Estimation of the geothermal potential of the Caldara di Manziana site in the Sabatini Volcanic District (central Italy) by integrating geochemical data and 3D-GIS modelling.

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Introduction

The Tyrrhenian margin of central Italy is an area characterized by crustal thinning (<25 km) and a high heat flow (>300 mW/m^2), which makes it attractive for medium to high-enthalpy geothermal projects. The main difficulties encountered in the geothermal exploitation of the area are not related to the thermal conditions, but rather to the lack of an adequate rock permeability at depth. The medium-high enthalpy geothermal reservoirs of central Italy are hosted in Mesozoic carbonate-evaporitic rocks. These rocks exhibit secondary fracture permeability, locally reduced by self-sealing processes, especially in areas of low seismicity. Also, a low partial pressure of CO_2 (P_{CO2}) may facilitate the complete sealing of the reservoir fractures, preventing the ascent of hot fluids and resulting in a low CO_2 flux at the surface. Conversely, a high CO_2 flux reflects a high pressure of CO_2 at depth, that is suggestive of the presence of an active geothermal reservoir. Despite the possibility that also part of CO_2 be dissolved into groundwater, a large amount of this non-condensable gas will reach the surface being emitted into the atmosphere by discrete manifestations (gas vents) or through diffuse soil emissions. This is particularly true in sites -such as Caldara di Manziana, hereafter (CM) characterized by cold-gas emissions, which have CO_2 concentrations up to 97 vol. %. In this paper we present the results of a study carried out in the western zone of Sabatini Volcanic District (SVD; north of Rome, Italy) that hosts CM (and also Solfatara di Manziana-SM), one of the most spectacular CO_2 gas manifestations of central Italy. This study estimated the temperature and pressure conditions of the reservoir and the depth of its top using geological, geochemical and geophysical data and the TIN (triangulated irregular networks) interpolator provided in the ArcGIS for Desktop software. A new structural setting of the Mesozoic carbonates in the CM site is proposed, and an estimation of its geothermal potential is presented on the base of the total (diffuse and viscous) CO_2 release.

The gas manifestation of Caldara di Manziana

Caldara di Manziana (CM) is located ~8 km SW of Lake Bracciano and represents the most important gas manifestation of the SVD (Fig. 1). It is characterized by a small elliptic depression (430 m ´ 350 m) elongated in the NNE-SSW direction (Fig. 2). CM also comprises a small central pond associated with strong gas emission. A CO_2 advective flow of 18 tons/day was estimated for the gas vent. Many other discrete gas emission points are present in CM, mostly aligned along N-S or NNE-SSW trending fractures. All CM gas emissions are characterized by low temperature (15–25°C) and high CO_2 concentration (>97 vol. %).

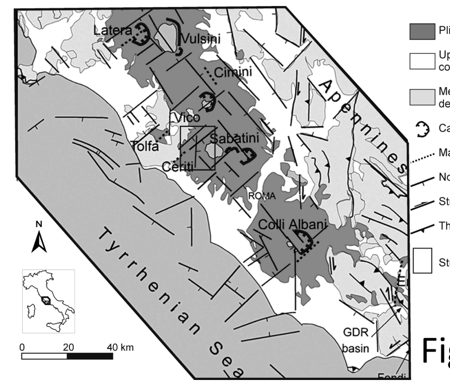

Fig. 1.

Fig. 3. Ice small vents

Fig. 2.

Gas composition and origin

The SVD gases display a general trend from air-saturated water (ASW) towards the N_2-He axis, showing an N_2/He ratio that varies from ~2500 to 15,600 (Fig. 4a). The CM gas composition analysed in this study follows the same trend, with N_2/He values of 3600-8000. In Fig. 4b, a dominant trend emerges, from the CH_4 vertex to the N_2/CO_2 axis, with a CO_2/N_2 ratio of 50-200. The distribution of samples is representative of a mixing between gases from deep and shallow sources (also including the atmosphere). For the SVD, an involvement of mantle (or magmatic) gases and crustal ^{4}He-enriched gases is suggested by the helium isotopic composition (R/R_A= 0.37-0.62 where R and R_A are the ^{3}He/^{4}He ratio in the sample and in the air respectively). Gas emissions at the investigated sites in Latium have δ^{13}C values ranging from -4‰ to -2‰ vs. PDB, suggesting that CO_2 originates from a mixing process between marine carbonate and a more-negative mantle or magmatic source.

