PROCEEDINGS, 50th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2025
SGP-TR-229

Geothermal Exploration Strategy in Turkiye

Coskun BULUT[1], Bayram SARIDAS[1], Ahmet AYTUNUR[1], Rob VESTRUM[2]

[1]SEYL Enerji, Bestepe Mah. Nergiz sk. 7/2-111 Yenimahalle-Ankara 06520 TURKIYE

[2]Thrust Belt Imaging, Calgary, Alberta, T2R 0E1 CANADA

coskun.bulut@seylenergy.com

Keywords: Geology, Geophysics, Exploration,

ABSTRACT

Turkiye is a country with great potential for geothermal energy and therefore there are many geothermal fields. It is necessary to carry out various exploration activities in order to determine these fields and reveal their potential. When we consider the geothermal power plants that produce electricity in Turkiye, almost all of them produce fluids from fractures that develop within metamorphic units. The Geothermal exploration process is divided into several stages during which different methods and techniques are used at various scales. However, finding the right exploration activities to produce this fluid is of great importance. Geological and geophysical studies that will be carried out in order to reveal the underground structure of geothermal fields in Turkiye are the main subject of this article.

1. INTRODUCTION

1.1. Geothermal Energy in Turkiye

According to the Turkish Government, Türkiye has the fastest growing energy demand among the Organization for Economic Co-operation and Development (OECD) countries in the past 2 decades. In this period, Türkiye ranks second to China in the increase in electricity and natural gas demand in the world.

On the other hand, Türkiye has a 74% import dependency to meet its energy demand. The versatile structure of Türkiye's energy strategy and its energy import dependency brings international relations into prominence in this field.

Türkiye attaches great importance to the development of renewable energy sources. In accordance with the National Energy Policy adopted in 2017, increasing the use of domestic and renewable energy resources is among the main priorities. Furthermore, Türkiye has ranked 5th in Europe and 12th in the world in terms of installed capacity in renewable energy. The share of renewables in Türkiye’s installed power reached to 54% at the end of 2022.

Geothermal energy is clean, cheap and environmentally friendly, which is our domestic energy source. Türkiye is located on an active tectonic zone as geological and geographical location and for this reason our country is rich in terms of geothermal energy resources. Our country have approximately 1.000 geothermal springs that located all over the country that have several of temperatures.

Turkiye, being located on the Alp-Himalayan orogenic belt, has a significant geothermal potential due to its abundant orogenic magmatic and volcanic activities. As a result, the country hosts geothermal resources with various temperatures, mainly in the Aegean Region, as well as in the Northwestern, Central Anatolia, Eastern, and Southeastern Anatolia regions, all of which are associated with active faults and volcanism. These regions have nearly 1,000 natural geothermal outlets. The first geothermal research and investigations in Turkiye began with the MTA (General Directorate of Mineral Research and Exploration) in the 1960s.

Turkiye is one of the leading countries in Europe in terms of geothermal energy potential and ranks fourth globally in installed capacity. In June 2022, Turkiye’s geothermal energy installed capacity reached 1,686 MW, accounting for 1.66% of the total installed capacity (Balcı, 2023). When examining the well and resource temperatures in Turkiye, it is evident that the country as a whole possesses geothermal potential (Figure 1). However, within this temperature map, there are hidden geothermal systems. When considered in conjunction with geology, it can be concluded that Turkiye's geothermal potential is much greater, including undiscovered resources..

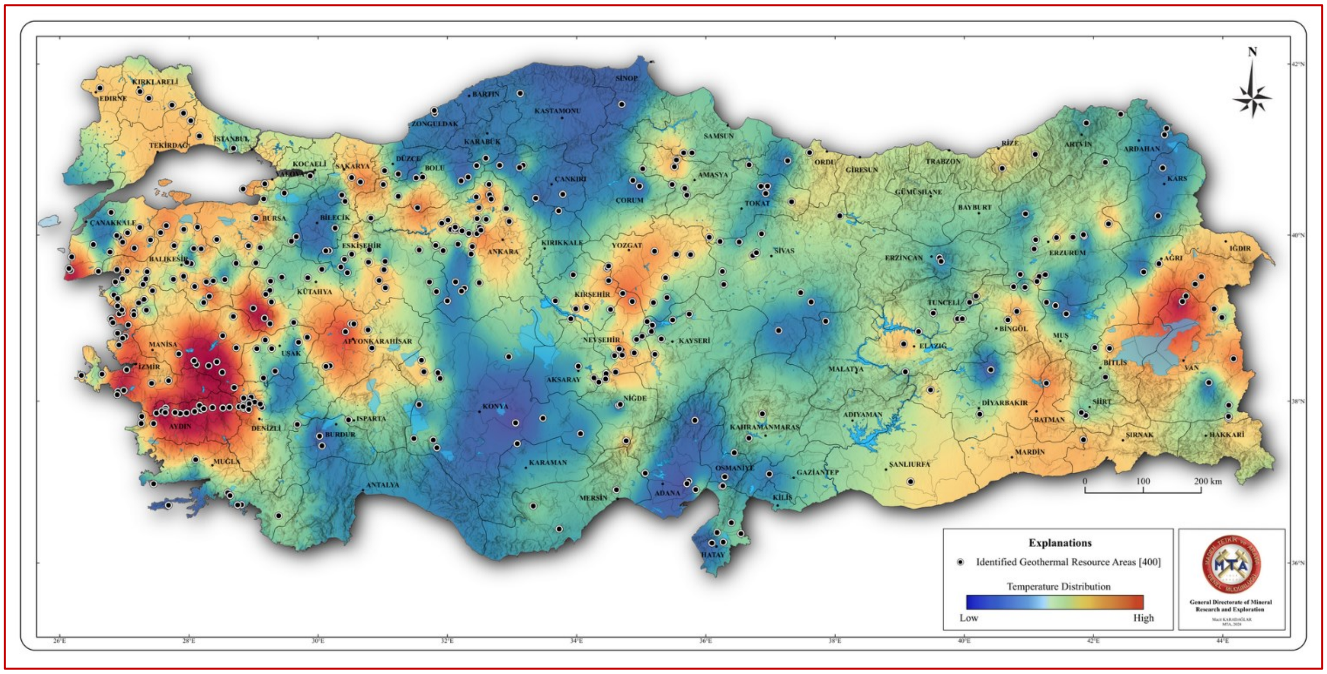

Figure 1: Identified Geothermal Resource Area in Turkiye (MTA, 2024)

As in the rest of the world, in Turkiye, geothermal energy is used in various industries, primarily for electricity generation, heating, and therapeutic purposes, depending on its temperature. High-temperature geothermal fluid can be integrated and utilized in many areas (Figure 2).

