European Geothermal Congress 2013
Pisa, Italy, 3-7 June 2013

Integrated Multidisciplinary Approach for the Study of the Geothermal Potential of Umbria (Central Italy)

M.R. Barchi [1], C. Cardellini[1], R. Checcucci[2], F. Frondini[1], P. Fulignati[3], C. Pauselli[1], F. Pazzaglia[1], A. Sbrana[3], A. Viterbo[2]

1 Università di Perugia, Dipartimento di Scienze della Terra, P.zza dell'Università 1 - 06100 Perugia, Italy
2 Regione Umbria, Corso Vannucci, 96 - 06121 Perugia, Italy
3 Università di Pisa, Dipartimento di Scienze della Terra, Via S. Maria 53 - 56126 Pisa, Italy
e-mail: mbarchi@unipg.it

Keywords: Geothermal resources, Geology, Geochemistry, Geophysics, Central Italy.

ABSTRACT

We present the results of a research project, developed by three research groups of Perugia and Pisa Universities, with the financial support of the Umbria Region, aimed to evaluate the geothermal potential of the region through a multidisciplinary approach.

1. INTRODUCTION

The geothermal potential of the western sector of the Umbria Region (Central Apennines) is of particular interest because in this area there are geothermal systems of medium to high enthalpy already explored in the past decades and many thermal springs and wells, with estimated temperatures of more than 50 ° C. Many of these sources are characterized by high pressures of CO_2 and could be the result of mixing between waters of shallow aquifers and deep fluids with a much higher enthalpy content.

The recent development of technology has made sustainable exploitation of low enthalpy geothermal energy, making it now one of the most efficient systems on the market, from the point of view of performance and energy savings.

The project has been focused on the low to medium enthalpy geothermal resources of the Umbria region, providing the following products:

- an integrated model of subsurface geology (down to about 8 km depth) of the western sector of the Umbria Region and surrounding areas (eastern Tuscany and northern Lazio), based on geophysical (gravimetry, seismic reflection profiles) and geological (wells) information, and subsequently integrated with hydrogeological and geochemical data of the most important aquifers;
- a catalogue of the main thermal springs of the whole Umbria region, with the identification of the main geothermal aquifers and their characterization in terms of recharge area, chemical composition, P and T condition;
- a regional-scale numerical model of the thermal state along a transect crossing the study area;
- 3D numerical modeling of hydrothermal circulation for specific case studies of particular interest in the western sector of Umbria region.

2. SUBSURFACE GEOLOGY MODEL

The definition of the subsurface geological setting of the region is preliminary and indispensable for the evaluation of the geothermal resource.

Western Umbria is located in the central portion of the Northern Apennines (fig. 1), a NNE verging fold-thrust belt, consisting of (top to bottom): Ligurian Units; Tuscan Units; and Umbria-Marche Units. The main thrusts are arc-shaped, with eastward convexity. The compressional structures are displaced by later extensional structures, bordering NNW-SSE trending half-grabens (Radicofani basin, Valdichiana basin and Tiber basin), infilled by Pliocene-Pleistocene shallow marine and/or continental successions.

In this study, we reconstruct the subsurface geological setting of Western Umbria, integrating all the available geological and geophysical information, including:

- geological maps of the area, produced by both national and regional geological surveys;

- deep wells and seismic reflection profiles acquired in the past decades by private companies during oil and/or geothermal exploration of the region;
- gravimetric data, as synthesised in the 1:250,000 national gravimetric map (ISPRA, ENI, OGS, 2009);
- heat flow data (Inventario delle risorse geotermiche nazionali, 2010);
- regional and local geological sections, available in the scientific literature.

In the elaboration of these data, we have taken into account the complex geological history of this portion of the Northern Apennines (e.g. ref). We also performed new geological surveys of selected areas, located in correspondence of geothermal springs and/or wells.