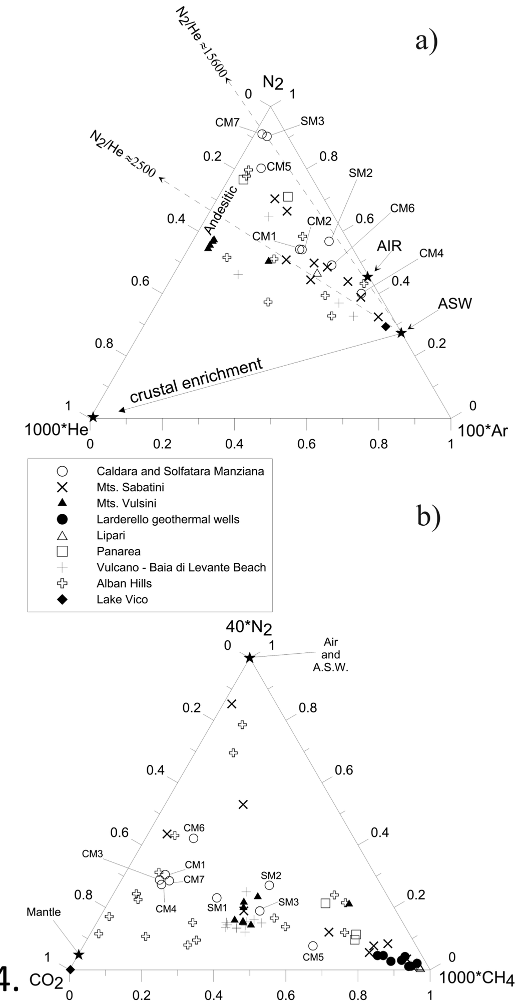

Fig. 4.

Geothermometric-geobarometric estimations

The thermodynamic conditions at the gas equilibration zone were estimated by using the CO_2-CH_4-CO-H_2-H_2O system.
Taking into consideration the following equilibrium reactions:

$CH_4 + 3CO_2 = 4CO + 2H_2O_{(liq)}$ (1)

$CO_2 + H_2 = CO + H_2O$ (2)

and using thermodynamic data the logarithms of the equilibrium constants are:

$$L1 = \log\left(\frac{X_{CO}^4}{X_{CO_2}^3 \cdot X_{CH_4}}\right) = 8.065 - \frac{13606}{T}; \quad L2 = \log\left(\frac{X_{CO} \cdot X_{H2O}}{X_{CO_2} \cdot X_{H_2}}\right) = 1.936 - \frac{2002}{T}$$

Supposing the presence of pure water, the water fugacity :

$$logP_{CO2} = 3.573 - \frac{46}{T} - L2, \quad \text{where } L2 = log\frac{X_{H_2}}{X_{CO}}$$

