

The Geothermal Area of Acquasanta Terme (Central Italy): Main Characteristics and an Attempt of Field Evaluation

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ABSTRACT

Acquasanta Terme is located in the southern part of Marche region, in the central Italy. From a geological point of view, the area, included in the Umbria-Marche Central Apennines, is placed between Mt.Sibillini thrust in the western part, and the Montagna dei Fiori anticline, to the east. In this area Thermal springs are present. In particular, hydrochemical characters are very interesting due to the presence of high content of sulfates, chlorides, CO₂ and H₂S. The water temperature is variable from 30 to 53 °C. Starting from 1990, several geological and hydrogeological investigations were carried out in the area to springs exploitation.

These studies confirmed the presence of the geothermal area.

1. INTRODUCTION

According to a recent estimate, the Italian average geothermal potential, calculated down to 2000 m., amounts to approximately 2200 billion tons of oil equivalent (T.O.E.). Chiodini et al. (1990), Sommaruga et al. (1989). Comparing this with the present energy consumption and the Italian perspectives (approximately 150-160 billion T.O.E.), one might optimistically conclude that the Italian energy problem could be easily solved as the national geothermal potential would meet the above-mentioned energy requirements for at least 1000 years. In fact such potential cannot be fully exploited as not all the areas where rocks capable of providing heat are located have the typical characteristics of a geothermal field, i.e. the presence of permeable rocks acting as reservoirs, fluid vectors and cap-rocks. Despite such limitation, several studies carried out in the sector of the thermal resource exploitation have shown that the Italian exploitable geothermal potential is very high because the above-mentioned conditions, i.e. high-enthalpy geothermal fields (e.g. Lardarello, Amiata), high-temperature waters used for hydrotherapy (e. g. Acquasanta, Bagni di Lucca, Montecatini Terme, Saturnia, Abano Terme) or as CO₂ deposits (e.g. Rapolano) are quite common. In this framework, and in line with the urgent need for energy sources alternative to hydrocarbons, this paper illustrates the first results of a multidisciplinary study aimed at finding and typifying a potential geothermal field in the area of Acquasanta Terme (Ascoli Piceno) and hypothesising the quantification of the exploitable resources.

2. BIBLIOGRAPHICAL KNOWLEDGE ABOUT THE AREA

2.1 Geological setting

The area being dealt with in this paper is located in the central part of the Italian peninsula, in the Umbria-Marche

Central Apennine, about 30 km west of Ascoli Piceno (Fig. 1).

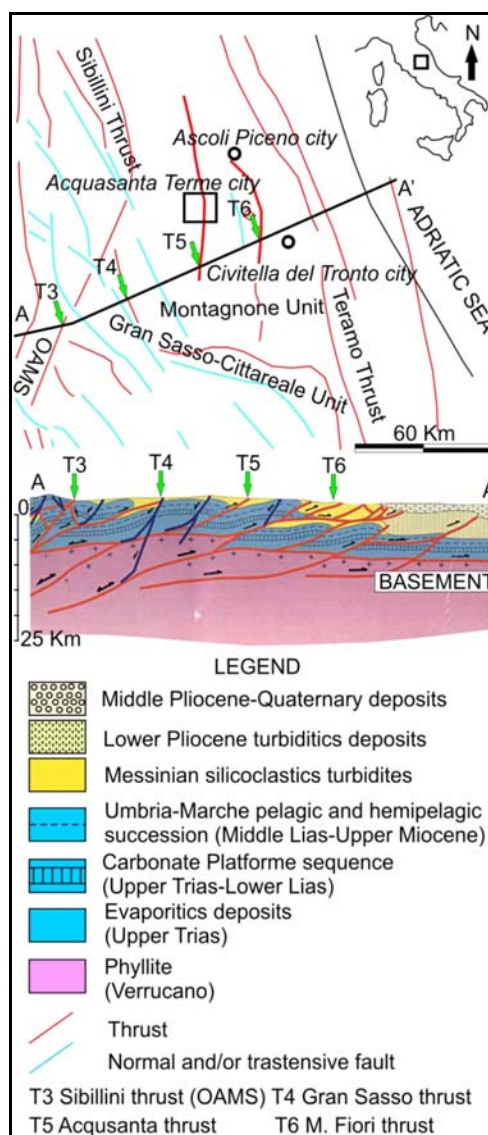


Figure 1: Geological setting of Umbria-Marche Central Apennines. From Calamita et al. (1997) modified.

