Preliminary insights from the Acquasanta thermal area (Marche, Italy)

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ABSTRACT

Acquasanta Terme is a thermal area located in the southern part of Marche region (Central Italy), within a positive structure in the footwall of the main Central Apennine thrust front. Our preliminary studies on structural analyses, water chemical analyses of major and minor elements, and quantification of water stable isotopes of oxygen and deuterium allowed to: i) distinguish the major fracture sets and the possible reservoir and seal formations; ii) establish a water infiltration altitude; iii) suggest water circulation paths.

1. INTRODUCTION

The awareness of global community about the problem of un-sustainability and high environmental impact in the use of not renewable energy resources has led in recent years to challenge the world about development of methodologies and explorative and productive technologies for renewable resources to be used in a sustainable and smart way, with a focus also on the energy needs of cities. Geothermal energy is one of the most promising resources for the forthcoming future, due to its low environmental impact and excellent sustainability, also from an economic point of view. In last decades, there has been an important increase in geothermal studies, both for the low enthalpy and for medium to high enthalpy geothermal systems. From recent works, a characterization method for medium-high enthalpy geothermal system comes out. It consists mainly of a detailed structural analysis (i.e. Dezayes et al 2010), in order to identify preferential infiltration or rising paths of fluids and to characterize the possible reservoir. Furthermore chemical and isotopic analysis of water are important and, if required, an analysis of gases, aimed to understand the water types, the heat origin and to calculate the maximum temperature (i.e. Minissale et al 2002). This method is already applied in many areas of Italy, a very attractive region for geothermal energy. The Tyrrhenian side of central-southern Italy is already well known for its high heat flow and promising regions, such as Larderello and Monte Amiata areas in Tuscany, Colli Albani and volcanic lakes in Lazio, Campi Flegrei in Campania. On the other hand, the Adriatic side of Italy with its relatively normal continental lithospheric thickness (about 70-90 km) and thick and deformed foredeep sequences, shows a low heat flow, also caused by a fast recent sedimentary deposition and by meteoric water infiltration, that depresses the geothermal gradient (Della Vedova et al 2001). Nevertheless, some interesting areas are present, and one of these is the Acquasanta thermal area, close to the small town of Acquasanta Terme, 30 km from Ascoli Piceno (Central Italy, Fig. 1). Here, thermal springs are present along the Tronto river valley and their temperatures range between 27° and 44°C (Galdenzi et al 2010).

The preliminary studies, presented in this work, regard qualitative fracture analyses, water chemical and stable isotopes (oxygen and deuterium) analyses, finalized to understand the hydrogeological pattern and the hot waters ascent path, and to estimate the maximum temperature, the geothermal features and the possible sustainable exploitation of the area.

2. GEOLOGICAL BACKGROUND

Acquasanta Terme is one of the positive structures cropping out within the outer part of the Umbria – Marche Central Apennine. It is an asymmetric periclinal structure inside the Laga Basin, and it is bounded to the west by the Monti Sibillini thrust, to the south by the Gorzano normal fault and the Gran Sasso thrust, and to the east by the Montagna dei Fiori structure (Fig. 1). This anticline is a 25 km-long east-vergent fold, trending about N 170°, and overlapping the external structure along a thrust with a displacement of a few km (Koopman, 1988).

2.1 Stratigraphy

As Tozer et al (2006) summarized, the pre-Messinian stratigraphy of the area is a record of the evolution of the southern margin of the Tethys Ocean. By analogy with the Tuscan area, the succession should begin with Permo-Triassic continental siliciclastic sediments (the Verrucano Group), followed by a thick succession of Triassic evaporites (Burano Anhydrites) and then by platform carbonates (Calcare Massiccio) of late Triassic–Liassic age. Rifting of the passive margin led

