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ScienceDirect

Energy Procedia 125 (2017) 300–309

Energy Procedia

www.elsevier.com/locate/procedia

European Geosciences Union General Assembly 2017, EGU Division Energy, Resources & Environment, ERE

Data integration and conceptual modelling of the Larderello geothermal area, Italy

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Abstract

In the frame of the Integrated Method for Advanced Geothermal Exploration (IMAGE) Project, a reliable exploration and resource assessment workflow was implemented on the basis of an integrated and multidisciplinary approach. Our study addressed to a better understanding of the thermal structure of the deepest part of the Larderello geothermal field (Southern Tuscany, Italy) by integrating structural, geological, geochemical, geochronological, petrological and geophysical data. With the aim to characterize the reservoir located nearby an important seismic reflector (the K-horizon), we systematized the available data and, successively, we applied a numerical thermal modelling approach to test our hypotheses and concepts.

Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).

Keywords: data integration; conceptual modelling; geothermal reservoir; heat source; Larderello area

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Peer-review under responsibility of the scientific committee of the European Geosciences Union (EGU) General Assembly 2017 – Division Energy, Resources and the Environment (ERE).
10.1016/j.egypro.2017.08.201

1. Introduction

Due to the growing interest in the technological development of unconventional geothermal resources, interdisciplinary geoscientific activities have been focused on the southwestern part of the Larderello-Travale Geothermal Area (LTGA), i.e. the Lago Boracifero locality, also referred as Lago area (Fig. 1). In the LTGA, two main geothermal reservoirs exist: the "shallow reservoir" hosted in the evaporite-carbonate units (about 0.7 – 1.0 km b.g.l. on average and with temperature from 150°C to 260°C) and the "deep reservoir" hosted in the metamorphic succession and Neogene granitoids (about 2.5 – 4.0 km b.g.l. and with temperature from 300°C to 350°C) [1,2]. Fluids dominantly of meteoric origin at vapor phase circulate in both reservoirs [3]. The meteoric recharge occurs through the carbonate outcropping formations; besides a lateral input from the regional aquifers surrounding the hydrothermal reservoirs is also assumed, presumably induced by the actual exploitation process [2,3].

In the Lago area, the occurrence of high temperature and high pressure fluids hosted below the hydrothermal systems currently under exploitation has been established in the frame of a deep exploration program carried out in the early 1980s. In particular, the San Pompeo 2 well encountered fluids with a temperature > 400°C and reservoir pressure far above 24 MPa, in a fractured zone at about 2900 m [4]. The main objective of this well was to verify whether exploitable fluids exist in correspondence to the anomalies detected by reflection seismic surveys. In fact, the 2D and 3D seismic exploration activities carried out in the last decades provided evidences of two distinct seismic markers, referred to as "H-horizon" and "K-horizon", discontinuously characterizing the entire LTGA. Drilling data show that in some cases (especially in the Travale area) the H-horizon is located in correspondence of the thermo-metamorphic aureole of Neogene granitoids [5] and many wells produced super-heated steam from this level. The deeper K-horizon has similar amplitude pattern, but locally showing bright spot features, and a more continuous spatial extension with respect to H-horizon. The nature and the origin of the K-horizon are still under debate [4,6,7], as it has not yet been drilled with the presumable exception of the San Pompeo 2 well. The thermobaric conditions extrapolated at this level (P ≈ 30 MPa and T > 400°C) do not seem to be compatible with the deep geothermal reservoir so far exploited characterized by a sub-hydrostatic pressure controlled by its current super-heated steam condition [2]. In order to improve the understanding of the physical conditions in the zone corresponding to the K-horizon, we systematized the available information from different geoscientific sources, briefly discussed in the following.

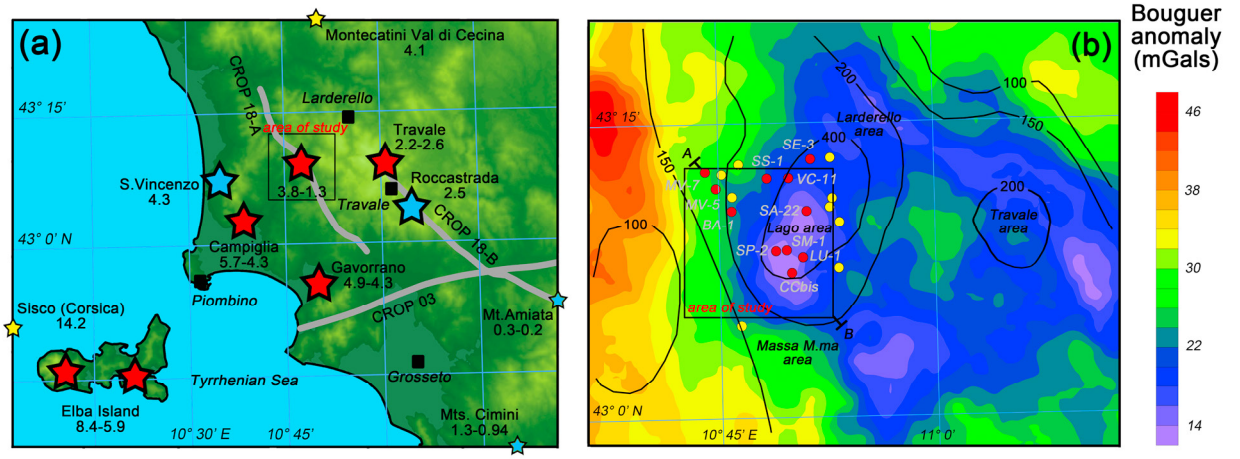

Fig. 1. (a) Location of the area of study. The sub-volcanic mafic (yellow stars), acid intrusive (red stars) and extrusive (cyan stars) centers and their ages (in Ma) are showed. The out-of-area magmatic sites referred to in the text are also reported (small stars) along the map borders; (b) Bouguer anomaly map of the Larderello-Travale Geothermal Area together with the heat flow isolines of the regional anomaly (in mW/m^2, modified from [20]). The studied boreholes and the NW-SE cross-section (A–B) are reported. Red circles are the deep wells of Table 1 (BD-1: Badia 1, CCbis: Carboli CBIS, LU-1: Lumiera 1, MV-5: Monteverdi 5, MV-7: Monteverdi 7, SM-1: San Martino 1, SP-2: San Pompeo 2, SA-22: Sasso 22, SE-3: Selvaccia 3, SS-1: Serrazzano Sperimentale 1 and VC-11: Valle Cornia 11). Yellow circles are additional wells used for the reconstruction of the Neogene-Pleistocene composite granitoid.