The main structural element of this area is the anticline of Acquasanta that is included in the Acquasanta- Montagna dei Fiori - Montagnone tectonic- stratigraphic unit bounded on the west by the overthrust of Monti Sibillini, on the south by the Gran Sasso-Cittareale unit, on the east by the Teramo overthrust. Bigi et al. (1992). With reference to the structural models proposed by the authors in relation to the types,

methods and time of deformation of this area of the central Apennines, some of the most recent models describe a basement affected by significant overlapping planes and the downsizing of the series duplication under the Acquasanta anticline, thus increasing the basement involvement. Paltrinieri et al. (1982), Koopman (1983), Bally et al. (1986), Calamita et al. (1991-1992-1994-1995-1997-1999), Centamore (1992), Marsili & Tozzi (1995), Mazzoli et al. (2002), Scisciani et al. (2002), Calamita and Deiana (1995), Calamita et al. (1997), Adamoli et al. (1997). Over a basement constituted by phyllites (Verrucano), the stratigraphic succession of Umbria-Marche Apennine, visible in the Montagna dei Fiori area, is constituted by evaporitic deposits of the Upper Trias (Anidriti di Burano Fm.), by the Carbonate platform sequence of the Upper Trias - Lower Lias (Calcare e Marne a Rhaetavicula contorta Fm. and Calcare Massiccio Fm.), by pelagic calcareous sequence and calcareous-marly sequence of the Middle Lias - Middle Eocene (Corniola Fm., Rosso Ammonitico Fm., Calcare e Marne del Sentino Fm., Calcare and Marne a Posidonia Fm., Calcare Diasprigni Fm., Maiolica Fm., Marne a Fucoidi Fm., Scisti ad Aptici Fm., Scaglia Rossa Fm.) and by hemipelagic marly and marly-calcareous sequence of the Upper Eocene - Upper Miocene (Scaglia Variegata Fm., Scaglia Cinerea Fm., Bisciaro Fm., Marne con Cerrognia Fm.). Bally et al. (1986). Particularly, in the Acquasanta Terme area, only terms going from the Scaglia Rossa Fm. to the Marne con Cerrognia Fm. crop up directly in contact with the Messinian silicoclastic turbidites, with Lower Pliocene turbiditic deposits (Laga Fm.) and Quaternary deposits (Fig. 2).

As far as Quaternary period is concerned, the Travertine deposits represent a peculiar characteristic of the area. Besides those of Acquasanta Terme, described in the chapter 3, also the deposits of Ascoli Piceno city (Colle S. Marco and Rosara), and those of Civitella di Tronto city in the Teramo Province should be pointed out. (Boni et Colacicchi (1966). This travertine probably dates back to the Villafranca period in Colle S. Marco and to the most recent Quaternary period in Rosara and Acquasanta. Demangeot (1965). The problem of travertine formation in the Tronto Valley has never been dealt with in depth; previous authors highlighted the link with the thermal springs, but did not present any exhaustive models of the geological results.

2.2 Hydro-geological spring features and water quality of Central Italy

About 40 springs were recorded and monitored in the Umbria-Marche area of the central Apennines, many of them are sulphur springs, but in most cases they are cold springs the values of which range between 8 and 22 °C, with the exception of the Baiana (in Emilia Romagna region), Triponzo (in Umbria region) and Acquasanta Terme springs. Scalise (1979). As a matter of fact, the Acquasanta Terme springs have a max. value of 31.5 °C. Egidij (1826), Trotterelli et al. (1897), Saccardi et al. (1955), Scalise (1979). The thermal water temperature may vary according to the spring and all the springs have gradually cooled down over the years. Their chemical characteristics are subject to seasonal changes. This is why one might assume that fresh water and thermal water mix: the former is characterised by surface circulation, while the latter is associated with medium-deep circulation, alkaline chloride, alkaline-earthly sulphates, bicarbonate- calcic elements and H₂S presence. Nanni & Zuppi (1986), Nanni (1991), Nanni et al. (1999).

3. RESEARCH REASONS AND GOALS

Our research has been done in the Acquasanta Terme area (Fig. 2) and it focused on various problems such as having a better understanding of the link between travertine and thermal water, the formation of thermal water and an estimate of the temperature in the deepest zones.