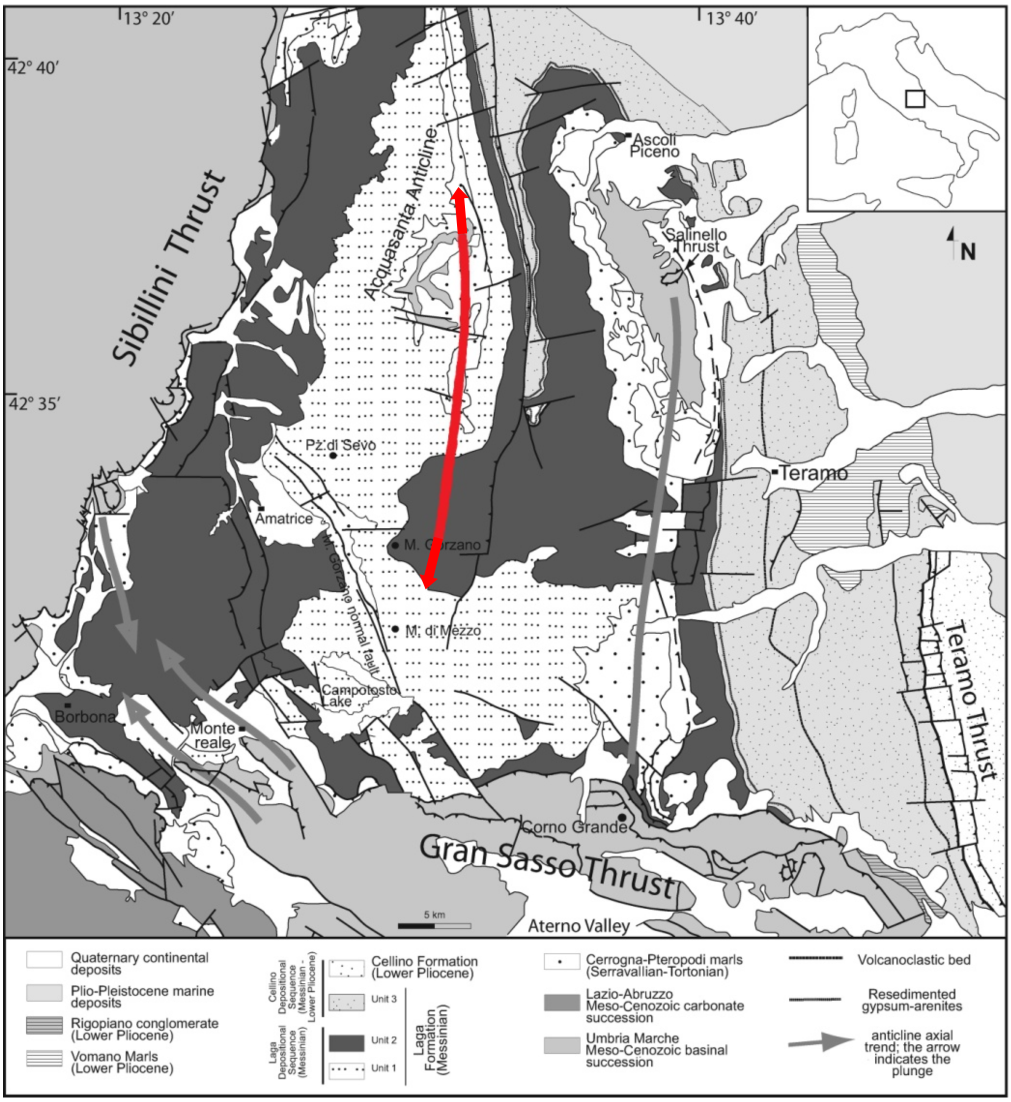


Figure 1: Geological map of the Laga Basin (modified from Bigi et al 2011). The red line represents the Acquasanta anticline axial trend.