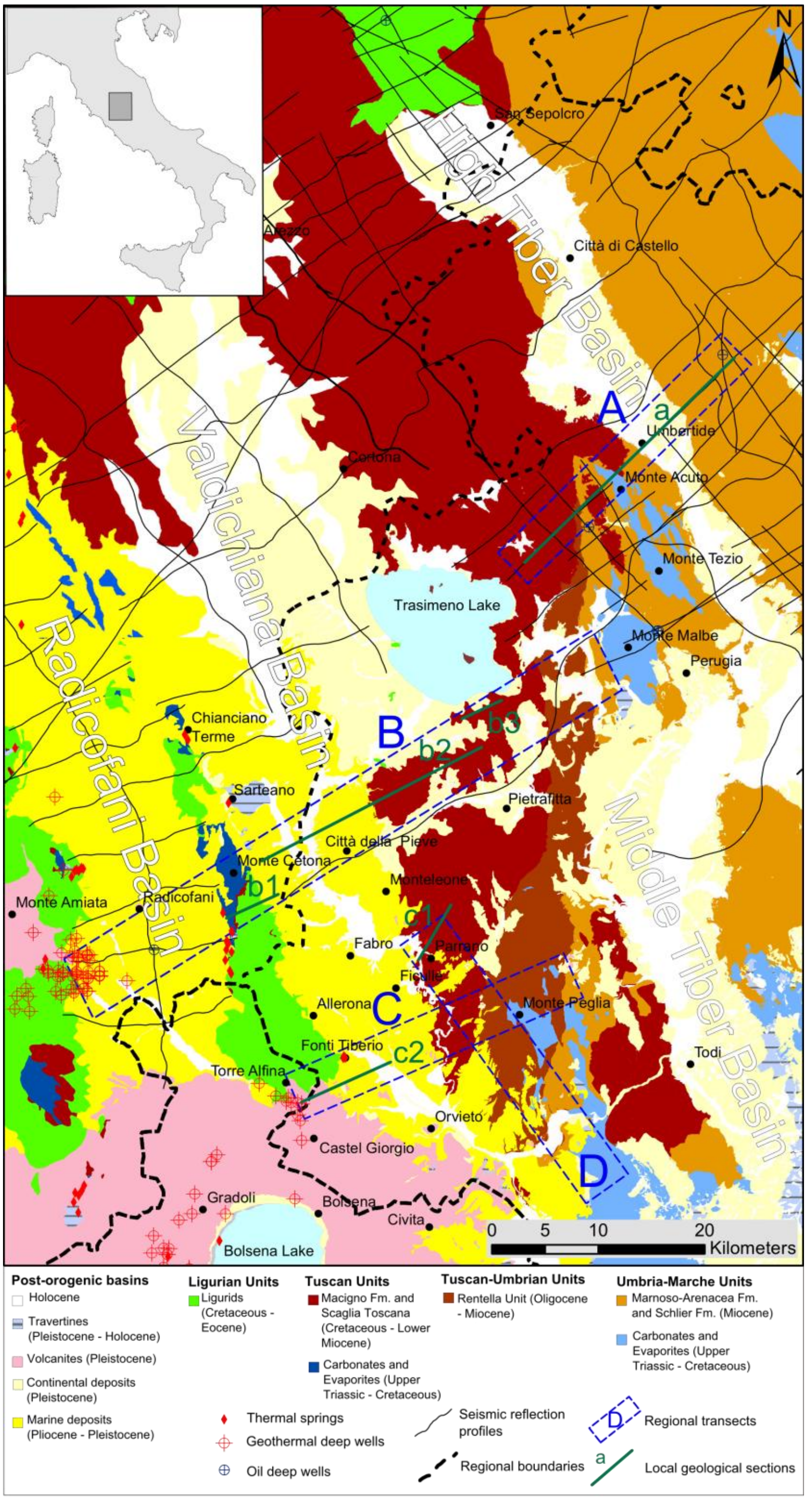

Figure 1: Geological map of the investigated area.

Using these data and information, we produced a set of new geological and geothematic maps and geological sections through the study area. The location of the sections is illustrated in fig. 1. The four regional transects (A, B, C and D in fig. 1) illustrate the style of deformation and the tectonic history of the region. In particular, we used the transect B (M. Amiata - M. Cetona - Tavernelle) as the base of a 2D Regional Thermal Modelling (see par. 4). We also constructed local geological sections, traced in correspondence of significant geothermal areas, were the 3D numerical modelling experiments of hydrothermal circulation was approached (see par. 5).

In this paper, we present a significant, representative example of these geological sections, crossing the Valdichiana Valley from M. Cetona to Città della Pieve (fig. 2).

The subsurface setting of the Cetona Ridge consists of an antiformal stack of Tuscan carbonates and evaporites, overthrusting the Umbria-Marche carbonates, as suggested by the extrapolation of the stratigraphy of the geothermal field of Torre Alfina (e.g. Alfina15 well, Buonasorte et alii, 1988). The Valdichiana basin is an asymmetric graben, bordered by a major east-dipping fault and by a set of west-dipping, antithetic faults. The infilling of the basin consists of Pliocene marine deposits (Aruta et alii, 2004), about 1,500 m thick, as also imaged by seismic reflection data (Barchi et alii, 1998).

