Scientific Research and Essays Vol. 5(20), pp. 3147-3151, 18 October, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Some geological and hydrogeochemical characteristics of geothermal fields of Turkey

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Accepted 13 September, 2010

Presently, active hydrothermal areas of Turkey can be divided into three major provinces which correlate particular volcano-tectonic features. These fields are essentially found at western, central and eastern part of the country. There has been no particular geothermal energy fields in the southern part of Turkey since this region is mostly covered by ~2 km thick carbonate sequences and has suffered little recent rifting. The western Turkish geothermal provinces, where horst and graben systems are well developed, have the hottest fluids among others. In this region, normal faults penetrate into the crust and thus the meteoric waters are heated to greater temperatures than in the east where a compressional tectonic regime dominates. In the western Turkish geothermal fields, the fluids have a distinctly higher pH (>7) values than those in the east. This resulted that the Si content of the western Turkish hydrothermal fluids is considerably higher than the others. The geothermal field at Tuzla, situated on the Aegean shore in NW Turkey, has ionic component twice that of conventional seawater. Because of this, the area provides a good opportunity to investigate the interactions between seawater and hot dry rock.

Key words: Geothermal fields, seawater, hot dry rock.

INTRODUCTION

The geological history of Turkey essentially began with the deposition of marine sediments, essentially of Palaeozoic age. These were deposited in the Tethyan Ocean. They were subsequently folded during the collision (in the early Mesozoic) of Laurasia and Gondwanaland (Africa). Turkey is a land squeezed between these two continental plates. This land is situated on the Alpine-Himalayan orogenic belt and as a result of this orogeny, some major fault systems, volcanoes, fumaroles and hot springs were developed in Turkey.

More than 600 hot springs exist in Turkey, many with temperatures exceeding 100°C. Thus, Turkey has an important geothermal energy potential. This potential has never been seriously considered in the international literature, despite the fact that some fields were discovered as early as the 1960s (for example Balçova, İzmir (1963) and Kızıldere - Denizli, in 1968).

Geothermal energy has several advantages as an energy source when compared to fossil fuels (oil and coal) and radioactive nuclides. Energy produced geothermally is usually cheaper economically, is environmentally acceptable, and is effectively as "unlimited" as solar, wind or wave power. However, geothermal energy has additional advantages for Turkey for the following reasons:

1. Turkish industry is largely established in the western part of the country where the most promising geothermal

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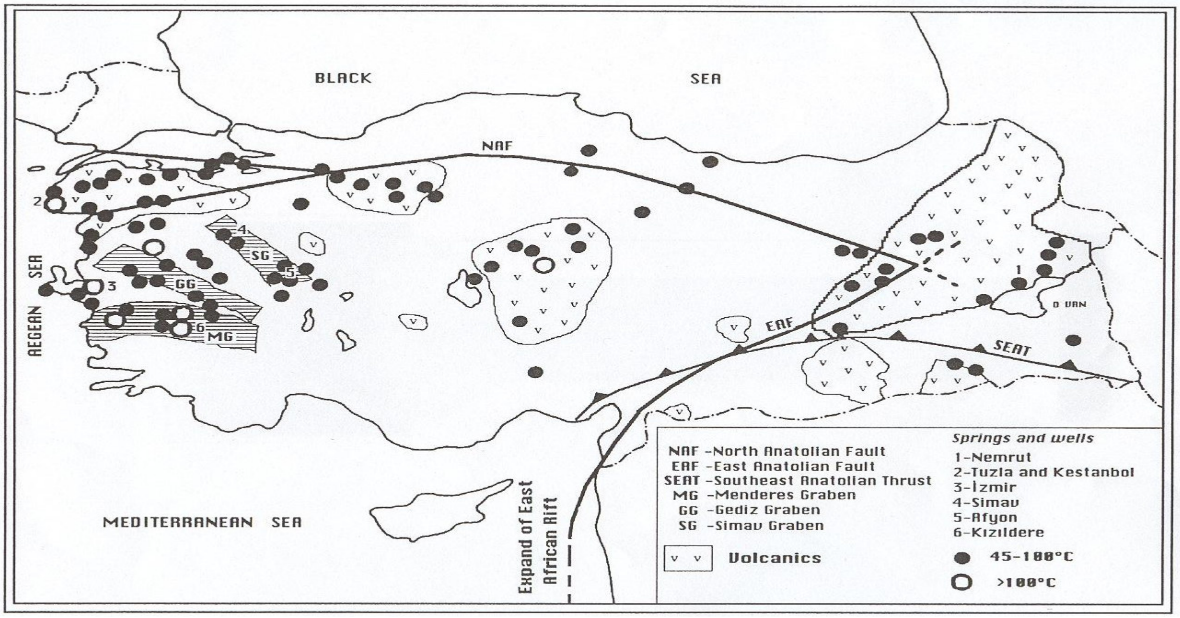

