Journal of Volcanology and Geothermal Research 309 (2016) 118–138

Contents lists available at ScienceDirect

Journal of Volcanology and Geothermal Research

journal homepage: www.elsevier.com/locate/jvolgeores

Hydrogeochemistry of the thermal waters from the Yenice Geothermal Field (Denizli Basin, Southwestern Anatolia, Turkey)

Hülya Alçiçek *, Ali Bülbül, Mehmet Cihat Alçiçek

Department of Geological Engineering, Pamukkale University, TR-20070 Denizli, Turkey

ARTICLE INFO

Article history:
Received 27 April 2015
Accepted 31 October 2015
Available online 10 November 2015

Keywords:
SW Turkey
Yenice Geothermal Field
Hydrogeochemistry
Thermal waters
Geothermometry
Fluid-mineral equilibria

ABSTRACT

The chemical and isotopic properties of thermal waters (Kamara and Çizmeli) and cold springs from the Yenice Geothermal Field (YGF), in southwestern Anatolia, Turkey are investigated in order to establish a conceptual hydrogeochemical-hydrogeological model. These thermal waters derive from Menderes metamorphic rocks and emerge along normal faults; they are commonly used for heating of greenhouses and bathing facilities. Discharge temperatures of thermal waters are 32 °C to 57 °C (mean 51 °C) for Kamara and 35 °C to 68 °C (mean 47 °C) for Çizmeli, whereas deep groundwaters are 15 °C to 20.1 °C (mean 17 °C) and shallow groundwaters are 12 to 16 °C (mean 15 °C). Kamara and Çizmeli thermal waters are mostly of Na–Ca–HCO_3–SO_4 type, whereas deep groundwaters are Ca–Mg–HCO_3 and Mg–Ca–HCO_3 types and shallow groundwaters are mainly Mg–Ca–SO_4–HCO_3 and Ca–Mg–HCO_3 types.

In the reservoir of the geothermal system, dissolution of host rock and ion-exchange reactions changes thermal water types. High correlation in some ionic ratios (e.g. Na vs. Cl, K vs. Cl, HCO_3 vs. Cl) and high concentrations of some minor elements (e.g., As, Sr, B, Cl, F) in thermal waters likely derive from enhanced water–rock interaction. Water samples from YGF have not reached complete chemical re-equilibrium, possibly as a result mixing with groundwater during upward flow. Geothermal reservoir temperatures are calculated as 89–102 °C for Kamara and 87–102 °C for Çizmeli fields, based on the retrograde and prograde solubilities of anhydrite and chalcedony. Based on the isotope and chemical data, a conceptual hydrogeochemical-hydrogeological model of the YGF has been constructed. Very negative $\delta^{18}O$ and $\delta^{2}H$ isotopic ratios (Kamara: mean of −8.43‰ and −56.9‰, respectively and Çizmeli: mean of −7.96‰ and −53.7‰, respectively) and low tritium values (<1 TU) reflect a deep circulation pathway and a meteoric origin. Subsequent heating by conduction in the high geothermal gradient setting (resulting from regional crustal thinning) drives geothermal waters upwards along faults and fractures that act as hydrothermal pathways. Positive $\delta^{13}C$ ratios (+9.45‰ for Kamara and +7.28‰ for Çizmeli) indicate a metamorphic origin of thermal waters. Negative carbon isotope ratios (−8.40‰) found in the cold groundwaters are linked to exchange in freshwater carbonates of the Sazak Formation.

1. Introduction

Western Anatolia (Turkey) (Fig. 1A), one of the world's best-known extensional terrains, is characterized by numerous moderate- to high-enthalpy geothermal fields located along the boundary faults of the major grabens (Fig. 1B; Vengosh et al., 2002; Güleç et al., 2002; Güleç and Hilton, 2006). The distribution of the geothermal systems in Turkey is strongly consistent with the distribution of the fault arrays. In the western Anatolia, entire hot springs (>50–100 °C) are related to young volcanic activity (i.e. Neogene–Quaternary) and block faulting which have been responsible for heating up the geothermal fields (Vengosh et al., 2002). The presence of more than 600 hot springs with discharge temperatures up to 100 °C indicates a significant geothermal potential in Turkey that has been supported by drilling studies implemented by the General Directorate of Mineral Research and Exploration of Turkey (MTA) since the 1960s (Çağlar, 1961; MTA, 2005). Geothermal resources of western Turkey have been used for heating of buildings and greenhouses, thermal spas, geothermal power plants and carbondioxide production. The origin of recharge and mixing trends of geothermal fluid are reflected in hydrogeochemical proxies (e.g. major and trace ion compositions). Therefore, understanding the dimensions, geological context and processes behind geothermal sources is important in order to enable its sustainable use.

