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Geothermal Water Potential of Bursa (Turkey) Province

Beşir Dağ*[1], Ali Bilgin[2]

[1]Department of Chemistry, Batman University, Batman, Turkey
[2]Department of Geology, Batman University, Batman, Turkey

***Corresponding author**
Beşir Dağ

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Abstract: In this study, the physico-chemical properties of hot spring water of Bursa province and Erikli cold water were investigated. Erikli cold water is bottled for commercial use. Water samples were collected in-situ for testing and some physical measurements were carried out. Other major analyses were carried out in the geothermal laboratory. Water samples were evaluated by both field observations in-situ and also geological and petrographical observations. Data collected were evaluated by using Aqua-Chem software program in consideration of field observations and the geology and petrography of the sampling area. Data obtained from Aqua-Chem and field observations of the sampling area in consideration of geology and petrography were used for interpretations of hot water samples and cold spring water. Consequently, water samples were characterized according to sources of magma or meteoric waters with the aid of isotope studies and cation and anion data. Also, information on water circulation leading to water-rock interaction where the water passes the Bursa Geothermal system helped the interpretation. The water sample radioactivity results were shown to be within acceptable limits. Water resources were determined for Bursa province and vicinity using Piper diagram. Waters in Cekirge, Kaynarca, Kükürtlü, Zeynine, Dumbuldek, and Inegol Oylat contain Ca-Mg-Na-SO_4, Na-Ca-SO_4, Na-Ca-HCO_3-SO_4, Ca-Na-Mg-SO_4, Na-Ca, Ca-SO_4-HCO_3 ions respectively.

Keywords: Hot spring water, Geothermometer, Geochemistry, Ions, Reservoir Rock, Isotope geochemistry.

INTRODUCTION

This research was performed in Bursa, which is a province in North-West (NW) Turkey, along the Sea of Marmara outskirts of Uludag Mountain (Fig-1). The meteoric waters seeping through the cracks of earth crust get heated by the underlying hot rocks, then heated waters and steam collected by the reservoir rock by convectional currents.

Geothermal energy which is extracted from the heat stored in the earth has gained importance as a renewable energy resource recently. In general, Turkey has large geothermal resources and will be a leading country in obtaining and producing geothermal power in the world, particularly; Bursa is one of the most important spot in geothermal resources of Turkey. There a lot of young igneous and volcanic rocks are rising due to lying in the edges of tectonic plate covering as a large area and the geothermal gradient show very high anomalies in the region. These hot fluids are stored in reservoir rocks and covered by impermeable cap rock. Cap rock also prevents cooling of the carbonate reservoir lying below Fig-1.

Hot springs and mineral waters carries dissolved minerals due to water rock interaction. This hot spring geothermal water is drinkable as mineral water. Hot spring water has a curing effect and is also used for physical therapy due to healing effect on some gynecological diseases and rheumatism.

It's a known fact that thermal water is a cure for healing many skin diseases. Human beings have enjoyed hot water and spas since ancient times and so many people visit Bursa for this purpose. Bursa is a thermal resort city in Turkey in the NW of Anatolia near the Marmara Sea. On the other hand, Turkey lies on the active Alpine-Himalayan Orogenic Belt, that is an important geothermal energy zone which is located at a geologically recent magmatic and volcanic activity. Turkey has more than 1000 hot springs with temperatures ranging from 25ºC to 230ºC with many fumaroles, and has numerous hydrothermal alteration zones that indicate occurrence of geothermal fields. Geothermal areas are widely spread in western Anatolia, extending up to the Sea of Marmara. Temperatures of hot springs are higher in the Western Marmara Region of Anatolia than Eastern Anatolia. Grabens which are thought to be an important structures that form existence of a geothermal energy area in the Marmara Region of Anatolia. The 9 hot springs around Bursa are mainly used by local people for balneological purposes. Widespread young volcanism, granitoids and

hydrothermal alteration are observed around hot springs which occur in Bursa and surrounding area. In Eastern Anatolia, 7 geothermal areas have been identified so far. To the south of the Marmara Sea at the northern slope of Mount Uludağ (2543 m), the highest mountain in north western part of Turkey. Bursa was the first Ottoman Capital City (1326-1451) and now it's population is over 900,000. Bursa thermal waters at Cekirge and Kukurtlu are very famous for hot springs which are used for bathing and curing purposes. Due to the differences in water temperature and chemistry, the two thermal water resorts have developed different curing effects for skin diseases.

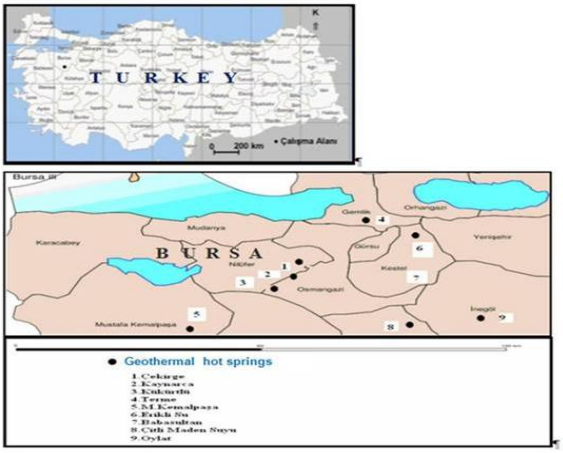

Fig-1: Location map of the study area.

In Cekirge, thermal water with low salinity, discharges from four springs and from some caves and boreholes within the Quaternary rock units. The temperature varies only slightly, from 14.6-68.5 ºC (TDS 23-2860 mg/l). Bathing at Çekirge which is dates back to 500 A.D. A well-organized health resort has been established until now. A common water authority distribution system shared by private and public rehabilitation centers controls the use of thermal water in this district.

In the Uludag Rehabilitation (Kukurtlu) which is located at 2 km east of Cekirge where thermal water flows out a small travertine complex which covers a tectonic contact. Temperature and mineralization of the Kukurtlu thermal water vary within the location from 68.5 ºC (TDS~652 mg/L) at the highest elevation of the travertine complex at the Kaynarca spring to 66.4 ºC (TDS~584 mg/L) in the shallow excavations and boreholes close to the plain. Until today, the geothermal power potential of the thermal waters has not been fully explored. The Uludag Rehabilitation water which is 68.5 ºC and it is cooled to 40ºC for bathing by the cooling system.