Figure 1. Major geological features of Turkey and distribution of hot springs as well as geothermal wells (Modified from Geothermal Energy, 1993).

energy fields are situated,
2. Geothermal energy is the main alternative energy source for Turkey, as Turkey's fossil fuel reserves are very restricted and the quality of the main fuel lignite is very poor.

The aim of this paper is to present the distribution of the geothermal fields of Turkey in a geological context and suggest possible relationships between the geochemical features of the hot fluids and the general volcano-tectonic features of Turkey.

Volcano-tectonic features and the distribution of geothermal fields and hot springs

As indicated, Turkey is located in the collision zone between Laurasia and Gondwanaland. As a result, the tectonic, stratigraphic, volcanic and magmatic features of Turkey are extremely complex and many aspects are still in doubt. In spite of these complexities, Ketin (1966) has divided the country into four major tectonic units.

1. The Pontides (in the north),
2. The Anatolides (in the centre),
3. The Taurides (in the south) and
4. The Border folds (in the southeast).

In terms of tectonic aspects, the North Anatolian Fault, East Anatolian Fault, Southeast Anatolian Thrust, Gediz, Simav and Menderes Grabens are the most notable tectonic features of Turkey (Figure 1). The core of central Turkey, and much of Eastern Anatolia as well as Northwest Turkey was covered by young (Upper Tertiary and Quaternary) volcanic rocks. There is a close relationship between geothermal fields, including hot springs and major fault zones, volcanic centres and horst-graben systems (Figure 1). Although hot springs are scattered all over the country, on the basis of volcanic, they can geographically be divided into three regions: The eastern, central and western portions of Turkey as for volcanic rocks (Sogut et al., 2007). The most important geothermal fields are found in Western Anatolia, since it has more than 56 hot springs (including wells) whose temperatures exceeding 45℃. On the other hand, the southern part of Turkey has only one hot (>45℃) spring. This is possibly due to the fact that this part of the country is largely covered by thick (>2 km), mainly carbonate, rocks. The geothermal area at Tuzla (Çanakkale, near the northwestern tip of Turkey) is probably one of the most interesting. Because, the hot water (upwelling from either wells or springs) originates from brine (Öngür, 1978) and it provides an opportunity to understand the mechanism of sea water-hot dry rock interactions.

Smith and Shaw (1973) noted that continental geothermal resources are more likely to relate to silicic volcanism rather than with the basaltic extrusions. In general, the eastern and central Anatolian volcanics are basic to intermediate in composition whilst the western Anatolian volcanics are acidic since they were formed as a result of anatexy (Ercan et al., 1985). In two districts, Kula and Denizli, in western Turkey, the major and trace element contents of volcanic rocks indicate that these rocks originated directly from the mantle rather than through anatexy (Ercan et al., ibid.). Central Anatolian volcanics are generally chalkalkaline in character (Öngür and Eriflen, 1978) while the eastern Anatolian volcanics have a tholeitic to chalk alkaline character (Arslan, 1994).

