Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

# A Comparison of Hydrothermal Characteristics of Newly Discovered Çamlidere Geothermal Field and the Kizilcahamam Geothermal Field, Central Anatolia, Turkey

Suzan PASVANOĞLU, Mehmet ÇELİK, Zafer ARIGÜN, Sunay GÜLER

spasvanoglu@hotmail.com

**Keywords:** New a Çamlidere geothermal Field, Kizilcahamam geothermal field, Galatian Volcanic Complex, hydrothermal model, Central Anatolia, Turkey

## ABSTRACT

The Galatian Volcanic Complex includes one of the most important geothermal fields in northern Central Anatolia. Among the known of these are Kizilcahamam, Seyhamam, Çamlidere, Çubuk-Meliksah, Beypazari and Ayaş geothermal fields. Among these fields, Çamlidere field has become a research base for Geosciences due to its geological and geomorphologic features. As a result of the drilling conducted by General Directorate of Mineral Research and Exploration of Turkey (MTA) and IL Bank (ILB) recently, Çamlidere field has been found that there is also thermal water potential in the area. Kizilcahamam geothermal field is located 27 km east to Çamlidere of Ankara province. Using geothermal energy for district heating and for the purpose of bathing and balneology (thermal hotel) is major benefit for the region. This field is characterized by thermal and mineralized springs, travertine deposits, with wide alteration zones. The temperatures of the thermal springs and wells in the Kizilcahamam area is 18-43°C and 67-86°C, respectively. The Çamlidere field is characterized by thermal and mineralized springs, with temperatures in the range 20–28°C and thermal water with temperature of 34-43°C has been produced. The Çamlidere and Kizilcahamam geothermal systems occur in a volcanic terrain, and issue through the faults and fracture zones of the volcanics. Çamlidere and Kizilcahamam geothermal systems is currently being investigated in relation with recharge area and interconnected fault/fracture networks providing conduits for groundwater flow. The thermal waters in Çamlidere and Kizilcahamam are Na-$HCO_3$ type. Based analysis results of isotops ($^{18}O$, $^{2}H$, $^{3}H$), it can be said that water samples from Çamlidere and Kizilcahamam are of meteoric origin, all thermal waters have low tritium content suggesting a source from high elevations and long residence time. The rainwater infiltrated downward through fractures and fault systems is heated by an intrusive-cupola and then rises to the surface along faults and effective fractures that act as hydrothermal conduits. The obtained results from hydrogeochemistry, during their rise to the surface, Çamlidere and Kizilcahamam thermal waters are inferred to lose some heat due to possible mixing with cold waters along the fracture zones. The potential of the Çamlidere waters must be increased and new drilling's must be performed to increase flow rates and the temperatures of the waters. Thermal waters of this field are estimated to be a potential for district heating. Our work in the area continues to create a hydrothermal model of the both Çamlidere and Kizilcahamam geothermal fields.

## 1. INTRODUCTION

Recently, geothermal activities in Turkey is growing faster. Eight years ago geothermal activities were virtually nonexistent. Geothermal energy investigations carried out so far have shown that active grabens and some young volcanoes are important from the geothermal energy point of view. In Central Anatolia one of the important grabens is Kizilcahamam Graben (Kurtman and Şamilgil 1975). Many of exploration activities such as drilling and testing were made by MTA, and by private sector. Galatian volcanic complex is one of two important volcanic complexes located in central Anatolia and covers an area of about 7000 km$^2$ (Güleç 1994; Toprak et al. 1994; Schumacher 2001; Figure 1). This Volcanic Complex comprises a number of composite volcanic complexes intimately associated with development of a series of sedimentary basins (Güleç 1994; Toprak et al. 1996; Wilson et al. 1997). The northern margion of the Galatian Volcanik Complex is bordered by the Northern Anatolian Fault, and the southern margin is bounded by a continental clastic sedimentary sequence which interfingers with the volcanics. The volcanic activity which built up this complex is reported to have started at the end of the Upper Cretaceous, but reached its climax during the Miocene age (Erol 1954; Keller et al. 1992; Tatli 1975; Erişen and Ünlü 1980; Güleç 1994; Koçyiğit 1991; Gevrek 2000). This Volcanic Complex includes one of the most important geothermal areas (Bilim 2011). Among knowing of these are Kizilcahamam, Seyhamam, Çamlidere, Cubuk-Meliksah, Beypazari and Ayas. Kizilcahamam and Çamlidere are two neighboring districts with significant thermal and mineral water potential. Çamlidere is one of a new geothermal field located 100 km NW of Ankara province. Due to its geological and geomorphologic features, Çamlidere has become a research base for Geosciences. As a result of the drilling conducted by General Directorate of Mineral Research and Exploration of Turkey (MTA) and IL Bank (ILB 2009) recently, Çamlidere field has been found that there is also thermal water potential in the area. Four artesian wells (AÇT-1, and AÇT-2 wells in Muzrupagacin, and ÇM-1, and ÇM-2 wells in Ahatlar region; see Figure 2) with a depth of between 155.4 to 1367.5 m, a temperature range of 34 – 56.1°C and discharge rate between 9 and 50 l/s was produced.

Kizilcahamam geothermal field is located 27 km east to Çamlidere of Ankara province. Using geothermal energy for district heating and for the purpose of bathing and balneology (thermal hotel) is major benefit for the region. The thermal waters in the Kizilcahamam area are located in and around the town of Kizilcahamam and issue through the faults and fracture zones of the volcanic. Drilling studies in the Kizilcahamam field were started in 1984 by MTA. 14 wells have been drilled, ranging from 180-1556 m to test the geothermal system, but none of the wells encountered temperatures exceeding 86°C. Geological, geochemical and geophysical studies have been previously carried out by Keskin 1974; Tatli 1975; Kutman and Samilgil 1975; Ongür 1976; Kocak 1977; Demirörer 1985; Gürer and Çelik 1987; Güleç 1994; Canik and Pasvanoğlu 1990; Burçak 1999; Pasvanoğlu and Arigün 2001; Kaya et al. 2006; Beyhan 2006).

