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Geothermal energy in Turkey: 2008 update

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ABSTRACT

Geological studies indicate that the most important geothermal systems of western Turkey are located in the major grabens of the Menderes Metamorphic Massif, while those that are associated with local volcanism are more common in the central and eastern parts of the country. The present (2008) installed geothermal power generation capacity in Turkey is about 32.65 MWe, while that of direct use projects is around 795 MWt. Eleven major, high-to-medium enthalpy fields in western part of the country have 570 MWe of proven, 905 MWe of probable and 1389 MWe of possible geothermal reserves for power generation. In spite of the complex legal issues related to the development of Turkey's geothermal resources, their use is expected to increase in the future, particularly for electricity generation and for greenhouse heating.

1. Introduction

Due to availability, economic and environmental issues it is expected that the worldwide use of oil, natural gas and coal is going to decline in the future and that geothermal energy will play an important role in the replacement of those fossil fuels (Fridleifsson, 2001). The rise of oil and gas prices during the last 3 years has made the development of the geothermal resources of Turkey more economically feasible.

Geothermal exploration in Turkey started in the early 1960s. At first, the work was focused on high-enthalpy fields for potential power production; Kızıldere (Fig. 1) was discovered in 1968. The Balçova and Seferihisar, two medium-temperature geothermal fields, were found and studied in the 1960s and 1970s, respectively. A second high-enthalpy system, Germencik, and various other medium-enthalpy fields, such as Salavatlı and Simav, were identified in the 1980s.

Turkey's low- and medium-temperature resources have yet to be thoroughly explored and evaluated. With proper exploration methods and investments, some might be shown to contain higher-enthalpy fluids; geochemical data seem to support such a hypothesis (Serpen, 2004; Palabiyik and Serpen, 2008).

A 17.8-MWe, single-flash power plant came on line at Kızıldere in 1984. Since then, on average, it has been generating 10 MWe (gross). An air-cooled binary cycle power plant with a gross capacity of 7.35 MWe was installed at Salavatlı geothermal field in 2006. Recently, a decision was made to build a 47.4-MWe, double-flash power plant at Aydın-Germencik; it is presently under construction.

Direct use of geothermal energy in Turkey has focused mainly on district heating. The first of these systems came on line at the low-temperature Gönen field in 1987. During 1991–2006 other 17 heating systems were installed.

Based on these recent projects it is clear that geothermal energy will contribute significantly to Turkey's future energy supply. Here we will examine the present status, potential, economics, trends and legislative aspects of Turkish geothermal energy resources and projects.

2. Turkey's geothermal resource potential

To substantiate the importance of geothermal energy in Turkey, we will present geo-scientific aspects of the country's geothermal resources that are relevant to the assessment of their potential.

Turkey is located in the central part of the Alpine-Himalayan Mountain Belt that began developing by the closing/shrinking of the Tethys Ocean in the Late Mesozoic. High-mountain ridges were formed along the northern and southern sides of Anatolia, while some pre-Cambrian-Paleozoic metamorphic shields (i.e. the Menderes and Central Anatolian Massifs) remained at its center.

The tectonic plate convergence and subduction history of the Menderes Metamorphic Massif (MMM) was developed based on the data for the major flyschoidal basin and ophyolithic fields of

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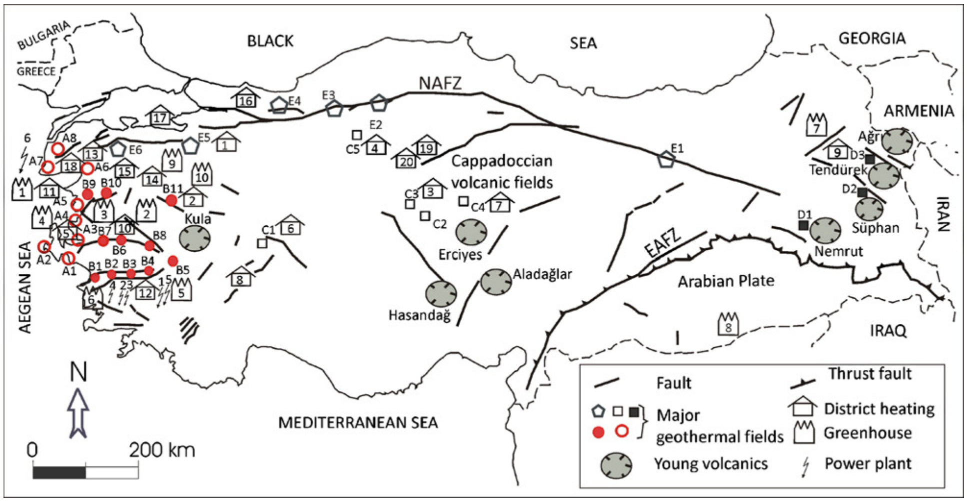