MATERIAL AND METHODS

Different types of water samples were collected from Bursa and vicinity. Some are hot spring waters, one is bottled Erikli cold water, and another one is a mineral water collected for the comparison according to their physical and chemical properties.

Results were evaluated using the AquaChem software program. Most of the diagrams are output obtained by this program.

The pH, Eh (eV), EC (mS/cm), O_2(mg/l), T(^{0}C), h(m) was determined in-situ Geothermal waters of the province. Besides, anion and cation in the geothermal waters of the province were analyzed for Na^+ (mg/l), K^+ (mg/l), Mg^{2+} (mg/l), Ca^{2+} (mg/l), NO_3^-(mg/l), HCO_3^- (mg/l), Cl^- (mg/l), SO_4^{2-}(mg/l), F^- (mg/l) and TDS (mg/l)., The water resources are having Na^{+1}, Ca^{2+}, SO_4^{2-}, Cl^{-1} , on the other hand, Erikli cold spring water resources are having Na^{+1}, Ca^{2+}, SO_4^{2} based on analytical results. The Na-K, Na-K-Ca, Na-K-Ca-Mg geothermometers were used in evaluation using Aqua-Chem diagrams in order to determine temperature of the reservoir rock. All the collected spring waters were evaluated in Bursa province and surroundings by using Piper and the other diagrams. Water in Cekirge, Kaynarca , Kukurtlu, Zeynine, Dumbuldek, Inegol Oylat are having Ca-Mg-Na-SO_4, Na-Ca-SO_4, Na-Ca-HCO_3-SO_4, Ca-Na-Mg-SO_4, Na-Ca, Ca-SO_4-HCO_3, respectively.

RESULTS AND DISCUSSION

Geology and tectonic setting

The scope of this study is to evaluate existing data from earlier work of Turkish Mining Exploration Institute (MTA) and other academic studies of the geothermal resources of Bursa province. The Bursa geothermal springs within the aquifer rocks are discharged mainly as hot spring waters from the Uludag which is a granitic massive, metamorphic rocks and travertines. The fracture paths are the most important flow paths in the travertine, metamorphic and igneous rocks. The Karapınar and Pınarbaşı springs which are huge karstic springs on the border of the Bursa Plain, show the importance of the karstified marble series as a groundwater aquifer above the valley on the Uludag massive that charge geothermal resources [1, 2]. Nilufer River waters and other meteoric waters from Uludag are naturally infiltrated into this karstified marble series to reach to volcanic and igneous rocks below which are the heat source, and then collected at the reservoir rocks which consist of carbonate rocks. The heat loss is prevented by cap rocks which consist of succession of shale and sandstone units.

The study area around Bursa has high seismic activity, due to existence of Northwest Anatolian Fault Zone (NAFZ) at the south of the Marmara Sea, in the investigated area of North Western Anatolia. Within this pattern of fault zones in Western Anatolia several strong earthquakes took place in the last century: Gonen magnitude (M) 7.2 (18.3.1953), Yalova, M 6.3 (18.9.1963), Manyas M 7.0 (6.10.1964) in the Western branches and Bolu Gerede M 7.3 (1.2. 1944) and especially Mudurnu M 7.1 (22.07.1967). In the eastern branch of the study area seismic activity is higher in the other parts of Bursa province. Therefore, Izmit earthquake [3] is a proof that the crustal movements as evidenced which is based by the GPS and geodetic measurements of the Marmara Poly-Project indicate strong earthquakes in the geothermal area in Bursa [4]. These earthquakes are created many cracks and fractures which allow meteoric water seepage through the surface rocks reaching to the cap rock. Therefore, seismic activity is vital for the geothermal area. The precipitation in the region is increasing during the winter months and this water feeds the geothermal area.

Bursa and vicinity are covered by metamorphic, igneous, volcanic and sedimentary rocks (Fig-2). Igneous rocks consist of phaneritic textured rocks that are composed of large crystals that are clearly visible to the eye with or without a hand lens or binocular microscope. The entire rock is made up of large crystals, which are generally 0.5 mm to several cm in size; no fine matrix material is present. This texture forms by slow cooling of magma at great depth in the plutonic environment. Light colored acidic type of granites constitutes orthoclase, oligoclase, hornblende and biotite minerals and some other accessory minerals. Volcanic rocks consist of rhyolite which contains phenocrysts of sanidine, oligoclase, biotite and quartz in a microcrystalline matrix. Magmatic rocks are very important for being as heat sources for geothermal systems.

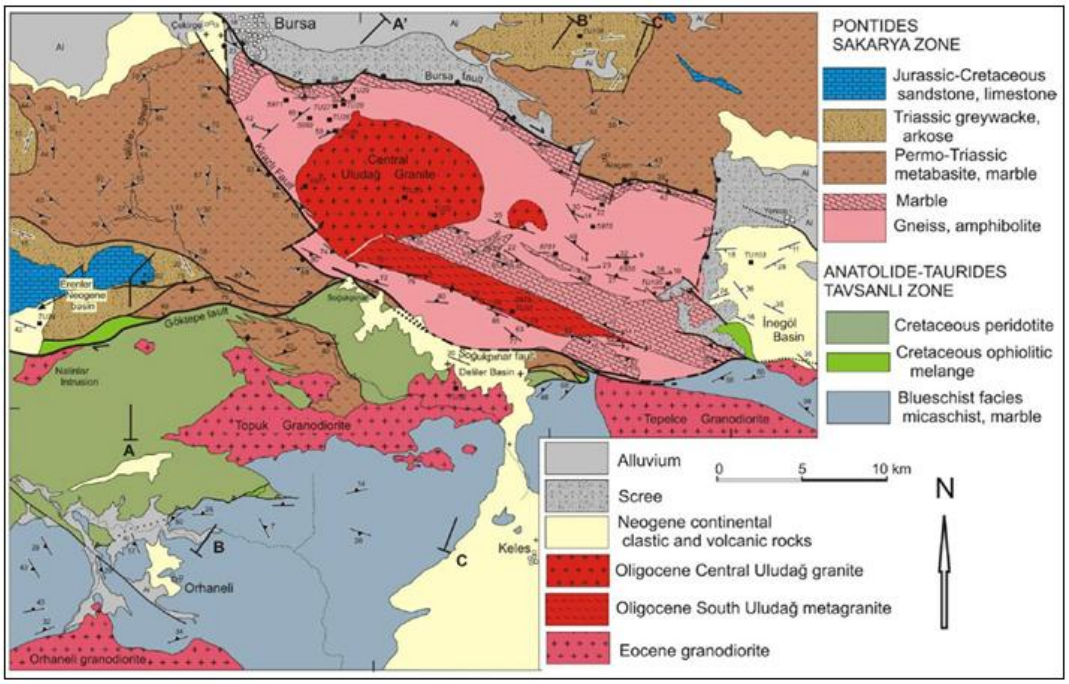

Fig-2: Geological map of Bursa and the surrounding area [5].

