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An Example of Electrical Resistivity Tomography Monitoring in Geothermal Sites: Balçova-Izmir Case Study

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Abstract

In this study, the shallow fluid flow changes according to climatic effects on a geothermal site were investigated using electrical resistivity tomography method (ERT). Monitoring studies achieved by time lapse electrical resistivity tomography, which were the key studies to observe the subsurface resistivity distribution of the investigated lines. The studies were performed at Balçova geothermal site, in the city of İzmir-Turkey, which has been operating in house heating since 1990's. The main source of the groundwater in the area is rainfall. Our ERT monitoring studies were performed between March 2010 and February 2011. We aimed to obtain information on the shallow conductive layers that allow the transport of the fluids. Therefore, the investigations which will be succeeded on shallow aquifer system near the boreholes could be important to characterize the subsurface while the geothermal operations. In conclusion, monitoring studies showed that subsurface characteristics were importantly changed according to borehole operation and seasonality rainfall. Results were also supported with the synthetic forward modeling studies.

Introduction

The geophysical surveys have commonly been applied in the investigation of geothermal sites since 1960's. These surveys have an important role on the determination of reservoir characteristic and geological properties of the geothermal system. One of the objectives of geophysical surveys is to determine the location of faults carrying hot waters, reservoir characteristic, various physical changes in the system. On the basis of these results, the appropriate drillsite locations are determined and the time-related physical changes around the drillsites are controlled. In recent years, the combinations of geophysical methods have been utilized in the exploration of geothermal systems in the world.

Important information about a geothermal site is obtained by different geophysical investigation techniques such as electrical resistivity, self-potential, electromagnetic, magnetics, seismic, etc. Electrical and electromagnetic prospection of geophysics is the most powerful research techniques in geothermal investigations. Using these techniques, faults and fissures, reservoir characteristics, altered and mineralized zones, the properties of geothermal fluids, the magma chamber locations and entire tectonic structures could be determined.

Recently, geophysical monitoring studies are of great importance in near surface geophysical applications. Many investigators gathered information about the temporal subsurface changes by using geophysical monitoring studies. These are very useful to define the permafrost environment, landslide, engineering, geothermal, hydrology, contamination and CO_2 monitoring investigations. In near surface applications of geophysics, the electrical resistivity tomography (ERT) monitoring studies have been progressively used recently. However, the geothermal application of ERT monitoring is rarely seen. This study aims to manifest the importance of ERT monitoring in near surface investigations of geothermal sites. Therefore we investigated a geothermal site that contains the shallow fluid flow by the ERT technique. Time lapse inversion was a key study to monitor the resistivity distribution under the measuring lines. In the modeling stage, inversion facilities were investigated by the simulation of a synthetic injection model. In the time lapse inversion process, the initial model approach was used to constrain the later time data sets.

Geothermal in Turkey

Neotectonic activity in Anatolia, Turkey, is mostly related to the northerly movement of the Arabian Plate towards the Eurasian Plate. The Anatolian Plate comprises many small fragments between seismically active fracture zones with numerous geothermal hot springs in the active areas (Figure 1a). On the basis of this tectonic framework, Turkey can be divided into four main geothermal regions (along the magmatic belts of western, eastern and central Anatolia and along the north Anatolian fault zone). The Büyük Menderes and Gediz grabens of western Anatolia tend to be important features from the geothermal viewpoint, with many hot water springs located along the fault zones of these grabens (DRAHOR and BERGE, 2006).

Turkey has extensive geothermal resources that have been utilized for heating of residences, power plant, greenhouse heating, and for spas. Since 2005 several new plants have been constructed. Four new binary units of about 8 MW each have been installed, three for exploiting medium enthalpy reservoir (two by Dora – MB group, in Aydın-Salavatlı area, and one by Tuzla – Dardanel Energy, at Çanakkale and one using the separated brine (140 ◦C)) from the Kızıldere plant, before its use for district heating, operated by Bereket. A new 47 MW double flash unit was commissioned in 2009 at Germencik with the possibility of a second 47 MW unit. It is one of the largest plants in Europe, just behind the Italian standard 60 MW units. Several additional areas have been allocated to private companies for further surface and deep exploration. Since 2005 an increase of about 70 MW in installed capacity has been achieved. The target for 2015 is about 200 MW. The geothermal potential of the country is estimated to be about 30,000 MW (MERTOĞLU et al., 2003; SERPEN et al., 2009).