We tried to explain these problems in an exhaustive way by reconstructing a new geological pattern used as a basis to estimate the potential exploitable resources of the Acquasanta geothermal field.

3.1 Depositional environments of the Acquasanta Terme travertine

The direct link between thermal springs and travertine deposits is well known. The formation of the latter is closely intertwined with the H₂O, CO₂ and CaCO₃ chemical-physical balance and especially with the need of having a CO₂ solution that allows the water to attack the carbon deposits. With reference to the Acquasanta thermal springs (Fig. 2), the deposition of travertine is still clearly visible in the Santa Maria spring (S3);

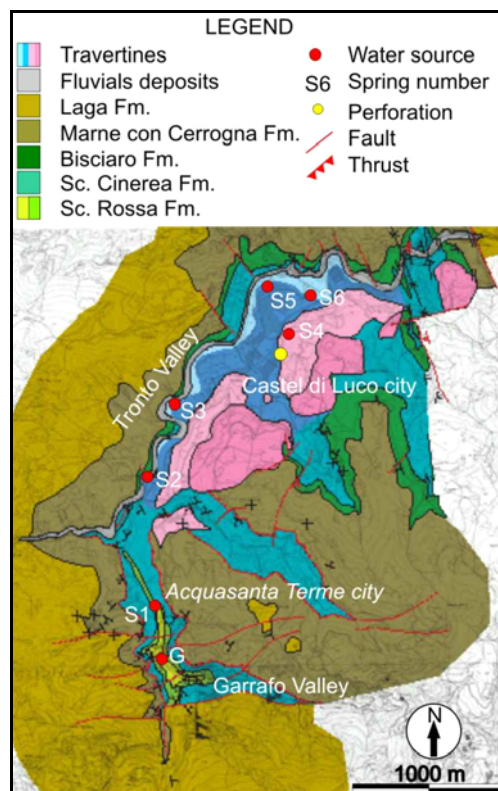


Figure 2: Geological and geomorphological map of Acquasanta Terme area. From Madonna (2001).

this phenomenon is not present in the other visible springs (with the exception of the Grotta Nuova spring (S1 and S2)). This is why one might assume that, after the pressure drop point, the water follows a route whereby it can be considered as a secondary spring. The analysis of the water coming out of the thermal spring has shown a powdery travertine deposition. These two deposition types have also been found in the oldest travertine deposits. The Acquasanta travertine has been divided into five main types depending on its physical, petrographic and genetic characteristics. Madonna (2001).

3.1.1 Rising zone of thermal waters

In the rising point of thermal waters, a compact, omogeneous, little porous travertine with domiform morphology may be observed (tr1) (Fig. 3a, 3b, 3c). In this depositional environment, where water flux is almost laminar, the inorganic chemical precipitation dominates, where it is possible to observe fast CO_2 de-aering, fast crystallization kinetics and then enucleation of small but numerous calcite crystals (Fig. 3d).



Figure 3a: Rising-zone travertine (tr1); chemical deposition.



Figure 3b: Castel di Luco area; domiform structure of the travertine.

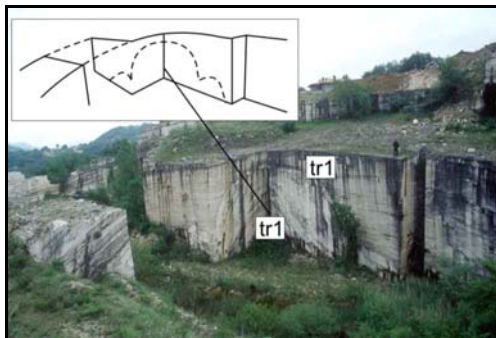


Figure 3c: Domiform structure of the travertine.

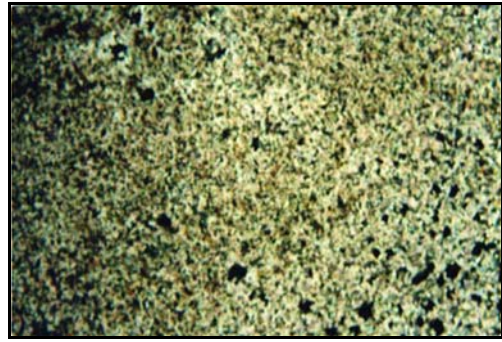


Figure 3d: Thin sections of travertine tr1; calcite crystals with high pleochroism may be noted

Sometime it shows up macroscopically vesiculated and slightly holed and in our opinion this is due to the presence of gas bubbles at the time of the deposition. This environment is also characterized by another kind of travertine, linked to algal and bacterial deposition. Chafetz et al. (1984), Golubic et al. (1993), Golubic (1993). In the Acquasanta deposits, biochemical depositional facies seem to be linked more to bacteria; well shown by the intense white color and the presence of the micropores, which generate honeycomb structures (Fig. 3e) and arborescence (well visible in the thin section of Figure 3f).