Metamorphic rock types are made up of gneiss, mica schist and marbles which are metamorphosed in amphibolites and greenschist facies. Orogenic movements are causing to the metamorphism around Bursa and surrounding area. Marbles are a very important type of carbonate rocks being the reservoir rocks for the percolation of the geothermal fluids which are heated by magmatic rocks that are deep seated in the geothermal systems. After heating the hot waters ascend by convectional currents and are deposited in the marble type reservoir rocks.

The cap rocks are neogene aged continental clastic rocks and or volcano-clastic rocks. The cap rock is made of sandstone and shale in succession. The thickness is changing between 60-200 m. That is the reason why a thick deposit prevents cooling of reservoir rock. On the other hand shale is containing clay minerals which make cap rock impervious strata.

Bursa and surrounding area is popular with the various types of rocks such as granite, volcanic and metamorphic rocks the latter made up of gneiss and marble. The carbonate rocks such as marble, limestone and shale which have vital importance for the geothermal systems. Granite type and their volcanic equivalent rocks are the heat source for geothermal energy. Carbonate rocks such as marbles belong to Nilüfer formations which are the reservoir rocks for geothermal fluids. Neocene aged conglomerate, sandstone and clayey type of clastic rocks are covering the reservoir forming cap rock.

Granite intruded during the Oligocene age as Uludag granite by cutting all the other older rocks. It is outcroped in a large area around the South of Bursa which is associated with sub intrusive equivalent hypabyssal porphyritic type of rocks and different volcanic dikes which cut Uludag Granite throughout the big batholiths.

Geochemical evaluation of Bursa hot springs

Water samples at hot springs were collected from Bursa and surrounding geothermal areas. The physical properties and chemical compositions are given in Table-1 and Table-2 respectively. The chemical parameters of geothermal spring waters play a significant role in classifying and assessing water quality. Chemical classification also highlights on the concentration of various predominant cations, anions and their relationship with each other in forming the geothermal water.

The pH is near neutral or slightly alkaline (6.6-8.4). The redox potential (Eh) is ranges from 50 to 647 mV. These values indicate oxidizing conditions (Table-1). Chemical data for samples which are collected from Bursa and the surrounding area is presented by plotting them on a Piper and related diagrams. These diagrams reveal the analogies and dissimilarities between different types of waters in the study area, which are identified and listed in Table-1 and 2. The concept of hydrochemical facies is developed in order to understand and identify the water composition in different classes.

Water hardness was caused basically by the presence of cations such as calcium and magnesium and anions such as carbonate, bicarbonate, chloride and sulfate in geothermal water. The Bursa geothermal water contains from 3.05 mg/l to 128.5 mg/l of Ca. If the water contains less than 75 ppm Ca, it is called soft water, if it contains more than 75 mg/l, it is moderate to hard water. According to above regulation, Dumbuldek and Oylat hot springs contain moderate to hard water, the rest of them are soft water (Table-1 and 2).

Flow rate of hot spring waters are changing from 10 l/s to 120 l/s (Table-3). Higher flow rate of spring water is important for space heating.

A Piper diagram clearly shows the variation or domination of cation and anion concentrations in geothermal water from Bursa and surroundings as Ca-type of water and for anion concentration, HCO_3-type of water. On the other hand, meteoric water passing through granite dissolves only small quantities of minerals because of the relative insolubility of the rocks.

Bursa hot springs were evaluated with respect to cations and anions using Stiff diagrams. Stiff diagrams give information on water-rock interaction. Water from carbonate rocks is rich in Ca-Mg-Na-CO_3, water from volcanic rocks **is** rhyolite rich in Na-Mg-HCO_3-SO_4, water from basalt **is** rich in Mg-Ca-Na-HCO_3-Cl, water from gypsum **is** rich in Ca-Mg-Na-SO4-Cl, water from shale **is** rich in Na-Mg-Ca-SO_4-Cl, water from oil fields **is** rich in Na-Mg-Ca-Cl-SO_4-HCO_3 (Fig-3).

Table-1: Physical properties of geothermal spring water samples from Bursa

Location	Date	Coordinates		Elevation (m)	T (^{O}C)	pH	Eh (µV)	EC (µS/cm)	O_2 (mg/lt)
		X	Y						
Çekirge	30.10.2009	35 671712	4452016	226	42.6	7,1	161	573	6,5
Zeynine	30.10.2009	35 671794	4452112	241	40.2	7,3	647	590	5,5
Kaynarca	30.10.2009	35 673576	4451972	153	66.4	7,4	366	1210	6,6
Uludağ Reh.	30.10.2009	35 673409	4452015	143	68.5	6,9	267	1410	3,2
Dümbüldek	29.10.2009	35 622257	4423155	79	51.1	6,6	50	2780	1,1
Gemlik	29.10.2009	35 683315	4477190	2	36.5	7,3	182	461	5,6
Oylat	31.10.2009	35 721067	4423064	693	40.6	7,3	282	716	4,9
Çitli M.Suyu	31.10.2009	35 725022	4433316	463	14	7	121	5720	6,1
Babasultan 1	31.10.2009	35 700804	4442808	728	14,5	8	270	291	11,3
Babasultan 2	31.10.2009	35 700796	4442814	729	10,4	8,4	275	292	11,2
Baba sultan 3	31.10.2009	35 700787	4442812	688	20	7,8	281	310	6,5
Erikli su	31.10.2009	35 688705	4450340	145	18,4	7	334	44	8,4

Table-2: Chemical composition of hot spring waters from Bursa.

