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Low Entalpy Geothermal suitability of North Sardinia (Italy)

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Abstract

Heat flow density over Sardinia is relatively high. Tertiary geodynamics and radiogenic heating from the Variscan batholith are the possible concurrent causes. Major anomalies were thought confined to the Tertiary basins, where 180 mW/m^2 are reported. New data ascertain that the occurrence of the hottest thermal springs does not mirror these basins, as they pour out from Variscan granites. Hence the high thermal flow from the basins can result from basin-wide heat redistribution by hot "granite" water flowing laterally in shallow aquifers. This scenario is particularly favourable for low-medium enthalpy fluids exploitation as well as for geoexchange.

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Keywords: Lindal Diagram, geoexchange, GSHP, thermal springs.

1. Introduction

The increasing interest on Geothermal energy derives from new chances in the direct exploiting of even minimal positive thermal anomalies (low enthalpy) for both domestic and economic activities, as sketched in the "Lindal diagram" [1].

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The heat flow in Sardinia reaches high values, ranging from 60 mW/m^2 (structural highs made of Variscan basement) to 180 mW/m^2 along the border of the Cenozoic basins. As a consequence, a great number of thermal - generally underexploited- manifestations occur all over the island. For this reason Cataldi *et al.* [2] ranked the geothermal fields of Sardinia on A-B categories in a scale from A to D. In any case, even in the absence of positive thermal anomalies, under favorable lithological and hydrogeological conditions, subsoil represents a tank able to store thermal energy in summer and give it back in winter through geoexchange. This method employs Ground Source Heat Pumps (GSHP), consisting of a thermal device connected with a vertical borehole. The control of the site and local geology on ground heat exchanger configuration and design is of basic importance [3]. Henceforth this paper, based on both field surveys and cross checking between thermal occurrences and geological features, focus on the suitability of both low-medium enthalpy fluids and geoexchange in North Sardinia (Italy), with the aim of encouraging their exploitation. The advantage for domestic and agriculture uses is even more evident taking in account the climate of the region, characterized by hot summers and moderately cold winters, which needs four month of conditioning and five month of heating respectively.

2. Geological setting

Sardinia consists of a Variscan basement metamorphosed at different grade, intruded by late orogenic granitoids (Corsica-Sardinia Batholith) [4, 5] and a cover consisting of sedimentary – partially carbonate – and volcanic rocks with maximum thickness of 2-3 km.

The Tertiary geodynamics of the Sardinia-Corsica microplate is related to the west directed subduction of the Ligure-Piemontese Ocean beneath the south European margin. According to Carmignani *et al.* [6], and Oggiano *et al.* [7], the onset of the Europe-directed subduction dates back to the Upper Cretaceous, generating a calcalkaline volcanism on the Island, which lasted from Eocene up to middle Miocene [8]. During the Burdigalian the drift of the Sardinia-Corsica microplate followed the collision with Adria ending in the opening of the back-arc Liguro-Provençal basin. Eastward, in the north Tyrrhenian realm the slab break off, and lower lithosphere delamination, generated an “asthenospheric window” accompanied by mantle upwellings, which, migrating eastwards [9], caused a still active, anomalous heat flows in the northern Tyrrhenian basin and Tuscany.

Whether the relatively high thermal flow in Sardinia is related to this geodynamics or to different heat source, such as radiogenic heating from the Variscan crust, is still to be established. In any case a concurrence of both causes is high probable. The Cenozoic geodynamic in Sardinia is responsible of an important Oligocene-Aquitanian ENE strike-slip tectonics, with transpressive (flowers) and transtensive (strike-slip basins [10]) structures. This dynamic is thought to be the result of the collision between Sardinia-Corsica and Adria and was followed by an extensional tectonic, which generated several, NNW trending, half grabens such as the Porto Torres, Castelsardo and Logudoro basins [11, 12].

A new extensional tectonic setting, linked to the opening of the south Tyrrhenian back-arc basin, started since early Pliocene giving rise to NS-trending faults and to a new volcanic cycle characterized by within plate basalts with alkaline and transitional signature, which ended in the middle of Pleistocene [13, 14].

