Heat Flow and Related Geothermal Potential of Turkey

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ABSTRACT

Heat flow maps based on geothermometers and temperature gradients were used to estimate the stored heat in Turkey. Stored heat computed from these maps was utilized to identify 3 categories of geothermal resources: (1) T< 100°C, (2) 100°C >T> 180°C and (3) T>180°C. A stochastic study is carried out on these data and the expected geothermal energy resource and convertible energy estimates for each group were computed and reported.

Introduction

Turkey is known for rich geothermal resources. But, up until now, there has been no substantial work on the potential of these resources. Although some figures are circulating on the geothermal potential such as 31500 MW_t reported by Simsek, (1985), we were not able to find out their scientific and engineering basis in the literature. Therefore, it is believed that they might be subjective estimations.

The thermal regime of the lithosphere affects all major tectonic, volcanic and metamorphic processes. Heat flow density data give some clues about present thermal conditions of the lithosphere. The heat generation in the earth originates from the earth's gravitational force, internal adiabatic pressure, radioactive decay, rotation of earth around its axis and tidal force due to gravity of moon. Average heat flow of the earthcrust reported by Pollack, *et al.*, (1988) is around 65 mW/m^2 in the continents and 101 mW/m^2 in the oceans. A study conducted by Ilkısık, (1992) in Turkey based on silica geothermometers revealed anomalous heat flow of 108 ± 44.5 mW/m^2 as a whole, and 111 ± 48.1, 103 ± 44.4 and 113 ± 39.8 mW/m^2 in Western, Central and Eastern Regions of Anatolia, respectively. Another study being conducted on heat flow in Aegean region of Turkey has reportedly given average heat flow value of 90 mW/m^2, and average heat flow in Turkey is thought to be 85 mW/m^2 (Ilkisik, 1999). These areas with anomalous heat flow are also known to have high geothermal activity. Around 600 of hot springs that are encountered in these tectonically active regions are also a clear evidence of anomalous heat flow.

Turkey's geothermal resource base estimation for 3 km depth is reported by Roberts, (1978) and calculated by Serpen, (1996), and they present similar results. Both authors used Eq. 2 for accessible heat computations. Assumptions for the Roberts' work are given by Rowley, (1982). Some of the assumptions can be given as follows: (1) a normal gradient of 25°C/km for all non-geothermal areas, (2) a gradient of 40°C/km for %90 of the area of a country that lies inside a geothermal belt, (3) a gradient of 90°C/km for the remaining %10 of the area of a geothermal belt, and etc. Some of the assumptions used in Serpen's work were similar, but, unlike aerial assumptions made by Roberts for each country depending upon geothermal belts, heat flow areas of Turkey for each temperature category were directly measured in the heat flow map given in Figure 1. Class temperatures in Serpen's work are estimated from gradients at 3-km depth. The results of these computations are presented in Table 1.

Table 1. Turkey's Geothermal Resource Base.

Resource base in temperature ranges at 3 km depth, J							
	Area, km^2	Geothe. Area,%	< 100°C 1. Class	100-150 2. Class	150-250 3. Class	> 250°C 4. Class	Total
Roberts	780000	50	19.0E22	8.40E22	2.30E22	1.40E22	3.10E23
Serpen	780000	89.4	16.0E22	9.25E22	3.21E22	–	2.85E23

This study does not claim to give a deterministic value of geothermal potential of the Turkey, which is a major task that requires substantial and long term studies on each resource, individually. But rather, it opens an insight of the possibilities on the geothermal potential of the Turkey in different temperature ranges.

Methodology

The heat content Q underlying a region of the earth, with a surface area A is calculated from the following formula given by Rowley, (1982):

$$Q(Z_f) = A\int_0^{Z_f} \rho(Z)C(Z)T(Z)d. \qquad [1]$$

Where,

- Q = Accessible stored heat,
- A = Surface area,
- Z = Vertical depth,
- Z_f = Depth for desired computation,
- T(Z) = Temperature as a function of depth,
- $\rho(Z)$ = Density as a function of depth,
- C(Z) = Effective specific heat of crust as a function of depth.

In order to be able to calculate the accessible stored heat the following average crustal characteristics and properties are assumed (Rowley, 1982):

Average crustal density	= 2500 kg/m^3,
Average specific heat	= 770 J/kg°C,
Averagevolumetric heat capacity	= 1.93x10^6 J/m^3 °C,
Average surface temperature	= 15°C,
Average thermal conductivity	= 2 W/m°C.

