

PAPER • OPEN ACCESS

Geological field investigation for the assessment of the low-grade geothermal resources from volcanic terrains of the Island of Salina (Aeolian Islands, Italy)

To cite this article: G Florida and M Viccaro 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **367** 012007

View the [article online](#) for updates and enhancements.

Geological field investigation for the assessment of the low-grade geothermal resources from volcanic terrains of the Island of Salina (Aeolian Islands, Italy)

G Floridia¹, M Viccaro^{1,2}

¹Università di Catania, Dipartimento di Scienze Biologiche Geologiche e Ambientali, Corso Italia, 57, 95125 - Catania (Italy)

²Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Catania, Osservatorio Etneo, Piazza Roma, 2, 95125 - Catania (Italy)

E-mail: giovanni_floridia@tiscali.it; m.viccaro@unict.it

Abstract. The subsoil as a "thermal reservoir" is a modern concept that is leading to continuous developments of innovative methods of energy production. If volcanic areas have been so far considered suitable for exploitation of medium-to-high enthalpy resources, it is also true that an incredible potential confined to low grade resources is available. The geological background of Sicily makes the island as one of the most suitable contexts of southern Italy where geothermal resources could have great potential to increase their whole usage. Several active volcanic zones or areas at high hydrothermalism offer advantageous exploitation from low to high enthalpy geothermal resources. Here we present a case study from Santa Marina Salina (Aeolian Island Arc) with a detailed field survey providing information on lithostratigraphic features and on hydrogeological conditions of the area. The study is aimed at testing the thermal conductivity distribution at various depths by means of a theoretical model. Such an approach allowed the definition of the most suitable areas and their low-grade geothermal potential through different thematic maps for thermal conductivity in the shallow subsurface (0-150 m). Collected data become crucial for correct sizing of low-enthalpy geothermal installations, leading to optimization of the final planned technical solutions efficiency.

1. Introduction

During the last years, the interest towards geothermal resources is continuously increasing in Sicily. The island has a very favorable geological context in this regard: part of the region is characterized by the presence of volcanic systems (Aeolian Islands, Pantelleria, Mt. Etna), which are indication for the existence of important thermal anomalies useful for the exploitation of geothermal energy. However, the geological and hydrogeological setting put into evidence how most of the Sicilian territory is affected by a low-to-moderate thermal regime. Hence, the potential from a wide spectrum of geothermal resources in Sicily is high, as it is confirmed by heat flow maps resulting from various research projects (e.g., IGG-Italy, VIGOR project, CNR).

This study is aimed at analyzing the low-grade geothermal resource of a volcanic area by means of investigations of the thermal conductivity variations of the explored terrains. Consequently, the production of conductivity gradient maps of the shallow subsurface allowed the definition of the



spatial low-grade geothermal potential and the correct evaluation for sizing installations designed for direct uses.

2. Geological background

The island of Salina belongs to the central sector of one of the most important volcanic province in Italy, i.e. the Aeolian Island Arc. It consists of seven islands, forming a volcanic arc displaying a complex geodynamic framework [1]. Located in the southern Tyrrhenian Sea, along the north-western side of the Calabro-Peloritan block [2], these volcanoes are emplaced on 15-20 km of continental crust and they are the expression of the subduction between the European and African plates [3].

The island of Salina is dominated by two main volcanic cones differing only 100 m in height, Monte dei Porri (860 m asl) and Monte Fossa delle Felci (760 m asl) and by two major depressions, the first between these two stratocones, the other in the area of Pollara. The lithological succession is characterized by distinct stratigraphic units related to different periods of volcanic activity that have emplaced deposits from fall-out and pyroclastic density currents, alternated to prolonged periods of rest (erosional phases) [4].

The island of Salina, as well as the other islands of the Aeolian Arc, is a key location where the multiple geological-volcanological features can be investigated. Most of research interests have been so far devoted to aspects including geodynamics, geochemistry, volcanology and hazard assessment [5]. However, new perspectives can offer relevant impact on the society, such those aimed at constraining the thermal properties of the subsoil as a function of the lithostratigraphic characteristics of rocks constituting the volcanic succession.

