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ESTIMATION OF GEOTHERMAL POTENTIAL OF BÜYÜK MENDERES REGION IN TURKEY

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ABSRTRACT

The aim of this study is to estimate the geothermal potential of Büyük Menderes region which is considered the most important geothermal province of Turkey. To achive this objective, a new methodology is proposed to estimate geothermal reserves of the characteristic geothermal regions. The available geological, geophysical, geochemical and drilling data of all geothermal areas and anomalies in B. Menderes region are evaluated. Then, distributions of all the necessary input data such as structure, surface area, depth, rock density and porosity are generated. Utilizing these distributions, accessible stored heat distribution of each anomaly is stochastically computed using Monte Carlo technique. By assigning suitable probability values for low and high enthalpy systems, recoverable heat and electrical power potential are computed. The resulting accessible and convertible energy is reported as the total geothermal potential of the B. Menderes graben.

1. INTRODUCTION

Located in the western part of Turkey, B. Menderes graben is a major tectonically formed structure. It extends 150 km in an E-W direction. This large structure has several discovered geothermal resources and is considered as a geothermal region. Heat flow anomalies stand out along the graben which contains many known geothermal areas, hot springs and other geothermal features. Stochastic and risk analysis methods are frequently used to estimate the range and probable distribution of oil reserves in sedimentary basins when there is considerable uncertainty. Known structures with reserves are extrapolated into the probable structures within the same basin using stochastic techniques. Then the outcome from those simulations is evaluated using a risk analysis approach. Brook *et al.*, (1979) used a similar approach to compute the distribution of accessible geothermal resource base within the United States. The same approach can be utilized to estimate the total geothermal energy reserve distribution of an entire region that was created by a single geological event such as tectonism or volcanism.

2. GEOLOGIC SETTING OF THE MENDERES MASSIF AND B. MENDERES GRABEN

The Menderes Massif is one of the largest metamorphic massifs in Turkey, measuring roughly 200 km N-S, and about 150 km E-W in western Anatolia (Fig. 1). It can be described as a dome-like structure, broken by faulting during the Alpine orogeny. The Menderes Massif includes a core of paragneisses and orthogneisses wrapped in a variety of schists and dolomitic marbles. These rocks have been intruded by a number of granites.

The crystalline Menderes Massif is divided into two major units: the core and the cover series. The core series consists of Precambrian to Cambrian high-grade schists, leptite-gneisses, augen gneisses, metagranites, migmatites and metagabbros. The cover series is composed of Ordovician to Paleocene micaschists, phyllites, metaquartzites, metaleucogranites, chloritoid-kyanite schists, metacarbonates and a meta- olistostrom [Karamanderesi, 1997].

The geological history of the Menderes Massif is divided into two parts: paleotectonic evolution and neotectonic evolution. The central Menderes Massif is characterised by a dome-shaped foliation pattern and a north to northeast-trending elongation/stretching lineation. The paleotectonic evolution includes metamorphism, magmatism, and deformation of the main rock formations. The data obtained from the geothermal wells at the Ömerbeyli and Salavatli fields proved that overthrusting followed by reverse faulting is a product of very recent tectonism. Small granite bodies and similar intrusive blocks are present within the overthrusted gneisses. The period of overthrusting was followed by a dome-forming period in the Menderes Massif. Early fossil geothermal systems developed along tectonic zones during the dome-forming period. The development and evolution of these systems are related to neotectonic activity. The neotectonic period of the Menderes Massif is characterized by the presence of cross-faults in western Turkey and, therefore, with the main E-W grabens. From Pliocene to Early Quaternary age a widespread normal faulting, in which approximately N-S extensional movements affected the whole of western Anatolia, formed the graben system. The N-S extensional tectonics had begun during latest Oligocene-Early Miocene time. Seismic studies indicate that the Late Miocene and Plio-Quaternary tectonic evolution of this region is of the extensional type and still active [Karamanderesi, 1997].

