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3D Geological Modeling to Support the Assessment of Conventional and Unconventional Geothermal Resources in the Latium Region (Central Italy)

Petracchini L., Scrocca D., Spagnesi S. and Minelli F.

Consiglio Nazionale delle Ricerche, IGAG, Rome, Italy

lorenzo.petracchini@igag.cnr.it

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ABSTRACT

In 1904 the first electricity production from geothermal resources took place in Larderello (Italy) inaugurating the geothermal exploration activity worldwide. After over one century, the peri-Tyrrhenian regions of Tuscany and Latium (Central Italy) has still a relevant unexploited geothermal potential. According to the Italian Ministry of Economic Development, 23 exploration applications in Italy out of 38 are within Latium (data referred at the end of 2013).

The Italian National Research Council (CNR), recognizing the value of geothermal energy, has promoted the "Geothermal Atlas Project" in central and southern Italy. The purpose of the project is to update and to organize all the relevant data (i.e., geological, geophysical, geochemical, hydrogeological) in order to evaluate the favourability of the central-southern regions of Italy for the exploration of conventional and unconventional geothermal resources for electricity generation. Through this project, CNR aims to encourage the development of the geothermal resources and to facilitate investment in this energy sector.

This work, part of the Geothermal Atlas project, focuses on the northern Latium, which is an area characterized, together with Tuscany, by the highest values of heat-flow in Italy and hence notably interesting for geothermal exploration. The work shows the first results of a review of geological, geophysical and hydrogeological data collected to define the geological structure of the northern Latium and to build up an updated 3D subsurface geological model. The revised structural setting and the 3D geological model of the area will be used in the further stages of the Atlas project to develop the favorability geothermal maps of the study area.

1. INTRODUCTION

The northern sector of Latium Region (Figure 1) shows a high heat-flow and high temperature at very shallow depth (Figure 2; e.g. Billi, 1986; Marini et al., 1993; Buonasorte et al., 1995; Cataldi et al., 1995). The geothermal exploration of this area started at the end of the ‘50s. Between the ‘70s and the ‘80s these exploration activities led to the discovery of the Latera, Torre Alfina and Cesano geothermal fields. During the following years the geothermal exploration showed negative results with the discovery of only small productive structures, such as the Marta field located in the South of the Bolsena lake.

With the diffusion of new exploitation techniques (e.g., binary plants), the northern Latium represents at the present time an area of great interest with a relevant unexploited geothermal potential, also in terms of unconventional resources. According to the Italian Ministry of Economic Development, an increase in submitted exploration applications and in awarded exploration permits has been observed in the last years in Italy. It is worth noting that 23 exploration applications out of 38 interest the Latium region (data referred at the end of 2013). To promote this interesting resource, to support public authorities, and to encourage private investments, the Italian National Research Council (CNR) has planned the "Geothermal Atlas Project". The project intends to update and organize all the relevant data (geological, geophysical, geochemical, hydrogeological etc.) aiming to place at public disposal a revised dataset and, where possible, an updated model of the potential geothermal systems for conventional and unconventional geothermal resources for electricity generation in the central-southern regions of Italy.

The present work shows the first results of an integrated review of the available data, in particular geological and geophysical, which have been collected and analyzed to develop an updated structural model of the northern sector of Latium Region. The 3D geological model and the revised structural setting will represent the base for following assessment of geothermal potential and will also contribute to comprehend the relationships between geothermal fluid circulation and faults.

2. GEOLOGICAL SETTING

The northern sector of the Latium Region is characterized by different stratigraphic units recognized both in outcrop and in borehole (Figure 1; e.g., Accordi et al., 1988; Barberi et al., 1994; Buonasorte et al., 1995; Batini et al., 2003; Acocella & Funiciello, 2006, Cosentino et al., 2010).

The main units, from the shallower to the deeper ones, are the following:

• alluvial deposits, travertine and slope debris (Pleistocene-Holocene);

• volcanic products deriving from two magmatic cycles: the acidic units and the K-alkaline units, respectively of the magmatic Tuscan and Roman province (Pliocene-Pleistocene);

• post-orogenic marine and continental deposits, mainly formed by clay, sand, and gravel (Upper Miocene-Quaternary);

• clay, sandstone, and marly carbonates belonging to the Ligurian and Sicilian internal nappes derived from the Ligurian-Piedmont branch of the Neotethyan Ocean (Cretaceous-Oligocene);

• mainly carbonate formations, made up by anhydrites-dolomites followed by shallow water and pelagic limestones, associated to the Tuscan and Umbria-Marche units, developed along the Meso-Cenozoic western passive margins of the Adriatic plate (upper Triassic-Eocene);

• metamorphic basement, documented in southern Tuscany, made up by: i) Meta-pelite, meta-sandstone and meta-conglomerate of the Verrucano Formation (Triassic); ii) Phyllite and meta-sandstone with dolomitic level (Carboniferous-Permian); iii) Mica schist and gneiss group.

The complex structural setting of the area represents a heritage of the tectonic events which characterized the area from the early Miocene time. Two principal tectonic phases affected the Latium Region: contractional deformation during the Alpine orogeny, and a subsequent extensional phase due to the Tyrrhenian back-arc extension.

