Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal Energy Consumption in Bergama Geothermal Field

Mine Alacali

Bergama Municipality, Turkey

minealaca@yahoo.com

Keywords: Geothermal, geochemistry, district heating,

ABSTRACT

Energy, in any form, is an essential need for a human being in order to meet his/her demands and any opportunity concerning energy forms must be evaluated and consumed. In the western region of Turkey there are many big and small geothermal fields, one being Bergama geothermal field, located in the northern part of İzmir, an ancient and touristic city. Geology of the region is comprised of Lower Triassic Kınık formation containing allochthon limestones taking place at the bottom of the stratigraphy of Bergama geothermal field, towards the top, Eocene-Oligocene aged Kozak granodiorites, Middle Miocene aged Yuntdağ-I and Yuntdağı-II volcanics, Upper Miocene aged Yeniköy formation and Upper Miocene-Pliocene Aged Yuntdağı-III volcanics take place. The youngest formation of all is the Quaternary alluvium. The volcanics located in the field, which have been fractured due to the tectonics, behave as the reservoir rock for the geothermal fluid to be stored in while the altered clay levels form the cap of the system. Possible heat source for this and its neighboring geothermal system is accepted as high geothermal gradient resulting from both the effect of the tectonics and volcanic activities in the region. There are several hot springs with low temperatures varying from 26 °C to 70 °C and six geothermal wells with temperatures varying from 43.2 °C to 62 °C, only one being used as a production well within the district heating system presently. This paper introduces and describes the geothermal system in Bergama and the geochemistry of the some of the hot water points. It also outlines the present district heating system within Bergama vicinity.

1. INTRODUCTION

Most of the geothermal systems located in the western parts of Turkey are liquid-dominated and low- temperature systems and have attracted the interest of many researchers (Küçüka, 2001; Dağıstan, 2008; Tarcan and Gemici, 2010). The geological structure prevailing in the region is effective for geothermal upflows so that most of the cities bear geothermal facilities within their borders. The Aegean region geographically has 8 cities and a total number of 116 hot water points are being consumed for various aspects including balneological usage, district heating, agriculture and tourism within these cities (Özşahin and Kaymaz, 2013) (Figure 1). Bergama geothermal field, one of these, is located in the east-west directed Bakırçay graben and geothermal sources of Bergama and has been consumed for different purposes since ancient times.

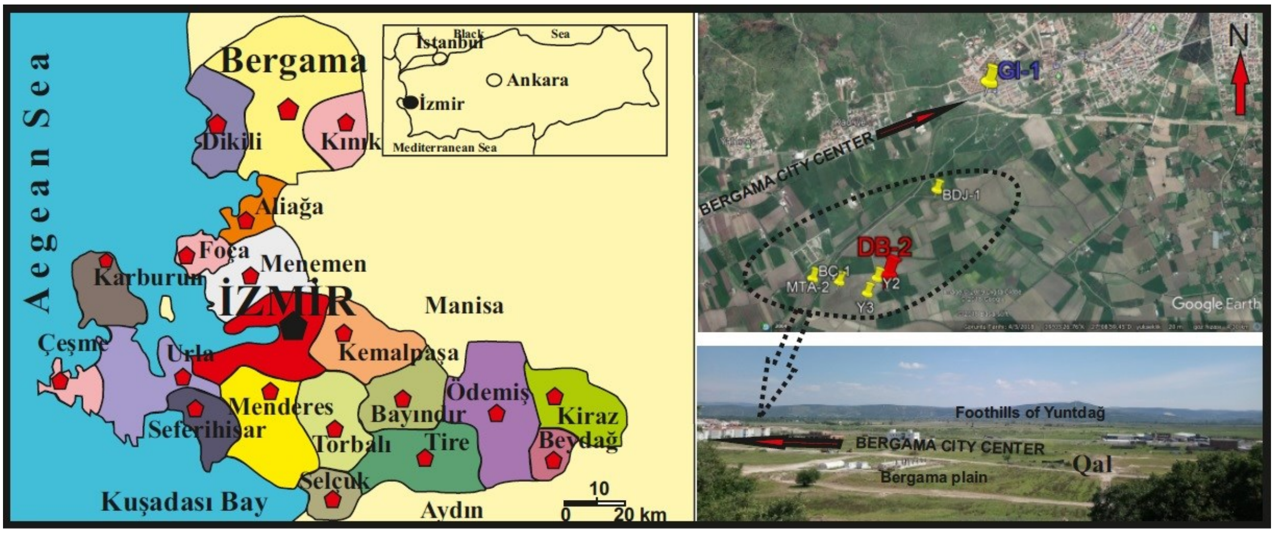

Figure 1. Location map and geothermal wells located in the Bergama geothermal field.