Figure 3e: Travertine (tr1) with honeycomb structures.

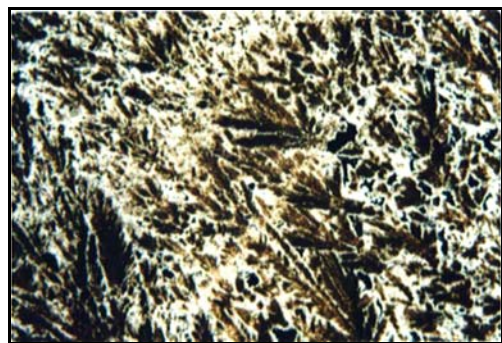


Figure 3f: Travertine (tr1) with arborescent structures.

3.1.2 Fluvial-marshy-lake zone

After the rising zone, depositional morphology of the travertine becomes more and more horizontal; incisions and discontinuities become leveled; domiform structures, generated by springs located at lower levels are also filled. Water flux is generally laminar. The presence of vegetation promotes the precipitation with incrustation on itself (tr2) (Fig. 3g).



Figure 3g: Travertine characterised by vegetation (tr2); biochemical deposition.

3.1.3 Deposit zone due to Turbulence

This is the area where geothermal waters flow in the Tronto river, which represents the most depressed geomorphological line. In this depositional environment, the very uneven morphology gives rise to a turbulent movement. The presence of sandy and soil levels, paleosoils, and red soils, as well as vegetation, allow the formation of earthy brown travertine (tr3) with poor consistency (Fig. 3h).

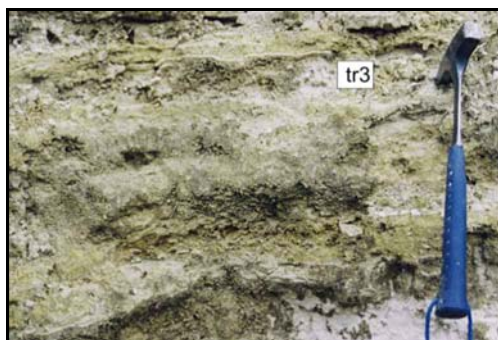


Figure 3h: tr3 travertine typology.

3.1.4 Spring ending zone (Self Sealing)

Acquasanta waters are very aggressive because of CO_2 excess, as well as H_2S presence; these waters can karstify those formations entirely composed by CaCO_3 , as well as calcareous-marly formations, as Scaglia Cinerea (Thermes' Cave). Residual part which does not become solubilized, generally clayey, is difficult to be expelled, mostly at the exit of the conduit where the pressure is low. It is in this way that, during the Self-Sealing phase, a grey travertine develops (tr4) the composition of which is calcareous-marly (Fig. 3i).

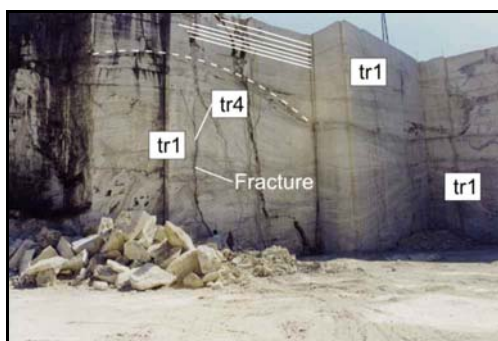


Figure 3i: Gray travertine (Self-Sealing – tr4).

3.1.5 Travertinous conglomerates

It is evident that in the travertine deposition, waters may generate travertinous conglomerates, when they interact with coarse fluvial deposits (Fig. 3l); the structure of travertinous cement indicates depositional phase.



Figure 3l: Travertinous conglomerate.

