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Terme Caronte geothermal area (Lamezia Terme-Calabria, Italy): preliminary results

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ABSTRACT

The investigated Lamezia Terme site is a low-medium enthalpy geothermal area located in Central Calabria (Southern Italy) at the westernmost edge of the Catanzaro Graben (Calabrian Arc). The area was part of the VIGOR project framework, aimed at defining the geothermal potentiality of 8 areas in Southern Italy through the application of geophysical, geochemical and geological techniques. The area was investigated by a multidisciplinary symposium work where geologists, geochemists and geophysicists meet to define the geological and hydrogeological deep structure as well as the hydrothermal resource, throwing light on the deep circulation of water along fractures delimiting the north portion of the Catanzaro Graben. These preliminary results point out Terme Caronte as an interesting area for low-enthalpy geothermal exploitation.

1. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The studied area (Fig. 1) is located at the westernmost edge of the Catanzaro Graben (Calabrian Arc-CA), where metamorphic and crystalline Alpine rocks and Hercynian rocks (Calabrian basement Complex) cropping out in the Sila massif (upperplate), overthrust on apennine carbonate units (underplate). Terme Caronte is a small tectonic windows of Mesozoic carbonate rocks, which occur in different place in northern Calabrian Arc due to the Pliocene-Quaternary tectonic evolution. In the frame of the Mediterranean mobile belt, the Calabrian Arc is a continental arc-shaped fragment located between the E-W trending Sicilian Maghrebides, to the south, and the NW–SE trending Apennines, to the north (Ogniben, 1973; Amodio Morelli et al., 1976; Bonardi et al., 2001, and references therein).

Ancient low-angle overthrust contacts between the units were obliterated by subsequent overprinting of high-angle faults. Terrigenous sequences of Eocene, Oligocene and Lower Miocene extend along main tectonic segments. All these rocks are dissected by a complex assemblage of high-angle faults, which can be ordered in a number of major systems and patterns, partly related to transcurrent faulting. As a whole, the regional structural framework is characterized by a low-angle thrust sheet assemblage, dissected by high-angle faults with normal/oblique kinematics.

The Mesozoic carbonate complex is part of the main tectonic-stratigraphic units crop out in northern Calabria. It is divided different unit. D*olostone and metalimestone Unit* (Late Triassic-Liassic) outcrops in "tectonic windows" along the Coastal Chain. These terranes, also named the Monte Cocuzzo Unit (Van Dijk et al., 2000), can be correlated with the San Donato-Campotenese Unit (Bousquet and Dubois, 1967; Bousquet and Gradjacquet, 1969). *Calabrian Terranes* are tectonic units belonging to the Calabrian Arc constituted, from bottom to top, by *Ophiolite Unit* ("Gimigliano Unit" of Amodio-Morelli et al., 1976), which is a HP-LT metamorphic serpentinite-metabasite polychrome schist-Calpionella limestone sequence (Tithonian-Neocomian), *Slate and metapelite Unit*, which is a dominantly foliated slates, black metapelites and metasilts, interbedded with quartzite strata defining isoclinal folds, and red mudrocks and thin levels of laminate marble (Paleozoic-Mesozoic). According to Ogniben (1973) and Amodio-Morelli et al. (1976), these terranes should be ascribed to two distinct units: the Mesozoic Frido Unit, and the Paleozoic Bagni Unit, belonging to two distinct complexes. The former (of oceanic origin) was, in fact, ascribed to the Liguride Complex, while the latter (of continental origin) to the Calabride Complex. The following units, located above the previous ones, are considered to be derived from Hercynian and pre-Hercynian terranes; they were traditionally ascribed to the Calabride Complex (Ogniben, 1969) and represent a remnant of the Paleozoic basement, mainly outcropping in the Sila Massif. They are *Orthogneiss Unit* (Castagna Unit of Amodio-Morelli et al., 1976), made of mylonitic augen-gneiss, micaschist, and subordinately marbles (Paleozoic), *Paragneiss Unit* (Monte Gariglione Unit of Amodio-Morelli et al., 1976; Sila Unit of Messina et al., 1994), made of high-grade metamorphic rocks (biotite-sillimanite-garnet gneiss), intruded by plutonic bodies (Paleozoic).