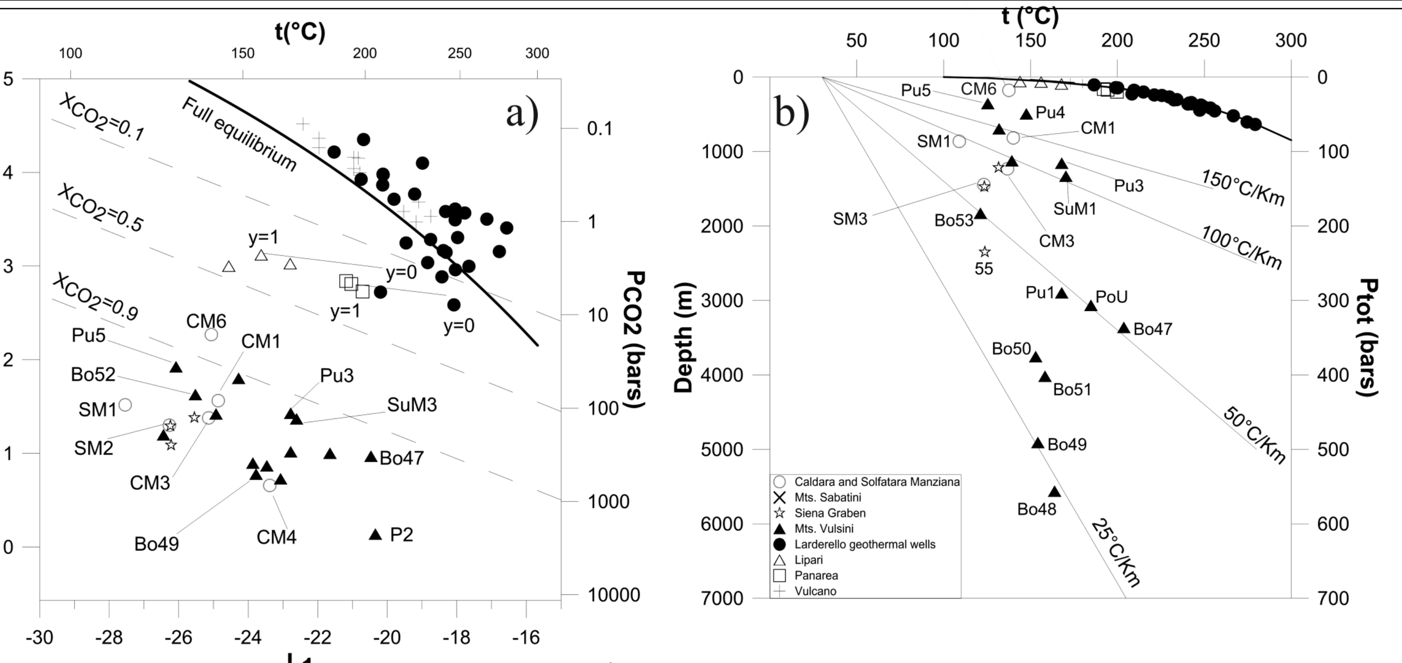

Fig. 5.

In Fig. 5, the representative points of CM, SM and various cold-gas emissions of central Italy are clearly separated from those of high-enthalpy geothermal systems, suggesting that the former gases originate from deep sources characterized by relatively lower temperatures (130–160 °C) and high P_{CO2} values (80–700 bar).

Estimation of the diffuse soil CO_2 flux and of the total CO_2 output

A soil CO_2 flux survey on a dense grid: investigated area 0,15 km^2, 838 CO_2 flux measurements, total diffuse CO_2 flux: 188±0.02. Diffuse gas flux anomalies oriented N-S and NW-SE. The soil CO_2 flux map has been obtained from these data using ordinary kriging interpolation and the semivariogram reported in Fig. 6. Advective flow measurements were performed at 25 vents of different sizes including the main one, yielding a advective CO_2 flow of 20.15 tons/day. The total CO_2 flow emitted by CM, obtained by summing the diffuse and advective flows, is estimated at 210 tons/day from an area of 0.15. km^2.