In short, in Fig. 4, a schematic model of travertine formation is proposed. When the non permeable cover of the geothermal reservoir is cut for any reason whatsoever, the water near the fracture comes out, a rapid pressure drop occurs in the emergence point, a large quantity of CO_2 is rapidly released and CaCO_3 precipitates. The pressure gradient at the rising point (i.e. the difference between the pressure in the reservoir (P_g) and the atmospheric pressure (P_a)) determines the maximum head, i.e. the maximum height that the water can reach. The high encrusting power of water favours the formation of cone-shaped elements and “fan-like” structures near the rising point. The water that might have emerged in a flat area initially creates very steep external walls; as this process continues, the water release level increases and when the the maximum head level is achieved the travertine deposition is almost sub-horizontal. In these conditions water can no longer flow and will start settling calcium carbonate inside the fracture; the water flow will be almost completely stopped (Self-Sealing). The plug is usually made of greyish marly limestone (tr4) coming from the residual mud of the karst process of the Scaglia Cinerea Fm. on which the spring originally rested. A sub-horizontal travertine layer might settle on this structure following the emergence of an upstream spring. Hence, the hypothesis that these deposits might have been formed by one of the following processes: the original pressure linked with the geothermal field and the Self-Sealing processes. From a general viewpoint, the maximum level of the existing travertine (Acquasanta, Colle S. Marco, etc.) seems to be linked with the geothermal reservoir pressure at the time of the deposition. However one should also outline that the Self-Sealing process might have significantly affected the deposition condition, also because the above-mentioned Self-Sealing is closely associated with the size of the fracture that made the water come out.

3.2 Origin of thermal waters and deep circulation

As far as the water formation process is concerned, the analytical results of the samples collected from various springs in the year 2000 (Fig. 5) and the daily sampling results of the Terme springs (Fig. 6) alone, clearly show two main aspects: a proportional relation between salinity and temperature and the very complex chemism of warmer water. Madonna (2001). The latter could be classified as chloride- sulphate- bicarbonate-sodium- calcic water containing free H_2S and CO_2 .

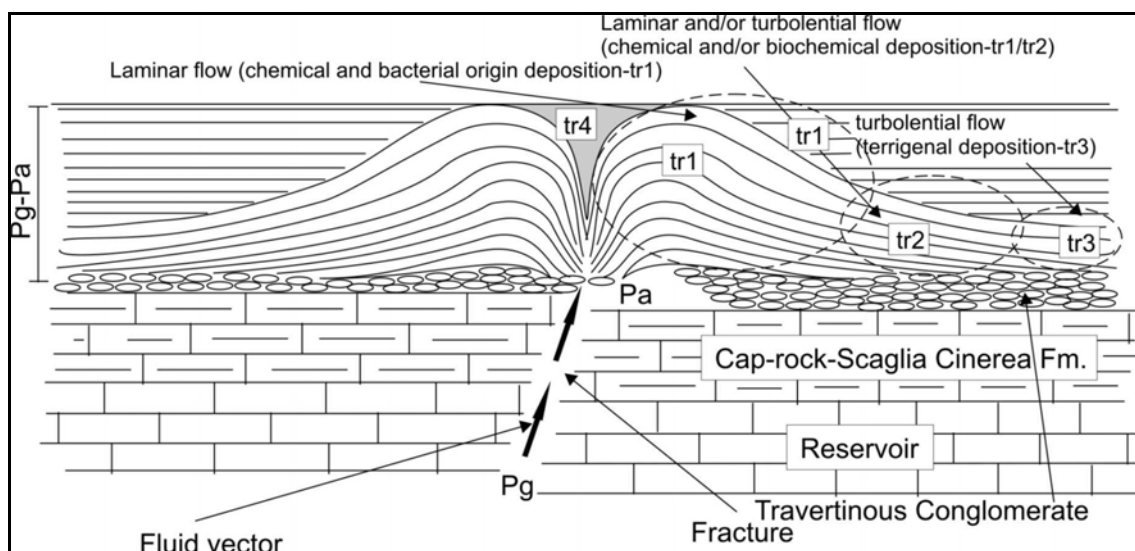


Figure 4: Schematic model of travertine formation. From Madonna (2001) modified.

