outside air and in the summer the ground is colder than the outside air.

GROUND SOURCE HEAT PUMP SYSTEMS



GROUND SOURCE HEAT PUMP SYSTEMS

GROUND SOURCE HEAT PUMP SYSTEMS



Head + horizontal connections

heat-carrier fluid

tubes of the probe (PE-Xa)

grout to seal the borehole

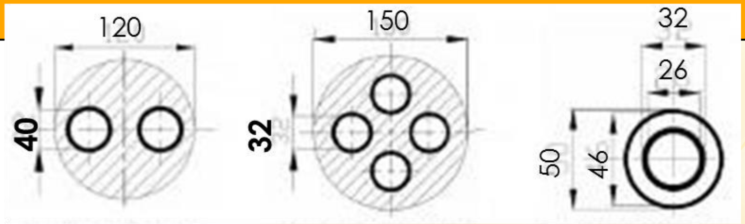
Foot of the probe

ballast

GSHP SYSTEMS DESIGN

1. EVALUATION OF THE HEATING AND COOLING BUILDING REQUIREMENTS → definition of the amount of heat the system has to provide
2. GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF THE SITE
3. TECHNICAL FEASIBILITY
4. IDENTIFICATION OF LOCAL LEGISLATION AND ENVIRONMENTAL CONSTRAINTS
5. HEAT PUMP SELECTION AND SYSTEM MANAGEMENT STRATEGY (auxiliary systems)

GSHP SYSTEMS DESIGN

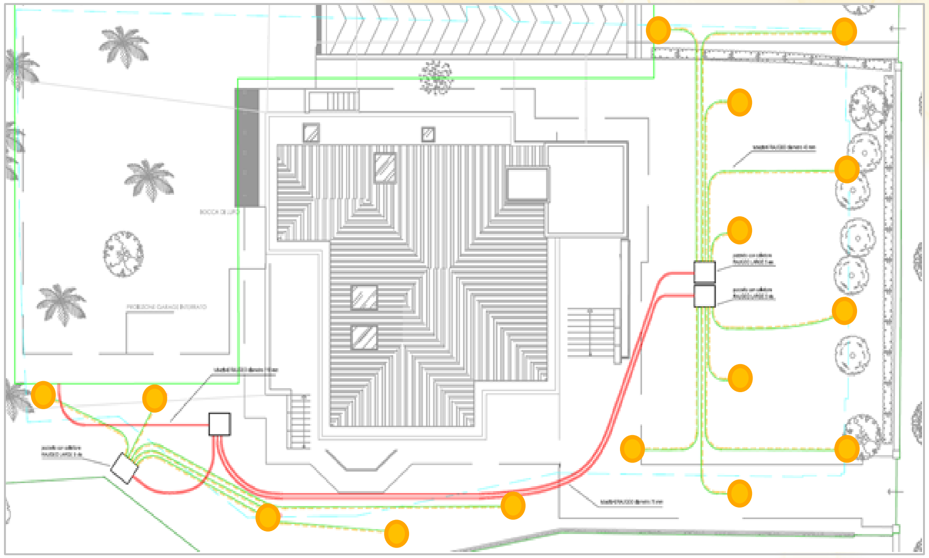


single U **Double-U** **coaxial**

- ✓ 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

GSHP SYSTEMS DESIGN

- Total length of the GHE
- Arrangement of the borehole field (6 BHEs of 100m or 10 BHEs of 60m?)



✓ Initial investment and construction costs (short term)

✓ Overall energetic performance of the GSHE system (long term)

GSHP SYSTEMS DESIGN – EED SOFTWARE

INPUT DATA

a) Ground and BHE characteristics:

- ✓ Ground thermal properties: conductivity, diffusivity
- ✓ Ground undisturbed temperature
- ✓ local geothermal heat flow
- ✓ tube / grout thermal resistance (depending on the construction technologies/materials)

b) System features:

- ✓ Building's heating and cooling requirements (monthly profile and peak)
- ✓ Seasonal average COP and EER of the heat pump
- ✓ Domestic hot water requirements

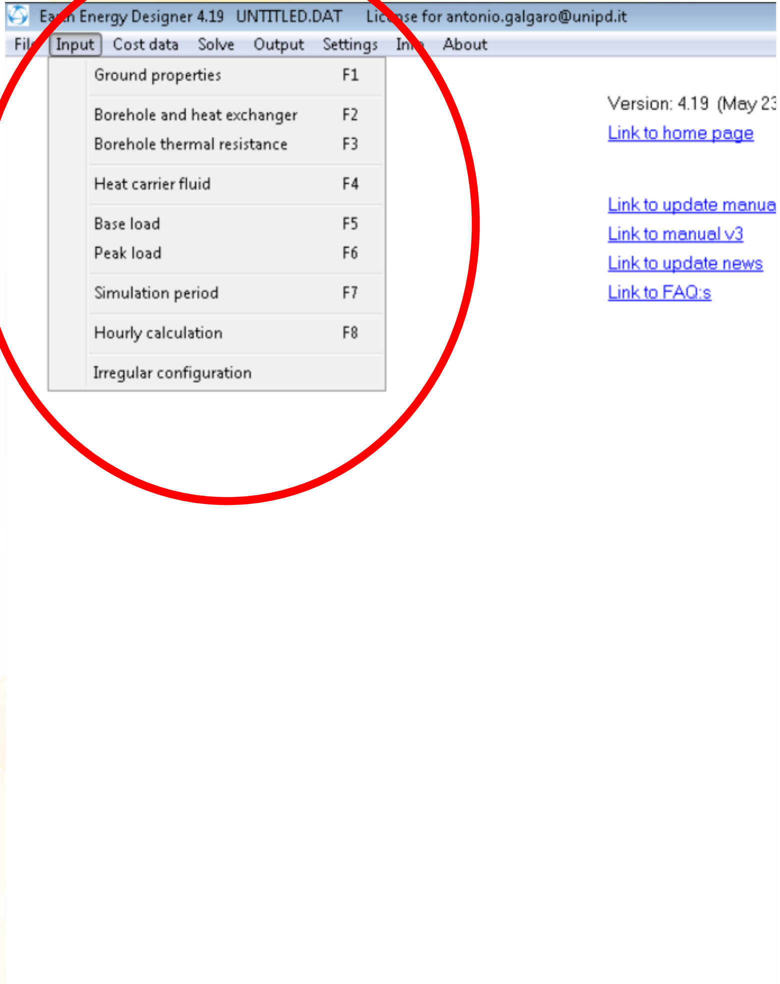
First BHE sizing + distribution

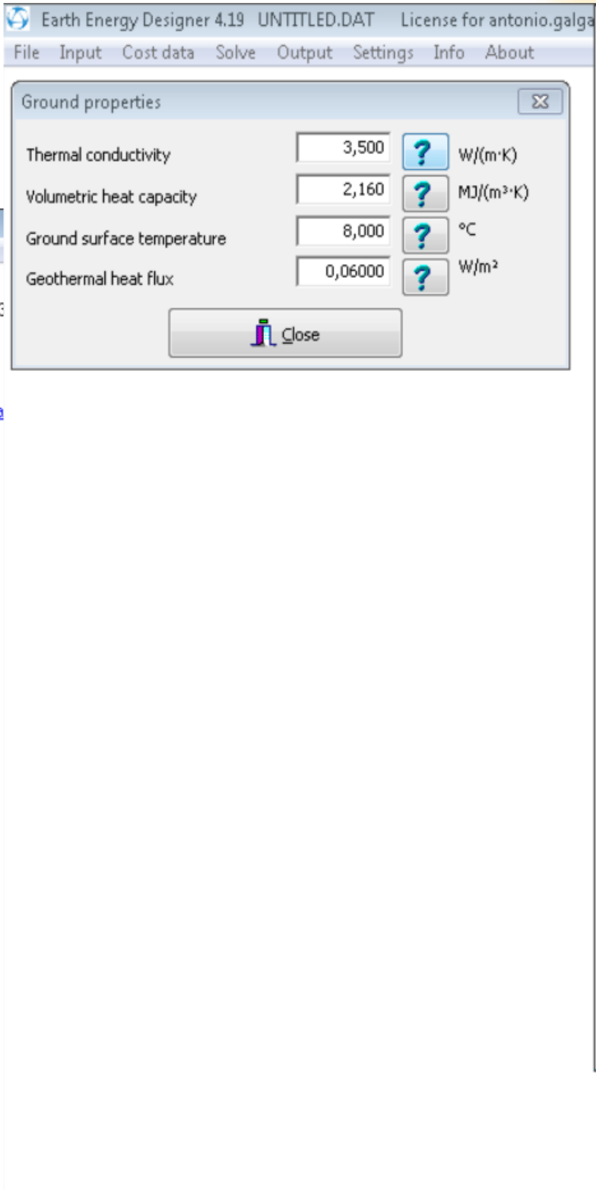
DESIGN OPTIMIZATION

OUTPUT

- ✓ BHE sizing and spatial distribution
- ✓ Evaluation of the heat carrier fluid working temperature
  - → to check the HP functioning
  - → + (with FEFLOW) evaluation of the thermal alteration induced in the underground
- ✓ Installation costs
- ✓ Investment repayment plan

GSHP SYSTEMS DESIGN – EED SOFTWARE



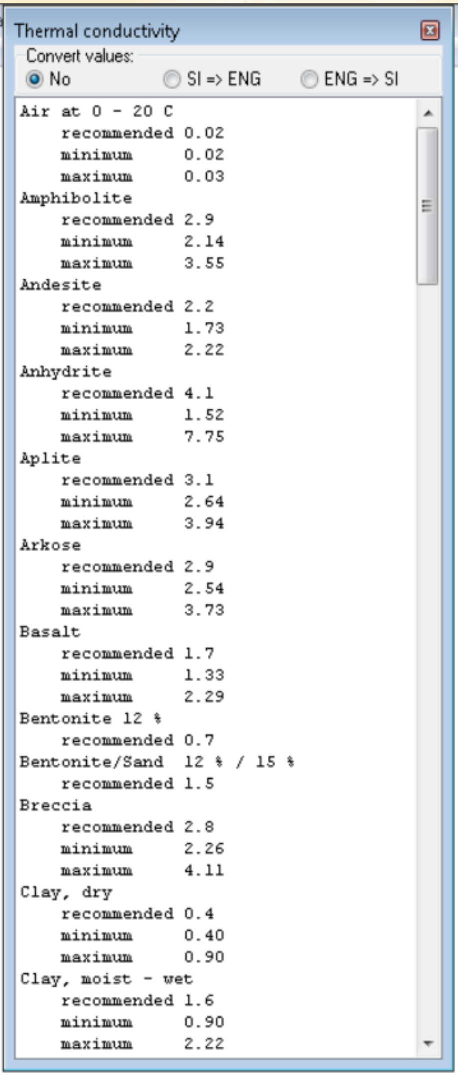


Thermal conductivity: 3,500 W/(m·K)

Volumetric heat capacity: 2,160 MJ/(m³·K)

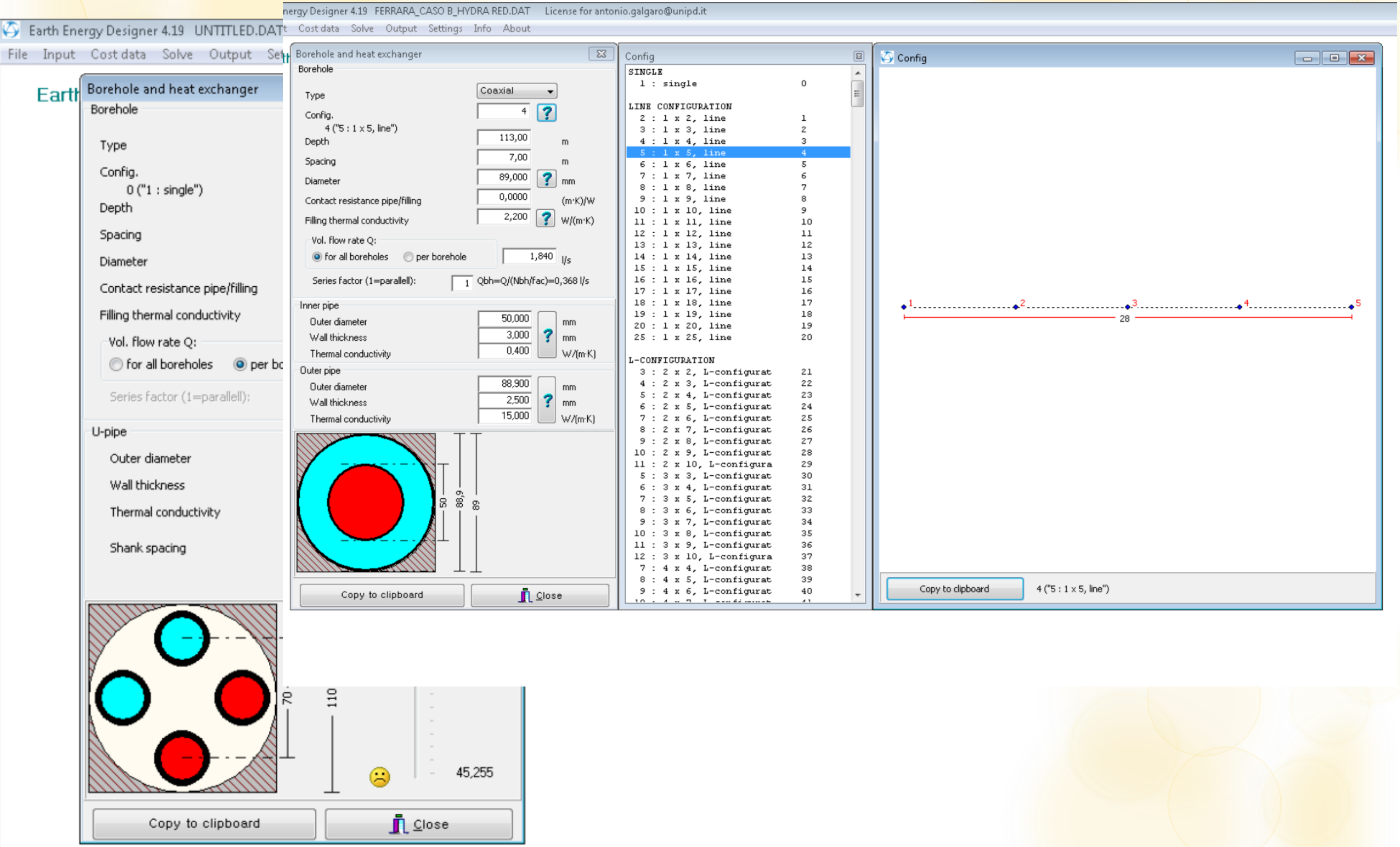
Ground surface temperature: 8,000 °C

Geothermal heat flux: 0,06000 W/m²



```
Air at 0 - 20 C
    recommended 0.02
    minimum     0.02
    maximum     0.03
Amphibolite
    recommended 2.9
    minimum     2.14
    maximum     3.55
Andesite
    recommended 2.2
    minimum     1.73
    maximum     2.22
Anhydrite
    recommended 4.1
    minimum     1.52
    maximum     7.75
Aplite
    recommended 3.1
    minimum     2.64
    maximum     3.94
Arkose
    recommended 2.9
    minimum     2.54
    maximum     3.73
Basalt
    recommended 1.7
    minimum     1.33
    maximum     2.29
Bentonite 12 %
    recommended 0.7
Bentonite/Sand  12 % / 15 %
    recommended 1.5
Breccia
    recommended 2.8
    minimum     2.26
    maximum     4.11
Clay, dry
    recommended 0.4
    minimum     0.40
    maximum     0.90
Clay, moist - wet
    recommended 1.6
    minimum     0.90
    maximum     2.22
```

GSHP SYSTEMS DESIGN – EED SOFTWARE



Borehole and heat exchanger

Borehole

Type

Config.
0 ("1 : single")

Depth

Spacing

Diameter

Contact resistance pipe/filling

Filling thermal conductivity

Vol. flow rate Q:
○ for all boreholes ● per bc

Series factor (1=parallell):

U-pipe

Outer diameter

Wall thickness

Thermal conductivity

Shank spacing

45,255

Borehole and heat exchanger

Borehole

Type: Coaxial

Config.: 4
4 ("5 : 1 x 5, line")

Depth: 113,00 m

Spacing: 7,00 m

Diameter: 89,000 mm

Contact resistance pipe/filling: 0,0000 (m·K)/W

Filling thermal conductivity: 2,200 W/(m·K)

Vol. flow rate Q: ● for all boreholes ○ per borehole 1,840 l/s

Series factor (1=parallell): 1 Qbh=Q/(Nbh/fac)=0,368 l/s

Inner pipe

Outer diameter: 50,000 mm

Wall thickness: 3,000 mm

Thermal conductivity: 0,400 W/(m·K)

Outer pipe

Outer diameter: 88,900 mm

Wall thickness: 2,500 mm

Thermal conductivity: 15,000 W/(m·K)

Config

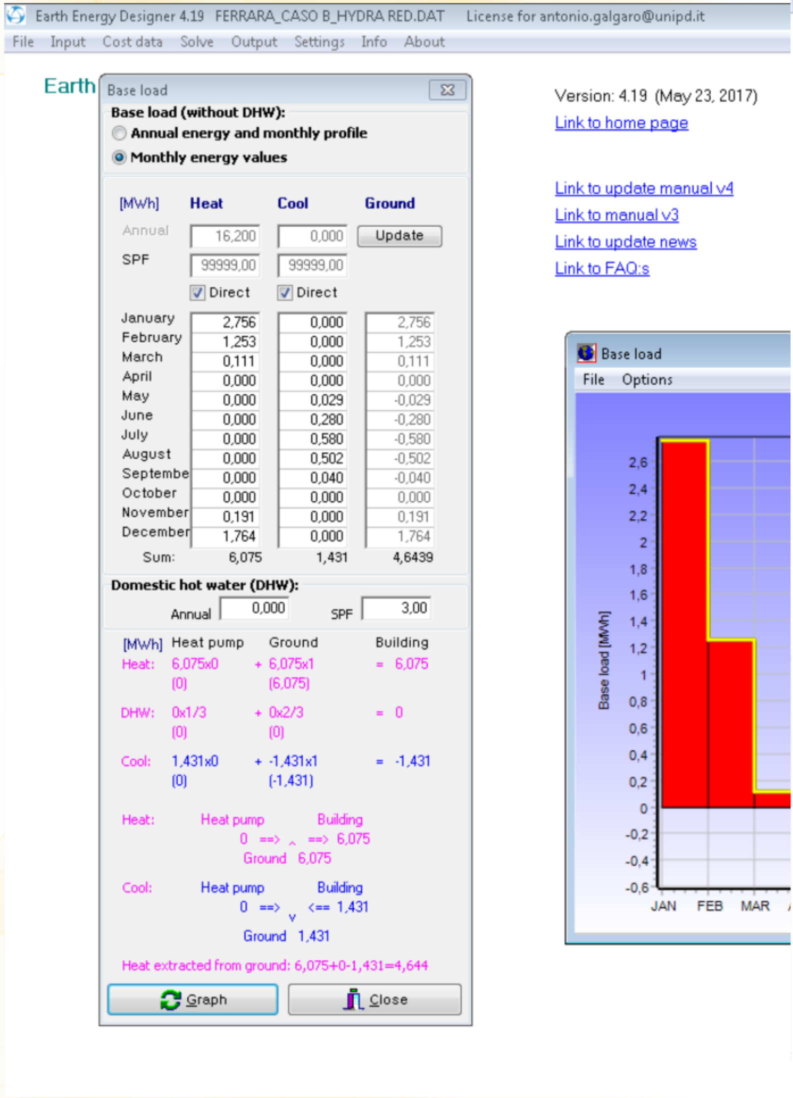
```
SINGLE
  1 : single              0

LINE CONFIGURATION
  2 : 1 x 2, line         1
  3 : 1 x 3, line         2
  4 : 1 x 4, line         3
  5 : 1 x 5, line         4
  6 : 1 x 6, line         5
  7 : 1 x 7, line         6
  8 : 1 x 8, line         7
  9 : 1 x 9, line         8
 10 : 1 x 10, line        9
 11 : 1 x 11, line        10
 12 : 1 x 12, line        11
 13 : 1 x 13, line        12
 14 : 1 x 14, line        13
 15 : 1 x 15, line        14
 16 : 1 x 16, line        15
 17 : 1 x 17, line        16
 18 : 1 x 18, line        17
 19 : 1 x 19, line        18
 20 : 1 x 20, line        19
 25 : 1 x 25, line        20

L-CONFIGURATION
  3 : 2 x 2, L-configurat  21
  4 : 2 x 3, L-configurat  22
  5 : 2 x 4, L-configurat  23
  6 : 2 x 5, L-configurat  24
  7 : 2 x 6, L-configurat  25
  8 : 2 x 7, L-configurat  26
  9 : 2 x 8, L-configurat  27
 10 : 2 x 9, L-configurat  28
 11 : 2 x 10, L-configura  29
  5 : 3 x 3, L-configurat  30
  6 : 3 x 4, L-configurat  31
  7 : 3 x 5, L-configurat  32
  8 : 3 x 6, L-configurat  33
  9 : 3 x 7, L-configurat  34
 10 : 3 x 8, L-configurat  35
 11 : 3 x 9, L-configurat  36
 12 : 3 x 10, L-configura  37
  7 : 4 x 4, L-configurat  38
  8 : 4 x 5, L-configurat  39
  9 : 4 x 6, L-configurat  40
```

4 ("5 : 1 x 5, line")

GSHP SYSTEMS DESIGN – EED SOFTWARE



Base load (without DHW):

○ Annual energy and monthly profile

● Monthly energy values

[MWh]	Heat	Cool	Ground
Annual	16,200	0,000	
SPF	99999,00	99999,00	
	☑ Direct	☑ Direct	
January	2,756	0,000	2,756
February	1,253	0,000	1,253
March	0,111	0,000	0,111
April	0,000	0,000	0,000
May	0,000	0,029	-0,029
June	0,000	0,280	-0,280
July	0,000	0,580	-0,580
August	0,000	0,502	-0,502
Septembe	0,000	0,040	-0,040
October	0,000	0,000	0,000
November	0,191	0,000	0,191
December	1,764	0,000	1,764
Sum:	6,075	1,431	4,6439

Domestic hot water (DHW):

Annual 0,000 SPF 3,00

```
[MWh]  Heat pump      Ground          Building
Heat:  6,075x0      + 6,075x1       = 6,075
       (0)            (6,075)
DHW:   0x1/3        + 0x2/3         = 0
       (0)            (0)
Cool:  1,431x0      + -1,431x1      = -1,431
       (0)            (-1,431)

Heat:      Heat pump        Building
              0  ==>  ^  ==> 6,075
              Ground  6,075

Cool:      Heat pump        Building
              0  ==>  v  <== 1,431
              Ground  1,431

Heat extracted from ground: 6,075+0-1,431=4,644
```

Version: 4.19 (May 23, 2017)

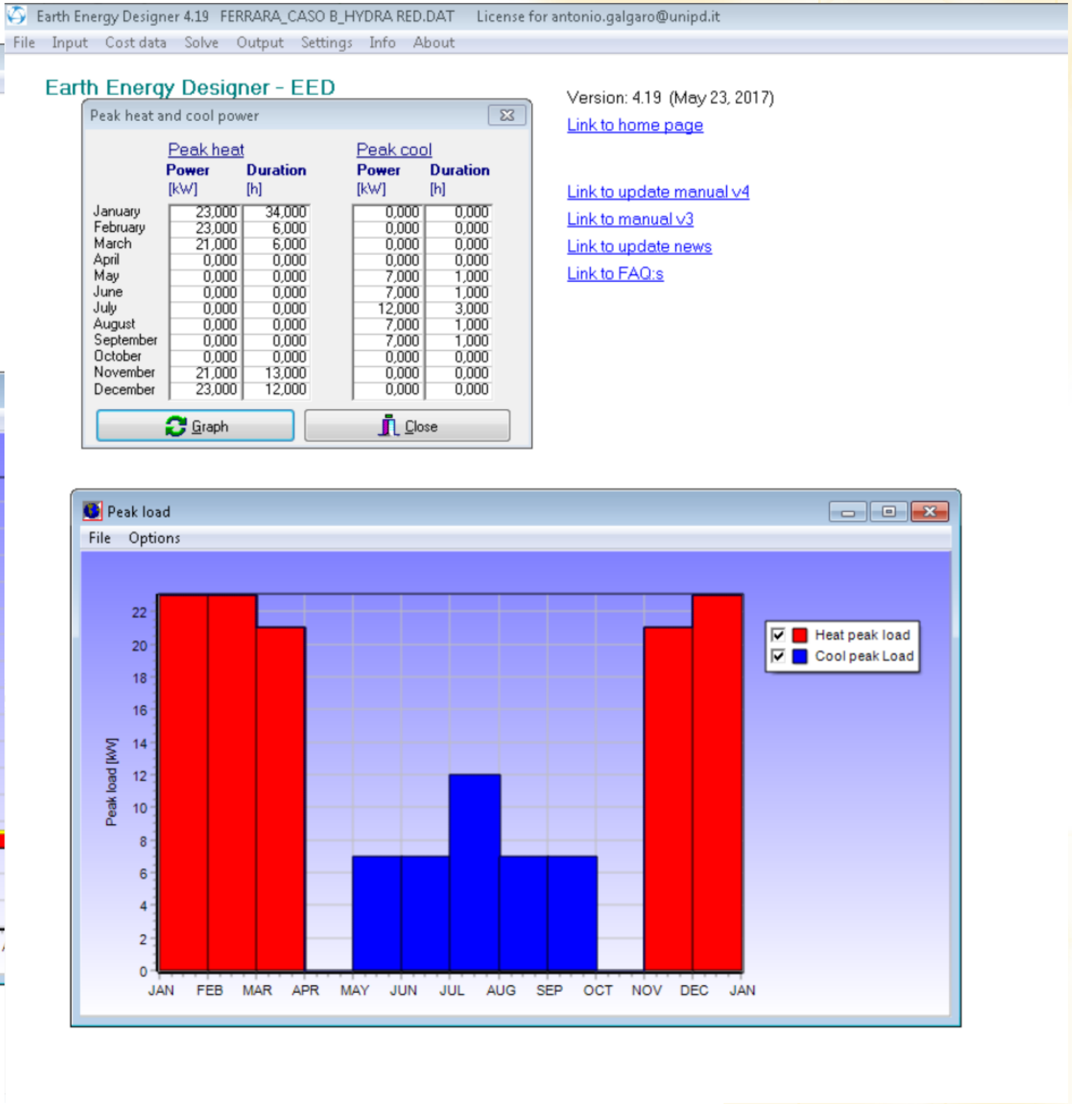
Link to home page

Link to update manual v4

Link to manual v3

Link to update news

Link to FAQ:s



Earth Energy Designer - EED

	Peak heat		Peak cool	
	Power [kW]	Duration [h]	Power [kW]	Duration [h]
January	23,000	34,000	0,000	0,000
February	23,000	6,000	0,000	0,000
March	21,000	6,000	0,000	0,000
April	0,000	0,000	0,000	0,000
May	0,000	0,000	7,000	1,000
June	0,000	0,000	7,000	1,000
July	0,000	0,000	12,000	3,000
August	0,000	0,000	7,000	1,000
September	0,000	0,000	7,000	1,000
October	0,000	0,000	0,000	0,000
November	21,000	13,000	0,000	0,000
December	23,000	12,000	0,000	0,000

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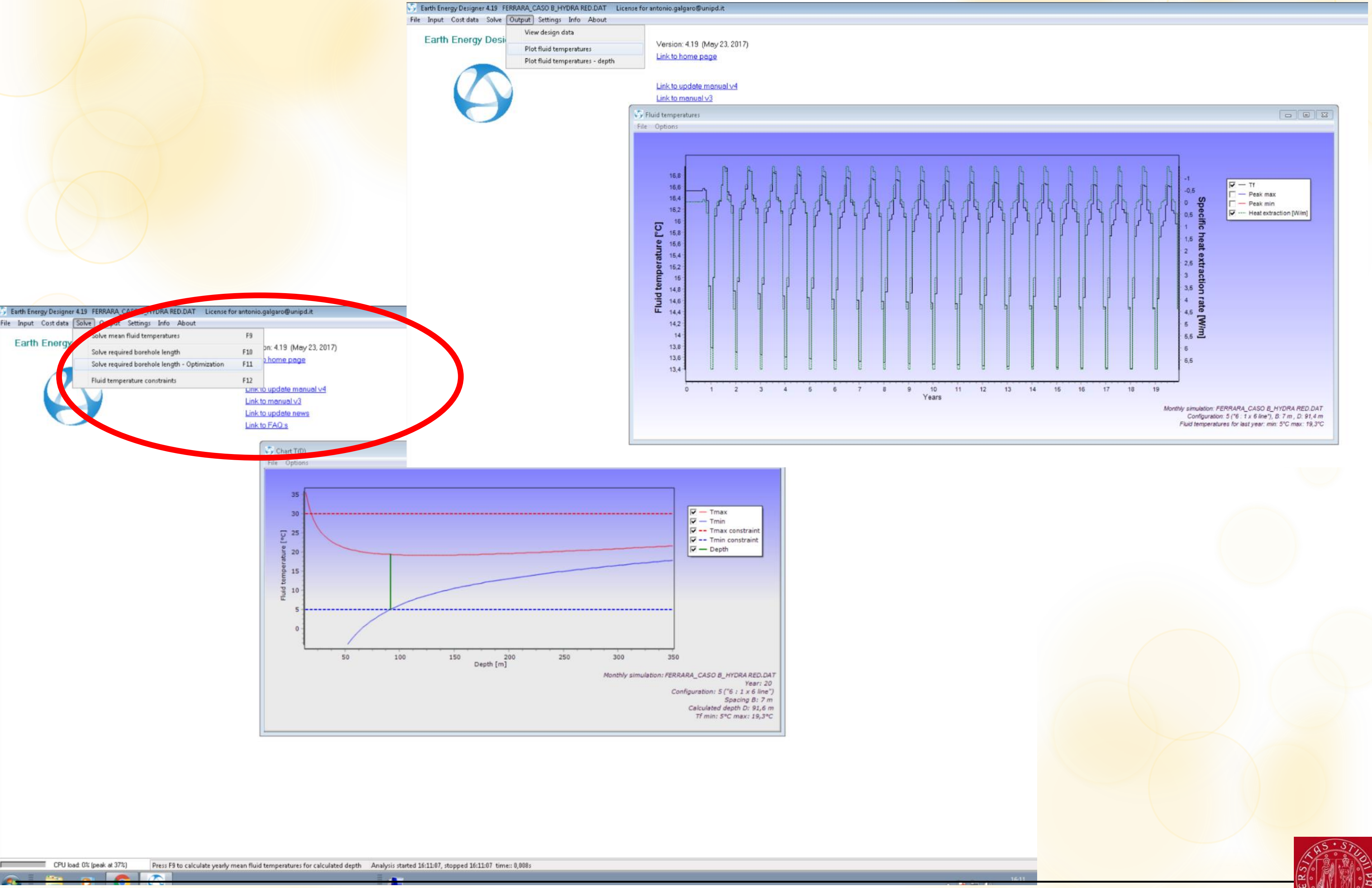
Link to FAQ:s