Between early to middle Miocene time, the study area was involved in the eastward migration of the Apennine thrust belt (e.g., Brogi, 2008; Cosentino et al. 2010). The result of this compression was the tectonic superposition of Ligurian unit on Tuscan unit, the latter subsequently overthrusted above the adjacent Umbria-Marche domain. The result of the compressive phase was the formation of NNE-SSW oriented trend characterized by fold-and-thrust-belts with associated piggy-back basins (Buonasorte et al., 1987 and 1995). The metamorphic basement was involved in the thrust belt and at the present time it outcrops in the western side of the Monti Vulsini.

From the middle Miocene, the northern Latium area has likely experienced the same extensional phase documented in southern Tuscany (e.g., Brogi et al., 2008 and references therein). As a result of this extension, low-angle normal faults developed in the area with tectonic elision of portion of the Tuscan stratigraphic sequences and formation of several basins.

Finally, since Pliocene time, high-angle NW-SE and NE-SW normal and transtensional faults developed in the area and controlled the geometry of the main Pliocene and Pleistocene basin. These fault systems played a crucial role for the setup of Plio-Quaternary volcanism (e.g., Acocella & Funiciello, 2006; Barberi et al., 1994).

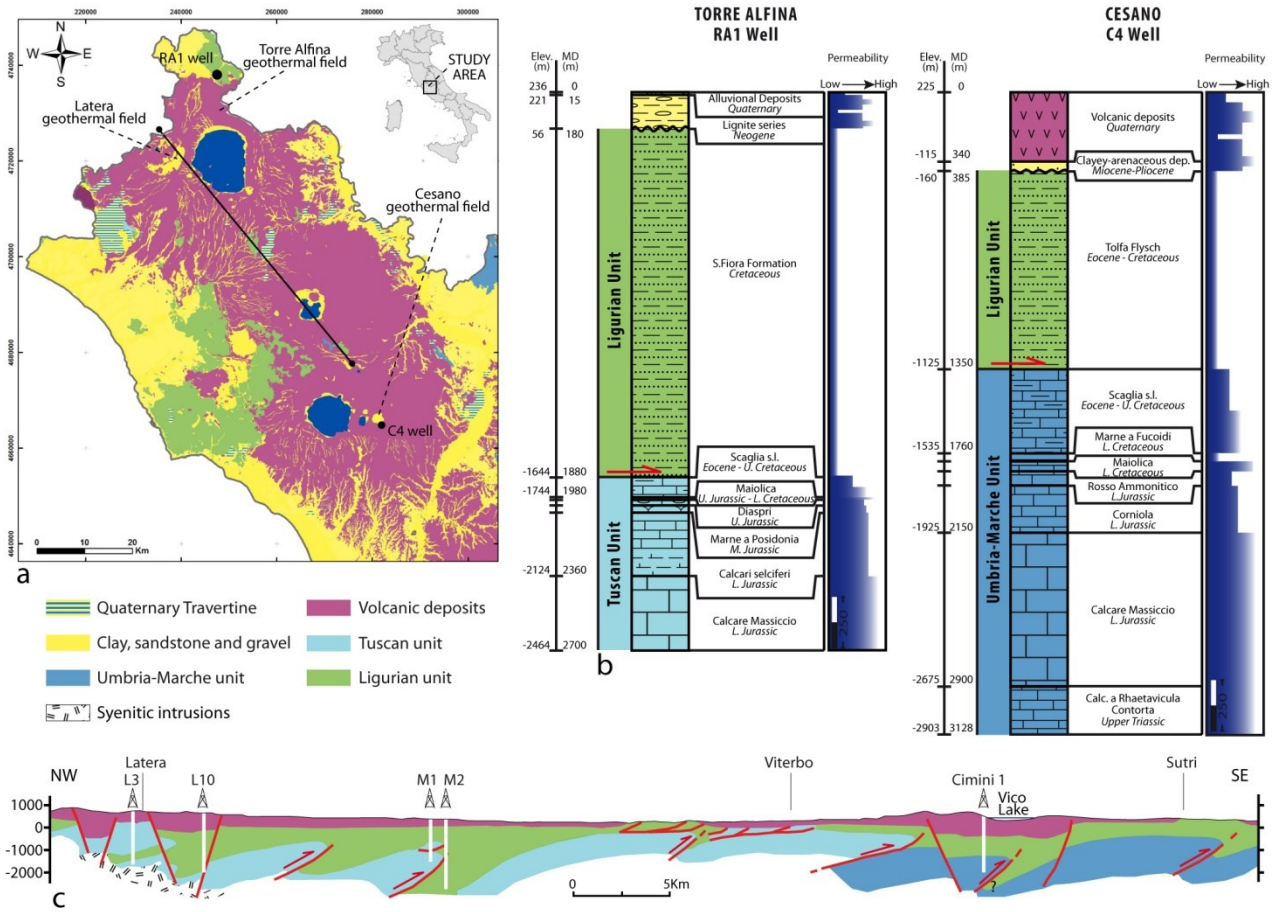

Figure 1: a) Geological map of the northern Latium (Italy) showing the main geological units. b) Schematic stratigraphy and relationship of the paleogeographic domain extrapolated through well data. Permeability attitude is shown (after Gragnanini et al., 2014). c) Geological profile of the northern sector of the Latium Region (section track in Fig. 1a; mod. after Buonasorte et al., 1987).