The study area is located in vicinity of Ankara in district of Çamlidere and Kizilcahamam. The objectives of this work are: (a) a chemical and isotopic characterization of thermal surface manifestations and reservoir fluids of the study area; and (b) the elaboration of a hydrogeological model of the sub terranean flow systems in the area

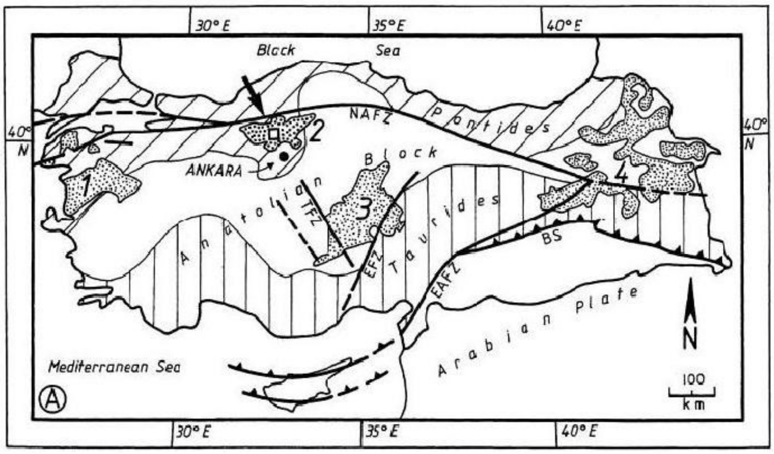


**Figure 1: Location of study area. (A) Geological sketch map of Turkey shows the major geotectonic elements such as the pontide and Tauride fold belts and the major fault zones. (NAFZ/EAFZ : North/East Anatolian Fault Zone; EFZ/TFZ: Ecemiş/Tuz Gölü Fault Zone). The dotted areas indicate the major volcanic provinces of West Anatolia(1), Galatian (2), Central Anatolia or Cappadocia(3) and East Anatolia(4) ( Schumacher et al. 2001). The arrow indicates the study area.**

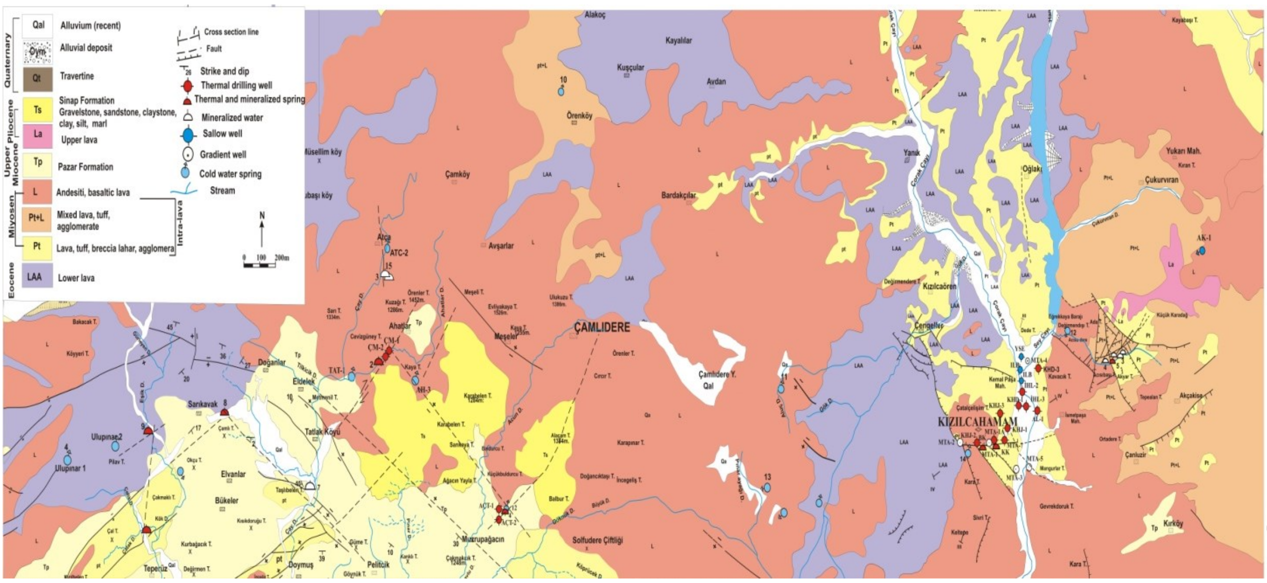


**Figure 1. Geological map of the study are**

## 2. GEOLOGY

The study area is within the Anatolian tectonic belt of Turkey. The basement beneath the province consists of Paleozoic schists and Permo-Triassic limestones. The Lower Cretaceous limestone and Upper Cretaceous flysch facies and limestone lie over the Paleozoic basement, and are overlain by the Galatian Volcanic Province (Güleç 1994; Gevrek 2000). The dominant rock type in the study area is volcanic type. The earliest lava flow took place in Paleocen- Eocene age called as lower lava of AA-type plateau basalt. The thickness of the lower lavas range between 250 to 400 m and are of fissure eruption .They show tectonic and cooling fractures and cavities. AA lavas are overlain by so called intra-lava level of Upper Miocene age over which unconformably comes Sinap Formation of Pliocene age. Intra-lava represent eruptions from single centered volcanos and are made up of lava flows and pyroclastic volcanic material. Pyroclastic material is widely observed in the study area and is composed of lahar volcanic breccia, tuffs, and aglomarates (Figure 2) of 150 to 200 m thickness. Intra-lava level is in the complex situation with Miocene age of Pazar Formation and shows very little permeability. Following the exploration of the volcano cones, the lava flows became dominant. The lavas are of andesitic and basaltic composition, and at some localities, they show slicified – lava character (Figure 2).This unit is compact with no porosity. Intra-Lava to the East of Kizilcahamam and west of Çamlidere are interfingering with the Pazar Formation and in the North with the diatomaceous clays. According to the fish remnants obtained from these clays, they are of Upper Miocene, with variable thickness up to 500 m (Erişen and Ünlü 1980).