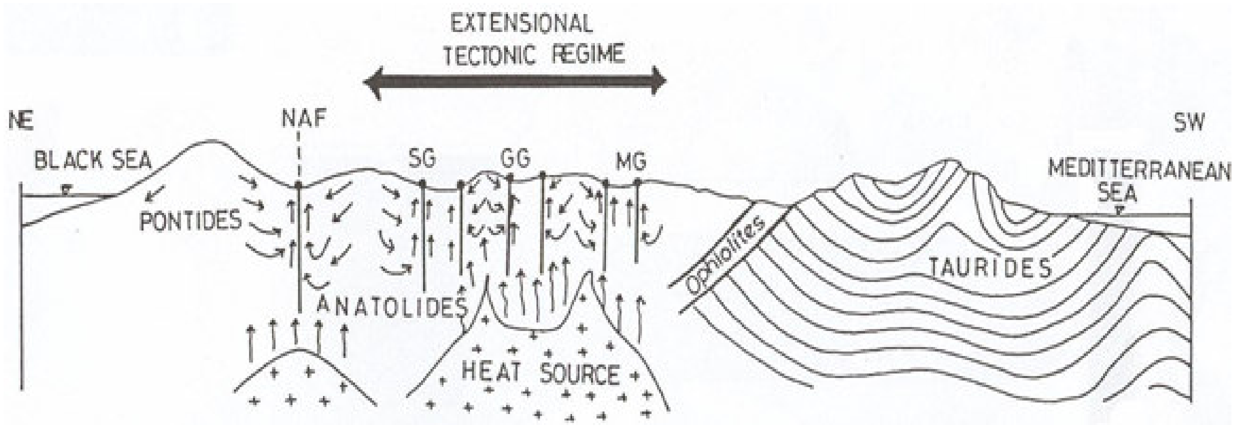

Figure 2. Simplified geological cross-section (between Black Sea and Meditterranean Sea) of western Turkey. Arrows indicate the circulating fluids. Thick vertical lines represent faults, and circules in black over the faults are the geothermal fields. NAF: North Anatolian Fault; SG: Simav Graben; GG: Gediz Graben; MG: Menderes Graben.

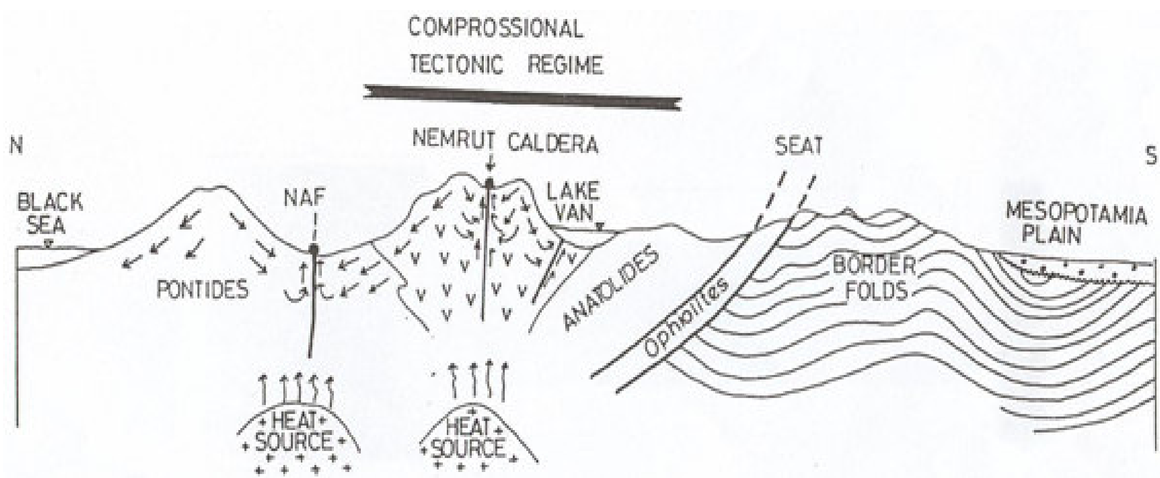

Figure 3. Generalized geological cross-section (between Black Sea and Mesopotamia Plain) of Eastern Turkey. Arrows represent circulating fluids. NAF: North Anatolian Fault.

It is notable that the hottest springs are concentrated in western Turkey, especially in and around the Menderes, Gediz and Simav grabens (Figure 1) where the cover rocks are generally thick (up to 1200 m) and where fault zones are deeply penetrating since an extensional tectonic regime is dominant in most of western Turkey (Figure 2). The cover rocks over the geothermal reservoirs in eastern Turkey are generally between 100 and 200 m thick, and the meteoric water circulates at shallow levels as the faults do not penetrate the deep as the existence compressional tectonic regime in the region (Figure 3). The age of volcanic rocks all over Turkey is predominantly Tertiary or younger.