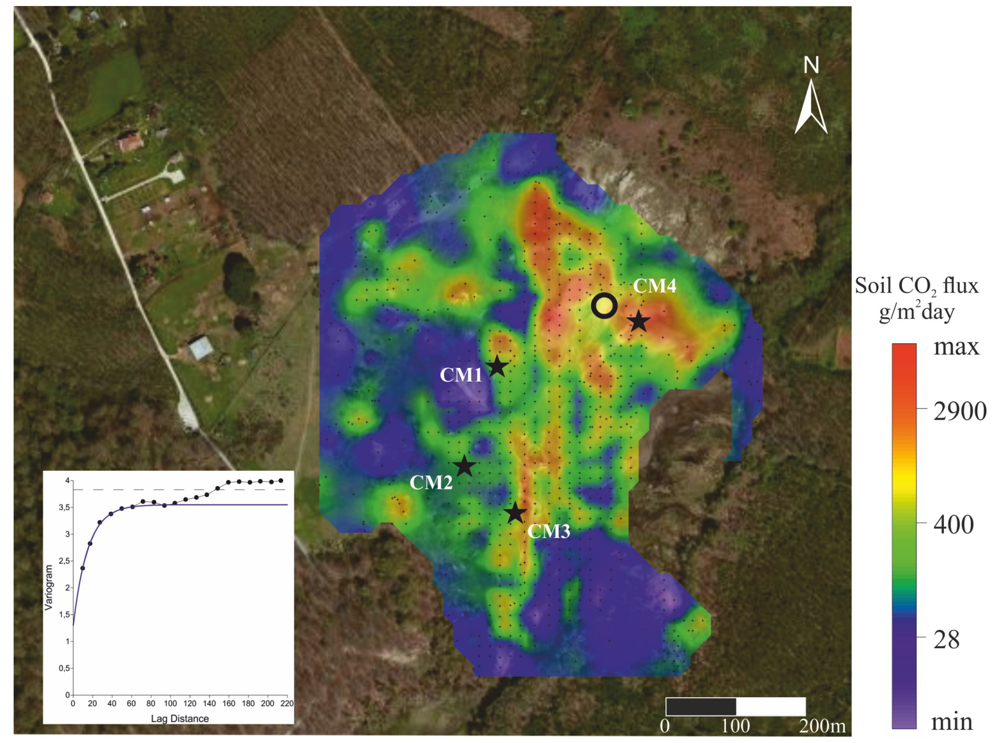

Fig. 6.

GIS analysis of the reservoir top and temperature

The depth and temperature of the top of the reservoir were reconstructed and estimated using GIS tools and functionality. Information regarding elevation data, the bottom of the volcanic formation, the top of the reservoir, the stratigraphy of 15 wells and the location of CM and SM gas emissions, were included in the data analysis. Two different TINs were used: 1) of the bottom of the volcanic formation; 2) of the top of the reservoir (Figgs. 7a, b). Geological cross sections obtained by TIN data are shown in Fig. 7c. The TIN of the top of the reservoir was analysed to derive the position and the trend of tectonic features that have affected the Mesozoic carbonate formations (Fig. 8). The thickness of the flysch formation was calculated as the difference between the two TINs. Temperatures at the top of the reservoir and at 1000 m b.s.l. depth were estimated using information on extrapolated gradient wells and actual values measured in deep. Temperature map at 1000 m b.s.l. depth was obtained using an inverse-distance-weighting (IDW) interpolator (Fig. 9).

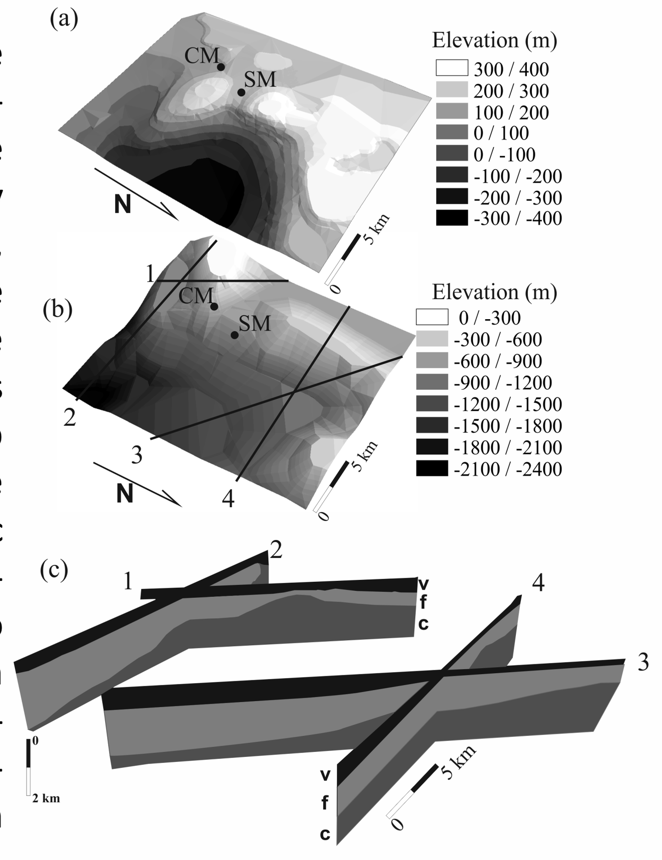

Fig. 7. (c): v= volcanites, f= flysch, c= carbonates.