Intra-lavas are overlain by the Pliocene acidic lavas flows and domes of the Upper lavas. The Upper lavas are the last units arround Kızılcahamam. The Upper lavas have altered, mainly they are ryolites, tracites and glassyfied tuff observed in the northeast part of Kizilcahamam, in Acisu creek. The Pazar Formation of Upper Miocene age have 600 m thickness and is composed of carbonate-cemented conglomerate sandstone, tuffit, marl siltstone and aglomerates. This formation is of low porosity, bedded and whitish –

yellow in color. Pliocene sediments are overlying the lava horizontally and they are in the shape of stream reservoir and composed of gravelstone, sandstone, clay alternate, silt and marl. Quaternary deposits (travertines and old and recent alluviums) at the top are unconformably covers the Galatian Volcanic Complex. There are many faults in the area improved depending on the North Anatolia Fault due to Alpine orogeny. Gravity faults, which strike dominantly in the ENE–WSW direction, are observed in the study areas. These faults, is a product of compressional tectonics.

## 3. BACKGROUND ON THE INVESTIGATED GEOTHERMAL FIELDS

Major thermal and mineral water sites of the Kizilcahamam graben are Kizilcahamam and Çamlidere summarizes the number of wells drilled, maximum and minimum drilled depths, measured down hole temperature ranges, total discharge rate, aquifer and cap rocks, present use, and references for Kizilcahamam and Çamlidere system(Table 1). Based on field observations, Kizilcahamam and Çamlidere geothermal fields show lithological continuity. They have similar cover and reservoir rocks and heating source. The general hydrogeologic setting of the Kızılcahamam and Çamlidere areas is summarized by Koçak (1977), Özmutaf (1984), Öktü (1985), Gevrek and Aydın (1988), Gevrek (2000), Özbek (1988), Hacısalihoğlu (1999), Taka (2001), Pasvanoğlu and Arigün (2001), Canik (2004). In the study area, the sedimentary units of the Miocene Pazar Formation are generally impermeable and thus seal pressured aquifers underneath the impermeable units are mostly altered tuffs, clay, marl and unfractured Lavas. Intercalated lavas are also generally impermeable in the study area, yet in some places they show fractures with water fill. Therefore, they overall are termed as low permeability units. The lower lava unit in the study area is generally fractured and permeable. Thus, it has good aquifer characteristics, being a good target for thermal water drilling. The lower lavas with permeable characteristics have made the percolation of thermal water in the area possible.

**Table 1: Well informations for Kizilcahamam and Camlidere geothermal systems**

| Geothermal System | NWD | MMDD | TDR (l/s) | Reservoir Rocks | Cap Rocks | Present Use | Well Temperature | Heat Source |
|---|---|---|---|---|---|---|---|---|
| Kizilcahamam Geothermal System | 14 | 180-1556 | 95 | Faults and fractuers of lower lava unit (andesite and basalts), aglomerates | Miocene Pazar Formation Altered tuff, clay, marl, silt, unfractured lavas | Spa, Green house heating and District heating | 67-86°C (Well head) | Geothermal gradient |
| Çamlidere Geothermal System | 4 | 155.4 -1367.5 | 9-50 | Faults and fractures of lava (andesite and basalts), agglomerates | Pliocene Sinap and Miocene Pazar Formations Altered tuff, clayston, marl, silt, unfractured lavas | - | 34 -56°C (Well head) | Geothermal gradient |

**NWD: Number of well drilled (m), MMDD: Maximum and minimum depth(m), TDR: Total discharge rate (l/s)**

However, due to compression and intense tectonism, fracture aquifers may be formed within the volcanic rocks (Canik 2004). Moreover, the alluvium of gravel, sand and clay is thermal water aquifer in the Kocaçay valley. The flow of springs is much more in faulting zone. The production and gradient wells in Kizilcahamam field indicated that only the Kızılcahamam fault zone has reservoir properties (Gevrek 2000). Since 1984 up to 2013 a total of 14 exploration and production wells with a depth of 180-1556 m have been tripped by the Kızılcahamam Municipality to test the geothermal system, but none of the wells encountered temperatures exceeding 86ºC. In 1986, five gradient wells were drilled in the area to determine the temperature distribution and to detect the presence of possible fault zones and hot water. Although the geothermal gradients were relatively high in the MTA-3, -4, -5 and -6 wells, none of the gradient wells encountered geothermal fluids (Gevrek et al. 1988; 2000). Stil in the Kizilcahamam geothermal area a total of 8 production wells ( MTA-1A and MTA-7, KHJ-1, KHJ-3, IHL-2, IHL-3, AL-1 and KHD-1) are used for a purpose of heating and thermal spas. While a total of 95 l/s flowrate and average temperature of 76°C can be produced, due to pressure drop in the production wells, in 2012 a total of 70 l/s were produced.

At Acisu Creek which is located about 4 km northeast of Kizilcahamam, there are numerous hot springs mostly emanate from the large fractures and fault zones and are of different discharge and temperature ranges. For those hot springs, 4 under operation for bottling. One of these four springs belongs to the municipality and is called Kizilcahamam Çamlik mineralized water, and the other three belongs to private (As-Koop) Company. Mineral water spring has a temperature of 18° C with a total flowrate of 0.353 l / s. The spring is emanating from a fault at Acısu hill (Pasvanoğlu and Arigün 2001). $CO_2$ is also emanating and at discharge reddish – brownish ironoxide deposits are observed. The thermal waters in the Çamlidere field are located around the town of Çamlidere and issue through the faults and fracture zones of the volcanic.