3. Results

3.1. Field survey

Objectives of the fieldwork are aimed at reconstructing the vertical stratigraphic succession of the first 100-150 meters in the area of the town hall of Santa Marina Salina (Figure1).

The presence of terrains belonging to four volcanic complexes has been established during the survey: Rivi, Capo, Monte Fossa delle Felci and Porri. Although the investigated area was mainly affected by the activity of only two of the above-mentioned eruptive centres (i.e., the Rivi-Capo complex and Monte Fossa delle Felci), volcanic deposits belonging to the Porri volcano complex have been identified in some sectors. The chronological-stratigraphic reconstruction allowed a detailed interpretation of the volcano-tectonic mechanisms leading to the current morphology, together with a detailed definition of stratigraphic relationships. The lowest stratigraphic level is characterized by fall-out deposits; these are welded scoriaceous levels deriving from Strombolian activity fed by different centres, as testified by the different orientations of tephra layers. Specifically, products studied in the southern part of the investigated area can be related to the eruptive centre of Fossa delle Felci (Figure 2-c), while those to the north (Passo di Megna) belong to the Rivi-Capo complex (Vallone del Castagno Formation – Figure 2-d). The Rivi-Capo complex consists of several welded scoriaceous fallout deposits [6]. For what regards fall-out deposits of the Fossa delle Felci succession, tephra layers, mostly lapilli and bombs with thickness of about 100-150 m, have been attributed to Strombolian activity of this centre. Furthermore, several cross-stratified beds are interlayered in different positions and the presence of different grain size suggests variable energy through time of the volcanic eruptions.

In various areas on the top of the fall-out units of Fossa delle Felci deposits (e.g., Vallone degli Zappini), heterogeneous materials were found, constituted by coarse-grained tuff-breccias, volcanic and sedimentary lithologies (Figure2-b). Such deposits were interpreted as due to events allowing wet and dry remobilization, such as lahars and debris avalanches. The activity of Fossa delle Felci culminated with emplacement of a deposit, yellowish in colour, with maximum observed thickness of

about 50 m (the Favarolo Unit), which suggests variation either of the chemistry of the erupted products either of the style of volcanic activity, which shifted to more energetic events.

Above the Favarolo Unit, other products different both in structure and colour with respect to all the previously identified volcanic rocks have been found: these were recognized as grey tuffs (Figure 2-a) that have been associated to the activity of Monte dei Porri. These show variable thickness from the south (10-15 meters) towards the north (1.5-2 meters).

The municipality of Santa Marina Salina is built on alluvial or detrital deposits, which can be also found into valleys and placed on top of the stratigraphic succession. The comparison of field data and analysis of MASW investigations conducted in the area allowed to define the thickness of alluvial deposits on the order of 30-40 meters [7].

All this considered, a detailed geological map of the area has been outlined in order to define a geological model for the subsoil (Figure 3)

3.2. Lithology and thermal conductivity

The importance of getting geological information for a sustainable exploitation of the subsoil through geothermal systems from low-enthalpy resources is significant [8]. Understanding of the lithological characteristics of the ground, along with the hydrogeological context is essential for a correct planning of the probe field allowing the geo-exchange [9]. Our geologically based evaluations have been verified to be fundamental for the optimization of a low-grade geothermal system [10].

Thermal conductivity of terrains generally shows high variability, ranging from about 1 up to 6 W/mK. The variegated terrains of the island of Salina are characterized by rocks variable in their nature, different structures and textures of deposits and therefore porosity, presence of organic particles, degree of water saturation, which all together strongly influence their thermal characteristics. In support of a preliminary feasibility studies for the direct use of low enthalpy geothermal energy, it was therefore necessary fixing the relationships between rock types and their thermal conductivity.

According to the characteristics of rocks investigated during the geological field work (Figure 2), values of thermal conductivity for the identified lithotypes have been obtained.

The recent alluvial deposits come from dismantling of upstream deposits and occupy a large part of the investigated area; they are characterized by heterogeneous and altered material. The low degree of cementation, high porosity and absence of pore water have led to the estimation of their thermal conductivity between 0.7 and 1 W/mK [11] (Table 1).