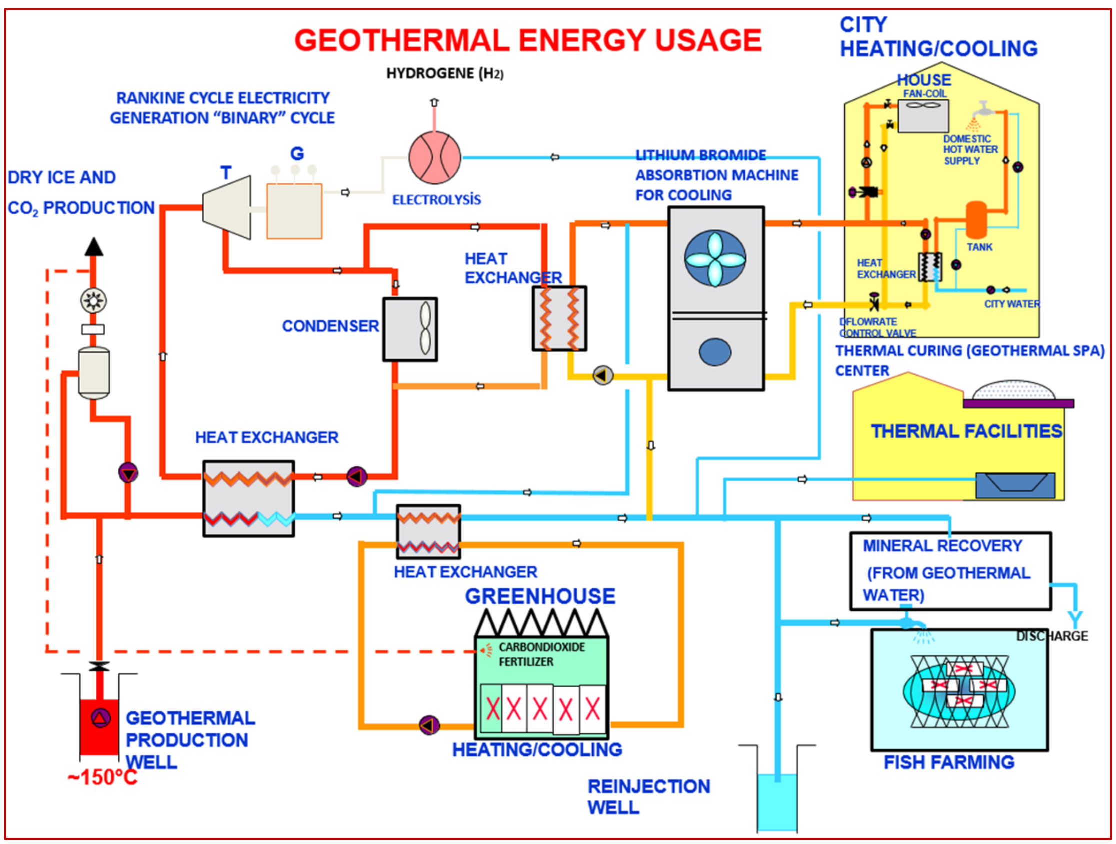

Figure 2: Direct and indirect usage of geothermal energy resources (Mertoglu, 2011)

1.2. Hydrothermal Geothermal Systems in Turkiye

The MTA (Mineral Research and Exploration) study in 1960 is considered the beginning of geothermal energy research in Turkiye. Since then, areas containing fluids suitable for various purposes, such as energy production and direct use, have been discovered. The period between 1970 and 2000 is primarily known for the discovery of high-temperature reservoirs (Akkuş, 2017).

The Western Anatolia Extensional Neotectonic Zone is known for its geothermal resources and numerous hot springs. The geothermal fields around Manisa, Denizli, Aydın, İzmir, and Muğla constitute the main resources of this region (Figure 3).

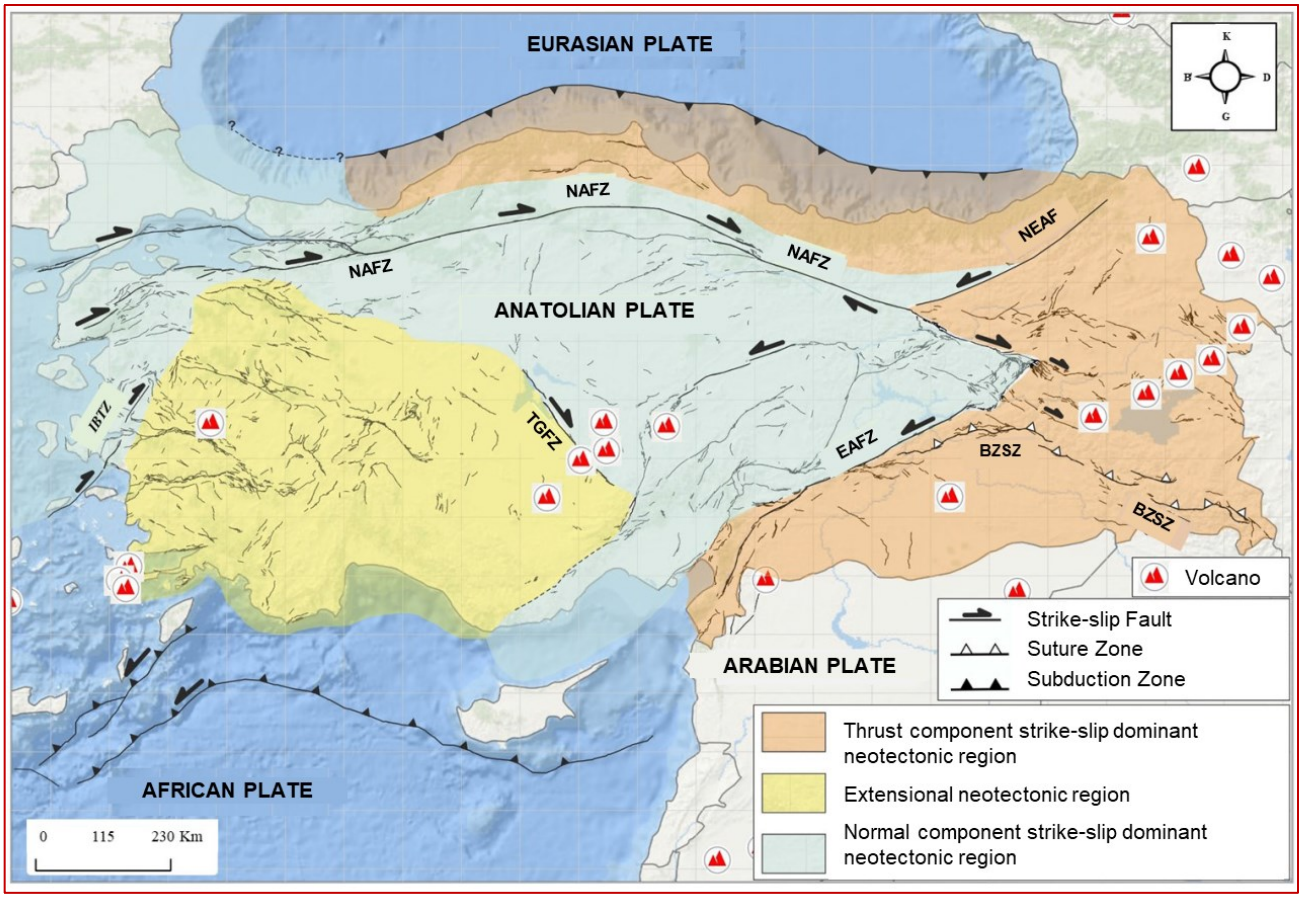

Figure 3: The neotectonic regions and structural characteristics of the Anatolian Plate (modified from Şener, M. F., Uzelli, T., Akkuş, İ., Mertoğlu, O., Baba, A. 2023).

The geothermal resources of the İzmir Gulf and to the north are formed under the control of both extensional tectonic regimes and strike-slip faults (İZKA, 2022). In some areas such as Manisa (Kula), Afyon, and Çanakkale, the geothermal system is also influenced by volcanism and magmatism. Additionally, geothermal systems in Çanakkale, Balıkesir, Bursa, Bolu, and Yalova are located within the neotectonic region.

Geothermal areas in the Central Anatolia Region are also influenced by the North Anatolian Fault Zone (NAFZ) to the north, the East Anatolian Fault Zone (EAFZ) to the east, and the Tuz Gölü Fault Zone (TGFZ) to the west. Furthermore, Tertiary granite intrusions, local and regional block faulting, and Pliocene volcanism form the geothermal systems (Şener et al., 2017). The geothermal fields in Ankara, Niğde, Yozgat, Nevşehir, Kırşehir, Aksaray, and Sivas are the most important geothermal resources in this region (Şener, 2019).