CONTINENTAL CRUST

According to Yılmaz (1990), Eastern Turkey was extensively deformed by a N-S compressional tectonic regime, and this compression still continues. As a result, the crust in Eastern Turkey is thickened to about 45 km. In Western Turkey, thickening of the crust began during the late Cretaceous and ended in the middle Miocene (Yılmaz, 1990). From the Miocene to the present, the tectonic regime has been mainly extensional and this has led to the development of E-W trending graben systems. The Menderes, Gediz and Simav grabens are the result of this extensional regime. The thickness of the crust in this part of Turkey is between 30 and 40 km (Yılmaz, ibid.). Relative thickness of the crust in Western, Central and Eastern Turkey is shown in Figure 4.

The positions of buried active faults in the Menderes Graben can be determined by radon measurements of the soils (Şimşek, 1983). This indicates that meteoric waters penetrate the deeper parts of the crust than in eastern Turkey, and explains why the most promising geothermal energy fields are concentrated in the Western Turkey.

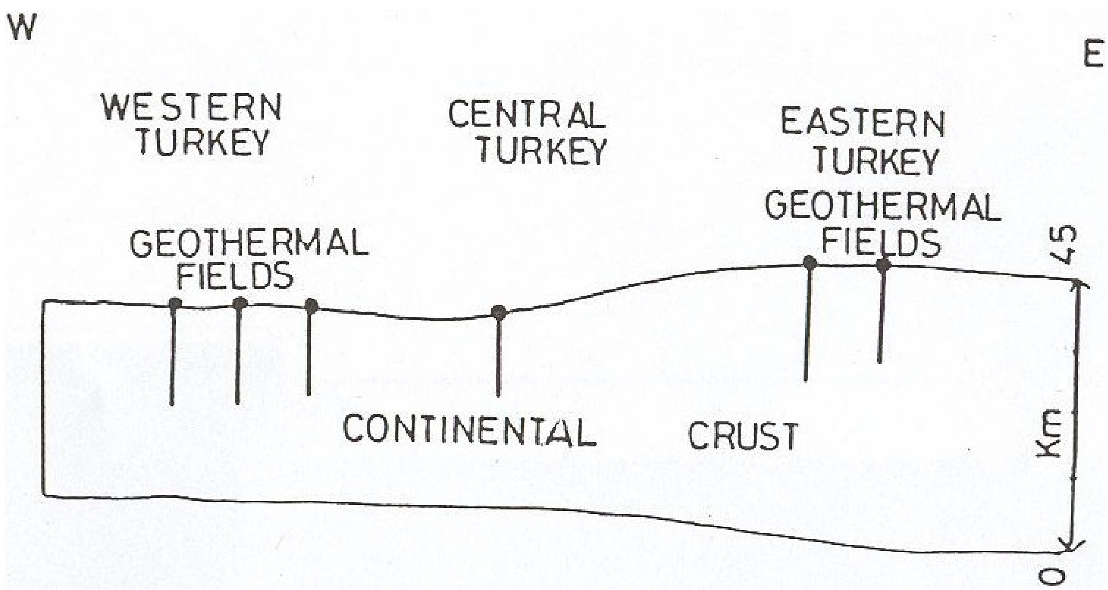

Figure 4. Relative thickness of the continental crust in Turkey. Thick lines represent faults.

GEOCHEMISTRY OF GEOTHERMAL FLUIDS

The geochemical features of the fluids from Western and Eastern Turkey are outlined in Table 1. Unfortunately, there are no appropriate geochemical data at hand for the central Anatolian geothermal area. Thus, interpretations and findings are restricted only to Eastern and Western Turkey. As seen in Table 1, there are distinct differences in pH values between Eastern and Western Turkish geothermal fluids. The pH of hot fluids at Nemrut, which emanate from a caldera, is 6.2 whilst the lowest value in Western Turkey is 7.2. The hot fluids upwelling from Tuzla, are characterized by extremely high values of Na^+, K^+, Ca^{2+}, Mg^{2+} as well as Cl^- compared to other geothermal fluids. The Tuzla fluid have almost twice concentrated in Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^- than the seawater. This is possibly due phase separation during seawater-hot dry rock interactions at depth as Tuzla is situated on the shore of the Aegean Sea. In this area the reservoir rocks are granite, gneiss and syenite (Table 1). During the chemical reaction, the rock/water ratio is probably high since the upwelling fluids are very dense.