The Cenozoic geodynamic generated a play of crustal faults, which form a plumbing network for water hosted in deep-seated reservoirs heated due to the relatively high thermal gradient.

3. Thermal evidences

Any direct relation between the relatively high thermal flow and the two Cenozoic volcanic cycles is hard to be established in north Sardinia as well in Corsica. Infact, the youngest calcalkaline products, with a possible crustal anatectic component [15], date back to 14 Ma ago and are represented by few lava extrusions in north-western Sardinia [16]. So, heating processes, related to recent crustal anatexis, comparable to those that affected the Tuscany Province must be ruled out all over the island. By other hand, the recent (Pliocene–Pleistocene) cycle is represented by subcrustal magmas, namely within-plate basalts, which mainly crop out in the northwestern and eastern part of the island, and are unable to sustain a long lasting heat generation.

Some evidences rise looking at the distribution of the heat flow and thermal manifestations in relation with the lithological and structural features:

i) The highest thermal flow (180 mW/m^2) is recorded around the faults that bounds the main NNW trending basins [17, 2], only a N-S strip corresponding to an eastern structural high records normal values in the range of 50-60 mW/m^2.

ii) Several springs, including some newly discovered in this research, are characterized by anomalous water temperatures and/or chemical-physical features (e.g., high salinity, carbon dioxide, radon and nitrogen content; [18 and references therein]). Temperatures range between 20 and 75 °C and, as a rule, the hottest waters pour out from the Variscan basement, particularly from granitoids, whereas hypothermal waters are mostly located within Oligo-Miocene volcanic rocks inside the main NNW trending basins (Fig.1).

iii) The extensional faults bounding the NNW extensional basins as well as the main strike-slip corridors along with the related transtensive/transpressive structures, host geothermal circuits, which can influence and enhance the heat flow when deep hot waters, rising along damage zones of regional faults, spread throughout relatively shallow aquifers.

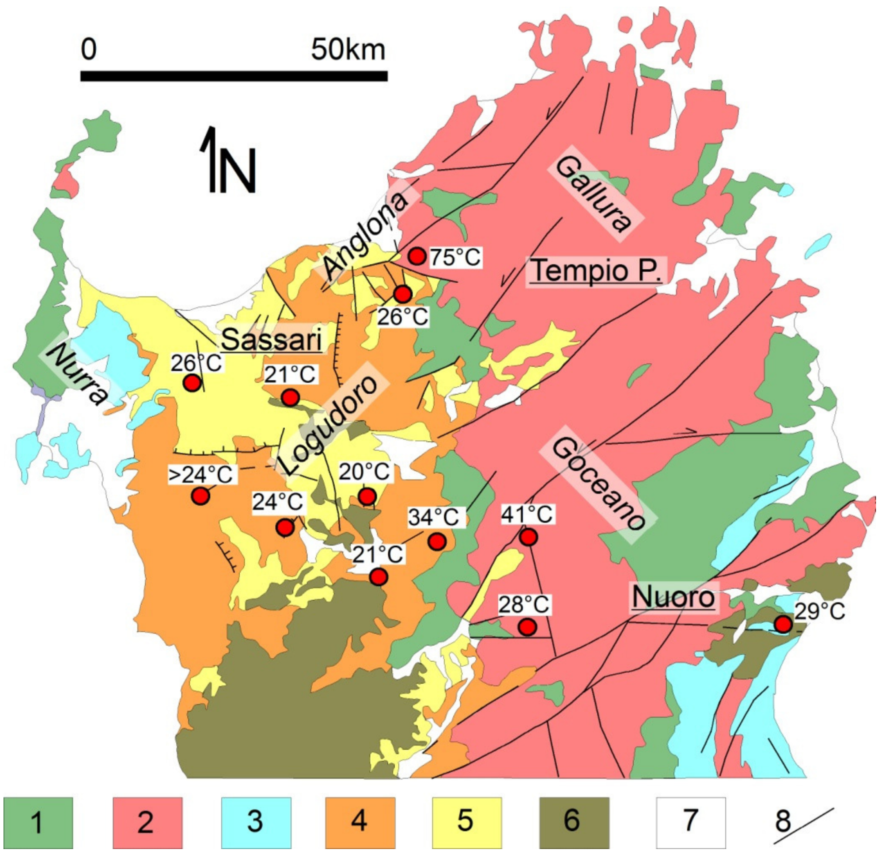

Fig. 1. Geological sketch map of Sardinia. Red points represent the analyzed thermal springs and relative water temperature. Legend: 1) Paleozoic metamorphic basement; 2) Variscan granitoids; 3) Mesozoic carbonates; 4) Tertiary volcanic rocks; 5) Tertiary sedimentary rocks; 6) Plio-Pleistocene volcanic rocks; 6) recent covers; 8) main faults.