to the formation of a pelagic basin during the Jurassic, with both a ‘complete’ (Corniola, Rosso Ammonitico, Salinello and Aptici Formations) and a ‘condensed’ (nodular limestones) pelagic successions, as a result of important normal faulting producing host and graben structures during Liassic age. These successions are followed by well-bedded limestones and marls from the Late Jurassic to the Mid-Miocene (Fig. 2). In particular, the lowest stratigraphic unit cropping out in this area is the Scaglia Rossa Formation (Cenomanian – Middle Eocene). Its thickness can vary between 200 and 500 m, but here only the upper part is present. The entire carbonatic sequence from Calcare Massiccio to Scaglia Rossa Formation, up to 1500–2000 m in thickness, host the most important aquifers, which are separated by two main marly levels (up to 50 m thick). The overlying Scaglia Variegata Formation (Middle Eocene – Upper Eocene) is about 50 m thick, and in the Acquasanta area, this unit has been karstified. The carbonate content further decreases in the Oligocene Scaglia Cinerea Formation, a marly unit up to 200-m-thick.

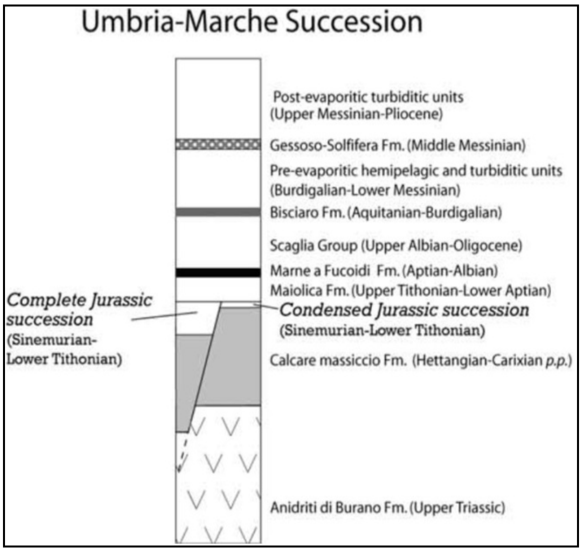


Figure 2: Schematic stratigraphic column for Umbria-Marche succession (Mazzoli et al 2005)

This Formation and the overlying Miocene marly units (Bisciaro Formation, Marne con Cerrogna Formation, Marne a Pteropodi Formation) constitute the most important regional aquiclude, with a total thickness that can exceed 500 m (Galdenzi 2010). Upward, the siliciclastic Laga Formation fills the Laga foredeep basin and represents an Early Messinian depositional system, subdivided into three main units with the intermediate one that is a gypsum–arenite horizon. (Bigi et al 2011 and references therein).

Finally, the Quaternary Travertine deposits represent a peculiar feature of the area (Boni and Colacicchi 1966). They show elevated thickness, hundreds of metres, and several square kilometres of extension. The deposition has been so far associated to thermal water (still present) oversatured with calcium carbonate which rises up along deep fractures (Farabollini et al 2003), and are present only on the right side of the Tronto River.

3. HYDROGEOLOGICAL FRAMEWORK

The most important river of the area is the Tronto River. This river and its tributaries have an irregular discharge due to the low permeability of their basins and to the contribution of snow thawing from the mountains. The groundwater in the area consists mainly of thermal sulfidic water that rises from the capped aquifer hosted in the carbonate sequence. The most important hot spring in the area is in Acquasanta Terme town at the outflow of the Acquasanta Cave. This spring is located in the right bank of the Tronto River, near the core of the anticline, in the Scaglia Cinerea Formation. It has an average discharge of about 180 L/s, sensible to seasonal variations. Some further minor thermal springs are present downstream within the river bed and also at higher altitude, along the right side of the valley. One spring is located at the bottom of a large shaft in the terraced travertine deposits, 100 m above the river bed. The thermal groundwater can be reached also in the lower sections

