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Hydrogeochemical Characterizations of Tekkehamam Region (Denizli, Turkey)

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ABSTRACT

Tekkehamam Region is located on the southern boundary fault of the Büyük Menderes Graben, Western Anatolia, Turkey. The study area has been a site of importance in terms of geothermal energy and is currently famous for its natural mud pools (having intense gas emissions), and is a center of balneological facilities. In this study, chemical analyses for thermal water of thermal wells and isotopic data (^{18}O, ^{2}H and ^{3}H) were obtained. To determine the scaling types and safe re-injection temperatures were the most important parts of the study. The basement of the study area consists of Paleozoic Menderes Massif that is characterized by metamorphic rocks. Neogene terrestrial sediments unconformably overlie the Menderes Massif. Quaternary alluvium is the youngest unit in the study area. The reservoir rocks of the geothermal systems are pre-Mesozoic-aged metamorphics such as marble, gneiss, and quartz-schist of Menderes Massif. In this study, hydrogeochemical characterizations of geothermal fields and scaling characterizations of geothermal fluid are investigated. Aquifer temperatures of the thermal wells in the study area vary from 145 to 170°C. Na-SO4-HCO_3 type is the dominant water type in the geothermal field. Cold waters are mainly dominated by the presence of HCO_3 and SO_4 as anions and Na, Ca, and Mg as cations. All waters are of meteoric origin and have minimum 50 years old circulation according to their ^{18}O, ^{2}H, and ^{3}H contents. Scaling is the most important problem in production wells and surface equipment in the study area. Mineral saturations at measured sampling temperature of thermal waters generally indicate calcite, aragonite, dolomite and amorphous silica scaling. Carbonate minerals are under the risk of scaling at all temperatures. Re-injection temperature must be above 80°C in order to prevent silica scaling.

1. INTRODUCTION

Tekkehamam geothermal systems are located in the western Anatolia active tectonic zones that are linked to graben systems and yield geothermal waters at temperatures between 40°C and 170°C. The Tekkehamam geothermal field is located 40 km west of the city of Denizli, in the eastern part of Büyük Menderes graben. The rift zone of the Büyük Menderes is marked by a large number of thermal waters and geothermal power plants such as Kizildere geothermal field, which is located north eastern part of the study area (Figure 1). Geothermal exploration for electricity production purposes have been focused on Kizildere and Tekkehamam areas owing to their high geothermal potential. The General Directorate of Mineral Research and Exploration of Turkey started the exploration in 1960s in these areas. The power plant constructed in 1984 has been operating with a generator output of 20.4 MWe in Kizildere since (Gokgoz, 1998). The construction of a new power plant is planned with a prospective output value of 60 MWe (Kindap et.al, 2010). Furthermore, after the admission of Law on Geothermal Resources and Natural Mineral Water in 2007, several companies started to explore and produce energy in the Büyük Menderes graben.

The Tekkehamam geothermal field is currently an attractive touristic place thanks to its natural spring, mud pools, and balneological facilities. There are six wells drilled in the Tekkehamam field with a maximum bottom hole temperature of 170^{o}C. The depths of the wells range between 115 m and 2001 m (Suer, 2010). All of them are production wells. The reservoir units are the same as Kızıldere geothermal field. The purpose of this paper is to report hydrogeological and geochemical properties of the Tekkehamam geothermal field and to introduce a new approach to assess the scaling problems in the wells of the study area.

2. GEOLOGICAL AND HYDROGEOLOGICAL SETTING

Western Anatolia has large-scale graben systems (e.g. the Büyük Menderes graben) because of the crustal thinning in the region. Metamorphic rocks of Menderes Massif, which comprises most of the western part of Turkey, are the oldest rocks as basement rocks in the graben (Bozkurt and Satir, 2000). Paleozoic Menderes Massif is represented by different types of metamorphic rocks such as schists, quartzite and marbles (Figure 2). Pliocene and Quaternary sedimentary rocks cover the metamorphics from bottom to top levels (Simsek et. al, 2005). From bottom to top these units are: Kizilburun formation, which is composed of alternating red and brown conglomerates, sandstones and claystones, and lignite seams; Sazak formation, which consists of intercalated gray limestones, marls and siltstones; Kolonkaya formation, which is composed of alternating layers of sandstone, claystone and clayey limestone, and Tosunlar formation, which is characterized by poorly consolidated conglomerates, sandstones and mudstones with fossiliferous claystone (Simsek, 1985). Quaternary alluvium as the youngest unit in the study area consists of terrace deposits, alluvium, slope debris, alluvial fans and travertine.