These thermal springs with their temperatures changes between 20°C and 28°C are basically clustered in different areas. Ahatlar, Murupağacın, Atça, Tatlak and Sarıkavak are important thermal waters in the area. In the Çamlidere geothermal field, thermal water (Except Muzrupağacin) is used in an uncontrolled manner and waters from well and springs flow out of control since wells have not been opened with appropriate drilling techniques.

The geological, and geophysical studies, aimed towards the determination of the geothermal potential of Çamlidere field, were first started by the MTA, IL Bank (2009), Canik (2004; 2005), Beyhan and Toy (2006), and by Muratcay (2006). With temperature of 23-27°C and discharge of 0.01-0.1 l/s, the Ahatlar main spring is the most important hot water spring of the area (Canik 2004; Beyhan and Toy 2006). In the Ahatlar region, two artesian waters (ÇM-1 and ÇM-2) have been obtained from IL Bank wells in 2009. At ÇM-1 well, the flowrate is 46 l/s at 34°C from 103 m depth. ÇM-2 well is penetrated water with 9 l/s and 43°C at 274 m. This spring is issue from N45°W strike slip fault within Ahatlar stream. Southeast of the Çamlidere the Muzrupağacin spring has a temperature of 24.5°C and discharge of 0.5 l/s. Artesian waters have been obtained from two (AÇT-1 and AÇT-2) MTA wells (MTA 2012). At AÇT-1 well, the discharge is 10 l / s at 43°C from 1020 m depth. AÇT-2 well are penetrated water with 7 l/s and 56°C at 1367.50 m.

Atça mineral water W-NW of Çamlidere (Özgür et al. 1999), is another mineral water springs which is taken from two shallow (6-7 m depth) wells. This spring waters were taken from two shallow wells. The flow rate of the mineral water is 3.5 l/s (Canik 2004, 2005) with a temperature of 13°C and $CO_2$ gas is also emanating with water.

Southwest of the Çamlidere a bout 17 km the Tatlak mineral water spring has a temperature of 22.5°C and discharge of 1 l/s. There is also another two thermal water springs which are located southwest of Çamlidere. These thermal springs are Sarikavak Ilıca and Sarikavak Uyuz thermal springs. Temperature and the flowrate of these waters are 25 and 27°C with 0.05 -1 l/s respectively. In addition to these thermal and mineral waters, a few cold springs are present in and around Kizilcahamam and Çamlidere. Surface manifestations, exploration and production wells show that the Kızılcahamam geothermal field is a fractured system with low-temperature fluids (Gevrek 2000; Pasvanoğlu and Arıgün 2001).

## 4. WATER CHEMISTRY

### 4.1 Hydrochemical characteristics of the two geothermal fields

The water samples were analyzed with a month of sampling. The temperature, pH and EC measurement were conducted in the field at the discharge points. Total 29 chemical analytical results of waters were selected and used to comment on hydrogeology and geochemistry. Eleven thermal and mineral water samples from Kızılcahamam, 11 samples from Çamlidere geothermal field. Also 3 cold water samples (2 from springs and one from stream) done from Kizilcahamam and 4 cold springs from Çamlidere field. The pH values for thermal waters are between 6.0 (Kizılcahamam, no 3) and 7.80 (Çamlidere, no 3 and 9), but those for cold spring range from 6.68 (Çamlidere, no 11) to 9.80 (Çamlidere, no 13). The TDS value for Kizilcahamam thermal waters range 1807 to 4249 mg/L, with the cold water having a maximum TDS value of 387 mg/l. Çamlidere thermal waters attain a maximum TDS value of 3266 (sample 1). Higher TDS concentration in Kızılcahamam thermal water than in Çamlidere thermal water probably reflect longer circulation and residence times. The dominant anion of thermal waters of Kizilcahamam and Çamlidere is $HCO_3^-$ varying from 210 (Çamlidere, no 8) to 2276 (Kizilcahamam, no 5) mg/l. They also show high concentrations of Na with maximum value of 1000 (Kizilcahamam, no 4 and 5) mg/l and 771(Çamlidere, no 1)mg/l respectively.

The cold waters attain a maximum $HCO_3^-$ value of 262 mg/l (Çamlidere, sample no 11). Cold waters in Kızılcahamam and Çamlidere are mainly dominated by $Ca^{2+}$, $Na^+$, and $HCO_3^-$, and their ion contents are low. The concentrations of major ions in both fields also vary, reflecting the processes governing their mineralization. Thus, cold groundwater with low salinity typically has a $HCO_3$–Ca/Na composition because of its meteoric origin. In contrast, thermal waters are saline, characterized by a dominant $HCO_3$/Cl–Na/Ca composition (Figure 3). The alkali-bicarbonate nature of the thermal waters in both fields is also well displayed on a Piper diagram in Figure 3 is typical for waters where groundwaters dissolve $CO_2$ arising from deep gas exsolution (Güleç 1994). The Piper diagram shows that cold water samples from a small group on the far left of the central diamond (10, 12,13), which is separate from the other samples because of its lower chloride and sulfate contents.