Locations	Na^{+} (mg/lt)	K^{+} (mg/lt)	Mg^{2+} (mg/lt)	Ca^{2+} (mg/lt)	NO_3^{-} (mg/lt)	HCO_3^{-} (mg/lt)	Cl^{-} (mg/lt)	SO_4^{-2} (mg/lt)	F^{-} (mg/lt)	TDS (mg/lt)
Çekirge	26.1	10.3	17.5	48.88	3.95	298.9	2.46	59.81	0.74	280
Zeynine	45.8	10.5	17.2	51.6	0.78	372.1	24.83	59.82	0.73	287
Kaynarca	135	19.2	7.7	66.64	2.45	481.9	10.35	249.3	3.93	584
Uludağ.Reh.	160	21.5	7.48	76.54	3.19	567.3	7.99	288.6	4.84	652
Dümbüldek	355	62.2	22.8	128.5	0.18	1562	50.63	<0.1	1.94	1241
Gemlik	14.7	8.24	12.2	41.5	1.38	244	15.22	10.33	0.15	233
Oylat	21.9	10.4	7.14	104.7	0.57	176.9	4.15	272.3	0.55	353
Çitli M.Suyu	1295	64.2	69	57.8	<0.1	4636	35.66	93	1.95	2860
Babasultan-1	8.72	8.52	3.96	42.62	1.33	146.4	1.36	10.96	0.03	145
Babasultan-2	8.76	8.54	4.36	45.6	1.04	152.5	1.47	11.43	0.04	146
Babasultan-3	12.54	8.96	7.82	31.3	0.08	176.9	1.15	23.9	0.52	154
Erikli Su	1.60	0.71	0.67	3.05	0.55	12.2	0.61	4.79	0.05	23

Table-3: Flow rate of hot spring water in Bursa Province.

Location of hot spring water samples	Flow rate (l/s)
Çekirge	55
Zeynine	18
Kaynarca	60
Uludağ Reh.	22
Dümbüldek	55
Gemlik	10
Oylat	50
Çitli M.Suyu	20
Babasultan-1	10
Babasultan-2	12
Babasultan-3	15
Erikli Su	120

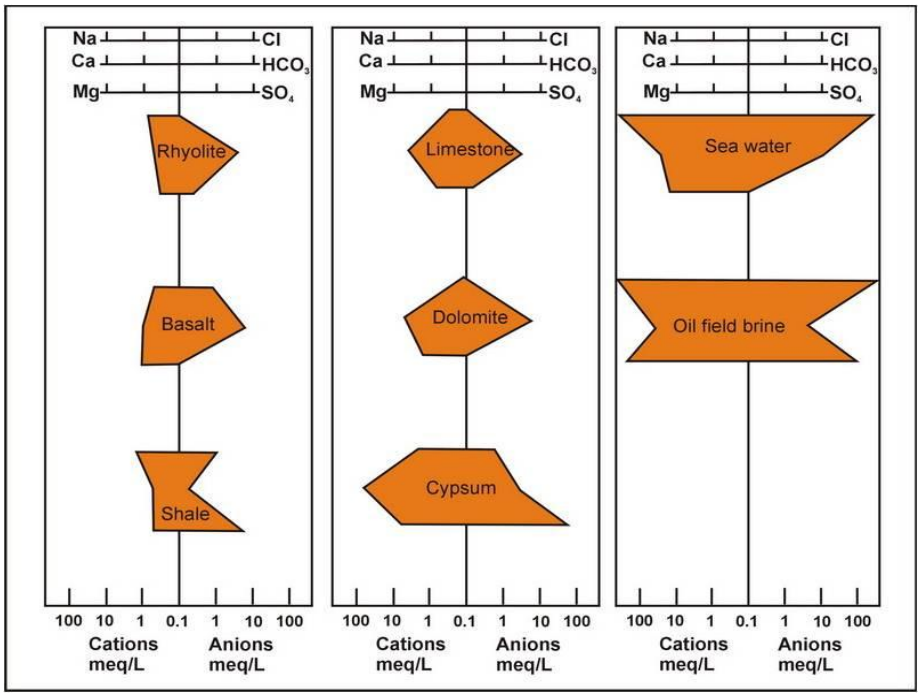

Fig-3: Stiff diagrams with respect to rock-water interaction [6, 7, 8].

Stiff diagrams for Bursa geothermal spring water imply that some of the hot springs are the result of the dissolving of marble which contains calcite ($CaCO_3$) and others are the result of the dissolving of shale that contains Ca, Mg, Na as cations and Cl, SO_4 and HCO_3 as anions (Fig-4 & 5).

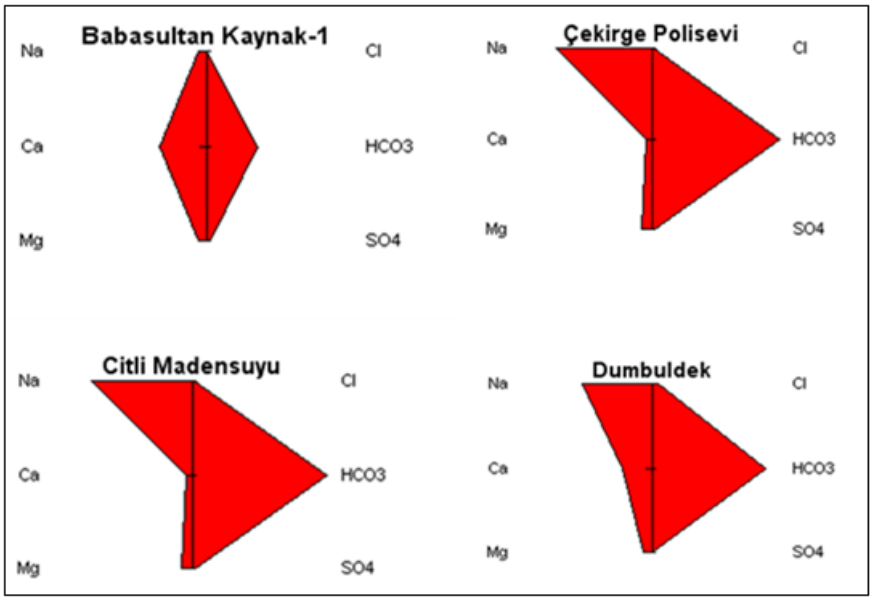

Fig-4: Stiff diagrams from Bursa Geothermal water (Babasultan Kaynak-1, Çekirge Polisevi, Citli Madensuyu, Dumbuldek).

Mineral weathering can contribute to the geothermal spring water chemistry in the study area. Feldspar and carbonates are the most important minerals regulating the chemistry of natural waters from the standpoint of reactivity and abundance in the earth's crust [9, 10]. During the water rock interaction, most of the Ca and HCO_3 ions are from carbonate rocks and Na, Mg, SO4 and Cl ions from shale. When shale and other mudrocks are weathered and washed by rain water, SO_4, HCO_3, Cl, Na, Mg and Ca ions dissolve in the percolating hot water as a result of interaction.