Substituting the above mentioned parameters into Eq. 1 we obtain the following formula to compute the accessible stored heat up to 3 km depth.

$$Q = 1.9\times10^{-3} A\int_0^3 (\nabla TZ+15)dZ \qquad [2]$$

Where,

- Q = Accessible stored heat,
- A = Surface area,
- Z = Vertical depth,
- C_v=Average volumetric heat capacity, 1.9x10^{-3} J/km^3 °C

Figure 1 illustrates heat flow map of Turkey based on gradient data, by Tezcan, (1979), Figure 2 shows another heat flow map of Turkey by Ilkisik, (1992) based on silica geothermometer and Figure 3 indicates a gradient map by Mihcakan *et al.*, (1998) made on a different data base. Though these 3 maps differ in some details they show similar trends and character in general. By using Eq. 2 and heat flow density-thermal gradient relationship, accessible stored geothermal energy up to 3 km is computed by using 3 available maps for three different temperature ranges. The temperatures for each class are estimated from gradients at 3 km depth. The results are presented in Table 2.

Table 2. Accessible Resource Base Estimates for Turkey (3-km integration depth).

Temperature Ranges	Map in Fig. 1 (J)	Map in Fig. 2 (J)	Map in Fig. 3 (J)
1. Class, (<100°C)	1.6E22	6.7E22	1.3E23
2. Class, (100-180°C)	9.2E22	1.8E23	8.2E22
3. Class, (180-250°C)	3.2E22	8.4E21	7.7E21

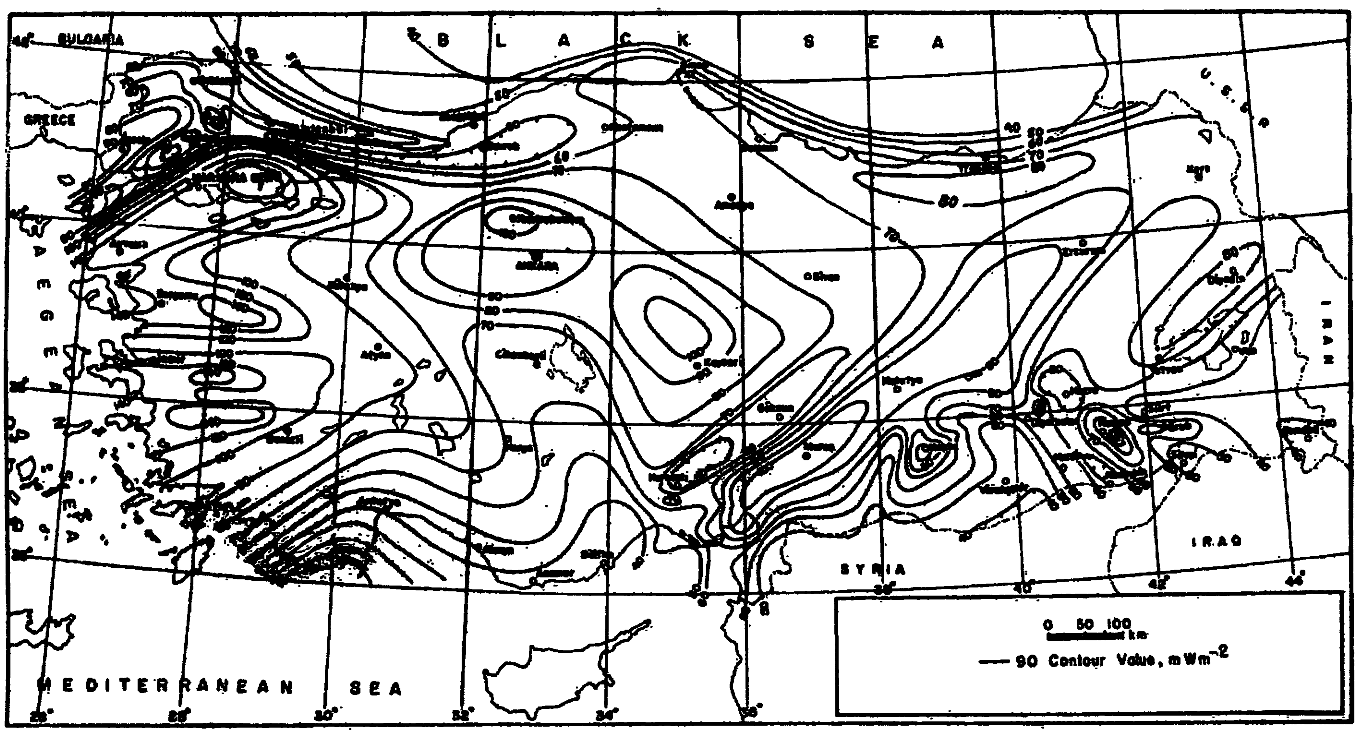

Figure 1. Heat flow map of Turkey based on gradient data, by Tezcan, (1979).