2. GEOLOGICAL FEATURES OF BERGAMA

Bergama geothermal field is within the Western Anatolian tectonics in terms of tectonic structure. The effect of neotectonic period expansion in Western Anatolia horst-graben structure seen in the wide western region also prevails here. There are two different models suggested for the formation of this horst-graben structure; the models developed by Şengör and Dewey (1979) and Doglioni et al (2002). Şengör and Dewey (1979), the classical model, accepts the extension of western Anatolia as a result of the westward escape of Anatolia, since it has been pushed northward by the Arabian plate but however, brings insufficient explanation to the spreading of the Aegean Sea. On the other hand, Doglioni et al. (2002), assert that subduction in the northeast direction of Africa underneath Greece and the Anatolian plate is effective in shaping Western Anatolia (Fig. 2).

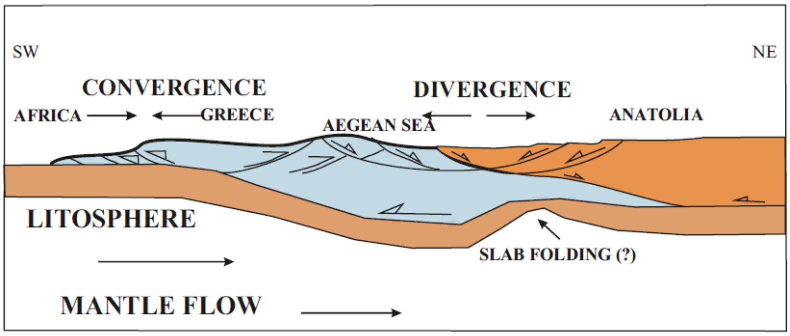

Figure 2. Schematic cross-section showing overriding of Western Anatolia and Greece to the African Plate. (Doglioni et al. 2002).

The N-NE-SW and EW trending faults that restrain the grabens and the horst and graben structures due to enlargement are effective structural factors in the formation of the tectonic structure (Kaya, 1979; Emre, 1996; Yılmaz et al., 2000; Emre et al., 2005; Akyol et al., 2006; Sözbilir et al.2008). The circulation of the thermal waters in the geothermal fields is also closely related to major fault and fracture zones (Tarcan and Gemici, 2010), as it is observed in Bergama geothermal field. Geology of the region is comprised of Lower Triassic Kınık formation containing allochthon limestones taking place at the bottom of the stratigraphy of Bergama geothermal field, towards the top, Eocene-Oligocene aged Kozak granodiorites, Middle Miocene aged Yuntdağ-I and Yuntdağı-II volcanics, Upper Miocene aged Yeniköy formation and Upper Miocene-Pliocene Aged Yuntdağı-III volcanics take place (Akkuş et al., 2005) (Figure 3). The volcanics located in the field have been fractured due to the active tectonics in the region. These volcanic units behave as the reservoir rock for the geothermal fluid to be stored. Also clayey levels of the volcanic units, altered clay levels occur and these levels form the cap of the system. The heat source for the geothermal system in Bergama and its neighboring geothermal system is possibly the high geothermal gradient resulting from both the effect of the tectonics and volcanic activities in the region.