The Denizli Basin of southwestern Anatolia (Turkey) (Fig. 1B) is characterized by the occurrence of high temperature geothermal fields aligned along NW–SE trending normal faults that are probably related to ongoing N–S extensional tectonic regime in the region. The geothermal exploration studies in this basin started with discovering of Kızıldere Geothermal Field by the cooperative MTA-UNDP project in 1968 (Şimşek, 2003a, b). In recent decades geothermal sources have

* Corresponding author. Tel.: +90 258 2963401; fax: +90 258 2963382.
E-mail address: halcicek@pau.edu.tr (H. Alçiçek).

http://dx.doi.org/10.1016/j.jvolgeores.2015.10.025
0377-0273/

been increasingly utilized in the Denizli Basin and their properties have been studied since 1967 (e.g., Şimşek, 1981, 1984, 1985; Gökgöz, 1998; Özgür, 2002; Vengosh et al., 2002; Şimşek, 2003a, b; Şimşek et al., 2005; and references therein).

The Yenice Geothermal Field (YGF) is a large and productive geothermal field located in the northwestern margin of the Denizli Basin (SW Turkey; Figs. 1B and 2). This field (also known as the Tripolis Geothermal Field) and the surrounding area (e.g. Pamukkale, Karahayıt, Gölemezli geothermal fields (Fig. 1B) are well known for their spectacular travertine formations having a major tourist attraction. The geothermal waters have been used at least since Roman times. This geothermal field exhibits a well-developed hydrothermal activity, resulting in several mineralized thermal springs (Kamara and Çizmeli sites) (Fig. 2). The Kamara and Çizmeli sites in the YFG contain fissure ridges built of travertine. At present, thermal sources in the YGF are used for a variety of purposes (including spa, greenhouse heating, etc.). Increasing interest in alternative energy sources has sparked new research projects in the region assessing potential of low enthalpy energy production from the hydrothermal systems.

In recent years, a number of studies on the western Turkey have primarily focused on chemical and isotopic composition of geothermal fluids. Some studies revealed the origins and hydrogeochemical features of geothermal fluids in western Turkey (e.g. Gemici and Filiz, 2001; Gemici and Tarcan, 2002; Vengosh et al., 2002; Gemici et al., 2004; Tarcan, 2004; Baba and Sözbilir, 2012; Karakuş and Şimşek, 2013). Also, some geothermal fields (e.g., Pamukkale–Karahayıt, Kızıldere) in Denizli Basin (e.g., Şimşek, 1981, 1984, 1985; Gökgöz, 1998; Şimşek, 2003a, b; Möller et al., 2004, 2008; Şimşek et al., 2005; Dilsiz, 2006; Kele et al., 2011; De Filippis et al., 2012, 2013) have been studied in considerable detail, but little attempt has thus far been made to draw hydrogeological and hydrogeochemical properties and model of the YGF (e.g., Şimşek, 1984, 2003b; Demirel and Tamgaç, 2004; Şengün, 2011; Khorshtd, 2013). In the recent years, several studies have concentrated on the regional geological and tectonic setting of geothermal activity of the region (Çakır, 1999; Uysal et al., 2007; De Filippis et al., 2012, 2013; Alçiçek et al., 2013).

This study deals with to define the geological, hydrogeological and hydrogeochemical characteristics of the thermal waters and cold springs of the YFG and to establish maximum reservoir temperatures by application of chemical geothermometers on published and new data. One of the aims is to provide a conceptual hydrogeochemical–hydrogeological model of the YGF hydrothermal system using various complementary tools. Special attention has been drawn to understand the aquifer fluid composition and fluid-mineral equilibria for exploration and evaluation of the geothermal resources in this field.

2. Geological setting

The western Anatolia is among one of the most active extensional regions in the world, where Neogene and Quaternary regional extension resulted in a series of E–W, NE–SW and NW–SE trending fault-bounded basins with common geothermal activity (e.g., Şengör and Yılmaz, 1981; Bozkurt, 2003; ten Veen et al., 2009). The Denizli Basin is such an extensional basin of southwestern Anatolia where crustal extension lasting from late early Miocene onward and accommodating 1300 m of sediment thickness. The basin is 50 km wide and 70 km long delimited by NW- and SE-faults and located at the junction of the E-trending Büyük Menderes and the NW-trending Gediz basins (Fig. 1B; Koçyiğit, 2005; Kaymakçı, 2006; Alçiçek et al., 2007). The pre-Neogene bedrock of the basin is exposed at its northwestern and southwestern margin, contain Paleozoic metamorphic rocks of the autochthonous Menderes Massif and Mesozoic carbonate rocks of the allochthonous Lycian Nappes constituting westernmost part of the Tauride orogen. The Menderes Massif, an Africa-derived microcontinent accreted to the Cimmerian margin of Eurasia in the early phase of Alpine orogeny, includes a crystalline core and metamorphic cover rocks with the core consisted of augen gneisses surrounded by schists, quartzite, marbles, and carbonates forming a dome-like structure (Pamir and Erentöz, 1974; Şengör and Yılmaz, 1981; Okay, 1989; Sun, 1990; Bozkurt, 2001; ten Veen et al., 2009; van Hinsbergen, 2010; van Hinsbergen and Schmid, 2012).