GSHP SYSTEMS DESIGN – EED SOFTWARE



Monthly simulation: FERRARA_CASO B_HYDRA RED.DAT
Configuration: 5 ("6 : 1 x 6 line"), B: 7 m , D: 91,4 m
Fluid temperatures for last year: min: 5°C max: 19,3°C

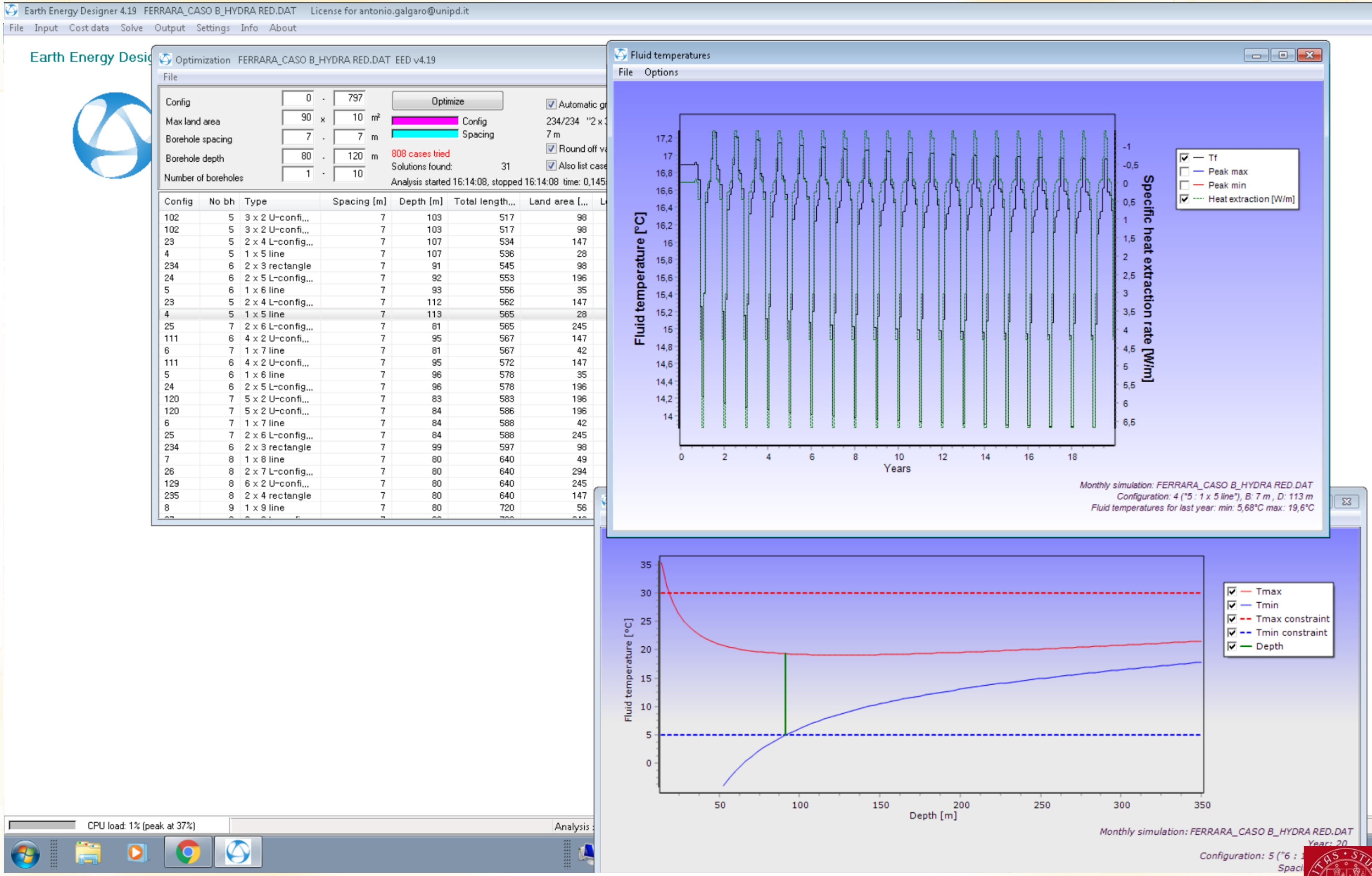
Monthly simulation: FERRARA_CASO B_HYDRA RED.DAT
Year: 20
Configuration: 5 ("6 : 1 x 6 line")
Spacing B: 7 m
Calculated depth D: 91,6 m
Tf min: 5°C max: 19,3°C

CPU load: 0% (peak at 37%)

Press F9 to calculate yearly mean fluid temperatures for calculated depth

Analysis started 16:11:07, stopped 16:11:07 time:: 0,008s

GSHP SYSTEMS DESIGN – EED SOFTWARE



Config 0 - 797

Max land area 90 x 10 m²

Borehole spacing 7 - 7 m

Borehole depth 80 - 120 m

Number of boreholes 1 - 10

🟪 Config

🟦 Spacing

808 cases tried

Solutions found: 31

Analysis started 16:14:08, stopped 16:14:08 time: 0,145

☑ Automatic gr

234/234 "2 x

7 m

☑ Round off va

☑ Also list case

Config	No bh	Type	Spacing [m]	Depth [m]	Total length...	Land area [...
102	5	3 x 2 U-confi...	7	103	517	98
102	5	3 x 2 U-confi...	7	103	517	98
23	5	2 x 4 L-config...	7	107	534	147
4	5	1 x 5 line	7	107	536	28
234	6	2 x 3 rectangle	7	91	545	98
24	6	2 x 5 L-config...	7	92	553	196
5	6	1 x 6 line	7	93	556	35
23	5	2 x 4 L-config...	7	112	562	147
4	5	1 x 5 line	7	113	565	28
25	7	2 x 6 L-config...	7	81	565	245
111	6	4 x 2 U-confi...	7	95	567	147
6	7	1 x 7 line	7	81	567	42
111	6	4 x 2 U-confi...	7	95	572	147
5	6	1 x 6 line	7	96	578	35
24	6	2 x 5 L-config...	7	96	578	196
120	7	5 x 2 U-confi...	7	83	583	196
120	7	5 x 2 U-confi...	7	84	586	196
6	7	1 x 7 line	7	84	588	42
25	7	2 x 6 L-config...	7	84	588	245
234	6	2 x 3 rectangle	7	99	597	98
7	8	1 x 8 line	7	80	640	49
26	8	2 x 7 L-config...	7	80	640	294
129	8	6 x 2 U-confi...	7	80	640	245
235	8	2 x 4 rectangle	7	80	640	147
8	9	1 x 9 line	7	80	720	56

Monthly simulation: FERRARA_CASO B_HYDRA RED.DAT
Configuration: 4 ("5 : 1 x 5 line"), B: 7 m , D: 113 m
Fluid temperatures for last year: min: 5,68°C max: 19,6°C

Monthly simulation: FERRARA_CASO B_HYDRA RED.DAT
Year: 20
Configuration: 5 ("6 : 1
Spaci

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF THE SITE

LOCAL GEOLOGICAL SETTING

→ is the "invariant" element of the system

→underground thermal/energetic performances

→best drilling and installation technique

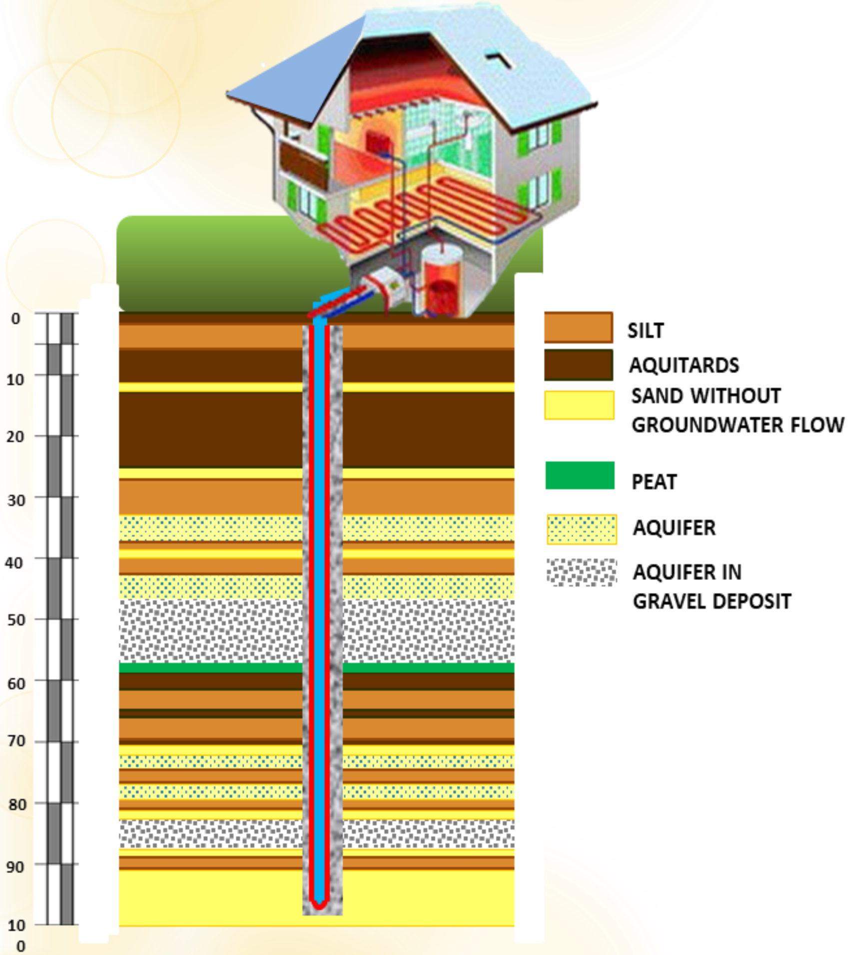
→GSHE geometry (total length/well diameter/single GHE length)

→environmental and regulatory constraints

identification of the best GSHE (technical + economic point of view)

1. UNDERGROUND THERMAL PERFORMANCES

The GEOLOGICAL variables mainly affecting the GHE performance

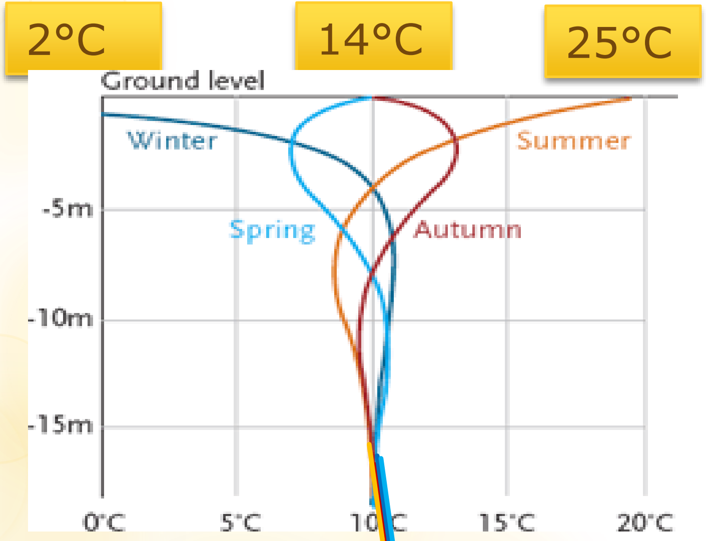


1. undisturbed <u>ground</u> temperature
2. local geothermal heat flux
3. thermal properties of the ground
4. Hydrogeological setting / water content within the ground
5. conduction / convection

1. UNDERGROUND THERMAL PERFORMANCES

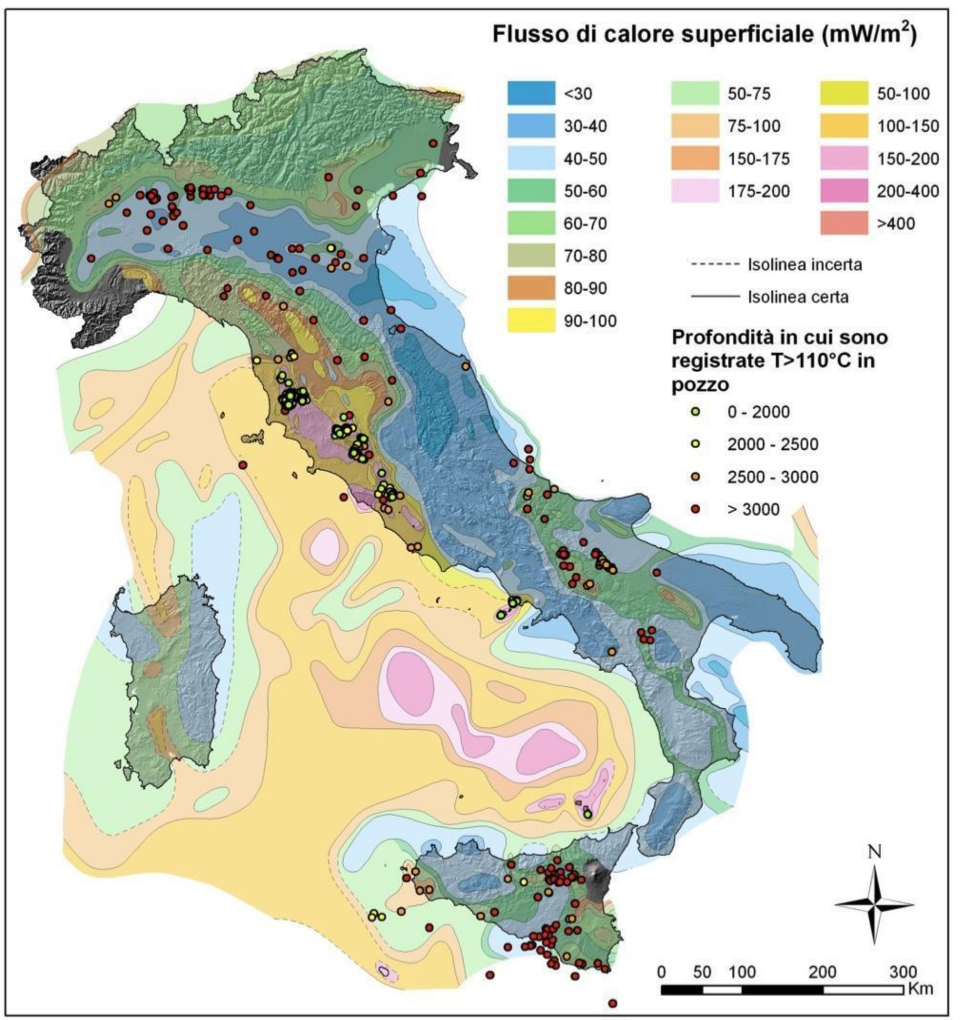
UNDISTURBED GROUND TEMPERATURE

- 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)



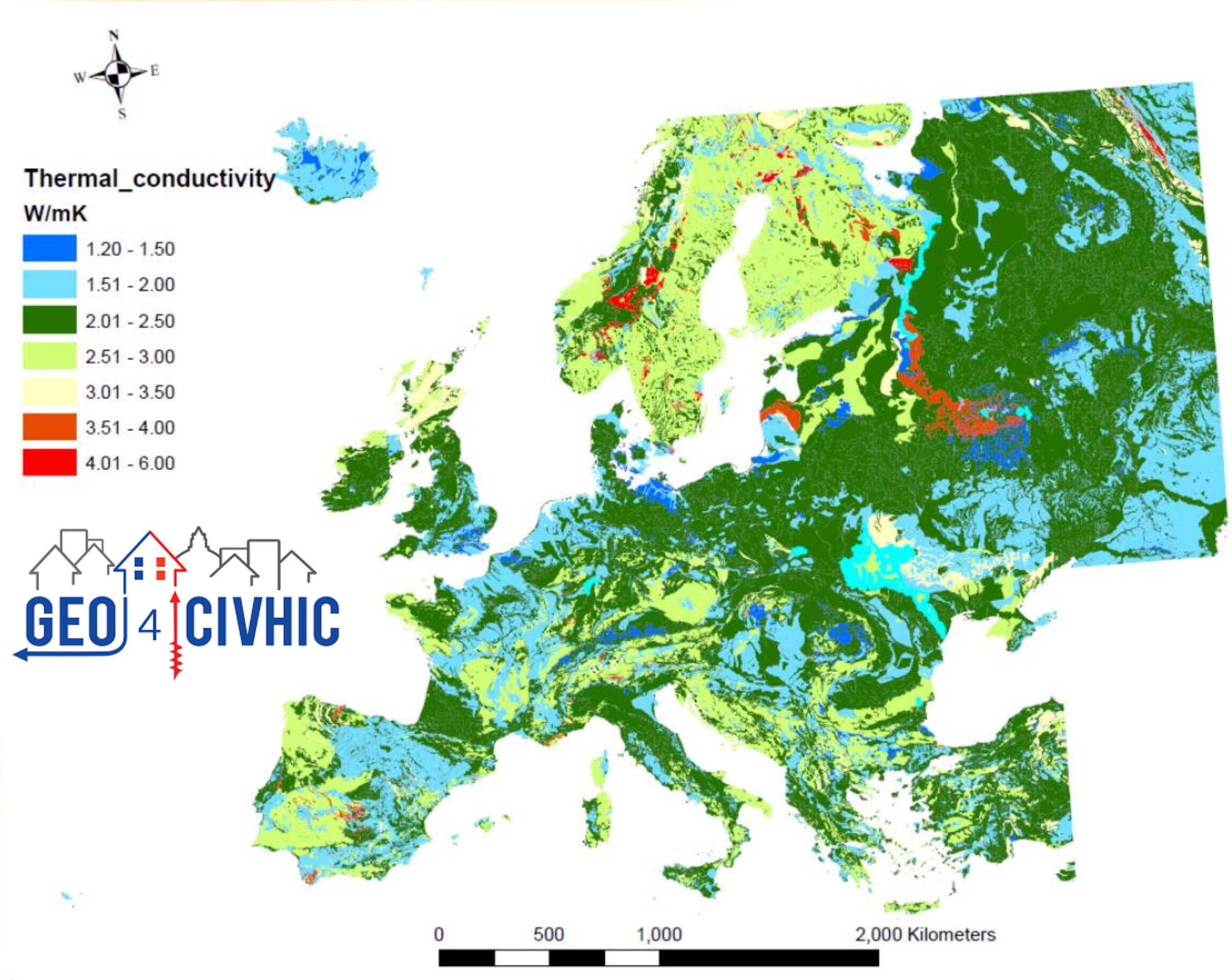
$$grad = 0{,}03\,\frac{K}{m}$$

LOCAL GEOTHERMAL HEAT FLUX



1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES



a) application of tabled values of ground materials thermal properties

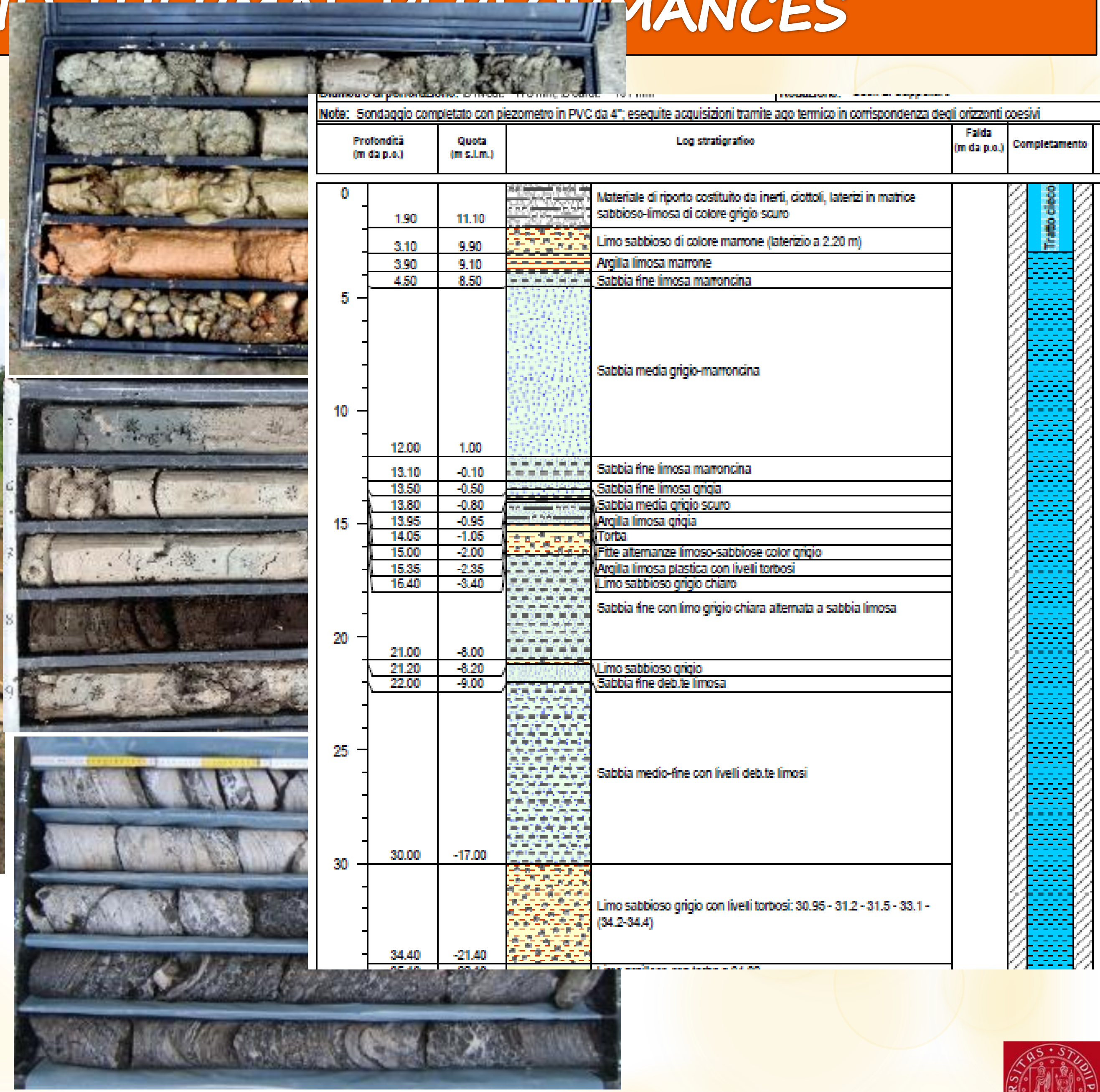
b) direct measurements of ground thermal properties

c) Thermal Response Test

d) Distributed Thermal Response Test

1. UNDERGROUND THERMAL PERFORMANCES

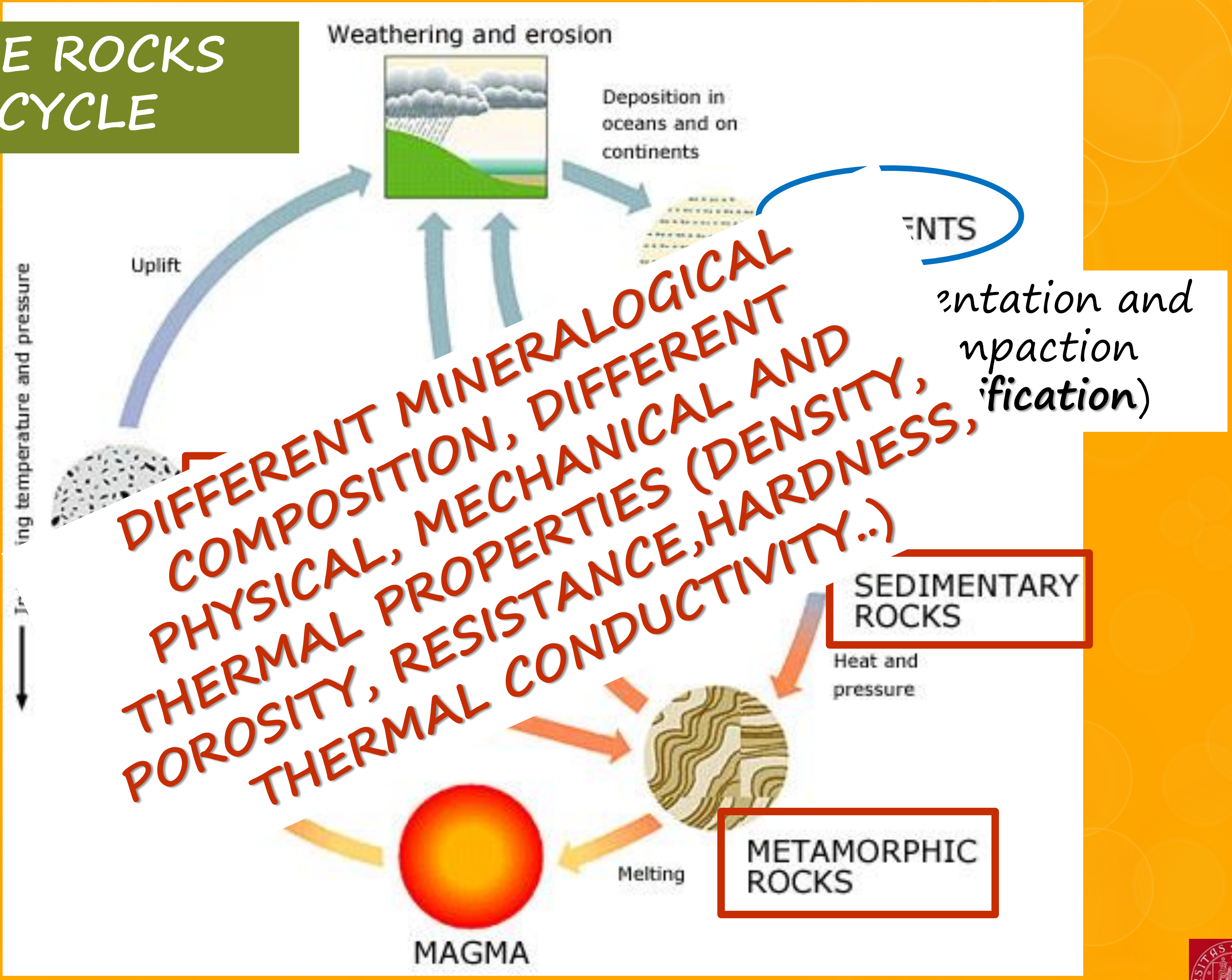
coring



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	Falda (m da p.o.)	Completamento
1.90	11.10	Materiale di riporto costituito da inerti, ciottoli, laterizi in matrice sabbioso-limosa di colore grigio scuro		Tratto cieco
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)		

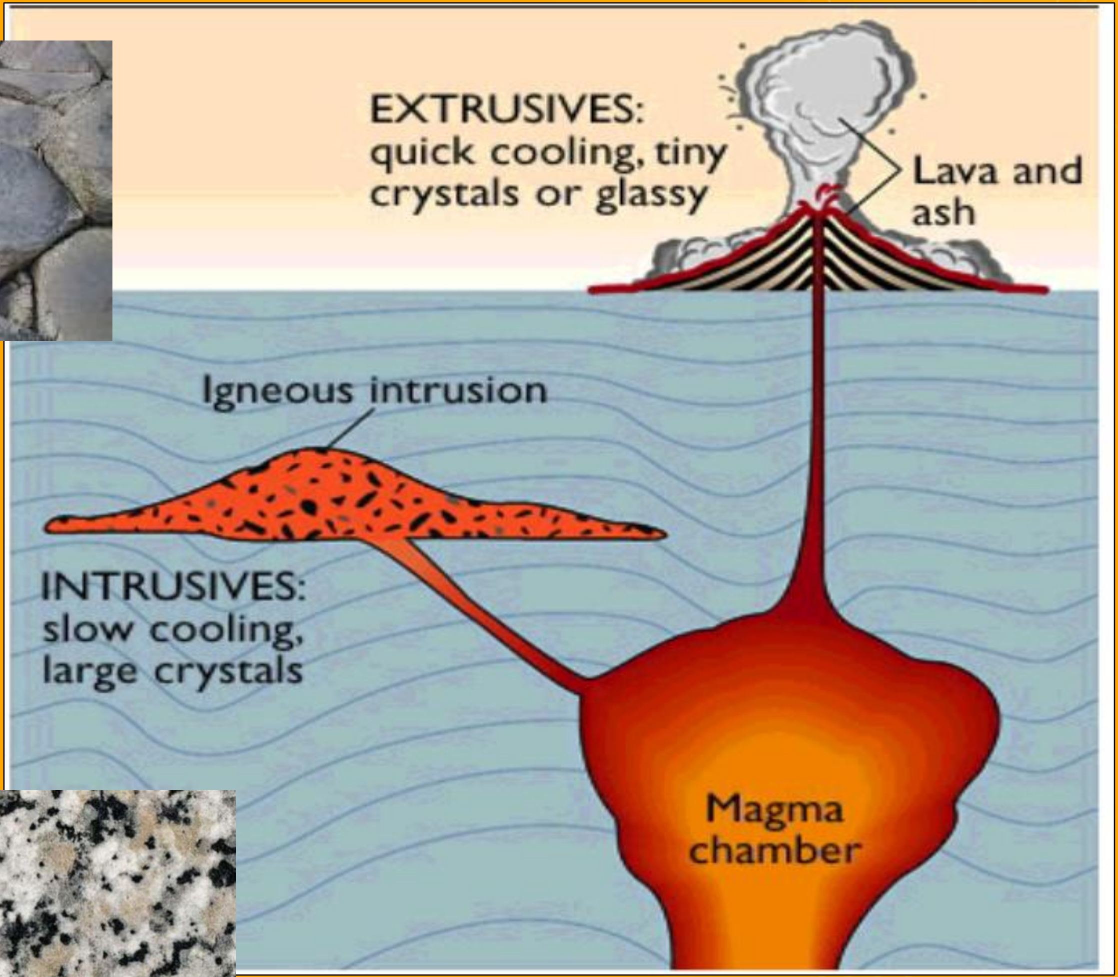
THE ROCKS CYCLE



DIFFERENT MINERALOGICAL COMPOSITION, DIFFERENT PHYSICAL, MECHANICAL AND THERMAL PROPERTIES (DENSITY, POROSITY, RESISTANCE,HARDNESS, THERMAL CONDUCTIVITY..)