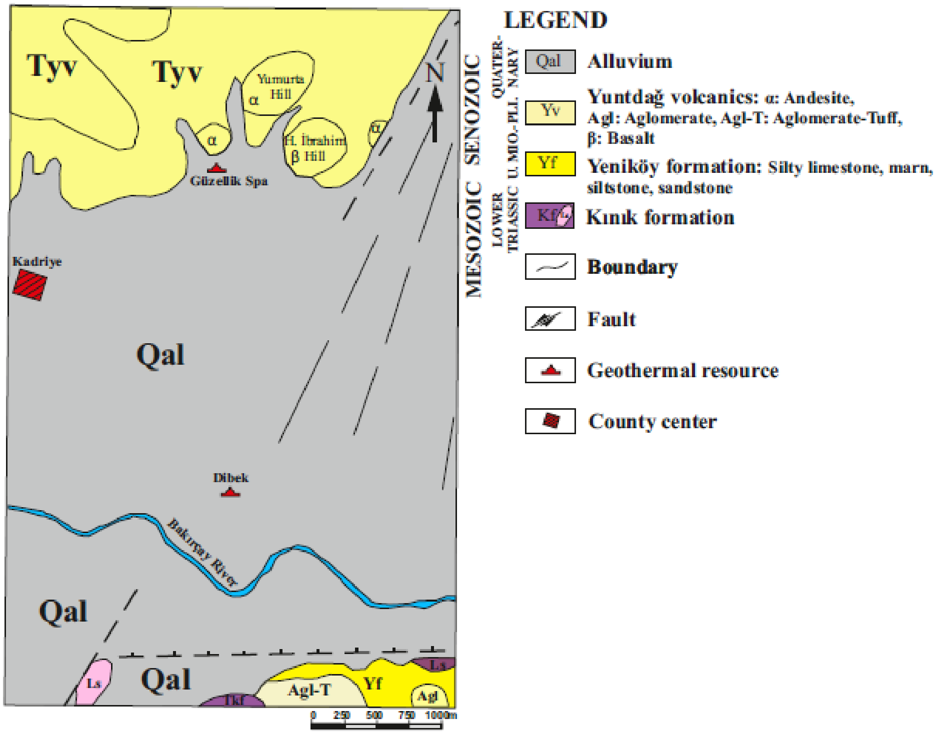

Figure 3. Geology map of the Bergama Güzellik and Dübek geothermal fields (modified from Akkuş et al., 2005).

3. HYDROGEOLOGICAL FEATURES

Depending on the geological features of the region, numerous geothermal studies and researches have been carried out in the field and these resulted in the drilling of 6 geothermal wells, being used for different purposes. The most productive well coded DB-2 is the only hot point being used for district heating in Bergama (Table 1). The drilled geothermal wells are located in the west of Dibek, almost along the fault passing through Dibek. Temperature of GI-1 is lower in Table 2, since the higher temperature belongs to the drilling site records. Kaynarca geothermal resource has been included in this paper since it is located on the border of Dikili and Bergama counties and also for comparison. BÇ-1 is the deepest well with the lowest temperature. The geothermal waters have temperatures varying between 29°C and 80°C with the maximum obtained electrical conductivity value as 1592 µS/cm. The results of chemical analyses of the hot waters of the Güzellik and Dibek subject to this study are given in Table 2, including the classification of waters according to the principles of the IAH (1979). The computer program named “Aquachem 3.70” has been used to interpret the chemical properties (Calmbach, 1997).Three geochemical water facies have been determined in which Na ion is the major cation and HCO_3 ion, partly accompanied by SO_4 and Cl, is the major anion for all. Sodium is more abundant in magmatic rocks than potassium, while it is lesser in sedimentary rocks (Hem, 1992). This is very distinctive in these samples. The plotting of Piper diagram indicates that Ca + Mg < Na + K, typical for alkaline thermal waters, and the sum of the weak acid of CO_3 + HCO_3 value are greater than Cl + SO_4 ($CO_3 + HCO_3 > Cl + SO_4$). The plotting of the samples on the semi-logarithmic Schoeller diagram has similar peak points, showing that these geothermal waters are of the same origin (Fig. 4a-4b). Na-HCO_3 type thermal waters are produced by rock dissolution and ion exchange reactions in deep aquifers (Tarcan et al., 2005; Tarcan and Gemici, 2005). The geothermal waters of Bergama are partially in equilibrium with the rocks they travel through (Fig. 5).

Sodium absorption ratio (SAR) in waters, which is known as the sum of calcium and magnesium, and magnesium hazard (MH) are two important parameters and affect the quality and consumption type of the waters. Especially high SAR is undesirable for irrigation waters and is high in the geothermal waters of Bergama (Şahinci, 1991).

Geothermometry calculations have been made to estimate the reservoir temperature of Bergama geothermal field. The results of the quartz geothermometers have given minimum and maximum reservoir temperatures of 55°C and 119°C, respectively. Quartz geothermometers are more useful for geothermal areas where surface temperatures are above 150 °C (Fournier 1985); thus it is sensible to underestimate the temperatures obtained by these geothermometers because the maximum surface temperature is below 150°C. The results of the cation geothermometers have given minimum and maximum reservoir temperature of 41°C and 119°C, respectively. In these circumstances, it is more sensible to accept the maximum and minimum estimated reservoir temperatures as 119°C and 41°C, respectively.