A good example of high heat flow linked to upwelling of thermal water is the Anglona region (i.e. the hottest geothermal district in Sardinia; [19]). Here deep penetrating rainwater, heated by geothermal gradient, upwells rapidly interacting with shallower aquifers that, hence, experience heating at different degree (Fig. 2). The pathway for hot water resides in a play of strike-slip and normal faults, which affect the Variscan basement and act as border faults of an Aquitanian basin (Castelsardo basin [12]). The thermal circuit is feed by meteoric water infiltrating the granitic massif of Tempio Pausania [20] at mean altitude similar to 550 m a.s.l, as pointed by $\delta^{18}O$ assessment. The hottest water (75 °C) springs out within the Casteldoria granite [20] at the intersection between two normal oblique faults. In any case some boreholes, dating back to the fifties of last century, documented thermal upwelling along all the main faults of the region. According to the water chemistry, the reservoir is located within granites at depths greater than 2 km [19]. This thermal manifestation is not isolated because other, less warm (in the range of 28 °C), waters occur in a wide area adjacent to Casteldoria as testified by several boreholes for domestic use drilled in the thick Oligocene-Aquitanian sandy conglomerate that rests on the Variscan basement.

Other important thermal manifestations in the range of 30-45 °C are linked to faults crosscutting the Variscan basement (Fig.1) or putting in contact the basement and the post Variscan cover. These waters are invariably characterized by geochemical features typical of granite water, with low CO_2 and high “granophyle” trace elements [18]. Conversely the thermal springs inside the Tertiary basins are characterized by lower temperature, in the range of 20-30 °C (in any case meaningfully higher than the local homoeothermic level) and show different geochemical features with high content in both CO_2 and calcophyle trace elements [18, 21].