A dominant strike-slip neotectonic regime controls the geothermal systems along the NAFZ, extending from Bingöl-Karlıova to areas surrounding the EAFZ. Geothermal fields in Hatay, Mersin, Kahramanmaraş, Osmaniye, Elazığ, Bingöl, and Muş are primarily controlled by the EAFZ and its segments. Additionally, the Bitlis-Zagros Suture Zone (BZSZ) and young volcanism areas have enriched the Southeast regarding geothermal resources and other geological events (Baba et al., 2021; Şener et al., 2021; Uzelli et l., 2021)..

Many tectonic, volcanic, and magmatic factors, such as calderas, domes, tension fractures, and magma chambers, are located in the eastern part of the Anatolian Plate and are bounded by the control of the BZC and EAFZ. Important areas formed under compressional tectonic regimes include Erzurum, Kars, Ağrı, Van, Bitlis, and Muş (Uzelli et al., 2021).

In the Southeastern Anatolia Region, south of the BZSZ, the Karacadağ volcanism and compressional tectonics have led to the formation of critical geothermal fields in Gaziantep, Adıyaman, Diyarbakır, Şırnak, Batman, and Siirt. Since the Southeastern Anatolia Region is an oil-producing area, it has been studied by many researchers. Several oil wells drilled around Adıyaman, Diyarbakır, and Batman have encountered medium-high temperature geothermal fluids. This study has identified that the currently unused and undiscovered wells in the region are highly suitable and vital resources for geothermal applications. It is emphasized that they should be reintegrated into the region's economy in the future (Baba et al., 2019).

2. GEOTHERMAL EXPLORATION

The purpose of exploration is to locate areas where geothermal resources may be present, to establish the quality and quantity of those resources, and to investigate the viability of extracting the resource. Exploration methods include a broad range of disciplines including geology, geophysics, geochemistry, hydrogeology and engineering. Exploration involves not only identifying hot geothermal bodies, but also low-density, cost effective regions to drill and already constituted plumbing systems inherent within the subsurface. This information allows for higher success rates in geothermal plant production as well as lower drilling costs.

In exploration, models related to regional geological evolution, regional seismic, gravity, and magnetic data, data on the seismicity of the region, the hydrogeology and chemical data of the hot and cold waters in the area, remote sensing findings, and, if available, data on heat flow, etc., should be consulted. This information infrastructure directs explorers to conduct a detailed investigation of areas where surface indicators are observed and the surrounding regions. Once such an investigation area is identified, a detailed work program can be implemented.

Each country may have different exploration strategies depending on its geological structure, level of development, the amount of resources allocated for exploration, skilled workforce, and accumulated experience. Undoubtedly, the exploration strategies of each country are different. In Turkiye, geothermal exploration is primarily focused on extracting hot water from fractures and cracks within hot metamorphic units that form the foundation of sedimentary basins in most fields, depending on the geology.

There are a range of activities that may be undertaken as part of an exploration program. These activities depend on a number of factors, including the nature of the mineral being sought and the geology of the area.

2.1. Geological Studies

Geological studies begin with surface geology work to identify the geological units, tectonic, and volcanic features, if present, in the relevant license areas. Indicators such as hot water sources, fumaroles, and alteration are added to maps. Parameters such as temperature, flow rate, and conductivity are measured for surface data. Without understanding the geology of the explored area, every step taken will remain as mere assumptions. The three-dimensional geological model that emerges from the studies will be very useful in evaluating the geochemical and geophysical characteristics of the geothermal system. Such 2D or 3D models approach the most accurate results when the detailed geological map is integrated with the geochemical and geophysical data collected from both the surface and underground. The creation of a reliable model is possible through detailed surface mapping, structural analysis of faults, evaluation of satellite images, analysis and distribution of alteration minerals, age determination of geothermal indicators, and consideration of well data if available. The application of geological studies provides a perspective on the behavior and evolution of active faults controlling the geothermal system. The distribution of permeability, fluid flow paths, and fault distribution are also among the evaluated parameters. The studies to be conducted and the data to be obtained include:

a) Lithological properties of the units, characteristics of magmatism and volcanism,
   - Faults (nature, extension, displacement, etc.),
   - Cracks,
   - Fissures and fractures,
   - Folds,
   - Structural features related to unconformities, including information for geological map work at a scale of 1/25,000 or larger.

b) Geothermal Geology Studies
   - The geological environment in which the geothermal source is formed,
   - Information on the heat source (magmatism and volcanic activity),
   - Heat flow,
   - Reservoir rock/reservoir zone,
   - Cap rock,
   - Heat-carrying fluid,
   - Hydrothermal indicators.

c) Geochemistry, Hydrogeochemistry, and Hydrothermal Alteration Studies
   - Chemical analyses (total dissolved solids, anion, cation, etc.),
   - Studies related to bacteriological properties (for uses that may affect living organisms)

d) Hydrogeology Studies,
- Evaluation of hydrological data,
- Hydrogeological properties of the units,
- Temperature, flow rate, etc., measurement studies on cold and hot water sources and wells,
- If available, relationships between hot and cold waters,
- Surface discharge forms,
- Studies to identify aquifer units

2.2. Geophysical Studies

One of the most important steps in geothermal exploration is geophysical surveys. The purpose of geophysical exploration is to reveal the geological structure beneath the surface, visualize the deep units and tectonic structure, and identify deep structures that represent the permeability in the geothermal system.

Different geophysical surveys measure various physical properties of Earth, and have different applications and equipment. Geophysical surveys can be conducted from the air, at surface, and down drillholes. They include: The integration of geophysical techniques such as magnetotelluric, gravity, seismic, and magnetic methods is used to determine the heat source, permeable structures, fluid movement, and drilling targets.

a) Electromagnetic Surveys

a. Electromagnetic surveys induce an electromagnetic field and measure the 3 dimensional variations in conductivity within the near-surface soil and rock. Conductive units can be studied to locate metallic minerals, and to understand groundwater and salinity. Ground readings are taken by a small crew who shift a ground array of transmission and receiver cables. This method is an indispensable method for geothermal exploration. They are most often used in Petroleum and metallic mineral exploration.

b) Seismic Surveys

a. Seismic surveys measure variations in reflected ground vibrations as they pass through the earth. The surveys use an energy source to create the high frequency vibrations, which can be truck-mounted vibrating weights or a simple hammer hit, depending on the scale of the survey. Small sensors that are linked by cables and spread either side of the source detect and relay the vibrations as they return to the surface. Seismic surveys provide information about rocks down to depths of several kilometres and are particularly suited to flat-lying sedimentary basins. They are most often used in petroleum, Geothermal and coal exploration.

c) Magnetic Surveys

a. Magnetic surveys measure the variations of Earth's magnetic field due to the presence of magnetic minerals. Subtle variations in the abundance of magnetic minerals are used to interpret rock types and can assist in identifying resources.

b. These surveys are typically undertaken by a geophysical technician on foot carrying a magnetometer and a sensor on a pole. They are most often used in Geothermal and metallic mineral exploration.surveys measure variations in reflected ground vibrations as they pass through the earth. The surveys use an energy source to create the high frequency vibrations, which can be truck-mounted vibrating weights or a simple hammer hit, depending on the scale of the survey. Small sensors that are linked by cables and spread either side of the source detect and relay the vibrations as they return to the surface. Seismic surveys provide information about rocks down to depths of several kilometres and are particularly suited to flat-lying sedimentary basins. They are most often used in Geothermal, petroleum and coal exploration.

d) Gravity Surveys

a. The gravity field is measured with a gravimeter to determine variations in rock density in Earth's crust. Ground gravity surveys require a geophysical technician to take gravity measurements at set intervals of distance and record the precise height at each location. Access to the recording sites can be by vehicle or helicopter, depending upon remoteness. They are used in Seothermal, Petroleum, mineral and energy exploration.