Table 1. Lithologies of the identified terrains, their thickness and thermal conductivities.

Lithology	Thickness (m)	Thermal conductivity (W/m ² *K)
Alluvial deposit	30-40	0.7-1
Grey Porri Tuff	8	0.5-1
Fall-out of Mt. Fossa delle Felci	150-170	1
Fall-out of Rivi-Capo complex	150	1.1

The deposit underlying the epiclastic material is that referred to the Grey Porri Tuff unit. It is characterized by a fine matrix (mm-sized) with some coarse elements (cm-sized) with a general low degree of cementation. Values of thermal conductivity have been estimated considering the degree of water saturation of volcanic tuffs, which range from very low values (0.5-1 W/mK) for dry tuffs up to 2.3 W/mK for wet tuffs [12]. In our case, values of thermal conductivity for tuffs are consistent to those of dry tuffs, being water not present (0.5-1 W/mK).

Deposits underlying the Grey Porri Tuff are those referred to the Strombolian activity of the Rivi-Capo complex and the Fossa delle Felci, which have rather basic compositions, grain size and degree of cementation consistent with those of volcanic pyroclastic materials having thermal conductivity ranging from 1.1 W/mK to 1.5 W/mK [13].

The potential presence of water would be relevant in modifying the final thermal conductivity, being this affected positively in porous materials saturated with water. In the investigated area, the presence of water in deposits at the surface is irrelevant, but interaction with sea water for layers beneath the sea level cannot be excluded due to the proximity to the shoreline.

3.3. Thermal mapping

One of the most interesting aspects of the study is the characterization and assessment of the thermal potential from low enthalpy resources of the area. This has been done by means of the production of thematic maps concerning the thermal conductivity of the analysed lithologies and their 3D development in the subsoil (Figure 3). The used method to get this type of information is based on the relationships between the geothermal characteristics of the explored geological units and their relative thickness. According to an empirical model for the calculation of thermal conductivity, based on the intrinsic characteristic of materials, an average thermal conductivity value, which is function of the thickness for each lithology, has been adopted for each sector. Consequently, a detailed mapping of the thermal conductivity fluctuations has been carried out for depths between 50 m and 150 m (Figure 4).

Maps of the thermal conductivity variation put into evidence the significant influence of alluvial deposits for the first 50 m of the succession, reflecting the alluvial fan shape. The thematic cartography shows a remarkable contribution of volcanic terrains for the depth range 100-150 m, which finally imply the increase up to the maximum extractable thermal energy in the investigated area (Figure 4-c).

The most important aspect of this study is the extrapolation of specific thermal conductivity data for a very narrow area, which leads to the innovative concept of geothermal micro-zonation (Figure 4). The idea principally starts from the need of data networking useful for the optimization of low enthalpy geothermal systems. Indeed, the creation of detailed geothermal mapping based on petrological (lithotypes, mineralogical structures and textures), geochemical (fluid) and petrophysical (thermal conductivity) characterization is the only way for obtaining reliable information on thermal characteristics of the subsoil [14]. These maps have the advantage to provide immediate information on the most suitable depths for the installation of geothermal probe systems [15]. Also, the arrangement and implementation of GIS tools through the use of these geo-referenced thematic maps are able to deliver a substantial number of information about the true thermal potential of a specific area.



Figure 1. View of the Santa Marina Salina fan.