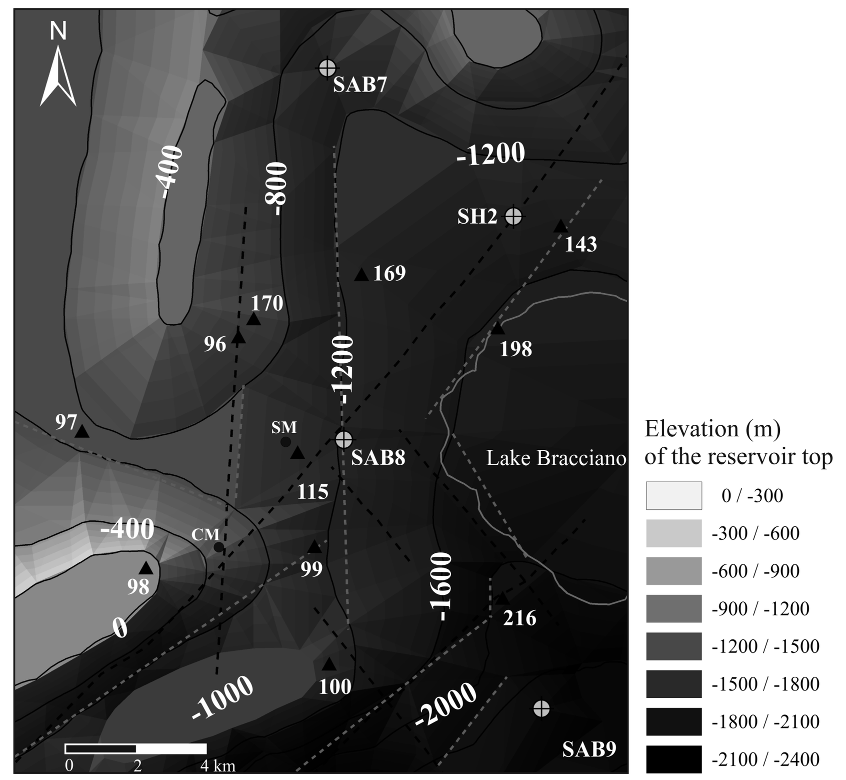

Fig. 8.