2.3. Drilling

Drilling is often conducted as part of an exploration program to obtain detailed information about the rocks below the ground surface. The drilling method used depends on the type of rocks and information sought. The degree of disturbance around the drillhole varies with each method, however, strict environmental safeguards ensure all drill sites are rehabilitated after the completion of drilling.

After drilling, information about the region's geothermal potential, temperature conditions, and subsurface model is obtained.

2.4. Geothermal Exploration in Turkiye

As mentioned above, the most important part of geothermal exploration is the accurate modeling of the underground and the discovery of potential through drilling. In this context, exploration activities are being carried out in many concessions in Turkiye. Due to Turkiye's geological and tectonic structure, almost all potential concessions are designed to extract hot water from marble reservoirs formed by the fracturing of the basement beneath sedimentary units along faults. Hot water circulates and warms up through fracture porosity in hot metamorphic units, and with the correct drilling, this hot water is extracted and used for energy production.

Therefore, in finding the correct drilling location, the exploration methods mentioned above must be applied in accordance with the geology. Initially, in the process that begins with field geology, a detailed geological understanding of the region must be developed (Figure-3). This detailed geological study also reveals the tectonic structure of the region.

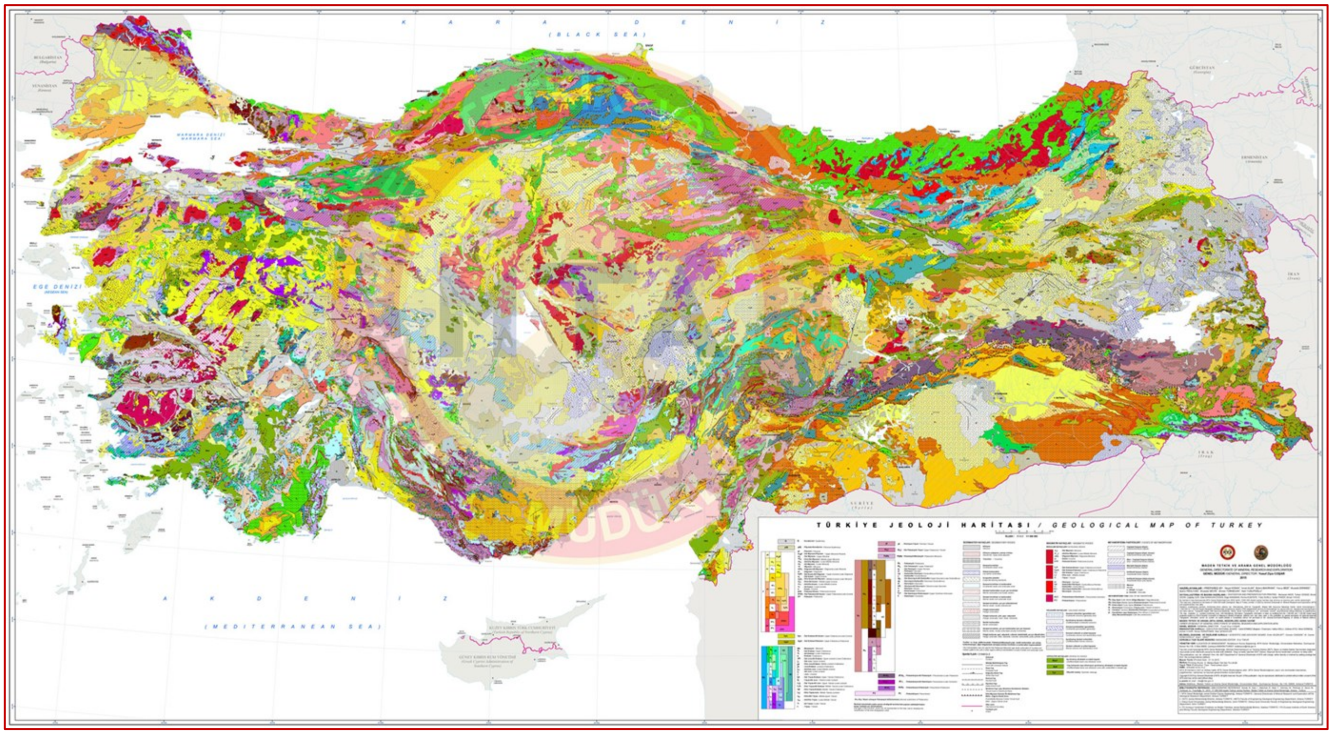

Figure 3: Geology map of Turkiye (MTA)

The presence of young volcanic activities in the region is crucial. These young activities indicate areas where heat sources are located (Figure 4). Therefore, in detailed field geology studies, mapping these units and conducting age dating on the collected samples is of great importance. Volcanic rocks, first and foremost, provide geothermal potential because they transport massive heat to the upper levels of the crust during their formation. Moreover, particularly stratovolcanoes, with their alternating products of varying permeability and complex internal structures, provide favorable environments for the establishment of geothermal systems.

During field geology studies, it is also essential to identify faults, determine their ages, and assess surface samples, metamorphic units, their thicknesses, bedding inclinations, and especially the presence of marbles, which are seen as reservoir units in many production concessions. The presence of large faults, through which fluids can descend and rise quickly, is crucial. Especially zones where faults formed in different periods and with different orientations intersect provide significant ease to fluid circulation due to the overlapping fractures of multiple stages. Sometimes, one of these fracture systems may not be traceable at the surface and may remain hidden. However, regional geological knowledge, and especially geophysical measurements, can predict their existence, orientation, and locations.

Although it is known that marbles do not have reservoir properties due to their metamorphic nature, they hold significant importance in the formation of geothermal systems, especially in our country. It is known that metamorphic belts have heat fluxes up to twice as high compared to other regions. Particularly, relatively young metamorphic environments, such as those formed during the Tertiary, are characterized by high heat flux. Moreover, after metamorphism, these masses rise rapidly and are consumed by erosion and shear faults, causing deeper, hotter sections to approach the surface without cooling sufficiently, resulting in an increased heat gradient. As a result, high temperatures can be reached at relatively shallow depths in these types of masses. Although these rock environments are initially not very permeable, the shear fault zones accompanying the rise of the massif and the graben faults that form along them acquire very high secondary permeability, allowing the development of geothermal systems. Furthermore, most metamorphic rocks are affected in such a way that they gain permeability rather than becoming impermeable due to hydrothermal alterations. This is one of the reasons why geothermal systems are more commonly encountered in metamorphic masses.

