D970 EGU2020-18915
Tue, 05 May, 14:00–15:45

Assessing underground heat exchange and solar heat storage capabilities based on ground thermo-physical properties: the Euganean hills demo site (Italy)

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ERE 2.8 Shallow geothermal systems for building heating and cooling: geoscience and engineering approaches

Aim of the project

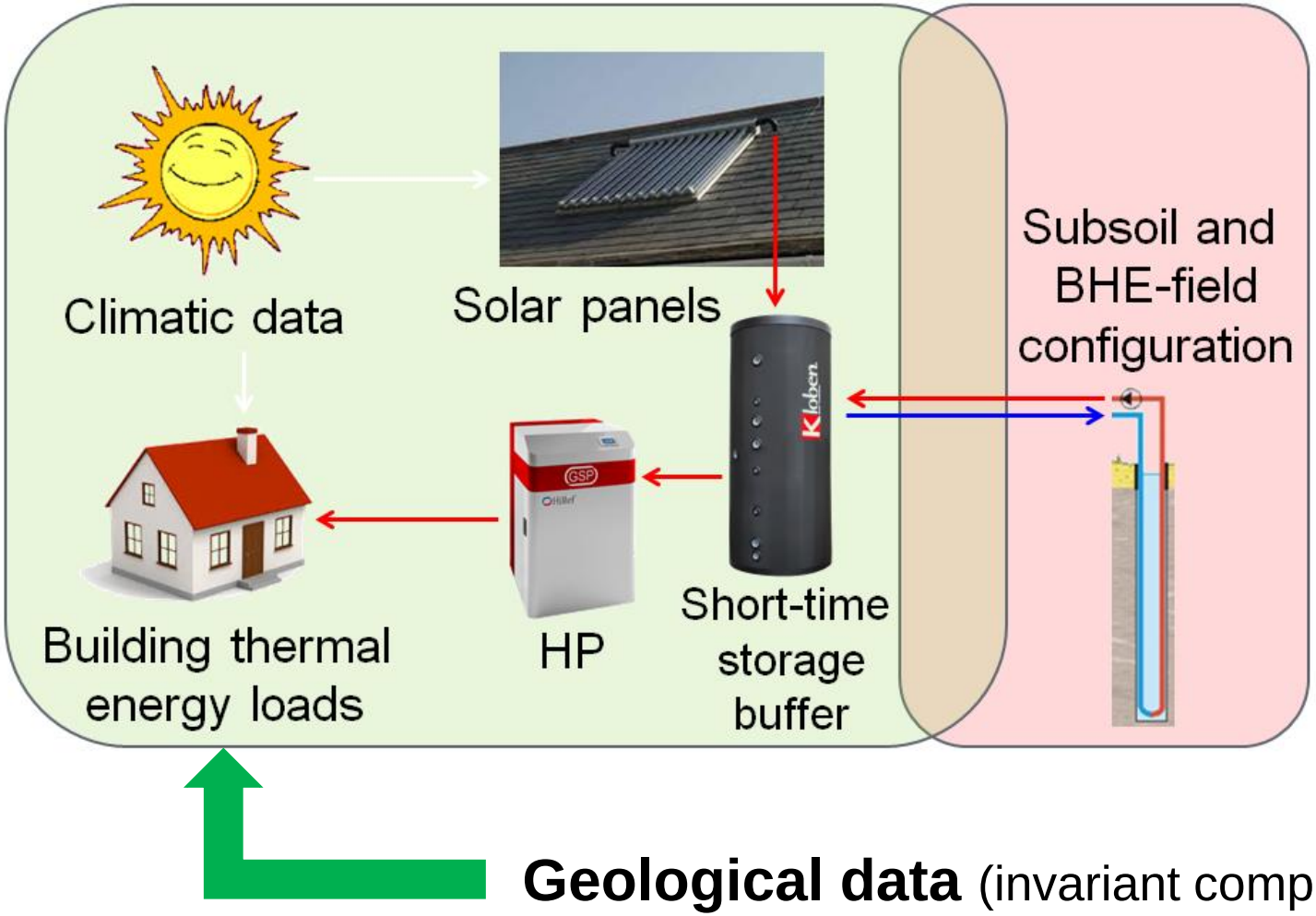
present **an innovative methodological approach** based on:

- combining information related to **underground thermal energy exchanging and storage capacity with the solar radiation**
- considering the **local distribution of possible end-users** (i.e. residential buildings in the territory)

to represent the **"Ground thermal suitability" of a territory to sensible heat storage**, that is the possibility to store solar energy in the underground for a later use

Ground thermal storage suitability

depends on the underground thermal conditions
(heat transfer and thermal storage capacity)



Aim *find the areas of the Euganean Hills where the ground has the best characteristics for the design of a solar thermal energy storage system*

METHODOLOGY

Ground thermal storage suitability (GTSS) is defined **as the attitude of the subsoil to store heat in the rock and, at a later stage, to transfer heat from the ground to the probe**.

three important quantitative parameters are considered to determine it

- ✓ **thermal conductivity (λ, $Wm^{-1}K^{-1}$),**

  governs the heat transfer in steady state from the ground to the probe (and vice versa); fundamental dimension the length and number of the borehole heat exchanger

- ✓ **volumetric heat capacity (ρc_p, $Jcm^{-3}3K^{-1}$)**

  reduces the necessary volume of the storage medium; governs the heat storage (the lower the volume, the lower the losses)