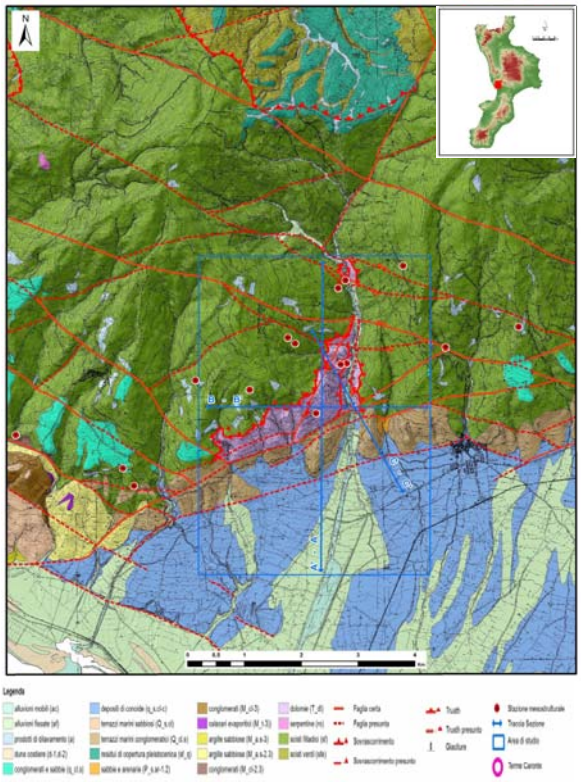

Figure 1: The structural geological map of Terme Caronte area (Geological map made by CNR-IRPI U.O.S. of Cosenza – Resp. G. Iovine, and by University of Cosenza – Resp. F. Muto).

Finally, it is possible to find the *Sheared basement remnants* (Tansi et al., 2007), which were ascribed to the Calabride Complex by Ogniben (1969). They are represented by Paleozoic phyllite and metalimestone (Catanzaro melange Unit), and by granite and granodiorite (Decollatura granites Unit), covered by Triassic-Cretaceous terrigenuous and carbonate rocks (Van Dijk et al., 2000).

The horst and graben structures developed after the deformations associated to tectonic evolution of Calabrian Arc. These events happen during an intense post-orogenic extensional tectonic phase, where several marine sedimentary basins developed, corresponding to the main segments of the faults, arranged both parallel and transverse to the direction of the Arc and raised in blocks (Ghisetti, 1979; Ghisetti and Vezzani, 1979).

A Plio-Pleistocene marine succession of clays, sands, sandostones and conglomerates outcrops in the investigated area. The terrigenous, evaporitic and carbonate mio-pliocenic sedimentary succession overlies the igneous-metamorphic basement of the Sila Unit and are strongly controlled by NW- strike-slip system, arranged in a right-hand en ´echelon pattern (Tansi et al., 2007). The Mesozoic-Tertiary continental-margin carbonates, outcropping in Terme Caronte district, were extruded within transpressional areas. Indeed, the uplift of deep-seated units of the Chain can generally be ascribed, at a regional scale, to reverse-oblique strike-slip movements along NW-SE regional shear zones (Tansi et al., 2007). Finally, three main aquifers were identified in the Terme Caronte area. The recent debris deposits complex, which is located along the main rivers and coastal plain, showing the most interesting geological characteristics in terms of resource volumes stored and favourable logistical conditions / exploitation. The Plio-Pleistocene sandstone and conglomerate, with high permeability and great thickness. The Mesozoic carbonate complex, in which deepwater circulation mainly occurs in high-permeability fractured zones associated to the main faults.

2. GEOCHEMICAL ANALYSIS

In the Terme Caronte investigated area, the geochemical data provide an overview of its geothermal potential. In order to define the origin and interactions of the circulating fluids and to investigate possible relationships with the local faults, a wide geochemical field trip was defined. The thermal waters sampled near Terme Caronte are close to intersection of two faults: a NS trending fault, along the Bagni River, and a WNW-ESE-trending regional strike-slip fault system (Ghisetti and Vezzani, 1981; Tansi et al., 2005; Tansi et al., 2007). The presence of magma intrusions at shallow depth in the crust is not sustainable, due to low heat flow measured both in the Caronte area and in the whole Calabria (50 mW/m2, Cataldi et al., 1995). This implies that the thermal character of the investigated waters is a consequence of the deepening of the hydrological circuit in fractured areas marked by a normal geothermal gradient (~30°C/km) allowing the existence of low to medium-enthalpy aquifers at a depth of about 1-3 km. For Calabria, the relationship between the tectonic setting and thermal waters looks much tighter with respect to other seismic areas of Southern Apennine, normally characterized by an anomalous thermal flux related to diffuse volcanism (Italiano et al., 2010). For some of the thermal waters, the temperatures calculated by different geothermometers show a limited cooling as a result of a fast up rise through highly permeable discontinuities as local faults. Classical geothermometric relations applied on thermal waters of Caronte (Na/K and K/Mg in Fig. 2, from Italiano et al., 2010) to test their suitability to be used for the estimation of deep temperature conditions provided contrasting and unreal values. This is mainly due to the particular geological and hydrochemical settings of the area; as a result, chemistry of thermal waters is due to isochemical dissolution of country rock-forming minerals rather than a real equilibrium with them. The only reliable geothermometer for the Caronte system (SO_4/F^2Marini et al., 1986) indicates a deep temperature in the range 55-65°C, confirming the low to medium enthalpy of the geothermal system as a whole.