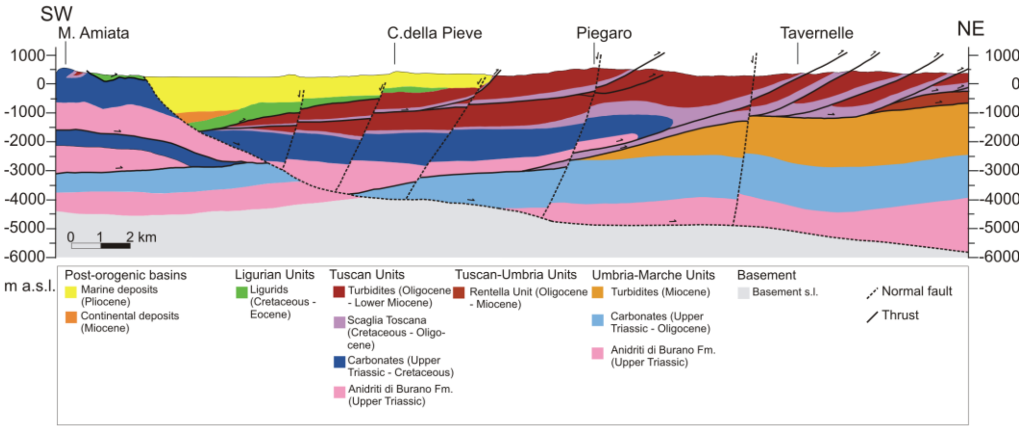

Figure 2: Geological section (sector B in Fig.1).

The surface geological structures of the eastern flank of the Valdichiana basin have been recently mapped in detail, in the framework of the new 1:50,000 maps, produced by the Italian Geological Survey (Barchi & Marroni, 2007). Between Città della Pieve and Pietrafitta, an imbricate fan of west-dipping, shallow thrusts crops out. The single thrust sheets, about 1 km thick, consist of Tuscan turbidites (Macigno Fm.), detached on the incompetent horizon of the Scaglia Toscana Fm., nicely imaged by seismic reflection profiles. In the easternmost part of the section, the thrust system directly overthrusts the Marnoso-Arenacea Fm. (Umbria-Marche turbidites), which covers the whole Umbria-Marche succession. In this area, an intermediate, Tuscan-Umbrian turbiditic succession (Rentella Unit) is interposed between the Tuscan units and the Umbria-Marche units (Brozzetti, Barsella). These shallow thrusts deepen towards the west, progressively involving the underlying carbonates and evaporites. In our reconstruction, the Tuscan Nappe (carbonates and evaporites) directly overthrusts the Umbria-Marche succession in the central portion of the section.

Our data show that beneath the Città della Pieve-Piegaro area two different geothermal reservoirs exist (Tuscan carbonates and Umbria-Marche carbonates), located at a depth of -1,000 and -2,500 m below sea level, respectively, and confined between low permeability units.

Since CO_2 during its ascent towards the surface is trapped into deep permeable structures (Chiodini et al. 1995a), pCO_2 in shallow groundwater is a good indicator of the presence of permeable structures at depth. Considering the analysis of 589 water samples from springs and wells, we computed the partial pressure of CO_2 by means of aqueous speciation calculations. The resulting pCO_2 values have been plotted in the map of Fig. **3** using the geostatistical software *gslib* (Deutsch e Journel, 1998). The distribution of pCO_2 values show that high pCO_2 values prevail in the western sector of the study area, with the higher values aligned along a NW-SE direction, while in the eastern sector are present only small isolated anomalies. The volcanic area of the Volsini Mts is characterised by very low pCO_2 values, probably because the low permeability deposits under the volcanic cover doesn't contain a relevant aquifer system.