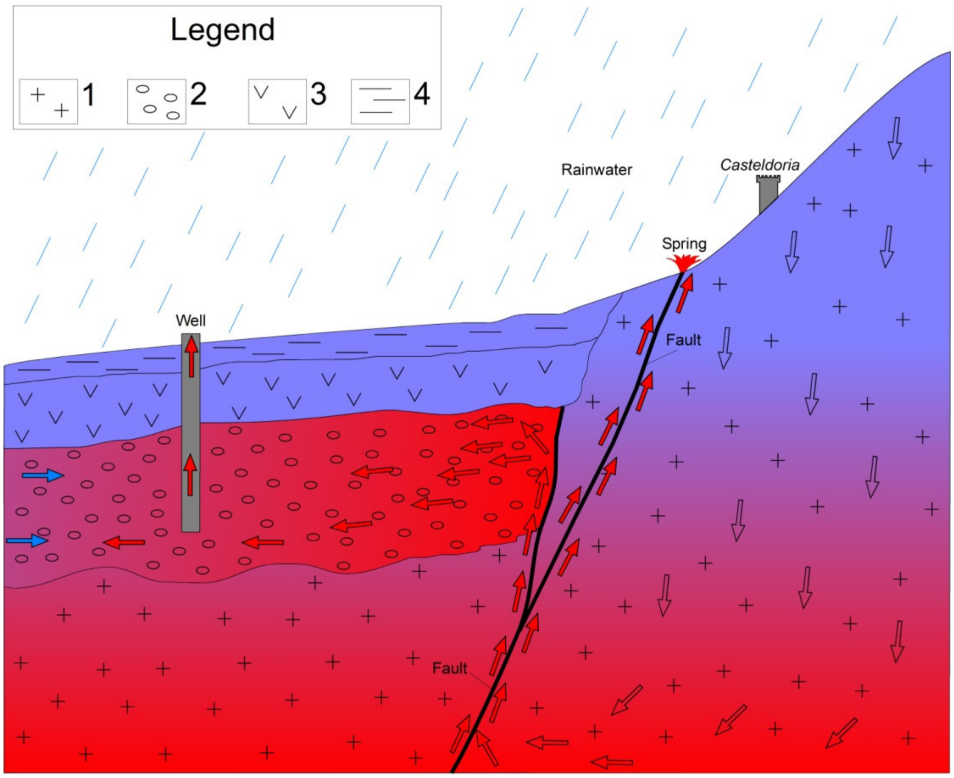

Fig. 2. Schematic circuit of the infiltrating rainwater in Anglona. Legend: 1) Variscan granites; 2) Oligo-Aquitanian conglomerates; 3) Aquitanian volcanites; 4) Langhiano-Serravalian marlstones.

4. Geoexchange

The climate of Sardinia is mesothermic with typically Mediterranean imprint, characterized by dry and hot summers and relatively rainy, moderately cold, winters. Mean annual temperature ranges from 11.6 to 18.0 °C; rainfall range from 411 to 1215 mm in the inner mountainous regions [22]. Cool and hot seasons, have roughly equivalent length. This is a very favorable climatic condition for the use of GSHP because the heat stored in summer is easily recovered in winter. In this way the heat subsoil balance is not altered throughout long lasting working times.

Moreover, taking into account the geographical position of north Sardinia (between 40° and 41° N of latitude), further advantage could be obtained coupling geoexchange and solar panels in order to provide electrical energy for heat pump, so making totally renewable and "CO_2 free" the GSHP.

As for the geological feasibility, among the main parameters directly related to the efficiency of the ground geoexchange systems, the thermal conductivity (TC) and the open porosity (OP) were evaluated on the rocks that characterize geology of northern Sardinia.

In this way four main geo-lithological complexes were evidenced with different thermal TC and OP (Fig. 3):

i) The metamorphic basement, which shows the highest variability in conductivity from 2 [W/(mK)] in the phyllites of Nurra and Goceano, up to 3 [W/(mK)] in the migmatite of Asinara and Gallura and >4 [W/(mK)] in quartzites, which occur in small outcrops in the Nurra district.

ii) The Sardinia Batholith, which in northen Sardinia is dominated by monzogranites and leucogranites with minor granodiorites and tonalites, has more constant values. In fact leucogranites and monzogranites gave values close to 3.5 [W/(mK)], whereas the few tonalities/quartzdiorites are less conductive with values of 2,6 [W/(mK)]. OP is never greater than 2%.

iii) Limestones and marlstones mostly represent the Mesozoic and Cenozoic carbonate rocks with conductivity in the range of 2.5 [W/(mK)] and 2 [W/(mK)] respectively. OP shows values in the range of 15-35%.

iv) The Cenozoic volcanic rocks, due to different composition and textures show a large variability of TC. The acidic terms (e.g. rhyolites and rhyodacites) are represented, almost totally, by pyroclastic flows that show variable values according with the welding grade. The dominant, poorly welded facies exhibit the maximum thickness (hundred metres) and has values between 0.5 and 1 [W/(mK)], conversely the vitreous welded ignimbrites form sheets not exceeding 10 metres in thickness but show higher values in the range of 2.5 [W/(mK)]. The mafic volcanics are represented by andesite and basaltic andesites pertaining to the Oligo-Miocene calcalkaline cycle, which form volcanic massives and by alkaline basalts of the Pliocene-Pleistocene cycle, which form several plateaux. These rocks show similar TC values ranging from 1.5 [W/(mK)] in the mildly vesciculate lavas to 2.5 W/(mK) in the compact Oligo-Miocene andesitic basalts. As for OP, poorly welded volcanic rocks can reach values > 25%. Conversely, massive rocks do not exceed 8-10% of OP. Besides the TC and OP values, the occurrence of a water table improves the thermal geoexchange due to the formation of convective cells, which homogenize the thermal perturbation around the probe [23]. In granitic areas, the occurrence groundwater depends on the fracturing density, even if surficial groundwater can be hosted in the weathered cap rock. The most important aquifers are represented by sedimentary lithologies particularly by limestones (high permeable for karstification) and sandstones characterized by high porosity and permeability, that, in addiction, allow the realization of open loop system.