Fig. 1. Location of major geothermal fields in Turkey. In the *Aegean Coastal Belt*: (A1) Seferihisar, (A2) Çeşme, (A3) Balçova, (A4) Aliağa, (A5) Dikili-Bademli, (A6) Edremit, (A7) Tuzla, and (A8) Kestanbol; in the *Western Anatolian grabens*: (B1) Germencik, (B2) Aydın, (B3) Salavatlı-Sultanhisar, (B4) Kızıldere, and (B5) Denizli; (B6) Salihli-Kurşunlu, Caferebeyli and Sart, (B7) Turgutlu-Urganlı, (B8) Alaşehir-Kavaklıdere, (B9) Dikili-Kaynarca, (B10) and Bergama and (B11) Simav; in *Central Anatolia*: (C1) Afyon, (C2) Cappadocia, (C3) Kırşehir, (C4) Kozaklı, and (C5) Kızılcahamam; in *Eastern Anatolia*: (D1) Nemrut Caldera, (D2) Erciş-Zilan, and (D3) Diyadin; in the *North Anatolian Fault Zone*: (E1) Erzincan, (E2) Çerkeş, (E3) Bolu, (E4) Düzce, (E5) Bursa and (E6) Gönen. NAFZ: North Anatolian Fault Zone; EAFZ: East Anatolian Fault Zone. *Geothermal district-heating systems*: (1) Gönen-Balıkesir, (2) Simav-Kütahya, (3) Kırşehir, (4) Kızılcahamam-Ankara, (5) Balçova-İzmir, (6) Afyon, (7) Kozaklı-Nevşehir, (8) Sandıklı-Afyon, (9) Diyadin-Ağrı, (10) Salihli-Manisa, (11) Dikili-İzmir, 12 Sarayköy-Denizli, (13) Edremit-Çanakkale, (14) Bigadiç-Balıkesir, (15) Bergama-İzmir, (16) Kuzuluk-Sakarya, (17) Armutlu-Yalova, (18) Güre-Balıkesir, (19) Sorgun-Yozgat and (20) Yerköy-Yozgat. *Geothermal greenhouses*: (1) Dikili-İzmir, (2) Salihli-Manisa, (3) Turgutlu-Manisa, (4) Balçova-İzmir, (5) Kızıldere-Denizli, (6) Gümüşköy-Aydın, (7) Diyadin-Ağrı, (8) Karacaali-Urfa, (9) Sındırgı-Balıkesir and (10) Simav-Kütahya. *Geothermal power plants*: (1) Kızıldere-Denizli, (2 and 3) Dora-1 and Dora-2, Salavatlı-Aydın, (4) Gürmat, Germencik-Aydın (5) Bereket, Kızıldere-Denizli and (6) Tuzla-Çanakkale.

the İzmir-Ankara range at its western and northwestern boundaries. Recent tectonics associated with the westward movement of the Anatolian Sub-plate and related N–S extension, particularly in Southeastern Anatolia, caused by the northward push of the Afro-Arabian Plate, created several major E–W oriented grabens. The faults bounding these structures created suitable conditions for deep circulation of infiltrating meteoric waters and their heating at depth. The tectonic forces and resulting structures are thought to be responsible for the present high-heat flow in the MMM, and for the existence of medium-to-high-enthalpy geothermal systems in Western Anatolia, and of the many low-to-medium enthalpy systems throughout the massif, especially in the Aegean Coastal Belt.

The displacement of the Anatolian Sub-plate, and particularly the extensional crustal stresses in Eastern and Central Anatolia, led to the development of vast volcanic fields between the Miocene and the Holocene. There are several hydrothermal manifestations and some indications of high-heat flow at these volcanic fields, but their geothermal potential has not yet been studied in detail.

Finally, the northern boundary of the westward moving Anatolian Sub-plate, i.e. the Northern Anatolian Fault Zone (NAFZ), provides permeable flow channels for the infiltration and circulation of waters within its up to 17-km deep brittle deformation zones, explaining the presence of several low-enthalpy hydrothermal systems in that zone.

Northwestern Anatolia and the Biga Peninsula (Fig. 2) have transitional characteristics between the relatively young (Miocene) volcanics, the NAFZ and the exhumation and rise of the Kazdağı Metamorphic Massif; these two regions host some unique geothermal systems.

In Turkey the geothermal systems (Fig. 1) mainly follow recent and regional structural lines and are more frequent in regions of recent tectonism and Tertiary volcanism and/or metamorphism. However, while these systems differ radically between regions, substantial similarities tend to exist among those of a given region. This zonation also defines the suitability of conditions for the existence of possible deep geothermal resources.

2.1. Aegean Coastal Belt

There are several similar, generally of low-to-medium temperature, geothermal fields in the Aegean Coastal Belt (Fig. 2), such as Seferihisar (A1), Çeşme (A2), Balçova (A3), Aliağa (A4), Dikili-Bademli (A5), Edremit (A6), Tuzla (A7) and Kestanbol (A8).

The Seferihisar geothermal system developed over normal faults that bound horst and graben structures. The thermal fluid is seawater strongly diluted by shallow groundwater.

The Balçova field is located in an active, E–W trending, normal-fault zone; i.e. the Agamemnon Fault on the northern side of the Seferihisar Horst. The geothermal system is limited to the narrow, nearly vertical zone where the flysch deposits appear fragmented largely by faults (Serpen, 2004; Aksoy et al., 2008).

The hot waters from the Çeşme system of the northern coast of the Çeşme Peninsula discharge from karstic Triassic limestones bound by normal faults. The chemical composition of these waters is very close to that of seawater (Gemici and Filiz, 2001); i.e. the system is connected to the Aegean Sea via karstic openings.

The Aliağa geothermal field is also located in an area of active normal faults (Gevrek et al., 1987). The thermal fluid is heated seawater circulating deep through these faults (Öngür, 1977). Similarly, the hot fluids at Edremit are considered to be waters that have reached large depths by flowing down the northern bounding faults of the asymmetrical graben of the Edremit Gulf Basin (Fig. 2).

The geothermal system at Tuzla occurs on the SW border of the young (Lower Tertiary) Kazdağ Metamorphic Massif (Fig. 2), where Miocene volcanism shaped the Biga Peninsula following two intersecting, roughly N–S and NW–SE trending regional fracture systems. During the Pliocene, several dacitic-rhyolitic lava domes were emplaced along a N–S line in the geothermal field and north of it (Öngür, 1977). Thermal recharge of the Tuzla system is by deep waters ascending through this N–S structural discontinuity,