Menderes Massif consists of metamorphic rocks and later sediment deposits during the Menderes rifting period. Geophysical studies and drilling showed normal faults and the development of a stepwise graben, which is also characteristic of the Germencik, Salavatli, and Kizildere geothermal fields in the B. Menderes graben. Several intermediate to basic volcanic extrusions and geothermal springs in the central parts of the Massif are directly related to the graben system (Fig. 1) [Karamanderesi, 1997].

3. METHODOLOGY

Mineral Research and Exploration Institute of Turkey (Erisen *et al.*1996) defines eighteen geothermal fields and anomalies along the B. Menderes graben. Except for one field (Tekkehamam) which is found in the southern part, most fields and anomalies are situated in the northern part of graben along a main E-W fault. Five anomalies are located at the intersection of B. Menderes graben with the Gediz and Curuksu grabens in the easternmost part of the region. Some

34 deep (up to 2300 m) and several hundreds of shallow gradient wells have been drilled in this region. The geology of the area has been extensively studied for the last 35 years. Regional and as many as 12 local resistivity and gravity surveys have been carried out. The most known high enthalpy field is Kizildere geothermal reservoir that was discovered in 1968. Since these anomalies and fields were created by the same geologic event-that is, tectonism within the same geological environment (Menderes Massif)-their stratigraphy, their resistivity anomalies and their water chemistry are very much similar. Therefore, this region can be considered a geothermal basin.

Since the similarities in the geological environment have been established, available porosity, density and fluid property data from well-studied geothermal reservoirs -such as Kizildere- may be extended to the other geothermal structures in the basin. For a deterministic approach to estimate the geothermal potential of the region, the available data for all eighteen anomalies, with the exception of Kizildere, is not adequate. In the presence of such uncertainties in the geological, geophysical and reservoir data; stochastic simulation techniques based on the distribution sampling process are more suitable.

In the context of this study, simulation is a method in which, a dependent variable (i.e. accessible heat) is calculated many times with varying input variables. Simulation under uncertainty has been used extensively for petroleum and natural gas exploration as a risk analysis technique (Newendorp, 1975). The simulation method used in this study to determine the geothermal potential of B. Menderes region is known as Monte Carlo simulation technique. The parameters used to calculate the potential of a reservoir should have single values in nature. But only a small portion of the pertinent data for all of the structures in the basin is known with a high level of certainty ahead of time. Usually all we can say is the range of most probable values of each of such parameters. To reflect the uncertainties in the parameters that determine accessible geothermal energy of individual structures, variables such as aerial extension, reservoir temperature, and formation thickness should be quantified as separate probability distributions.

Since the independent variables are sampled at each step of simulation, complete representation of all possible outcomes can be achieved if the number of steps become large. Sampling in Monte Carlo simulation process is intended to retrieve possible values for independent variables selected randomly from assigned probability distributions. The set of sampled independent parameters are then used to calculate the dependent parameters. Each sample set computed at each simulation step represents a possible combination of input parameters.

Monte Carlo sampling refers to sampling from an assigned probability distribution using computer generated random or pseudo-random numbers between 0 and 1. In the Monte Carlo sampling technique the outcome is entirely random and will fall anywhere within the limits of an assigned input distribution.

The logical sequence of the one pass of the geothermal basin simulation algorithm with assigned probabilities is straight forward and spreadsheet implementation will be discussed here briefly:

- Step 1: After setting total reserves for the region to zero, input total number of structures and ultimate ratio of productive structures to total structures in the region (p).
- Step 2: Assuming sampling without replacement, calculate the current probability for success.
- Step 3: Obtain a random number between 0 and 1 to test if the current structure is productive. This number is the random probability pR.
- Step 4: If $pR < (1-p)$ then sample the independent variables, calculate the dependent variables and compute the potential for the current structure. Increase total reserves, decrease number of the structures to be tested and number of the productive structures by one. Otherwise decrease the number of the structures to be tested by one.
- Step 5: Repeat Step 2 to Step 4 for all structures while $p > 0$.