IGNEOUS rocks

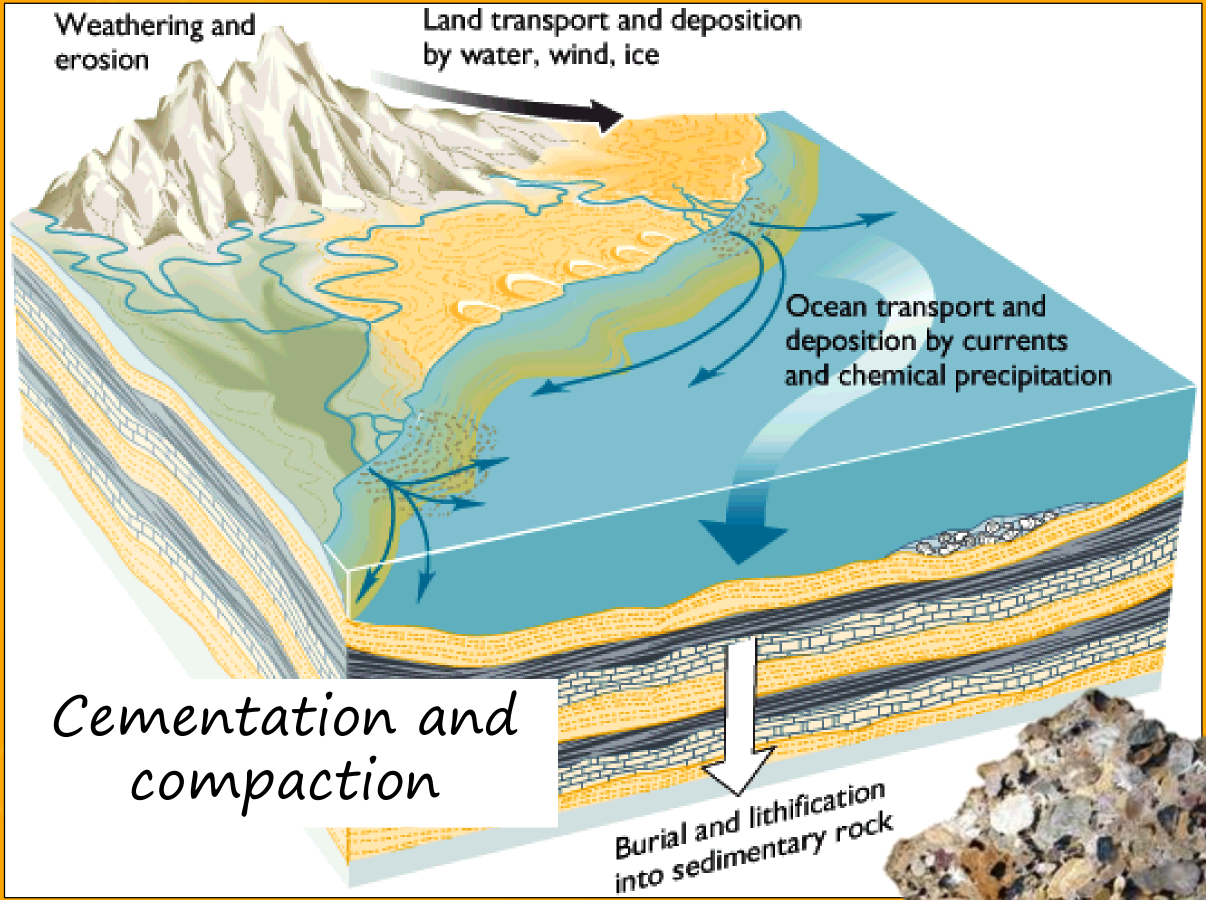
Extrusives:
Ex. BASALT,
ANDESITE,
TRACHYTE



Intrusives:
Ex. GRANITE,
SYENITE,
GABBRO

SEDIMENTARY rocks

Unconcolidated SEDIMENTS

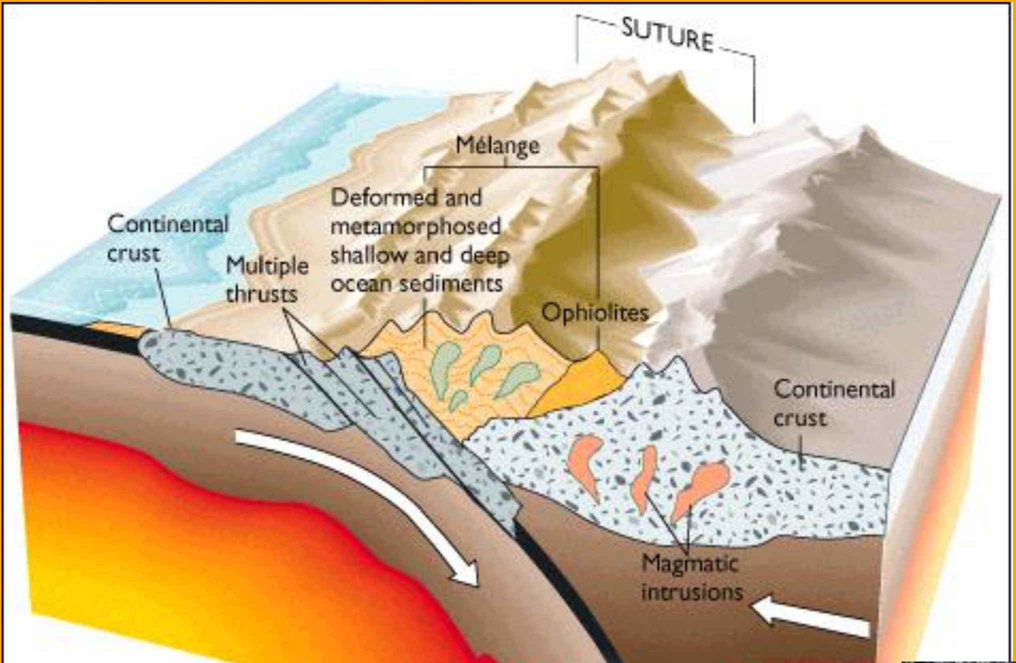


Cementation and compaction

SANDSTONE
LIMESTONE
CLAYSTONE
CONGLOMERATE
DOLOMITIC ROCK

METAMORPICH rocks

Processing of other rocks (of all types), caused by increases in pressure and temperature. It occurs under the earth's crust but the material is in the solid state.



before → after

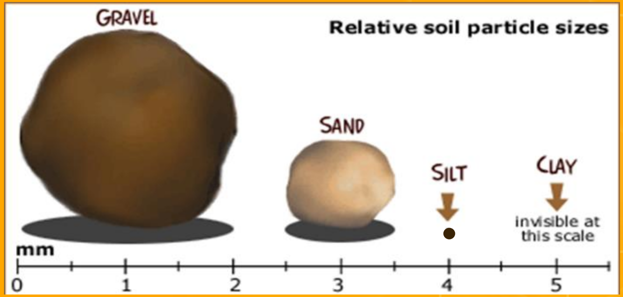
(granite) → (gneiss)

SHALE
MARBLE
QUARZITE
MICASHIST
GNEISS

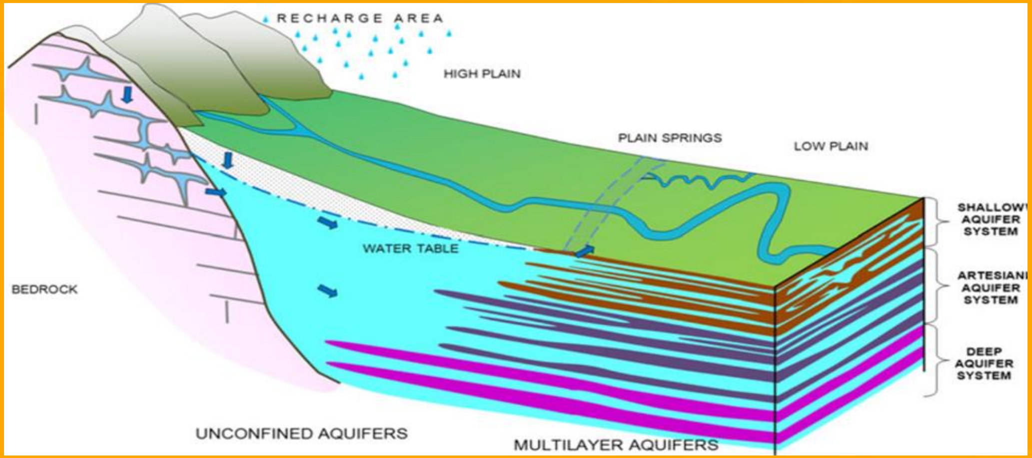
Unconsolidated SEDIMENTS

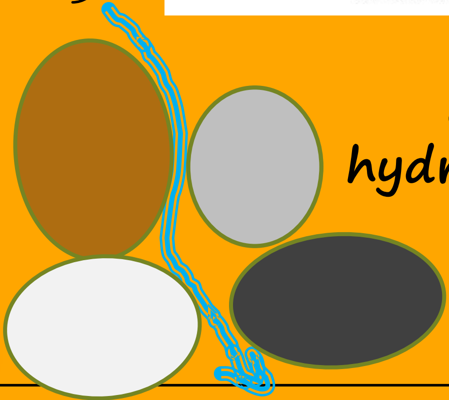
erosion

transport and deposition

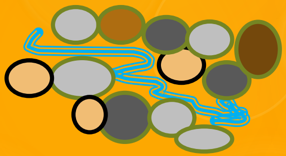


1. different mineralogical composition
2. different particle sizes
3. different deposit area





different mechanical, hydraulic, thermal properties



1. UNDERGROUND THERMAL PERFORMANCES

→THE ROCKS/SEDIMENTS THERMAL PROPERTIES *depend on:*

- ✓ *mineralogical composition*
- ✓ *granulometric distribution, gradation*
- ✓ *porosity/density*
- ✓ *state of consolidation*
- ✓ *water content / saturation*
- ✓ *environmental conditions (temperature/pressure)*
- ✓ *texture*

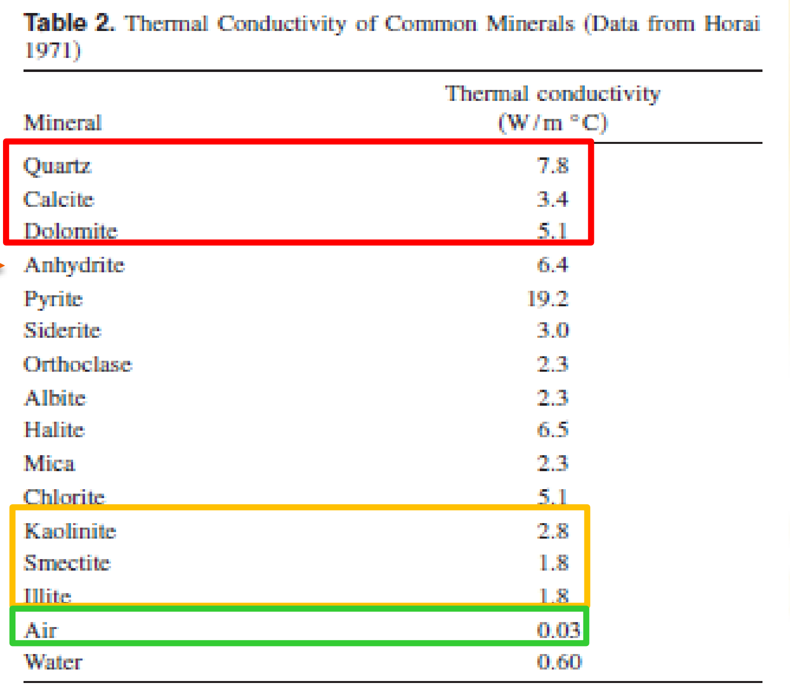
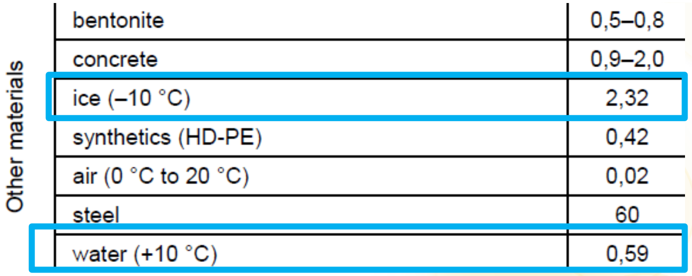


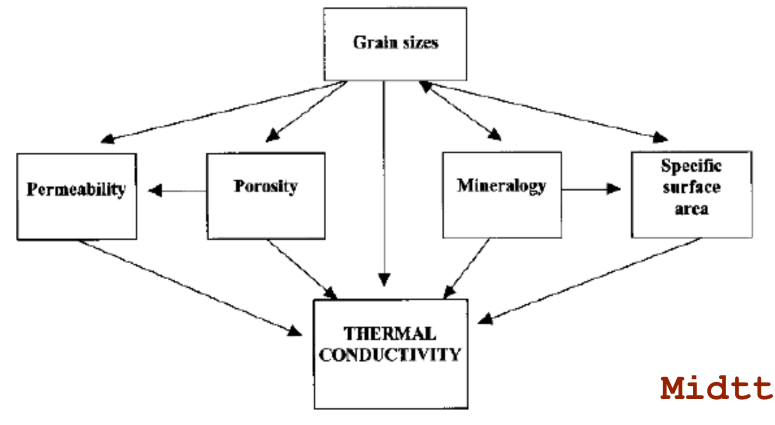
Table 2. Thermal Conductivity of Common Minerals (Data from Horai 1971)

Mineral	Thermal conductivity (W/m °C)
Quartz	7.8
Calcite	3.4
Dolomite	5.1
Anhydrite	6.4
Pyrite	19.2
Siderite	3.0
Orthoclase	2.3
Albite	2.3
Halite	6.5
Mica	2.3
Chlorite	5.1
Kaolinite	2.8
Smectite	1.8
Illite	1.8
Air	0.03
Water	0.60



Other materials	bentonite	0,5–0,8
	concrete	0,9–2,0
	ice (–10 °C)	2,32
	synthetics (HD-PE)	0,42
	air (0 °C to 20 °C)	0,02
	steel	60
	water (+10 °C)	0,59

VDI 4640 Blatt 1_2010

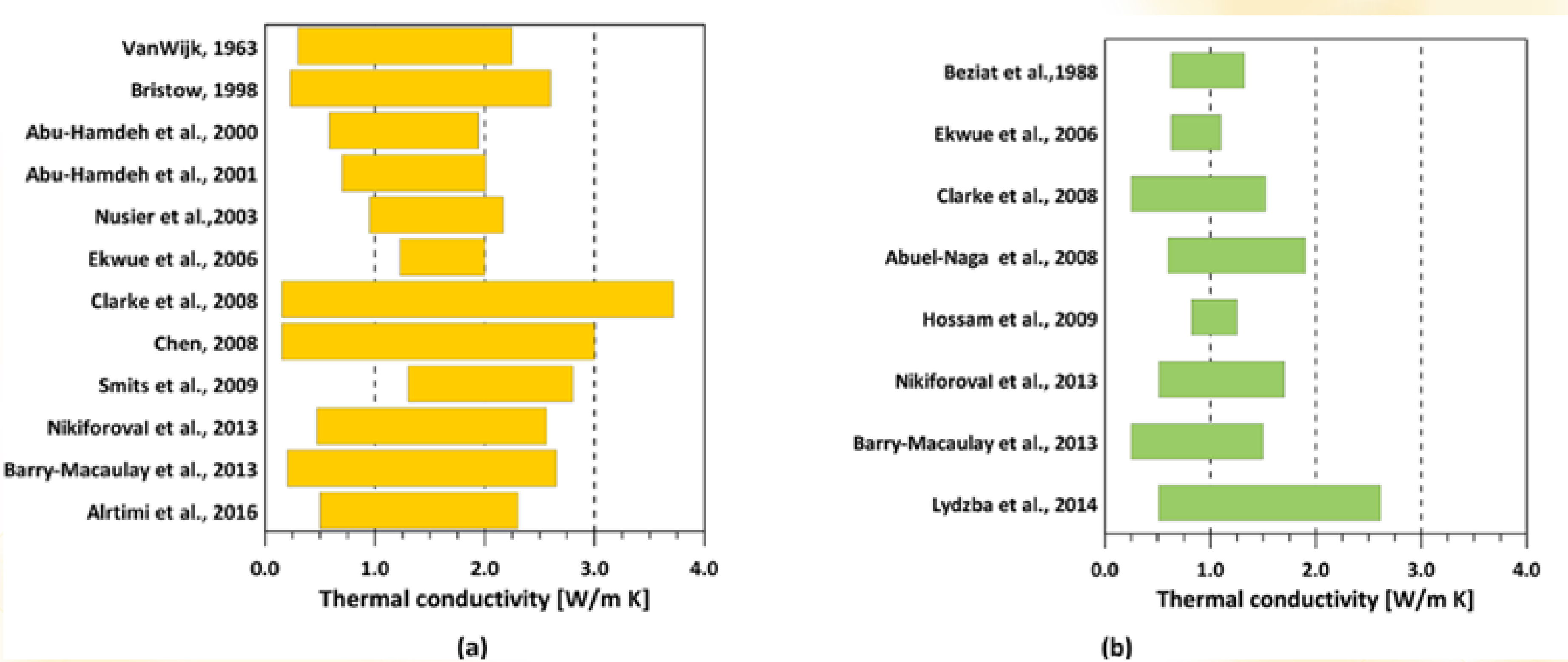


Midttomme, Kirsti e Roaldset, 1998

1. UNDERGROUND THERMAL PERFORMANCES

→ *Effect of mineralogy, water content, state of compaction…*

SAND **SILT / CLAY**



(a) (b)

Dalla Santa et al., 2020 Geothermics

1. UNDERGROUND THERMAL PERFORMANCES

→ Effect of mineralogy, water content, state of compaction…

SAND

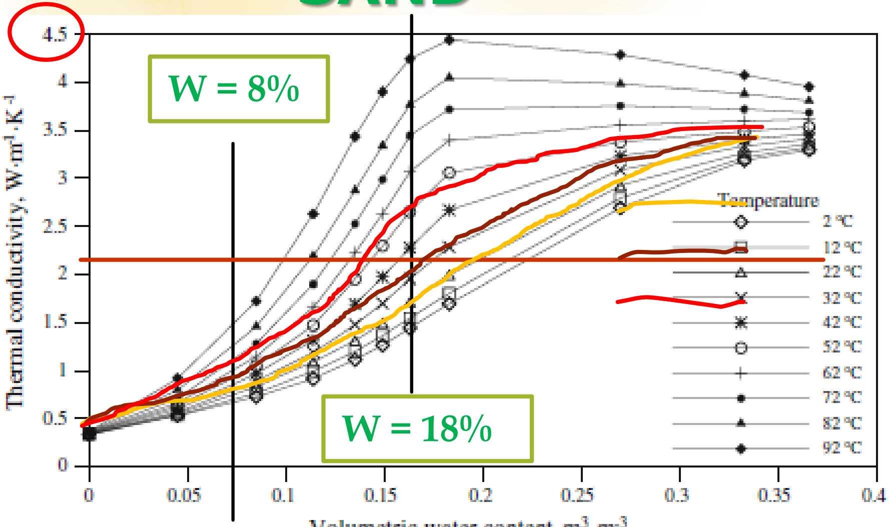
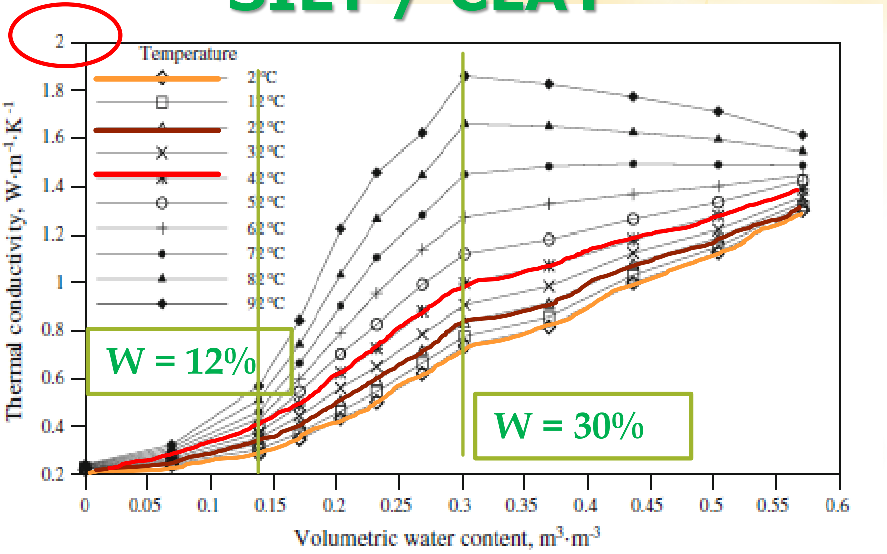


Fig. 2 Variation in thermal conductivity of Ottawa sand with volumetric water content and temperature

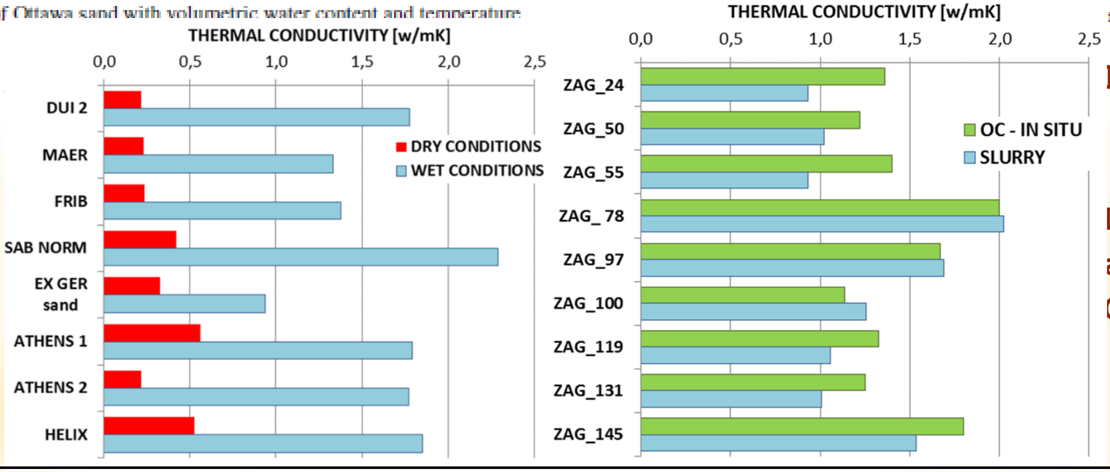
Nicolaev et al.

SILT / CLAY



sandy loam with volumetric water content

laev et al., 2013

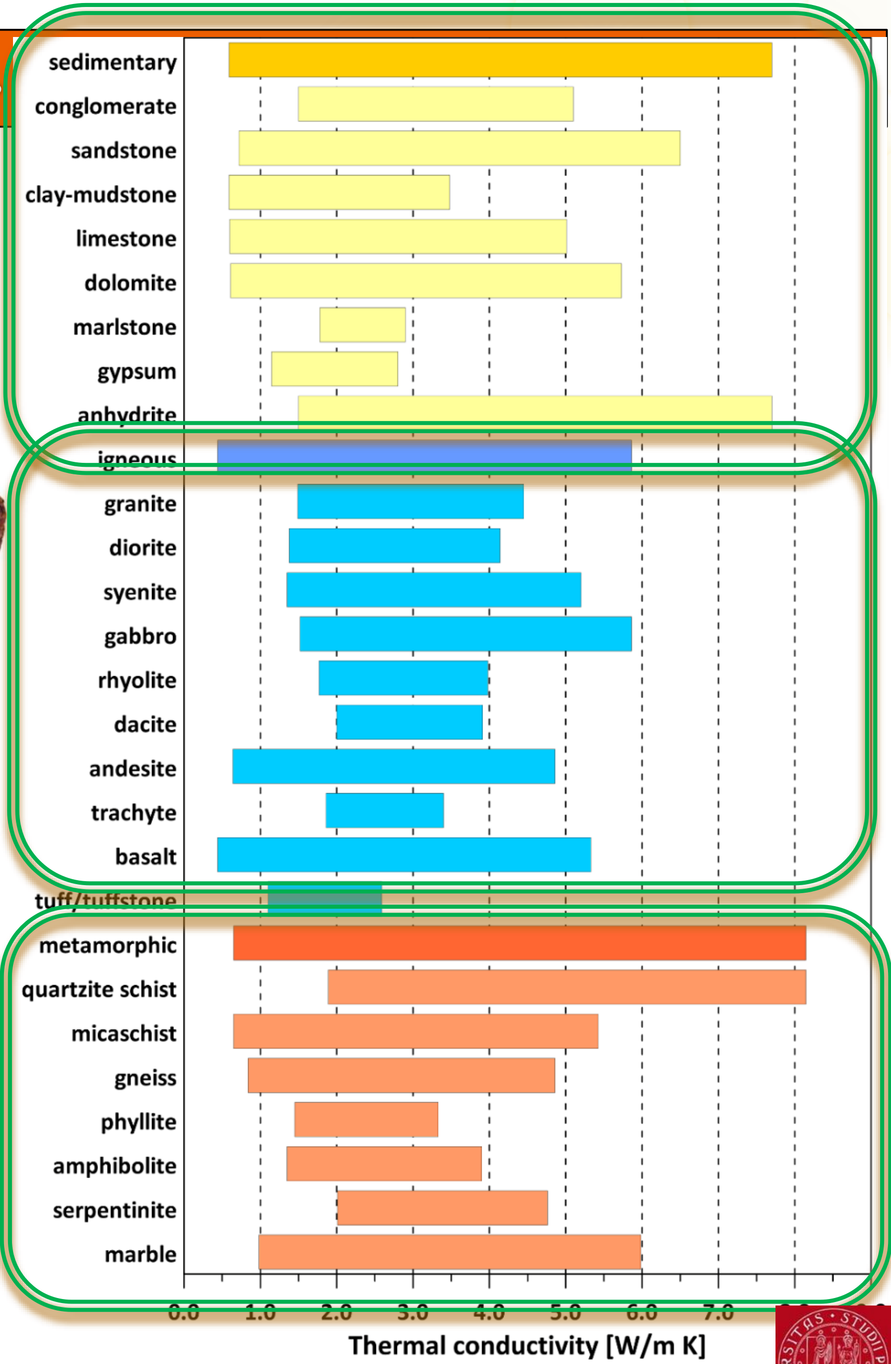


a)

b)