4. PRESENT GEOTHERMAL UTILIZATION

Geothermal fluid started to be used in district heating in Bergama in 2005. At the beginning, 42 houses of a building complex, named Yuvam, were being heated by using geothermal energy which rose to 53 houses in 2015. In 2005 Bayatlı building complex was also included in the geothermal heating system. The number of subscribers using geothermal energy for heating their houses is 658 at present. System enlargement studies regarding increasing the subscriber number are in progress at the moment.

Although there are 6 operation-licensed geothermal wells located in the geothermal field, only one geothermal well, coded DB-2, is being used in district heating. Well GI-1, with a depth of 857 m, is being used for reinjection.

Table 1: Properties of the geothermal drilling wells located in Bergama

Well code	Drilling date	Depth (m)	Temperature (°C)	Flow rate (l/s)	Used for
DB-2	2002	360	62	30	Space heating
GI-1	2003	857	43.2	60	Re-injection
BÇ-1	2005	694	58	28	--
BDJ-1	2007	565	62	9	--
Y-2	2012	384	62	50	--
Y-3	2012		45	3	Fish farm

Table 2. Hydrogeological features of the hot waters

No	Name of the sampled point	T (°C)	pH	EC (µS/cm)	TDS (mg/l)	Total Hardness (Fr)	SAR (%)	MH	Water Facies
1	G-Well*	29	8.22	1592	858.5	2.0	30.68	17.99	Na- HCO_3-Cl-SO_4
2	GI-1*	36	7.53	1574	831.2	3.4	29.21	22.94	Na-HCO_3-SO_4
3	Kaynarca**	80	7.9	---	1561.6	7.47	27.17	16.52	Na- SO_4-HCO_3
4	Dübek**	60	8.7	---	866.4	4.49	23.28	11.00	Na- SO_4-HCO_3
5	Güzellik**	35	8.9	---	705	3.98	25.87	37.25	Na-HCO_3-SO_4

