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SI: Geothermal Energy for Sustainable Development

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SCOPE OF JOURNAL

- The Turkish Journal of Earth Sciences is published electronically 6 times a year by the Scientific and Technological Research Council of Turkey (TÜBİTAK).
- It is an international English-language journal for the publication of significant original recent research in a wide spectrum of topics in the earth sciences, such as geology, structural geology, tectonics, sedimentology, geochemistry, geochronology, palaeontology, igneous and metamorphic petrology, mineralogy, biostratigraphy, geophysics, geomorphology, palaeoecology and oceanography, and mineral-deposits.
- The journal publishes the highest quality papers and comprehensive review papers on hot topics of current interest, with high quality illustrations.
- Submitted papers should have regional implications and attract international interest as the journal aims to provide a medium for interdisciplinary papers that would be of interest to many different specialists.
- Specialized papers can be submitted if they illustrate significant progress in that specific area of the earth sciences. In addition to original and review articles, we are also interested in publishing discussions of papers that have already appeared in recent issues of the journal.
- The journal also publishes thematic sets of papers on topical aspects of geology or special issues of selected papers from conferences.
- Short articles (6 printed pages maximum) for rapid publication reporting a significant advance in the earth sciences with regional impact are welcome. Contribution is open to researchers of all nationalities.

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ABSTRACTED AND INDEXED

- Science Citation Index Expanded
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Preface

In the current context of climate change and global warming, it is becoming important to control the use of fossil fuels to reduce GHG emissions. This is possible by increasing the share of renewable energy as a primary energy source globally, and Turkey is no exception. In recent years the world has experienced unprecedented floods, forest fires, rise in summer temperatures, rain, and other natural calamities due to climate change. As the Australian Prime Minister in his recent Cop 26 address to the world leaders, rightly said that the solution to this problem is with the scientists and engineers. It is true. As scientists, engineers, and technologists, we have to come together and discuss various innovative methods to adopt to solve climate issues. Realizing this, TUBITAK has thought of bringing earth scientists and technologists to bring on a common platform to breed interdisciplinary ideas and programs through this special issue related to geothermal energy. TUBITAK is always the front runner in organizing and taking initiatives and supporting scientific knowledge exchange through conferences, webinars, workshops, and publishing special thematic volumes. TUBITAK always encouraged international collaboration by supporting various fellowships and research grants and brought the international scientific community together to solve global natural issues and Turkey's natural disasters. TUBITAK supported various basic and applied grant programs related to earth sciences. TUBITAK encouraged innovative research programs, modeling studies, application of digital technology in earth sciences, material sciences, and renewable energy programs. TUBITAK is aware that geothermal energy in Turkey ranks fourth in the world with the generation of 1650 MWe electricity and surging ahead to increase this generation to 3000 MWe in the near future. TUBITAK is not lagging behind in implementing innovative technologies in the field of geothermal energy. It has taken the solid initiative to support Enhanced Geothermal Systems to harness the heat available in the rocks for power and heat generation and reduce dependence on fossil fuels and imported fuels. TUBITAK has supported a program to capture carbon dioxide for the use of manufacturing dry ice to combat accidental fires.

TUBITAK always encouraged scientific collaboration and created a culture of working together for the betterment of humanity. Now that the Turkish government has endorsed the CoP25 Paris agreement to reduce carbon dioxide emissions, TUBITAK is preparing a roadmap to enhance the development and production of energy from geothermal sources for electricity generation and direct application.

While underlining the possibilities that can be achieved with the approach of co-operation and collaboration together in the field of geothermal energy resources, I would like to thank all scientists who contributed to scientific collaboration for bringing out the Turkish Journal of Earth Sciences special issue 'geothermal energy for sustainable development". As the title rightly says, it is very important to increase the footprint of geothermal energy for sustainable development. I wish researchers success in their impact-oriented research in geothermal energy resources.

Hasan Mandal
The President of the Scientific and Technological Research Council of Turkey (TÜBİTAK)

Preface

The Turkish Journal of Earth Sciences has dedicated this second special issue, published in 2021, to geothermal energy, which has been increasingly used in Turkey as a renewable energy source in recent years. The use of geothermal energy dates back to ancient times. To generate heat and electricity from this ancient energy resource, the heat accumulated in various depths of the earth's crust, hot water containing chemicals, steam, and gases are used. Located on one of the most important active tectonic belts, Turkey has many geothermal fields formed in different tectonic environments. Some of these geothermal fields are used to generate energy, heat, or greenhouse cultivation, while others are used in thermal tourism.