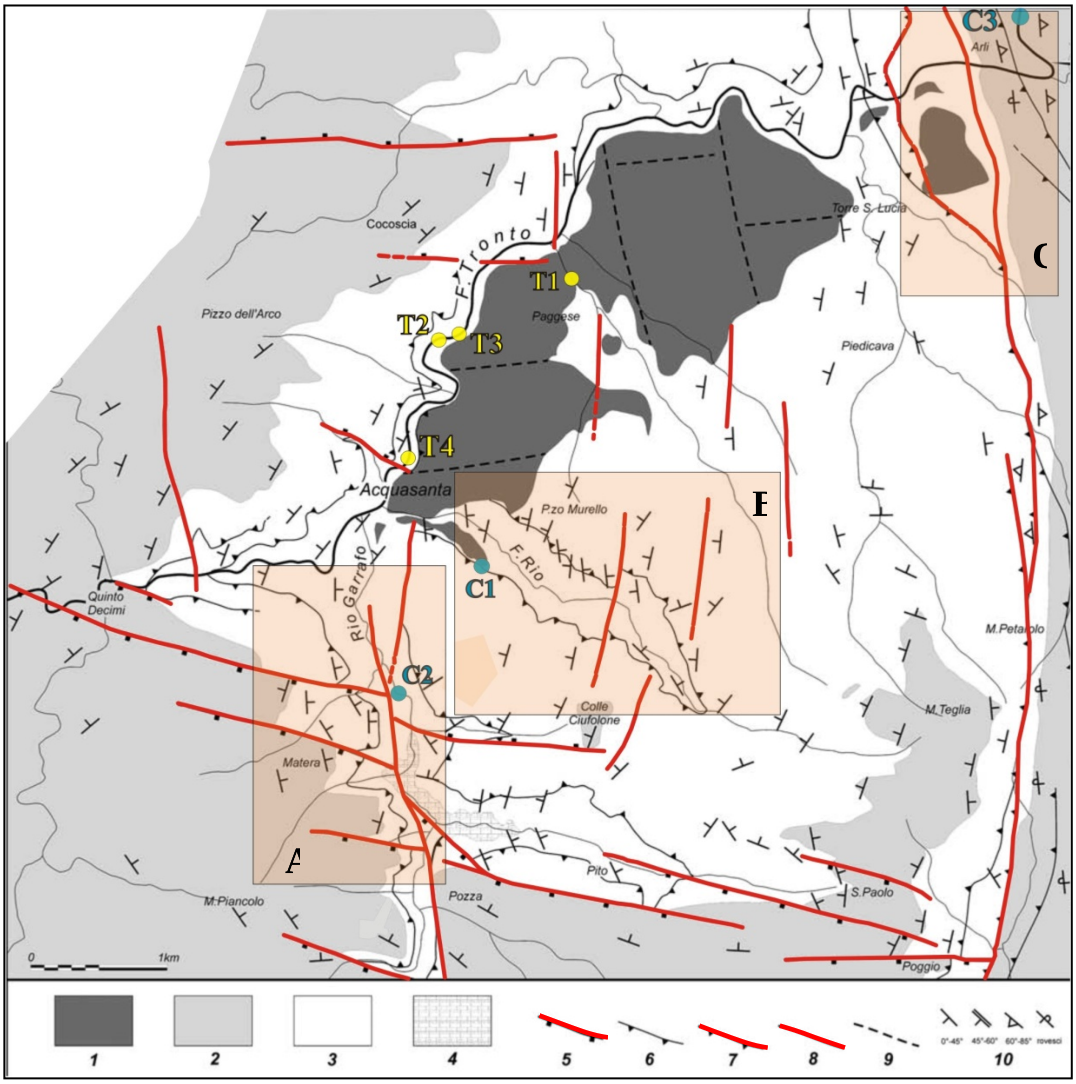
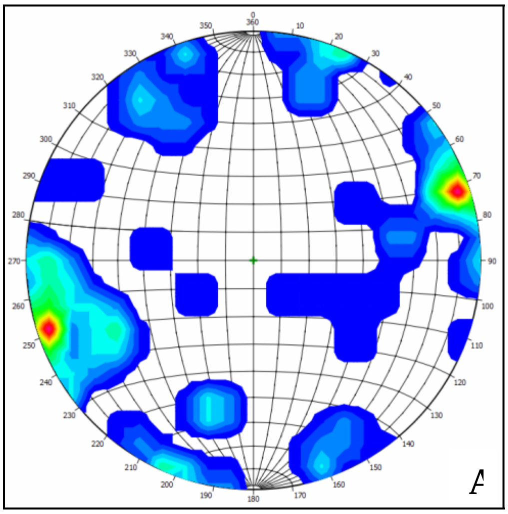