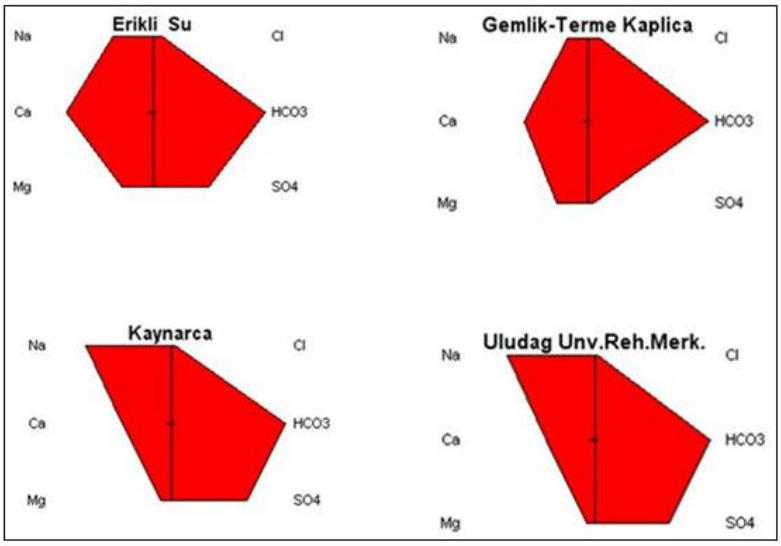

Fig-5: Stiff diagrams from Bursa geothermal water (Erikli Su, Gemlik-Terme Kaplica, Kaynarca, Uludag Unv.Reh.Merk.).

Based on the Durov diagram in Fig-6, the main anions and cations were found to be HCO_3 and Na-Mg-Ca respectively.

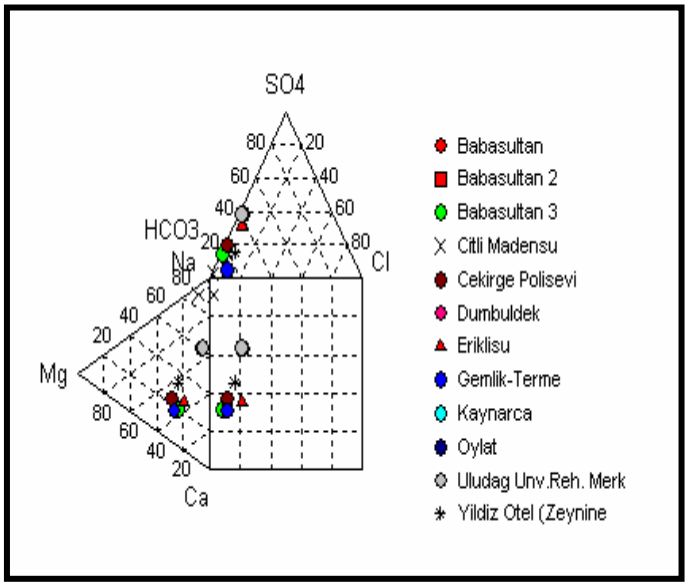

Fig-6: Durov diagram for mineral hot and cold water

H. Scholler (Fig-7) and Stiff diagrams (Fig 4-5) were prepared as well as Wilcox and ABD salinity diagram. Based on the present analytical results, Bursa province hot water resources contain Na-Ca-SO_4-Cl ions and Erikli cold water contains Na-Ca-SO_4 ions. Reservoir rock temperatures using Na-K, Na-K-Ca, and Na-K-Ca-Mg geothermometer equations, were found to be as follows:

Çekirge 42.6 ^{0}C, Zeynine 40.2 ^{0}C, Gemlik-Terme 61 ^{0}C, Kaynarca 115^{0}C, Uludağ Rehabilitation 125 ^{0}C, Dümbüldek 99 ^{0}C, İnegöl-Oylat 155 ^{0}C.

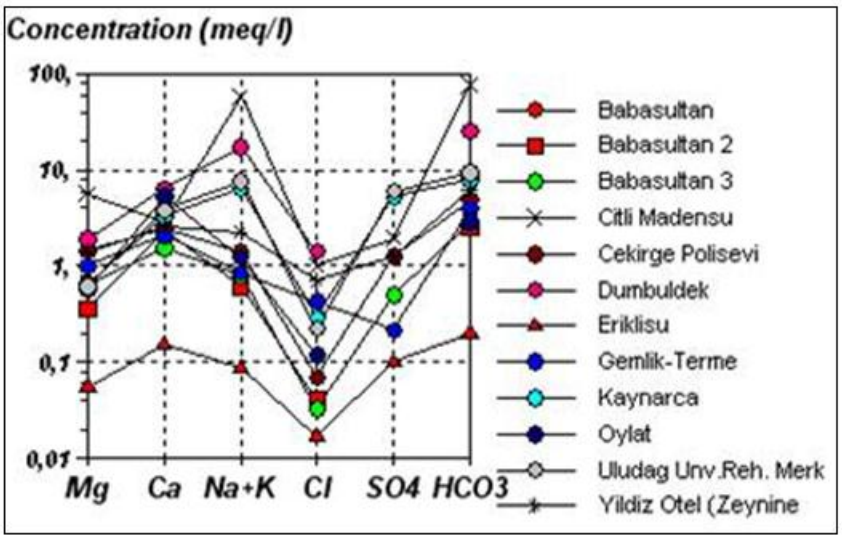

Fig-7: Scholler diagram.

According to the Piper diagram, Çekirge Region geothermal waters are Ca-Mg-Na-SO_4 type, Kaynarca Region waters are Na-Ca-SO_4, Kükürtlü region waters are Na-Ca-HCO_3-SO_4, Zeynine region geothermal waters are Ca-Na-Mg-SO_4, Dümbüldek Region geothermal waters are Na-Ca, Inegol-Oylat geothermal waters are Ca-SO_4-HCO_3 type of spring waters. Dissolved Mg concentration is generally lower than Ca in the study area. There is no significant Ca contribution. On the other hand SO_4 is lower than HCO_3 (Fig-8).