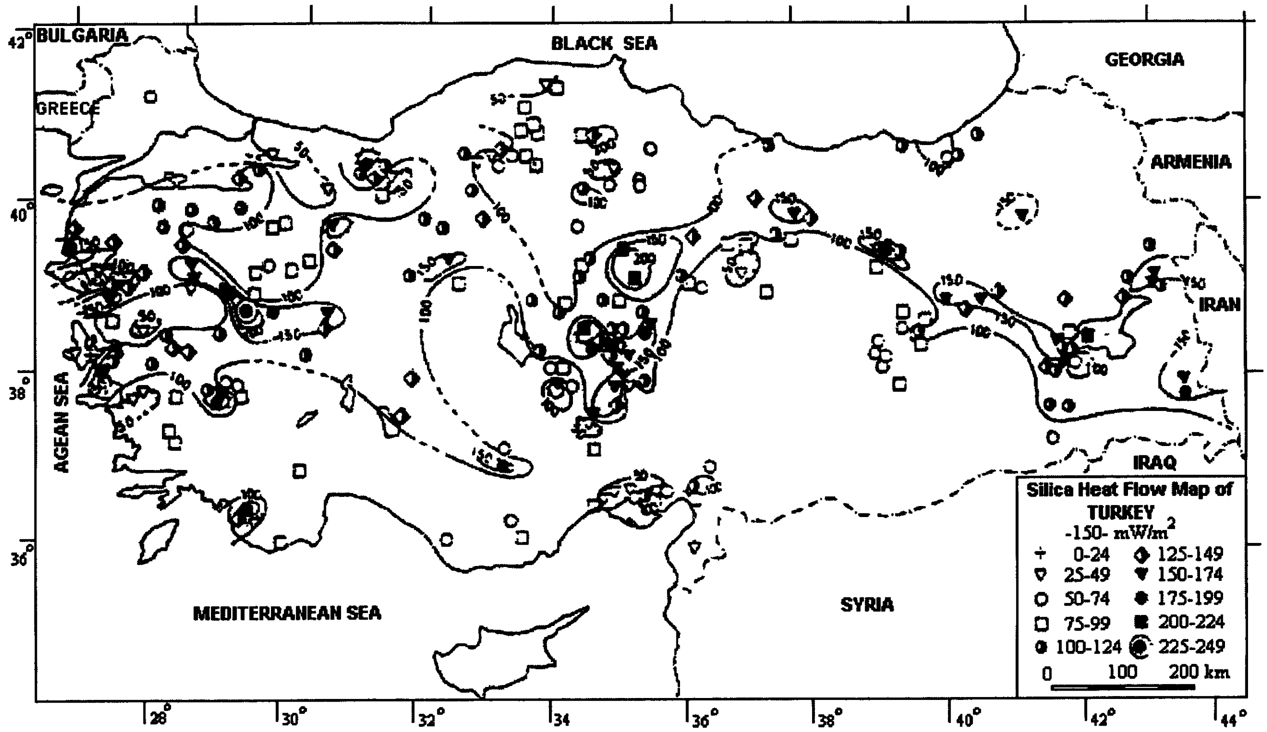

Figure 2. Heat Flow Map of Turkey by Ilkisik, (1992).