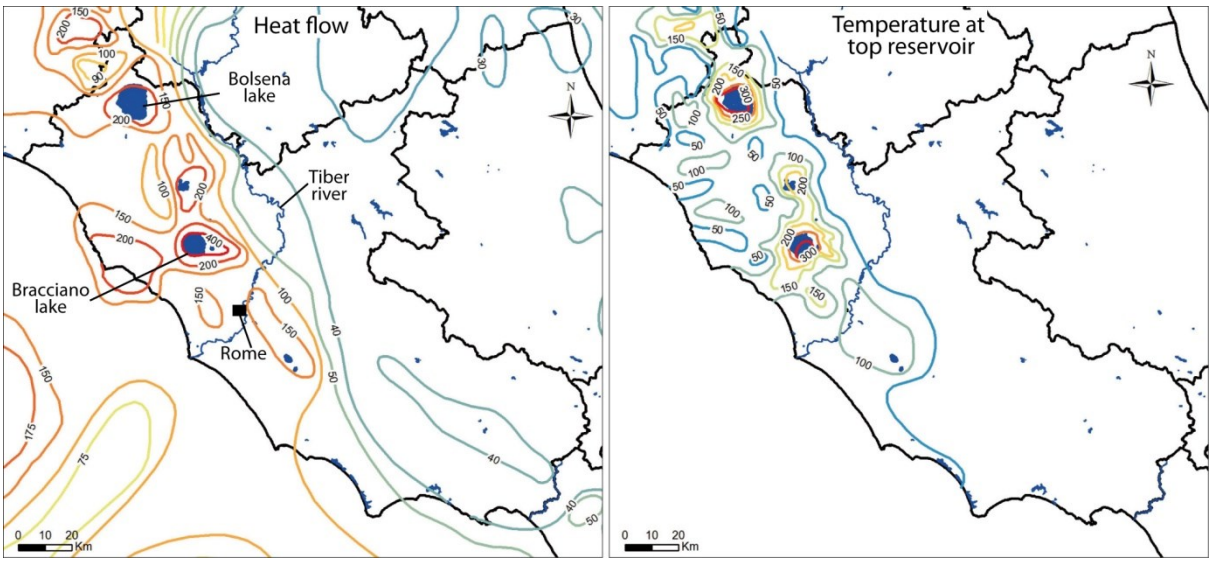

Figure 2: Heat flow characterizing the Latium Region (left) and extrapolated temperature in °C of the top of the potential reservoir of the Latium Region (right; e.g., ENEL, 1988).

3. GEOTHERMAL RESERVOIR AND SEAL

The principal reservoir of the study area is represented by Meso-Cenozoic carbonates and evaporites of the Tuscan and Umbria-Marche units (Figure 1). These sediments, normally characterized by a low primary porosity, are considered a potential reservoir and a regional geothermal aquifer as they are affected by intense fracturing which enhance the secondary porosity (Figure 1).

The seal is generally represented by the superimposed allochthon Ligurian unit, which is characterized mainly by clay and marls. Furthermore, the post-orogenic sediments, lying beneath the volcanic deposits, are constituted by clays, sandstones and conglomerates and they are characterized by low permeability too (Figure 1).