Balçova Geothermal Site and Geology

ERT monitoring studies were performed on an important geothermal site found in the southern part of İzmir Bay. This area named Balçova geothermal system is about 20 km west of city of İzmir, and operated in heating by Balçova Termal Ltd since 1990's. Many injection and re-injection holes were drilled in the area during the operational processes. Approximately 50 wells have been drilled by the General Directorate of Mineral Research and Exploration of Turkey (MTA) both for developing and monitoring geothermal energy production (Figure 1b). The depths of the wells vary from 100 m (shallow) to more than 2 km (deep). The first geophysical surveys in Turkey were carried out in this area in the mid of 1960's. These studies consist of electrical resistivity, self-potential (SP) and drilling. Later on, large scale SP studies (ERCAN et al., 1986) and resistivity and magnetotelluric soundings (MTA, 2001) were also applied.

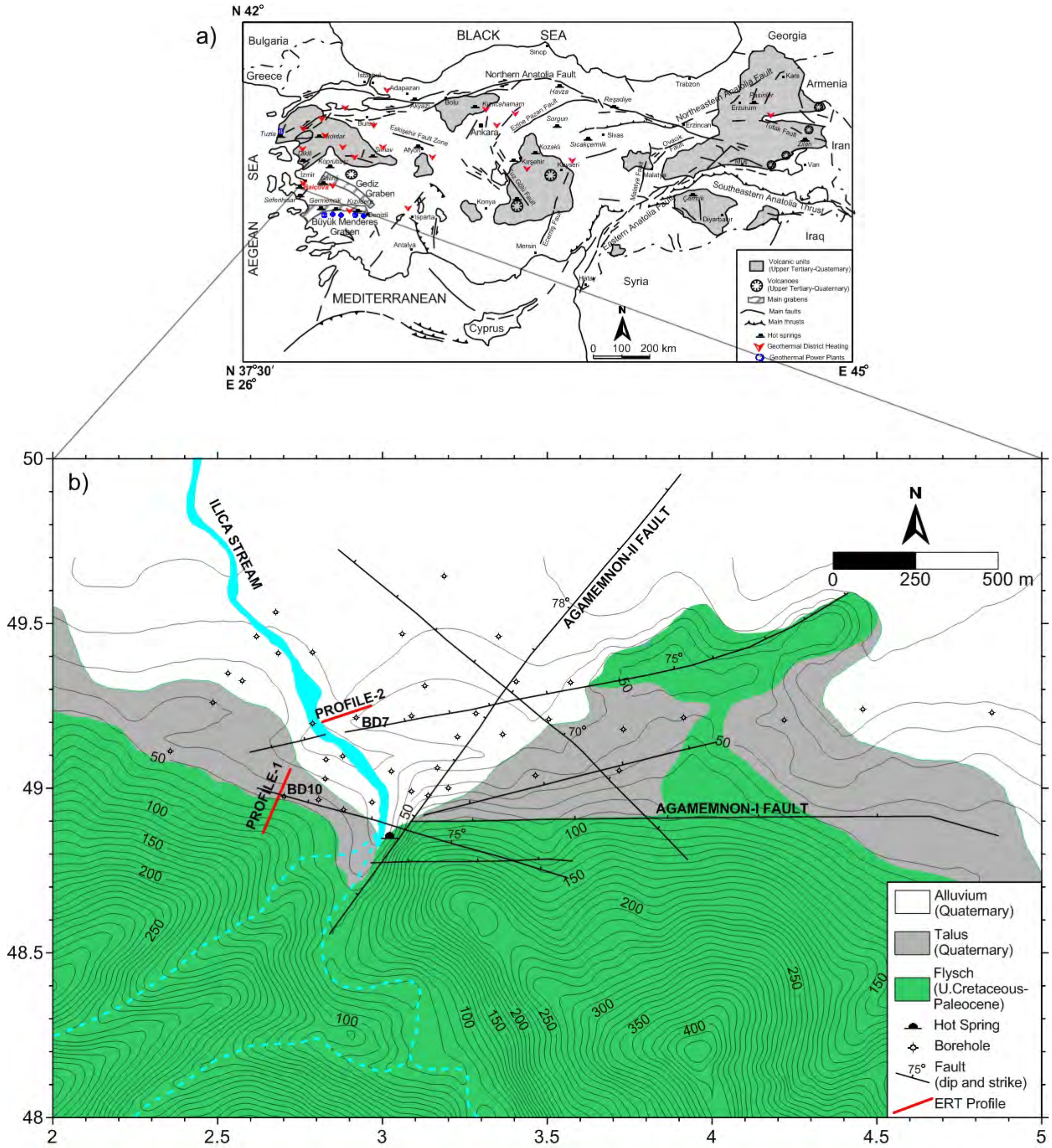

Fig. 1: a) Tectonic and geothermal activity map of Turkey (after ŞIMŞEK, 2001) and b) geological map of Balçova Geothermal Site (modified from YILMAZER, 1989 and AKSOY, 2001).

The area around the Balçova geothermal site consists of Alluvium, talus and Izmir flysch (Fig. 1b). Upper Cretaceous Izmir flysch consists of metasandstones, limestone, granodiorites, serpentinite-diabase, rhyolites and phyllites. Fractured metasandstones and fault zones existing in limestone and granodiorites are permeable. Other zones of the Izmir flysch formation can be thought as impermeable. Flysch formation exceeding 2000 m depth, occupies the most of the volume of the field. This formation has some fissures, fractures and faults and the permeability is appeared in these zones. Limestone and granodiorites have fractures and faults that create secondary permeability. Serpentinite and rhyolites are thought as impermeable zones (SATMAN et al., 2001). Above the flysch formation alluvium and talus thickness of which change between 0 and 200 m take place. Although alluvium has some permeability, most parts of talus are impermeable. Alluvium existing over the field has good porosity and some permeability. Some shallow wells produce water mainly from this zone. Talus exists in southern part of the field in small amounts compared to area covered by alluvium (POLAT, 2010).

The thermal activity is manifested by hot springs that form mainly along the major fault systems in the area (EŞDER and ŞIMŞEK, 1975). As a result of intense graben tectonics, the aquifer of the geothermal system is controlled by dipping strike-slip and active normal faults (TEZCAN, 1966; YILMAZER, 1989).