With the exception of Kızıldere (Denizli), geothermal fluids in eastern and western Turkey have Si concentrations of between 96 and 205 ppm. At Kızıldere, the Si concentration exceeds 300 ppm. The pH of the fluids at Kızıldere is also distinctly higher than others. The high pH values could be the reason for the high Si contents, as silicate minerals may be more easily dissolved at higher pH.

The δD and $\delta^{18}O$ values of waters from the spring at Nemrut in NE Turkey are -73 and -10%, respectively (Ünlü and Can, 1983). When these values are plotted on the commonly used δD v $\delta^{18}O$ diagram, these water are seem to be on the so-called "meteoric water line" indicating that the water at Nemrut is predominantly of meteoric origin. These results may not be enough to make a reliable interpretation, but they do provide a strong indicator. More data are required.

It has long been known that some geothermal systems are associated with caldera structures. There are many examples of these, such as Rotorua and Okataina, in New Zealand; Yellowstone and Long Valleys, in the USA and Krafla in Iceland. We can add the Nemrut Caldera to this list. According to Henley and Ellis (1983), it is possible that deep penetration of meteoric water along fault zones may be related to the formation of the caldera itself. Presumably, a cooling intrusive is the heat source driving convective flows of meteoric water in the Nemrut Caldera so explaining the hot springs around it.

CONCLUSIONS

1. Geothermal energy fields of Turkey can be divided geologically and geographically into three major provinces, in Western, Central and Eastern Turkey. There is no geothermal energy potential in Southern Turkey.
2. The hottest geothermal fluids are found in Western Turkey. In this area, fields are often related to graben systems where meteoric water is able to penetrate deeper parts of the crust (the Menderes, Gediz and Simav grabens). In Eastern Turkey geothermal systems are developed in and around caldera structures, such as that at Nemrut.

Table 1. General geochemical features of the fluids from Eastern (Nemrut) and Western Turkish geothermal fluids.

Location	pH	T (°C)	Na^+	K^+	Ca^{++}	Mg^{++}	Cl^-	Si	δ D	$\delta^{18}O$	Reser. rock	Cap rock	References
Nemrut NE spring	6,2	59,5	350	38	38	6	Trace	205	-73	-10,2	Lms, Gdy	An, Ml, Tu	Ünlü and Can (1983)
Nemrut NW spring	6,2	46	330	37	38	4	Trace	200	----	----	--------	--------	
Kestanbol	7,7	73	7144	451	931	87,8	13116	96			G, Gns, Sy	Ss, Ms	Şamilgil (1983)
Tuzla, TK-1	7,3	102	19000	1800	3080	30	35500	113	----	----	--------	--------	
Agememnon, İzmir	8,7	100	380	29	12	7	192	145			No inform	No inform	Mertoğlu (1983)
Eynal, Simav, EY-1	8,9	74	530	65	4,3	1	69	167			Bs, Sh	Tu, Ml, Ss	Erişen (1989)
Çitgöl, Simav, CT-1	7,2	77	245	37	43	3,7	30	158	----	----	--------	--------	
Gecek, Afyon, G-1	8,1	82	1510	45	40	12	1830	156	----	----	Mr	Ms, Ss, C, Ag, Tu	Şamilgil (1973)
Kızıldere, KD-1	8,9	>100	1380	166	2,4	0,4	106	320			Lms, Mr	Ms, Ss, C, Cs	Başkan (1973)

Ml-Marl; Gns-Gneiss; C-Clay; Cs-Claystone; Lms-Limestone; Ss- Sandstone; Bs-Basalt; Tu-Tuff; Gdy-Granogiyorite; Ms-Mudstone; Sh-Schist; Sy-Sienit; An-Andesite; G-Granite; Mr-Marble; Ag-Aglomera.

3. Although the geochemical data at hand are very limited, it can be said that there is a close relationships between the Si contents and pH values of the fluids.
4. The Tuzla (Çanakkale) geothermal area is one of the most interesting as the fluids of this field is clearly of seawater origin. There is a good opportunity to study seawater-hot dry rock interactions at this field.

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