Turkey is among the few countries in the world in terms of geothermal potential. Most of the geothermal fields, having a total energy potential of 31,500 MWt, are located in Western Anatolia. In terms of installed power, Turkey increases its potential each day, and, by the end of 2021, 1650.2 MW of electricity will be produced from geothermal energy resources in Turkey. Considering the fact that the amount of fossil fuels will be depleted in the 2050s, it becomes clear how crucial it is to include renewable energy sources into the national energy policies. In this context, within the Eleventh Development Plan covering the years 2019-2023, it is aimed to increase exploration, production, and R&D activities for domestic resources with high geothermal potential. Following the special issues on the hydrocarbon potential of the western Black Sea region and October 30, 2020, Samos Earthquake, published at the end of 2020 and in October 2021, respectively, The Turkish Journal of Earth Sciences is glad to share another special issue called "Geothermal Energy for Sustainable Development" with the academic world.

I would like to express my special thanks to the President of TÜBİTAK, Prof. Dr. Hasan Mandal, for his invaluable support in the organization of the workshop and the preparation of the special issue, to ULAKBİM Manager Mehmet Mirat Satoğlu, Dr. Cihan Aksop, journal administrator Seval Özgül, and to all for providing technical and organizational support.

I would also like to express my gratitude to the guest editors Profesor Alper Baba (İzmir Institute of Technology, Turkey) ve Profesor Dr. Dornadula Chandrasekharam (Indian Institute of Technology, India) for evaluating the articles meticulously and to all authors who contributed to this issue by their valuable pieces of works.

Sincerely,

Orhan Tatar
Editor in Chief

Geothermal Energy For Sustainable Development

Preface

Turkey, being on the top 5 countries in geothermal resource use, both electricity generation and direct application, is surging ahead with further development of this resource for sustainable development. The geothermal fluids and heat are currently being utilized for electricity generation, greenhouse cultivation, and space heating and cooling. About 1650 MWe electricity is being generated, followed by 2000 MWt being used for space heating and greenhouse cultivation. Soon Turkey is going to increase the power generation to 3000 MWe. Turkey is panning in a big way to tap the heat from its radiogenic granites spread over an area along the western Anatolian region for electricity and heat. TUBITAK though the time is ripe to bring all those scientists involved in geothermal research on one platform to collate recent work in this energy sector. The Turkish Journal of Earth Sciences Chief Editor assigned this responsibility to two well-known scientists. Thus we took the responsibility of bringing international scientists on one platform and showcasing their work. The outcome is the present special issue. We need an energy source that can provide base-load electricity with a low carbon footprint and land footprint for any sustainable development. Geothermal energy qualifies both the tests, and it can sustain the environment and economy. When we floated the flyer for this special volume, we never expected that the response would be overwhelming. We received more than 26 abstracts and full MS. It has become a task for us to find reviews and pick up the best quality of MS. We thank the reviewers who helped us with this job. We were helpless because some of the good MS did not pass through the review screen. Below are the highlights of the papers selected for this volume.