There are two different aquifer systems in Balçova geothermal site. One of them is the hot water aquifer system found in the allochtonous limestone with Upper Cretaceous Age in the İzmir flysch formation. This formation is impermeable, and the hot waters in the aquifer are discharged by faults. The primary fault zone in the area is the Agamemnon-1 fault that cuts directly the aquifer system. The second aquifer has cold water found in the alluvium with Quaternary Age, and it is charged by surface waters. In the area, there are many water wells in the alluvium, their depths are changed 25-80 m generally. The water table is mostly changed between 11 and 20 m depths in the northern part of the area. Underwater flow direction is mainly from south to north direction (ERDOĞAN, 1990).

Our ERT monitoring studies were performed between March 2010 and February 2011. The investigations were continued along this period. We aimed to obtain the information on the difference of physical changes of shallow parts of aquifer zone in the geothermal system. These consist of fluid changes, environmental characteristics, temperature changing and re-injection process in the site. To reach this goal ERT monitoring study was preferred. ERT investigation was repeated over two lines during the different investigation periods (Figure 1b).

Synthetic Modelling Studies for Injection Model

To show the effectiveness of the ERT monitoring studies on geothermal applications, we generated a synthetic injection model using Res2Dmod software (Geotomo software). The forward and inversion modeling studies were performed during this study to determine the changes related with time. In the first stage, we carried out a forward modeling studies for various time scales (t = 0, 1, 2 and 3 unit; unit is equal to month for our problem). At first there is no any injection process in this model (t = 0). Five horizontal layers that show the alluvium in the area are extended to 50 m below. The resistivity and depth of horizontal layers are given in the figure as 250 Ωm-10 m, 150 Ωm-3 m, 75 Ωm-7 m, 25 Ωm-5 m and 15 Ωm-25 m respectively. The borehole resistivity is 200 Ωm and its thickness is 2 m, while the depth of borehole is extended to 20 m. The affected area from injection was considered as a conductive zone, and the resistivity of this zone was given as 2 Ωm in the model. Thus, the resistivity value of adjacent area of the borehole was reduced according to time of injection process (Figure 2). During the forward modeling stage we used 61 electrodes with 5 m interval. Data sets were produced for Wenner and Wenner-Schlumberger arrays. Therefore the synthetic apparent resistivity data were produced for various time periods (for before and after pumping periods; t = 0, 1, 2 and 3 unit). In the second stage, the inversion process was achieved to present the effects of temporal changes for various time slices. This stage was investigated in two different approximations; smoothness inversion and time-lapse smoothness inversion using Res2Dinv software. The time-lapse inversion of the data sets was carried out using a joint inversion technique where the model obtained from the reference data set was used to constrain the inversion of the later time data sets (LOKE, 1999). Thus, reliability and resolution of the ERT method could be investigated by the modeling stage.