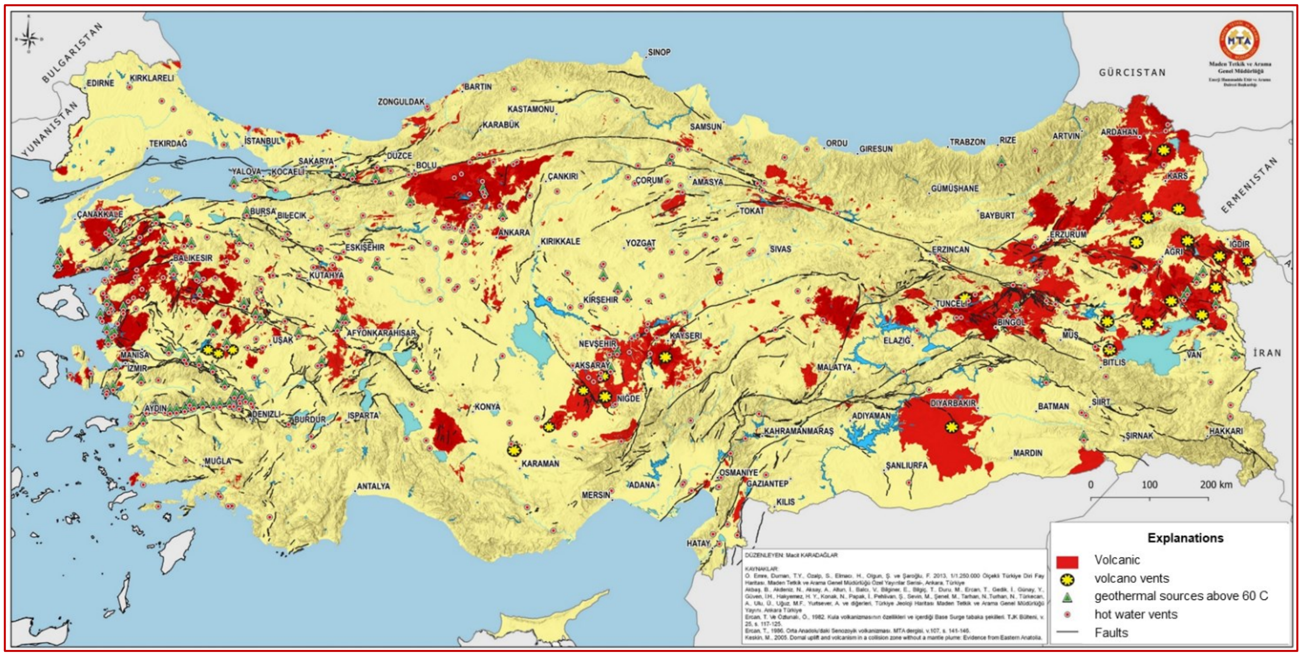

Figure 4: Geothermal resources and volcanic areas in Turkiye (MTA)

Prior to drilling, geological studies conducted in the concession areas are used to determine the appropriate geophysical methods, as mentioned above. Seismic reflection, which is an essential method, especially in deep exploration, is performed if the geology is suitable.

As is well known, the seismic reflection method is based on acoustic impedance. Therefore, reflections occur depending on the differences in velocity and density of geological units. It is one of the most reliable methods in the world for revealing the geological structure of the underground. Before drilling, it provides very reliable results in determining the metamorphic basement level and identifying the faults that cut through it (Figure-5).

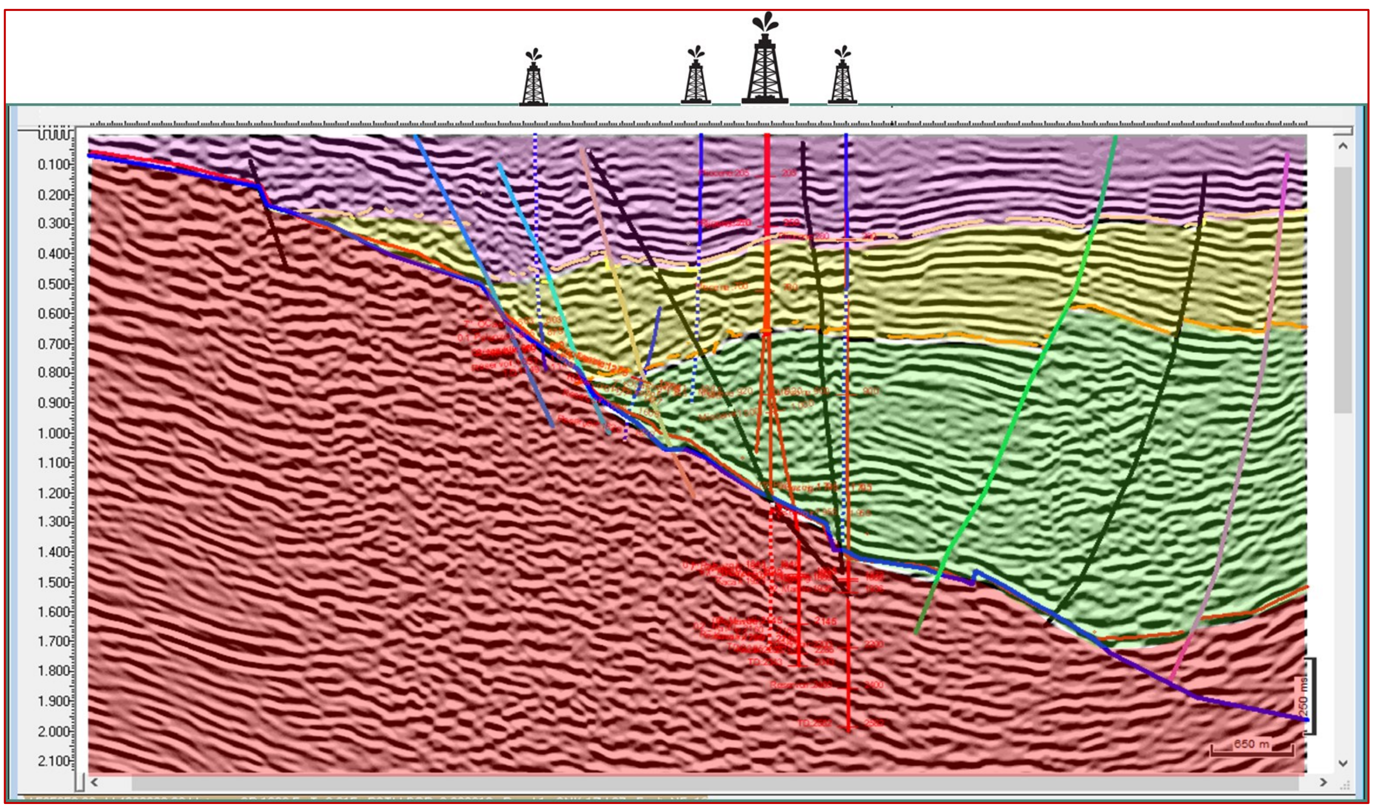

Figure 5: Seismic reflection method in the Geothermal Area

The Magnetotelluric (MT) method is the most widely used geophysical technique for geothermal resource exploration worldwide. Depending on the research objectives, it is used to investigate geological structures ranging from a few meters to depths of up to 50 km. Additionally, compared to resistivity methods, it offers ease of application in rugged terrains. As a natural electromagnetic method, the MT (Magnetotelluric) method combines data collected from the field with subsurface two- or three-dimensional geological modeling, along with geological and seismic reflection studies to reveal subsurface characteristics (Figure-6).