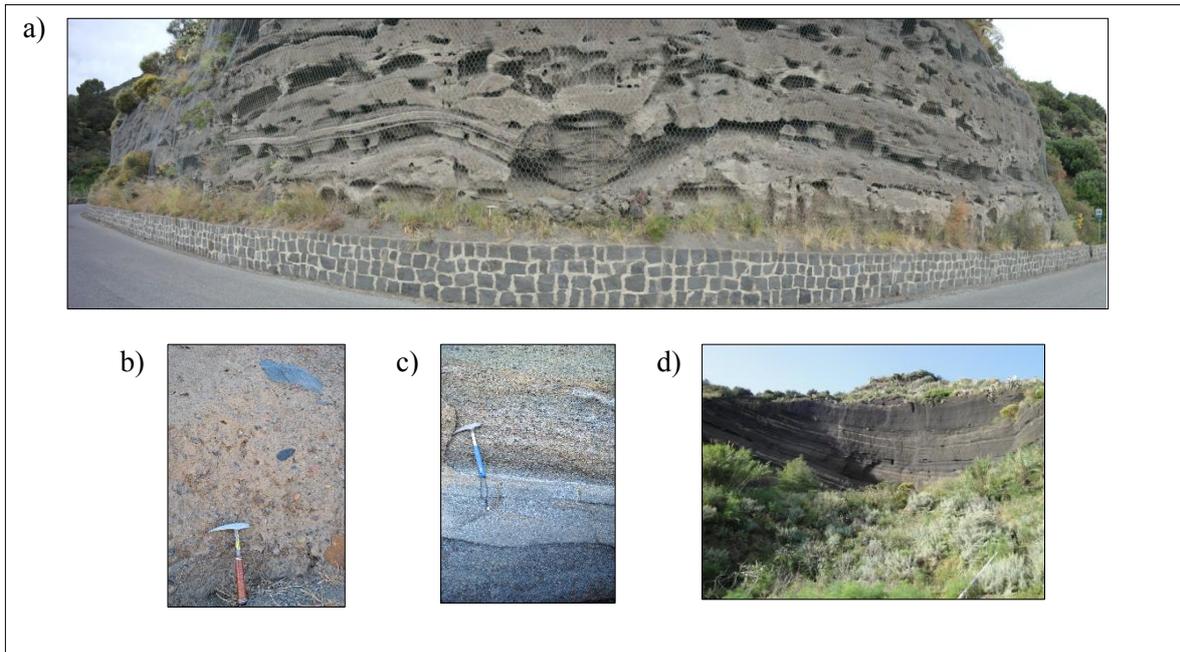


Figure 2. Examples of investigated lithologies a) Grey Tuff; b) Coarse-grained tuff-breccia; c) Felci Fall-out; d) Rivi-Capo Fall-out.