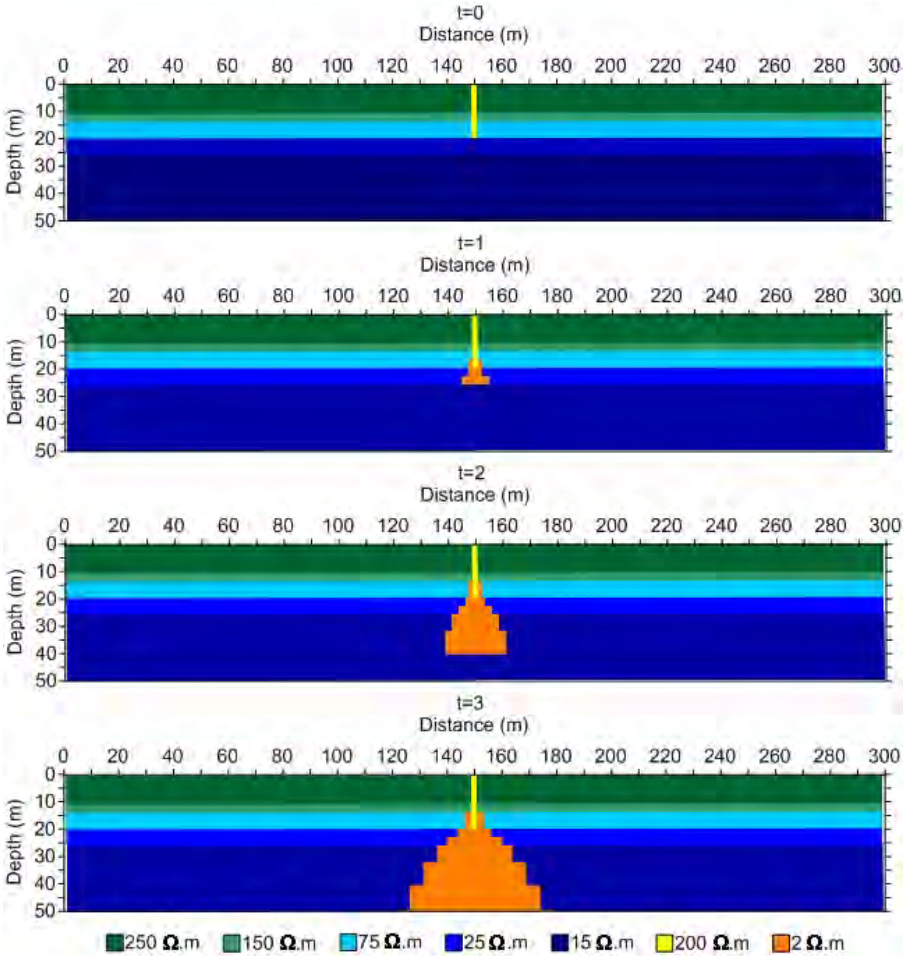

Fig. 2: Synthetic subsurface resistivity models for injection process related with different times (t = 0, 1, 2 and 3 unit; unit is equal to month for our problem).

Inversion results of injection model for different monitoring times are given in Figure 3 for Wenner and Wenner-Schlumberger arrays. These arrays produced close resistivity models to the synthetic injection models after the inversion. We can closely identify the subsurface resistivity values. Besides, after the t = 1 period, reduced resistivity zone clearly appeared on the inverted models. The changes caused by the injection process are appeared at the 20 m depth in both Figures 3a and 3b. Therefore, increasing in conductive zone is clearly seen in the inverted model sections. But, Wenner-Schlumberger array gives more reliable results than Wenner. The resistivity reducing effect is clearer under the borehole. In addition, we did not confirm the important changes between the standard and time lapse inversion models. Finally, we can clearly conclude that ERT is the useful technique to monitor the temporal changes in the subsurface according to the injection scenario. Also Wenner-Schlumberger configuration was given more reliable result than the Wenner array in the synthetic modeling stage.