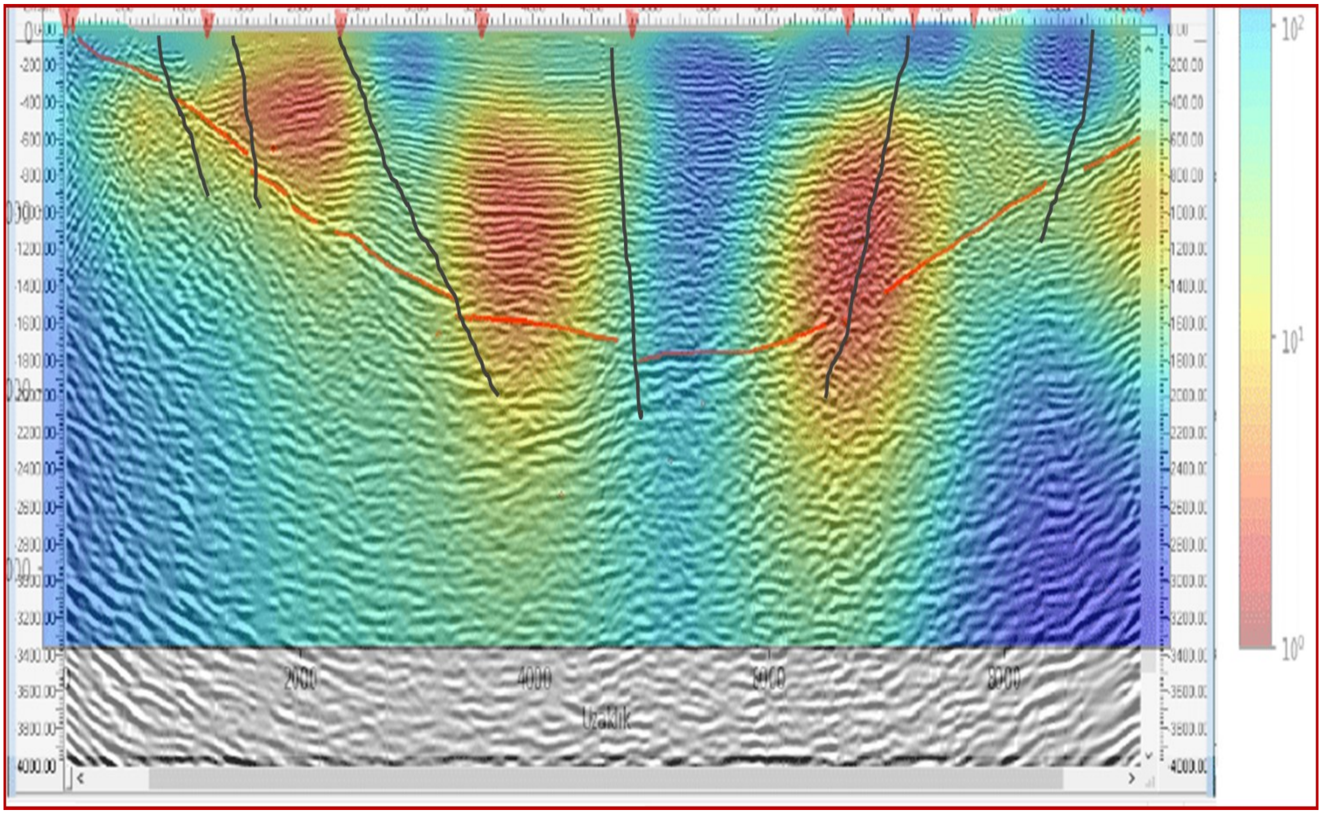

Figure 6: Seismic reflection & MT method in the Geothermal Area

Geological models identified in the concession area are supported by gravity-magnetic measurements. In the gravity-magnetic method, the presence of hidden volcanic intrusions, the distribution of volcanic rocks underground, and other geological events can be easily observed. The discovery of these volcanic intrusions, which are also the source of heat, is crucial in the concession area.

In gravity measurements, both the Bouguer anomaly map and first derivative maps provide accurate information about the potential of the concession. These data give insights into depth, volcanic units and intrusions, as well as the bedrock depth (Figure-7, Figure-8).