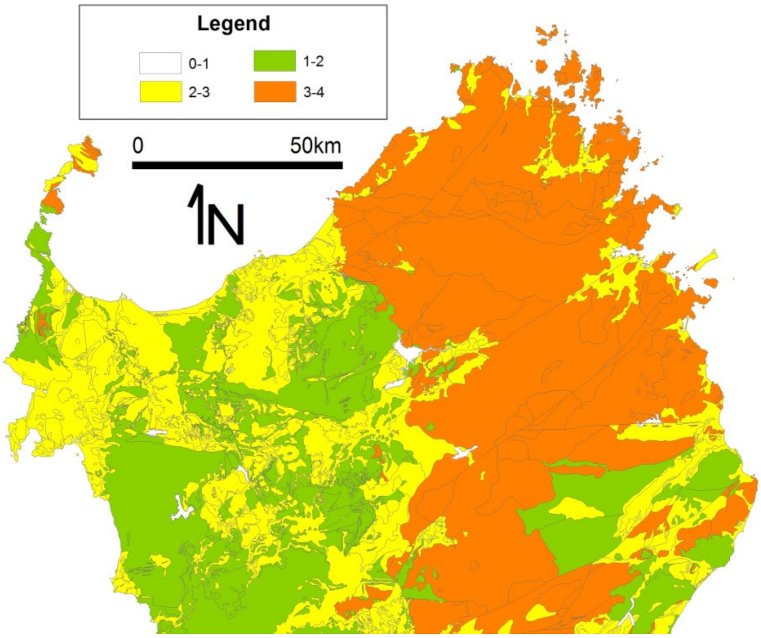

Fig. 3. Map of the potential Thermal Conductivity in North Sardinia, based on the Geological Map of Sardinia [24]. Value are in [W/(mK)].

5. Conclusions

The field work and lab characterization of the different rocks collected in North Sardinia evidenced widespread occurrence of thermal water and allowed a first characterization of the main geological complexes in term of TC and OP.

The hotter springs are invariably located within the late Variscan granites or close to their contact with post-Variscan covers. The geochemical features of these waters suggest a deep fractured granitic reservoir. The thermal waters pouring from the Cenozoic volcanic and sedimentary succession filling the assembly of NNW trending basins, have lower temperature and different geochemical signature that point to meteoric water involved in shallower circuits. Hence, any relation between the Cenozoic volcanic activity and thermal waters can be excluded.

The high heat flow in the Cenozoic graben can results from basin-wide heat redistribution by hot "granite" waters flowing laterally in shallow aquifers (Fig.2). The origin of these deep waters has to be sourced in meteoric waters that infiltrated in the granitic basement at depth greater then that of the bottom of North Sardinia Basins, which does not exceed 3 km [25].

The interplay of petro-physical properties, structures and interferences between the movements of deep hot waters and groundwater, in each geo-lithological complex, can furnish a predictive picture of the potential uses of low enthalpy waters as well as a picture of the favorable conditions for the employment of GSHP systems.

In particular:

i) The wide granitic complex hosts thermal circuits, which can provide water suitable for uses such as tele-heating, greenhouse, SPA etc. Moreover, along the main regional faults, medium enthalpy fluids can rise at depth less than 1 km [19]. Such fluids are suitable also for generation of electric power by mean of binary cycle power plants. The granitic complex is that with a thermal conductivity that meets the most encouraging conditions for GSHP.

ii) In the Cenozoic volcanic complex thermal manifestations are more frequent even if, due to the minor depth of the circuits, the waters has temperatures values that restrict the employment (fish farming, swimming pool, fermentation etc.). As for geoexchange this lithological complex, apart the massives andesite, is characterized by poorly favorable parameters.

iii) The sedimentary covers generally do not host thermal springs even if some wells encountered waters in the range of 25 °C at depth of one hundred metres. As for GSHP, the petro physical parameters were not the best to predict a profitable employment, yet the common occurrences of water tables makes, in any case, this complex suitable for geoexchange.

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