Data Acquisition and Processing

To monitor the shallow changes near the boreholes, we selected two different investigation lines in Balçova site. The lines are represented in Figure 1b as profile 1 and 2. Profile 1 has almost north-south direction, while the profile 2 has almost east-west orientation. The lengths of profiles are 220 and 140 m for line 1 and 2 respectively. Profile 1 is located near the borehole-BD10, which is a re-injection hole. This borehole was used between beginning of October 2010 and the end of April 2011 as a re-injection well. Profile 2 is also located near the borehole BD-7, is a production well. This borehole did not work between April and September 2011. Overall 2D ERT data was collected by Wenner and Wenner-Schlumberger configurations along these two lines. During the measurements electrode intervals were selected as 5 m and data was collected for 8-10 levels. Before the interpretation, measured apparent resistivity data was processed by using 2D inversion technique (LOKE and BARKER, 1996; TRIPP et al., 1984; DEGROOT-HEDLIN and CONSTABLE, 1990; SASAKI, 1992). Res2Dinv software, which tries to optimize a starting subsurface model by minimizing the differences between the measured and calculated data, was used in this study. Finite-element method was used in the forward modeling to produce the calculated data. In the time lapse inversion scheme, one data set was selected as a base and inversion process was implemented on this data set. Then, obtained resistivity model was used as a starting model in the inversions of the consecutive data sets. The inversion models were obtained after 6 iterations.