Limestones of the Pliocene Sazak formation, which are intensely faulted and fractured, represent first, upper reservoir rock in the field. The alternations of marble, quartzite and schist layers of the Menderes Massif metamorphics, having high degrees of secondary porosity and permeability represent the second and main reservoir rock in the field. Siltstone and sandstone alternations of the Tosunlar formation and the Kolonkaya formation act as cap rocks for the upper limestone reservoir of the Sazak formation. The well-consolidated conglomerates, sandstone and claystone alternations of the Kizilburun formation lying below the first upper reservoir act as the second cap rock for the second and main reservoir in the field. The marl and claystone alternations of the Sazak formation act as a cap rock. The micashists lying above the gneisses of the Menderes Massif metamorphics act as cap rocks for the third, deep reservoir. Geothermal fluids are mainly recharged by meteoric waters after being heated at depth and subsequently rise to reservoirs via major fault zones and flow towards the center of the graben, where the mix with cold groundwater (Simsek, 1985).

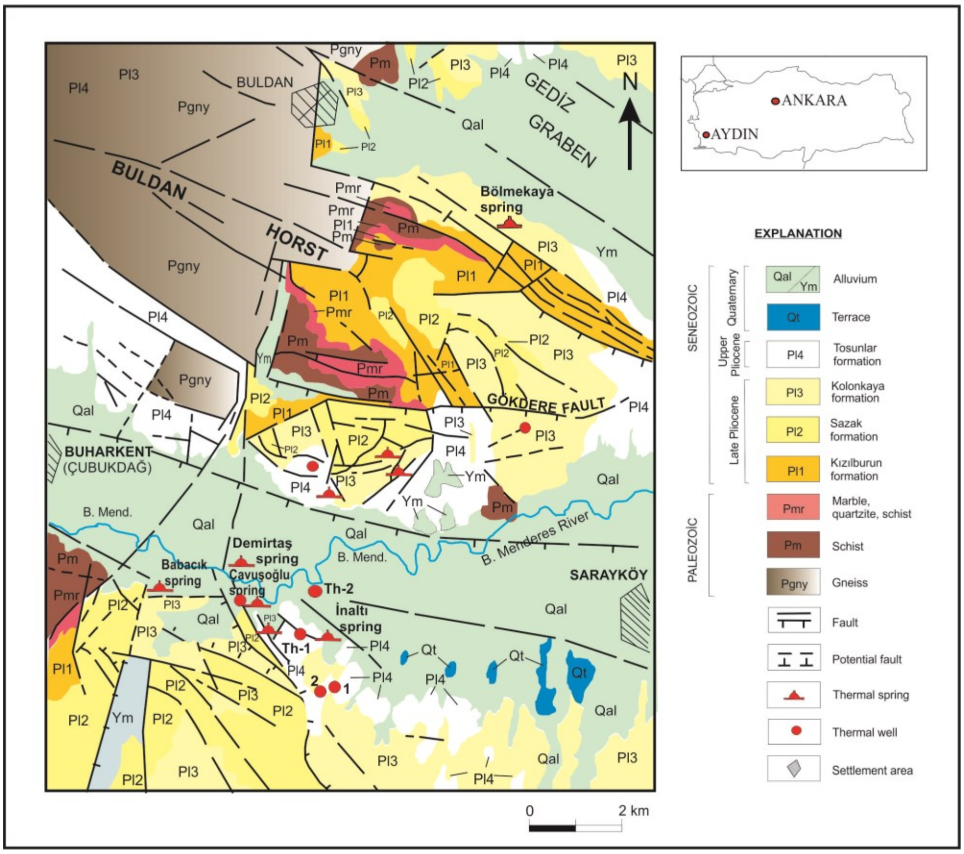

Figure 1: Geological map of the study area (modified from Simsek et al., 2005).