- ✓ **solar radiation (Hg, Wh/m^2).**

  considered as the total incoming solar radiation; allows to estimate the solar energy that can be used by solar thermal collectors to charge the reservoir rocks and can be stored underground for later reuse

METHODOLOGY

Ground thermal storage suitability (GTSS) is composed of two parts defined as follow:

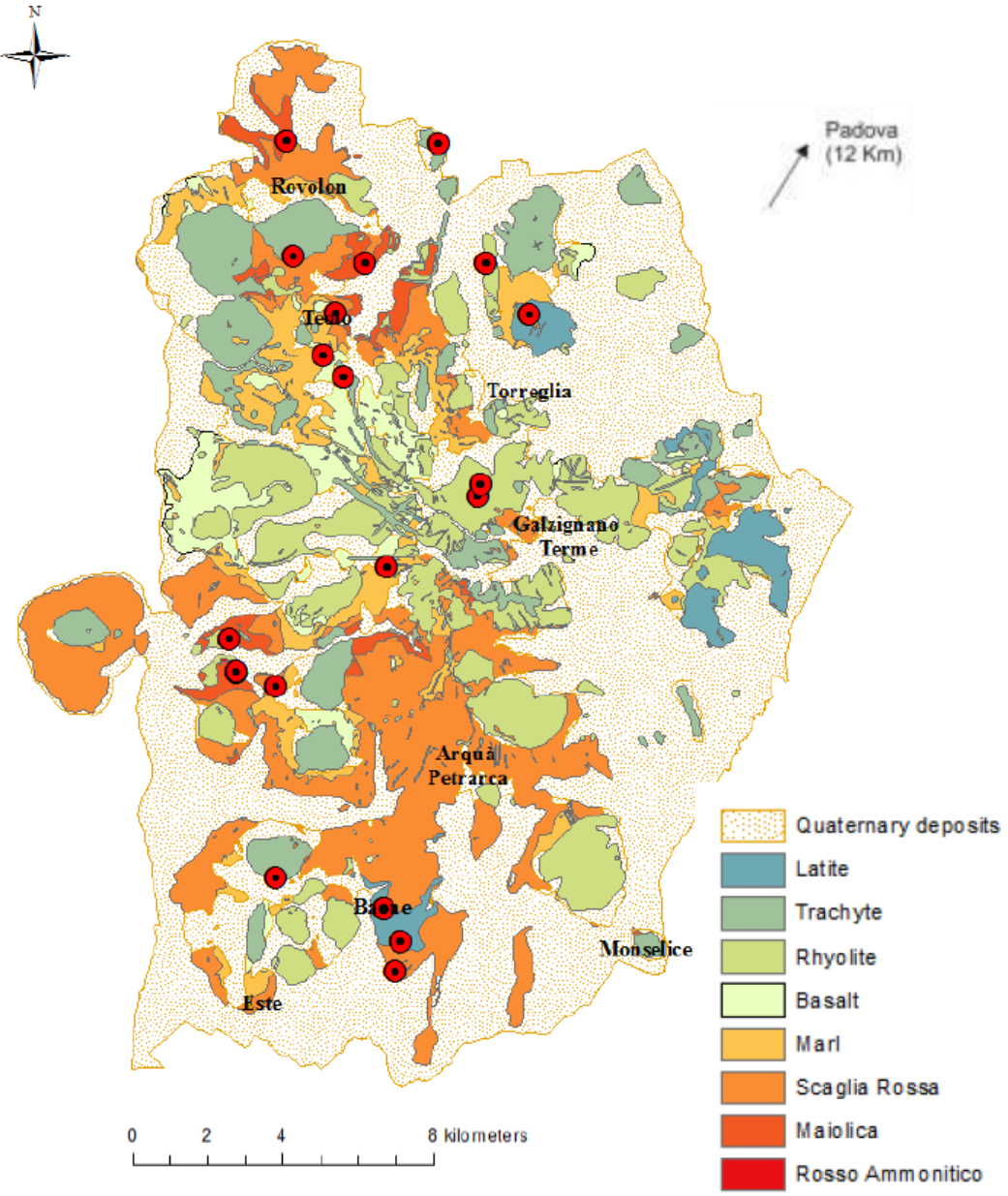
$$Storage\ contribution = \frac{(\rho c_p)_i}{(\rho c_p)_{max}} \cdot \frac{Hg_j}{Hg_{max}}$$

$$Transfer\ contribution = \frac{\lambda_i}{\lambda_{max}} \cdot \frac{Hg_j}{Hg_{max}}$$

In this study, only a teorethical GTSS qualitative value has been evaluated. *The only heat source considered is solar radiation. Even if only a fraction of the total radiation reaching the solar panel arrives to the rock and can be stored due to losses occuring along the path from the solar panel to the rock, no energy losses have been considered in this study.*