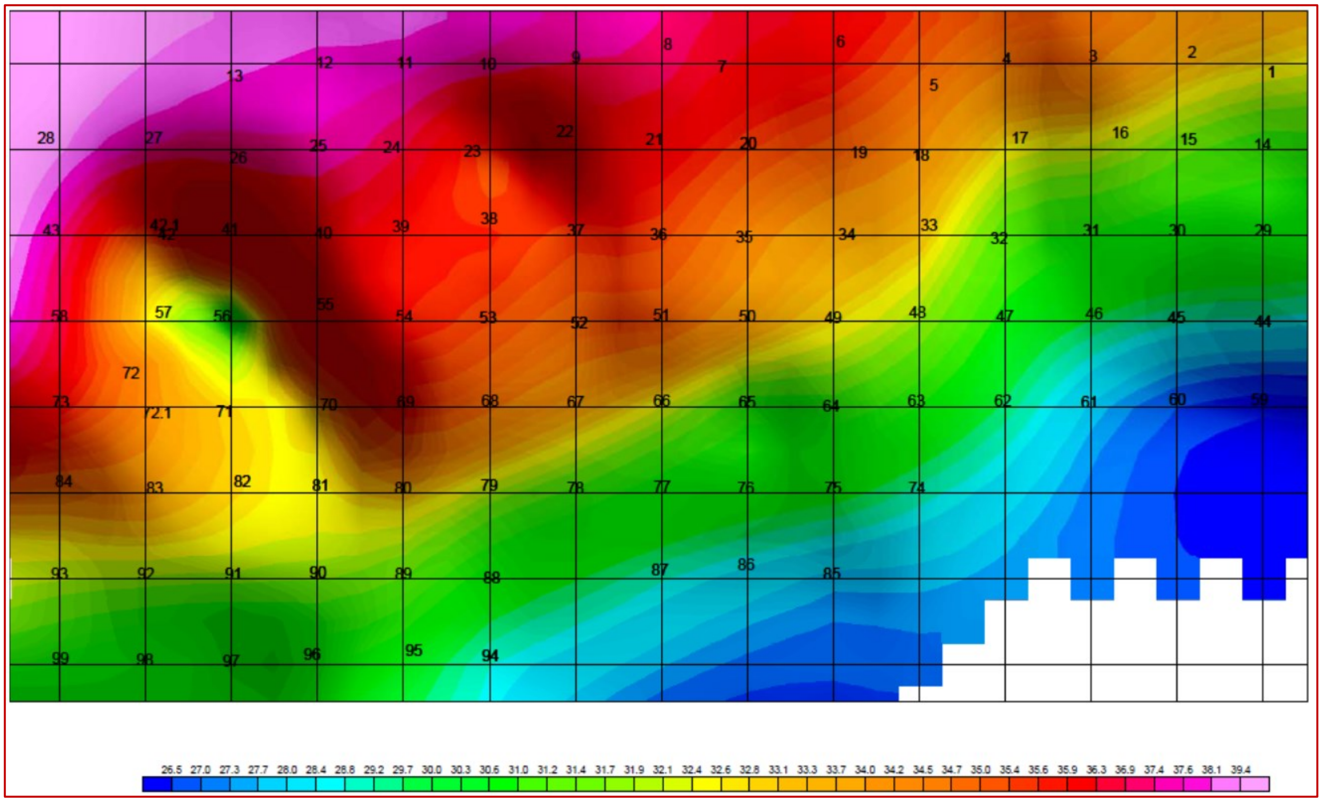

Figure 7: Bouguer Anomaly Map in the Geothermal Area

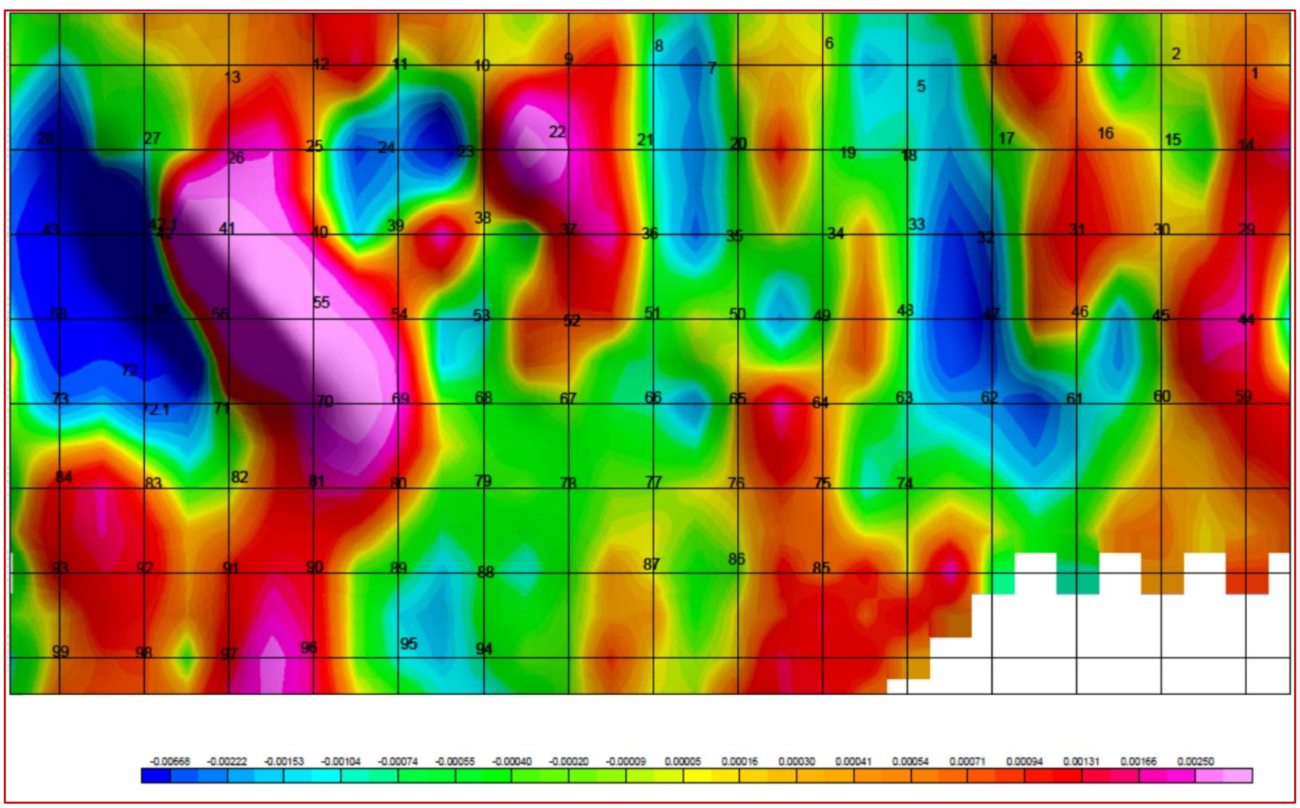

Figure 8: First Horizontal Derivative Map in the Geothermal Area

Once the geological and geophysical studies are completed and the underground model is developed, exploration drilling begins. Exploration drilling is also of great importance for the further development of the underground model. It is crucial that engineers present at the site closely monitor the samples extracted from the well and drilling parameters, especially when the drilling intersects faults within the metamorphic units. When designing the casing for drilling, perforated casings are placed in the areas where these faults are located. Therefore, it is important not to bypass and leave behind the zone with developed fracture porosity behind the cement.

Another important issue is the tests conducted in the wells and well completion operations. Acid treatments in wells, in particular, are essential for improving the efficiency of both production and re-injection wells. Since marble units react very well to HCL acid, it provides significant benefits in opening fractures. Of course, in all of these operations, nature and environmental factors are always prioritized.

When determining the locations of production wells, the locations of re-injection wells are also planned simultaneously. This planning is done together to avoid the cooling of production wells due to re-injection. To achieve this, appropriate depths and distances for both production and re-injection wells should be selected (Figure-9). While determining these distances, tracer tests are especially helpful. These tests provide crucial information such as which production well is fed by which re-injection well and the temperatures at which water injected from a well travels to other wells. Therefore, these data help prevent production declines at geothermal power plants, ensuring the continuity of geothermal energy as a renewable resource.

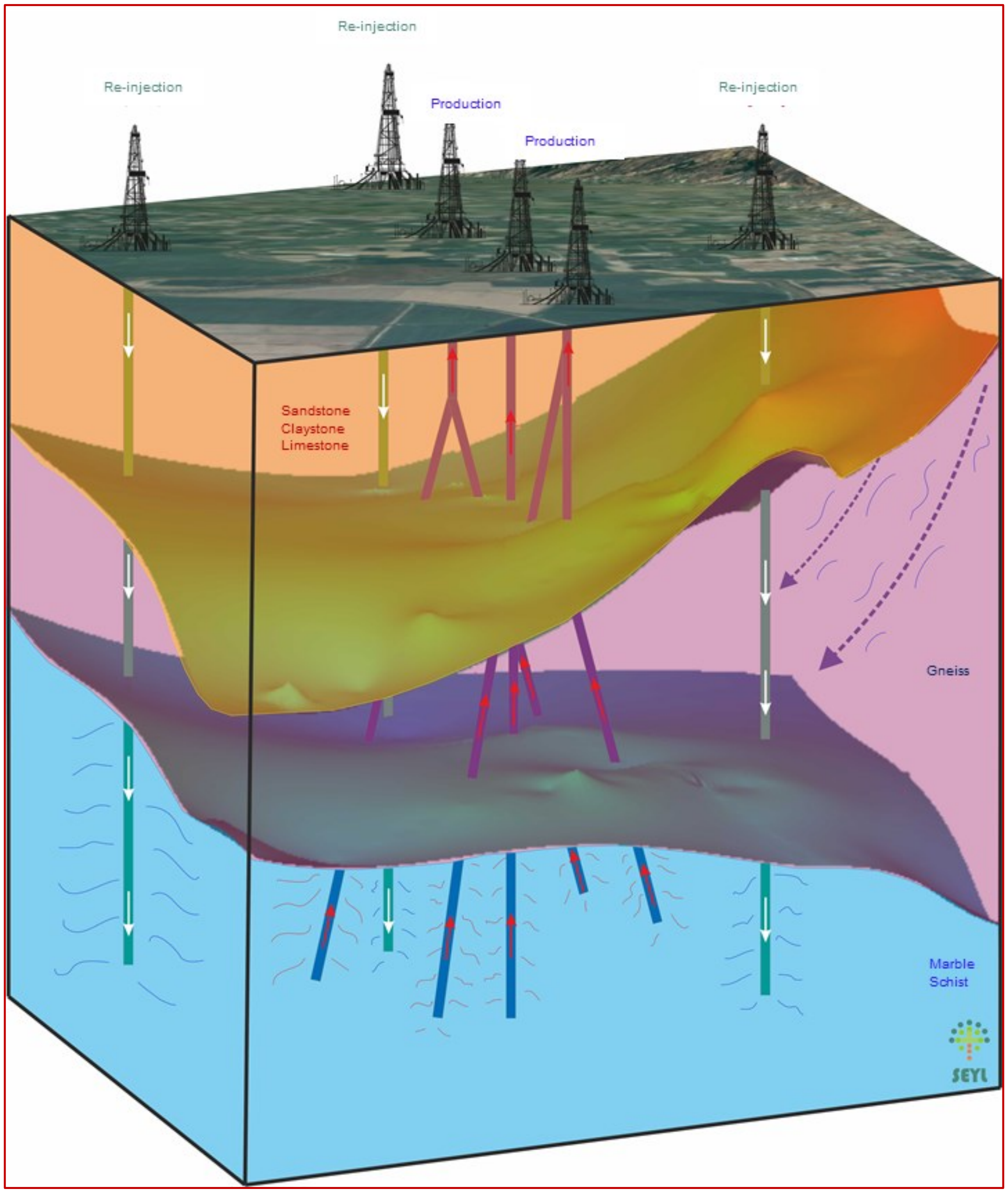

Figure 9: Wells desing in the Geothermal Area

3. CONCLUSIONS

Turkiye is a country with significant potential in geothermal energy. This energy is used in many fields, such as electricity generation, greenhouse farming, heating, and more. However, much of Turkiye's geothermal energy potential remains unexplored, offering significant opportunities for the future.

The exploration phase, which is the first and most important step in uncovering this potential, requires the correct application of geological, geophysical, and drilling techniques to use it effectively. These techniques play a critical role in the discovery of geothermal resources, their sustainable use, and local energy production.