4. ESTIMATION OF GEOTHERMAL POTENTIAL

In this study, the collected data such as aerial extension, reservoir temperature, formation thickness, porosity, formation rock density, specific heat and formation fluid specific heat are expressed in triangular distributions. Each parameter is represented with minimum, most likely and maximum values as required by triangular probability distribution function. Triangular distribution is especially suitable when actual data is limited. Aerial extensions of the structures are obtained from resistivity anomalies (5, 7 and 10 ohm-m) which are very characteristic of the region and reservoir temperatures are computed by applying different geothermometers to the samples taken from hot springs and well fluids. Other parameters, such as porosity and rock density are taken from the data collected for Kizildere reservoir characterization efforts by using analogy, since the potential fields would have similar geological environment.

In the first stage, a number of simulation runs are carried out to estimate the individual and overall accessible geothermal heat potential of the B. Menderes region. In the case of individual structures the independent variables are sampled and the accessible geothermal energy are computed by using the following volumetric equation (Muffler and Cataldi, 1979):

$$\begin{aligned} H_{Total} &= H_R + H_F \\ &= (1-\phi)c_R\rho_R V(T_R - T_A) + \phi c_F \rho_F V(T_F - T_A) \end{aligned} \quad (1)$$

where

H	is heat energy in J
ϕ	is porosity,
c	is specific heat in kJ/kg-°C
ρ	is density in kg/m^3
V	is hot rock volume in m^3
T	is temperature in °C

and subscripts R, F and A stand for rock, fluid and atmospheric respectively.

The density of the hot reservoir fluid is considered as a function of temperature only and computed from the following correlation:

$$\rho_F = \frac{1000}{A + 3.0564410^{-6}(T_F + 273.15)^2} \quad (2)$$

where

$$A = 1.16849 - 0.001477(T_F + 273.15)$$

A step size of 10,000 is set for individual structure simulation and basin simulation runs. The large number of steps guarantees that all possible outcomes within the current scenario are taken into account to determine a realistic geothermal potential of B. Menderes region. Fourteen potential geothermal fields in the region are then simulated together and a mean value for the accessible geothermal energy of an individual structure is computed. The computed mean value is especially important since we have four other occurrences of hot springs and geothermal occurrences in the region with very limited data. In the absence of the relevant data, the mean value is assigned to each of the four fields to include those in the overall geothermal potential estimation. The simulation results are illustrated as cumulative probabilities in Figures 2 through 4 and summarized in Table 1 as expected values of accessible geothermal resource base for individual fields and anomalies.

After assigning the mean accessible heat value ($3.74\ 10^{18}$ J) to those four structures and anomalies, the overall geothermal potential distribution of B. Menderes region is computed over 14 and 18 structures and anomalies with Monte Carlo simulation technique. The simulation results are illustrated in Figures 5 and 6. The computed expected value for B. Menderes region is $5.22\ 10^{19}$ J and $6.74\ 10^{19}$ J when 14 and 18 structures are considered respectively. The former number ($5.22\ 10^{19}$ J) is a conservative estimate since all the potential structures and anomalies are not included.

When the estimated accessible heat values are computed from the simulations above, the uncertainty factor is not included in the algorithm. Currently three fields in the region are known to be productive (Kizildere, Germencik and Salavatli) and the rest of the structures and anomalies must be evaluated under a degree of uncertainty. In the light of the previous work, it is assumed that the probability of a successful discovery in the region is 0.5 (p=0.5). By assuming p=1.0 for three productive fields and p=0.5 for the rest of the structures and anomalies, a better estimate for the accessible heat is computed by using the algorithm given in the methodologies section of this paper. The resulting probability distributions from the simulation run are given in Figures 7 and 8. Since the assigned probability determines the outcome for the accessible heat, several sensitivity runs are also shown in the same graph to demonstrate the effect of assigned probabilities. The expected value for the region when only half of the drilled structures are productive is $4.75\ 10^{19}$ J. The expected values for p=0.39 and p=0.61 are $4.07\ 10^{19}$ J and $5.41\ 10^{19}$ J respectively. As the results of the sensitivity runs reveal, the computed accessible heat distribution is probability dependent and the success probability should be assigned as precisely as possible.