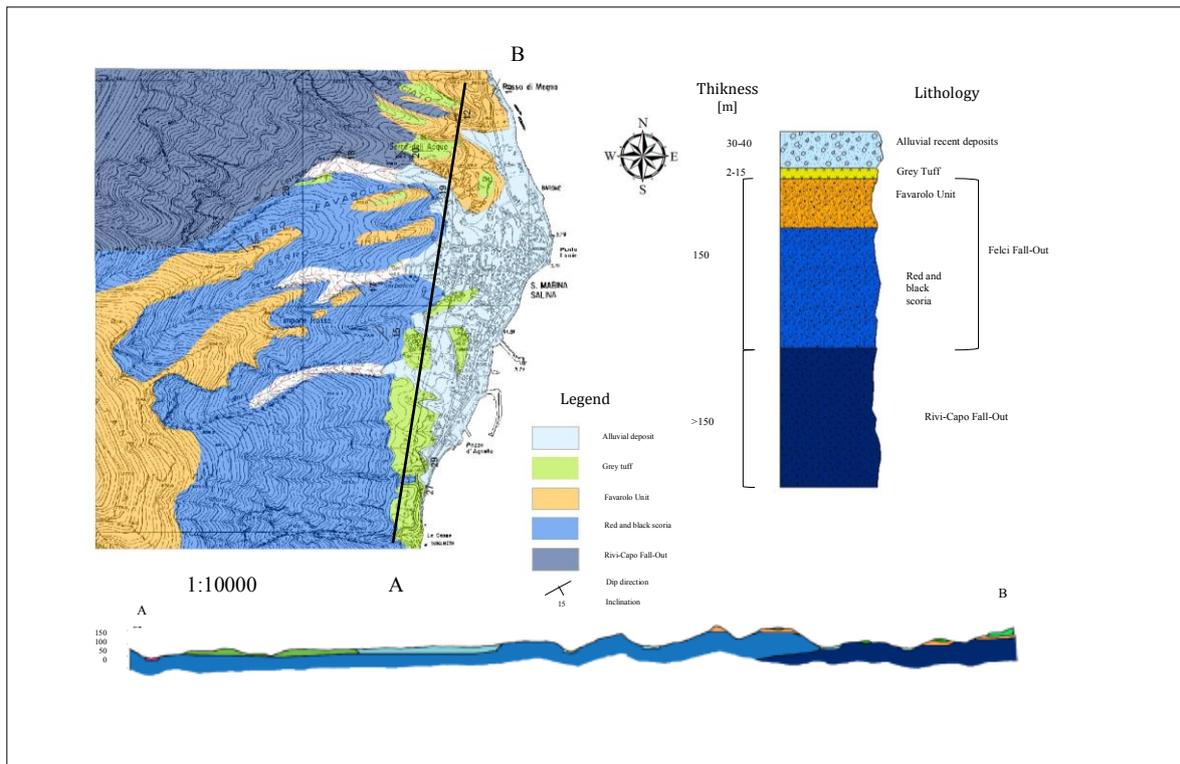


Figure 3. Geological map, litho-stratigraphic configuration and geological subsoil model of the investigated area of the Salina Island.

4. Discussion

Our geologically based evaluation of the low-grade source geothermal potential of the selected areas was verified to be fundamental for the optimization of all the main components of a low-enthalpy geothermal system. Results furnished for a number of lithologies investigated in this work have been used for evaluations of physical properties useful for the direct use of low-grade geothermal energy, emphasizing the fundamental role played by the lithology, structural and textural characteristics of the rocks on the final thermal conductivity of a layer.

The empirical method we have taken into account in this work considers thicknesses of the lithostratigraphic units and the thermal conductivity for each type of lithology investigated [16]. Evaluations on these rock types, has led us to fix an average thermal conductivity value for each analysed lithology (Table 1).

Table 2. Low enthalpy power plant dimensioning.

Geothermal Heat Exchanger	
Maximum extraction per GHE [kW]	6
Maximum insertion per GHE [kW]	7
Appropriate number of GHE	5
GHE Depth [m]	125
Drilling meter [m]	625

Our geological survey and the thermal conductivity data have been then used for sizing a direct use power system for a specific building in Santa Marina Salina. Understanding of the lithological characteristics of the subsurface, along with petrographic characteristics of rocks [17], revealed to be essential for the correct planning of the probe (geo-exchanger) field and the associated ground source heat pump (Table 2).

Starting from the assessment of the thermal requirements of the construction, a value of approximately 35 kW has been derived through an energetic diagnosis. This allowed the definition of the optimal configuration for the probe field. Assuming that one heat exchanger covers a power of about 40 W/m in heating mode and 50 W/m in cooling mode, we need to extract 6 kW of thermal power for each probe in heating mode and 7 kW/per probe in cooling mode. A probe field with 5 elements exchanging a total of 30 kW in heating mode (during the winter) and 35 kW in cooling mode (during the summer) has been therefore designed (Table 3).

With reference to the total energy requirement of the building both in heating and cooling mode, the electrical kWh required for the entire structure has been calculated. One of the most interesting technological aspects of the designed low enthalpy geothermal system is that it covers heating during winter, cooling during summer and ensures continuous production of domestic hot water through a unique system [18]. This configuration leads to saving of a considerable amount of energy if compared to the traditional power sources, with environmental impact almost zero [19]. In contexts such as those of Aeolian Islands, with severe limitations on the potential environmental impact imposed by the National law, low enthalpy geothermal systems seem therefore the best solution to encounter needings of carbon-based reduction of emissions, sustainable usage of renewable energies and strong limitation of their impact on the environment.