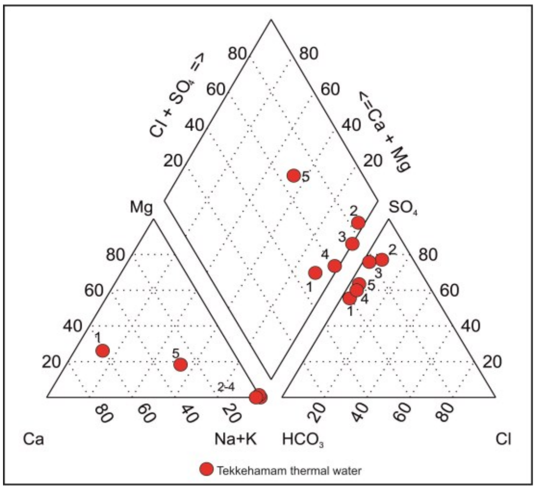

Figure 2: Piper plot showing the chemical variability of waters in the study area.

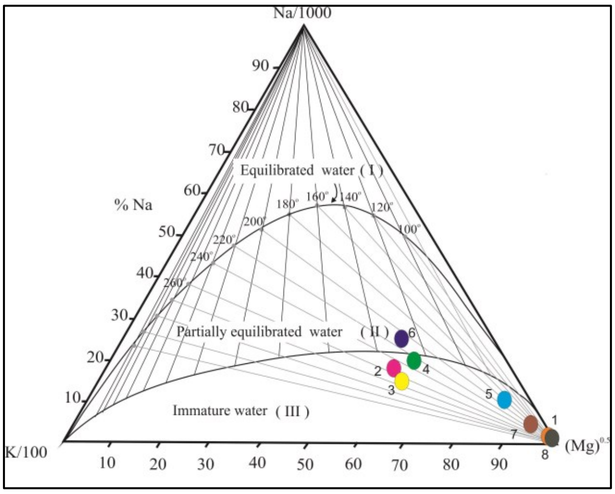

Figure 3: Water composition of selected well discharges in Tekkehamam geothermal field plotted in Na-K-Mg diagram (Giggenbach, 1988).

3. METHODS

Some of the physicochemical analyses and measurements of the waters were carried out during the period of 2010–2012. Temperature, pH and electrical conductivity values were measured using a WTW 340i multi pH meter. HCO_3 values were determined volumetrically by titration methodology using HCl (0.1M). Water samples were collected for chemical analyses and each water sample consists of two 500 ml polyethylene bottles. One of the bottles was acidified with ultrapure HNO_3 (pH: 2) after filtering with 0.45 mm cellulose membrane filters for the determination of cations. Other bottle was un-acidified for anion analyses. Soil and scale samples were collected for mineralogical, petrographical and geochemical analysis (including major and trace elements). Major constituents of water were determined at the geochemistry laboratory of the Environmental Engineering Department at Dokuz Eylul University (Turkey). Mineral saturation indices of hydrothermal minerals were calculated using the PHREEQC computer code (Parkhurst and Appelo, 1999). The mineralogy of the scale samples were determined by X-ray diffraction (XRD) methodology at the Laboratory of İzmir Institute of Technology (Turkey).