*: Tarcan and Gemici, 2009; **: Akkuş etal., 2005

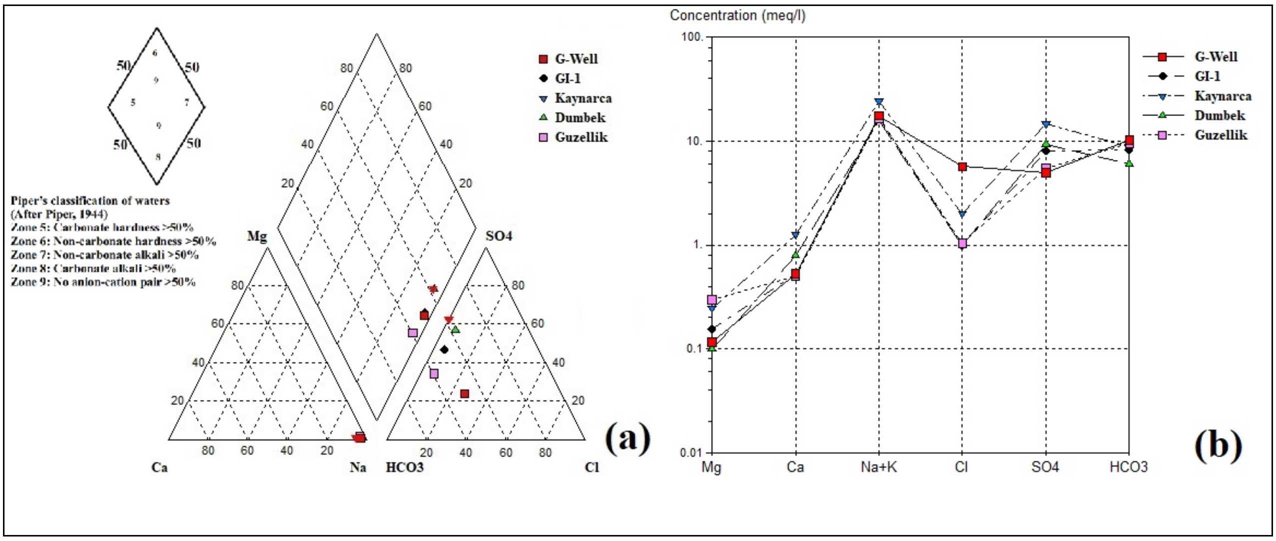

Figure 4. (a) Piper and (b) Schoeller diagram of the samples

Table 6. Silica geothermometry applications

Geothermometers	Formula	S. Temp (°C)	Sample Name				
			G-Well	**GI-1**	**Kaynarca**	**Dibek**	**Güzellik**
			29	**36**	**80**	**60**	**35**
SiO_2 (Amorphous Silica) [a]	$t=731/(4.52-\log SiO_2)-273.15$		-2	1	48	-7	-28
SiO_2 (α-Cristobalite) [a]	$t=1000/(4.78-\log SiO_2)-273.15$		65	68	121	60	36
SiO_2 (β- Cristobalite) [a]	$t=781/(4.51-\log SiO_2)-273.15$		17	21	71	13	-10
SiO_2 (Chalcedony) [a]	$t=1032/(4.69-\log SiO_2)-273.15$		87	91	149	81	55
SiO_2 (Quartz) [a]	$t=1309/(5.19-\log SiO_2)-273.15$		116	119	171	111	89
SiO_2 (Quartz- Steam Loss) [a]	$t=1522/(5.75-\log SiO_2)-273.15$		115	117	161	110	89
K/Mg [b]	$t=4410/(13.95-\log K^2/Mg)-273.15$		88	63	116	68	65
Li/Mg [c]	$t=2200/(5.470-\log(Li/Mg^{0.5}))-273.15$		-	69	-	-	-
Na/Li [d]	$t=1590/(0.779+\log(Na/Li))-273.15$		-	107	-	-	-
Na/K [e]	$t= 933/(0.933 + \log(Na/K))-273.15$		86	41	167	45	63
Na/K [e]	$t=777/(0.70 + \log(Na/K))-273.15$		65	11	138	15	33
Na/K [e]	$t=1319/(1.699 + \log(Na/K))-273.15$		119	80	184	83	99
Na/K [f]	$t=856/(0.857 + \log(Na/K))-273.15$		66	23	145	27	44

[a]: Fournier, 1977; [b]: Giggenbach et al., 1983, [c]: Kharaka and Mariner, 1989; [d]: Kharaka et al., 1982; [e]: Arnorsson etal., 1983; [f]: Truesdell etal., 1976

5. DISCUSSION

In geothermal systems, the necessary components such as heat source, reservoir, cap rock and recharge area, form depending on factors such as geology and tectonic activity of the region. Tectonic activities along with withdrawal of the fluid from underground will affect the elevation of the exploited region. In some cases these affect the productivity of the geothermal field as well. In some cases, withdrawal of fluids from the underground of the earth may result subsidence or tectonic activity may cause subsidence/elevation of the ground (Allis et al., 2009; Karamanderesi et al., 2012). In the geothermal wells (with an average depth of 500 m) drilled on a fault zone extending in the E-W direction at the Dikili Kaynarca geothermal field, an upward movement of the production casings was observed in the geothermal wells (Karamanderesi et al., 2012). The tectonic and geological structure of Dikili and Bergama are very similar to each other. In many papers, these two fields have been evaluated together (Karamanderesi et al., 2012). Depending on the population of Bergama county, the temperature and flowrate of the geothermal wells, Bergama geothermal system may not be enough for the purpose of district heating of the whole county, but may answer the present district heating system.