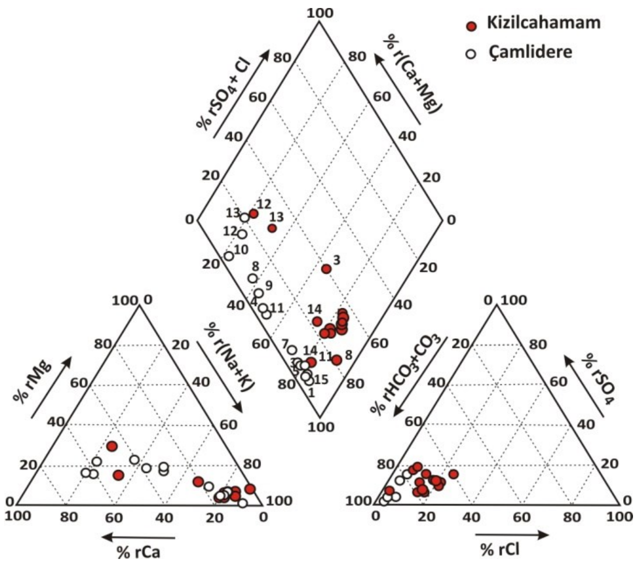


**Figure 3: Piper diagram**

This group is the least mineralized of all the samples tested. $Na^+$ in waters is derived from dissolution of Na-bearing salts or alteration of feldspars in ultrabasic rocks and schists. Clay minerals also enhance exchange of Na with Ca. High bicarbonate concentrations are due to reaction of $CO_2$-rich waters and limestone during the circulation of meteoric waters**.** The $Cl^-$ concentration (107-486 mg/l) is relatively rich in the Kızılcahamam water samples taken from fields to reservoirs, which can be explained by dissolution of rock units or as a result of circulation for a long residence time with rocks. It has high $Na^+$, $K^+$, B, and Cl, which indicates strongly that the water is in contact with silicic rocks. K-gain during the rise of fluid could be related to K-alkaline volcanism in the region (Pasvanoğlu 2013). The ion contents of deep groundwater in Çamlidere are more variable than those in

Kizilcahamam. This is probably due to the greater variety of mixing extents between cold and thermal groundwater in the field. Low $Cl^-$ concentration in this type of waters is attributed to mixing of ascending thermal waters with cold groundwater. All thermal waters in both Kizilcahamam (7-19 mg/l) and Çamlidere contain high (2-7 mg/l) values of boron. High boron content is attributed to deep water circulation. Its source could be the Neogene volcanism.

The Na–K–Mg diagram of Giggenbach (1988) can be used to determine the maturity of water samples as well as to obtain Na/K and Mg/K geothermometer temperatures. Figure 4 shows Kizilcahamam and Çamlidere analyses plotted on Na–K–Mg diagram showing fields of two distinct clusters, one made up of Kizilcahamam and Çamlidere thermal water ( Except no 8 and 9), samples away from the Mg corner and a second consisting of Camlidere thermal waters ( 4, 8 and 9 samples ) and all cold water plot near the Mg corner below the partial-equilibrium line in the field of immaturewaters. The high relative concentration of Mg in these spring samples suggests that they are immature waters that are not in equilibrium with the host rock.

There are two probable reasons for the observed difference in the positions of the two clusters, and for the proximity of the Çamlerdere waters to the Mg corner: (1) mixing of deep immature thermal waters with shallow cold meteoric waters; (2) circulation of hot water through evaporitic formations and alteration zones (Giggenbach 1988).The high Cl content, relatively low $SO_4$ content and low temperature indicate that the most probable mechanism is mixing of deep immature thermal waters with shallow cold ground water, i.e. they are not in chemical equilibrium with the host rocks.

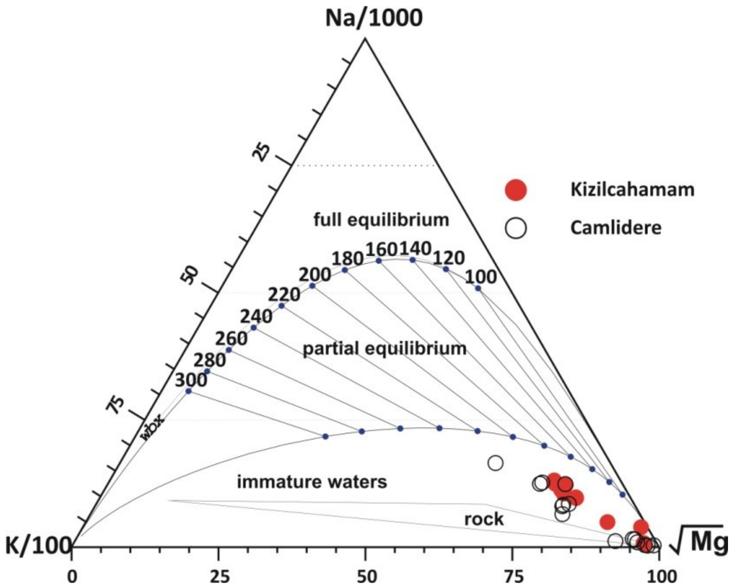


**Figure 4: Giggenbach diagram for the study area**

### 4.2 Geothermometers

Chemical composition of the spring's water is used to estimate the reservoir temperature. For this reason the solubility and Exchange reactions of various solid phases must be taken into account. Application of the Na–K and K-Mg geothermometers yielded inconsistent and unrealistic estimates, as might be expected considering the lack of equilibrium between the water and rocks (Figure 4).

Hence, we applied silica geothermometry (quartz and chalcedony) developed by Arnorsson (1983) to the concentrations obtained for Kizilcahamam and Çamlidere estimate the temperature before mixing occurred. The estimates obtained from quartz geothermometers (90-129°C Kizilcahamam, and 91-150°C for Çamlidere samples) are not the same (Table 2). On the other hand, chalcedony temperatures (72-109°C for Kizilcahamam, and 73-130°C for Camlidere samples) are lower than the quartz temperatures. Mixing of hot, silica-rich geothermal water with cold, silica-deficient, shallow groundwater maybe the reason for lower reservoir temperatures indicated by $SiO_2$ geothermometers.

The rather fast equilibrating K-Mg geothermometer (Giggenbach, 1988) can be used for all samples. The resulting equilibrium temperatures are listed in Table 3, which shows that the $SiO_2$ and the K-Mg equilibrium temperature are not the same, namely between 98 to 106 °C for Kizilcahamam, and between 68 to 127 °C for Çamlidere samples These temperatures are similar to those obtained from the chalcedony geothermometer, temperatures, but lower than those of quartz geothermometer. The thermal waters derive from conductive heating and geothermal gradient. These waters seep into the subsurface system along fault and fracture zones, get heated and discharge at the surface. Another heat source may be due to regional volcanic activity.