Geological Research and Its Strategic Importance:

Geology is a fundamental scientific field in the exploration of geothermal energy. Geological studies conducted to determine Turkiye's geothermal energy potential help accurately map the structure of the earth's crust and the location of hydrothermal resources. The volcanic areas and active fault lines in western Turkiye make it essential to conduct these geological analyses correctly. Geological maps and underground water channels help determine the potential of geothermal reserves and assist in selecting appropriate drilling locations.

The Role of Geophysical Methods:

Geophysical surveys play a significant role in detecting underground hot water and steam reserves. In Turkiye, geophysical methods are used to understand underground temperatures, fluid movement, and the structural characteristics of reservoirs. These methods allow for the mapping of deep underground resources that are not visible at the surface. Specifically, gravity, magnetic, and seismic methods are widely used in Turkiye to identify geothermal fields. These techniques provide essential preliminary data to guide drilling activities.

Analyses conducted using geophysical methods provide critical data for the efficient use of geothermal resources. Additionally, these methods help minimize drilling costs and narrow down potential exploration areas, allowing for a more targeted exploration process.

The Prominence of Drilling Techniques:

Drilling is the most important method for verifying the accuracy of geothermal resources and ensuring their efficient use. Turkiye has made significant advancements in geothermal drilling activities. Through drilling, the depth, temperature, and flow rates of underground hot water and steam reserves are measured, allowing for the identification of suitable areas for geothermal energy production.

Proper drilling practices contribute to minimizing environmental impacts and improving energy efficiency. In Turkiye's geothermal fields, the correct application of drilling techniques is not only essential for energy production but also for ensuring the sustainability of these resources. Deep geothermal drilling is crucial for long-term energy production and environmentally friendly solutions. Therefore, the development of drilling technologies and the enhancement of deep drilling efficiency is a strategic priority for Turkiye.

Future Outlook:

In the future, the growth of Turkiye's geothermal energy sector will rely on innovative technologies in geology, geophysics, and drilling. It is expected that deeper drilling will be conducted, underground energy storage systems will be developed, and environmentally friendly drilling methods will be applied in geothermal exploration and production strategies. Particularly, new drilling technologies are expected to play a larger role in Turkiye's energy strategy, especially concerning the use of deep geothermal energy and the efficiency of geothermal power plants.

In conclusion, to maximize Turkiye's geothermal energy potential, the holistic integration of geological, geophysical, and drilling methods is essential. The combined use of these disciplines will increase efficiency in geothermal energy production, ensure the sustainable use of resources, and shape Turkiye's energy future. As research and investments in geothermal energy continue to grow in the coming years, Turkiye's energy supply security will strengthen, and the use of geothermal resources will expand to cover a broader range of areas.

REFERENCES

Akkuş, I., Akıllı, H., Ceyhan, S., Dilemre, A., Tekin, Z.: Türkiye Jeotermal Kaynaklar Envanteri. Maden Tetkik ve Arama Genel Müdürlüğü Envanter Serisi, 201 (2005), Ankara.

Akkuş, İ.: Neden jeotermal enerji? Türkiye için önemi, hedefler ve beklentiler. Mavi Gezegen Dergisi, 23, (2017), 25-39.

Arslan, S., Darıcı, M. and Karahan Ç.: Türkiye'nin Jeotermal Enerji Potansiyeli, Jeotermal Enerji Semineri, Turkiye (2001), 21

Baba, A., Şaroğlu, F., Akkuş, I., Özel, N., Yeşilnacar, M. İ., Nalbantçılar, M. T., Demir, M. M., Gökçen, G., Arslan, Ş., Dursun, N., Uzelli, T., Yazdani, H.: Geological and hydrogeochemical properties of geothermal systems in the southeastern region of Türkiye. Geothermics 78 (2019), 255-271.

Baba, A., Uzelli, T., Sözbilir, H.: Distribution of geothermal arsenic in relation to geothermal play types: A global review and case study from the Anatolian plate (Turkiye). Journal of Hazardous Materials 414 (2021), 125510.

Balcı, A.: Enerji Güvenliğinde Türkiye'nin Rolü Ve Yenilenebilir Enerji Kaynaklari, Adiyaman Üniversitesi Sosyal Bilimler Enstitüsü Dergisi, 2023, 200-233

Bozkurt, E. 2: Neotectonics of Türkiye-a synthesis. Geodinamica Acta 14 (2001), 3-30.

Çemen, I., Goncuoglu, M.C., Erler, A., Kozlu, H., Perincek, D.: Indentation tectonicsand associated lateral extrusion in east, southeast and central Anatolia. Elsevier (1993), A116

Çemen, I.: Extensional tectonics in the Basin and Range the Aegean, and Western Anatolia: Introduction. GeologicalSociety of America Abstracts 25 (2010), A116

Eyidoğan, H. and jackson, J.A.: A seismological study of normal faulting in the Demirci, Alaşehir and Gediz earthquakes of 196970

in Western Turkiye : implications fort he nature and geometry of deformation in the continental crust, Jour. Of Geophys. Res., 81 (1985), 569607

Koçyiğit, A., Özacar, A. 2003. Extensional neotectonic regime through the NE edge of the Outer Isparta Angle, SW Türkiye: New field and seismic data. Turkish Journal of Earth Science 12 (2003), 67–90.

Mertoğlu, O., Simsek, S.,Basarir, N.,and Paksoy, H.: Geothermal Energy Use, Country Update for Turkiye, European Geothermal Congress, Netherlands (2019)

Mutlu, H., Güleç, N.: Hydrogeochemical outline of thermal waters and geothermometry applications in Anatolia (Turkiye). Journal of Volcanology and Geothermal Research 85 (1998), 495–515.

Özgür, N.: Geochemical signature of the Kızıldere geothermal field, Western Anatolia, Turkiye. International Geology Review 44(2) (2002), 153 – 163.

Pasvanoğlu, S.: Geochemistry and conceptual model of thermal waters from Erciş – Zilan, Geothermics 86 (2020), 101803.

Seyitoglu, G., Scott, B.C.: The cause of N-S extensional tectonics in western Turkiye:Tectonic escape vs back-arc spreading vs orogenic collapse. J. Geodyn. 22 (1996), 145–153.

Şener, M. F., Baba, A. : Geochemical and hydrogeochemical characteristics and evolution of Kozaklı geothermal fluids, Central Anatolia, Turkiye, Geothermics 80 (2019), 69-77.

Şener, M. F., Uzelli, T., Akkuş, İ., Mertoğlu, O., Baba, A.: The potential, utilization, and development of geothermal energy in Türkiye. Bulletin of the Mineral Research and Exploration 171, (2023), 69-90.

Şengör, A. M. C., Dyer, J. M. N.: Neotectonic provinces of the Tethyan orogenic belt of the eastern Mediterranean; variations in tectonic style and magmatism in a collision zone. Eos, Transactions, American Geophysical Union 60(1979), 390.

Şengor, A.M.C., Yilmaz, Y.: Tethyan evolution of Turkiye: a plate tectonic approach.Tectonophysics 75 (1981), 181–241.

Şengor, A.M.C., Gorur, N., Saroglu, F.: Strike-slip faulting and related basinformation in zones of tectonic escape; Turkiye as a case study. Spec. Pub. Soc. Econ.Paleo. Mineral 37 (1985), 227–264

Şimşek, Ş.: Geothermal model of Denizli, Sarayköy-Buldan area. Geothermics 14(2-3) (1985), 393 – 417.

Yılmazer, S.: Ege Bölgesi'ndeki bazı sıcak su kaynaklarının hidrojeoloji ve jeokimyasal incelemeleri (in Turkish). Master Tezi, Dokuz Eylül Üniversitesi, Fen Bilimleri Enstitüsü (1984), İzmir.