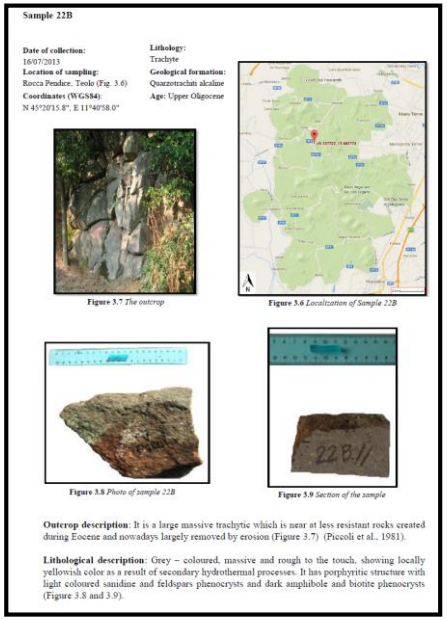
EUGANEAN HILLS AREA

Localized in North-East of Italy (Eastern Po Plain)



- cover an area of 100 km^2
- 4 main residential areas considered (Arquà Petrarca, Teolo, Torreglia and Rovolon), with great number of SME
- the rock outcrops are mainly sedimentary (limestone, marl) and volcanic (trachyte, rhyolite, latite, basalt), ranging in age from Cretaceous to Oligocene
- 21 samples were collected

Thermal properties measurements


Sample 22B

Date of collection: 16/07/2013
Location of sampling: Rocca Pendice, Teolo (Fig. 3.6)
Coordinates (WGS84): N 45°20'15.8", E 11°40'58.0"
Lithology: Trachyte
Geological formation: Quarzotrachiti alcaline
Age: Upper Oligocene

Figure 3.7 The outcrop

Figure 3.6 Localization of Sample 22B

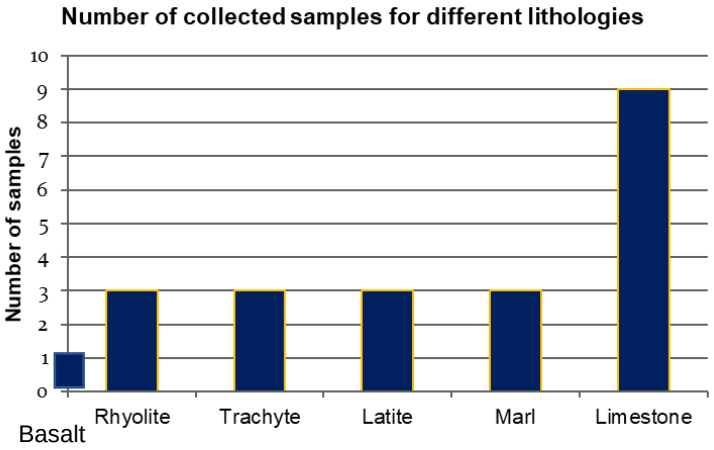
Figure 3.8 Photo of sample 22B

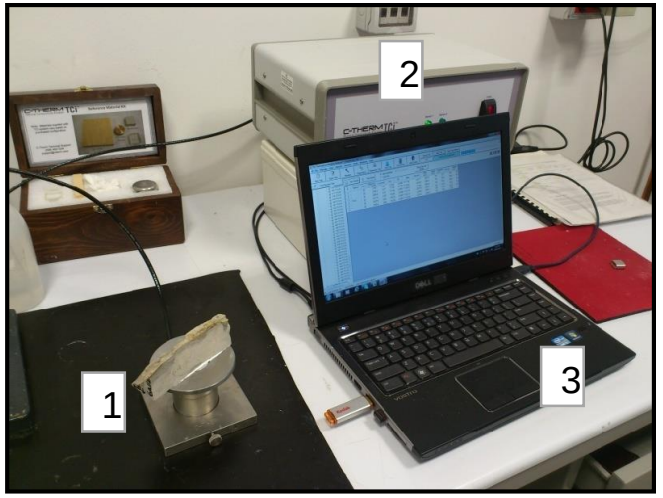
Figure 3.9 Section of the sample

Outcrop description: It is a large massive trachytic which is near at less resistant rocks created during Eocene and nowadays largely removed by erosion (Figure 3.7) (Piccoli et al., 1981).

Lithological description: Grey – coloured, massive and rough to the touch, showing locally yellowish color as a result of secondary hydrothermal processes. It has porphyritic structure with light coloured sanidine and feldspars phenocrysts and dark amphibole and biotite phenocrysts (Figure 3.8 and 3.9).