Agricultural irrigation by geothermal waters has added a new dimension to the direct application of geothermal energy. **Meriç et al. (2021)** brought of a novel method of utilizing geothermal spent fluids for irrigation using experimental investigation in the Balcova-Narlidere geothermal field. With the development of drilling technology, extracting heat from granites for power generation direct application of heat will be huge innovative technology in the geothermal industry. Western Anatolia has a large volume of high radiogenic granites waiting to be harnessed for electricity and heat. **Chandrasekharam and Baba (2021)** presented a glimpse of this technology by presenting the potential of Kestanbol granites of western Anatolia. This is for the first time evaluation of the EGS potential of granite intrusive in Turkey has been made. Due to the thin continental crust that has resulted due to the Alpine-Himalayan orogeny, the heat flow values of the western Anatolian region are anomalously high. This is reflected especially around the Menderes graben, as documented by **Balkan-Pazvantoğlu et al. (2021).** Their investigation as direct implication on the EGS sites around the graben associated with the granites. Innovative technologies are very important to assess the potential of geothermal energy for various applications. Fuzzy logic and analytical hierarchy methods are integrated to understand the potential of geothermal sites for agricultural application. This study by **Şener and Şener (2021)** integrates field-based and laboratory investigation over the geothermal fields around Patnos, Eleşkirt, and Doğubayazıt regions of eastern Turkey. Field-based investigations of geological structures on the evolution of geothermal systems for the Varto region in Eastern Anatolia by **Uzelli et al. (2021)** indicate that the fluid flow is controlled by strike-slip faults in this region. **Siefert et al. (2021)** applied a novel multi-proxy method to correlate stratigraphic geothermal marble reservoir units separated by about 3900 m using petrographic geochemical, radiometric, and physical parameters. This method is very useful to the geothermal industry during the pre-drilling stage. Geothermal waters sometimes contain high metals content (like arsenic and manganese) are termed greywater. The grey water footprint (GWF) of geothermal water in the south-eastern Anatolian region was assessed by the Monte Carlo simulation method by **Yapıcıoğlu and Yeşilnacar (2021).** The biochar adsorption method is recommended by the author to reduce this pollution by geothermal spent water. The major fault zones like North and eastern Anatolian faults zones are very important structural elements that control major stress acting over entire Turkey. These stress patterns play an important role in the fracture pattern within the radiogenic granites located within the grabens between these two major tectonic structures. FEFLOW numerical modeling software was utilized by **Akar et al. (2021)** to understand the geothermal fluid flow and heat flow regime in Kursunlu geothermal field located in the western Anatolian geothermal province. The model shows convective flows flowing from a depth of 1000 m and the presence of high-temperature zones below this region. Volcanic flows associated with subduction tectonics are also loci for convective geothermal systems, as evident from the Indonesian and New Zealand geothermal provinces. Geothermal industries generally utilize ORC type of turbines and generators for generating power. However, Kalina cycle-supported geothermal power plants are very few in number. Developed by Alexander Kalina, this system uses an ammonia-water mixture to generate power from hydrothermal systems. The ratio of ammonia to water mixer can be varied depending on the reservoir temperature, an advantage this system has which is not available in the ORC system. Utilizing the data from the Husavok geothermal power plant that works on Kalina cycle, **Lei et al. (2021)** et al present an improved Kalina cycle that gives more efficiency in power generation than the currently used Kalina cycle system. This modified system is more suitable for EGS supported power plants, according to the authors. The hydrogeochemistry of thermal waters from Kestanbol by **Şanlıyüksel Yücel et al. (2021)** complements the work presented by Chandrasekharam and Baba on the Kestanbol granites. The geochemistry of the thermal waters shows circulation within the granites indicated by high Ba and Li content. The data presented by Yucel et al. indicates the reservoir rock to be the Kestanbol granite. **Çarıkcı et**

al. (2021). analyzed the geothermal waters of the Konya plain project and recommend that the waters are best suited for the balneological purpose. This geothermal province can be developed as a tourist resort by developing accommodation and infrastructure facilities for tourists. This will help the local authority to increase their annual revenue. Geothermal waters are gaining importance for their power generation capacity and their ability to provide energy transition elements like Li. **Can et al. (2021)** in their paper, present an adsorbent that can effectively remove Li from geothermal waters from Omer-Gecek geothermal site. Fixed bed column experiments by the authors using $MnCO_3$–LiOH and $NaSiO_2$ adsorbent is able to extract Li from geothermal waters to commercially viable product. The Li content in the geothermal water is 3.5 mg/L. Using the above adsorbent, the authors report that the Li content recovered is of the order of 236 g. From the classical method of extracting heat from radiogenic granites using water, the technology has advanced in replacing the water with supercritical carbon dioxide. The advantage of using supercritical carbon dioxide is that this gas is inert at such temperatures and does not react with the host rock. Hence, the chances of secondary mineral precipitation are minimum, and hence the chance of fractures clogging and hampering the free flow of fluids in EGS systems. In the supercritical CO_2 water Hartcourt granite system, **Avanthi Isaka and Gamage (2021)** demonstrate based on high-temperature experimental work that the secondary minerals that form are helping in forming a layer over the upper boundary of the reservoir, thereby acting as an insulator in trapping the heat and also trapping the CO_2 by forming calcite. Emission of non-condensable gases such as CO_2 is one common feature of most geothermal energy. **Parlaktuna et al. (2021)** presented seismic velocity characterisation and survey design to assess CO_2 injection performance at Kızıldere geothermal field. They mention that field seismic survey designs for the pilot sites will be refined further once the source positions in the field are finalised, taking into account the logistic environmental access conditions for the vibrator source.

We are most grateful to the reviewers for their constructive criticism and suggestions, which undoubtedly improved the quality of the papers published in this special issue.

Thanks are also due to Prof. Dr. Orhan Tatar, the Editor-in-Chief of the Turkish Journal of Earth Sciences, for his constant support and encouragement during the preparation of this issue.

Alper BABA, Dornadula CHANDRASEKHARAM
Guest Editors