3. GEOPHYSICAL INVESTIGATION

The geophysical investigation had the purpose to give a contribute on the deep geological and hydrogeological structures.

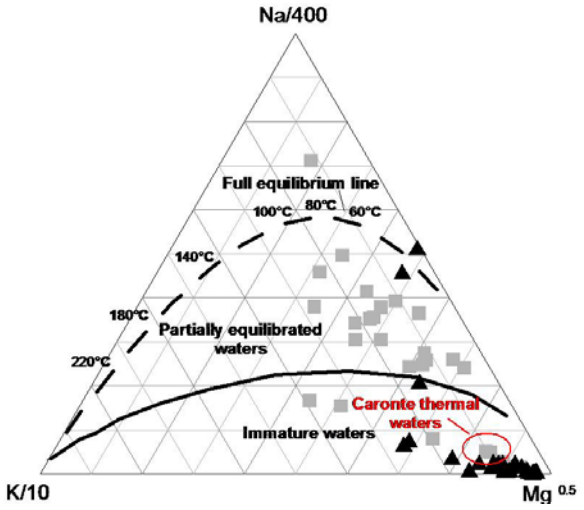

Figure 2: Mg-Na-K ternary plot of the waters sampled in Calabria (modified from Italiano et al., 2010). Squares = thermal waters; Triangles = cold waters.

The investigated area misses deep borehole, therefore a deep indirect investigation was necessary. The geophysical work started from the analysis of previous seismic data available from ENI. The main target zones for geothermal utilization is the Carbonate basement rocks, made of limestones/dolostones of Mesozoic age (Figure 1). These data gave the possibility to trace the lateral extent of these rock types and to locate fault zones within them. Seismic interpretation was focused on the identification the following seismostratigraphic horizons: slate and metapelite (bottom of Calabrian Terranes) and Mesozoic carbonate horizon. Mesozoic carbonate seismic unit consists of low continuity, moderate amplitude and low frequency reflectors with chaotic configuration, poor quality is attributed to seismic lines showing these layers and their tectonic features controlling both permeability and flow patterns. The E-W seismic profile shows low-angle overthrust contacts with basement units (Mesozoic Carbonate and bottom of Calabrian Terranes) obliterated by subsequent overprinting of high-angle faults. Seismic profiles covering the Terme Caronte area demonstrate the presence of a fractured carbonate reservoir, which is deformed to shape a partly buried positive flower structure.

New Deep Geophysical data were acquired in the area (Fig.3): one Deep Electrical Resistivity Tomography and one MT profile. The Deep Electrical Resistivity Tomography (Rizzo et al., 2004) is a "dipole-dipole" array survey in which the electrical distance is large (>100 m), the electric current (I) is sent into the ground via two contiguous electrodes (AB), and the potential drop (ΔV) is measured between two other electrodes (MN). The Deep Electrical Resistivity Tomography carried out in the Terme Caronte area used an electrode distance of 400 m and a maximum spacing between the electric and potential probes of 8 times (n) the electrode spacing. This configuration allowed us to reject an investigation depth of about 1000 m and a total of 23 stations, obtaining a line distance of about 8600 m. The device system (build by Geophysics Laboratory of CNR-IMAA) includes a man made device, composed by a transmitter unit to inject a square-wave signal, and a multichannel receive devices which record the generated voltage signals (mV).