Sample collection and classification

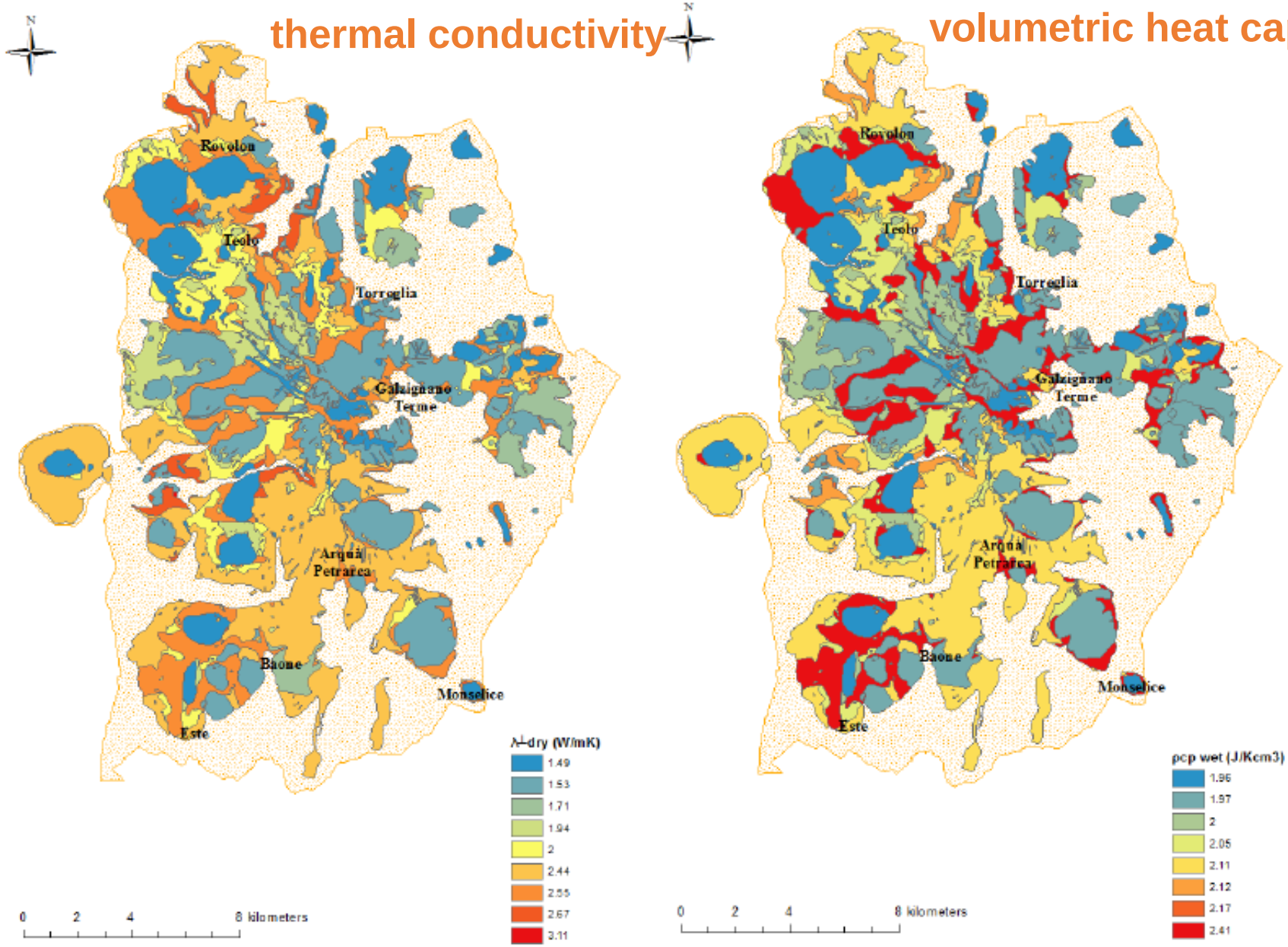




(1) Sample above the sensor; (2) Thermal Analyzer; (3) Laptop with specific software

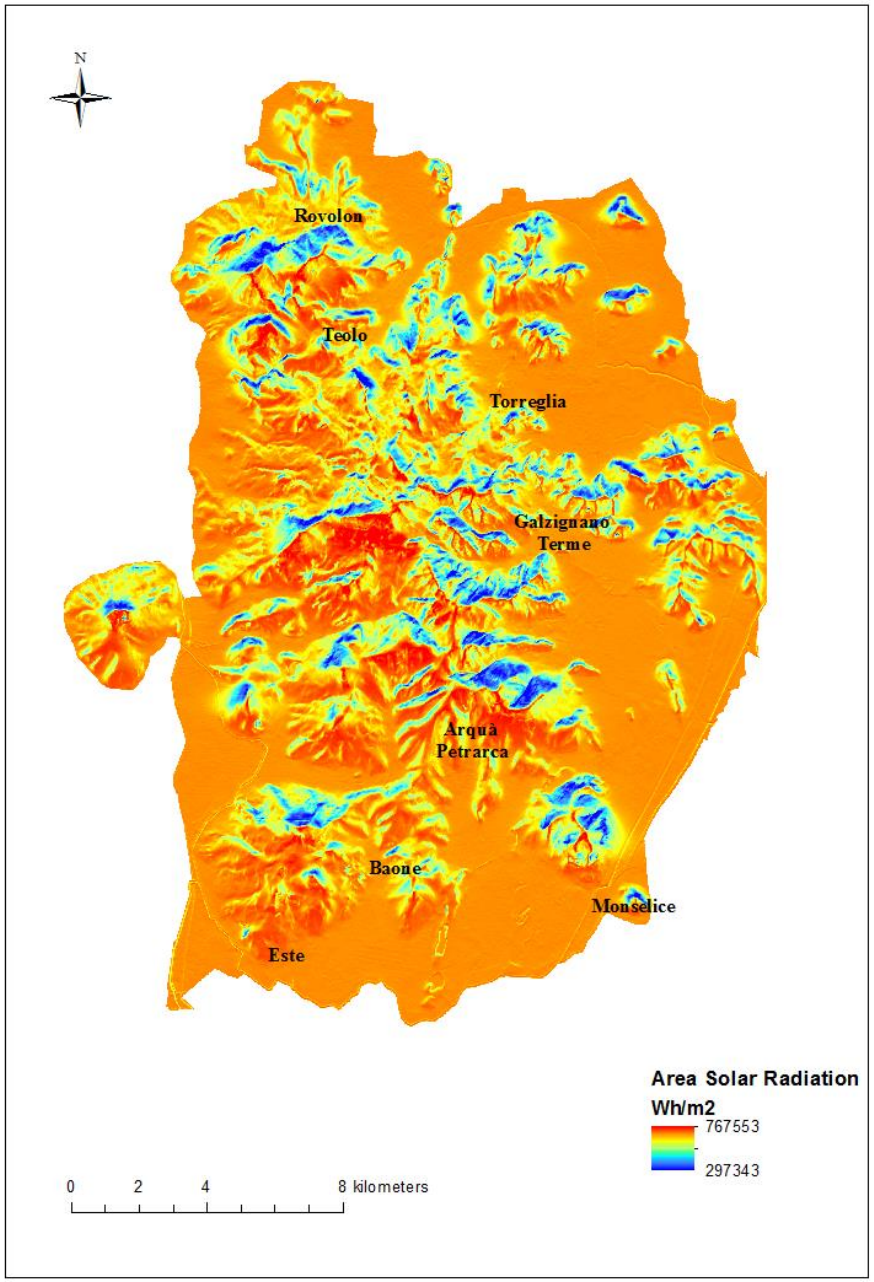
Average laboratory values for all the lithologies present within the Euganean Hills