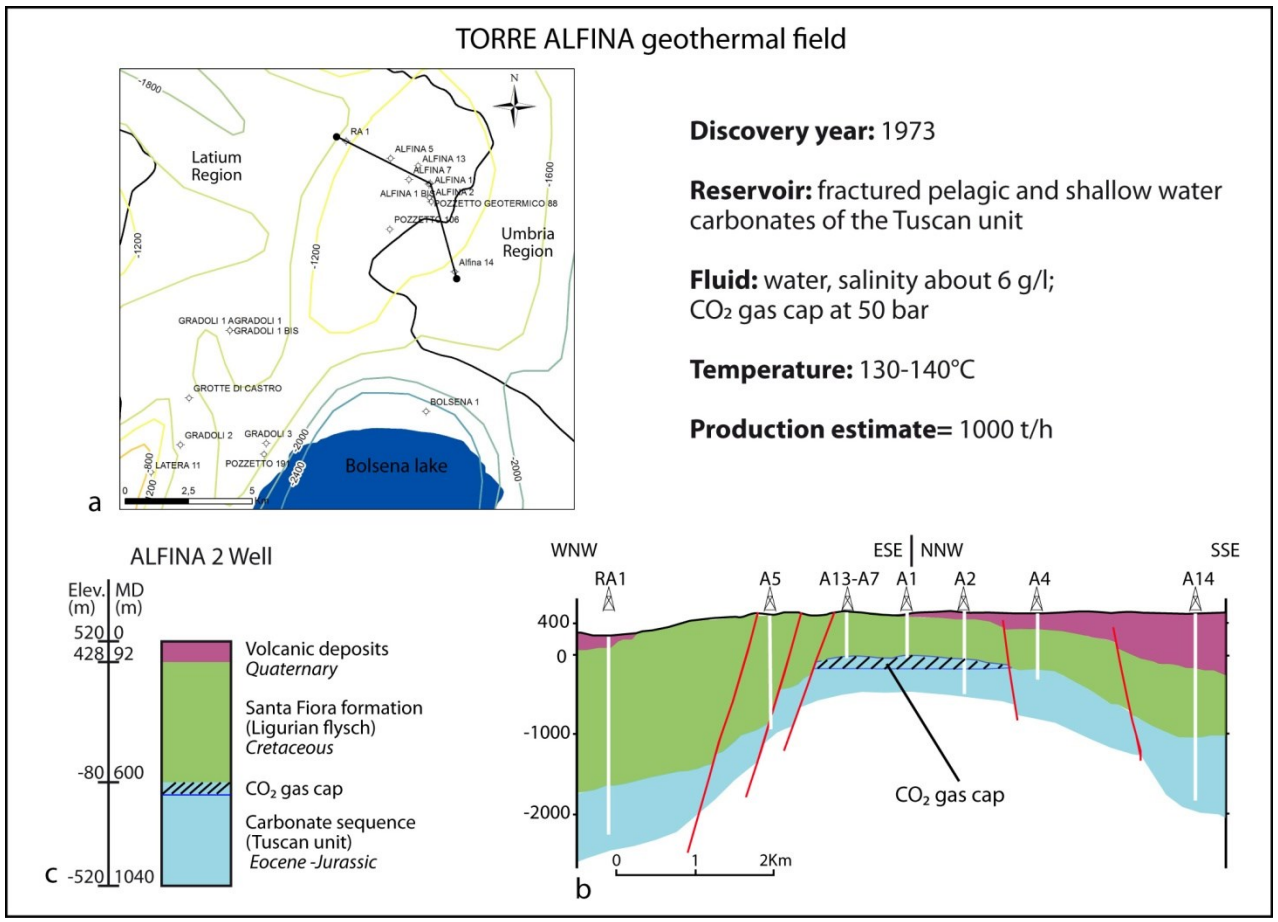

Figure 3: Torre Alfina geothermal field. a) Isobaths of the potential reservoir. b) Geological profile crossing the Torre Alfina geothermal field (mod. after Buonasorte et al., 1995). c) Simplified stratigraphy of Alfina 2 well.

4. MAIN GEOTHERMAL FIELD IN NORTHERN LATIUM

The main discovered geothermal fields in the northern Latium are the following:

• Torre Alfina (Figure 3)

The geothermal reservoir of Torre Alfina field is formed by fractured carbonate rocks of the Tuscan unit with good permeability. The reservoir is located on a structural high at depth from 550 to 2000 m. The geothermal fluid is made of water at 130-140 °C with a salinity of 6 g/l and piezometric level at a depth of 200 m. A gas cap, mainly formed by CO_2 and H_2S in traces, characterizes the reservoir top. The pressure of the gas cap is 50 bar. The estimate production is of 1,000 t/h (Marini et al., 1993).

• Latera (Figure 4)

The geothermal reservoir of Latera field is represented by fractured carbonate rocks of the Tuscan unit (Barberi et al., 1984). The reservoir is located on a NNE-SSW oriented structural high where the Tuscan and Ligurian units have been deformed forming an overturned fold. The geothermal fluid is made of water at 190-230 °C with a salinity of 8-12 g/l. A gas cap, mainly formed by CO_2 and H_2S in traces, characterizes the reservoir top. The permeability is good at the top of reservoir and decrease towards NE and W where dry wells were drilled.

• Cesano (Figure 5)

The geothermal reservoir of Cesano field is formed by the fractured pelagic and shallow water carbonate rocks of the Umbria-Marche unit. The geothermal fluid is made of brine with a salinity up to 350 g/l rich in sodium and potassium chlorides and sulfates over-pressurized. The temperature ranges between 145 to 300 °C.