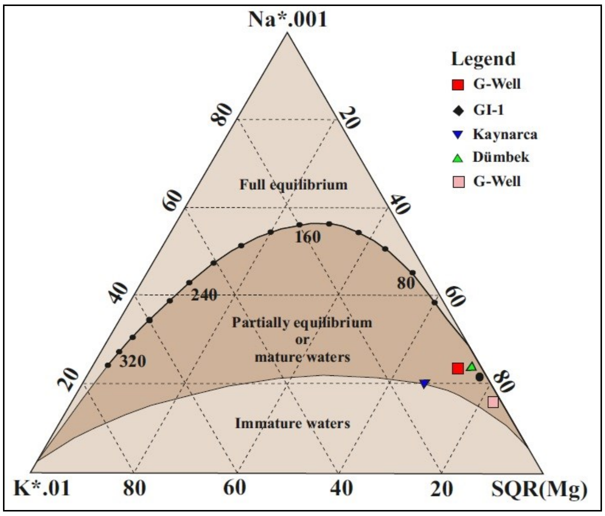

Figure 5. Giggenbach's Na–K–Mg diagram of the samples

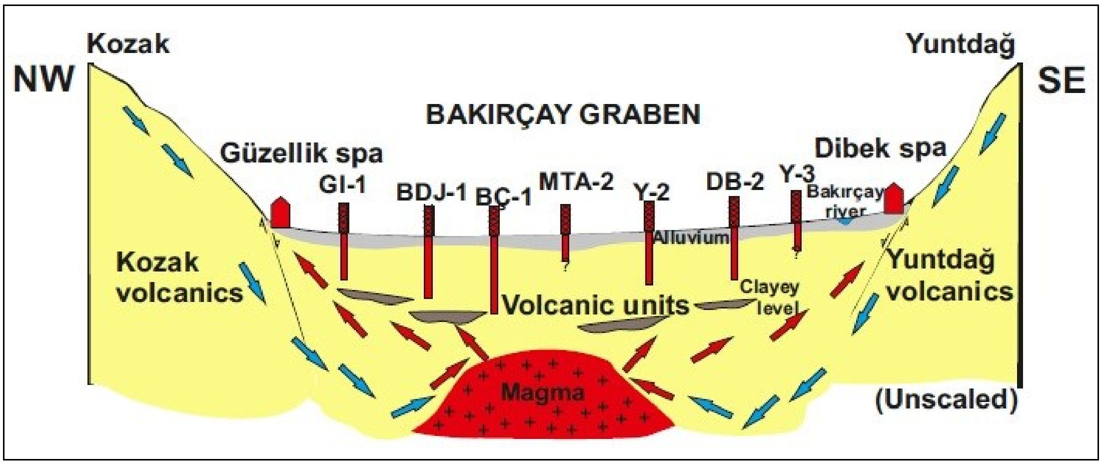

Figure 6. Conceptual model for Bergama geothermal system

6. CONCLUSION

Depending on the analyses of the waters, three different water facies have been classified as Na- HCO_3-Cl-SO_4, Na-HCO_3-SO_4, Na-SO_4-HCO_3, none of them suitable for either drinking or irrigation. Since values of Na and HCO_3 ions are high, scaling may cause a problem in the pipelines. The volcanics located in the field, which have been fractured due to the tectonics, behave as the reservoir rock for the geothermal fluid to be stored, while the altered clay levels form the cap of the system. Possible heat source for Bergama and its neighboring geothermal system is accepted as high geothermal gradient resulting from both the effect of the tectonics and volcanic activities in the region. A conceptual model has been given in Figure 6. Tectonic activity around the region is effective in Dikili in terms of elevation, so over a long term period it may be also effective for Bergama geothermal system as well. Monitoring is essential and proper analyses must be carried out periodically in order to recognize the difference in the elevation of the ground. Depending on the geothermometry calculations, the maximum and minimum estimated reservoir temperatures are as 119°C and 41°C, respectively. In all geothermal systems, reinjecting the geothermal water after extracting its heat is important in terms of maintaining the internal balance of the reservoir and protecting the future of the site. Concerning the flowrate and temperatures of the wells in Bergama geothermal system, reinjection must be continually and carefully carried out.

REFERENCES

Akkuş, İ., Akıllı, H., Ceyhan, S., Dilemre, A., and Tekin, Zeki.: Türkiye Jeotermal Kaynakları Envanteri. Envanter Serisi–201. MTA., Ankara, (2005).

Akyol, N., Zhu, L., Mitchell, B.J., Sözbilir, H., and Kekovalı, K.: Crustal structure and local seismicity in Western Anatolia. *Geophysical Journal International*, **166**, (2006), issue 3, 1259-1269.

Arnórsson, S., Gunnlaugsson, E., and Swarsson, N.: The Chemistry of Geothermometry in Geothermal Investrgations. *Geochim. Cosmoschim*. Acta, 47, (1983), 567-577.

Binan, D.U., Kaptı, M., Kıraç, B., and Töre, T.: Bergama (İzmir) Kentsel kültür Varlıkları Envanteri, *TÜBA Kültür Envanteri Dergisi* 4/2005, (2004),79-110.

Calmbach L.: AquaChem computer code-version 3.7. 42, Waterloo hydrogeologic. Waterloo, Ontario, Canada, (1997).