Lithology	λ// dry $Wm^{-1}K^{-1}$	$\lambda^{\perp}$ dry $Wm^{-1}K^{-1}$	ρcp dry $Jcm^{-3}K^{-1}$	λ// wet $Wm^{-1}K^{-1}$	$\lambda^{\perp}$ wet $Wm^{-1}K^{-1}$	ρcp wet $Jcm^{-3}K^{-1}$
Clay/silt	1.50	1.50	1.80	2.00	2.00	1.80
Latite	1.68	1.71	1.94	2.10	2.07	1.97
Trachyte	1.44	1.49	1.93	1.92	1.94	1.96
Rhyolite	1.57	1.53	1.93	2.12	2.07	1.97
Basalt	2.15	1.94	1.94	2.15	1.94	2.00
Marl	2.07	2.00	1.97	2.75	2.63	2.05
Scaglia Rossa	2.59	2.44	2.02	3.23	3.17	2.11
Maiolica	2.68	2.67	2.05	3.67	3.11	2.12
Rosso Ammonitico	2.99	3.11	2.08	3.60	3.57	2.17



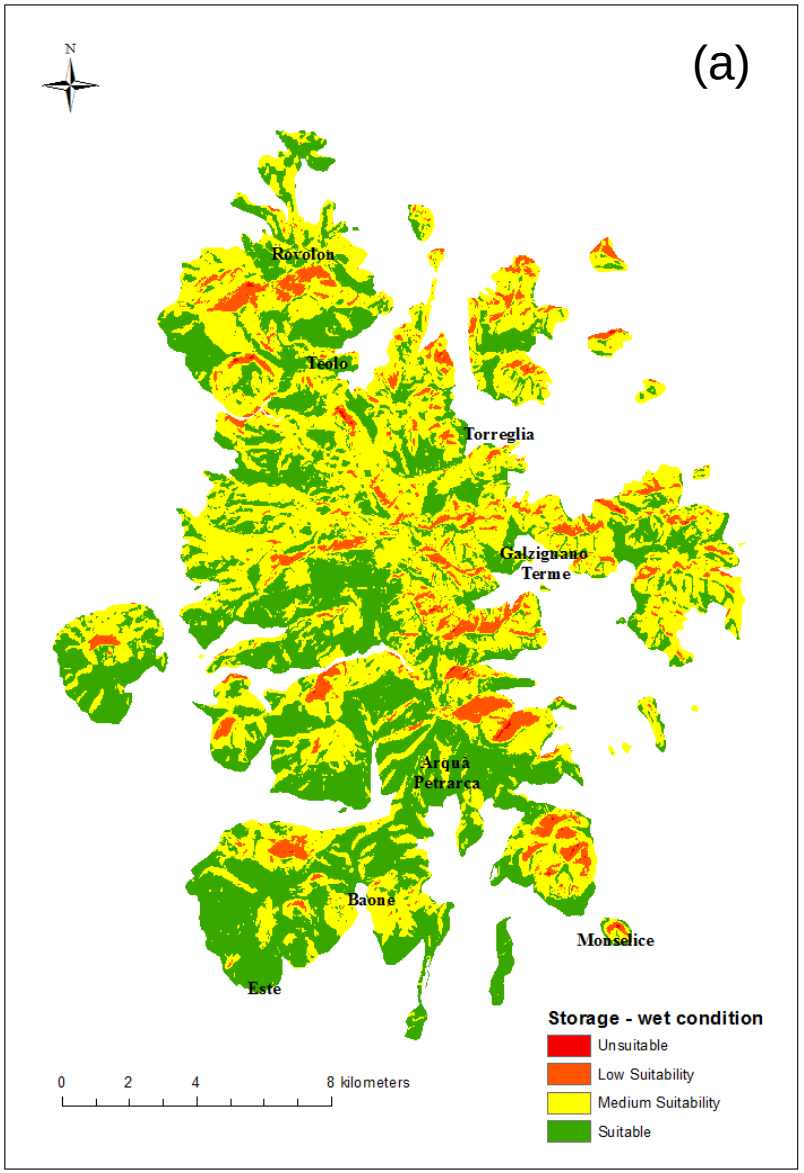
areas characterized by lithologies having both **a high thermal conductivity and a high volumetric heat capacity** presents the best condition for thermal storage suitability in the underground