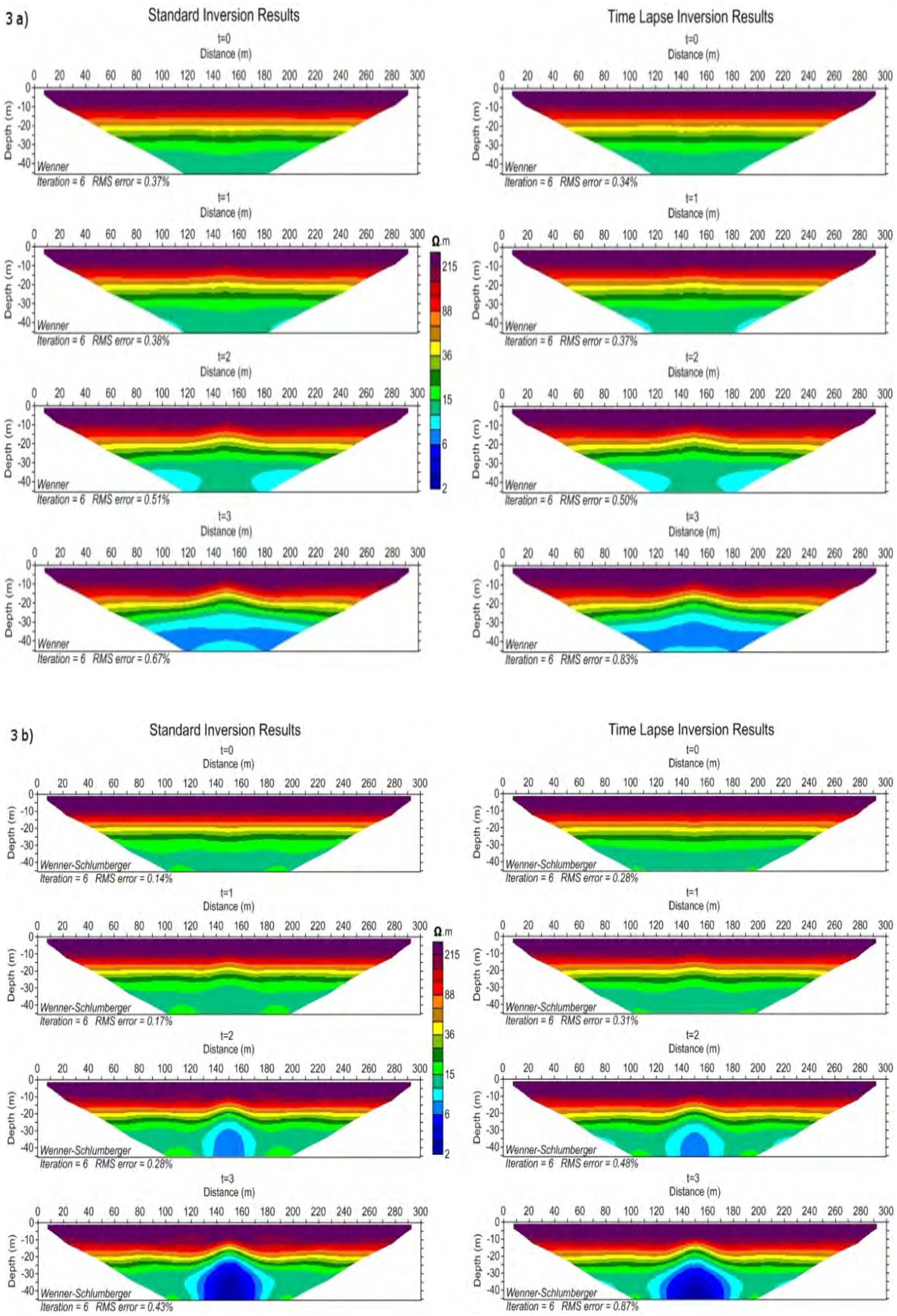

Fig. 3: 2D model sections obtained from the synthetic injection models; a) Wenner and b) Wenner-Schlumberger arrays.