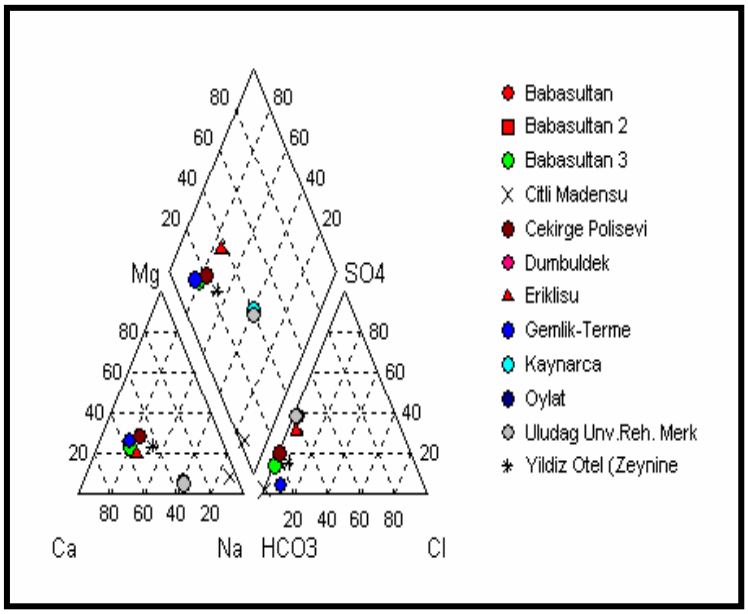

Fig-8: The Piper diagram for Bursa and surrounding geothermal waters.

Electrical conductivity and spring water temperatures were measured for every geothermal spring. All the data are plotted in the graph, and there is a positive correlation between electrical conductivity and temperature of spring water (Fig-9).

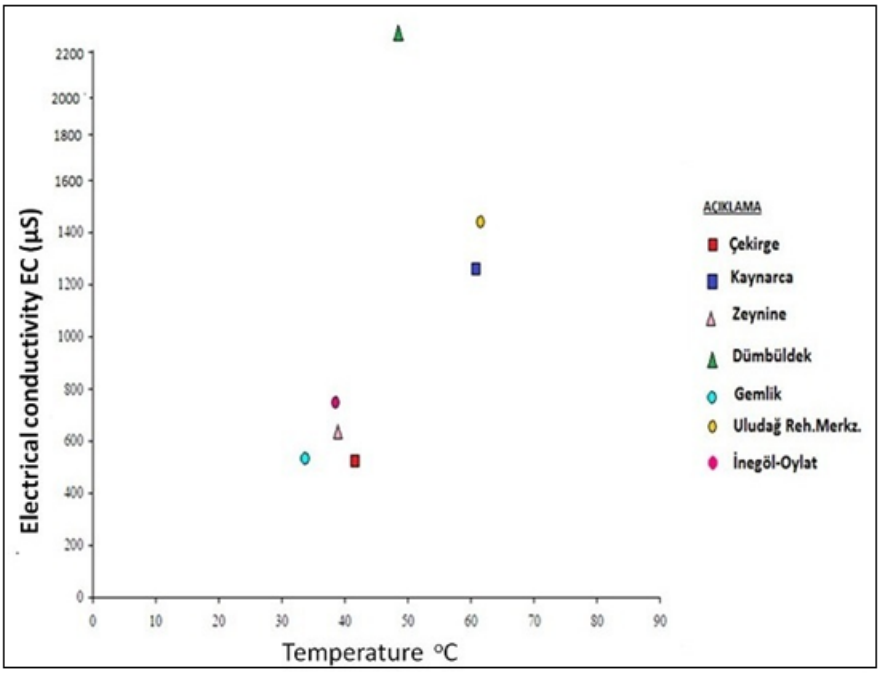

Fig-9: Electrical conductivity EC(µS)-Temperature (^{o}C) diagram for Bursa hot spring waters

Determination of Reservoir Temperature

Geothermometers are one of the most important indicators used for prediction of the geothermal water reservoir temperature, chemical composition of the geothermal hot spring that was acquired by the water-rock interaction which is used in the geothermometer equations. Determination of possible reservoir temperature of the thermal spring water is quite important for the development and operation of the geothermal area. There are many methods of geothermometers like cation, silica, gas and isotope, generally used for the prediction of reservoir temperature; cation and silica

geothermometers are generally preferred. Since their chemical analyses and evaluations are easy. By applying a computer programme, it has been prepared by using of the Aqua-Chem computer programming, which determines the thermal water reservoir temperature by cation geothermometer equations.

The maturation index is an important parameter for the chemical results in determination analysis can be used for geotermometer. The obtained results are between 2.0 and 2.66, so they are suitable for geotermometers. The Na-K, Na-K-Ca and Na-K-Ca-Mg were measured to be 155 ^{o}C at Inegöl Oylat, at Uludağ Rehabilation Center is 125 ^{o}C, at Kaynarca is 115 ^{o}C, at Gemlik Termal is 61 ^{o}C and at Zeynine is 48 ^{o}C. So a detailed prospection study is important for Inegol-Oylat and Uludag Rehabilation Center.

Isotopic characteristics of Bursa geothermal hot spring waters

It has long been recognized that the chemical and isotopic composition of geothermal water is important for studying its origin and history. We have taken water samples which are collected from 5 different locations to determine water isotope radios. Isotope analyses for thermal water (Çekirge-Polisevi, Kaynarca, Dumbuldek, Oylat Hotel) are showing in Table 4 and isotope analyze for Erikli cold water in Table-5, respectively.

Table-4: Bursa thermal water samples $\delta^{18}O$ and δD analysis results

LOCATION	Source No	Coordinates		Date	$\delta^{18}O$ %	δD %	^{3}H (TU))	2σ(TU)
		X	Y					
Dümbüldek	B-D-2	35 622257	4423155	30.10.2009	-10.38	-68.3	<0.7	-
Çekirge	B-D-3	35 671712	4452016	30.10.2009	-10.78	-69.5	<0.8	-
Kaynarca	B-D-5	35 673576	4451972	30.10.2009	-10.47	-68.9	<1.3	-
İnegöl-Oylat	B-D-11	35 721067	4423064	30.10.2009	-10.84	-67.5	3.6	0.7

Table-5: Bursa -Erikli cold water $\delta^{18}O$ and δD analysis results

LOCATION	Source No	Coordinates		Date	$\delta^{18}O$ %	δD %	^{3}H (TU))	2σ(TU)
		X	Y					
Erikli Su	B-D-7	35 688705	4450340	31.10.2009	-11.10	-69.3	5.2	0.7

Çekirge thermal water region: Stable isotope radios for the samples taken from Çekirge thermal water region are shown in Table-4. This region's $\delta^{18}O$ and δD values were determined as -10.78 ‰ and -69.5‰, respectively.

