Geothermal anomalies in a sector of the eastern Po Plain

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The European and National strategies for the climate and the energy have as major targets the decarbonisation process before 2050 and the drastic reduction of the PM10 concentration in the Po Plain. In order to achieve these goals, the request, the exploitation, the use and the diffusion of renewable energies should greatly increase in the next future. Due to the recent evolution of technological plants, like district heating, the low-to-medium enthalpy geothermal plants perfectly fulfil the above needs with important environmental, economic, societal, and health benefits. The present research is motivated to contribute to the above needs and particularly to the characterization of the geothermal reservoirs existing in the broader Ferrara-Modena territory, Northern Italy, which hosts in the subsoil some major tectonic structures with a high geothermal potential, like the Ferrara anticline (Fig. 1).

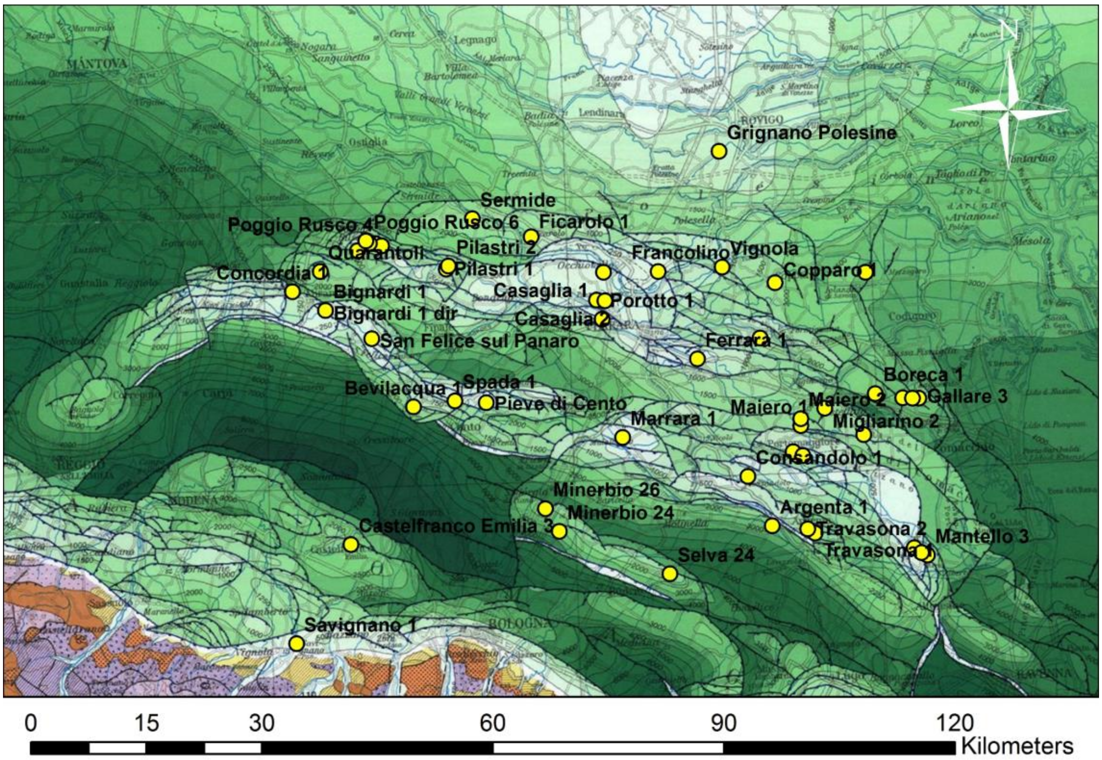

Fig. 1: The 55 boreholes (yellow circles) analysed in the present research. Base map from Bigi et al. (1990).

The research was based on the analysis of 55 boreholes drilled in the past all over the investigated area for hydrocarbon explorations and available from the VIDEPI database (web site of the *Ufficio Nazionale Minerario per gli Idrocarburi e le Georisorse*). The temperature data of these wells have been published in the inventory of the national geothermal resources edited by Agip (1977-1987). It is noteworthy that the available values of the measured temperatures were affected by the fluids (water and mud) used during the drilling operations. The difference between the temperature of the mud and that of the rock depends on several factors like the borehole depth, the time required by the muds for a complete circulation cycle, the thermal gradient, the porosity of the stratigraphic units, the time lag of the measurement. In order to discriminate the influence of the circulation fluids and estimate the real temperature of the surrounding rocks, we applied the methodological approaches proposed by Horner (1951), Zschocke (2005) and Pasquale et al. (2013). In case at least two measurements at the same depth were available, the former method is likely the most appropriate.

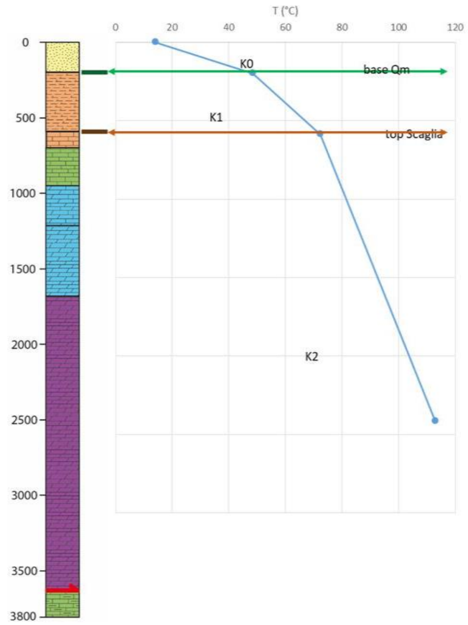

Fig. 2: Example of geothermal gradients calculated for the three reference intervals.