Figure 3: Schematic structural map of the Acquasanta area (modified from Menichetti 2008). Legend: 1) Travertines; 2) Laga Formation; 3) Marly units, from Scaglia Variegata Formation to Marne a Pteropodi Formation; 4) Scaglia Rossa Formation; 5) Normal faults; 6) Detachment thrust; 7) Regional thrust; 8) Strike-slip fault; 9) Inferred fault; 10) Bedding attitude; C/T = Analyzed springs (C=cold, T=thermal); Boxes A, B, C = Areas of fracture data acquisition.

of the caves in the Rio Garrafo Valley. The groundwater flowpath in the area is heavily influenced by the geologic setting. The prevailing low permeability formations that cap the thermal aquifer reduce the local recharge of the latter. Probably only in the Rio Garrafo gorge, sinking stream water directly reaches the thermal water inside caves, creating a fluid mixing and a dilution of the hot water (Galdenzi et al 2010).

4. PRELIMINARY STRUCTURAL RESULTS

Data about bedding and fractures orientation are especially referred to cap rock formations, because they diffusely crop out in the area, while outcrops of a possible reservoir, such as Scaglia Rossa Formation, are more difficult to reach and less extended. Bedding along the western side dips few tens of degrees to the west, with a main trend N175/20°W, while it becomes very steep, and subvertical to reverse in the eastern flank, with a main trend N155/90° (Fig. 3). The Marne con Cerrogna, Bisciaro and Scaglia Cinerea Formations are involved in important detachment planes locally developing complex shear zones with doubles and elisions of the stratification (Marsili and Tozzi 1995). Shear planes have an approximately N-S direction (N10/20°W) with a vector of maximum compression oriented N 70°. A preliminary fracture analysis has been carried out in few areas (Fig.3), and important systems of open fractures, about E-W oriented (Fig. 4), and extensional faults, about N110-trending, have been recognized. Other systems of fractures are constituted by joints aligned along the NNW-SSE direction (Fig. 4). These fracture systems can affect the hydraulic conductivity of the rock mass and can be considered preferential paths for surface and deep water drainage as shown by the karst corrosion in limestone layers, and clay or calcite filling in marly levels.