Kizildere and Germencik fields in the region are proven to have high enthalpy and can produce electricity. Currently an installed power plant with a capacity of 20.4 MW is operational in Kizildere. The overall electricity potential of B. Menderes region can also be estimated by assigning 180°C to the discharge temperature. During the sampling process, the fields and occurrences with the temperatures less than 180°C are not taken into account. In the simulation runs only 14 structures and anomalies are considered since the other four structures are not possibly capable of producing electricity. The overall probability of success is set to 0.28 (this means at most four of 14 fields and occurrences can possibly produce electricity in our model). The heat recovery factor is assumed 15 per cent and the conversion efficiency is set to 10 per cent in the model. The expected available energy for the electricity production is $2.12\ 10^{18}$ J. By using the recovery factor and conversion efficiency values stated above a value of $3.19\ 10^{16}$ J available energy for electricity production is computed for B. Menderes region. Table 2 summarizes expected convertible geothermal energy for direct and electricity use for the region. The reader is referred to Armstead (1989) for conversion calculations.

5. CONCLUSIONS

- It is shown that stochastic and risk analysis methods used in petroleum exploration can be applied (extrapolated) to potential heat energy estimations of geothermal regions.
- The expected accessible geothermal energy value for B. Menderes region is $5.22\ 10^{19}$ J. This value is predicted from 18 known fields and occurrences.
- The basin simulation runs reveal that, if only half of the structures are productive (p=0.5), the predicted accessible heat value is $4.75\ 10^{19}$ J.
- The expected available energy for electricity production is $2.12\ 10^{18}$ J. Under the current technology only $3.19\ 10^{16}$ J of energy may be converted to electricity.
- The expected convertible energy for direct use (heating purposes) is $3.50\ 10^{18}$ J whereas for electricity production the expected convertible energy is $3.15\ 10^{16}$ J in B. Menderes region.

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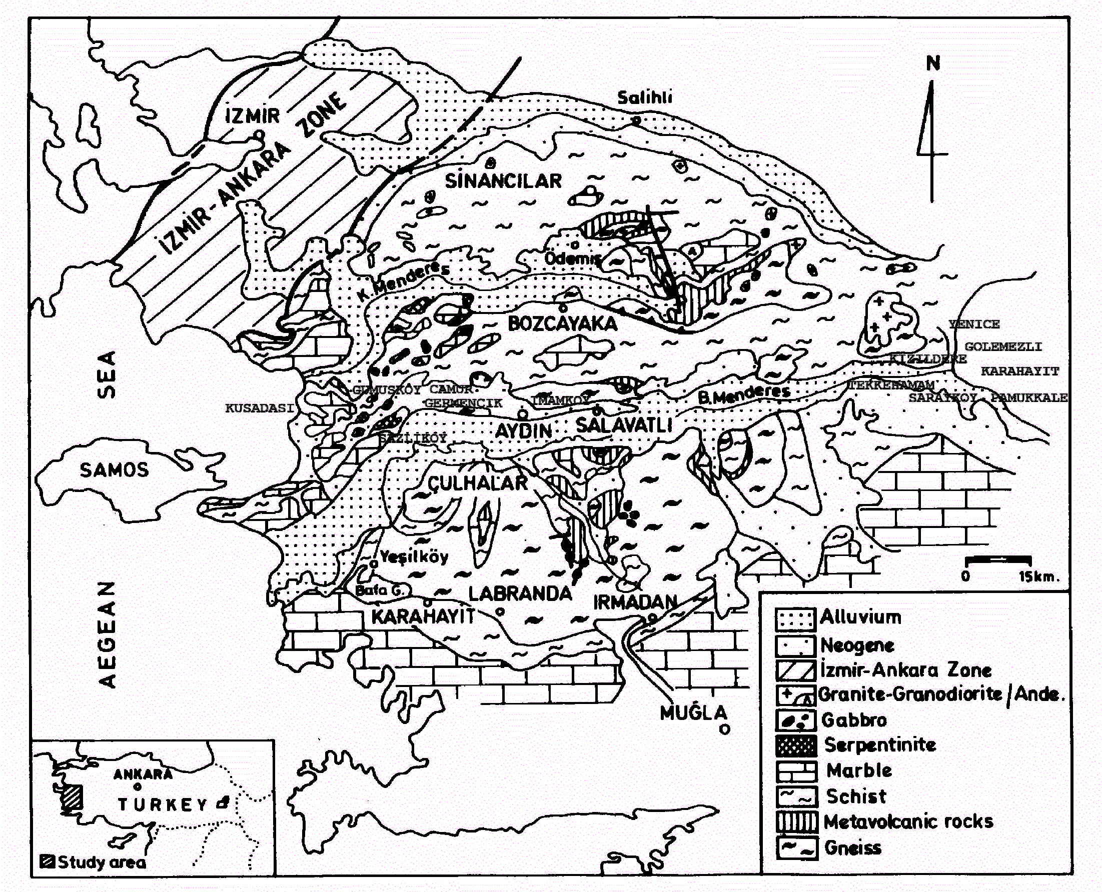