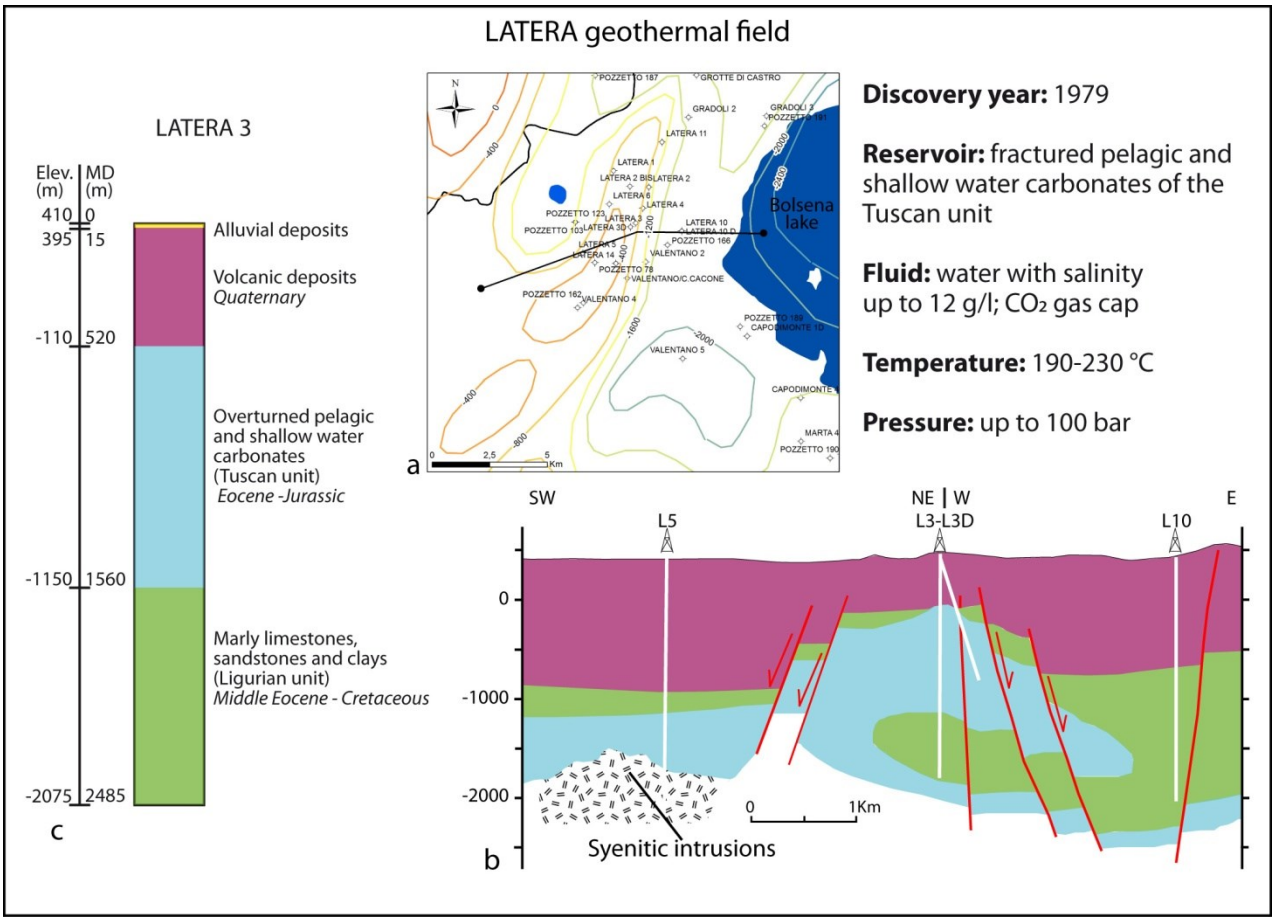

Figure 4: Latera geothermal field. a) Isobaths of the potential reservoir. b) Geological profile crossing the Latera geothermal field (mod. after Barberi et al., 1984). c) Simplified stratigraphy of Latera 3 well.

5. METHODS

In order to build up a structural model of the northern sector of Latium Region several data sets have been collected and analyzed. Numerous boreholes have been drilled in the past years in the study area mainly for geothermal purposes. As they offer excellent subsurface information, we have used well-data as primary input for the geological model. The well-data collected derive from different databases, hence we have firstly homogenize all the information in order to build up an unique and uniform database. We have carefully analyzed the deviation survey and the stratigraphic data defining the following units: recent deposits, volcanic sediments, post-orogenic deposits, Ligurian units, Meso-Cenozoic carbonate succession of the Tuscan and Umbria-Marche units,

metamorphic basement. Of the 92 available wells in the study area, only 78 have complete and certain information. The well-data have been imported and checked in the software Petrel of the Schlumberger (Figure 6).

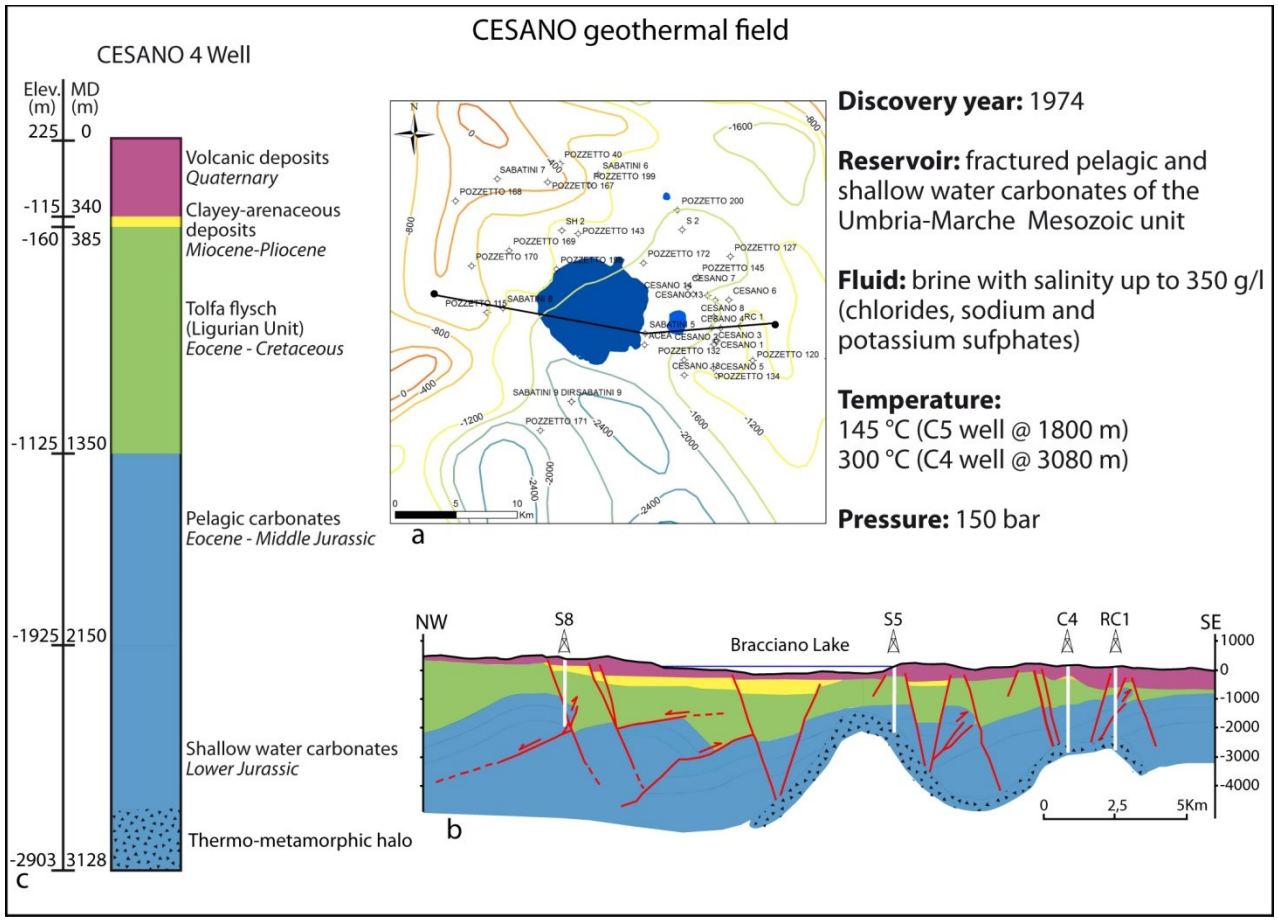

Figure 5: Cesano geothermal field. a) Isobaths of the potential reservoir. b) Geological profile crossing the Cesano geothermal field (mod. after Capelli & Mazza, 2005). c) Simplified stratigraphy of Cesano 4 well.