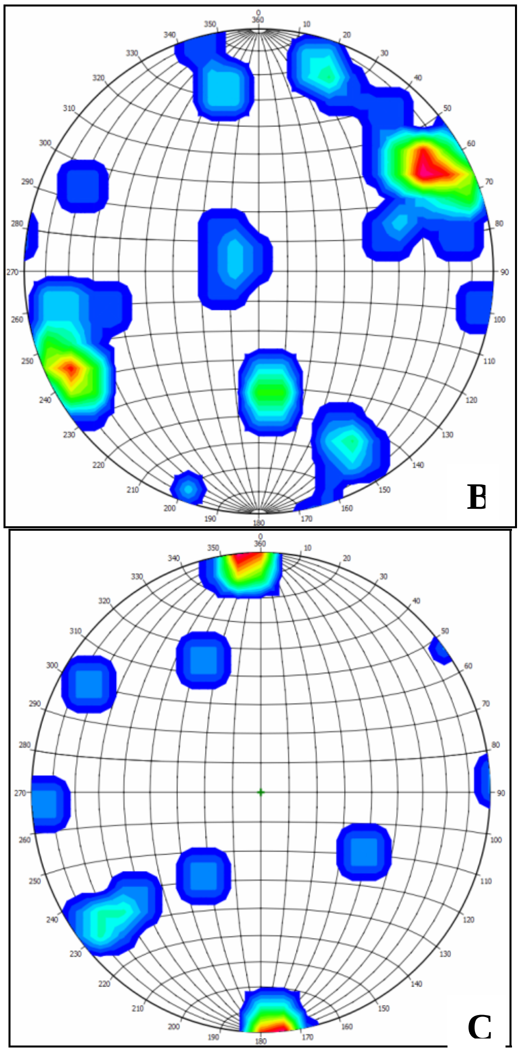


Figure 4: Contour plots from poles to fracture planes of the three areas analyzed.

5. PRELIMINARY GEOCHEMICAL RESULT

For chemical and isotopic analyses, seven springs were selected for sampling. Four of these are thermal springs and represent almost all the thermal output of the area: T1 about 100 m higher than the bed of the Tronto River, T2 and T3 along the right side of the river, T4 is the outflow of the Acquasanta Cave. The other three are cold waters, sampled near the hot springs, to serve as a comparison: C1 along a slope, C2 in Rio Garrafo stream, C3 from a fountain at the base of the Laga Formation (Fig. 3). Water sampling was done at the end of October 2012, after a summer poor in rainfall (about -55%), but an autumn extremely rainy (about +152%) related to average precipitation from 1961 to 2000. Cold samples are bicarbonate-calcic, except for the C3 water, that presents much higher quantities of SO_4 and Chlorine. Data obtained show that thermal waters can be classified as chloride-sulphate rich in Na, K, Ca and Mg (Fig. 5) and containing H_2S. Among major elements, an important amount of Magnesium is present, suggesting further contributions in addition to the common water – clays interaction.

Table 1: Chemical analyses of sampled waters (elements are in mg/L)

Sample	Springs	T °C	pH	Cond mS/cm	Na	K	Ca	Mg	Cl	B	F	Sr	Li	SiO_2	SO_4
C1	Pomaro	11.7	8.43	0.458	7.82	0.00	65.45	7.09	9.87	0.00	0.26	0.77	0.00	7.67	10.67
C2	Rio Garrafo	9.9	9.32	0.341	6.64	0.86	51.90	17.03	4.96	0.01	0.62	0.19	0.00	3.51	21.68
C3	Ponte d'Arli	14.5	8.17	0.924	75.62	5.27	59.34	25.70	42.99	0.43	6.99	1.63	0.03	9.51	122.61
T1	Centrale	27.0	6.85	7.58	1133.56	59.15	637.01	161.99	2157.60	7.85	21.34	11.25	0.86	24.80	1118.73
T2	Tronto river bed	28.0	6.86	3.55	340.67	22.40	402.52	106.08	594.91	2.57	2.10	6.29	0.29	19.30	801.61
T3	Tronto river bed	28.1	6.51	3.56	337.49	22.33	398.82	104.77	702.16	2.56	2.58	6.22	0.28	19.18	824.42
T4	Acquasanta Cave	30.3	6.80	6.25	1188.25	52.60	389.85	84.28	1905.72	7.30	3.04	6.31	0.81	26.98	904.82

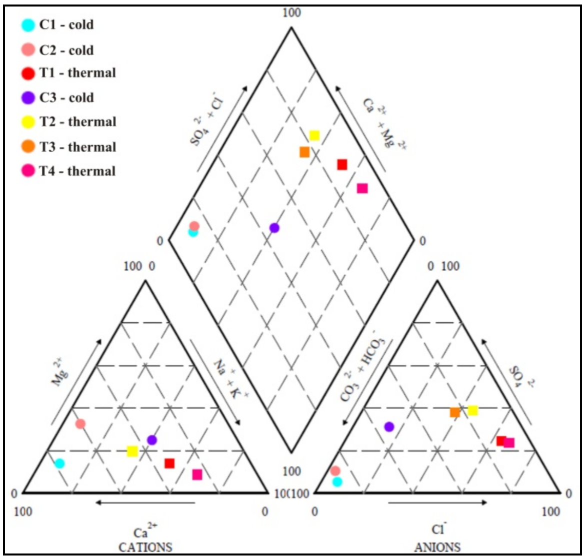


Figure 5: Piper's diagram of waters sampled.