4. HYDROCHEMICAL SETTINGS

Thermal waters have yielded the outlet temperature range of 30–155°C with electrical conductivity values changing from 1590 to 4350 µS/cm, and pH values varying between 6.2 and 8.2. Thermal waters of the study area can be generally classified as $Na\text{-}SO_4\text{-}HCO_3$ type (Fig. 2). Reservoir rocks in the Tekkehamam geothermal field consist of metamorphics (gneiss, schist and marble) and sedimentary rocks including limestone. The origin of Na^+ in thermal waters is linked to metamorphic rocks, while carbonate rocks in the reservoir are the sources for Ca^{2+} and Mg^{2+}. Application of some geothermometers to the mixed-sourced waters can provide poor results. The Na-K-Mg diagram (Fig. 3) proposed by Giggenbach (1988) is often used to evaluate aquifer temperatures and to recognize water types, which have reached the equilibrium state between the host lithology and waters that are affected by mixing and/or re-equilibration at low temperatures along their circulation path. Immature waters plot rather close to the Mg corner. The waters that plot between the full equilibrium and immature water curves may result from mixing fully or partly-equilibrated water with cold immature water. Thermal waters in the study area fall into the partially-equilibrated field. Other waters fall into the immature field and reflect reservoir temperatures ranging between 200 and 250°C.

Prediction of the scaling tendencies from geothermal waters is important for evaluating the production characteristics of geothermal aquifers and for taking necessary precautions to prevent or control the scale formation. Scale samples were analyzed using a X-ray diffractometer. X-ray diffractometer diffraction patterns for deposits at the pipe (Fig. 4a). Calcite peaks are present in the X-ray diffraction pattern (Fig. 4b). Additionally, assessment of scaling tendencies involves calculation of the saturation state of the scale forming minerals. Saturation indices in the aquifer waters were calculated at outlet temperature and measured pH using PHREEQC computer code (Parkhurst and Appelo, 1999) at LLNL database for the following minerals: Aragonite, calcite, amorphous silica, celestite, chalcedony, dolomite, quartz, celestite and strontianite. Saturation indices for each mineral were then plotted versus temperature and trend curves depicted (Fig. 5). The saturation states of thermal waters with respect to selected minerals suggest that the carbonate minerals (i.e. calcite, aragonite and some dolomite) are most likely to be precipitated as scales during geothermal exploitation and well production. Moreover silica polymorphs (e.g. quartz and chalcedony), and strontium minerals (e.g. celestite and some anhydrite) seem to be possible additional precipitates at various temperatures during production applications.

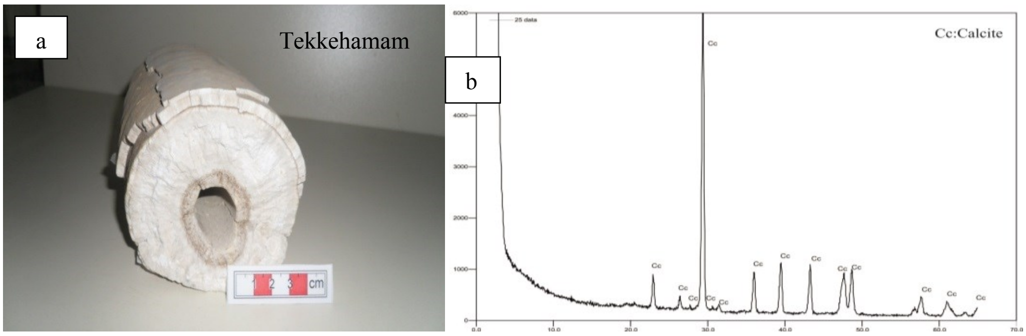

Figure 4: a) Calcite scaling on the surface equipment in a pipe at Tekkehamam field, b) X-ray diffraction pattern of scale samples taken from surface material in the study area.

5. RESULTS

Limestones of the Pliocene Sazak formation represent upper reservoir rock in the Tekkehamam geothermal field. The alternations of marble, quartzite and schist layers of the Menderes Massif metamorphics, which are characterized by high secondary porosity and permeability, represent the second and main reservoir rock in the field. Kizilburun formation act as the second cap rock in the field for the second and main reservoir. The micashists lying above the gneisses of the Menderes Massif metamorphics act as cap rock for the third, deep reservoir. Thermal waters of the study area can be classified generally as $Na\text{-}SO_4\text{-}HCO_3$ type. The origin of Na^+ in the thermal waters is related to the metamorphic rocks, while carbonate rocks in the reservoir constitute the sources for Ca^{2+} and Mg^{2+}. Carbonate scaling is the main problem in the study area. During the re-injection, carbonate scaling is observed to have occurred in the production and re-injection wells.