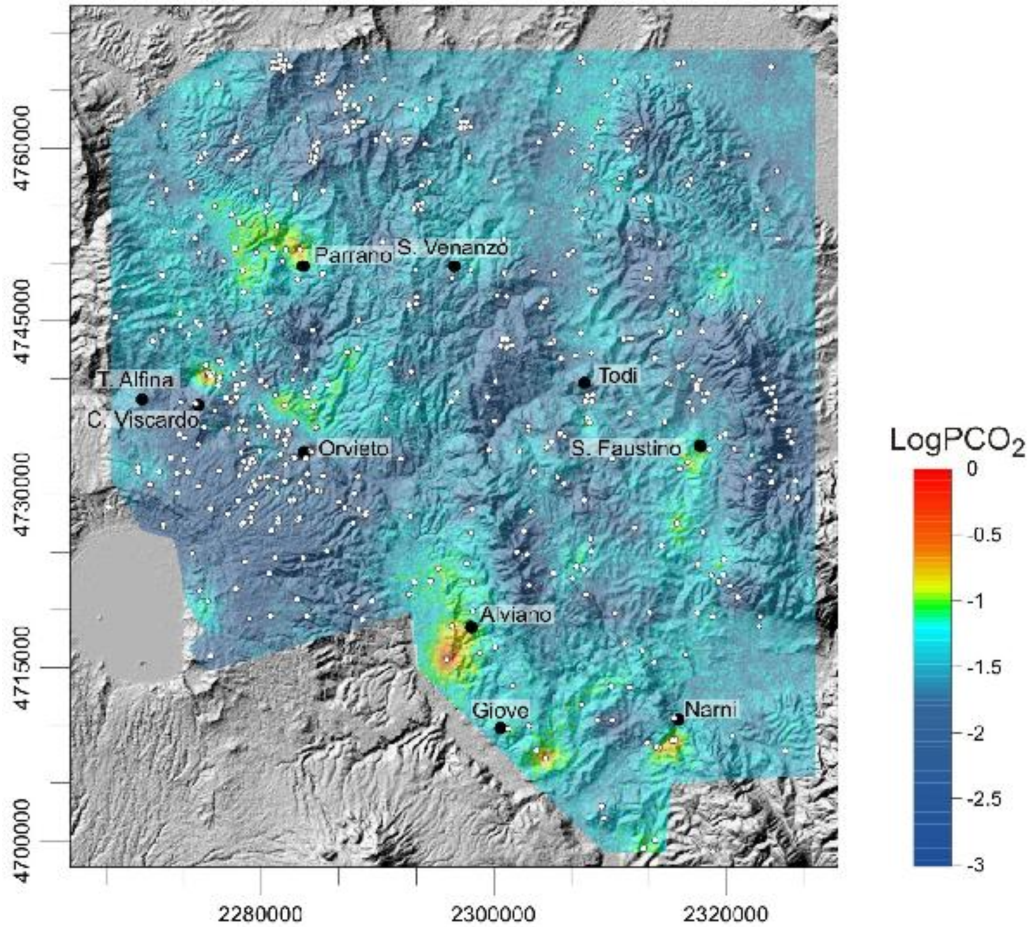

Figure 3: Map of pCO_2 distribution.

3. CATALOGUE MAIN THERMAL SPRING

In the catalogue we considered 11 groups of thermal springs; for each spring we reported the geographical, geological and hydrogeological data and all the available chemical and isotopic analyses.

Thermal water composition varies from a bicarbonate (sulphate)-Earth alkaline to sodium-cloride composition. Aqueous speciation calculations show that the main geochemical processes characterising the thermal springs are the dissolution of calcite, the influx of deeply derived CO_2, dedolomitization and mixing with deep saline fluids.

The occurrence of saline fluids, characterised by a Na-Cl(HCO_3) composition, is related to the presence of deep regional aquifers at the base of Mesozoic carbonates. Normal faults allow the mixing of the deep Na-Cl(HCO_3) fluids with the shallow groundwater causing the increase of salinity and temperature observed in many springs.

The approximate estimation of temperature and pCO_2 at depth (Chiodini et al., 1995b), indicates that most of the considered waters are characterised by equilibrium temperatures of about 50 °C or lower, with the exception of some Na-Cl(HCO_3) springs of the western sector for which the temperature ranges from 50 to 100 C° (Fig. 4).

The equilibrium pCO_2 values vary over a large interval, from 0.1 to more than 10 bar. In particular, Na-Cl(HCO_3) samples generally show the highest equilibrium pCO_2, suggesting that most of these waters come from deep confined aquifers where pCO_2 is controlled by the hydrostatic conditions. The extremely high pCO_2 values computed for these waters suggest that the deep aquifers are also a structural trap for the mantle derived CO_2 during its ascent towards the surface (Chiodini et al. 1995a; Chiodi et al., 2004; Frondini, 2008).