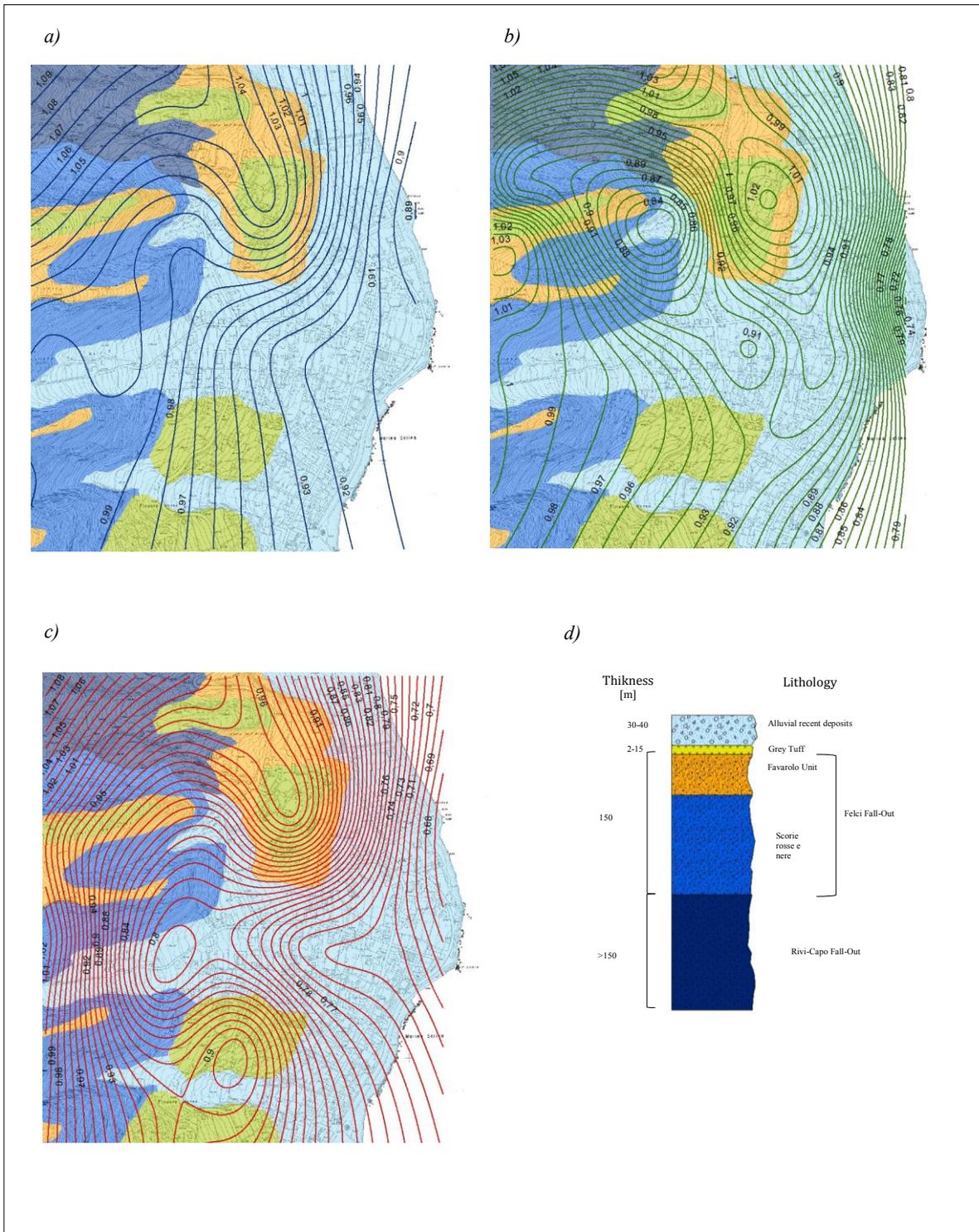


Figure 4. Map of the geothermal potential for the studied area from 0 to 150 m depth (1:2000). a) 0-50 m in depth; b) 50-100 m in depth; c) 100-150 m in depth; d) Reconstruction of the lithological units.

Table 3. Low-enthalpy power system configuration.

SYSTEM CONFIGURATION	
Heating	
System Type	Fan coil
Hot water	Yes
Maximum heating power [kW]	26.2
COP	3.5
Cooling	
System Type	Fan coil
Hot water	Con PdC
Maximum cooling power [kW]	35.8
COP	4
Subsoil data	
Type of terrains	Volcanic terrain
Estimate heating production [W/m]	40
Estimate cooling production [W/m]	50

5. Conclusions

In this study, geological and structural field work combined with thermal data of the subsoil have been established to be fundamental for the optimization of low-grade geothermal systems. Identification of lithological features and understanding of their areal distribution put into evidence important variations of thermal conductivity. This suggests that small-scale variations can affect significantly the final thermal conductivity value, indicating that studies aimed at constraining the geothermal micro-zonation are of great impact.