Dalla Santa et al., 2020 Geothermics

1. UNDERGROUND THERMAL

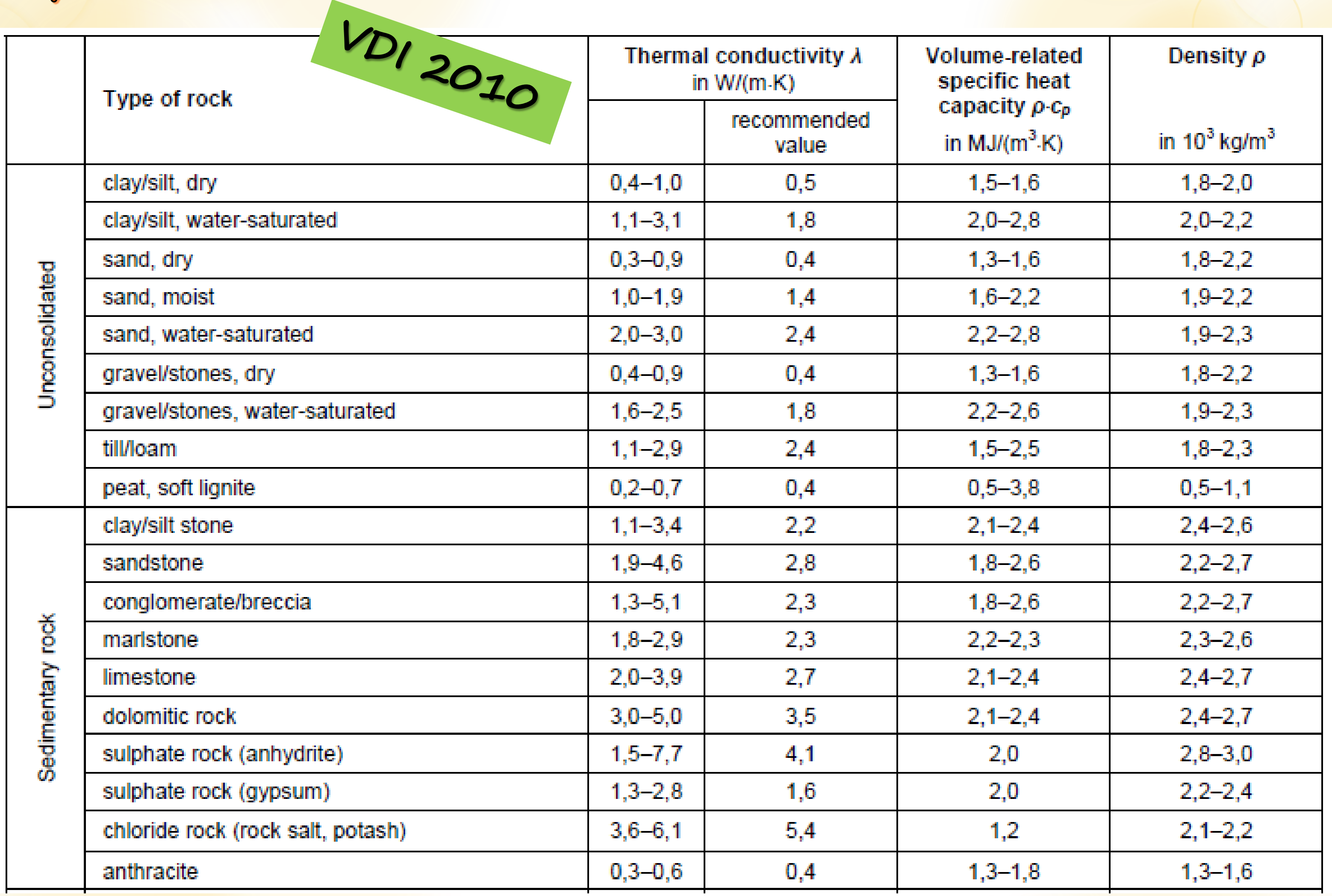


Dalla Santa et al., 2020 Geothermics

1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

a) tabled values



VDI 2010

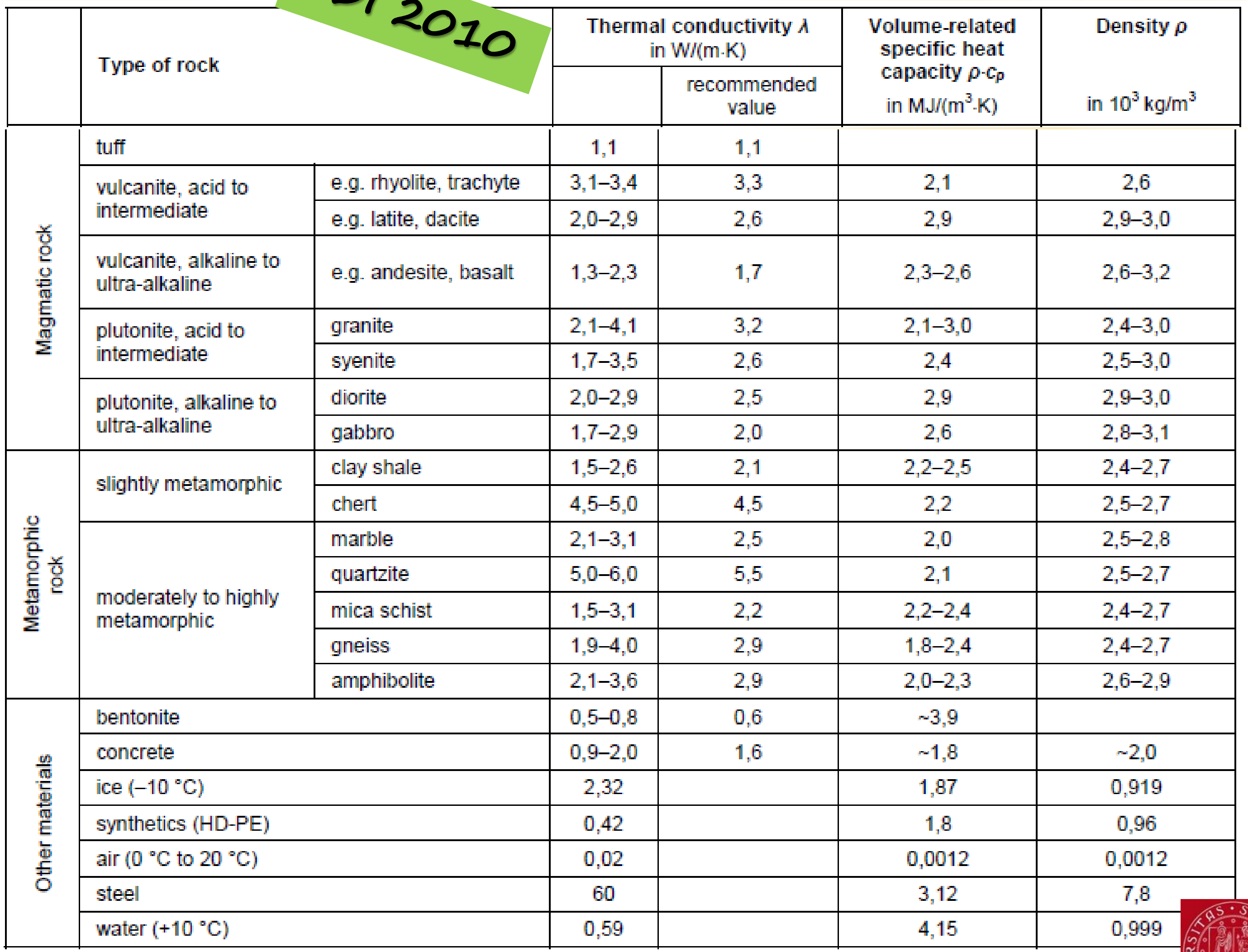
	Type of rock	Thermal conductivity λ in W/(m·K)		Volume-related specific heat capacity $\rho \cdot c_p$ in MJ/(m³·K)	Density ρ in 10³ kg/m³
			recommended value		
Unconsolidated	clay/silt, dry	0,4–1,0	0,5	1,5–1,6	1,8–2,0
	clay/silt, water-saturated	1,1–3,1	1,8	2,0–2,8	2,0–2,2
	sand, dry	0,3–0,9	0,4	1,3–1,6	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

1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

a) tabled values

VDI 2010



	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		
Magmatic rock	tuff		1,1	1,1		
	vulcanite, acid to intermediate	e.g. rhyolite, trachyte	3,1–3,4	3,3	2,1	2,6
		e.g. latite, dacite	2,0–2,9	2,6	2,9	2,9–3,0
	vulcanite, alkaline to ultra-alkaline	e.g. andesite, basalt	1,3–2,3	1,7	2,3–2,6	2,6–3,2
	plutonite, acid to intermediate	granite	2,1–4,1	3,2	2,1–3,0	2,4–3,0
		syenite	1,7–3,5	2,6	2,4	2,5–3,0
	plutonite, alkaline to ultra-alkaline	diorite	2,0–2,9	2,5	2,9	2,9–3,0
		gabbro	1,7–2,9	2,0	2,6	2,8–3,1
Metamorphic rock	slightly metamorphic	clay shale	1,5–2,6	2,1	2,2–2,5	2,4–2,7
		chert	4,5–5,0	4,5	2,2	2,5–2,7
	moderately to highly metamorphic	marble	2,1–3,1	2,5	2,0	2,5–2,8
		quartzite	5,0–6,0	5,5	2,1	2,5–2,7
		mica schist	1,5–3,1	2,2	2,2–2,4	2,4–2,7
		gneiss	1,9–4,0	2,9	1,8–2,4	2,4–2,7
		amphibolite	2,1–3,6	2,9	2,0–2,3	2,6–2,9
Other materials	bentonite		0,5–0,8	0,6	~3,9	
	concrete		0,9–2,0	1,6	~1,8	~2,0
	ice (–10 °C)		2,32		1,87	0,919
	synthetics (HD-PE)		0,42		1,8	0,96
	air (0 °C to 20 °C)		0,02		0,0012	0,0012
	steel		60		3,12	7,8
	water (+10 °C)		0,59		4,15	0,999

1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

a) tabled values

from ASHRAE 2011

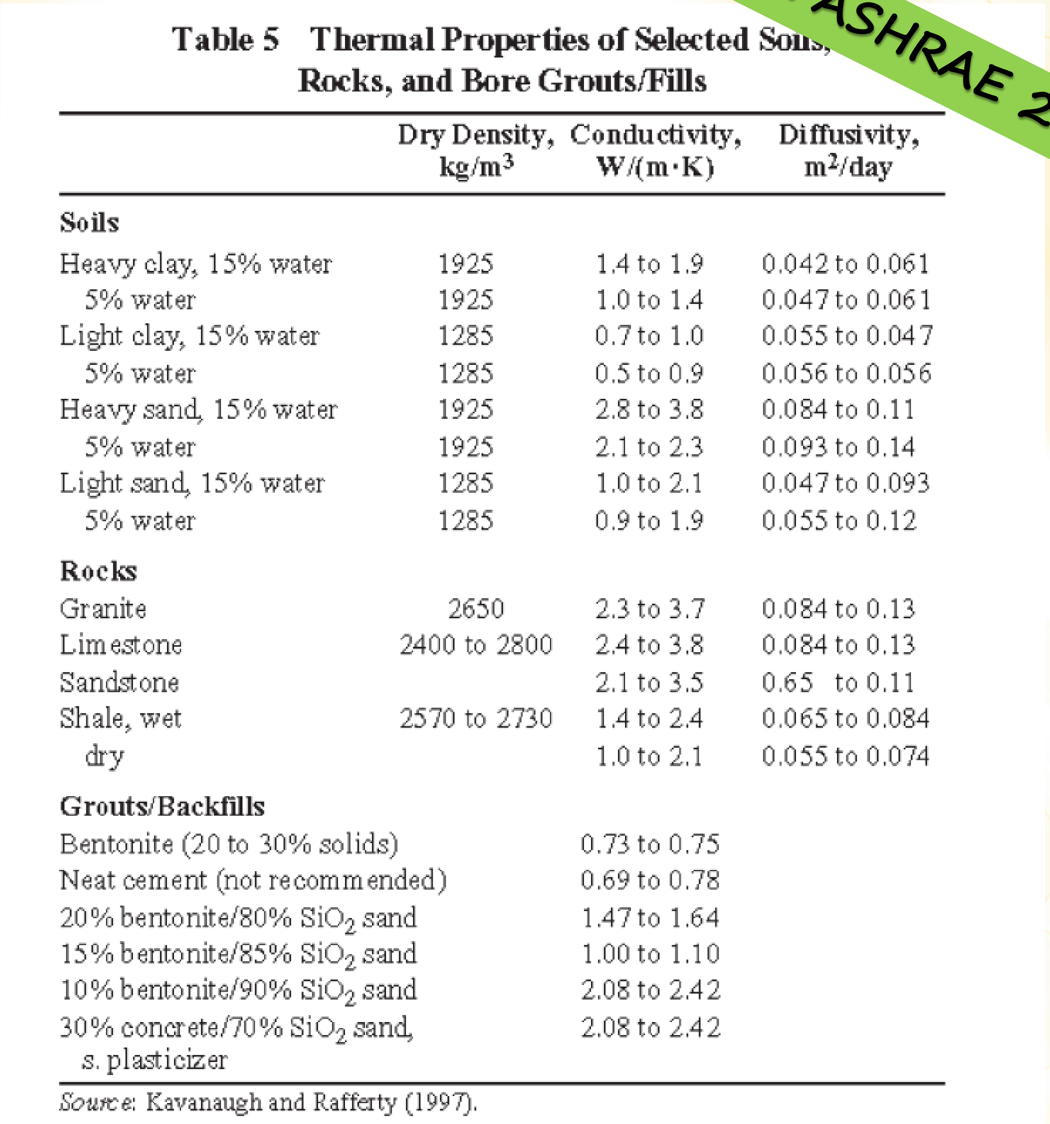


Table 5 Thermal Properties of Selected Soils, Rocks, and Bore Grouts/Fills

	Dry Density, kg/m^3	Conductivity, W/(m·K)	Diffusivity, m^2/day
Soils			
Heavy clay, 15% water	1925	1.4 to 1.9	0.042 to 0.061
5% water	1925	1.0 to 1.4	0.047 to 0.061
Light clay, 15% water	1285	0.7 to 1.0	0.055 to 0.047
5% water	1285	0.5 to 0.9	0.056 to 0.056
Heavy sand, 15% water	1925	2.8 to 3.8	0.084 to 0.11
5% water	1925	2.1 to 2.3	0.093 to 0.14
Light sand, 15% water	1285	1.0 to 2.1	0.047 to 0.093
5% water	1285	0.9 to 1.9	0.055 to 0.12
Rocks			
Granite	2650	2.3 to 3.7	0.084 to 0.13
Limestone	2400 to 2800	2.4 to 3.8	0.084 to 0.13
Sandstone		2.1 to 3.5	0.65 to 0.11
Shale, wet	2570 to 2730	1.4 to 2.4	0.065 to 0.084
dry		1.0 to 2.1	0.055 to 0.074
Grouts/Backfills			
Bentonite (20 to 30% solids)		0.73 to 0.75	
Neat cement (not recommended)		0.69 to 0.78	
20% bentonite/80% SiO_2 sand		1.47 to 1.64	
15% bentonite/85% SiO_2 sand		1.00 to 1.10	
10% bentonite/90% SiO_2 sand		2.08 to 2.42	
30% concrete/70% SiO_2 sand, s. plasticizer		2.08 to 2.42	

Source: Kavanaugh and Rafferty (1997).

1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

b) direct measurements

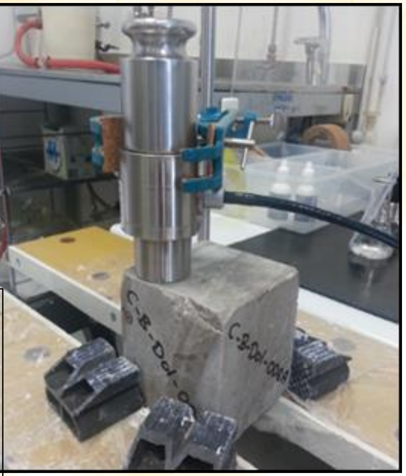
→STEADY STATE METHODS:

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



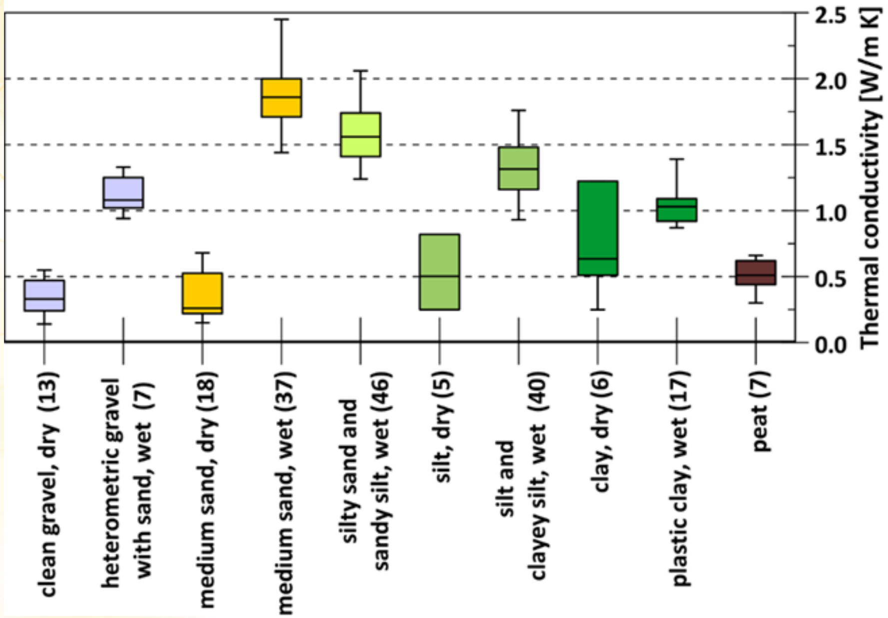
→TRANSIENT STATE METHODS:

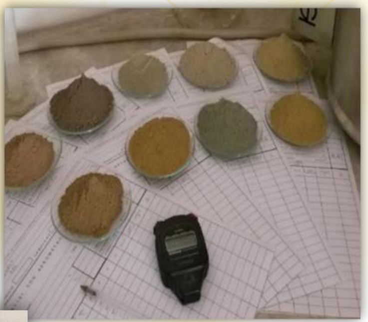
the time-dependent heat dissipation within a material is monitored, by applying a momentary and known heat IMPULSE to the sample

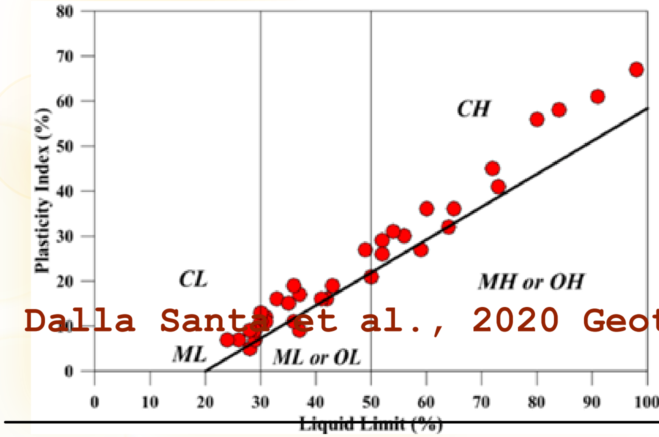
1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

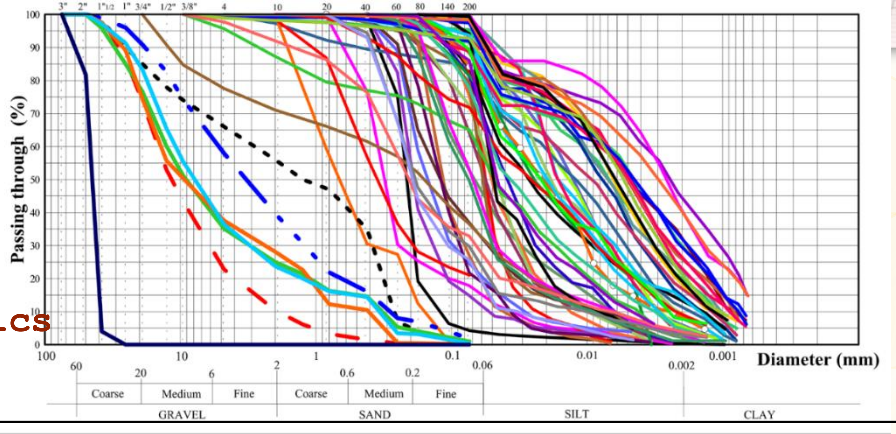
b) direct measurements







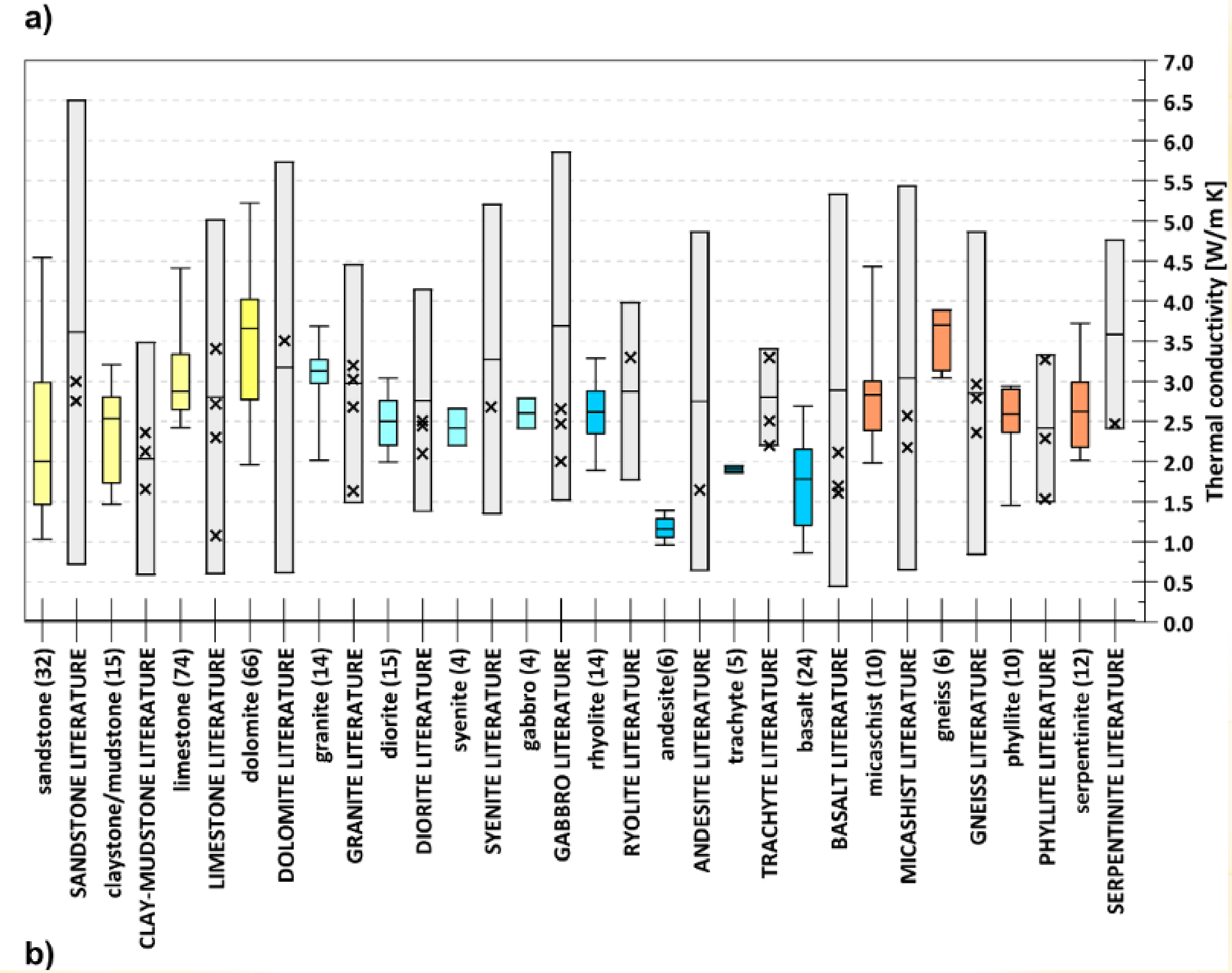
Dalla Santa et al., 2020 Geothermics



1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

b) direct measurements

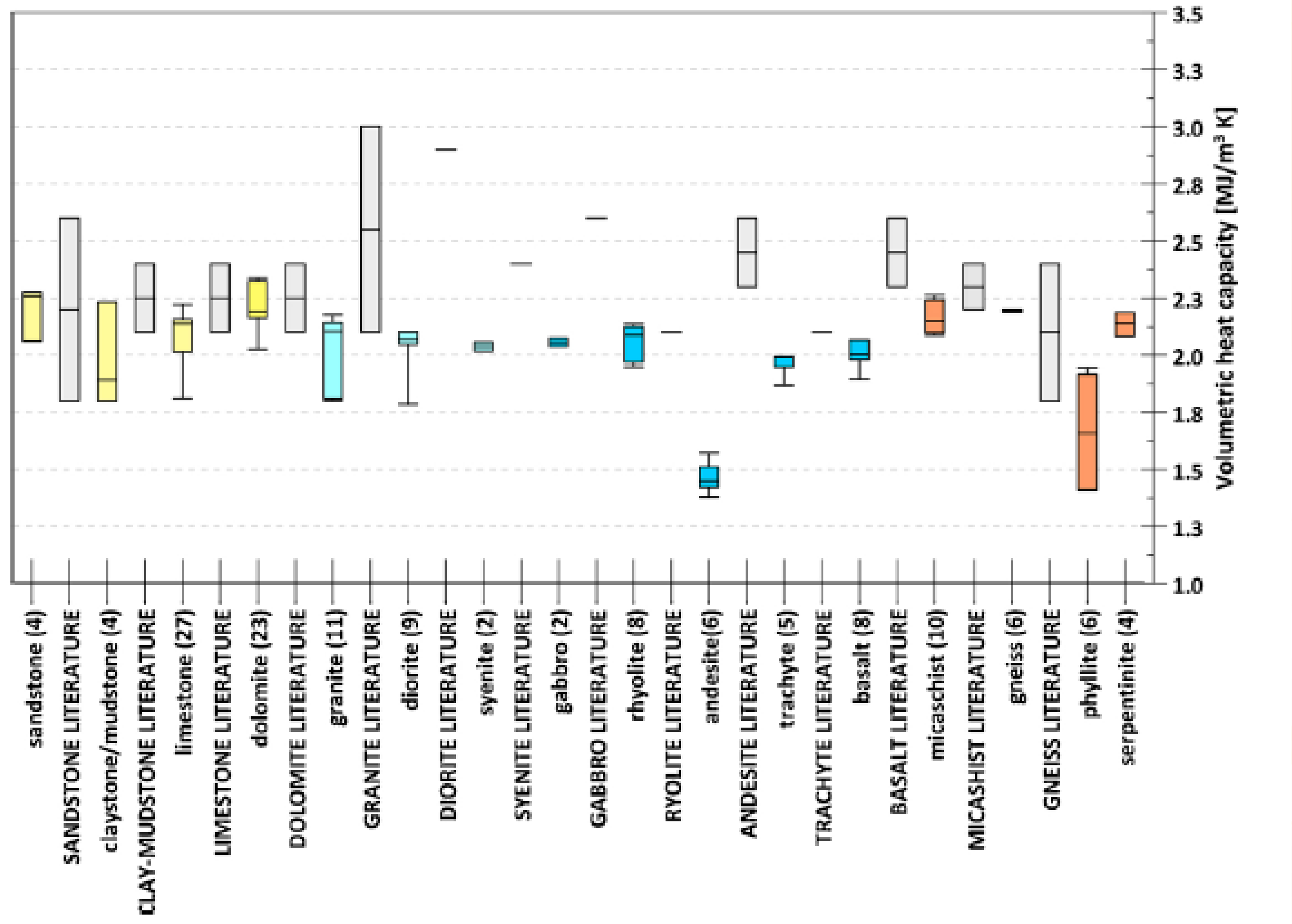


Dalla Santa et al., 2020 Geothermics

1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

b) direct measurements

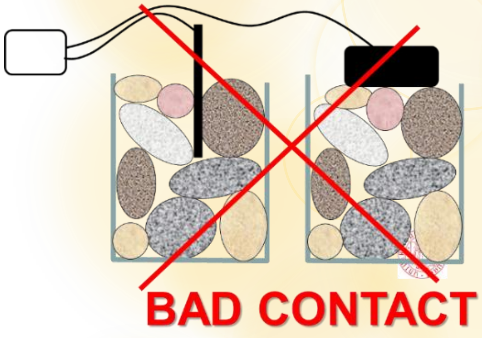


Dalla Santa et al., 2020 Geothermics

1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

b) direct measurements

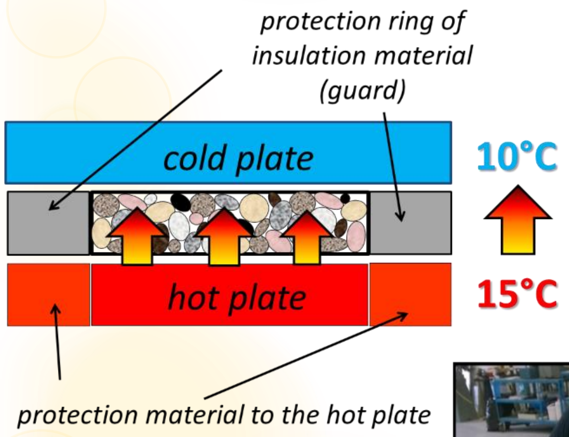


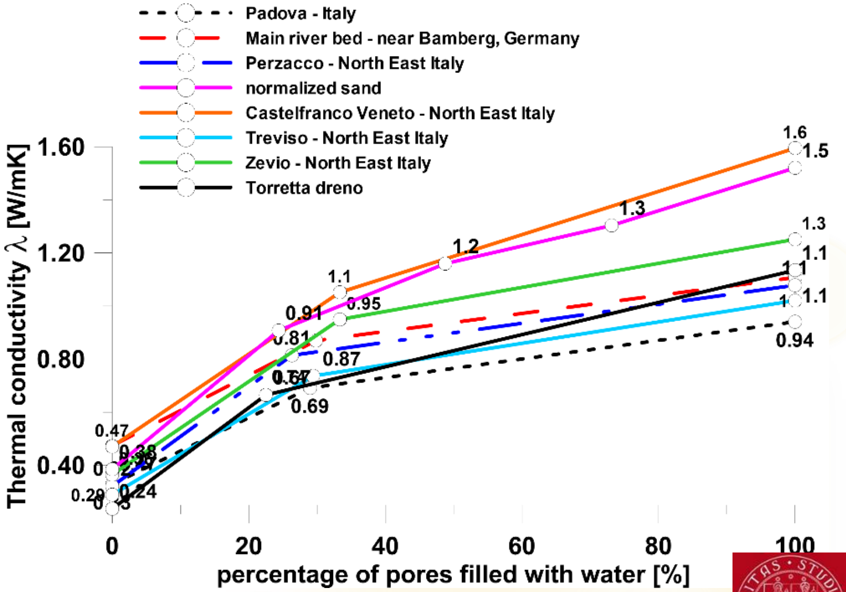
GRAVEL

- ✓ very coarse sediment size
- ✓ variability of the mineralogical composition

GUARDED HOT PLATE INSTRUMENT (steady state method)

TAURUS 800 modified on purpose





1. UNDERGROUND THERMAL PERFORMANCES

ROCK / SEDIMENTS THERMAL PROPERTIES

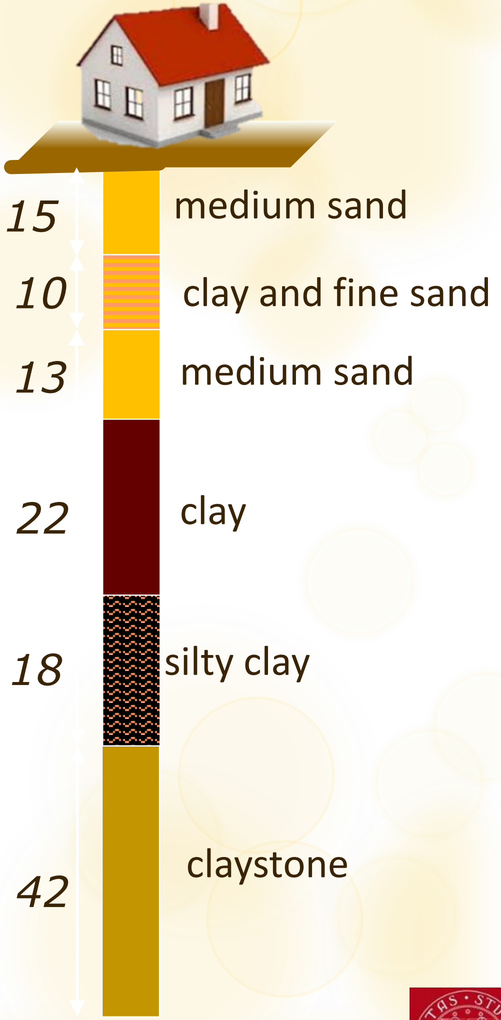
both a) and b) HOW DO YOU APPLY THEM?