### 4. 3 Evaluation of isotopic data

Isotopic compositions of waters in the study area have not been investigated before. The isotopic concentraton and ratios of ($^{18}O$), ($^{2}H$), and ($^{3}H$) of the waters from springs and wells in the Kizilcahamam and Çamlidere fields was used to interpret the circulation of the groundwater system, its recharge-discharge and the hydrogeologic character of the aquifers. The relationship between $\delta^{18}O$ and δD values are plotted on Figure 5, which also shows the worldwide meteoric line(WMWL) ($\delta D = 8\delta^{18}O + 10$) of Craig (1961) and the Konya meteoric water line (KMWL) ($\delta D = 8\delta^{18} O + 16$) of Şentürk (1970). On the $^{18}O$–$^{2}H$ diagram (Figure 5), all the thermal waters from Kizilcahamam and Çamlidere plot close to the global meteoric water line indicate that they are likely to be of meteoric origin.

**Tablo 2: Geothermometer results for the study area**

| No | T°C | TQ1 | TQ2 | TC1 | TC2 | TK-Mg |
|---|---|---|---|---|---|---|
| Kizilcahamam | | | | | | |
| 1 | 77.6 | 105 | 105 | 78 | 81 | 98 |
| 2 | 77 | 103 | 112 | 85 | 88 | 98 |
| 5 | 32 | 90 | 101 | 72 | 76 | 102 |
| 6 | 72 | 113 | 120 | 95 | 96 | 106 |
| 7 | 76 | 113 | 120 | 95 | 96 | 106 |
| 8 | 81 | 111 | 118 | 93 | 94 | 104 |
| 9 | 78 | 125 | 129 | 106 | 106 | 104 |
| 10 | 70 | 115 | 122 | 97 | 98 | 103 |
| 11 | 70 | 128 | 132 | 109 | 109 | 103 |
| Camlidere | | | | | | |
| 1 | 42 | 115 | 121 | 97 | 97 | 127 |
| 2 | 23 | 149 | 148 | 128 | 126 | 68 |
| 4 | 25 | 91 | 101 | 73 | 77 | 69 |
| 5 | 40 | 139 | 140 | 119 | 117 | 103 |
| 6 | 37 | 113 | 119 | 94 | 96 | 101 |
| 7 | 21 | 128 | 132 | 109 | 109 | 108 |
| 8 | 28 | 111 | 118 | 92 | 94 | 68 |
| 9 | 28 | 112 | 119 | 93 | 95 | 87 |
| 14 | 27 | 150 | 149 | 130 | 127 | 107 |

TQ1: Quartz no steam loss; TQ2: Quartz steam loss (Arnorsoon 1983); TC1: Chalcedony no steam loss TC2: Chalcedony steam loss; TK-Mg: (Giggenbach 1988)

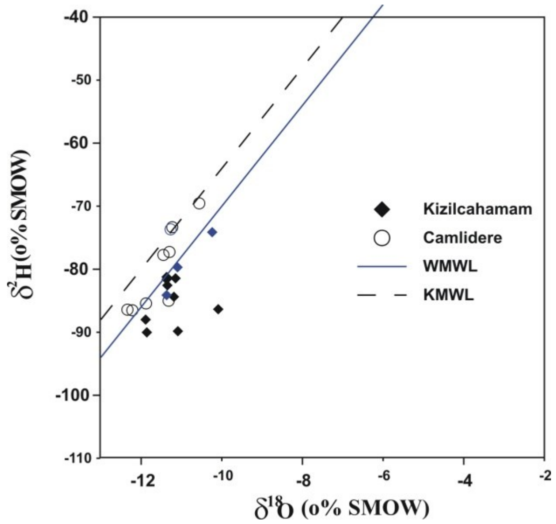


**Figure 5: Oxygen-18 deuterium diagram**

It is suggested that the rainwaters percolated downward through faults and fractures are heated by geothermal gradient and then rise to the surface along permeable zones that act a hydrothermal conduits. Both thermal waters from Kizilcahamam and Çamlidere show $^{18}O$ shift from the meteoric water line indicating that their isotopic composition is affected by water-rock interaction process, evaporation and different rock types of aquifer. It is noticeable that Kizilcahamam thermal waters represent more negative oxygen-18 values than Çamlidere thermal waters.

It suggests that thermal waters below Çamlidere have likely mixed with more cold groundwaters ratio enriched than Kizilcahamam thermal waters. This is also confirmed by water chemistry and temperatures of these waters. However, they are affected by fluid–rock interaction and the differences in the ratios of Cl-B,and Li concentrations between Kizilcahamam and Çamlidere imply that there are different subsurface temperatures and host rock in both areas. Cold waters from Kizilcahamam and Çamlidere areas are characterized by low chloride. In addition, tritium values suggest that water comes from shallow circulating and are recharged by recent, low-altitude precipitation.

## 5. CONCLUSION

The Kizilcahamam and Çamlidere (Ankara) geothermal systems occur in a volcanic terrain, with interconnected fault/fracture networks providing conduits for water flow. According to previous research (Pasvanoğu and Arıgün, 2001, the two geothermal fields belong to low temperature–convection system with different reservoir temperature.(Figure 6) For both thermal provinces, thermal waters have been cooled and mixed with different quantities of shallow cold groundwater during their ascent to the surface. Therefore, they are different in hydrochemical type and compositions. Based on the main constituents, Çamlidere thermal waters can be classified as $NaHCO_3$, and Kizilcahamam thermal waters can be classified as $NaHCO_3$ and $CaHCO_3$ type, with high concentrations of B, Li, and Cl.