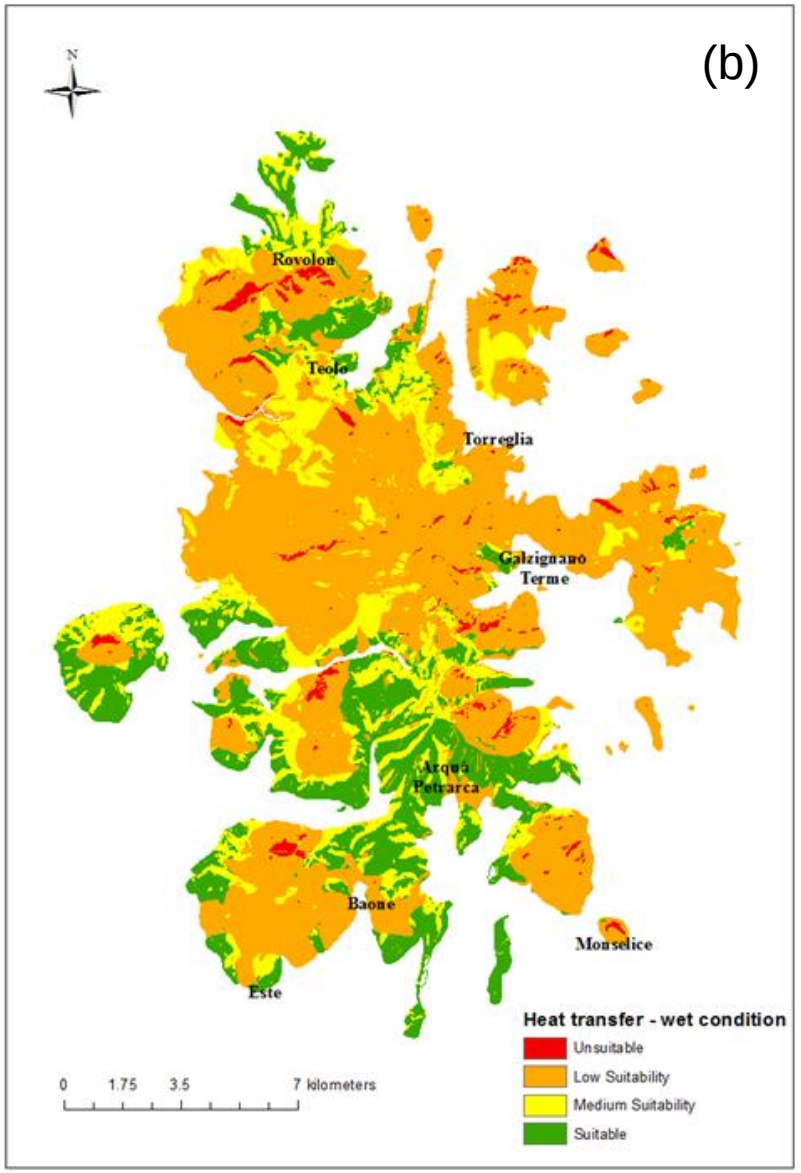
Topographic solar radiation (01.05-01.09.2015)



- the **total amount of incoming solar radiation** is calculated for each location as the sum of the total direct insolation and the total diffuse solar radiation for the location
- based on **a digital elevation model (DEM)** by TerraSar (interferometry derived, cell 5 m) **of the Euganei Hills** aggregate to a cell size of 10 m
- the **time period considered** goes from 01.05 to 01.09 2015, so it **represents the charging period of the subsoil**
- **7 days and 6 hours intervals** used for calculation of sky sectors for the sun maps