Dağıstan, H.: Yenilenebilir Enerji ve Jeotermal Kaynaklarımız (in Turkish), 5th World Water Forum, Termal ve Maden Suları Konferansı, Proceedings, 24-25 Nisan 2008, 11-23

Doglioni, C., Agostini, S., Crespi, M., Innocenti, F., Manetti, P., Riguzzi, F. and Savasçin, M.Y.: On the extension in western Anatolia and the Aegean sea. *Virtual Explorer*, **8**, (2002), 169-183.

Emre, T.: Gediz Grabeni'nin tektonik evrimi. *Türkiye Jeoloji Bülteni*, 39, 2, (1996), 1-18.

Emre, Ö., Özalp, S., Doğan, A., Özaksoy, V., Yıldırım, C., and Göktaş, F., 2005. İzmir ve Yakın Çevresinin Diri Fayları ve Deprem Potansiyelleri Raporu, MTA No: 10754, Jeoloji Etütleri Dairesi, 2005, 80s. Ankara.

Fournier, R.O.: Chemical Geothermometers and Mixing Models for Geothermal Systems. *Geothermics*, 5, (1977), 41-50.

Giggenbach, W.F., Gonantini, R., Jangi, B.L., and Truesdell, A.H.: Isotopic and Chemical Composition of Parbati Valley Geothermal Discharges, NW-Himalaya, India, *Geothermics*, 12, (1983), 199 –222.

Hem, J.D.: Study and interpretation of the chemical characteristics of natural water, 3rd edition. In: U.S. Geological Survey water-supply, International Association of Hydrogeologist, 1979, Map of mineral and thermal water of Europe, scale:1:500.000, (1992).

Kaya, O.: Ortadoğu Ege çöküntüsünün (Neojen) stratigrafisi ve tekniği, Türkiye Jeoloji Kurumu Bülteni, 22, (1979), 35-38.

Karamanderesi, İ.H., Şengün, R., and Helvacı, C.: Operating problems and suggestions for solutions of the Dikili (İzmir) geothermal area, *Proceedings*, 65th Geological Congress of Turkey, 2-6 April, (2012) Ankara.

Kharaka, Y.K., and Mariner, R.H.: Chemical Geothermometers and their Application to formation waters from sedimentary basins. In: Naser ND, McCulloh TH (eds), Thermal History of Sedimentary Basins; Methods and Case Histories Springer Verlag, (1989), 99-117.

Kharaka, Y.K., Lico, M.S., and Law, L.M.: Chemical geothermometers applied to formation waters, Gulf of Mexico and California Basins. *Am. Assoc. Petrol. Geol. Bull.*, 66, (1982), 538-558.

Küçüka, S.: Jeotermal bölge ısıtması dağıtım sistemlerinin genel esasları (in Turkish), *Proceedings*, V. Ulusal Tesisat Mühendisliği Kongresi ve Sergisi, 3-6 Ekim, (2001).

Özşahin, E., and Kaymaz, Ç.K.: Türkiye'nin termal su kaynaklarının coğrafi açıdan değerlendirilmesi (in Turkish), Atatürk University, Faculty of Literature, *Journal of Social Sciences*, Number 50, June, (2013), 25-38

Sözbilir, H., Uzel, B., Sümer, Ö., İnci, U., Ersoy, E.Y., Koçer, T., Demirtaş, R., and Özkaymak, Ç.: D-B Uzanımlı İzmir fayı ile KD-Uzanımlı Seferihisar Fayı'nın Birlikte Çalıştığına Dair Veriler: İzmir Körfezi'ni Oluşturan Aktif faylarda Kinematik ve Paleosismolojik Çalışmalar, Batı Anadolu. *Türkiye Jeoloji Bülteni*, **51**, (2008), 2, 91-114.

Şahinci, A.: Doğal suların jeokimyası, İzmir, (1991).

Tarcan, G., and Gemici, Ü.: Hydrogeochemical assessment of the Bergama thermal waters, İzmir, Turkey, *Proceedings* World Geothermal Congress, Bali, Indonesia, 25-29 April (2010)

Truesdell, A.H.: Summary of section III geochemical techniques in exploration. In: *Proceedings*, Second United Nations Symposium on the Development and Use of Geothermal Resources. San Francisco, 1975, v. 1, (1976).

Yılmaz, Y.: Ege Bölgesinin Aktif tektoniği, Batı Anadolu'nun Depremselliği Sempozyumu, *Proceedings*, 3-14, (2000).