The Magnetotelluric (MT) method is a natural source electromagnetic method which allows to retrieve information on the distribution of the electrical properties within the subsoil. The MT sources are the Electromagnetic fields generated by the thunderstorm activity and by the interaction of the solar wind with the Earth magnetosphere. Measuring the variations of the electric (E) and magnetic (B) fields on Earth surface, it is possible to investigate the electrical conductivity structure of Earth itself. Taking into account the range of variability of resistivity within the Earth and the frequency range of the MT source, the MT investigation depth can range from hundred meters till tens of kilometers. Under this point of view, the MT method can be considered a useful and non-invasive tool to investigate the Earth interior. In the framework of the project, MT data will be acquired by using a receiver MT24LF (Magnetotelluric 24-bit A/D Low Frequency system manufactured by EMI-Schlumberger) which records the horizontal magnetic fields by means two induction coils (EMI Inc., BF4), and the electric fields by means different electrical dipoles. The sampling frequency can be set from 500 Hz to 6.25Hz on the base of the presumed depth of the investigated target. In order to retrieve the magnetotelluric impedance tensor Z which relates co-located (acquired) electric and magnetic fields, the MT data will be then analysed applying the Robust Transfer Function Estimation Program for data reduction described in Egbert and Booker (1986).

The Deep Electrical Resistivity Tomography and the Magnetotelluric method define two tomography images of the subsoil, DERT tomography until 1000 m and the MT section until 4 km. The EM data clearly highlight the contact between different electrical layers which should be associated to the geological formations. Moreover, the main structure associated to the geothermal system and the connection with the hot springs of Terme Caronte are detected, and a first geological and hydrogeological conceptual model is made.

4. CONCLUSIONS

The potential geothermal reservoirs of the study area have been investigated to select well sites, to indicate the target depth, expected outflow temperature, of the expected reservoir. This study was accomplished by integrating geological, geophysical and geochemical data.

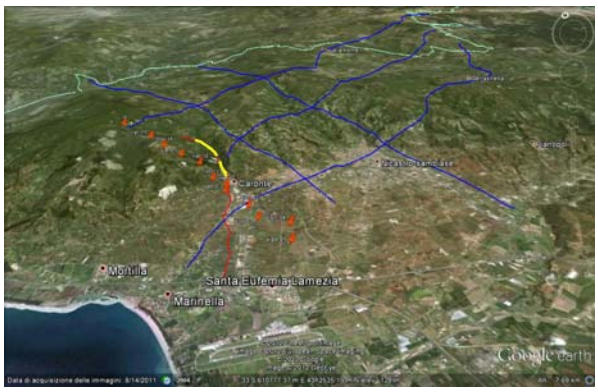

Figure 3: Location of the geophysical profiles on a google map image. Blue lines indicate the seismic Eni profile; Red marks indicate the MT stations, red and yellow line are the SERT and DERT profiles.

The integrated interpretation of surface geology, geochemical analysis, seismic reflection profiles, and geophysical data, allowed to define the main features of the overall reservoir/caprock system and its structural and stratigraphic setting.

Thermal waters in Terme Caronte are rising along the NW-SE-trending left-lateral strike-slip fault system that separates the Plio-Quaternary Catanzaro Graben from the southern edge of the Sila Massif, i.e. where the entire pile of the Calabrian Terranes and underlying Mesozoic Carbonate Complex crop out. This fault segment partly corresponds to the sinuous NW-SE-trending fault system recognized by Van Dijk et al. (2000). Several large alluvial fans and marine terraced deposits developed in the hangingwall of this main structure.

The Mesozoic carbonate reservoir was extruded within the transpressional area along the regional shear zone associated to the mentioned NW-SE tectonic system. Through seismic interpretation, the structural model of the study area could be refined, in particular the carbonate "tectonic window" outcropping near Terme Caronte.

The EM results, calibrated with surface geology, focus on the structural contact between Mesozoic carbonate and alluvial fans marked by most of the thermal spring clusters of the area.

The calcium-sulphate chemistry of the waters sampled in the vicinity of Terme Caronte could generally be attributed both to the leaching of evaporite formations (mainly consisting of gypsum), found either at the bottom of the Mesozoic carbonate succession (Trias) outcropping in northern Calabria, or in the Mesozoic carbonate and dolomite rocks outcropping (as tectonic window) in the Catanzaro graben.

Among the results of this study, an integrated 3D geological model was produced which will provide the base for detailed assessments of possible geothermal exploitation of the carbonate reservoir. The preliminary results of this analysis suggest that Terme Caronte may well constitute an interesting area for geothermal low-enthalpy exploitation.

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