For the estimate of the geothermal gradient (*K*) and the heat flux (*q*), based on the Fourier law, we considered three reference intervals: S_0, S_1 and S_3, respectively corresponding to i) the silicoclastic sedimentary succession down to the base of the marine Quaternary; ii) the stratigraphic units underlying the marine Quaternary and overlying the Scaglia formation; iii) from the top of the Scaglia formation and the bottom of the borehole analysed. For each interval both the geothermal gradient (K_0, K_1 and K_3; Fig. 2) and the heat flux (q_0, q_1 and q_3) have been calculated, while for calculating the overall heat flux of each borehole the thermal resistance method proposed by Pasquale et al. (2012) has been applied. The results of all the investigated boreholes have been plotted to generate thematic maps thus emphasizing first order geothermal anomalies.

The calculation of the thermal conductivity was initially based on literature values (e.g. Robertson et al. 1988; Viganò et al. 2011) and subsequently corrected based on the porosity and compaction coefficient of each lithotype (Pasquale et al., 2013). The analysis of the obtained geothermal gradients clearly suggests that the thermal conductivity (*viz.* conductive flux) alone could not justify such vertical variations. On the other hand, these variations could be attributed to the occurrence of convective motions affecting the Mesozoic carbonate rocks, therefore generating a strong geothermal gradient decrease within these units and an increase in the overlying deposits. This thermal model could obviously work only in case a heat source is present at depth and a sufficient permeability allows the upwards circulation of the deeper fluids.

Accordingly, we focused our attention on the carbonate sedimentary successions representing the geothermal reservoirs. In particular, the heat transmission characterizing these rocks is a consequence of both conduction and convection phenomena. Moreover, the largest differences in geothermal gradient and heat flux characterizing succession S_1 and S_2 do occur in correspondence with the major structural highs, like that associated to the Ferrara Thrust. For example, this phenomenon is observed at the boreholes of Casaglia (with a gradient difference of 90-100 mW/m^2), Ferrara-1 (30-40 mW/m^2) and Vignola-1 (50-60 mW/m^2). In the latter, the calculated values could be likely attributed to the upwelling of fluids across fracture systems extending to shallow depths as it could be observed in Fig. 3.

On the other hand, small variations of the gradient in other boreholes suggest that the heat flux occurs prevailingly or exclusively by means of conductive phenomena.

In conclusion, the integrated analysis of deep seismic reflection profiles (Fig. 3) and the estimate of the thermophysical parameters, down to a depth of *ca*. 3 km, allowed to infer both the horizontal and vertical temperature distributions, which are clearly strongly affected by the geological, hydrogeological and tectonic evolution characterizing the region. Accordingly, the most promising areas in terms of potential geothermal reservoirs and their exploitations have been recognized in a sector of the eastern Po Plain.

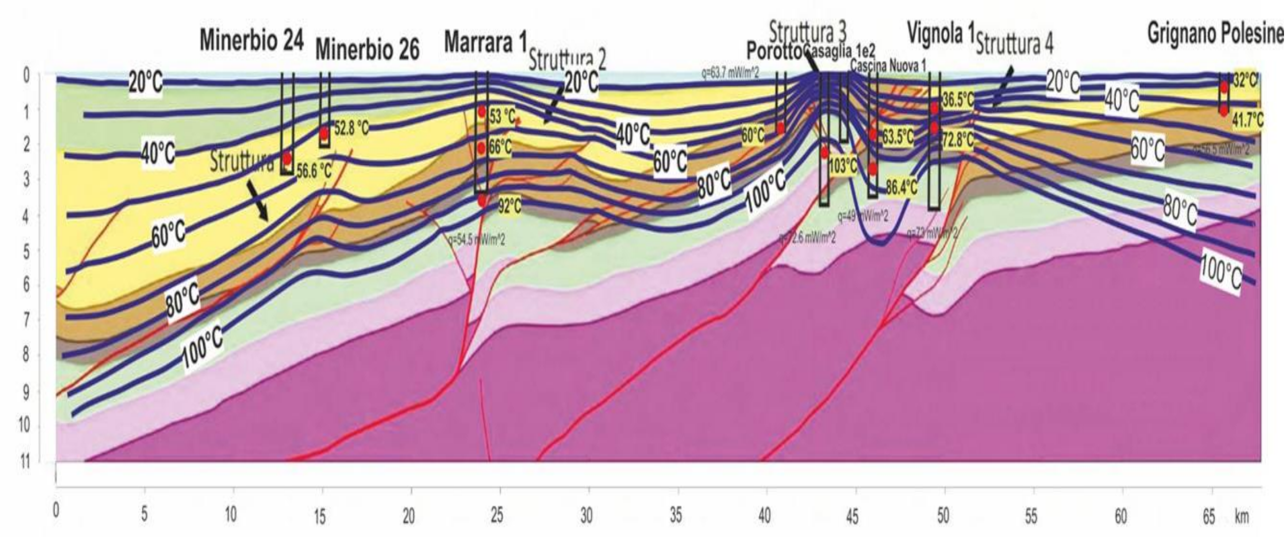

Fig. 3: Example of thermal gradient distribution showing both vertical and horizontal variations. The seismic profile is from Mistroni (2016).

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