Since well-data are not homogenously distributed in the study area, other data sets have been used to define the geological model of the northern Latium. Geological and structural maps, geological profiles, isobaths and isopachous maps of the most important geological units, geophysical data, such as gravity data and aereomagnetic maps, and hydrogeological data have been georeferenced, and analyzed.

All the data collected, both direct and undirected, have been compared and integrated in order to build up a 3D geological model of the area.

6. DISCUSSION AND CONCLUSION

The exploration efforts carried out in the northern Latium ended up with the discovery of some water dominated geothermal areas. According to the economic evaluation based on the available technologies in mid '90s, the production of electric power was considered viable only for the Latera geothermal field. A power plant was constructed and it was in operation between 1999 and 2002 when it has been closed due to environmental concerns.

The main limitations to the geothermal resource exploitation were due to the limited size, structural complexity and highly variable permeability of the potential reservoir (e.g., Buonasorte et al., 1995). Other negative factor was related to the scaling, highly reactive nature of the geothermal fluids which were also associated with polluting gases.

However, as demonstrated by following studies, interpretation of new structural data, also derived from the analysis of deformation affecting the outcropping volcanic deposits, new geochemical and hydrogeological information, modern explorative techniques may allow to improve the definition of the structural setting at depth and the distribution of secondary permeability within the geothermal reservoir (e.g., Annunziatellis et al., 2008; Cinti et al., 2011; Vignaroli et al, 2013; Giordano et al., 2014). Moreover, the application of the most recent technologies may be useful to solve, or at least to mitigate, some of the negative issues related to the scaling properties of the fluids and to the presence of polluting gases. For these reasons, we reviewed the structural setting of the main potential geothermal reservoir, represented by fractured and faulted Meso-Cenozoic carbonate rocks lying at depth in the northern Latium, and of the overlaying units.