Our investigations provide specific data for the optimization of sizing during planning of the low enthalpy geothermal systems. We think that innovative approaches to the evaluation of low-grade geothermal resources could be certainly applied to other geological contexts and could increase the penetration degree into still reluctant markets - like in Italy - towards this type of renewable energy.

References

- [1] Piromallo C Morelli 2003 A P wave tomography of the mantle under the Alpine-Mediterranean area *Journal of Geophysic Research* vol **108** NO **B2**
- [2] De Astis G Ventura G Vilardo G 2003 Geodynamic significance of the Aeolian volcanism (Southern Tyrrhenian Sea, Italy) in light of structural, seismological, and geochemical data *Tectonics* vol **22** issue **4**
- [3] De Ritis R Ventura G Chiappini M 2007 Aeromagnetic anomalies reveal hidden tectonic and volcanic structures in the central sector of the Aeolian Islands, southern Tyrrhenian Sea, Italy *Journal of Geophysic Research* **112** B **10**
- [4] Di Sipio E Chiesa S Destro E Galgaro A Giarretta A Gola G Manzella 2013 A rock thermal conductivity as key parameter for geothermal numerical models *EGU General Assembly*
- [5] Nicotra E Viccaro M De Rosa R Sapienza M 2014 Volcanological evolution of the Rivi - Capo Volcanic Complex at Salina, Aeolian Islands: magma storage processes and ascent dynamics, *Bull Volcanol* vol **76** art. number 840 doi:10.1007/s00445-014-0840-8
- [6] Lucchi F Peccerillo A Keller J Tranne C A Rossi P L 2013 The Aeolian Islands Volcanoes *Geological Society of London* vol **37**
- [7] Giuliano A 1994 Studio geologico per i piani particolareggiati di recupero del P.R.G zona A

- (Santa Marina Salina, Aeolian Island)
- [8] Moeck I 2014 Catalog of geothermal play types based on geologic controls *Renewable and Sustainable Energy Reviews* vol **37** pp 867 – 882
 - [9] Hellstrom G 1998 Thermal Performance of borehole heat exchangers *International Geothermal Conference* (Stockton)
 - [10] Viccaro M 2018 Doped bentonitic grouts for implementing performances of low-enthalpy geothermal systems *Geothermal Energy* vol **6** doi:10.1186/s40517-018-0090-7
 - [11] Robertson E C 1988 *Thermal properties of rocks* U.S. Geological survey
 - [12] Johnstone J.K 1980 Evaluation of tuff as a medium for a nuclear waste repository: Interim status report on the properties of tuff (Wolfsberg)
 - [13] Clauser C, Huenges E 1995 Thermal conductivity of rocks and minerals Ahrens T J, editor *Rock physics and phase relations handbook of physical constants* (Washington, D.C) vol **3** pp 105 – 26
 - [14] Viccaro M Pezzino A Belfiore G M and Campisano C 2016 The significance of “geothermal microzonation” for the correct planning of low-grade source geothermal systems *Geophysical Research Abstracts* vol **18** EGU General Assembly (Vienna, Austria)
 - [15] Claesson Eskilson P 1987 Conductive heat extration to a deep borehole: Thermal analyses and dimensioning rules (University of Lund, Sweden)
 - [16] Jorand R Clauser C Marquart G 2015 Pechnig R Statistically reliable petrophysical properties of potential reservoir rocks for geothermal energy use and their relation to lithostratigraphy and rock composition: The NE Rhenish Massif and the Lower Rhine Embayment (Germany) *Geothermics Journal* vol **53** pp 413–428
 - [17] Tinti F 2009 *Geotermia per a climatizzazione applicazioni, tecnologia, analisi costi-benefici* (Palermo)
 - [18] Banks D 2012 *An introduction to thermogeology: ground source heating and cooling* Wiley-Blackwel (Hoboken, New Jersey) pp 526
 - [19] Lund J W Freeston D H Boyd T.L 2011 Direct utilization of geothermal energy *Geothermics Journal* vol **40** pp. 159 – 180