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

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

VDI 2010

	Type of rock				Density ρ in 10^3 kg/m^3
Unconsolidated	clay/silt, dry	0,4–1,0	[illegible]	[illegible]	1,8–2,0
	clay/silt, water-saturated	1,1–3,1	1,8	[illegible]	2,0–2,2
	sand, dry	0,3–0,9	0,4	[illegible]	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	CONS
Very quick	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	CONS
Performed directly on purpose	Quite hard: • Requires samples • Time/cost consuming • Prone to measurement errors

1. UNDERGROUND THERMAL PERFORMANCES

c) THERMAL RESPONSE TEST

- **From TRT results**

PROS

- Measurement of the undisturbed ground temperature
- **Global** thermal exchange capacity + thermal resistance of the probe

Global = (of the whole system = local geological setting + testing probe)

CONS

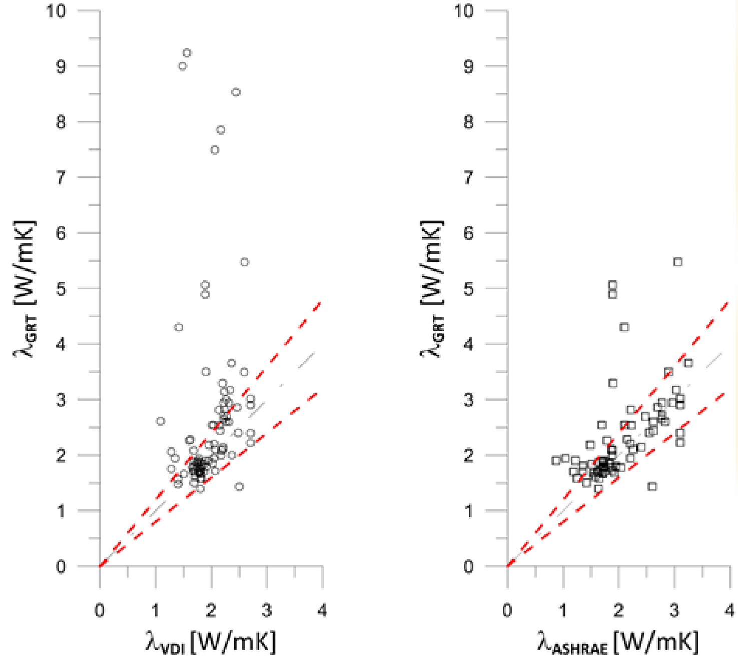
- **Global** thermal exchange capacity

Cannot detect the contribution of each deposit/ geological layer

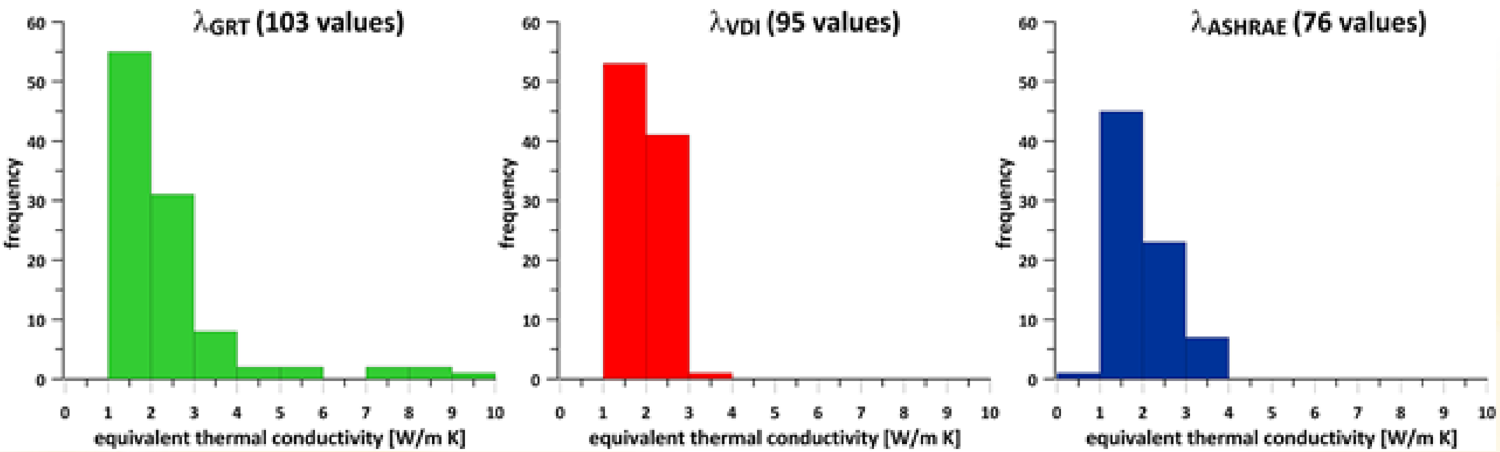
1. UNDERGROUND THERMAL PERFORMANCES

a) b) and c) COMPARISON

103 TRTs/stratigraphies



- **Convection contribution** in correspondence to the crossed aquifers → in geological context with aquifers only the TRT can correctly evaluate the global λ



- **The tabled values neglect some lithologies** → it is impossible to apply in particular contexts

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF THE SITE

LOCAL GEOLOGICAL SETTING

→ <u>is the "invariant" element of the system</u>

→underground thermal/energetic performances

→best drilling and installation technique

→GSHE geometry (total length/well diameter/single GHE length)

→environmental and regulatory constraints

identification of the <u>best</u> GSHE (technical + economic point of view)

2. UNDERGROUND THERMAL PERFORMANCES

d) DISTRIBUTED THERMAL RESPONSE TEST

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

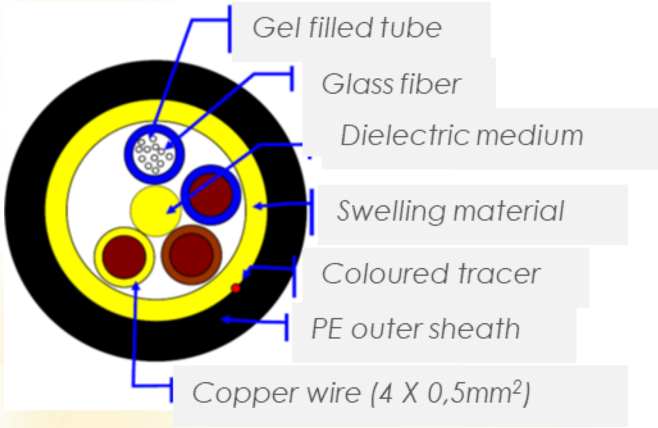
Monitoring well equipped with an **hybrid fiber optic cable**:

- several copper wires
- bundle of optic fibers

to **inject heat** by means of electric input (Joule effect) to perform the TRT

✓ **Measure temperature over time** both when the wires are heating or not (active/passive mode)

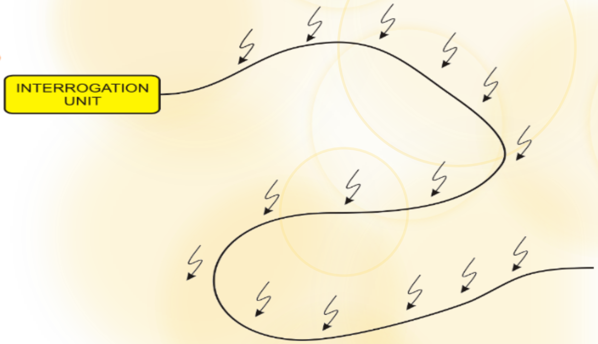
✓ with **high temporal** and **spatial resolution (Distributed Thermal Sensing)**

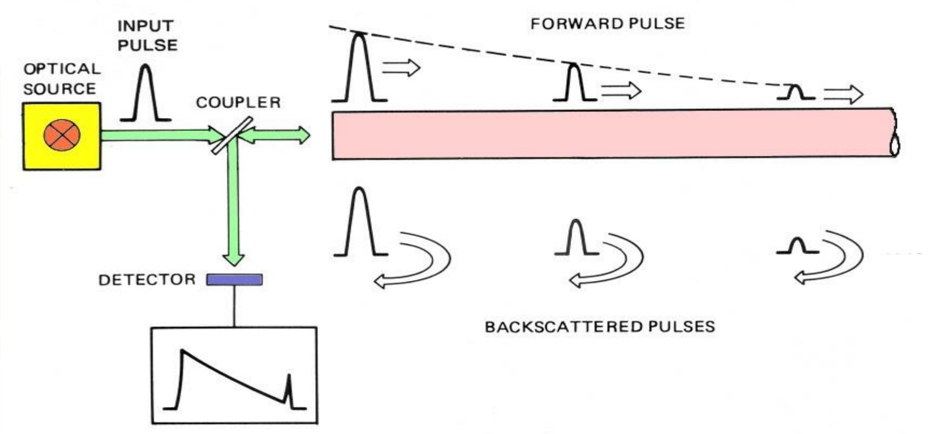


Aim: Distinguish the thermal behaviour of single geological layers

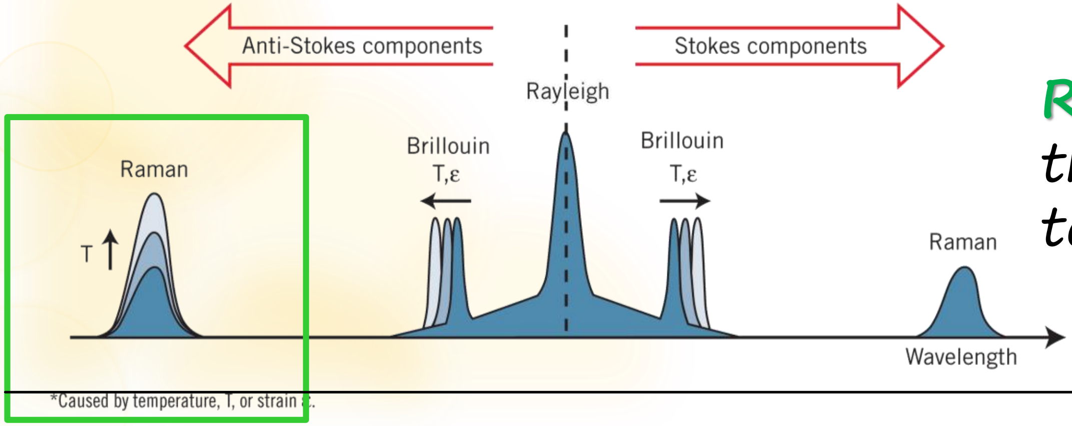
d) DISTRIBUTED THERMAL RESPONSE TEST

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**

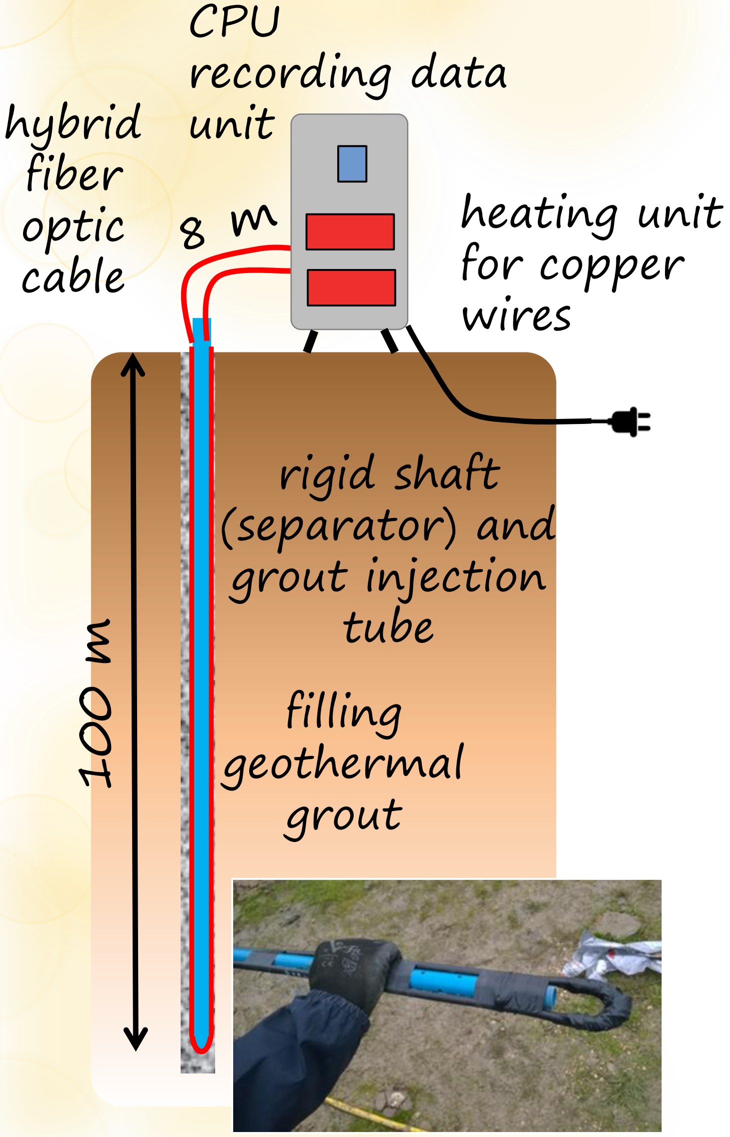


*Caused by temperature, T, or strain ε.

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)

1. UNDERGROUND THERMAL PERFORMANCES

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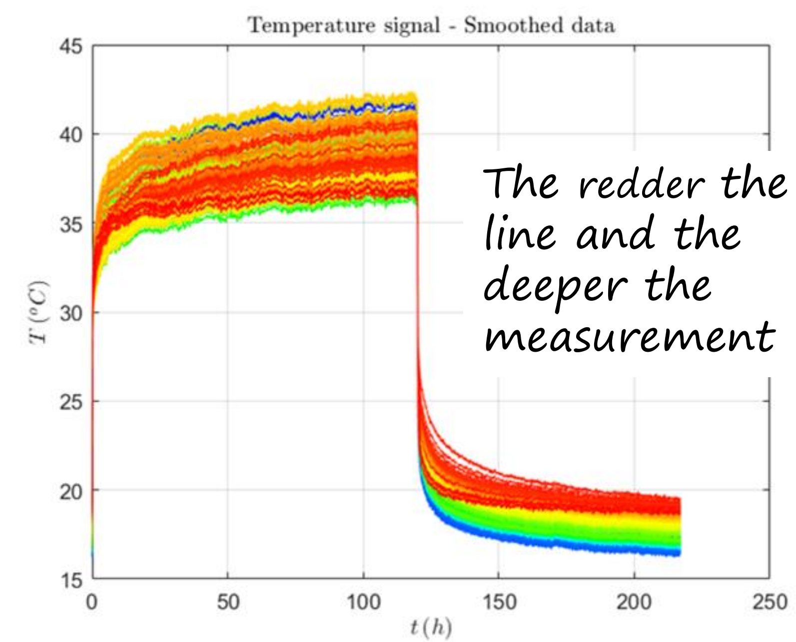
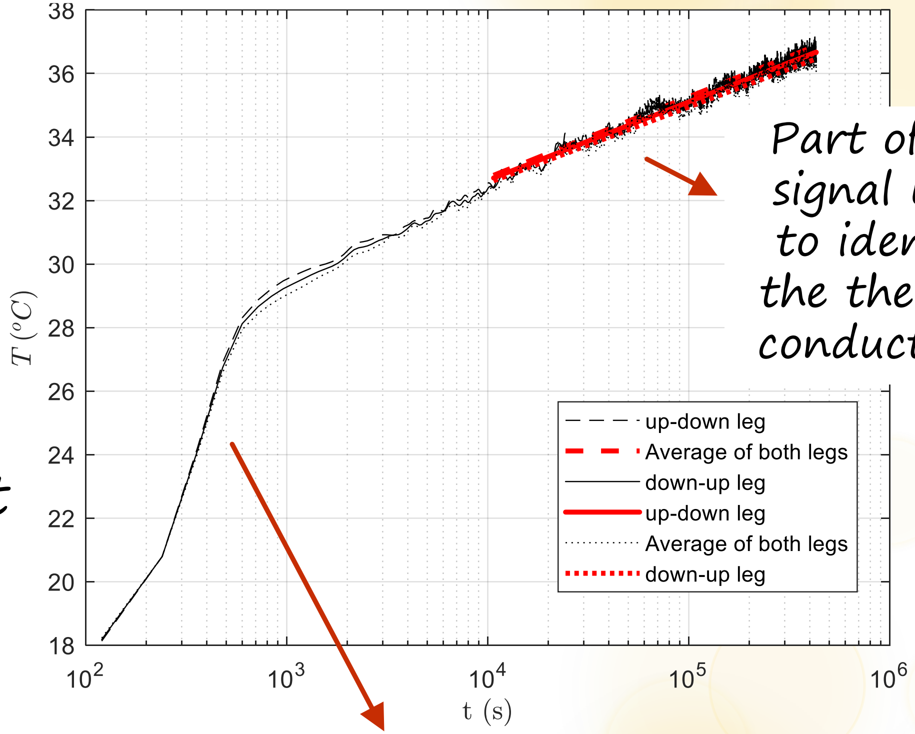
d) DISTRIBUTED THERMAL RESPONSE TEST



The redder the line and the deeper the measurement

1-order approximation of the Infinite Line-Source model



Part of the signal used to identify the thermal conductivity

signal related to the thermal resistance of the probe and the grout

- the temperature measured at different depths cooled down at different rates, **depending on the thermal properties of the surrounding deposits.**

→ the values were derived every 1m

→ the entire vertical profile

1. UNDERGROUND THERMAL PERFORMANCES

d) DISTRIBUTED THERMAL RESPONSE TEST

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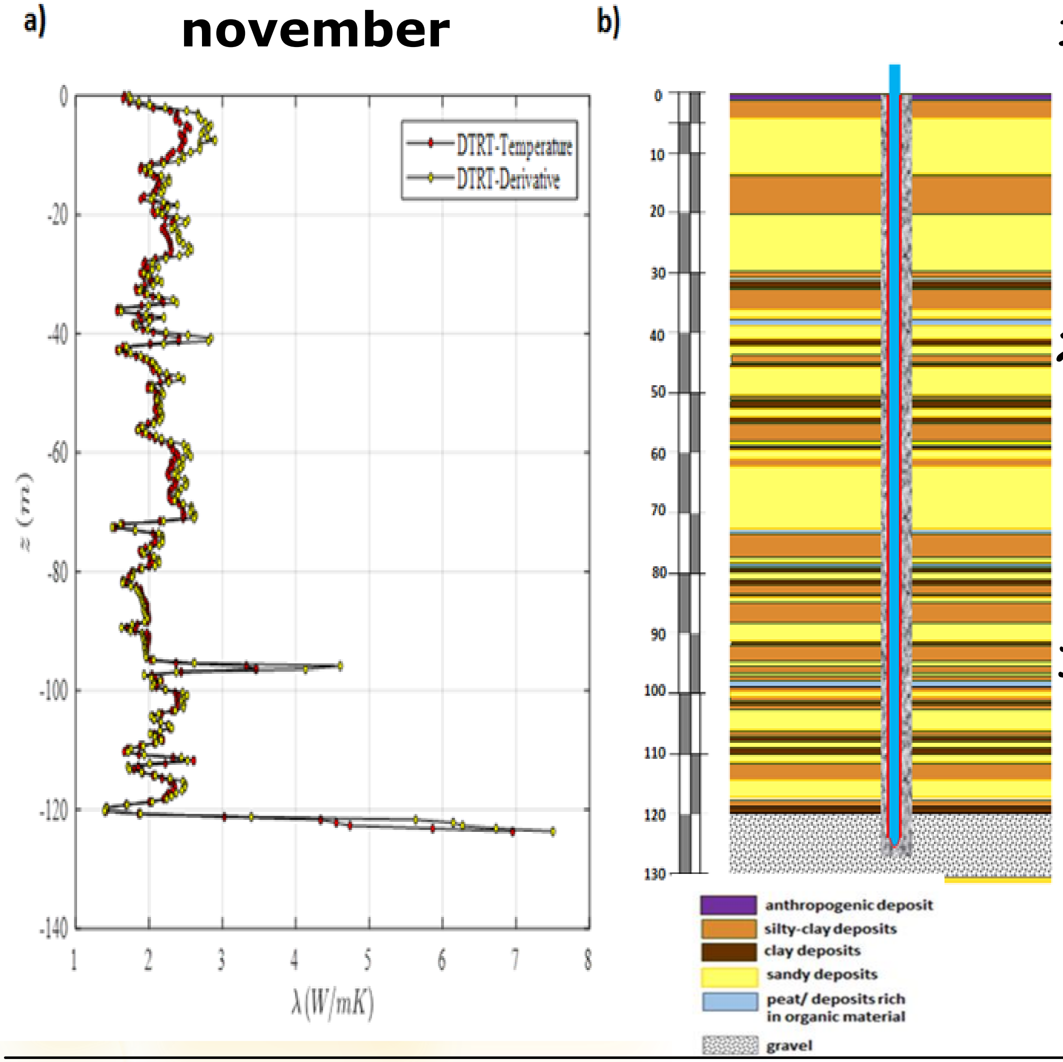

1. **correlation between the λ values and the geology** (DTS spatial resolution 1 m → better in the layers of higher thickness)
2. **correct identification** of a very high heat exchange capability in correspondence to the ***gravel deposit*** (→high groundwater flow)
3. significant contribution → causes the measured difference

Method	Thermal conductivity λ (W/mK)	Monitored length (m)
TRT	**1.68**	**119**
DTRT - Temperature	**2.17**	**124**
DTRT - Derivative	**2.28**	**124**

1. UNDERGROUND THERMAL PERFORMANCES

d) DISTRIBUTED THERMAL RESPONSE TEST

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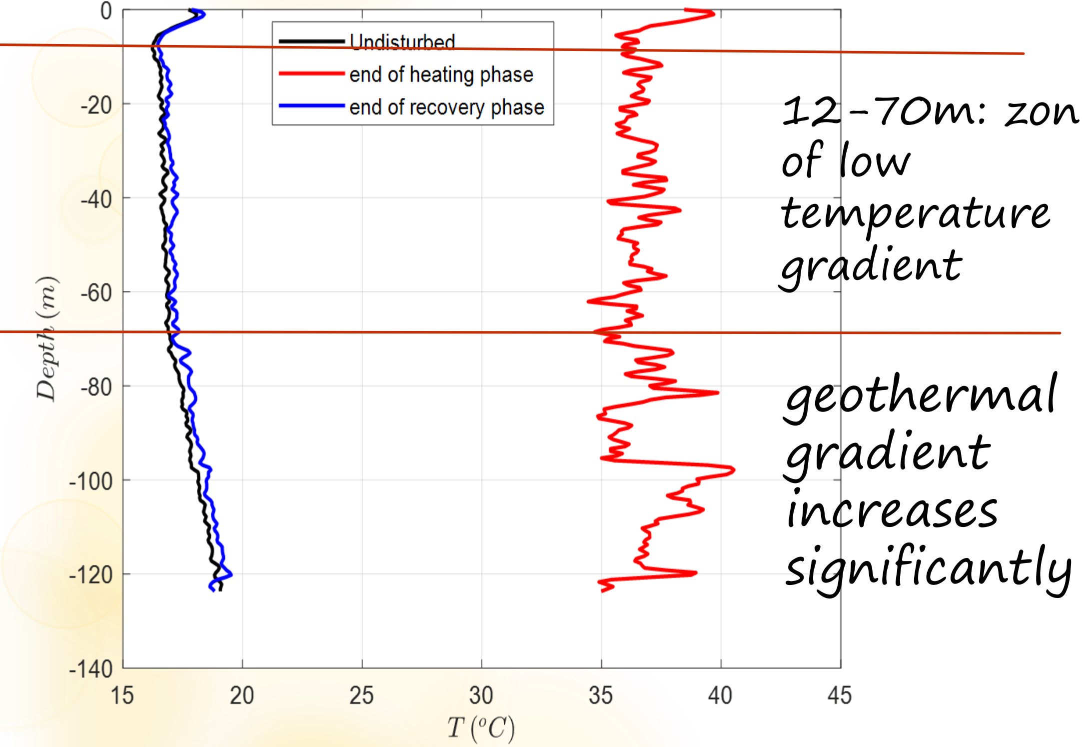
TEMPERATURE PROFILE



0-12m: clearly visible seasonal variation

12-70m: zone of low temperature gradient

geothermal gradient increases significantly

FINAL REMARKS

→ able to detect the different thermal behavior of the different layers

can drive the optimization of the GHE design

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF THE SITE

LOCAL GEOLOGICAL SETTING

→ *is the "invariant" element of the system*

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→best drilling and installation technique

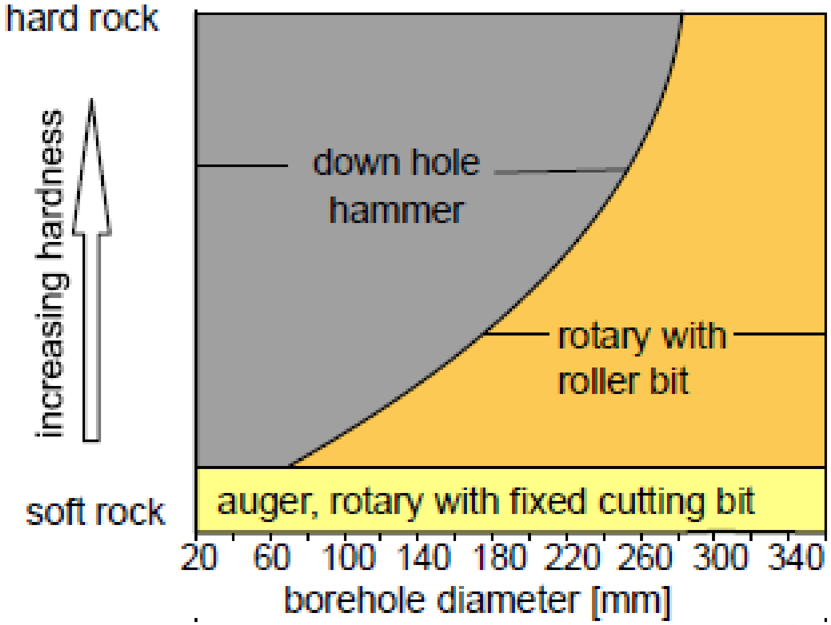
→GSHE geometry (total length/well diameter/single GHE length)

→environmental and regulatory constraints

identification of the best GSHE (technical + economic point of view)

2. BEST DRILLING AND INSTALLATION TECHNIQUES

- ✓ **auger** (a screw-type drill removing soil from the hole while rotating, the way standard drills for wood and metal work)
- ✓ **the rotary system** with a fluid flushing the borehole (with different tools for cutting)
- ✓ **various hammer systems** (including cable-tool drilling)

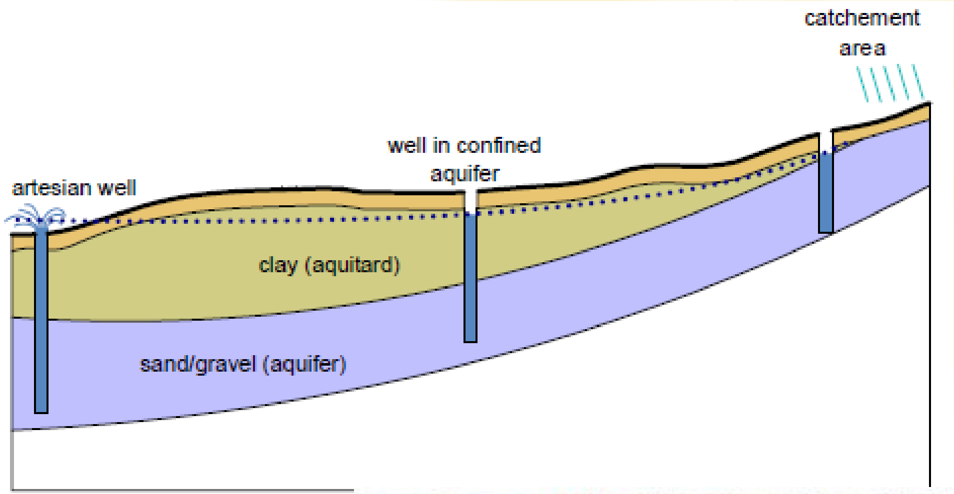


after data from Hytti (1987)

Choosing elements:

1. **Rock hardness**
2. **Presence of aquifers**
3. **Hole stability**

2. BEST DRILLING AND INSTALLATION TECHNIQUES



The pressure of the groundwater controls the water table in a well

\+ in layers where the catchment area is higher than the drilling site

\+ where layers with low permeability cover the aquifer

→ groundwater pressure level > physical upper boundary of the aquifer

→water in the well will rise

It is better to not to install a BHE in an artesian aquifer

2. BEST DRILLING AND INSTALLATION TECHNIQUES

Auger drilling

The drill cuttings are transported to the surface by a rotating auger

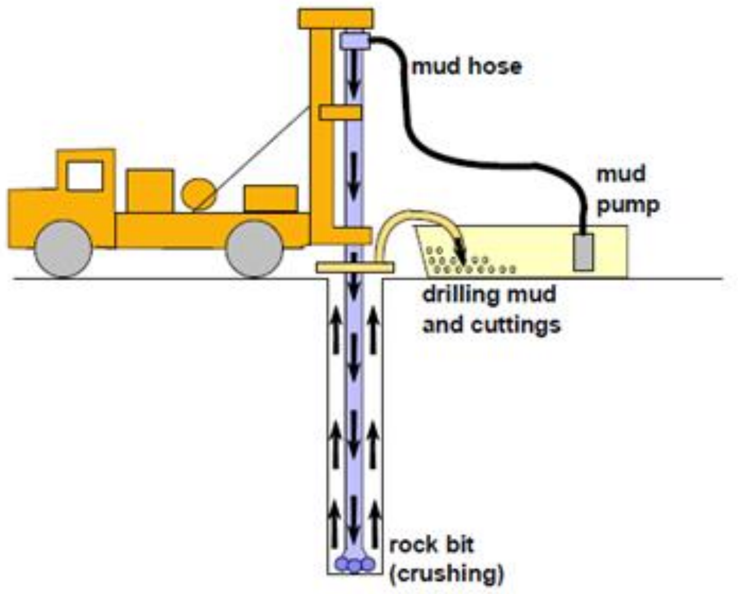
→ Augers are available at various diameters and with either a solid rod in the centre or a tube

Ø: 63-350 mm
depth: 15-20m MAX

→ used in soft, but sufficiently stable ground

2. BEST DRILLING AND INSTALLATION TECHNIQUES

Rotary drilling technique



by rotating a **drill bit** (tricone or chevron bit) to cut or crush the rock and the sediments, and flushing the hole