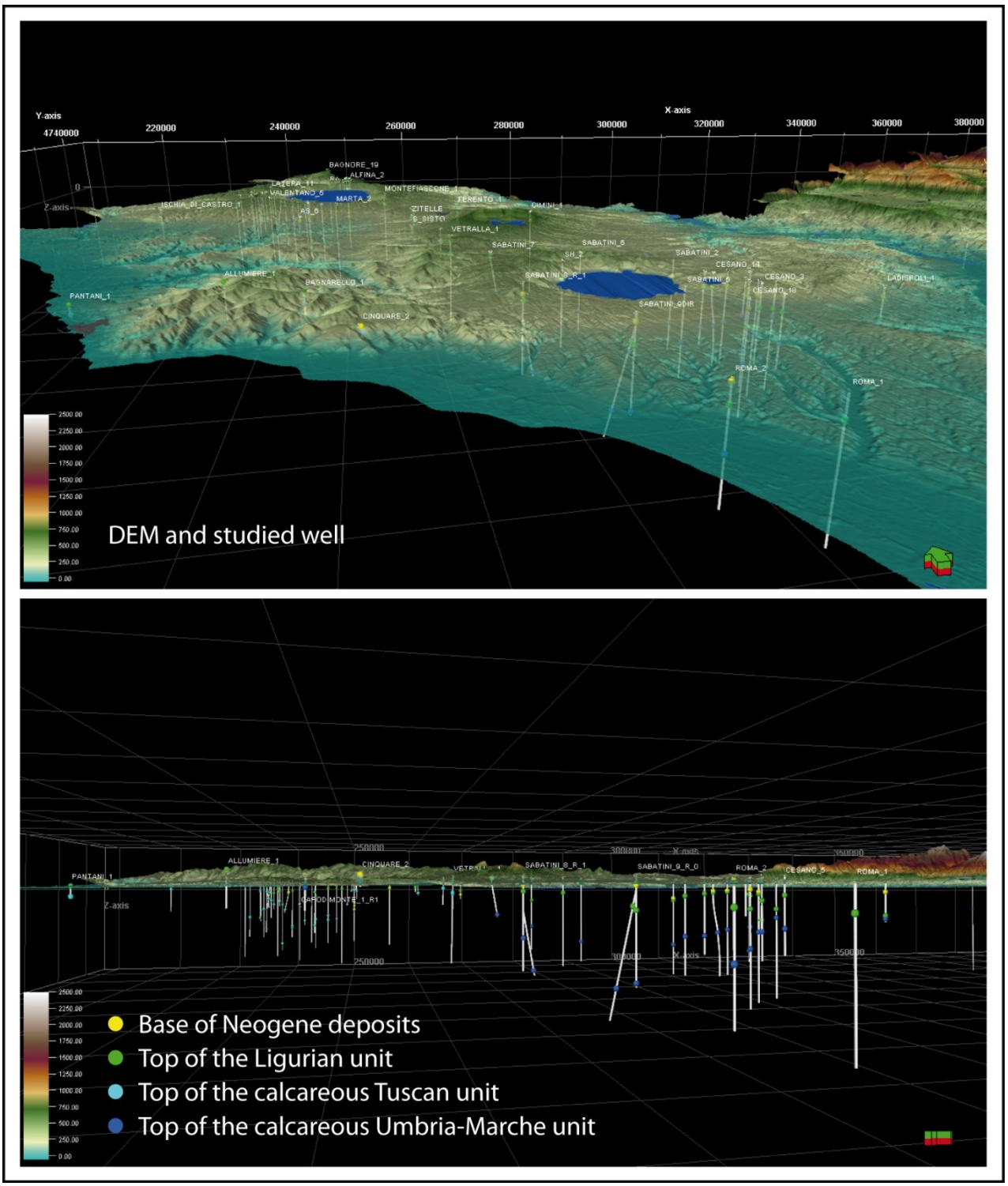

Figure 6: 3D rendering of the northern Latium digital elevation model (resolution = 90 m) with the location of the analyzed wells (above) and stratigraphic well tops of the main sedimentary units (below).

This work shows the first results of an integrated reinterpretation of geological data to create a new 3D geological model of the study area. The model has been organized by considering the different thermal conductivity properties of the sedimentary sequences in order to define the principal lithothermal units. Updated 3D surfaces have been generated for the potential reservoir, made up of the calcareous deposits of the Tuscan and Umbria-Marche units, for the base of the Neogene and for the base of the volcanic deposits (Figure 7). In particular the surface of the potential reservoir interpolates carbonate deposits of different sedimentary units (various Formations of the Tuscan and Umbria-Marche units) and of different ages. Hence, this surface corresponds to the first Meso-Cenozoic carbonate sediments observed, through well-data, or supposed, through indirect data and geological interpretation, beneath the surface. Therefore, the surface of the potential reservoir does not represent a cronostratigraphic surface.

The new 3D geological model provides the base for the definition of the structural setting which will be used in the further stages of the Atlas project workflow to support the assessment of conventional and unconventional geothermal resources in the Latium Region and to develop geothermal favorability maps for the study area.

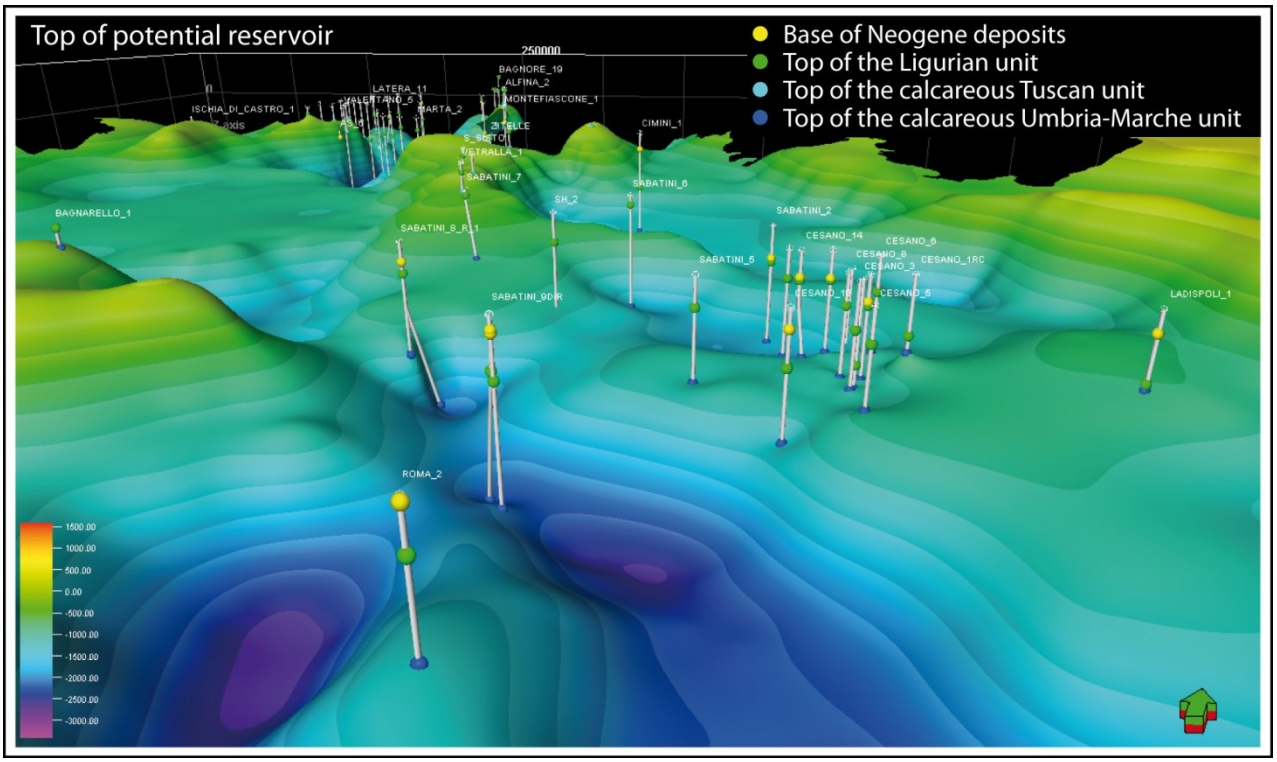

Figura 7: 3D model of the revised top of the potential carbonate reservoir. Analyzed well dataset is projected.