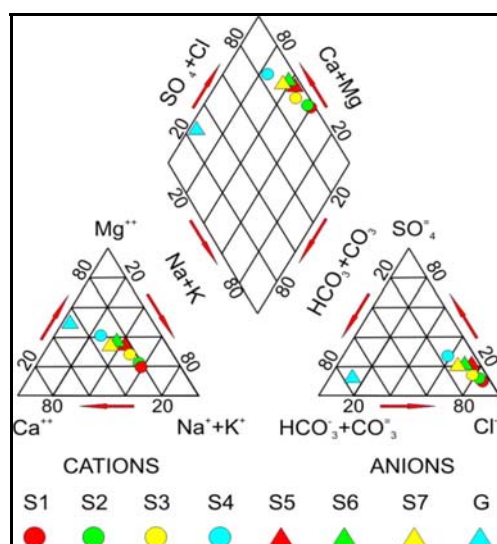


Figure 5: Piper's diagram.

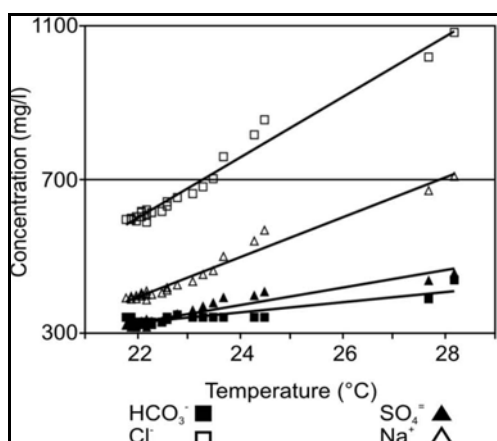


Figure 6: Terme spring (S2); relation between salinity and temperature.

With reference to secondary elements (tab. 1), the significant quantity of Boron and the presence of Ammonia, Litium and H₂S might suggest a chloride-sodium type of water

associated with a perivolcanic system. This water, when flowing through the evaporitic-Triassic level, would be charged with SO₄²⁻ e Ca⁺⁺ ions (witness the presence of Strontium), while, when flowing through the Mesozoic carbonates, the H₂S and other elements associated with a volcanic environment (Skarn facies) would be replaced, with the consequent release of CO₂ and an additional increase in Calcium, then leading to the formation of travertine. Moreover, as the waters of the Mesozoic series are fresh waters, the fluid would be progressively diluted. The analysis of the Italian thermal waters have shown a close link between CO₂, H₂S and the emergence temperature. More specifically, the highest-temperature emergence is always associated with a large quantity of CO₂ and little H₂S, while at a lower temperature H₂S is present in larger quantities. We have been able to experimentally verify this phenomenon as the replacement of CO₂ with H₂S significantly depends on the system temperature (tab. 2). With reference to the temperature reached by the fluid in the deepest zones, the data obtained from the geothermometers are not very reliable as they are based on waters that are very mixed. The temperature data measured by the most common geothermometers are shown in table 3. The temperature range is very wide and is comprised between 60 °C and 150 °C. Moreover, as the Grotta Nuova spring water still contains some Tritium and the spring temperature can reach 53 °C (the samples S* and S** were taken far from the main rise), in our opinion 90 °C to 100 °C temperatures can be expected.

3.3 Proposed Geological-gravimetric model

The proposed geological models did not explain the presence of the thermal water and the large deposits of travertine associated with it. Likewise the heat needed to dissolve CaCO₃, i.e. 50 Kcal per mole of CaCO₃, could by no means be provided by the exothermic leaching reaction of the Triassic anhydrides into gypsum. Charles et al. (1956). We have thus decided to develop a geological model consistent with the above-mentioned situation; in particular a detailed surface geological map was created (Fig. 2), gravimetric (Fig.7a and Fig. 7b) and magnetic data were analysed. Chiappini et al. (2002), Bigi et al. (1992).

Table 1: Chemical analysis (mg/l) of the secondary elements

Samples	Springs	T °C	Cond. (μS/cm)	pH	B ³⁺	Sr ⁺⁺	Li ⁺	NH ₄ ⁺	Br ⁻	F ⁻	I ⁻	S ⁼	SiO ₂
S1*	grotta nuova**	37,8	8010	6,5	1,84	0,11	0,12	0,27	0,02	0,14	0,01	0,84	20,70
S2**	grotta nuova*	28,4	7480	6,6	1,60	0,10	0,10	0,23	0,02	0,12	0,01	0,04	20,40
S3	terme	23,4	3810	7,2	0,65	0,06	0,05	0,10	0,01	0,07	0,01	/	11,50
S4	s. maria	26,7	2980	6,3	0,44	0,08	0,03	0,06	0,01	0,11	0,01	0,15	11,80
S5	pozzetto	27,7	5860	6,7	1,00	0,11	0,07	0,15	0,02	0,12	0,01	0,03	13,90
S6	centrale	25,9	5150	6,7	0,99	0,11	0,06	0,12	0,02	0,12	0,01	/	14,10
S7	s. emidio	24,4	4360	6,7	0,82	0,09	0,05	0,01	0,01	0,11	0,01	/	13,40
G	garrafo	8,1	2380	7,6	0	0,003	0	0,00	0,00	0,01	0	/	2,85

- the samples S* and S** were taken far from the main rise.