The drill cuttings are carried to the surface by a drilling fluid (water or mud/bentonite) pumped down through the hollow drill string

→ wide amounts of water supply + equipment for mud handling
→ additional space

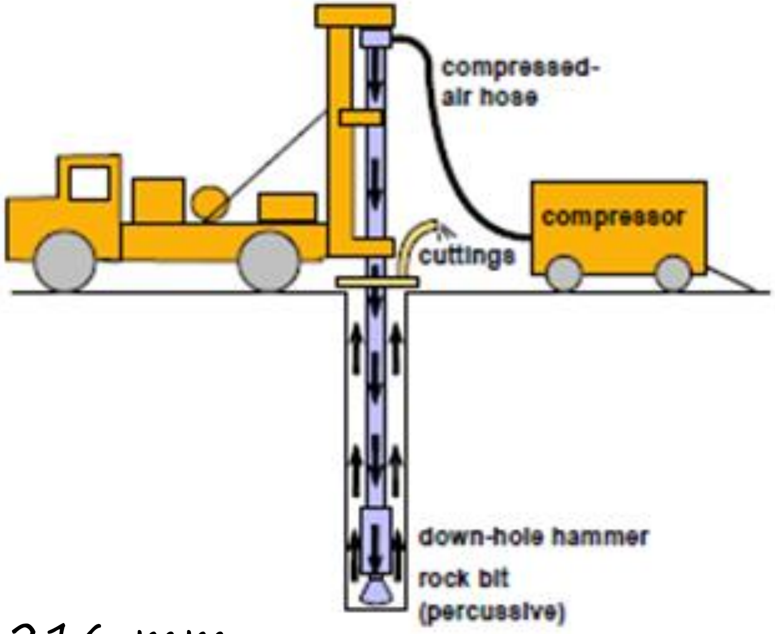
Ø: 89 - 300 mm
depth: 100 - 200 m

→ in sediments as well as in medium to hard rock
→ quite fast only in loose sediments, always relatively slow in the other cases
→ In loose sediment requires casing

2. BEST DRILLING AND INSTALLATION TECHNIQUES

Down-hole hammer drilling

combines rotation and percussion



Compressed air is used for operating the hammer and for transporting the cuttings to the surface
→ powerful compressor
→ higher costs (use of the compressor) + consumed fuel

Ø: 100-216 mm
length: > 100 -150 m

→ relatively high drilling velocity in medium hard to very hard rock
→ if presence of loose sediments in the stratigraphic succession→ casing required, thus elongating the drilling time and costs

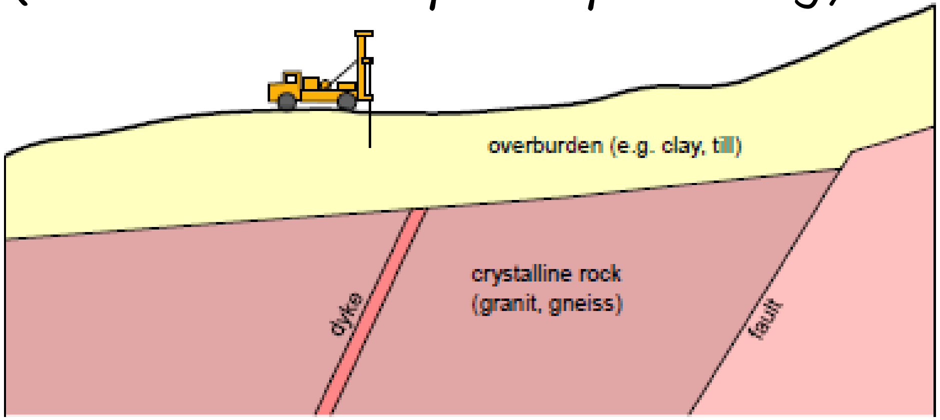
2. BEST DRILLING AND INSTALLATION TECHNIQUES

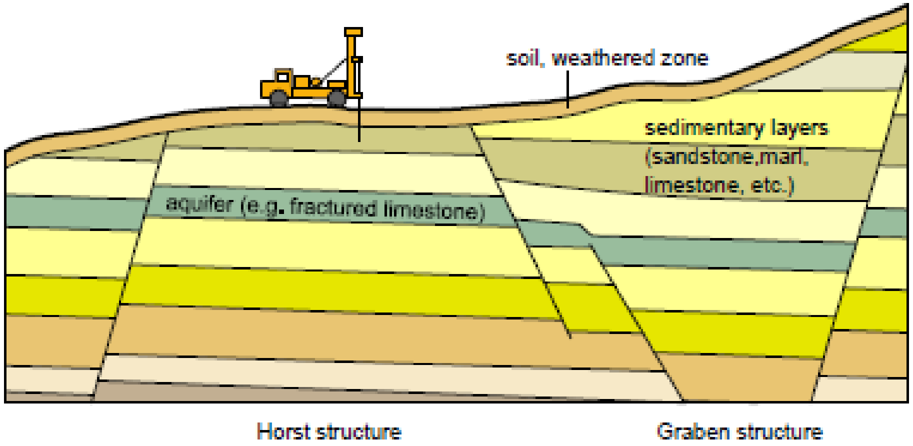
The drilling technology suitable on a given site is mainly dictated by the geological and hydrogeological conditions

1). Hard rock under a softer layer of sediments (from less than 1m to tens of m)

drilling with casing through the overburden depositional cover and open hole in rock (BHE mostly not grouted)

(Northern Europe, Alps Valley)





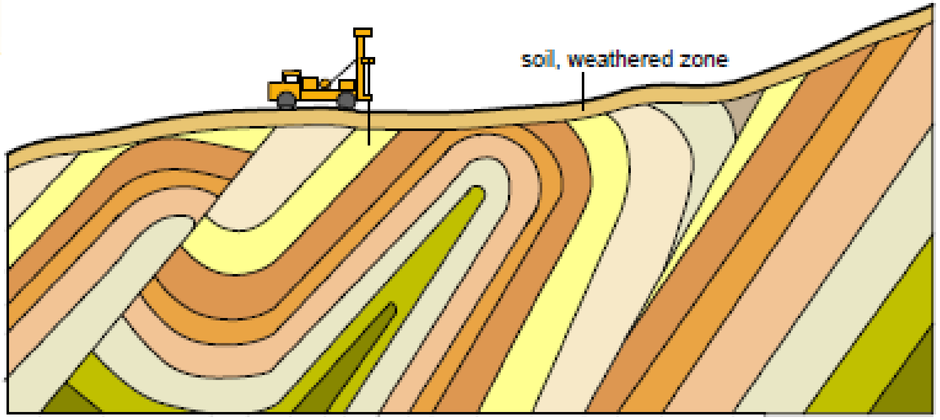
2) Mesozoic sediments resting sub-horizontal or titled, often intersected by faults.

Risk for confined or artesian aquifers

Drilling technique depends on rock hardness

BHE needs to be grouted

2. BEST DRILLING AND INSTALLATION TECHNIQUES



Saddle structure

3) Sedimentary rock strata folded and faulted, often metamorphosed

Groundwater can be found in fissures and fractures

Drilling mostly with DTH, sometimes rotary

Grouting always required

(Pyrenees, Alps, Carpathians)

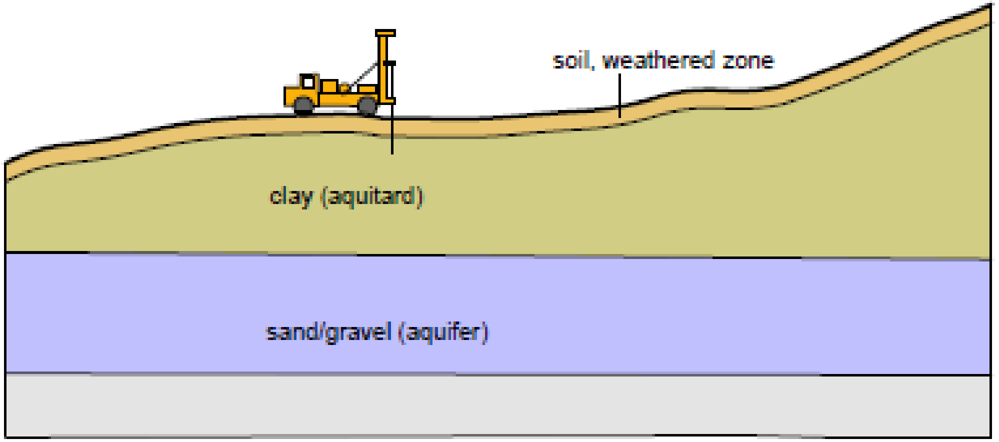
4) Mostly unconsolidated sediments stacked on each other

Risk of confined or artesian groundwater

Drilling mostly with auger or rotary rigs, often using casing to stabilize the hole

BHE needs to be grouted

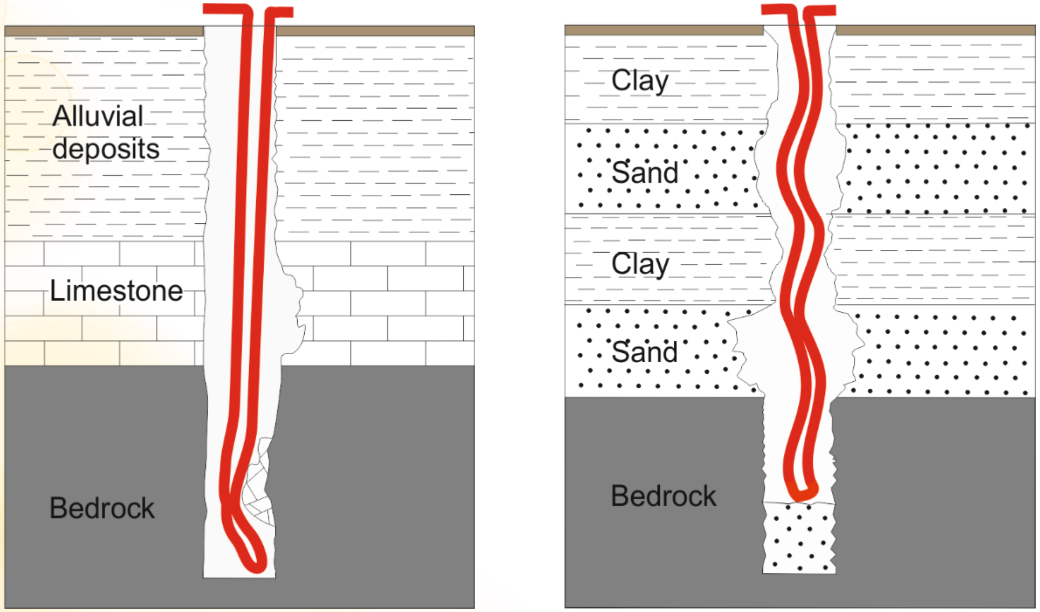
(sedimentary basins)



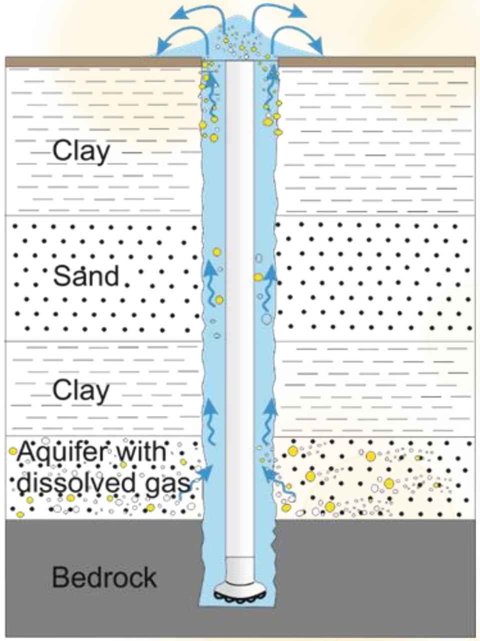
2. BEST DRILLING AND INSTALLATION TECHNIQUES

Uncorrect installations due to geological occurrences

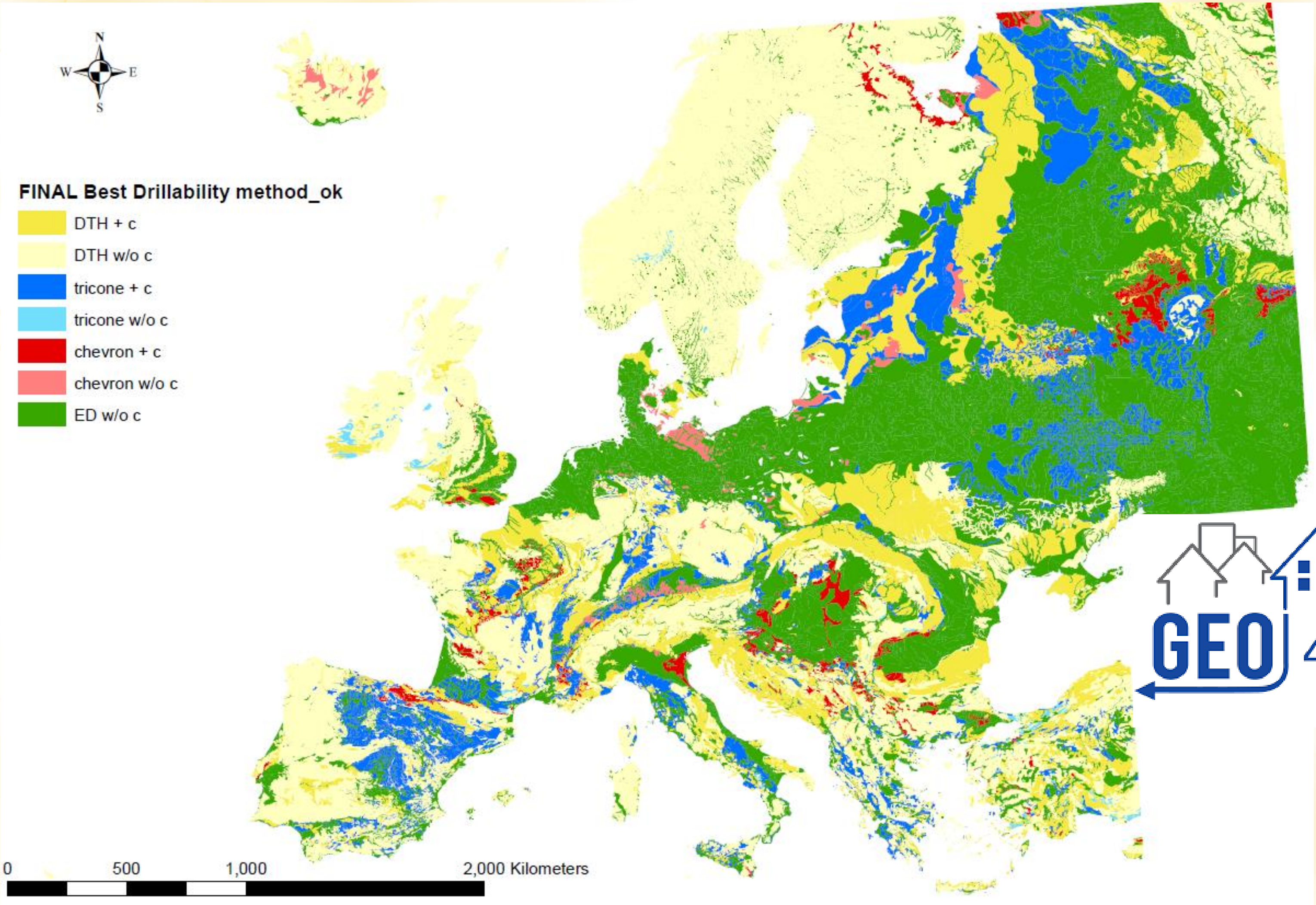
partial collapse of the material into the well



high groundwater pressure

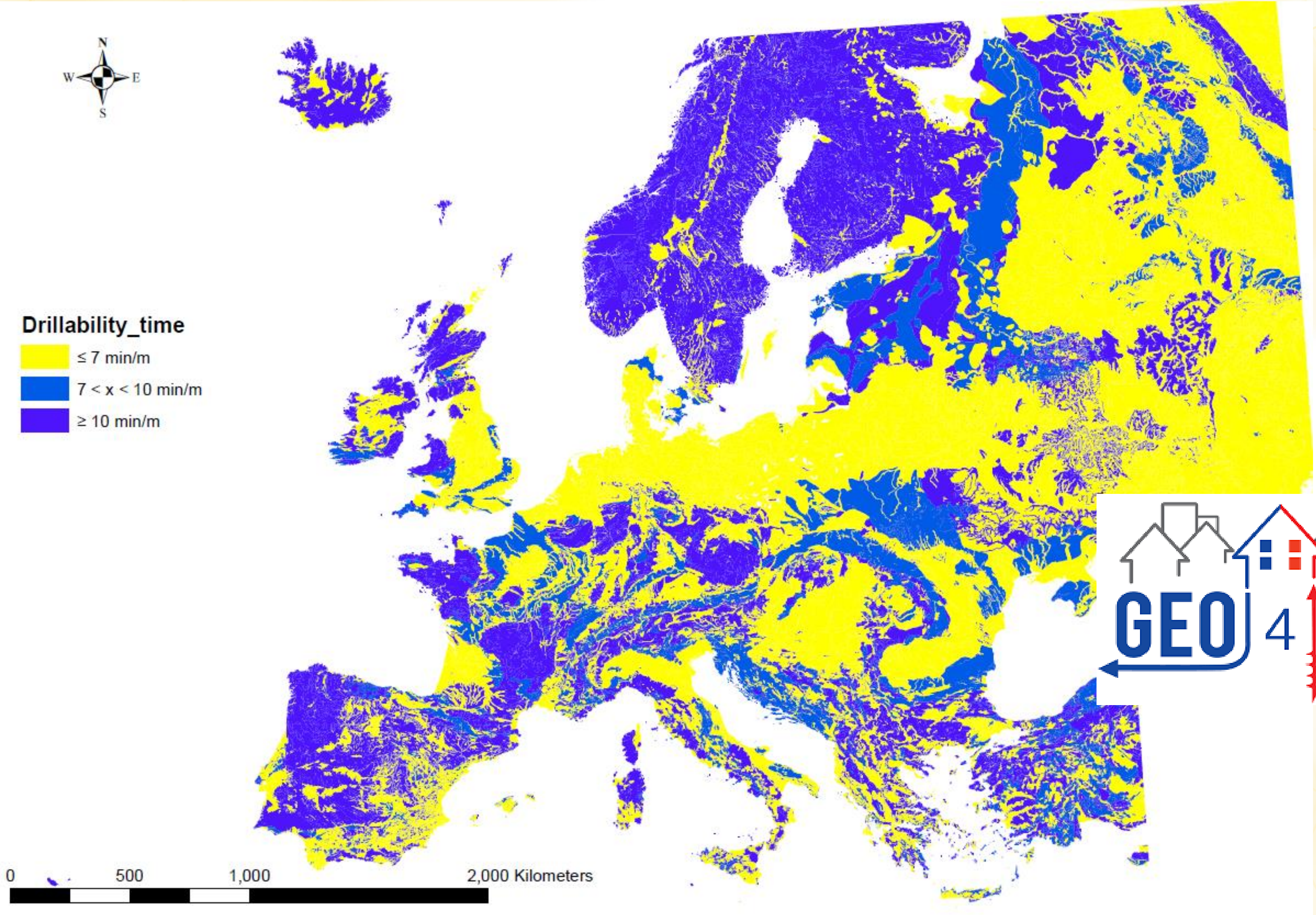


2. BEST DRILLING AND INSTALLATION TECHNIQUES

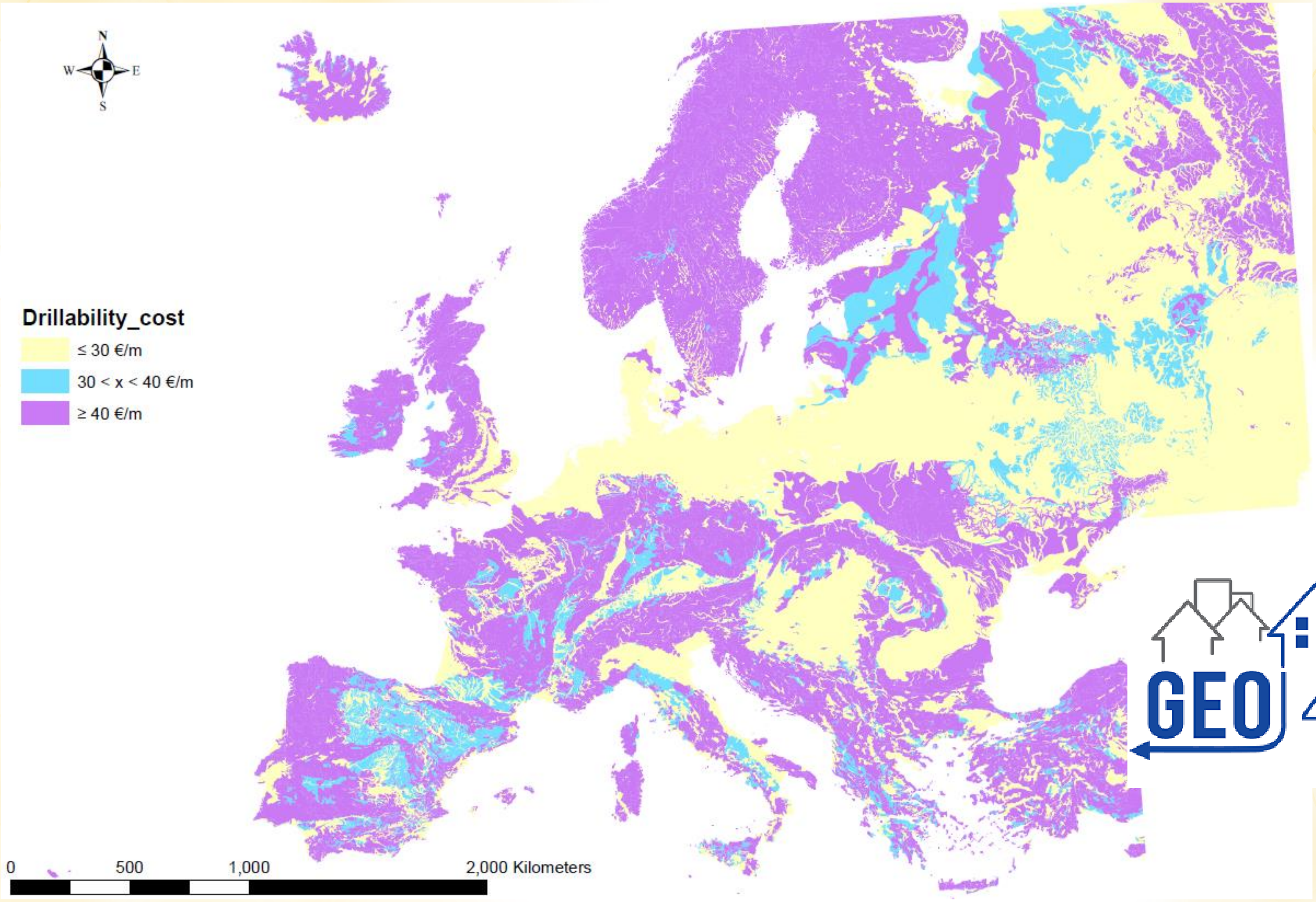


GEO 4 CIVHIC

2. BEST DRILLING AND INSTALLATION TECHNIQUES



2. BEST DRILLING AND INSTALLATION TECHNIQUES



GEO 4 CIVHIC

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF THE SITE

LOCAL GEOLOGICAL SETTING

→ is the "invariant" element of the system

→underground thermal/energetic performances

→best drilling and installation technique

→GSHE geometry (total length/well diameter/single GHE length)

→environmental issues and regulatory constraints

identification of the best GSHE (technical + economic point of view)

GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF THE SITE

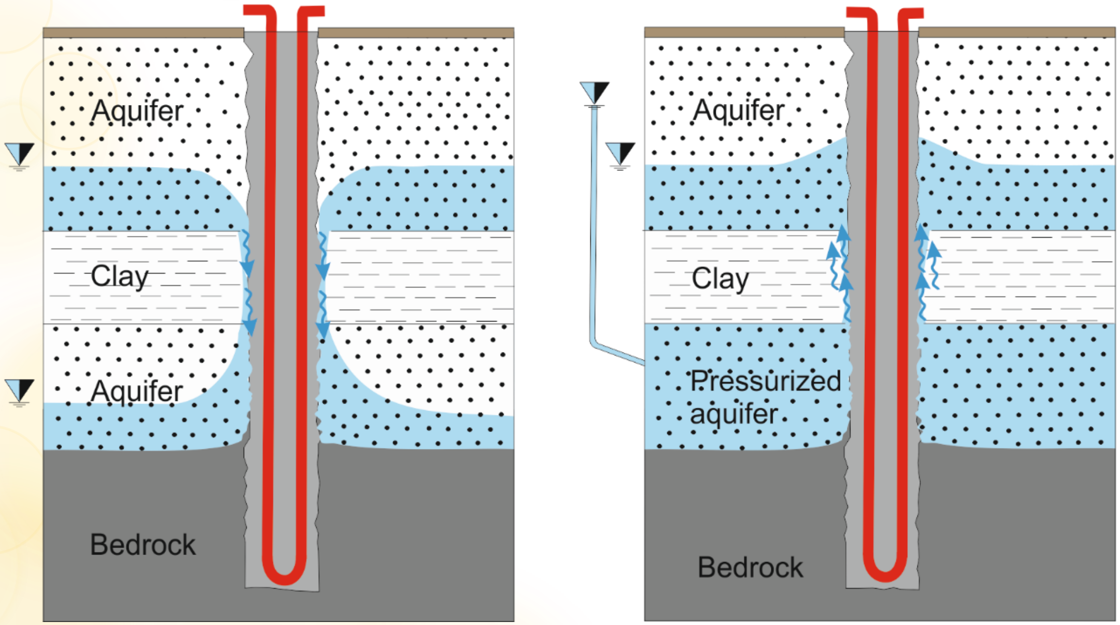
→environmental issues and regulatory constraints

1. Protection areas for hydrogeological reason: presence of drinkable water aquifers
2. Protection areas for presence of extraction water wells for drinkable water → imposed distances
3. Area of superficial pollution (contaminated sites)
4. Areas where the BHE are forbidden due to the presence of particular geological configuration (ex. Germany)
5. Thermal alteration induced in the ground
6. Possible thermal interactions with other geo-exchange systems

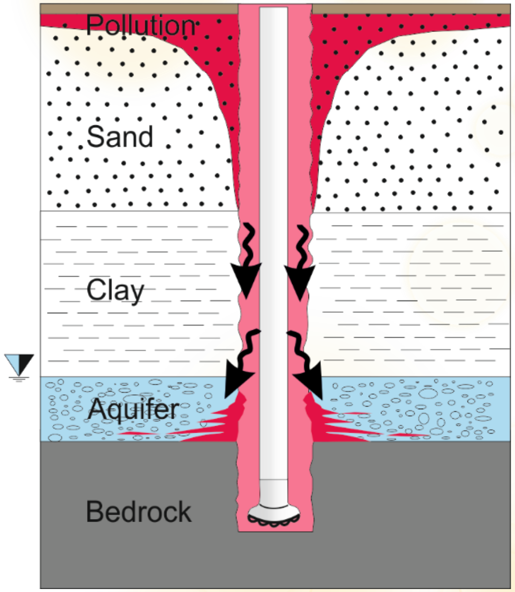
3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

Hazards related to particular geological sequences

interconnection between aquifers previously separated



penetration of the superficial pollution underground



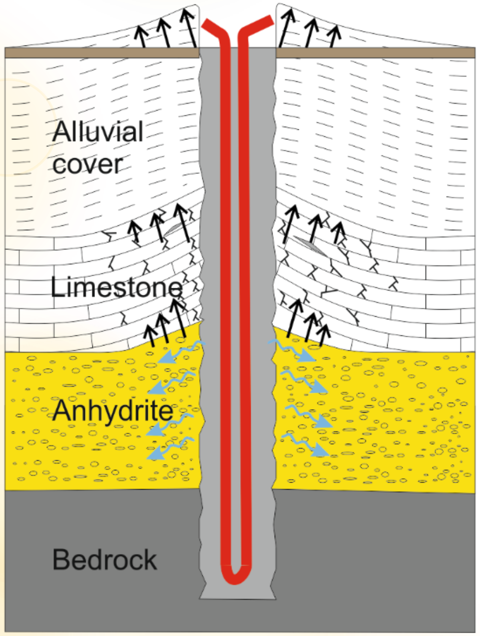
3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

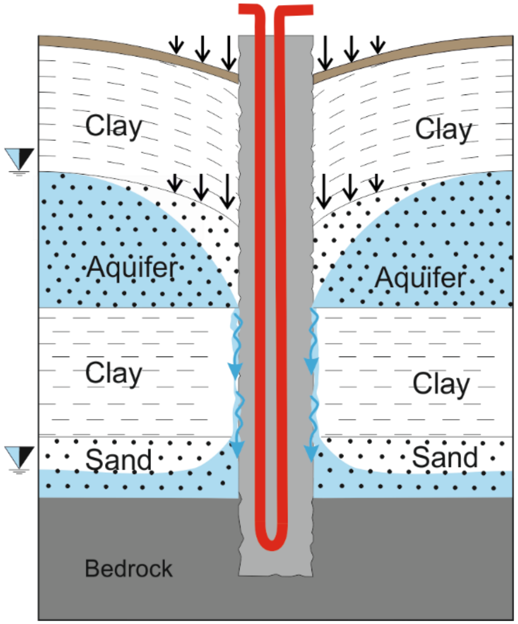
Hazards related to particular geological formations

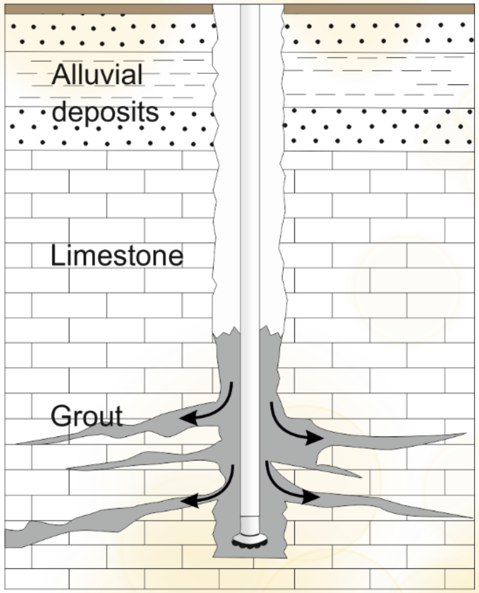
Anhydrite deposits (water free) → high volume increase if in contact with water

drainage of aquifers possibly resulting in land subsidence

grout loss into fissures in the underground (karstic cavities in limestone areas)