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REFERENCES

Acocella, V., Funiciello, R.,: Transverse systems along the extensional Tyrrhenian margin of central Italy and their influence on volcanism. Tectonics, 25, (2006).

Accordi, G., Carbone, F., Civitelli, G., Corda, L., De Rita, D., Esu, D. Funiciello, R., Kostakis, T., Mariotti, G., Sposato, A.,: Note illustrative alla Carta delle litofacies del Lazio-Abruzzo ed aree limitrofe. CNR Quaderni della Ricerca Scientifica 114, vol. 5 (1988).

Annunziatellis, A., Beaubien, S.E., Bigi, S., Ciotoli, G., Coltella, M., Lombardi, S.,:. Gas migration along fault systems and through the vadose zone in the Latera caldera (central Italy): Implications for CO2 geological storage. International journal for greenhouse gas control, 2, (2008), 353-372.

Barberi, F., Innocenti, F., Landi, P., Rossi, U., Saitta, M., Santacroce, R., Villa, I.M.,: The evolution of Latera Caldera (central Italy) in the light of subsurface data. Bull. Volcanol., 47-1, (1984).

Barberi, F., Buonasorte, G., Cioni, R., Fiordelisi, A., Foresi, L., Iaccarino, S., Laurenzi, M.A., Sbrana, A., Vernia, L., Villa, I.M.,: Plio-pleistocene geological evolution of the geothermal area of Tuscany and Latium. Mem. Descr. Carta Geol. D'Italia, XLIX, (1994) 77-134.

Batini, F., Brogi, A., Lazzarotto, A., Liotta, D., Pandeli, E.,: Geological features of Larderello-Travale and Mt.Amiata geothermal areas (southern Tuscany, Italy). Episodes, 26, (2003), 3.

Billi, B., Cappetti, G., Luccioli, F.: ENEL activity in the research, exploration and exploitation of geothermal energy in Italy, Geothermics, 15, (1986), 765-779.

Buonasorte, G., Cameli, G.M., Fiordelisi, A., Parotto, M., Perticone, I.: Results of geothermal exploration in Central Italy (Latium-Campania). Proceedings of the World Geothermal Congress, Florence, Italy, 18–31 May 1995, 2. International Geothermal Association, Inc., Auckland, New Zeland, (1995), pp. 1293–1298.

Buonasorte, G., Fiordelisi A., Rossi, U.,: Tectonics structures and geometric setting of the Vulsini volcanic complex. Period. Mineral., 56, (1987), 123-136.

Brogi A.: The structure of the Monte Amiata volcano-geothermal area (Northern Apennines, Italy): Neogene-Quaternary compression versus extension. International Journal of Earth Sciences, 97, (2008), 677-703.

Capelli, G., Mazza, R.,: Inquadramento geologico del domino vulcanico laziale. In: Capelli, G. Mazza, R., Gazetti, C., (Eds). Strumenti e strategie per la tutela e l'uso compatibile della risorsa idrica nel Lazio. Quaderni di tecniche di protezione ambientale, vol 78, (2005), pp. 15-39.

Cataldi, R., Mongelli, F., Squarci, P., Taffi, L., Zito, G., Calore, C.,: Geothermal ranking of Italian territory. Geothermics 24, (1995), 115–129.

Chiodini, G., Baldini, A., Barberi, F., Carapezza, M.L., Cardellini, C., Frondini, F., Granieri, D., Ranaldi, M.,: Carbon dioxide degassing at Latera caldera (Italy): evidence of geothermal reservoir and evaluation of its potential energy. J. Geophys. Res. 112, (2007).

Cinti, D., Procesi, M., Tassi, F., Montegrossi, G., Sciarra, A., Vaselli, O., Quattrocchi, F.,: Fluid geochemistry and geothermometry in the western sector of the Sabatini Volcanic District and the Tolfa Mountains (Central Italy). Chem. Geol. 214 (1–2), (2011),160–181.

Cosentino, D., Cipollari, P., Marsili, P., Scrocca, D.,: Geology of the central Apennines: a regional review. Journal of the Virtual Explorer. 36, paper 12, (2010).

ENEL, ENI-AGIP, CNR ENEA: Inventario delle risorse geotermiche nazionali. Indagine d'insieme sul territorio nazionale. Ministero dell'Industria, Rome, (1988), 75 pp.

Gragnanini, V., Mastrorillo, L., Vignaroli, G., Mazza, R., Rossetti, F.,: Hydrolithology of the area between Tuscany, Latium and Umbria regions (Italy), Journal of Maps, (2014), DOI: 10.1080/17445647.2014.942528.

Giordano, G., De Benedetti, A.A, Bonamico, A., Ramazzotti, P., Mattei, M.,: Incorporating surface indicators of reservoir permeability into reservoir volume calculations: Application to the Colli Albani caldera and the Central Italy Geothermal Province. Earth Science Reviews. 128, (2014), 75-92.

Marini L., Franceschini F., Ghigliotti M., Guidi M., Merla A.: Valutazione del potenziale geotermico nazionale. Rapporto a cura di Geotermica Italiana srl su incarico ENEA, (1993),194 pp.

Vignaroli, G., Pinton, A., De Benedetti A.A., Giordano, G., Rossetti, F., Soligo, M., Berardi, G.,: Structural compartmentalisation of a geothermal system, the Torre Alfina field (central Italy). Tectonophysics, 608, (2013), 482-498.