Table 2: Relation between calcium dissolved and temperature (experimentation in progress, unknown data).

Samples	Temperature (°C)	[Ca] (mg/l)
N° 1	25	8.375
N° 2	50	27.97
N° 3	70	36.89

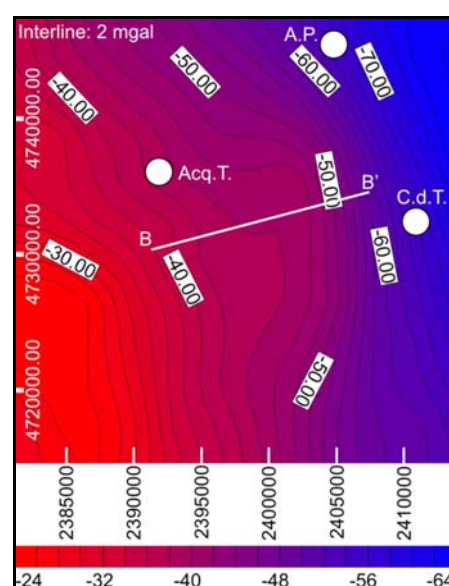
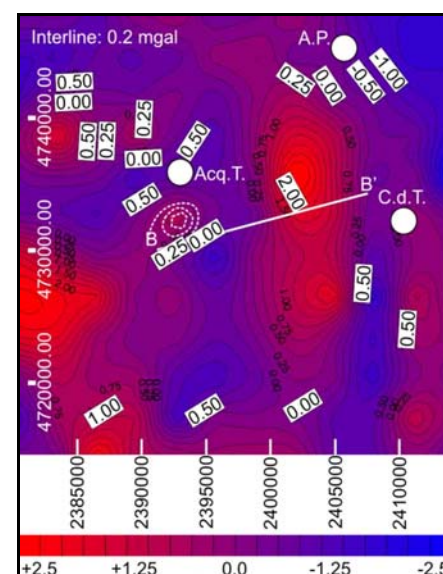
Table 3: Geothermometers and Tritium analysis.

Springs	SiO ₂ (ppm.)	Geothermometer SiO ₂	Geothermometer Na-K-Ca (β=1/3)	T.U.
S1*	20.7	60 c.a.	153	4.34
S2**	20.4	60 c.a.	150	3.94
S3	11.5	< 40	146	/
S4	11.8	< 40	150	4.1
S5	13.9	41 c.a.	152	3.1
S6	14.1	45 c.a.	152	/
S7	13.4	44 c.a.	150	4.5
G	2.85	/	/	5.0

With reference to the final model obtained from the processing of these data (Fig. 8), a scheme should be created in which the Acquasanta maximum gravimetric level is related to a dense and magnetically active body (2.75 g/cm³) having a minimum depth of 3000 meters and corresponding to the maximum magnetic level. In line with the structural models proposed, the presence of infrasedimentary and/or dyke volcanic bodies can be suggested, deposited on the base or with in the Anidriti di Burano Fm. which are displaced by décollement planes. This framework does not seem to diverge from the results of the reflection seismic surveys, which are difficult to interpret as they are not close enough to each other.

3.4 Potential exploitable resources of the Acquasanta geothermal field

If the proposed model, which explains the Acquasanta thermal and hydro-chemical phenomena, is accepted, the Mesozoic carbon formation emerging in the Apennines could be recharged and the local structure, based on the Umbria – Marche sedimentary sequence, should have one or two non permeable levels (Marne a Fucoidi Fm. and Scisti ad Aptici Fm.) that could be a good cap-rock.