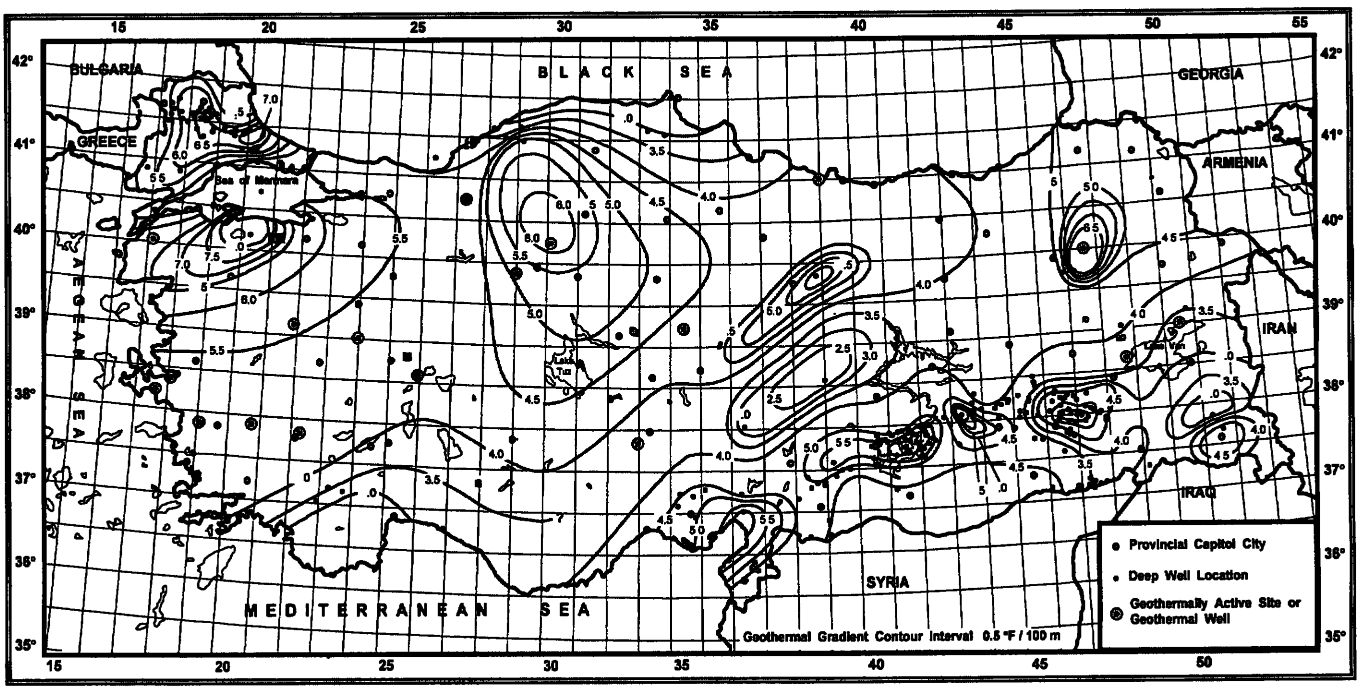

Figure 3. Gradient Map of Turkey, by Mihcakan *et al.*, (1998).

Our investigation on these maps pointed out that Figure1 is most reliable heat flow map and it complies well with known geological features of Turkey. But, since in some regions shallow well data were used shallow underground water temperatures might have influenced the gradients. Although reliable in general terms, heat flow map in Figure 2 lacks detailed data, and it may also contain errors due to assumptions of silica solubility, pH of waters, ashes in soil, etc. Because it is based mainly on oil well data around Turkey, gradient map on Figure 3 misses some details, especially in the Aegean region. As it can be observed from the above-mentioned information, computed accessible stored energy values vary widely (see Table 2), because each map has some sort of uncertainty. Therefore, a stochastic study is carried out using Monte Carlo simulation on the stored heat energy distributions for each class. Triangular distributions of accessible stored heat are formed for each temperature range in the following manner. Minimum and maximum stored heat values obtained from three different maps for each class are taken as min. and max. values of triangle distributions and the remaining computed value in between is considered most likely value of triangle distribution. So formed accessible stored heat triangle distributions are presented in Table 3.

Table 3. Triangular Accessible Resource Base Estimate Distributions for Different Temperature Ranges.

Temperature Ranges	Minimum, (J)	Most Likely, (J)	Maximum, (J)
1. Class, (<100°C)	1.6E22	6.7E22	1.3E23
2. Class, (100-180°C)	8.2E22	9.2E22	1.8E23
3. Class, (180-250°C)	7.7E21	8.4E21	3.2E22

Results and Conclusions

Monte Carlo simulations were run for each group indicated in Table 3. Results of risk analysis are obtained as distributions and they are illustrated as cumulative probability distributions in Figure 4.and in Figure 5. The expected accessible stored energy values obtained from Figure 4 and Figure 5 are presented in Table 4. From these figures accessible resource base for different confidence limits. Expected values are defined at 50 percentile levels in the figures.