Dumbuldek thermal water region: Stable isotope radios for the samples taken from Dümbüldek thermal water region are shown in Table-4. This region's $\delta^{18}O$ and δD values were determined as -10.38‰ and -68.3‰, respectively.

Oylat thermal water region: Stable isotope radios for the samples taken from Oylat thermal water region are shown in Table-4. This region's $\delta^{18}O$ and δD values were determined as -10.84 ‰ and -67.5‰ respectively.

Cold water source: Stable isotope radios for the samples taken from Kaynarca thermal water region are shown in Table-5. This region's $\delta^{18}O$ value and δD value were determined as -11.10 ‰ and -69.3‰ respectively.

A $\delta^{18}O$ vs. δD diagram showing results for $\delta^{18}O$ and δD ratios in both thermal and cold waters in Fig-10. Reference lines in the diagram include Global Meteoric Water Line (KMSD) [11], the Bursa Meteoric Water Line (BMSD) [12], and Mediterranean Meteoric Water Line (AMSD) [13]. The Erikli cold-water is more close to the linear

line and more takes place between Mediterranean Meteoric Water Line (AMSD).Thermal water from Bursa is closer to BMSD. Different characteristics fields show them, Samples from the Çekirge thermal water region between BMSD and AMSD in Fig-10.

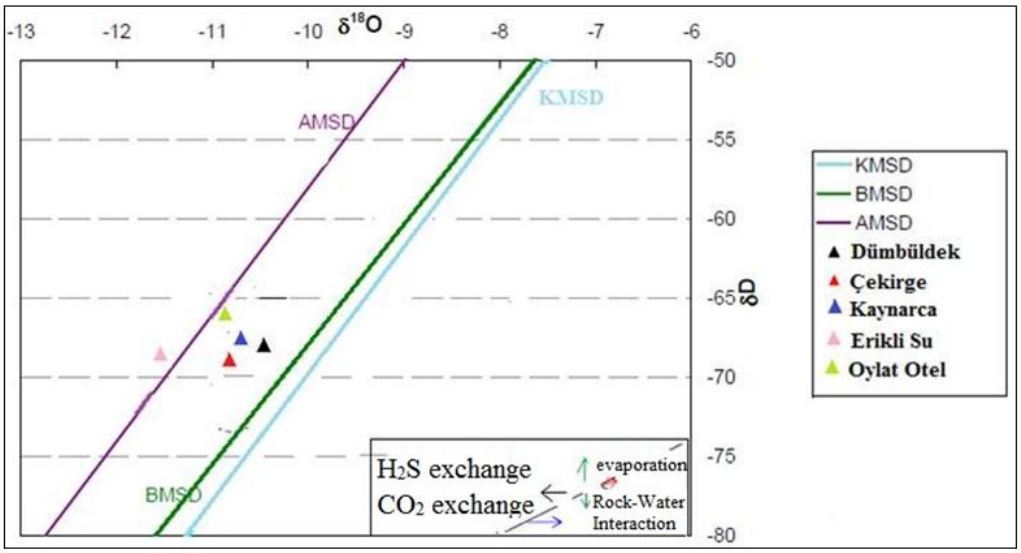

Fig-10: Distribution of Bursa hot springs stable isotopes in $\delta^{18}O$ and δD diagram (cold water blue, hot water red, mineral water purple colored, KMSD Global meteoric line, BMSD Bursa meteoric water line, AMSD Mediterranean water line)

Benefits and economy of Bursa geothermal energy

Turkey has great potential of geothermal energy possessing one-eighth of the world's total geothermal energy capacity. Besides, Turkey has upgraded all geothermal energy projects planning to install 500 MWt electricity power systems in the Western Anatolia.

Bursa, through the history, has well known thermal spas which attracts attention of people around the world. Many spas in the region are about to update their technologies.

Geothermal energy is used directly in Bursa for growing flowers, heating swimming pools and heating buildings. There are a number of basic types of direct use applications in aquaculture, greenhouses, industrial and agricultural processes, resorts and spas, space and district heating, and cooling. Bursa hot springs have a capacity of heating energy which can heat directly 821 dwellings, which provides important contribution to the economy of Bursa in Turkey [14].

Bursa and the surrounding area are covered by igneous and volcanic rocks which are intruded in the cracks by depositing sedimentary rocks along the NS directed faults. They are heat sources for the geothermal system which related to Bursa Geothermal hot springs. Metamorphic marbles have high porosity. Heated waters ascending by conventional currents are filling those porous spaces in the metamorphic marbles. However, the upper part of the marbles is covered in succession by shale and sandstone acting as cap rocks preventing cooling of reservoir rocks as shown in Fig-11.

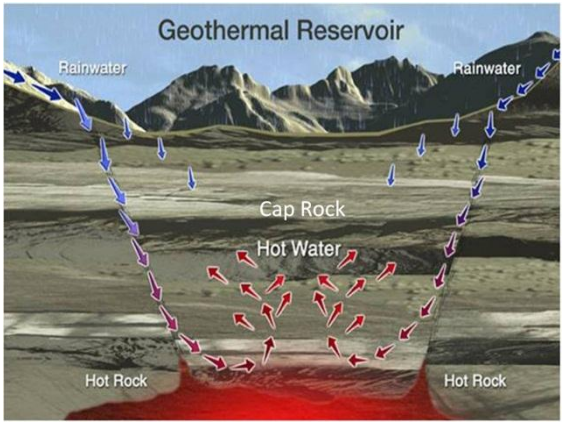

Fig-11: A simplified geothermal system.

Balneologists generally accept the following classification of mineral springs: Cold Springs with temperatures below (25° C); Tepid Springs - temperatures ranging from (25°-34° C); Warm Springs - temperatures ranging from (34° - 42° C); Hot Springs-temperatures above (38° C). Bursa and surrounding waters are classified according to their temperature; Cold Springs temperatures below (25° C): Erikli cold spring sold in Turkey and exported abroad. We have no tepid spring. Warm Springs temperatures ranging from (34° - 42 °C) are Gemlik, Zeynine and Cekirge springs. Hot Springs - temperatures above (38° C): Oylat, Gemlik, Dumbuldek, Uludag Rehabilitasyon, Cekirge, Kaynarca, and Zeynine.