Figure 1. Geology and geothermal occurences of B. Menderes graben.

Table 1. Computed expected value of accessible geothermal resource base for individual fields and anomalies.

Fields or Anomalies	Expected Accessible Geothermal Energy, 10^{18} J
Kizildere	3.53
Germencik	7.16
Salavatli	7.00
Tekkehamam	0.519
Imamkoy (Aydin)	0.571
Camur-Bozkoy	3.55
Gumus	3.61
Saraykoy	4.24
Golemezli	13.4
Yenice	1.45
Karahayit	1.97
Pamukkale	1.52
Aydin-Sazlikoy	1.36
Kusadasi	1.36
TOTAL	51.24

Table 2. Expected convertible geothermal energy for direct and indirect use.

Utilization Method	Expected Convertible Geothermal Energy, J
Direct use	$3.50\ 10^{18}$
Indirect use (electricity)	$3.19\ 10^{16}$

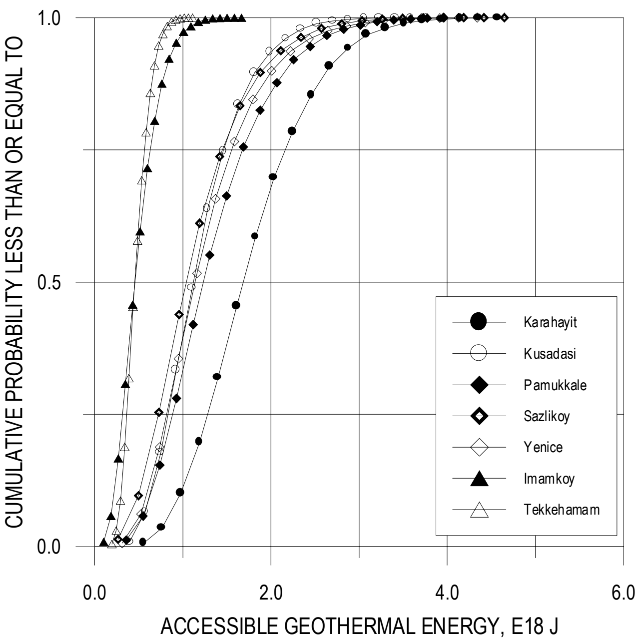

Figure 2. Accessible geothermal energy cumulative probability distribution.for individual occurences.