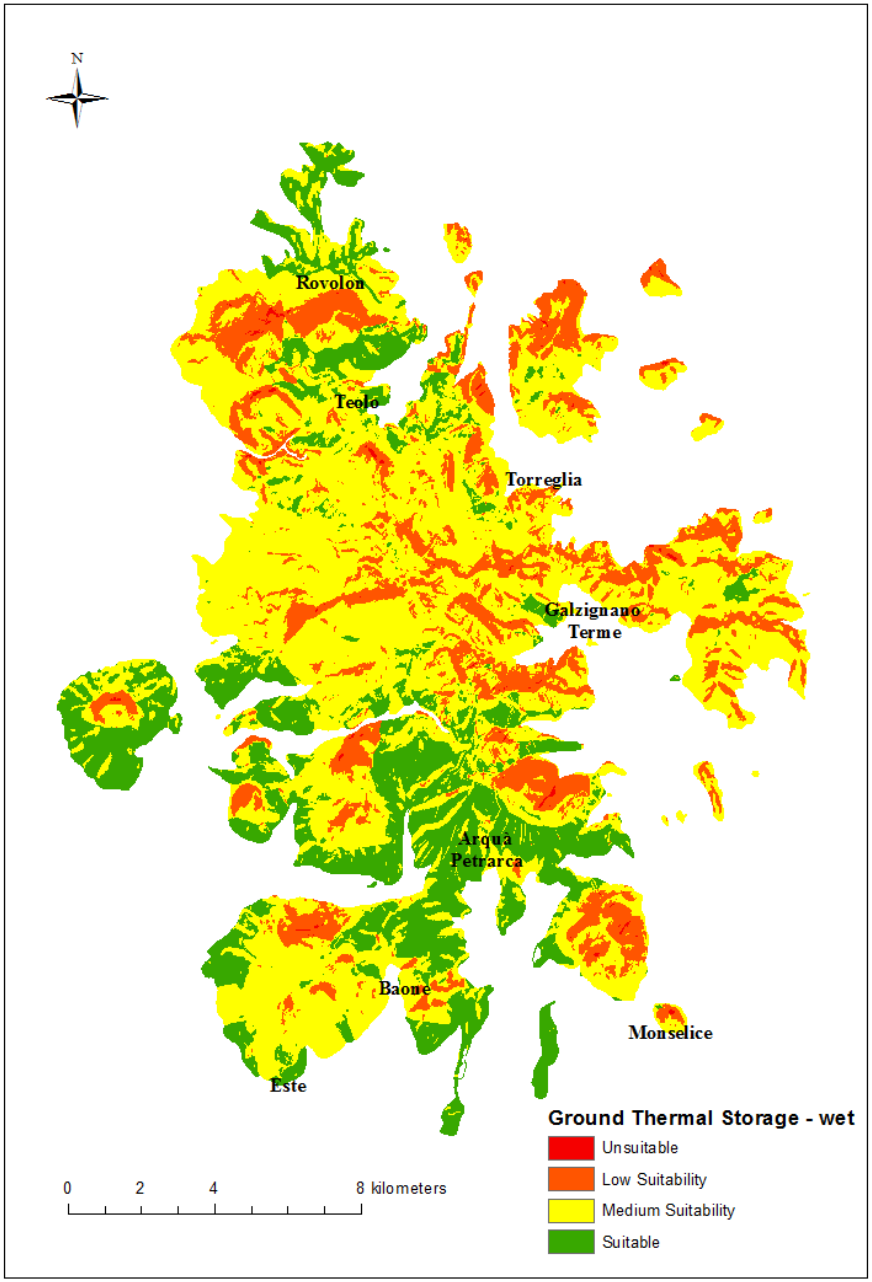
WET: Storage and transfer heat suitability





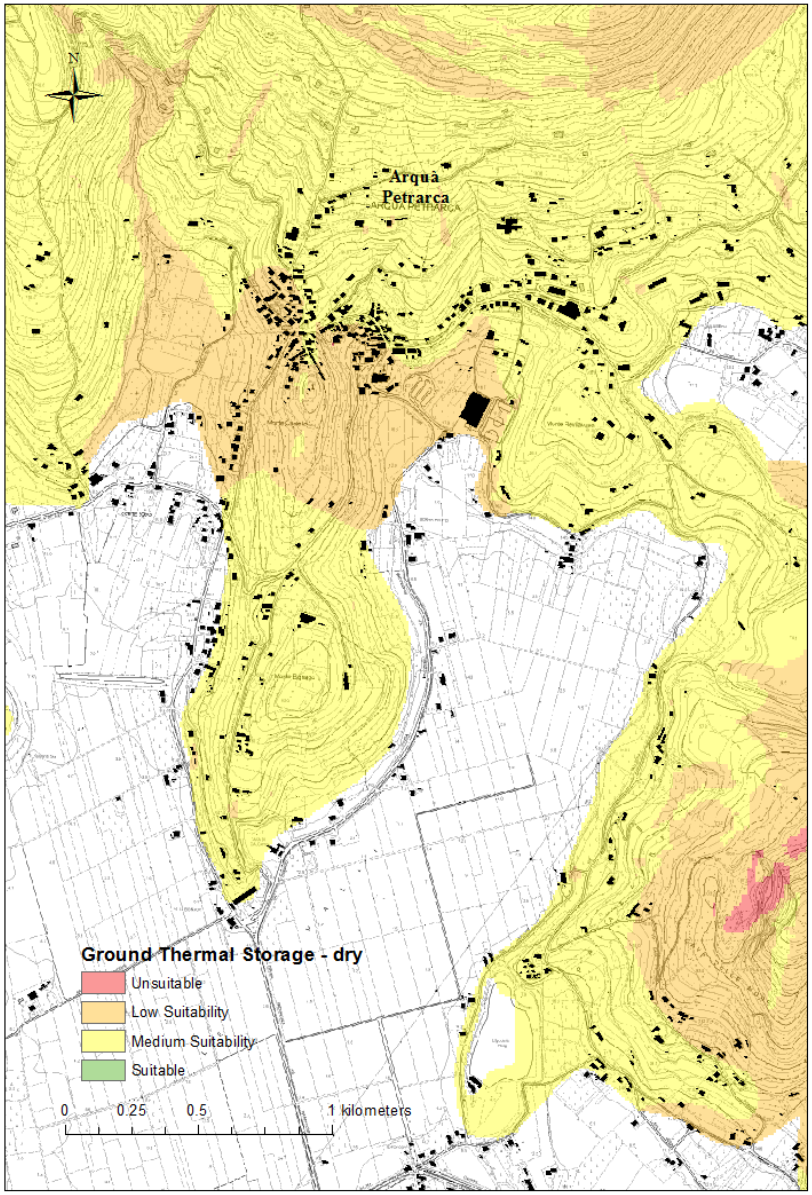
Areas where (a) volumetric heat capacity and solar radiations and (b) thermal conductivity and solar radiations are combined together