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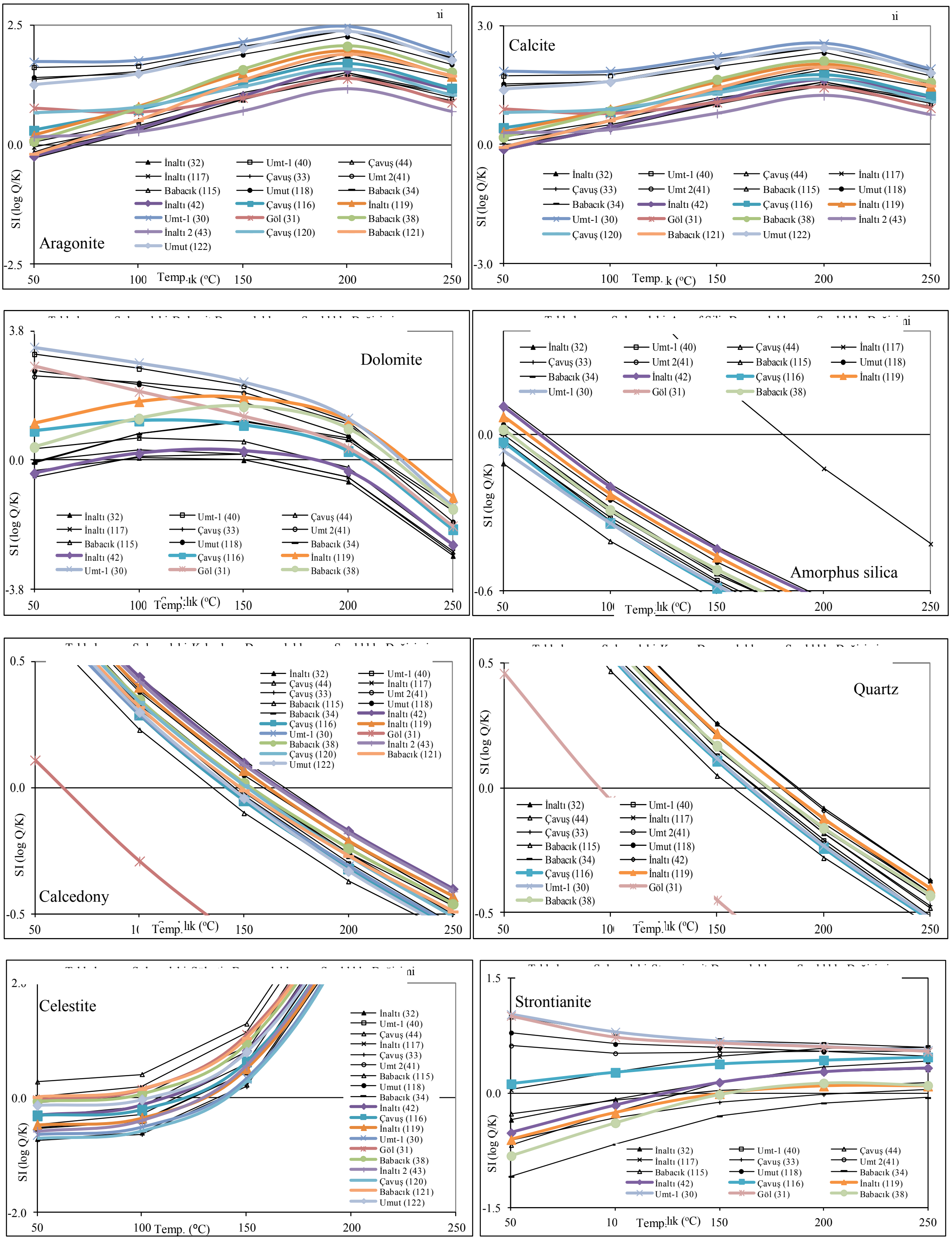

Figure 5: Mineral saturation-temperature diagrams for the selected minerals in the study area.