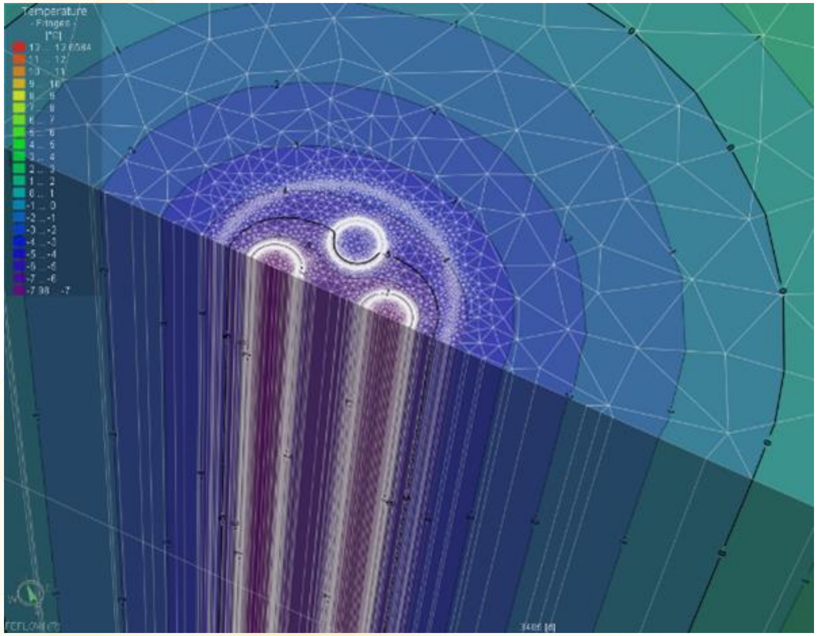


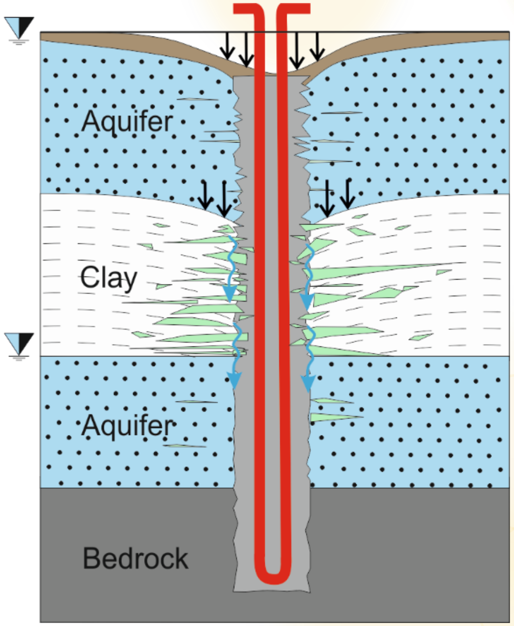
3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

Hazards related to high induced heat alteration

evaluation of the thermal alterations induced in the ground

Freeze-thaw cycles induced in cohesive sediments around the BHE → deformations of the ground level + change in the permeability + alteration of the thermal exchange and energetic performances

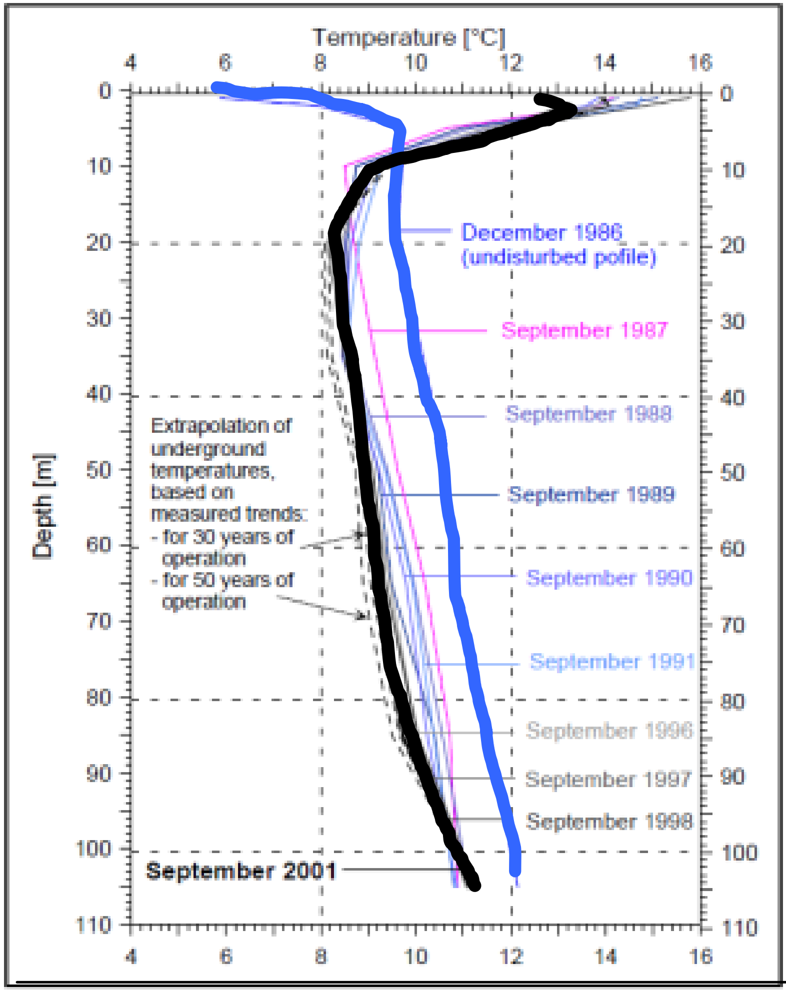


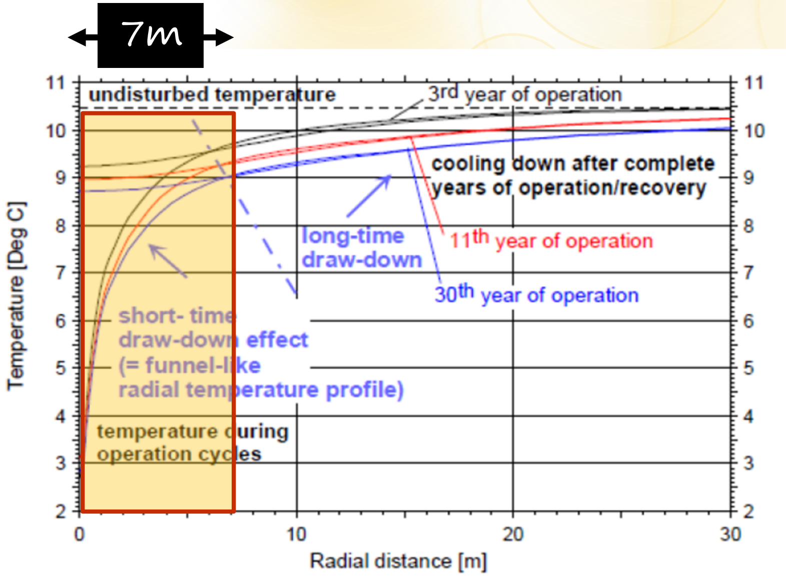


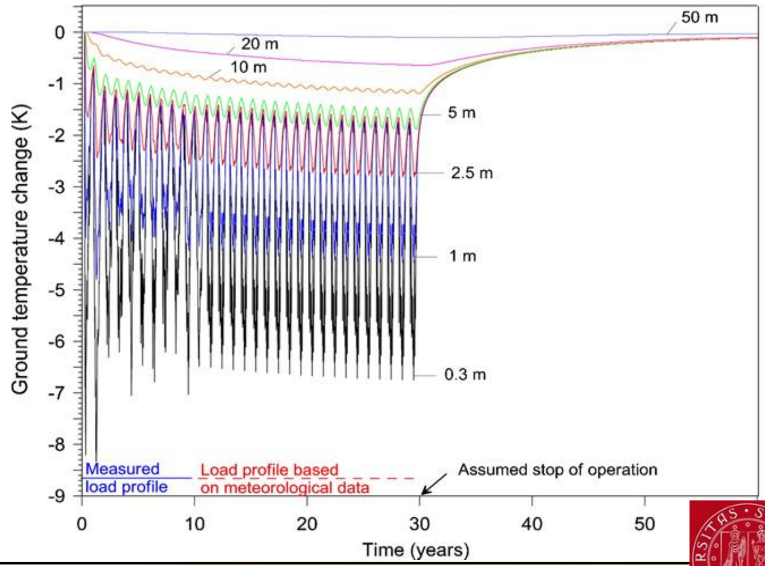
3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

Measured vertical profile induced by a single BHE:

- ✓ 1m distant
- ✓ From 1986,
- ✓ Only heating mode + summer recovery







3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

Boundary conditions and initial conditions (temperature/hydro)

- ✓ air temperature
- ✓ geothermal flux
- ✓ initial temperature
- ✓ piezometric setting

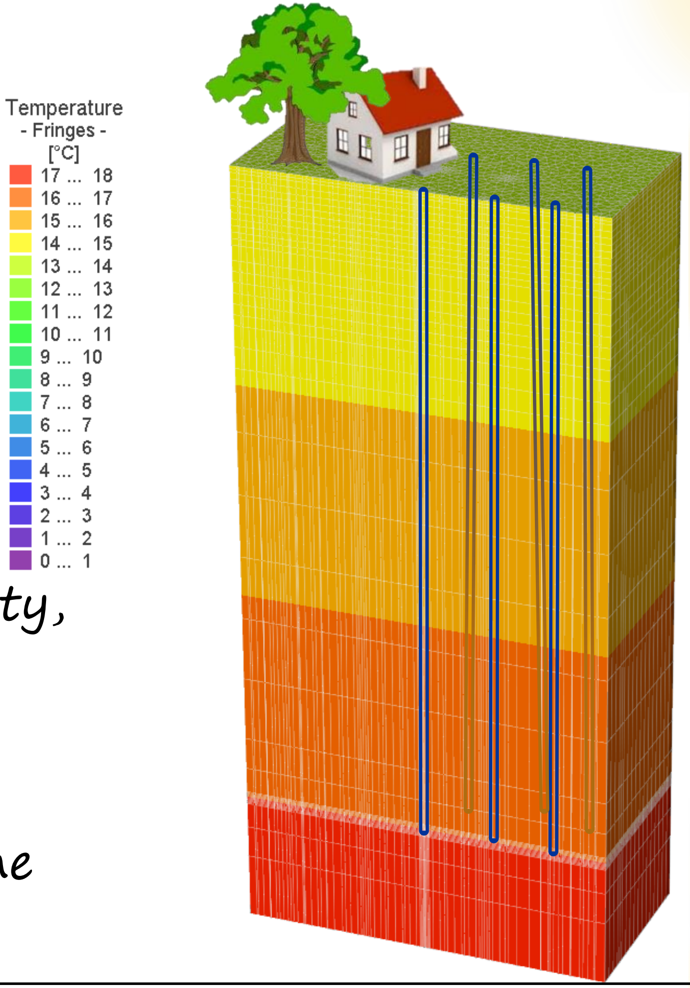
- software FEM
- hydro-thermal transport in porous media

→ evaluation of the thermal alteration induced in the ground

→ ground properties (porosity, permeability, thermal properties,..)

→ borefield geometry

→ BHE functioning over time (Q+power / Q+T)



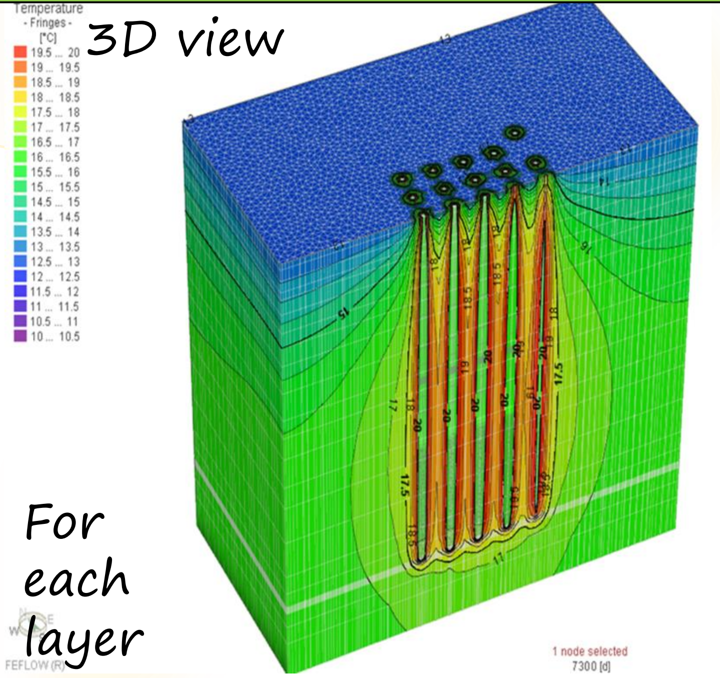
TO CHECK:

*** THERMAL GRADIENT in the ground**

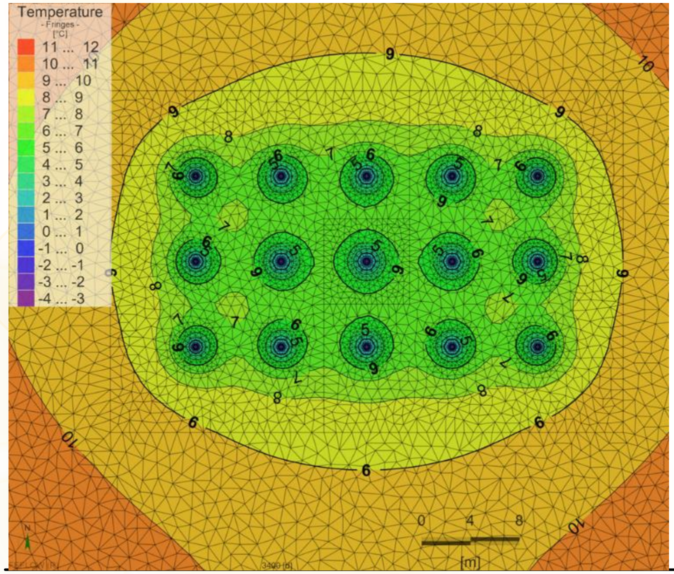
*** heat carrier FLUID TEMPERATURE**

3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

3D view



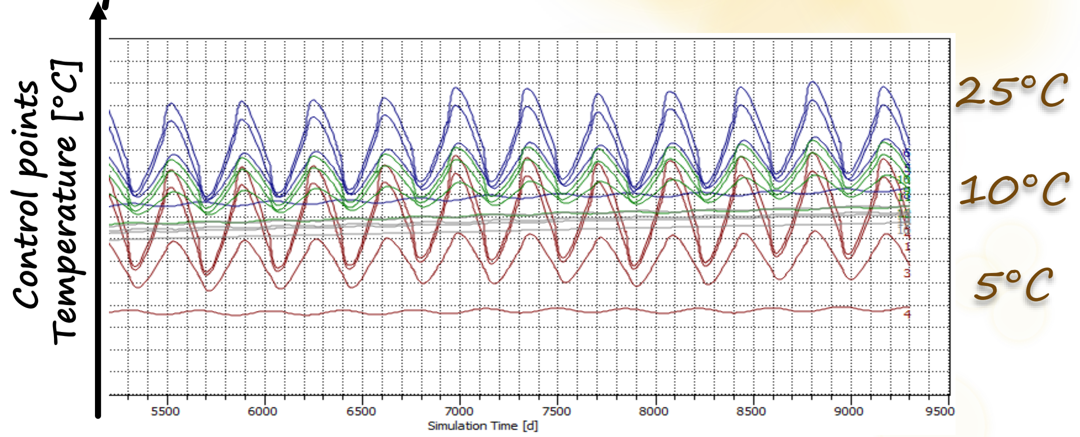
For each layer



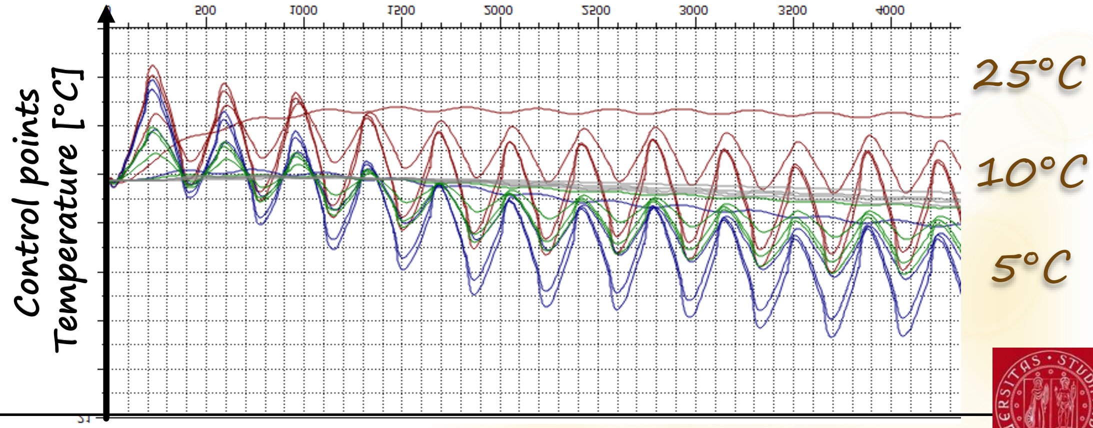
OUTPUTS: temperature induced in the underground

→ check the thermal alteration

Importance of the LOAD BALANCE



UNBALANCED THERMAL REQUESTS

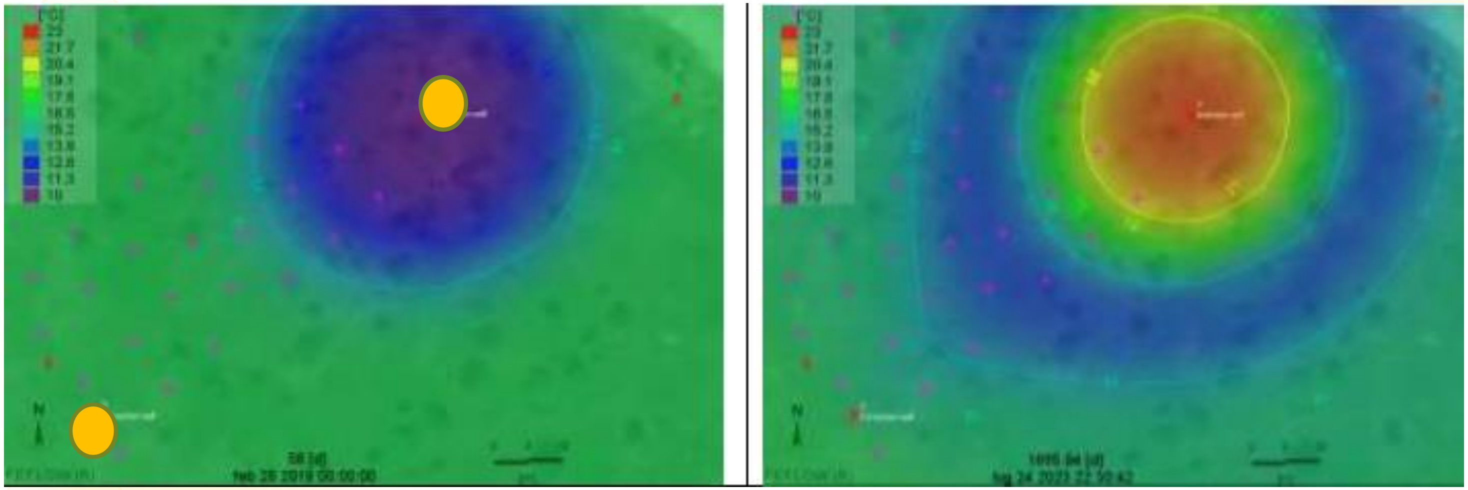


3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

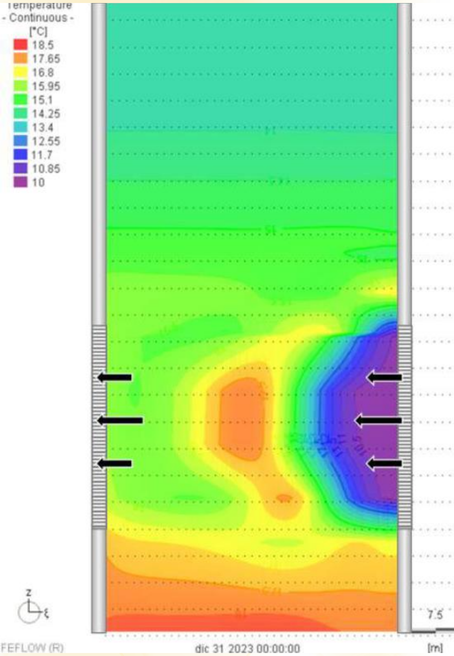
Local thermal interference between closed loop and open loop systems