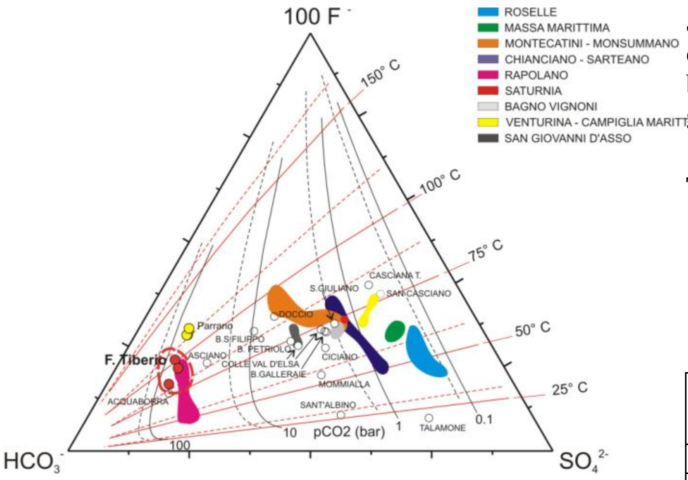

Figure 4: Graphical geoindicators for carbonate-evaporite reservoirs (after Chiodini et al., 1995b). The main systems of Umbria are compared to some geothermal systems of Tuscany and Latium.

4. 2D RHEGIONAL SCALE THERMAL NUMERICAL MODEL

A 2D rhegional scale thermal model has been performed along a section in the sector B, reported in Fig.1, where a geological section has been constructed (Fig.2) as described in par.2. The proposed methodology provides for the resolution of the heat equation in 2D, discretizing the heat conservation equation with finite difference. The used program has been modified by a program proposed by Gerya (2010).

The input parameters of the geological model (such crustal thicknesses and lithologies involved) are obtained both from previous information, such as seismic refraction / reflection, and, as regards the first 8 km, from the model of subsurface geology obtained from this project (fig.2). The physical parameters necessary for the model (such as heat flux surface, thermal conductivity, density, radioactive heat production) has been obtained from wells in the area and from literature data. In table 1 the adopted values of physical parameters are reported and the choice has been based on the thermal characteristics of the geological structures.

Table 1: Adopted values for the physical parameters. K is the thermal conductivity, A is the volumetric heat generation rate (after Pasquale, 1987 and Cermak and Bodri, 1995: Qs is the surface heat flux, ρ is the density, Cp the specific heat.

	K ($Wm^{-1}K^{-1}$)	A (μWm^{-3})	ρ (kgm^{-3})	c_p ($JKg^{-1}K^{-1}$)
Upp. crust	2.5	$0.04 \cdot Qs \cdot e^{-z/10}$	2600	1000
Low. crust	2.5	$2.5 \cdot e^{-z/10}$	2900	1100
Upp. Mant.	3.5	0.01	3300	1200

The 2D geometry of the model is such that the x-axis is horizontal and displaced along the free Earth surface, the z-axis is directed downward. The upper surface at z=0 is maintained at a constant temperature T=273 K, the lower surface at z=30 km is set at lateral varying value of heat flux density (HFD) in order to simulate the thermal influence of the underlying mantle. On the right-hand and on the left-hand side of the model as boundary conditions it is assumed that the horizontal heat flow is zero. The simulations are carried out for long period until the steady state was reached.

The reliability of the obtained results has been verified using information from the observed and from the depth of lithosphere-asthenosphere boundary in the studied region.

The result of the model is reported in Fig.5. Our data show that the temperature field varies significantly from West to East, according to the HFD. From this temperature field, we have obtained the initial temperatures to be assigned as input at the base of 3D models reported in sec. 5.