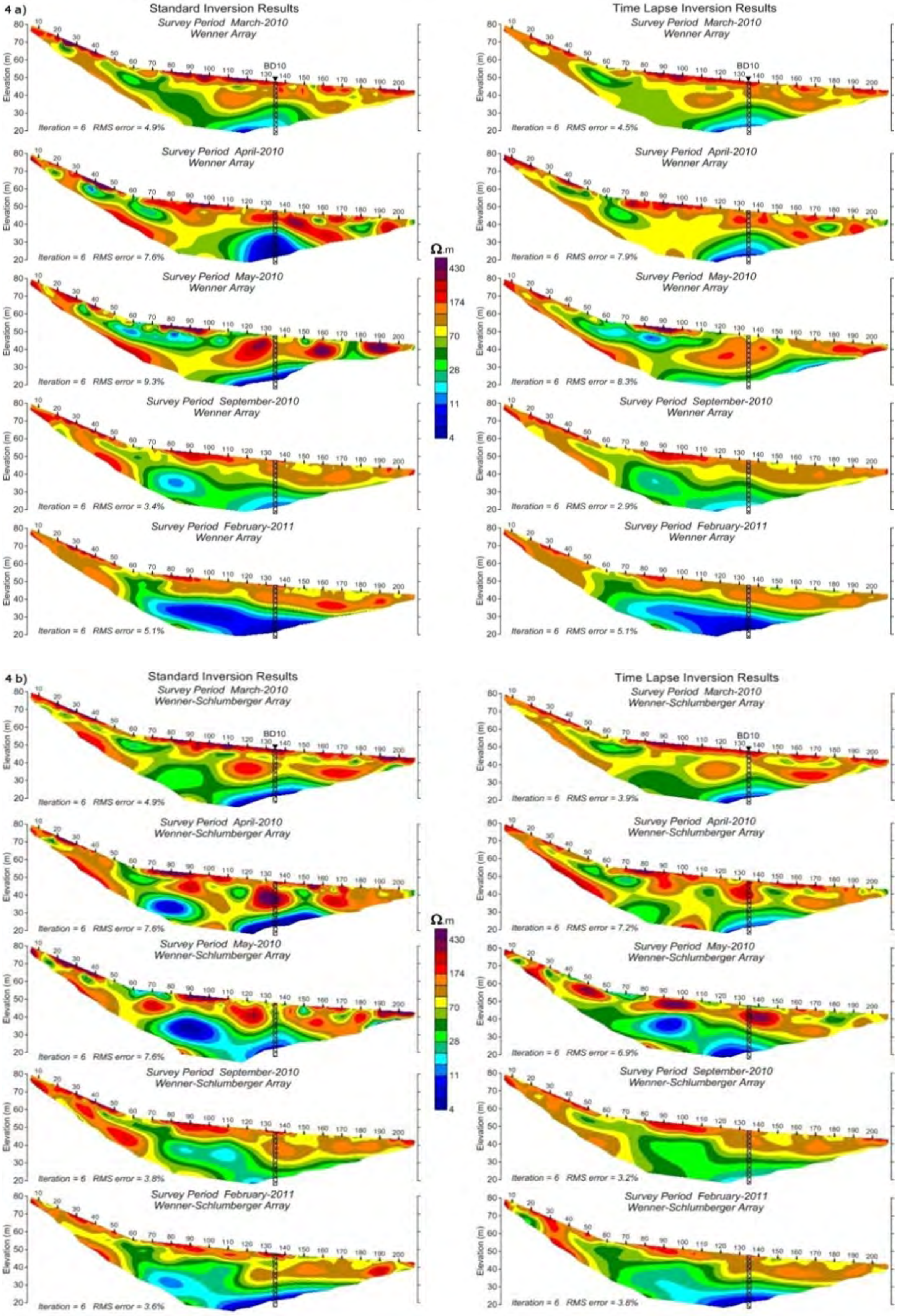

Fig. 4: 2D standard and time-lapse ERT model sections of Profile-1; a) Wenner and b) Wenner-Schlumberger arrays.

Interpretation

Standard and time-lapse inversion results of profile 1 are given in Figure 4. As can be seen from the figure, Wenner and Wenner-Schlumberger arrays are generally produced similar inversion models after six iterations for standard inversion approach. In all inverted resistivity sections, we can firstly observe resistive layers, which is almost 5m thickness. This layer has an interruption between 60-70 m of the line. This interruption could also be followed to the deeper part of the inversion models for all measuring periods. Therefore, we think that it could be a fault zones (possibly Agamemnon-1 fault given in Figure 1b). According to geologists, this fault has almost vertical angle. We know that this kind of fault zones that have extremely fracture and fissure properties might be recharge passages in the porous and permeable environments. Therefore, the groundwater streaming from the surface or the reservoir can be transported inside these zones. The section obtained from March 2010 data shows that the conductive zone is almost displayed in proximity of borehole-BD10. Overall model sections have closely similarity for standard and time-lapse inversion results. The conductive zones are importantly changed during the monitoring periods. The conductive zone is enlarged in the results of April 2010 data for standard inversion sections. But there is no any important change in time-lapse models of April 2010. This situation depends on the selected initial inversion model in time-lapse approximation. The conductive zone is increased in the results of Wenner-Schlumberger of May 2010 data, while it decreases in the results of Wenner configuration of May 2010 data. In September 2010 result, all sections are very similar to each other (for standard and time-lapse results). After the yearly period, the results obtained February 2011 data are partially resembled again the first model (March 2010). However, the conductive zone in the deeper part of the sections is still enlarged in whole sections both standard and time-lapse inversion. Therefore, we can determine that the important changes are formed by the climatic effects (rainfall, etc.), fault recharges and production process, which is valid the re-injection operation for this line due to the BD-10 re-injection well.

Profile-2 has almost a flat topography and lie near the borehole-BD7, which is a production well. The production was not made between April and September 2010 due to the moderate and hot weather conditions. All inversion sections show the horizontal layering model, which is used during the synthetic modeling stage (Figure 5). Resistive strata (>150 Ωm) are almost horizontal and extended 10 and 15 m below from the surface. Conductive strata are located under this zone, and their average resistivity is about 15 Ωm. High conductivity in the deeper part of the sections is commonly observed in the results of March and April 2010. The harmony between used configurations is very good in all sections. In addition, the results of standard and time-lapse inversion are very compatible. As a result, we can say that the climatic conditions in this profile could be affected the resistivity changes in the subsurface more than the production process.