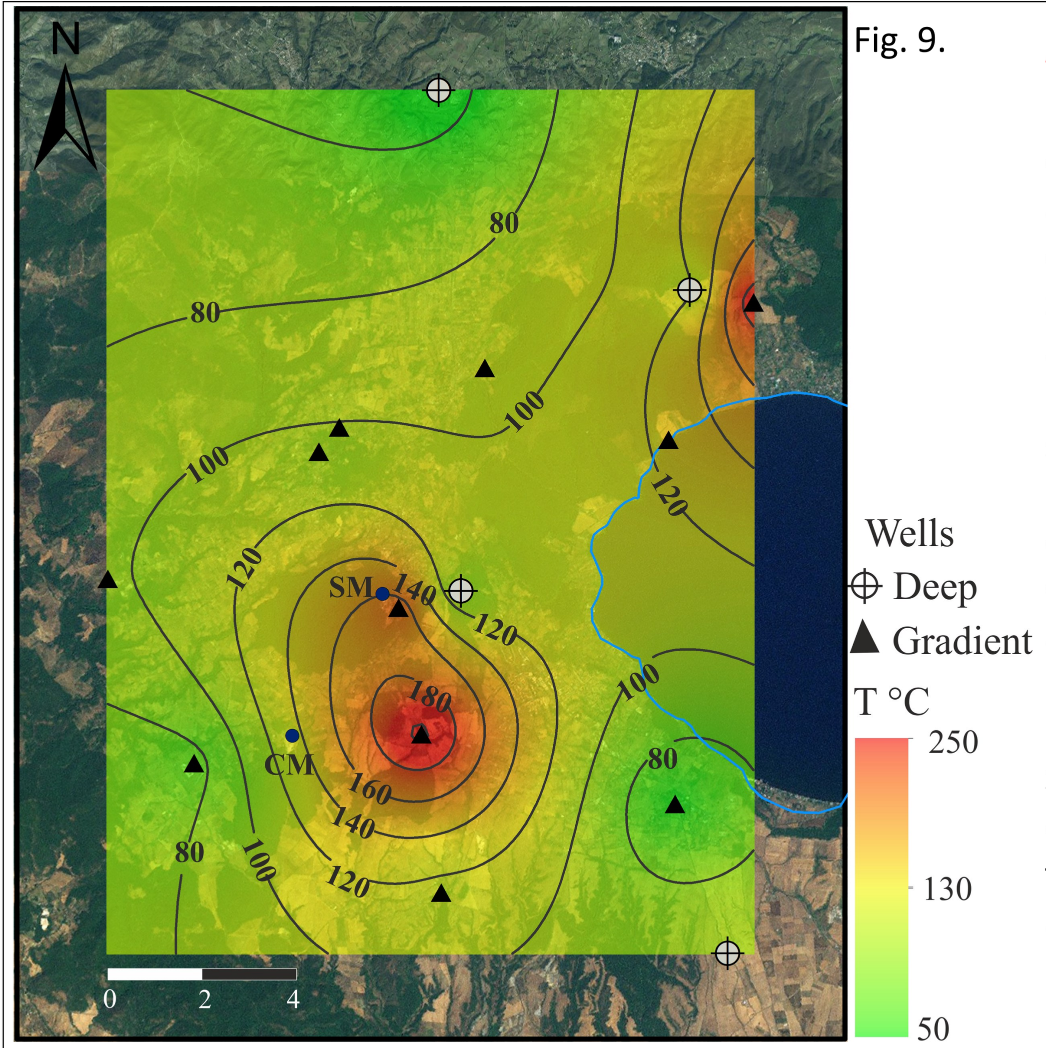

Fig. 9.

Results and geothermal implications

It was possible to produce a temperature map for a reference depth of 1000 m b.s.l., corresponding to the depth of the reservoir top below CM (Fig. 9) and finding for CM a temperature value around 140 °C; such a temperature is compatible with the geochemical estimate of 120-165 °C (Fig. 5). Moreover, the depth of the gas equilibration zone (900-1400 m) estimated for CM (samples CM1 and CM3) and SM (samples SM1 and SM3) is consistent with the depth of the top of the carbonate reservoir as calculated by the GIS elaboration used in this study. Assuming that the CO_2 emitted at the surface from CM (210 tons/day) mostly originates from degassing of the geothermal liquid in the reservoir, the thermal energy capacity of the studied system (W) can be estimated by following the approach: $\Phi_{CO2}=W/H*m_{CO2}$ (4) where Φ_{CO2} is the total CO_2 output from a 0.15 km^2 area m_{CO2} is the CO_2 molality of the geothermal liquid and H is its enthalpy. At 150 °C the enthalpy of the liquid is 632.2 J/g and P_{H2O} is 4.76 bar. P_{CO2} was calculated using the difference between the total hydrostatic pressure (P_{tot}) and P_{H2O} (P_{tot}= P_{H2O}+P_{CO2}), while m_{CO2} (0.73 mol/kg) was calculated using the SUPCRT92 software package. The heat released by the system below CM, as calculated using equation (4), is ~48 MWt. A fluid with a temperature of 210°C was encountered in a well drilled in the southern part of Lake Bracciano; if this temperature is assumed to be representative of the thermal conditions of CM reservoir, the heat release would amount to 68 MWt.

Conclusion

This study evaluated the geothermal potential of C.M.. The chemical composition of gas emissions was used for geothermometric-geobarometric estimations and the total amount of CO_2 released was assessed. The subsurface geology was reconstructed using data from deep exploratory and shallow temperature-gradient wells. The bottom of the superficial volcanic deposits, the thickness of the impervious flysch cover and the top of the geothermal reservoir hosted in fractured Mesozoic limestones were reconstructed by a 3D-GIS modelling. A medium-enthalpy (T~140 °C) thermal power of 48–68 MWt was estimated, and the shallow depth of the reservoir top (~1000 m) indicates that the resource is economically attractive.