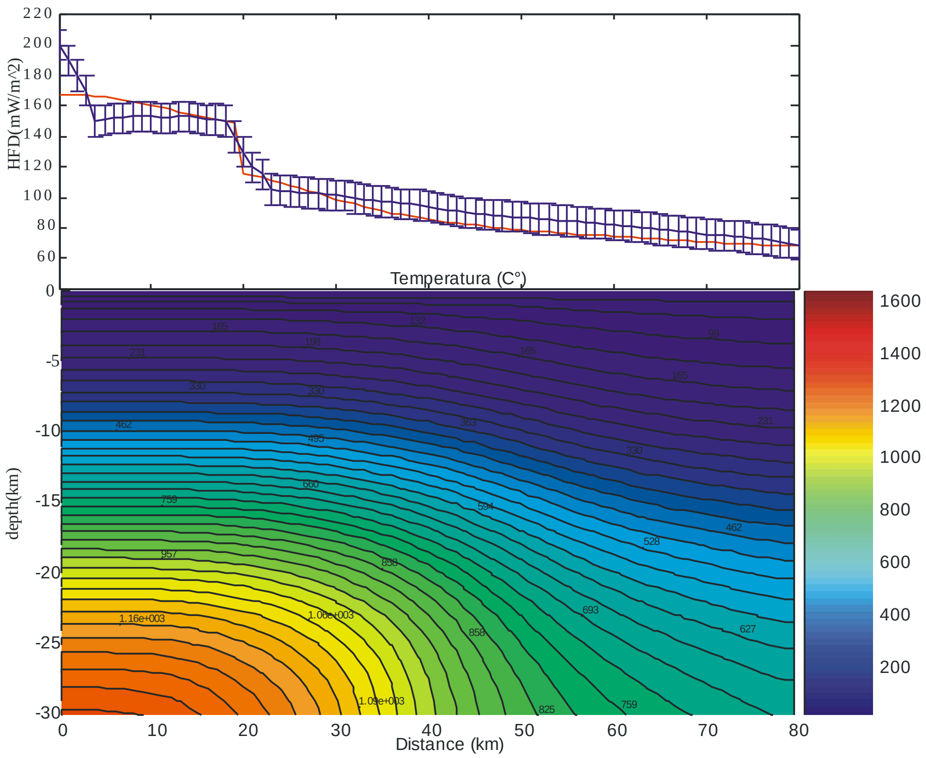

Figure 5.: Measured (blue line, errorbar represents 10% of error in the measurements) and calculated (red line) HFD (upper part), temperature field (lower part).

5. 3D NUMERICAL MODELING OF HYDROTHERMAL CIRCULATION

Numerical modeling is a mature technology that is employed in more than 100 geothermal fields all over the world, and is commonly used for the planning of sustainable development of exploitation of geothermal fields.

The Torre Alfina area was simulated using the THOUGH2 code. This is a specific code for modeling multi-dimensional, multiphase/multi component flow and heat transport in porous and fractured media (Pruess et al., 1999).

The modeling was performed using the equation of state EOS1 for pure water. The simulation domain has an area of 12,5 km X 8 km (100 km^2) and a thickness of 8600m.

The conceptual model used in the simulation is based on the subsurface geological model developed above. The physical parameters used in the model (permeability, porosity, density, wet heat conductivity, specific heat) have been taken from literature data. Temperature and pressure are considered time invariant in the cells at the top and bottom of the simulation grid.

A fixed temperature of 15°C and atmospheric pressure were set for cells along the upper boundary. A variable temperature (from W to E) between 350°C and 280°C was assumed for the cells in the bottom layer.

The simulation (Fig.6) of the natural state of the geothermal system (steady state) covers a period of 500.000 years. We carried out also simulations on longer periods (up to 2 My) but the steady state was always reached before. During the simulation some parameters (mainly permeability and heat fluxes) were tuned to match the temperature distribution at depth.