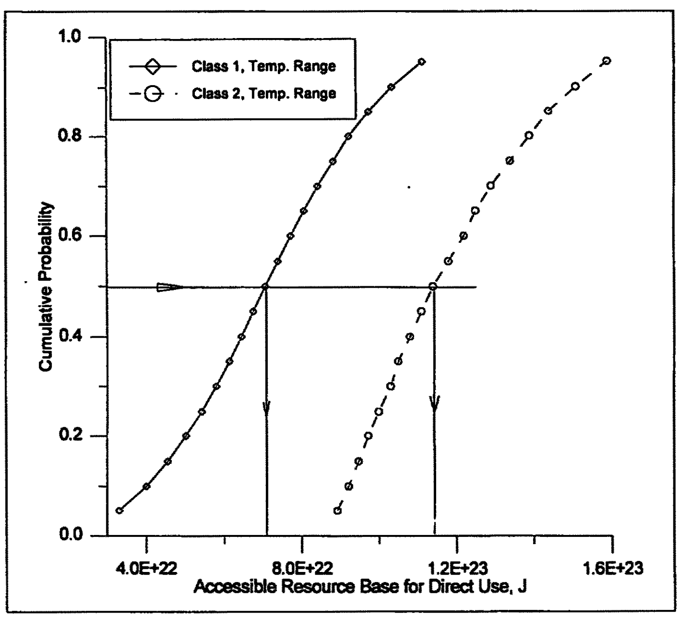

Figure 4. Accessible resource base distributions for Class 1 and 2 temperature ranges.

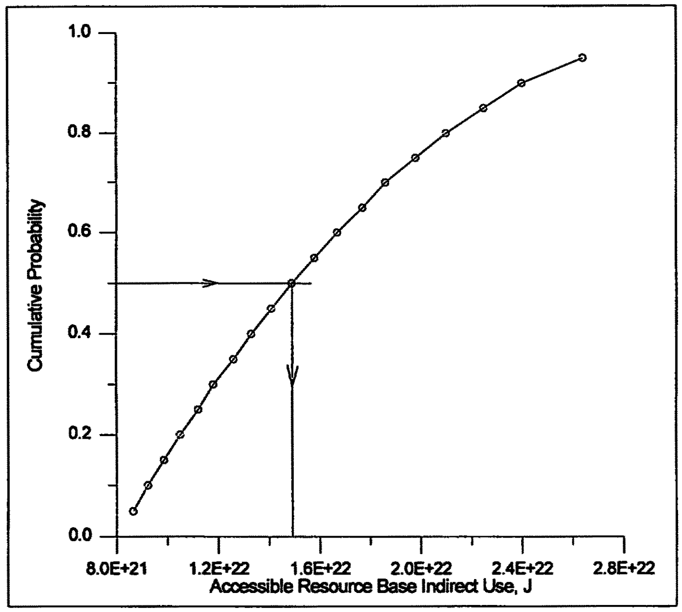

Figure 5. Accessible resource base distribution for indirect use.

Table 4. Monte Carlo Simulation Results (at 3 km depth).

Temperature Ranges	Expected Energy, J
1. Class, (<100°C)	7.1 E22
2. Class, (100-180°C)	11.4E22
3. Class, (180-250°C)	1.5 E22

In World Energy Resources, (1980), (WEC) presented a simple estimation approach to convert the estimated geothermal energy in place to a useful energy form by using existing technology. WEC suggests two different approaches for direct and indirect use of geothermal energy. In indirect use, 2% of the computed resource base is considered suitable for electricity generation. Combined conversion efficiency is assumed 2.2%, and of this value only 20% is supposed to be convertible through actual existing technology. For direct use, a similar approach results in approximately 7% of resource base as convertible energy. These approaches are applied on the expected energy values in Table 4 and results on convertible energy are presented in Table 5. As it can be observed from the Tables 3 and 4, resources in Class 2(100-180°C) which fall in industrial use category are much bigger than the others. Direct use of Turkey's geothermal resources, both for industrial and for space heating projects should have priority in development of these resources due to the large size of the resource.

Table 5. Convertible Energy Obtained by WEC Estimation Approach.

Temperature Ranges	Convertible Energy, J
1. Class, (<100°C), for direct use	4.9 E21
2. Class, (100-180°C), for direct use	8.0 E21
3. Class, (180-250°C), for indirect use	1.3 E18

In the light of above mentioned the following conclusions are obtained:

1. Accessible geothermal energy base of Turkey is estimated as 7.1 E22 J, 11.8 E22 J and 16.0 E21 J, for temperature ranges of (<100°C), (100-180°C) and (180-250°C) respectively.
2. Convertible geothermal energy of Turkey is estimated as 4.9 E21 J, 8.0 E21 J and 1.3 E18 J for temperature ranges of (<100°C), (100-180°C) and (180-250°C) respectively.
3. Resources for direct use, especially in industrial use appear to exceed substantially the others, and they might play an important role in developing geothermal resources in Turkey.

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