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Editorial

Geothermal Systems: Interdisciplinary Approaches for an Effective Exploration

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The main goal of geothermal exploration is to identify favourable reservoirs that may be exploited for energy extraction. While drilling is the only direct method to access the subsurface structure of a given system (and its physical state), various techniques have been developed to investigate the targeted reservoir before drilling [1]. The most reliable methods for investigating geological structures at depth are geological field observations, structural geology, exhumed analogues, and geophysical methods. Parameters such as temperature or permeability can be inferred mainly from hydrogeological, geochemical, petrographic, or geophysical investigations. The information retrieved from each of these methods is a piece of a complex puzzle. Gathering and combining these pieces is the key for a comprehensive interpretation of the investigated system [2–8]. That is why, as much as possible, data coming from various disciplines are combined to enhance the understanding of a geothermal area. A multifaceted workflow is the most envisaged approach to understand the dynamics driving fluid flow at depth. However, the more data are available the more complex is the interpretation. This is because geothermal systems are characterized by the interaction of complex nonlinear physical process.

Despite the difficulties, geothermal exploration is increasingly focusing on the extensive integration of multidisciplinary data. This combined approach is leading to a new and reliable exploration and assessment process, able to determine a significant risk reduction. Furthermore, production technology is constantly evolving. Recent technological developments have significantly improved plant efficiency and performance creating new targets for exploration and revised approaches to focus them better.

This special issue contains 13 studies focusing on the interplay between different exploration approaches, reservoir characterization, and numerical models implemented throughout the various phases of geothermal exploration until the definition of the exploitation strategy.

One of the papers F. F. Amanda et al. of this special issue addresses the potential of geothermal resources beneath calderas by means of melt inclusion analysis. F. F. Amanda et al. studied the interaction between crustal fluids in the exploited reservoirs investigating the Miocene Fukano Caldera, NE Japan. The authors pointed out the total amount of fluids stored in the magmatic reservoir fuelling the ongoing geothermal system. This led to an estimation of the available electric energy equivalent of about 45 GW over 30 years of power generation.

One of the tools to guide geothermal exploration are favourability maps that can help to target promising areas. In that scope, A. Santilano et al. developed a methodology for geopressured geothermal resource, an unconventional system in sedimentary basins. Their analysis is based on the use of geological and hydrothermal 3D models to cross several parameters that play a role in the detection of prospective zones. The approach is demonstrated in the central part of Italy, on the Adriatic coast.

J. M. Marques et al. adopt an interdisciplinary approach to investigate the Chaves geothermal system in Northern Portugal. This setting is characterized by low temperatures

and an abundant emission of carbon dioxide. Geochemical analyses of sampled fluids pointed out an upper mantellic origin of the sampled CO_2 emissions. J. M. Marques et al. combined these observations with geophysical studies to better describe the geothermal processes occurring at depth.

M. Zentilli et al. present a study about the past and present day hydrology and genesis of some fascinating saline springs that are claimed to be the most northerly on Earth, in the Canadian Arctic Archipelago. This paper reviews and updates descriptive features of the perennial springs and compares their mineralogy, geochemistry, and geology to some vein array which is interpreted as a hydrothermal predecessor of the springs. Authors suggest that the perennial springs are related to deep plumbing systems established by expulsion of overpressured fluids from salt structures (diapirs) at depth. The conduit system was finally proposed as a viable analogue environment for the establishment of microbial life in similar situations on other planets.

L. R. Pastoriza et al. present the results of a structural field study addressing tectonic elements in the Negros geothermal field, Philippine archipelago, providing a valuable example highlighting the importance of careful structural analysis in geothermal exploration. This work illustrates how a strongly field-based geological approach can inform exploration and eventual development strategies for drilling, even at the early stages of the field exploration (i.e., even prior to drilling), becoming certainly powerful when integrated with geochemical, geophysical, and hydrological data.

B. Walter et al. integrated structural interpretation of remote sensing images, field work, and geochemistry to determine the role of the different regional structural features that may control different fluid outflow zones, as well as the nature and the source of the different fluids along a rift zone in western Uganda. This study therefore documents the complexity of a composite hydrogeological system hosted by a major rift-bounding fault system, to the recognition of structural intersections as prime targets for exploration of fault-controlled geothermal systems.

C. Dezayes et al. focused on the paleocirculation at the Hercynian basement/sedimentary cover interface. The main purpose was to understand the behavior of the fracture-fault network and the origin of the hydrothermal fluids by means of a multidisciplinary approach based on the study of fracture-fault network orientation, mineral fillings, and fluid origins.

Remaining in the Upper Rhine Graben study area, J. Freymark et al. used a data-based 3D structural model of the central Upper Rhine Graben for 3D coupled simulations of fluid and heat transport. To assess the influence of the main faults bordering the graben on the hydraulic and the deep thermal field, the authors carried out a sensitivity analysis on fault width and permeability, evaluating the implications for the deep temperature distribution.

In their paper, T. Mackowski et al. discuss the importance of seismic methods during the geothermal exploration phase. In particular, the seismic interpretation provides not only information about the geometry of the geothermal reservoir but also relevant petrophysical figures such as porosity. The authors rely on a case study in the central part of Poland, already known for its geothermal potential and exploitation, to demonstrate the benefits of seismic survey.

R. de Franco et al. illustrate the use a synthetic seismic reflection modelling approach to investigate the structure of a geothermal system characterized by supercritical fluids. Specifically, the authors provide an interpreted image of the debated K-horizon at the Larderello-Travale geothermal field, Italy, by integrating geological and geophysical data. R. de Franco et al. use two geophysical models to study numerically the seismic response of the K-horizon. Their investigation points out that a "physically perturbed layer" best explains the reflectivity signals observed on the active reflection seismic profiles imaging the K-horizon.

M. Osvald et al. investigate the field of possible technologies for the exploitation of metal-bearing geological formations with geothermal potential at depths of 3–4 km or deeper. The authors describe laboratory leaching experiments aimed at quantifying the relative rates and magnitudes of metal release and seeing how these vary with different fluids. The results are intended to use for upscaling to reservoir scale and calculate likely dissolved loads achievable, given reaction rates and solubility of the various elements involved. In this study, the first steps were described to ensure the sustainability of the proposed technology: in the frame of the coproduction of energy and metals that would be possible and could be optimized according to market demands in the future.

Fluid scaling is an important issue that can hamper geothermal use. A. Varga et al. study the matter by combining geology, mineralogy, and chemistry to analyse the process leading to carbonate scaling in a zone of the Pannonian basin in Hungary. They break down the causes of the phenomenon and proposes a multifactor explanation that could be used in other areas, especially during exploration to assess the potential risk of cementation related to the geothermal fluid.

F. Li et al. developed a numerical optimization of the exploitation parameters through a 1D-3D fluid and heat transport model based on existing well data. They assessed energy production in a geothermal doublet in eastern Tianjin (China) to make the production as sustainable as possible, preventing the resource from heat breakthrough. Even if this work focuses on the exploitation, it can also help to forecast the location of wells to develop a geothermal sector.

Conflicts of Interest

The editors declare that they have no conflicts of interest regarding the publication of this special issue.

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