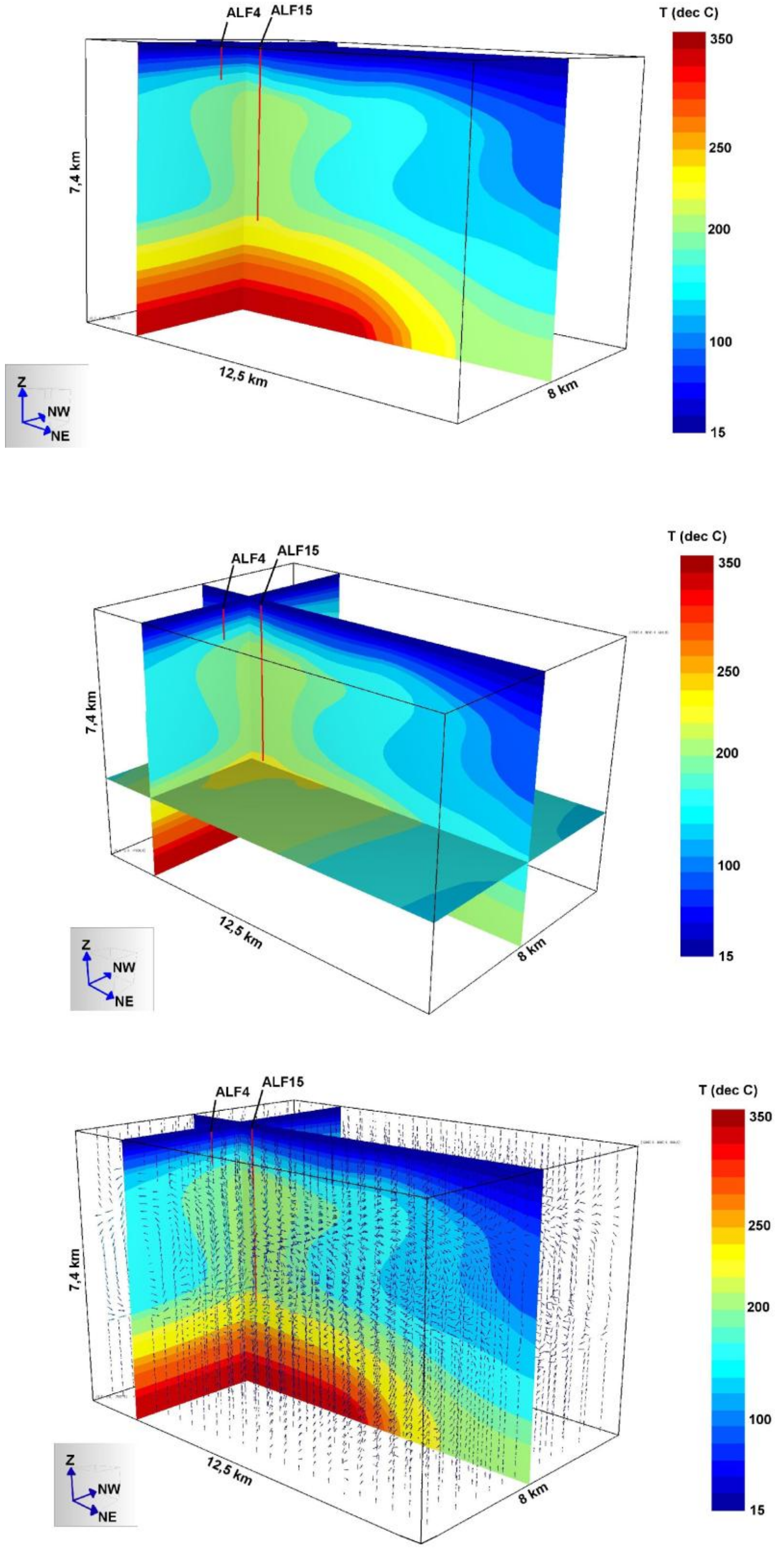

Figure 6: Results of simulation experiments.

To verify the reliability of the simulated values of temperatures, simulated well temperature profiles were compared with temperature profiles of well drilled in the area (particularly Alfina 15 well that reached ~ 4800m of depth).

A good match between simulated and measured temperature in Alfina 15 deep well was obtained (Fig.7), suggesting that a satisfactory simulation was achieved.

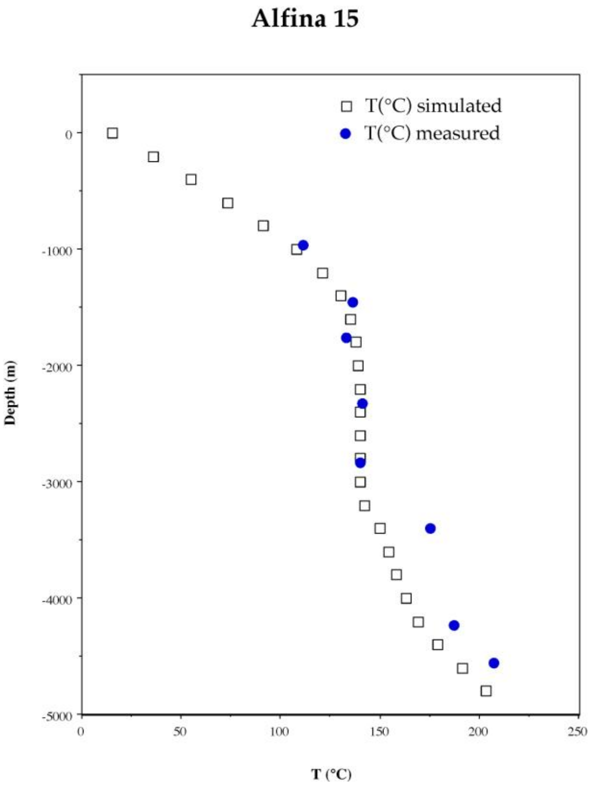

Figure 7: Comparison between the measured and simulated temperature profile in Alfina 15 well.

6. CONCLUSIONS

The main aim of this study was to carry out an integrated research approach (geological, geochemical, geophysical, 3D geological and thermo-fluid-dynamical modeling) on geothermal resources of the Umbria region, which could lead to the assessment of as much as possible well defined conceptual models of potential thermal systems located in Umbria. This will help providing to potential users (local agencies, regional and national companies, both private and public) a regional framework, as far as possible complete and updated, of geothermal knowledge. It will facilitate the development of concrete project proposals, both for the use of geothermal resources for power production, and for direct uses of thermal energy.