**Figure 7a: Gravimetric anomaly; regional field.****Figure 7b: Gravimetric anomaly; residual field.**

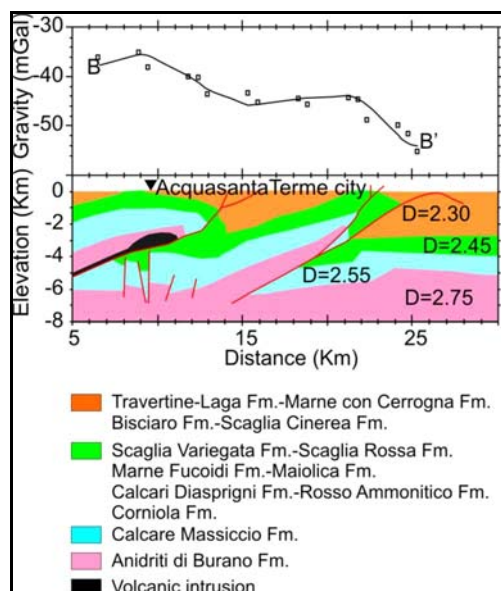


Figure 8: Gravimetric geological model.

The depth of the limestone, i.e. the affected reservoir, should not exceed 1000 metres near the Acquasanta anticline. The above-mentioned study was followed by a survey of the thermal waters that led to the drilling of a 60-meter deep well for thermal purposes, producing water at 32 °C and an absolute artesian level of 411 m.s.l.m.. The well was located in an area characterised by an old emergence closed by means of Self-Sealing, the geoelectric analysis of which (Fig. 9) had shown a very low resistivity near the Scaglia Bianca Fm. – Scaglia Rossa Fm., characterized by much higher resistivity values in the absence of mineralized thermal waters.

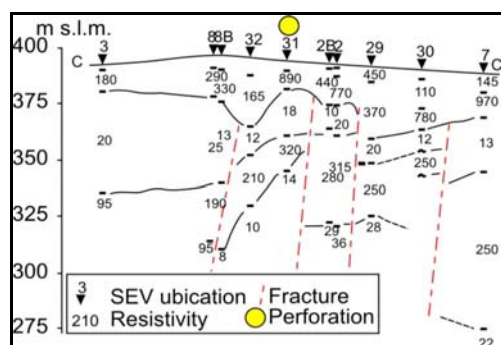


Figure 9: Electrostratigraphical section and drilling location.

4. CONCLUSIONS

This paper presents and illustrates the first results of a multidisciplinary study aimed at finding and typifying a potential geothermal field in the central part of the Umbria - Marche Apennines, where large quantities of travertine, genetically associated with ancient artesian springs of thermal sulphurous waters, deposited in the Quaternary period. Such link is particularly evident in Acquasanta Terme, where the S. Maria sulphurous spring, i.e. the only primary spring still capable of depositing travertine, is located. Thanks to the five different types and the morphological characteristics of travertine we have developed a genetic hypothesis whereby two main formation processes occurred. The first process is related to the pressure in the geothermal reservoir that led to the maximum travertine deposition level; the second process is related to

the Self-Sealing phenomena and to the size of the fractures in which water flowed, thus determining a local deposition scheme. This travertine was formed by water with a very complex chemistry, probably primary chloride-sodium water linked with a volcanic system. In this environment high temperatures, as experimentally proven, guarantee a high CO_2 concentration. This water gets charged with Ca^{++} and SO_4^- ions when flowing through the Triassic-evaporitic series and richer in CO_2 when flowing through the Mesozoic series as a result of the replacement of H_2S and other elements associated with a volcanic environment, thus obtaining the calcium bicarbonate over-saturation necessary for the deposition of the travertine on the surface. We have tried to explain these geologic results in a consistent way by acquiring and interpreting new geological, geomorphological, hydro-geological, hydro-chemical, petrographic and geophysical data. Hence the development of the hypothesis of a subsurface geologic model characterized by volcanic intrusions at the base or in the Triassic anhydrites, taken into consideration by various décollement plane authors. This study was followed by a research on the exploitation of the Acquasanta geothermal field; a well, producing water for thermal purposes at 32°C, was drilled. The above-mentioned problems will undergo further analysis and additional hydro-chemical data for S_{34} , ^3He and ^4He will be collected. Moreover the gases in the primary in S. Maria and Grotta Nuova springs will be analysed and geophysical analysis based on the use of reflection seismic will also be used. Finally a new well will be drilled into the Calcare Massiccio Fm. down to 1000 meters to have a better understanding of the situation.

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