Conservative elements indicate that the types of analyzed waters have similar origin, and the difference in concentration is due to the dilution of thermal water with shallow groundwater. Long circulation of meteoric waters within the basement rocks is indicated by low tritium values in the thermal waters. Surface and cold waters are of Ca–Na–$HCO_3$ type and represent shallow circulating groundwaters with low TDS and EC. From the schematic geological profile illustrating the flow patterns of the two geothermal fields (Figure 6), the recharge origin of thermal water is precipitation, and concentration of heat depends on groundwater transport processes in the fault and fracture zones in bedrock, where the main heat source is located. Rainfall in the mountain areas penetrates through deep fault and fracture zones, flowing downwards to join with deep circulating water and absorbing heat from the surrounding rocks. The thermal groundwater is then transported upwards into the shallow groundwater system in Quaternary sediments, along fault and fracture zones in the basin. Regional geological structure is thus the dominant control on the formation of the geothermal fields. Çamlidere geothermal field has low temperature geothermal system, and geothermal energy can be used district and green house heating as well as health and turistict purposes.

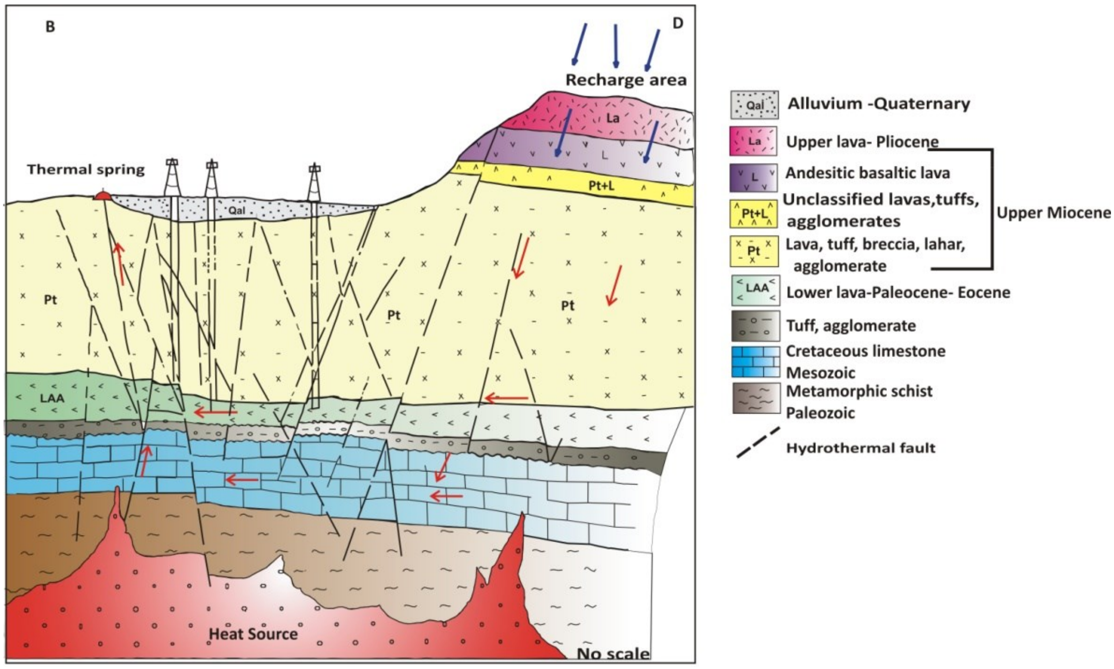


**Figure 6: Conceptual model for both geothermal area**

## ACKNOWLEDGEMENTS

This study is financially supported in part by the Research Foundation of the Ankara University (Bap Grant Project No: 91-25-00-94 and Project No. 13L4343011). Prof. Dr. Serdar Bayarı and Prof. Dr. Mehmet Ekmekçi of the Hacettepe University are greatly acknowledged for performing the tritium, chemical analyses and stable isotops.

## REFERENCES

Arnōrsson, S., Gunnlaugsson, E., Svavarsson, H.: The chemistry of geothermal waters In Iceland. III. Chemical geothermometry investigations. Geochim.Cosmochim. Acta , 47,(1983), 567-577.

Beyhan, A., Toy, E.: Çamlıdere (Ankara) Belediyesi jeotermal ön etüt raporu, Iller Bankası 7. Bölge Müdürlüğü raporu, Ankara, (2006).

Bilim.F.: Investigation of the Galatian volcanic complex in the norther central Turkey using potential field data, Physics of the Earth and Plantery Interiors, 185, (2011) 36-43

Canik, B.: Kızılcahamam dolayındaki sıcak ve maden su hakkında not (1972), Ankara.

Canik, B., Pasvanoglu,S.: Kizilcahamam dolayındaki sıcak ve mineralli kaynakların hidrojeoloji incelemesi, Project no. 91-25-00-94 Project of University of Ankara (1990).

Canik, B.: Ankara- Çamlidere jeotermal sahası arama projesi,(2005), Ankara

Canik, B.: Çamlidere maden suyunun jeoloji, hidrojeoloji ve jeofizik incelemesi raporu, (2004), Ankara

Craig, H.: Isotopic variations in meteoric waters, Science, 133 (1961), 1702 - 1703.

Demirörer, M.: Ankara Kızılcahamam resistivite etüd raporu, MTA report, no: 7781, (1985) Ankara.

Erisen, B., ve Ünlü, M.R. : Ankara , Çubuk , Kızılcahamam ve Kazan alanının jeolojisi ve jeotermal enerji olanakları MTA report ( 1980) , Ankara.

Erol, O.: Köroğlu-Isıkdaglari volkanik kütlesinin orta bölümleri ile Beypazarı- Ayas arasindaki Neojen havzasinin jeolojis, hakkinda rapor, MTA report no. 2279 (1955) Ankara

Gevrek, A. I. , ve Tekin, Z. , ve Tuncay, M.N.: Ankara Kızılcahamam jeotermal alanı gradyan sondajlarının (MTA-2, MTA-3, MTA- 4 ), kuyu bitirme raporu, MTA report, no: 8749, Ankara.