REFERENCES

Aruta, G., Borgia, A., Bruni, P., Cecchi, G., Cipriani, N. & Tredici, Y.: Pliocene and Pleistocene unconformity bounded stratigraphic units (UBSU) in Val di Chiana. In: The “Regione Toscana” project of geological mapping. Morini D & Bruni P.(Eds.), 133- 136, *Regione Toscana*, Firenze, (2004).

Brozzetti, F., Luchetti, L., Pialli, G.: La successione del Monte Rentella (Umbria occidentale): biostratigrafia a nannofossili calcarei ed ipotesi per un inquadramento tettonico regionale, *Boll. Soc. Geol. It*., **119**, (2000), 407-422.

Barchi, M. R., De Feyter, A., Magnani, M. B., Minelli, G., Pialli, G. & Sotera, B. M.: Extensional tectonics in the Northern Apennines (Italy): evidences from the CROP03 deep seismic reflection line. *Mem. Soc. Geol. It*., **52**, (1998), 527-538.

Barchi, M.R. & Marroni, M. (Eds.): Note illustrative del Foglio 310 - Passignano sul Trasimeno. Progetto CARG (CARtografia Geologica), *ISPRA*, (2007), 196 pp. http://www.isprambiente.gov.it/MEDIA/carg/310_PASSIGNANO/Foglio.html)

Barsella, M., Boscherini, A., Botti, F., Marroni, M., Meneghini, F., Motti, A., Palandri, S. & Pandolfi, L.: Oligocene-Miocene foredeep deposits in the Lake Trasimeno area (Central Italy): insights into the evolution of the Northern Apennines. *Ital.J.Geosci. (Boll.Soc.Geol.It.)*, **128 (2)**, (2009), 341-352. (DOI: 10.3301/IJG.2009.128.2.341)

Buonasorte, G., Cataldi, R., Ceccarelli, A., Costantini, A., D'Offizi, S., Lazzarotto, A., Ridolfi, A. Baldi, P., Barelli, A., Bertini, G.M, Bertrami, R., Calamai, A., Cameli, G., Corsi, R., Dacquino, C., Fiordelisi, A., Ghezzo, A., Lovari, F.: Ricerca ed esplorazione nell'area geotermica di Torre Alfina (Lazio-Umbria). *Boll. Soc. Geol. It*., **107 (2)**, (1988), 265-337

Cermak, V., and Brodi, L: Three-dimensional deep temperature modelling along the European geotraverse. *Tectonophysics*, **244,** 1-11.

Chiodini, G., Frondini, F. and Ponziani, F.: Deep structures and carbon dioxide degassing in Central Italy, *Geothermics*, **24**, (1995a) 81–94.

Chiodini, G., Frondini, F. and Marini, L..: Theoretical geothermometers and PCO2 indicators for aqueous solutions coming from hydrothermal systems of medium-low temperature hosted in carbonate-evaporite rocks. Applications to the thermal springs of the Etruscan Swell, Italy, *Appl. Geochem*., **10**,(1995b) 337-346.

Chiodini, G., Cardellini, C., Amato, A., Boschi, E., Caliro, S., Frondini, F. and Ventura, G: Carbon dioxide Earth degassing and seismogenesis in central and southern Italy, *Geophys. Res. Lett*., **31**, (2004) L07615.

Deutsch, C.V. and Journel, A.G.: GSLIB: Geostatistical Software Library and Users Guide. Applied Geostatistical Series. *Oxford University Press*, New York (1998).

Frondini, F.: Geochemistry of regional aquifer systems hosted by carbonate-evaporite formations in Umbria and southern Tuscany (central Italy), *Appl. Geochem.*, **23**, (2008), 2091–2104.

Gerya, T. 2010. Introduction to Numerical Geodynamic Modelling. Cambridge University Press**.**

Inventario delle risorse geotermiche nazionali **(**Decreto Legislativo 11 febbraio 2010, n. 22**.** Riassetto della normativa in materia di ricerca e coltivazione delle risorse geotermiche) (http://unmig.sviluppoeconomico.gov.it/unmig/geotermia/inventario/inventario.asp)

ISPRA, ENI, OGS (2009). Cartografia Gravimetrica Digitale d'Italia alla scala 1:250.000. http://www.sinanet.apat.it/it/cgd/index_html

Pruess, K., Oldenburg, C., Moridis, G., (1999) TOUGH2-user's guide, version 2.0. Report LBNL-43134. Lawrence Livermore Laboratory, Berkeley, CA, USA, pp. 198.

Acknowledgements (optional)

In case you want to add some acknowledgements, this would be the space to do so.