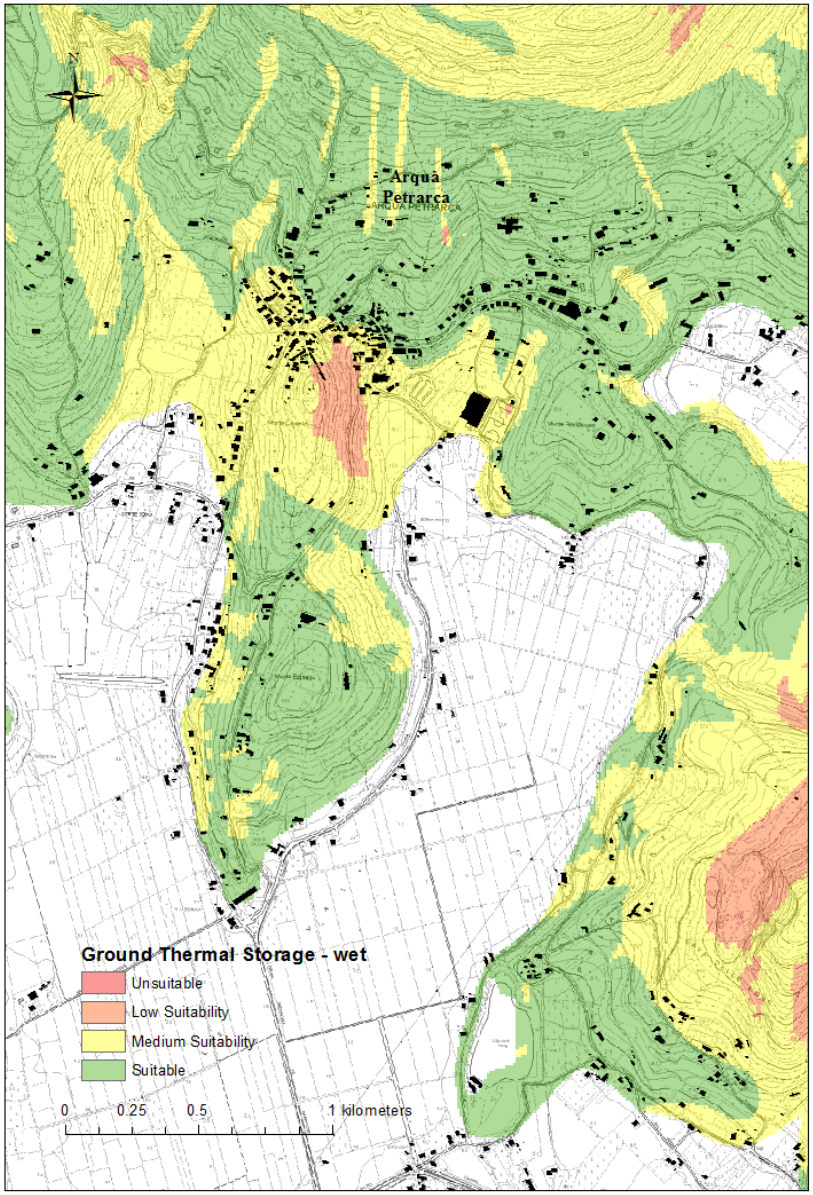
Ground thermal storage suitability



- **qualitative analysis** of the areas most suitable for the design of a solar thermal energy storage system and more interesting for in situ investigation
- **wet condition** are considered because aquifers are usually present in depth (to be verified in situ)
- Outcrops with better ground storage suitability are **Rosso Ammonitico** (0.03% of the Euganean Hills outcrops), **Maiolica** (3.7%) and **Scaglia Rossa (33%).**

Arquà Petrarca case study: **residential area** in the Euganean Hills area





Conclusion

- **a qualitative map of the Euganean Hills areas suitable for solar heating plants with seasonal storage has been created, based on quantitative data (λ, ρcp, Hg)**
- **a first approach** that **associates two representative thermal properties**, thermal conductivity and volumetric heat capacity, **with solar radiation** as the only energy source
- the **ground thermal storage suitability** of the subsurface, a "storage suitability" and a "heat transfer suitability" parameters have been formulated
- **areas with high thermal storage capacity**, essential to reduce the system volume and to increase the system efficiency, **and a good heat transfer rate** between the heat storage material and the heat transfer fluid, needed to ensure that thermal energy can be released/absorbed at the required speed, **are identified**
- **the residential areas** in the Euganean Hills have been considered **to identify the possible distribution of end-users**
- the maps provide **an immediate information on the suitability of the Euganean Hills to accumulate the heat resulting from solar energy and then to extract it during the coldest periods**. They can also be considered as a first series of thematic maps useful to local administrators.

Further developments

- **Identification of the role played by thermal conductivity and volumetric heat capacity in underground thermal energy storage system**

- **design and performance evaluation of a solar thermal energy storage system in a real case study in the Euganean Hills area**

- **Evaluation of the possible energy losses related to:**
  - solar collector: energy losses due to absorption and conversion of incident solar radiation into thermal energy within the solar collectors
  - pipes connections: losses due to the energy transfer through pipes in the whole installation;
  - injection of the heat to the liquid: the heat injected is higher than the transferred heat, determining thermal losses;
  - heat escape from the underground volume interested by the probed: conduction and convection in the ground favor part of the heat transferred by solar radiation underground to escape and to not contribute as expected to the heat exchange

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Thank you for your attention

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