Lycian allocthon units (Fig. 1B) contain Mesozoic recrystallized dolomitic limestones, marbles, and turbiditic sandstones which are tectonically overlain by ophiolitic mélange (De Graciansky, 1972; Okay, 1989; Sun, 1990). A recrystallized dolomitic limestone succession in the nappes is intercalated with Triassic evaporitic units in the easternmost part of Denizli Basin (Alçiçek et al., 2007; Gündoğan et al., 2008). The bedrock units represent the closure of the Neotethyan oceanic basin during the Mesozoic–early Cenozoic with the emplacement of large-scale platform carbonate and ophiolitic rocks (Collins and Robertson, 1997; 1998). The nappes extending between Menderes Massif to the north and Beydağları autochthonous to the south are attributed to an orogenic-belt segment originated in a northerly Neotethys ocean and comprise allochthonous sheets transported from NW to SE during the Late Cretaceous and early Cenozoic (Collins and Robertson, 2003; Robertson et al., 2003).

The Neogene and Quaternary basin-fill succession of the Denizli Basin is up to 1300 m thick and consisting of alluvial-fan, fluvial, and lacustrine deposits (Alçiçek et al., 2007). This succession unconformably overlies the bedrock units referred to as the Denizli Group by Şimşek (1984), and subdivided into four lithostratigraphic units: the alluvial fan to fluvial Kızılburun (late early–early middle Miocene), lacustrine Sazak (middle middle–early late Miocene), lacustrine to fluvio-lacustrine Kolankaya (middle late Miocene–early Pleistocene), and alluvial fan to fluvial Tosunlar (late Pleistocene) formations (Fig. 3).

The regional extension in the Denizli Basin has been ongoing since the late early Miocene. The basin was initially a half graben during the late early Miocene controlled by the Babadağ fault to the south (Alçiçek et al., 2007). The Neogene half graben turned into a full graben by the early Quaternary due to activity associated with the Pamukkale and Tripolis (Yenice) faults to the north, which gave rise of hot springs that led to the formation of major travertine/tufa precipitation (Fig. 2; Altunel and Hancock, 1993; Altunel, 1994; Hancock et al., 1999; Alçiçek et al., 2007; Brogi et al., 2014). It is suggested that the travertine masses in the basin have formed where dip-slip normal fault segments display step-over zones along the fault-strikes (e.g. Çakır, 1999).

3. Hydrogeology

The Yenice Geothermal Field is part of the larger Kızıldere–Buldan–Sarayköy-Pamukkale geothermal area in the Denizli Basin (Fig. 1B). Numerous thermal springs occur in the Denizli Basin. The hot springs of Babacık, Demirtaş, Tekkehamam, Uyuz and İnaltı are situated at the southern margin of the Denizli Basin, whereas Yenice, Gölemezli, Karahayıt, Pamukkale, Buldan, Bölmekaya and Kızıldere are located at the northern margin of the basin (Fig. 1B). The two main thermal springs (Kamara and Çizmeli) of the YFG are located on the Tripolis (Yenice) fault footwall (Fig. 2; Şimşek, 1984; Çakır, 1999).

The Kamara spring discharge began to fall off in September 1996. This spring discharged 0.1 l/s of water at 38 °C in September 1998 (Bülbül, 2000). During May 1997, a well was drilled to a depth of 145 m in the Kamara locality (Fig. 4A). The well initially discharged 4 l/s of water at 56.7 °C and is presently used for spa facilities. Kamara spring was an active fissure ridge until 1999, where bedded travertine was being deposited from emerging carbonate-rich hot waters. The fissure ridge is N125°-trending (the long axis), ca. 63 m in length, 15 m in width and 6 m in maximum height over the surrounding plain (De Filippis et al., 2012). Both flanks of the fissure ridge consist of bedded travertines dipping away from the axial fissure. U–Th dating was provided ca. 1.7 and 2.5 ka for two samples of banded travertine from the Kamara fissure ridge (De Filippis et al., 2012).