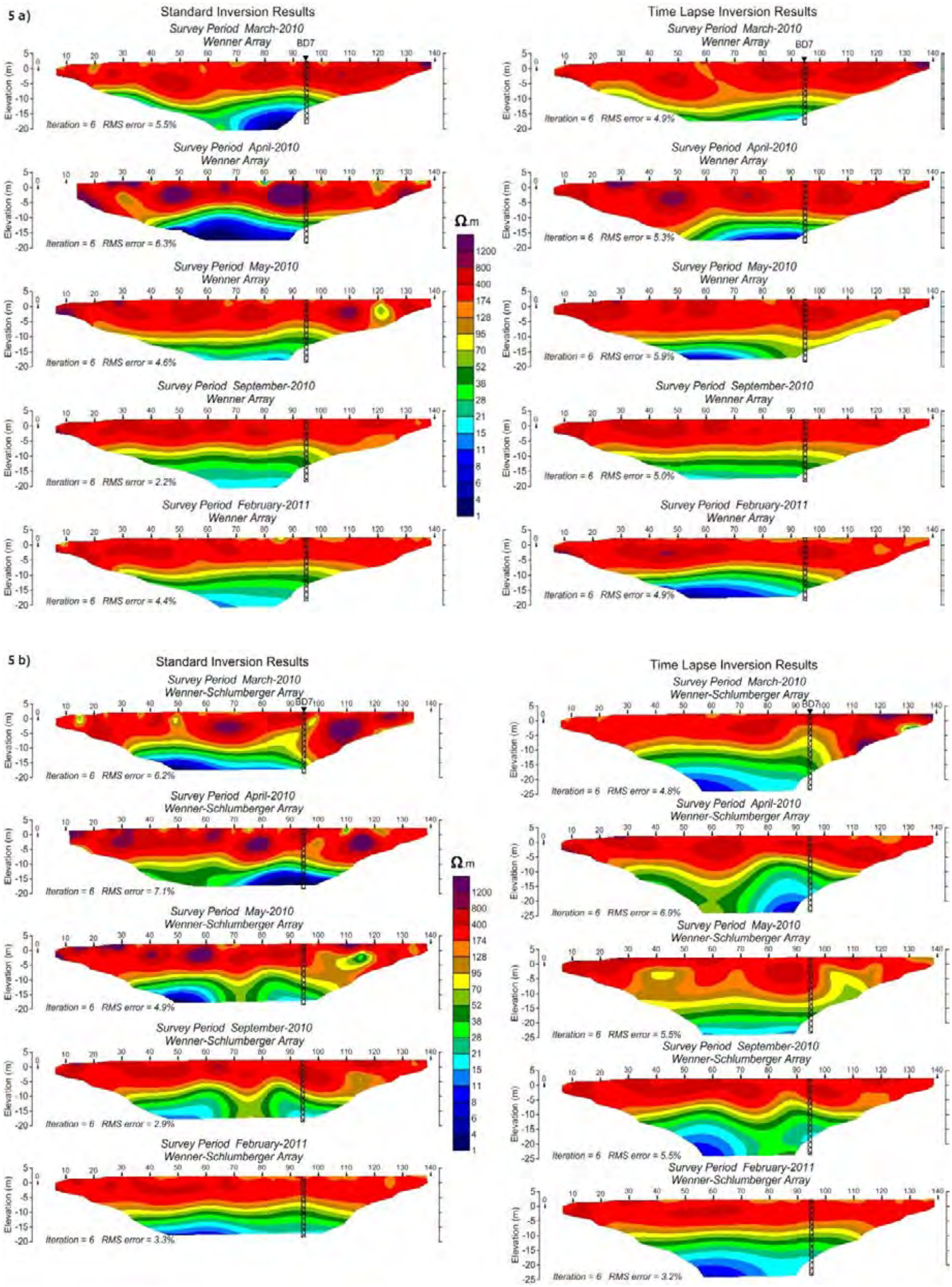

Fig. 5: 2D standard and time-lapse ERT model sections of Profile-2; a) Wenner and b) Wenner-Schlumberger arrays.

Conclusion

The results of shallow ERT monitoring studies in Balçova geothermal site indicated that the used method was very useful to investigate the changing of different physical characteristics of shallow parts in a geothermal system. Particularly, the determination of these changes can be very important to determine the liquid runaways during the production stage. Therefore we can say that operational processes make an impact on physical alterations resulting together with the changes on the shallow subsurface characteristics. But, it should not be forgotten that the climatic effects such as rainfall and rapid daily temperature changes could be very important in the changes of resistivity in near surface investigations. Therefore, the rainfall and temperature records should be compared with the inversion results to achieve more interpretive results.

Time-lapse inversion results give us more interpretive results than the standard inversion approximation for both synthetic and field studies. But we can determine that the identification of initial model is also important to constrain the later time data sets. In addition, this study showed that the selection of configuration type is essential to obtain more interpretive results. Thus, various configurations should be tested to confirm the suitable configuration for this problem.

Overall results presented that ERT monitoring gives us very informative results on the determination of changes of subsurface characteristics during the operations. Therefore, we can observe the noticeable near surface changes depending on the operation processes in an operated site.

As a result, operating system of geothermal companies could be run more efficiently by the help of geophysical monitoring studies.

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