Gevrek, A. I., Aydin, S.N.: Hydrothermal alteration studies in Kizilcahamam (Ankara) geothermal field and its evolution on the development of this field, Proceding International Medditerranean Congress on Solar and Other New Renewable Energy Resources, !4-!9 November, Antalya, (1988) 606-616.

Gevrek, A. I.: Water rock interaction in the Kızılcahamam geothermal field ,Galatian Volcanic Province Turkey, a modelling study of a geothermal system for reinjection well locations. Journal of Volcanology and Geothermal Research, (2000),(96) 207–213.

Giggenbach, WF. : Geothermal solute equilibrium. Derivation of Na-K-Mg-Ca geoindicators. Geochim. Cosmochim. Acta, 52, 2749 - 765. NITAR/UNDP Publication, Rome, (1988) 119–142.

Güleç, N.: Geochemistry of geothermal water and its relation to the volcanism in the Kizilcahamam Ankara area, (Turkey) . Journal of volcanology and geothermal research , 59, (1994),295-312

Gürer, A. , ve Çelik, I. , Kızılcahamam sahası jeotermal aramaları yüksek ayrımlı sismik etüd raporu,. MTA raporu, No: 8255, (1987)Ankara.

IL Bank: Çamlidere - Ahatlar(Ankara) bölgesi jeotermal sular kuyu bitirme raporu (2009), Ankara

Keller, J., Jung, D., Eckhardt, F.J., Kreuzer, H., Radiometric ages and chewmical charaterization of the Galatian andesite masif, Pontus, Turkey, Acta Vulcanalogy, 2, (1992), 267-276.

Keskin, B.: Ankara bölgesi Kızılcahamam kaplicasi hidrojeoloji, MTA report, (1974) Ankara.

Koçyiğit, A.: An example of an accretionary forearc basin from northern Central Anatolia and its implications for history of subduction of Neo-Tethys in Turkey. Geological sociaty of America bulltein, (1991) 103, 22-36.

Koçak, A.: Kızılcahamam kaplıcası hidroloji etüdü, MTA report, no. 8565, (1977) Ankara.

Kurtman, F., Şamilgil, E.: Geothermal energy posibities, thier exploration and evaluation in Turkey. Proceding Second U.N. Symposium on Geothermal Resources, San Francisco, CA, (1975), 447-457

Muratçay, EV. : Çamlıdere (Ankara Kuzeybatısı) Yöresi volkanik kayaçların petrolojisi ve jeokimyası. Hacettepe Üniversitesi Doktora tezi, ( 2006).

Schumacher, R., Schumacher, U.M., Toprak, V., The Sarikavak Tephra, Galatea, north central Turkey: a case study of a Miocene complex plinian eruption deposit. Journal of Volcanology and Geothermal Research, 112, (2001), 231-245.

Şentürk, F., Bursali, S., Omay, Y., Eran, I., Güler, S., Yalçin, H., Önhon, E.:, Isotope Techniques Applied to Groundwater Movement in the Konya Plain, Isotope Hydrology (Proc.Symp. Vienna, P.153, IAEA,(1970) Vienna.

Öngür, T.: Kızılcahamam - Çamlıdere -Çeltikçi - Kazan dolayının jeoloji durumu ve jeotermal enerji olanakları, MTA report, no: 5669,(1976) Ankara.

Öngür, T.: Kızılcahamam GB' sının Volkanolojisi - Petroloji İncelemesi, Türkiye Jeoloji Kurumu Bülteni, (1977) c-20; 1 - 12, Ağustos; Ankara.

Öktü G.: Ankara-Çamlıdere ilçesinin su ihtiyacı ile ilgili olarak mahallinde yapılan ön incelemeye ait rapor, MTA report no:7683, 20, (1985).

Özbek, T.: Interpretation of Ankara- Kizilcahamam geothermal area, U.N. Seminer on new developments in geothermal energy,(1988) 22-25 May 1989, Ankara.

Özgür, R., Yurtsever, D., Uğur,H., Yildirim, T., Yildirim, N., Güner, N. Aydoğdu, Ö.: Aktaş-Salur Dereköy (Gerede, Bolu) vePeçenek(Çamlidere, Ankara) alanının jeolojisi ve jeotermal enerji olanaklari raporu, MTA report no 962, 45 (1995), Ankara.

Özmutaf, M.: Ankara Kızılcahamam kaplıcası 1 Nolu sıcak su sondajı kuyu bitirme raporu, MTA report no. 7723 (1984) Ankara.

Pasvanoğlu., S. Arıgün, Z.: Hydrogeological investigation of the mineral waters of Kizılcahamam Acısudere Greek, Geological Symposium of Fırat (ELAZIĞ) University,12-16 October, (2001) Elazığ-Turkey,12-16.

Pasvanoğlu, S.: Hydrogeochemistry of thermal and mineralized waters in the Diyadin (Ağri) area, Eastern Turkey, Applied Geochemistry, 38,(2013), 70-81

Piper, A.M.: A Graphic Procedure in Geochemical Interpretation of Water Analyses, American Geophysical Union Transactions 25, (1944), 914–923.

Taka, M., Şener, M. and Gevrek, A. I.: Seben-Gerede-Kıbrıscık (Bolu)-Beypazarı-Çamlıdere - Güvem (Ankara) alanındayüzeylenen Üst Miyosen volkanikleri altındaki birimlerin enerji hammadde potansiyeli, MTA report no: 10440, 74 s (2001).

Tatli; S.: Kızılcahamam Doğu Alanın Jeolojisi ve Jeotermal Enerji Olanakları MTA report no. 5749, (1975) Ankara.

Toprak, V., Savaşcın, Y., Güleç, N. and Tankut, A.: Structure of the Galatean Volcanic Province, Turkey, International Geology Review, 38 (1996), 747-758.

Wilson, M., Tankut, A., Gulec, N.: Tertiary volcanism of the Galatian province, North-west Central Anatolia, Turkey, Lithos, 42, (1997), 105-121.