Bursa geothermal reservoirs of low and moderate temperature (between 20^{o}C - 68.5^{o}C) are convenient for heating homes, offices, and greenhouses; in aquaculture and food processing plants; and a variety of other applications. Hot waters are used in balneology curing for certain sicknesses such as rheumatism, containing certain cations and anions like Na, HCO_3, and SO_4, of these ions, especially Na is beneficial for muscle system which activates stomach, secretes HCO_3 [15].

Sodium chloride and other natural salts assist in the alleviation of arthritic symptoms, and may stimulate blood circulation when used in baths. Citli and Dumbuldek hot springs are rich in Na with 1295 and 355 ppm, respectively. Both these two spas are useful for stimulating the body's lymphatic system and assist their work which is useful by alleviating arthritic symptoms [15].

Hot spring waters rich in sulfur in Bursa and surroundings and other places, are used to address a wide variety of sicknesses, including skin infections, respiratory problems, and skin inflammations. Hot springs rich in sulfates (i.e. sulfur compounds) have far reduced "sulfur" effect compared to sulfur-rich springs. Such waters are often prescribed internally for liver and gastrointestinal conditions, as well as for some respiratory conditions with inhalation therapy, in European spas [15].

Spring waters that contain bicarbonate (sodium bicarbonate, calcium bicarbonate, carbon dioxide, etc.) may be utilized for the water observed benefits which commonly associated with bicarbonate hot springs. Sodium bicarbonate values ın Bursa hot springs vary between 244 and 1562 ppm. The balneologist believe that bathing in bicarbonate water, assists opening peripheral blood vessels and helps to improve circulation to the body's extremities. European balneotherapists also utilize bicarbonate waters for bathing to address hypertension and mild atherosclerosis. For these conditions, from tepid to warm baths are utilized (25°C -34°C). Some researchers believe that bicarbonate baths also assist cardiovascular disease and nervous system imbalances [15].

Fluoride varied between 0.3-4.84 ppm but according to World Health Organization (WHO) limitations, the concentration of Fluoride must not exceed 1.5 ppm. The fluoride concentration of Kaynarca, Uludag and Dumbuldek hot waters have higher than the limit value. When this water is drunk, the flouride concentrations of the water damage to the teeth, as fluorosis sickness changes the original teeth color to brownish. The other water sample concentrations were below the limit so there was no harm to teeth [7]. NO_3^{1-} values is varied 0.1-3.95 ppm. Acceptable daily intake (ADI) nitrate 0–3.7 ppm nitrate ion/kg body weight. This intake appears to be safe for healthy children, and adults [16, 17]

Radioactivity in hot springs cures rheumatism and gynecological sicknesses. It must not exceed a certain level. Turkish spas' radioactivity is showing in Table 5 [15]. According to Table 3, the Bursa geothermal hot springs radioactivity is 5540 pCi/L. This value is relatively low compared to other Turkish spa radioactivity.

Table-5: Radioactivity of Turkish spa waters [15].

Location of Spa	Temperature (^{0}C)	Radioactivity (pCi/L)
Büyükhamam (Köyceğiz)	39	20020
Büyükkaplıca (Bolu)	45	11428
Kepekler (Susurluk)	60	10965
Kayırlı Mineral Water (	19	10960
Emendere (Sındırgı)	32	8284
Ilıca (Kuşadası)	24	7593
Ömerköy (Susurluk)	32	7580
Hüdaverdi (Sandıklı)	60	7333
Hıdırlar (Yenice)	38	6370
Karamustafa Paşa (Bursa)	53	5540
Ekşidere (Gönen)	18	5314

Bursa hot spring waters descend through the cracks of the Uludag granites and rhyolites to hot rocks, and are then heated by a heat source. After that, heated waters ascend by convectional currents to the reservoir rocks. These waters were classified as meteoric waters according to results of their isotope studies. These results are comparable to the other researchers findings [18].

CONCLUSIONS

In this study, the physico-chemical properties of Bursa and surrounding spring hot waters and Erikli cold water which is bottled were investigated. Water samples were collected in-situ and some physical measurements were performed during sampling. Other major analysis was carried out in the geothermal laboratory. Water samples were evaluated by both field observations and geological considerations with respect to petrographical formation of the sampling area. The data were evaluated using Aqua-Chem program with respect to the field observations and the geology and petrography of the area. Water samples were characterized by type according to their sources, whether waters were magma origin or meteoric waters by the isotope studies and with the help of cations and anions data on water circulation geosystem by the interaction where the water passes through the Bursa Geothermal system (Fig.12). The radioactivity is below acceptable limits. Using Piper diagram hot water resources were determined for Bursa province and surroundings. The waters in Cekirge, Kaynarca, Kukurtlu, Zeynine, Dumbuldek, Inegol Oylat are Ca-Mg-Na-SO_4, Na-Ca-SO_4, Na-Ca-HCO_3-SO_4, Ca-Na-Mg-SO_4, Na-Ca, Ca-SO_4-HCO_3 waters respectively.

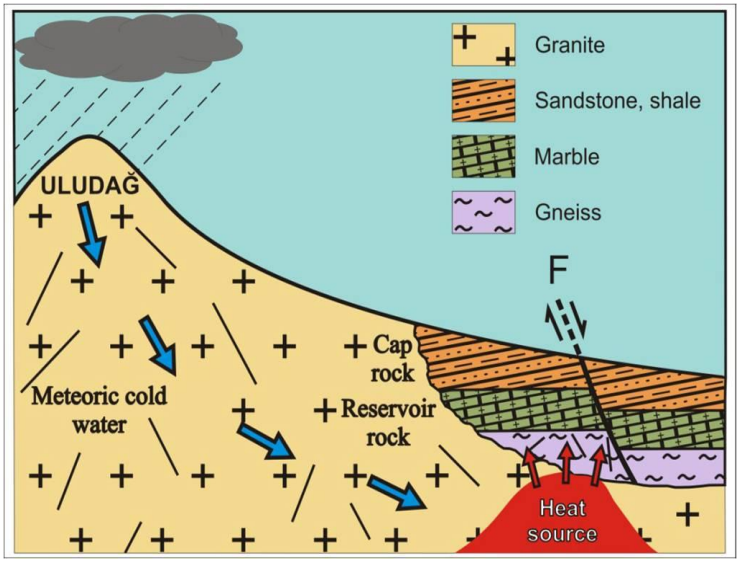

Fig-12: As simplified geothermal modeling for Bursa Province geothermal area.

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