Then, looking at minor elements of thermal waters, it is easy to note an anomalous enrichment in Lithium, Strontium, Fluorine and Boron. Madonna et al (2005) hypothesized a contribution of volcanic fluids to explain this water chemistry. They thought the high temperature of the geothermal field of Acquasanta could be due to a magmatic intrusion at the core of the anticline. This, however, is largely speculation, lacking definitive evidence and based mainly on analysis of the deep structure of the anticline (Ghisetti and Vezzani 2000, Mazzoli et al 2002, Tozer et al 2006, Scisciani 2009). More realistically, the high salt content and the minor elements mentioned above could be acquired by waters flowing through the underlying Triassic evaporites at the core of the anticline or through Messinian gypsum in the footwall of the Acquasanta thrust. In this framework, isotopic analyses of oxygen and deuterium provide useful results. From Fig. 6, C1 and C3 show higher isotopic values, thermal waters (T1-T4) have the lowest ones, while C2 sample, from Rio Garrafo stream, shows intermediate values, closer to thermal ones. These values are compatible with a meteoric origin of deep waters (Craig 1961, Longinelli and Selmo 2003). Comparing our values with a correlation line $\delta^{18}O$/altitude, we can estimate an altitude of water infiltration of approximately 1500 m a.s.l. (Zuppi et al 1974, Conversini and Tazioli 1993). This allows identifying possible recharge areas both to the west and to the south.

A first interpretation of these preliminary analyses, allows the inference of a double circulation model: the presence of a deep circuit, involving hot waters with a probable meteoric origin, that rises to the surface, and a shallower circuit of cold waters. Variations in conductivity among the four thermal springs, that present similar temperatures (Tab. 1), allow us to hypothesize that these thermal waters dilute with a variable amount of cold water coming from the shallow circuit. We also can suppose that the shallow path could happen within marly formations, due to their intense fracturing, while the deep one could flow within the Scaglia Rossa Formation and/or the carbonate formations below.

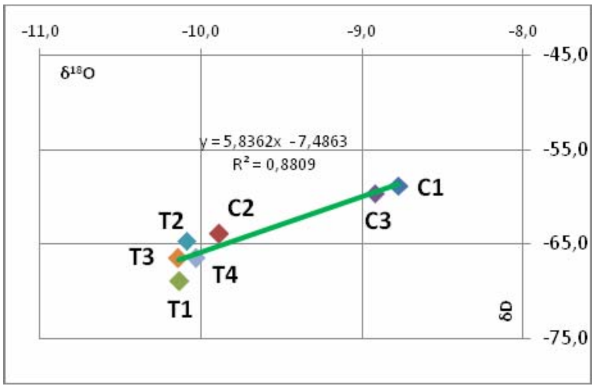


Figure 6: Relation between Oxygen isotopic ratio and Deuterium.

6. CONCLUSIONS

This work illustrates the preliminary results of our investigations in the Acquasanta thermal area, aimed to better characterized the possible geothermal potential of this region. Results can be summarized as follow:

- from isotopic data, a meteoric origin of thermal waters is evident, with an infiltration altitude of about 1500 m a.s.l.;

- a double circulation of waters is proposed: one deep thermal circuit and one shallower of cold waters. In addition, conductivity data seem to indicate a mixing between these two different water flows;

- structural data allow us to identify two main fracture trends, that could be considered as preferential paths for fluid circulation at depth.

Further studies to achieve a more quantitative model of the geothermal system will include:

- a water monitoring through time to better constrain the deep water circuit;

- geothermometers calculations to unravel the maximum water temperature.

- a volumetric reconstruction of the reservoir through a detailed fracture analysis and hydrogeologic balance;

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