The induced hydraulic gradient actracts the groundwater → the thermal alteration

Injection well



Extraction well

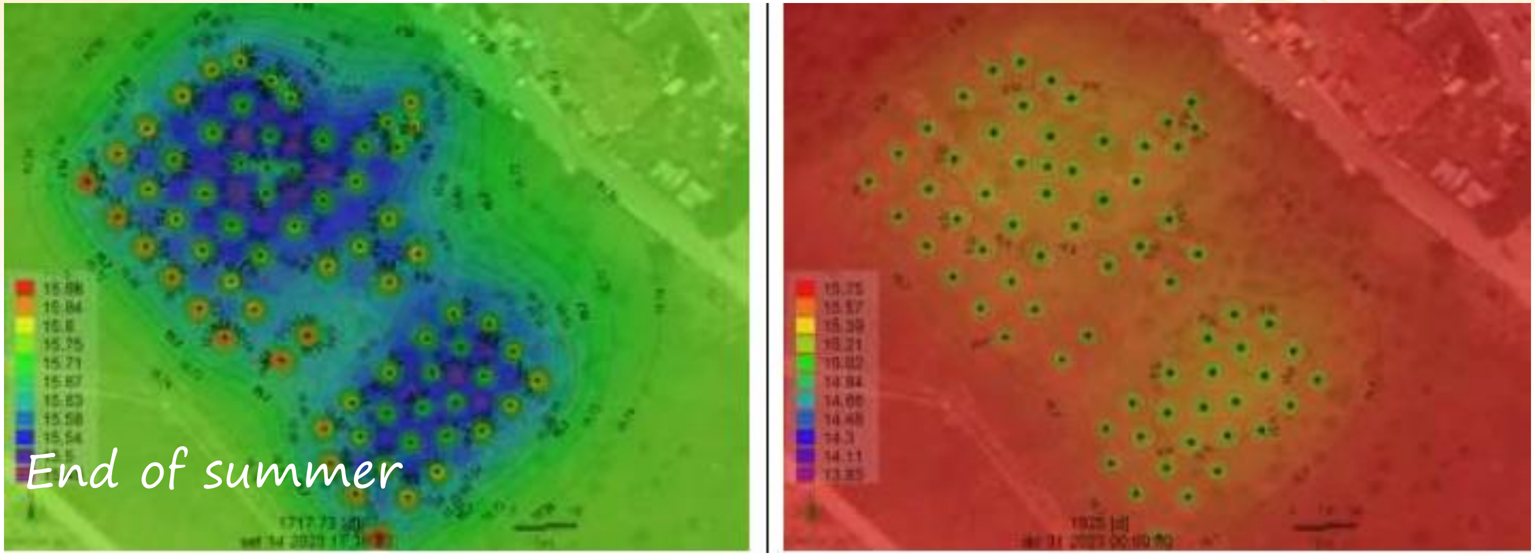


3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

Local thermal interference between closed loop and open loop systems

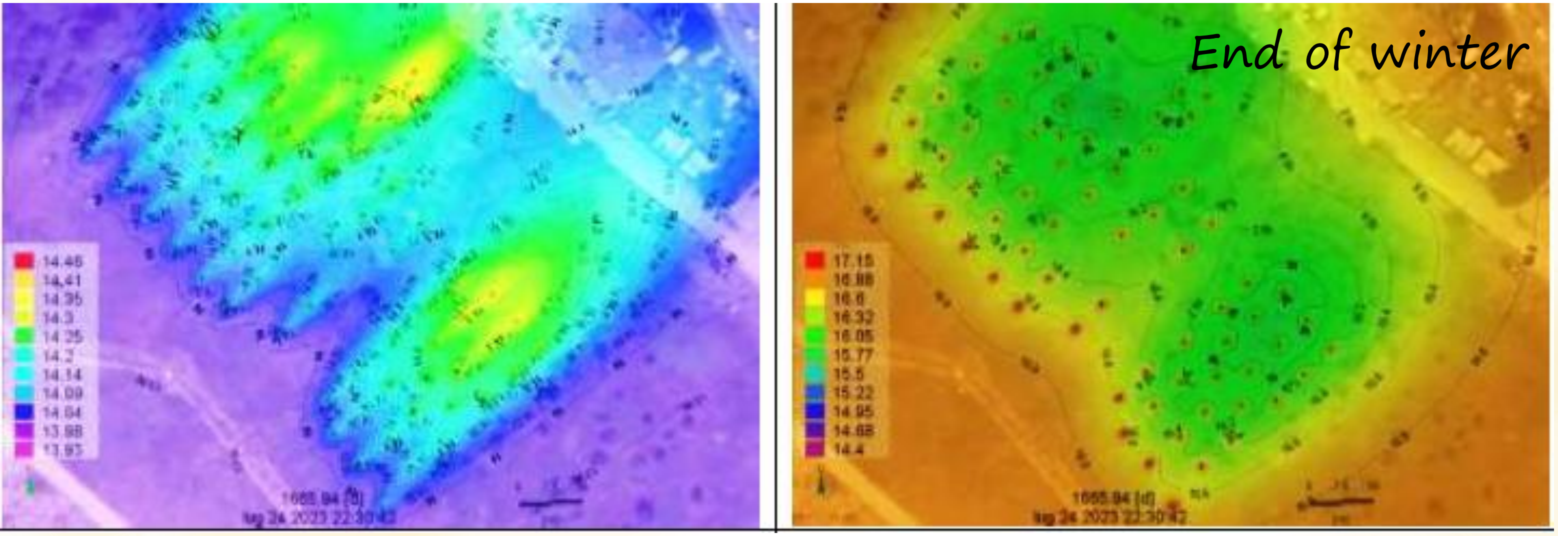
After 5 years functioning

aquitard



End of summer

End of winter

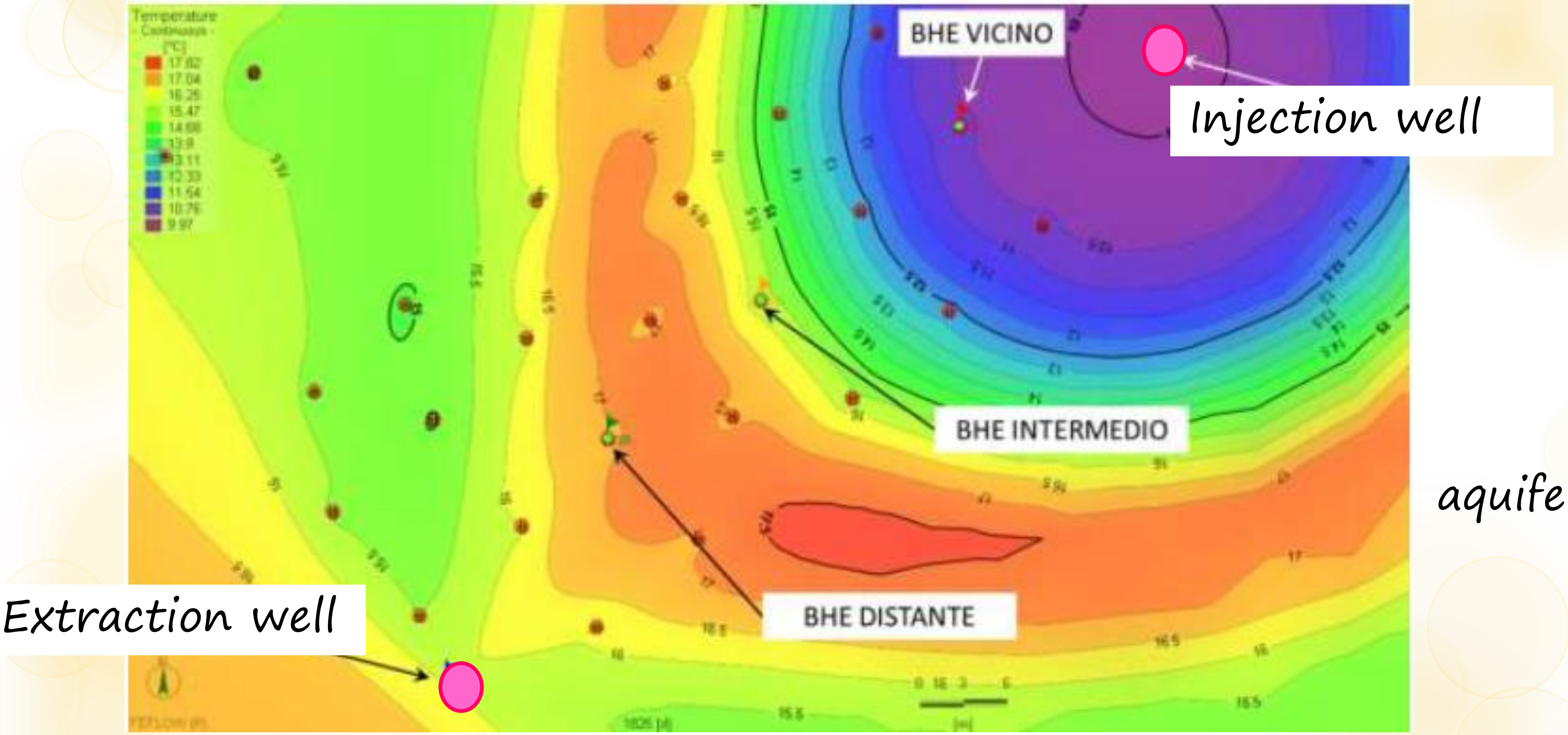


aquifer

3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

Local thermal interference between closed loop and open loop systems

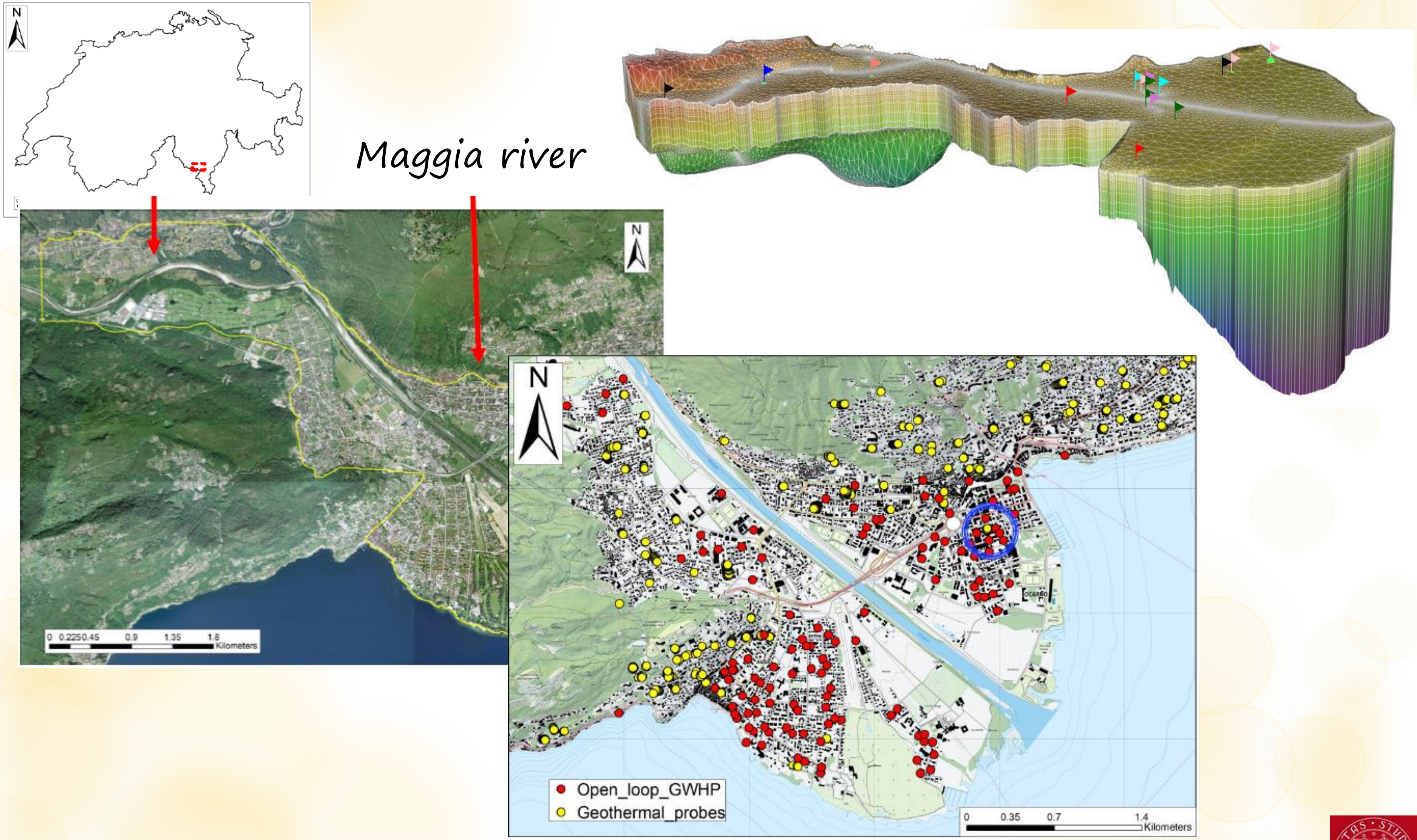
After 5 years
functioning



aquifer

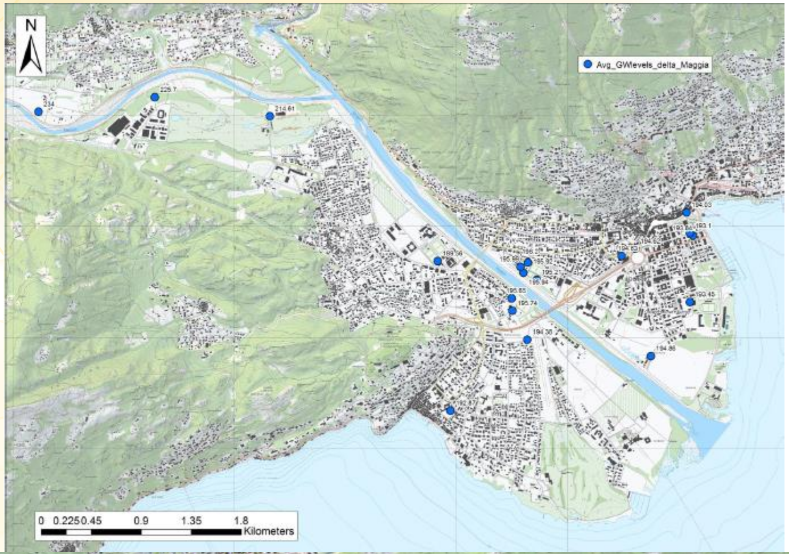
3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

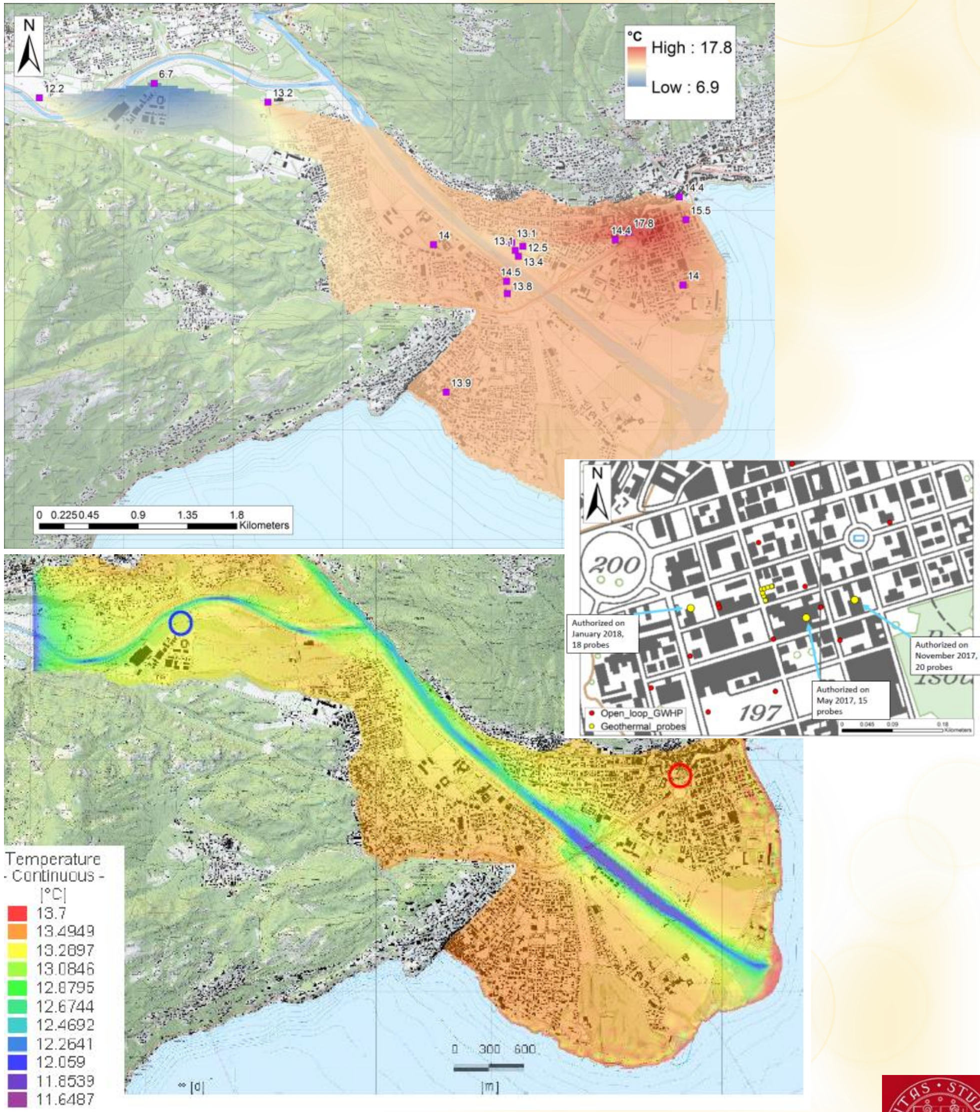
Regional thermal intereferences: Maggia river, Locarno (Svizzera)

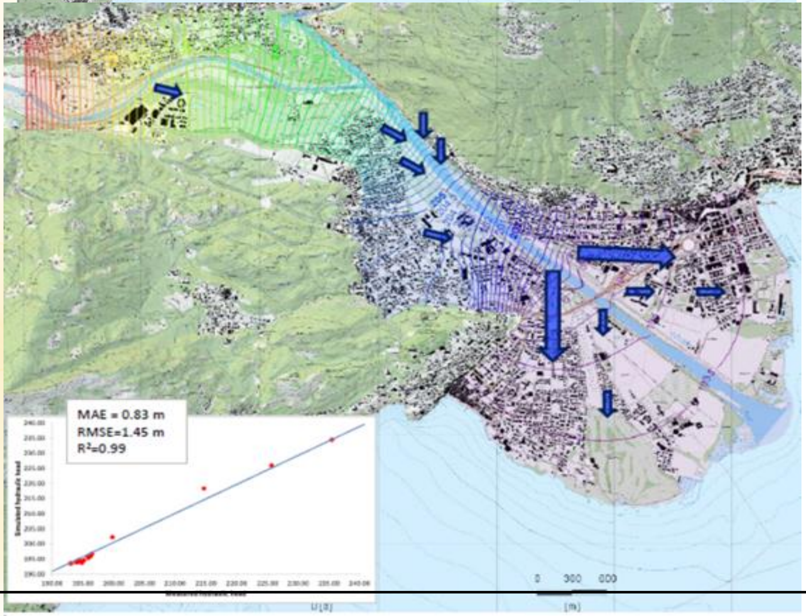


3.ENVIRONMENTAL AND REGULATORY CONSTRAINTS

Regional thermal intereferences: Maggia river, Locarno (Svizzera)







GEOLOGICAL AND HYDROGEOLOGICAL CHARACTERIZATION OF THE SITE

LOCAL GEOLOGICAL SETTING

→ *is the "invariant" element of the system*

→underground thermal/energetic performances

→best drilling and installation technique

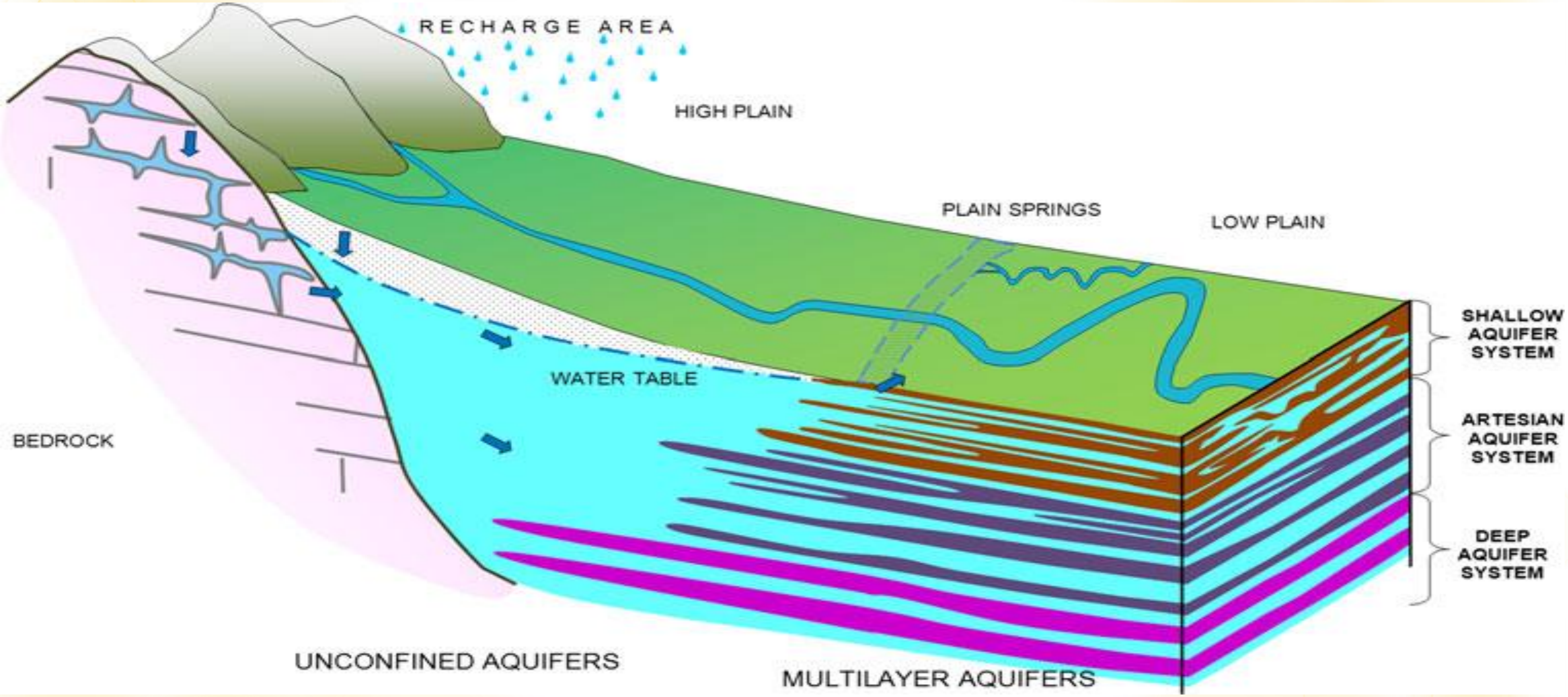
→GSHE geometry (total length/well diameter/single GHE length)

→environmental issues and regulatory constraints

identification of the best GSHE (technical + economic point of view)

IDENTIFICATION OF THE BEST GHE

Depending on the local geological setting..



IDENTIFICATION OF THE BEST GHE

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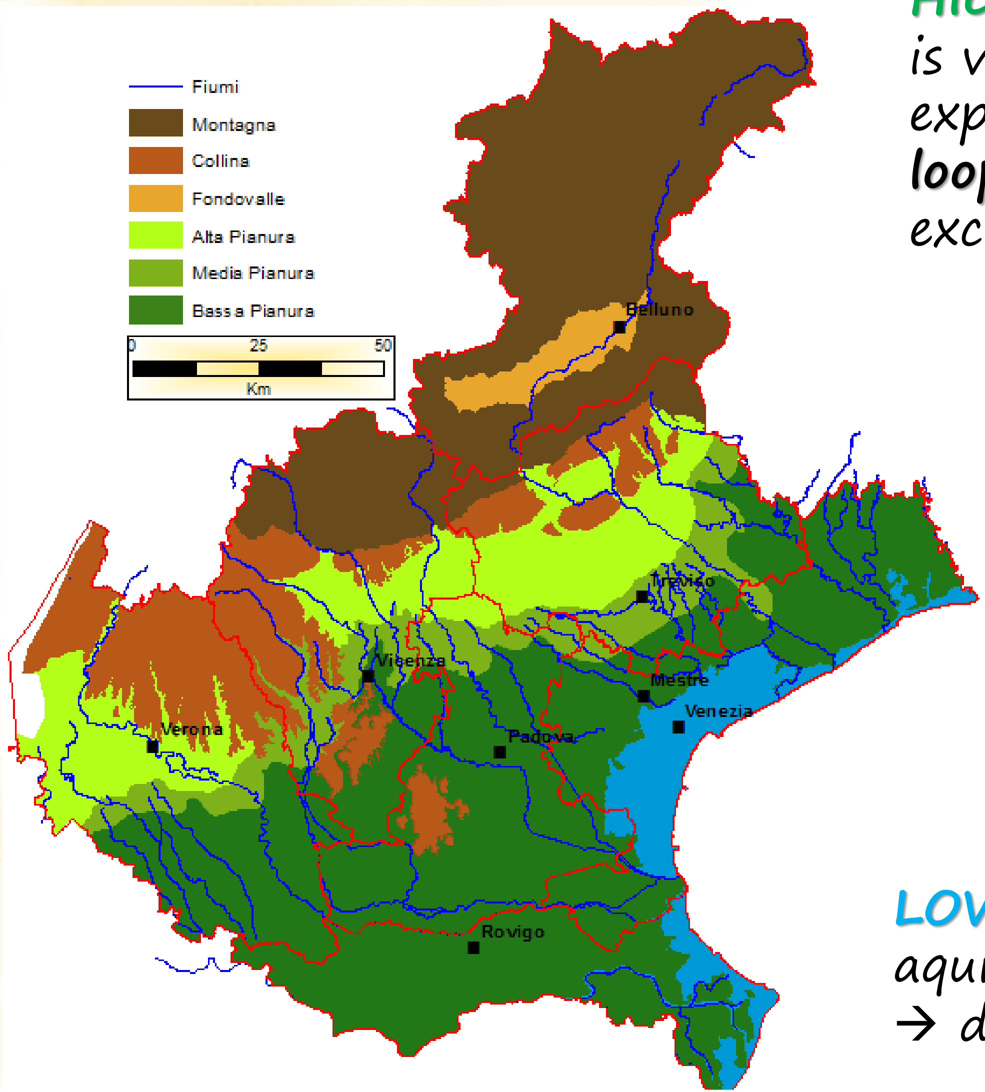


HIGH PLAIN AREAS: the water table is very low→ open loop systems are expensive and not effective / **closed loop** are higly efficient, high thermal exchange due to high groundwaterflow

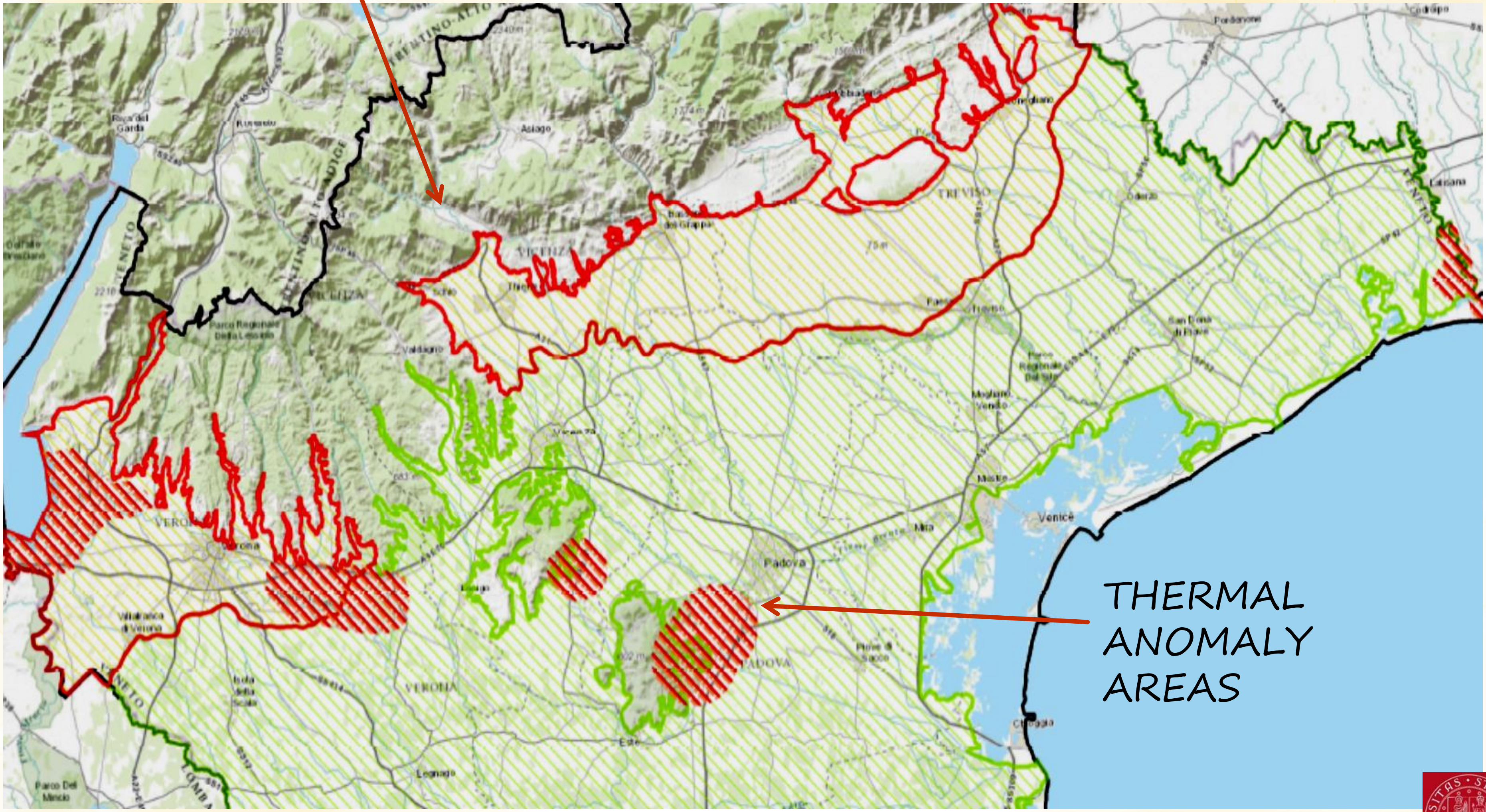
MIDDLE PLAIN AREAS:
Open loop systems with highenergetic performances BUT presence of SPRINGS→ HYDROGELOGY PROTECTION AREAS → necessary to respect Q and distances from the caption wells + evaluation of the thermal plume

LOW PLAIN AREAS: pressurized aquifers, medium-low permeability → difficult renijection **closed loop**

IDENTIFICATION OF THE BEST GHE

Depending on the local geological setting..

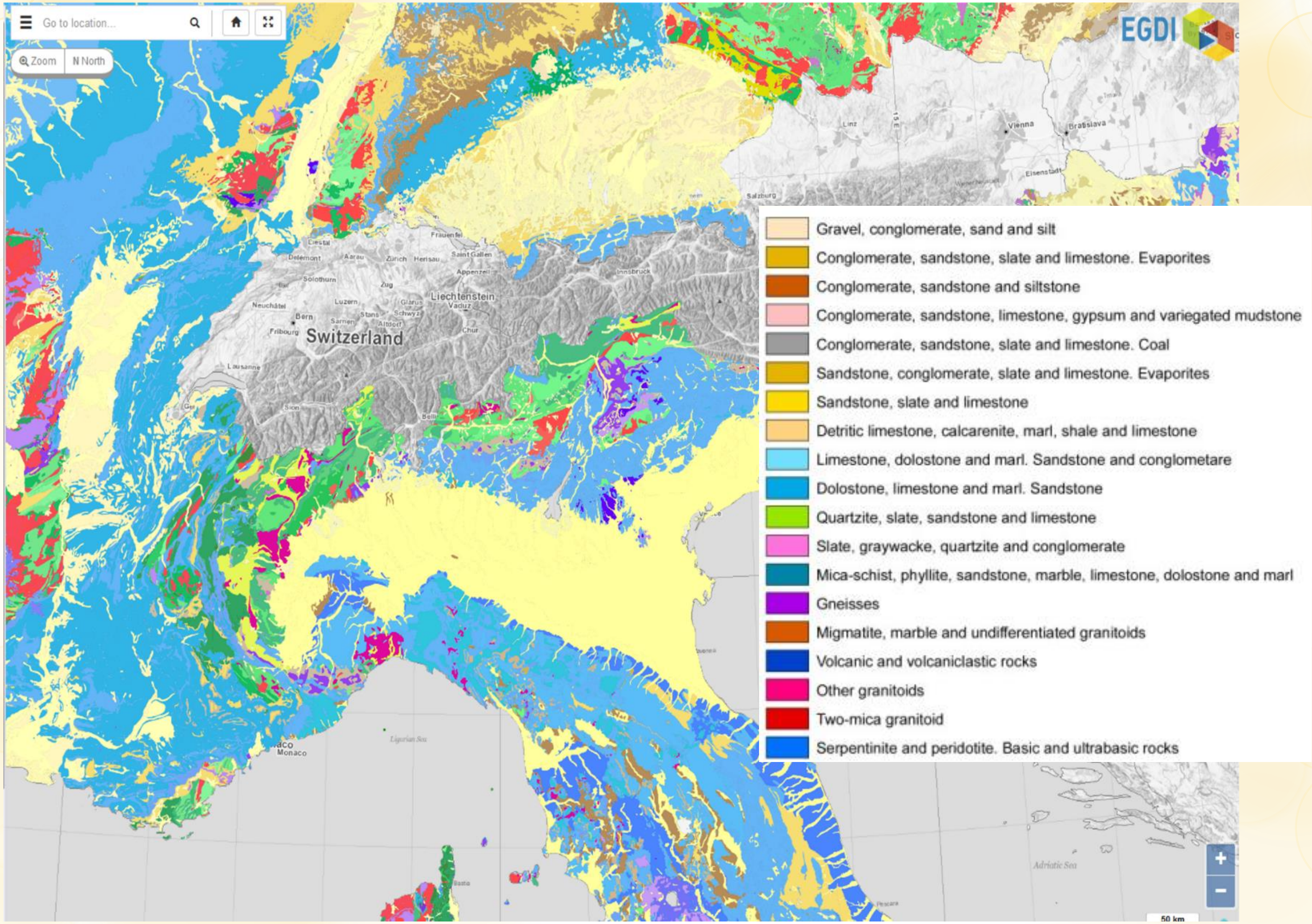
HYDROGEOLOGICAL PROTECTION AREAS



THERMAL ANOMALY AREAS

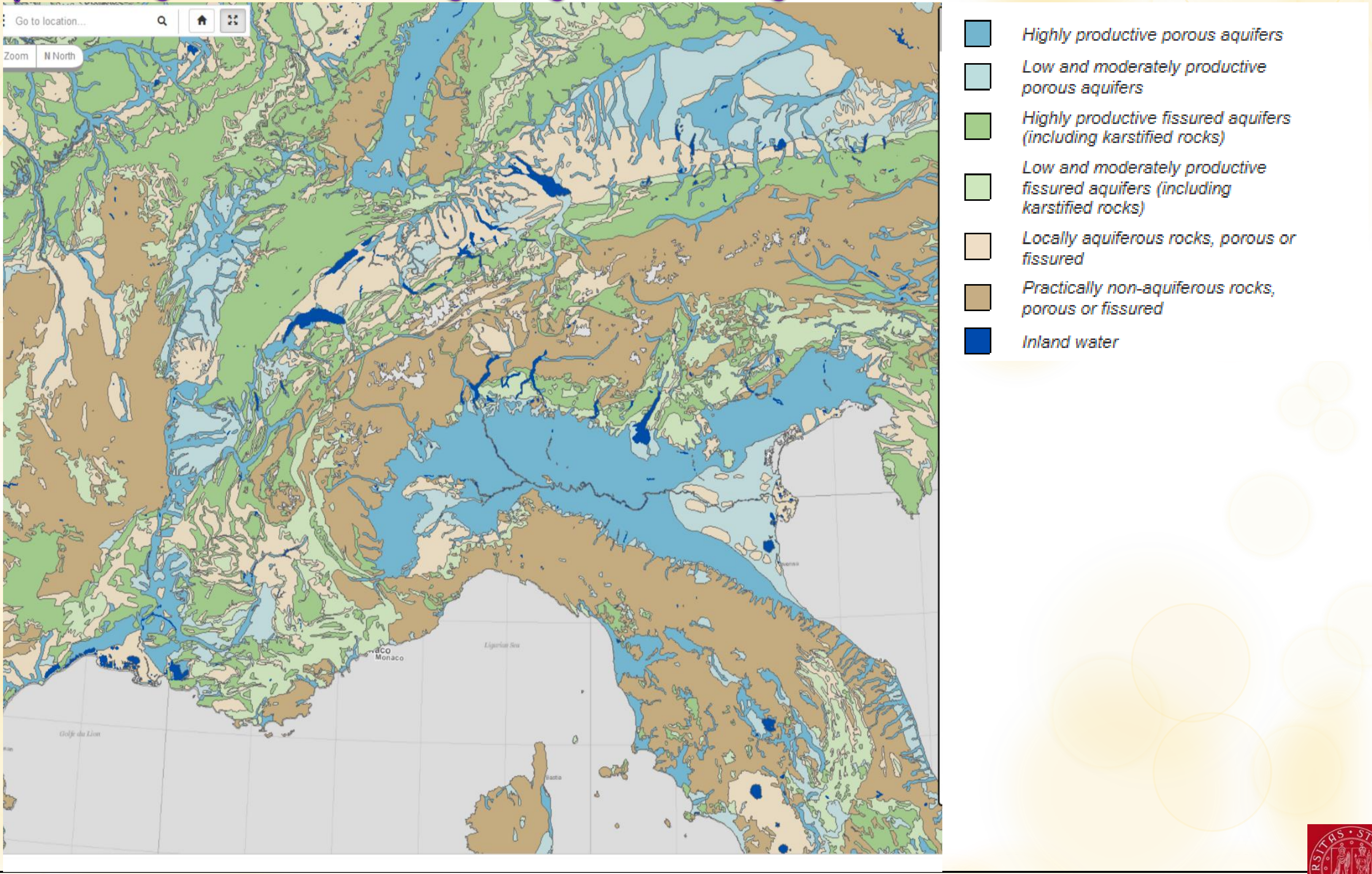
IDENTIFICATION OF THE BEST GHE

Depending on the local geological setting..



IDENTIFICATION OF THE BEST GHE

Depending on the local geological setting..



CONCLUSIONS

LOCAL GEOLOGICAL SETTING

→ *the "invariant" element of the system*

→underground thermal /energetic performances

→best drilling and installation technique

→GSHE geometry (total length/well diameter/single GHE length)

→environmental issues and regulatory constraints

identification of the best GSHE (technical + economic point of view)

SHOULD BE CONSIDERED WITH GREAT ATTENTION DURING THE DESIGN PHASE !!