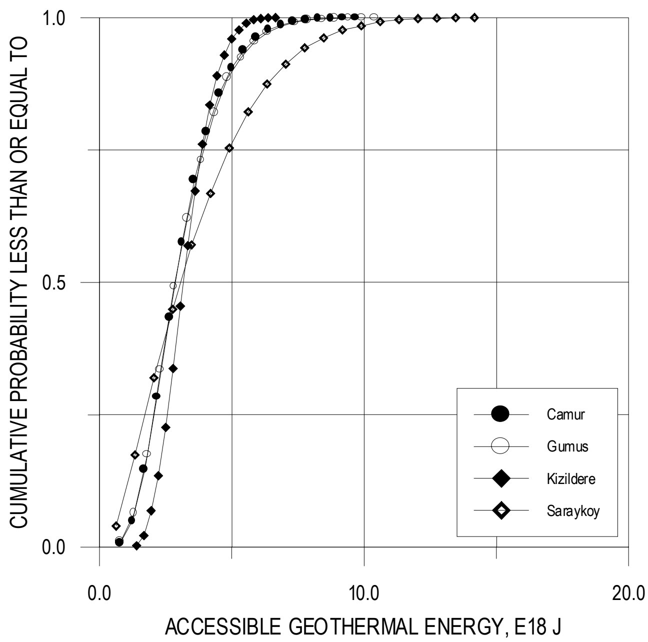

Figure 3. Accessible geothermal energy cumulative probability distribution.for individual occurences.

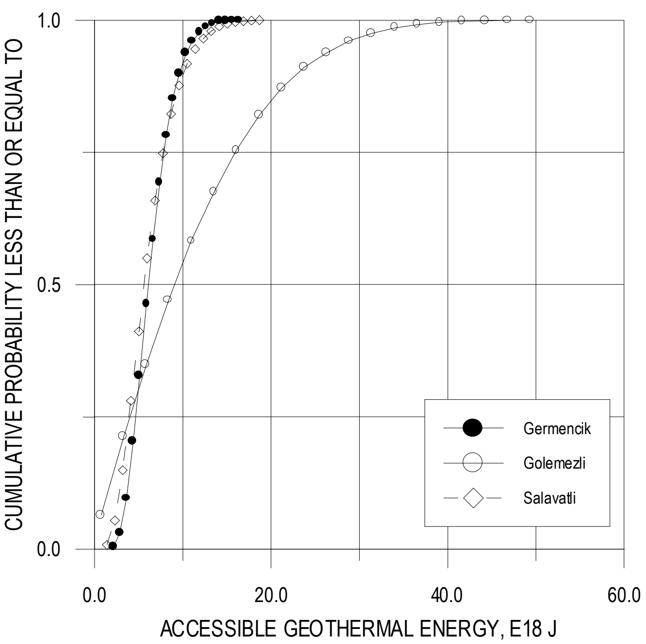

Figure 4. Accessible geothermal energy cumulative probability distribution.for individual occurences.

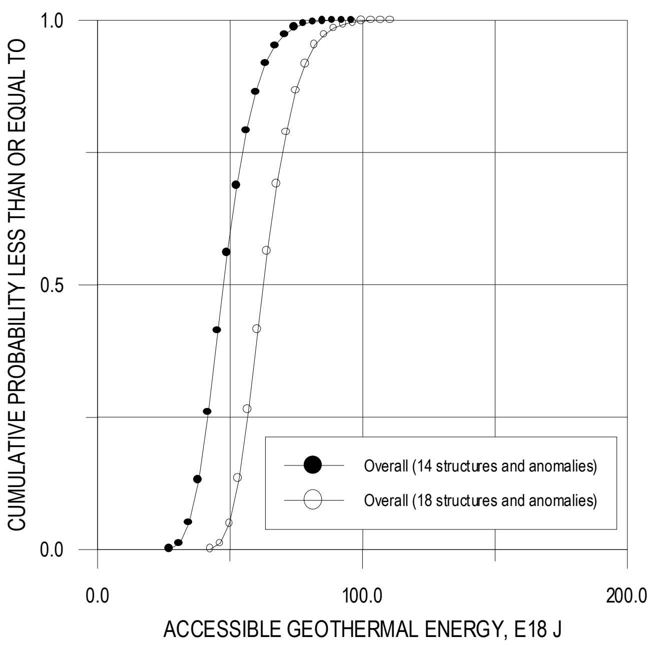

Figure 4. Overall cumulative probability distribution for accessible geothermal energy.

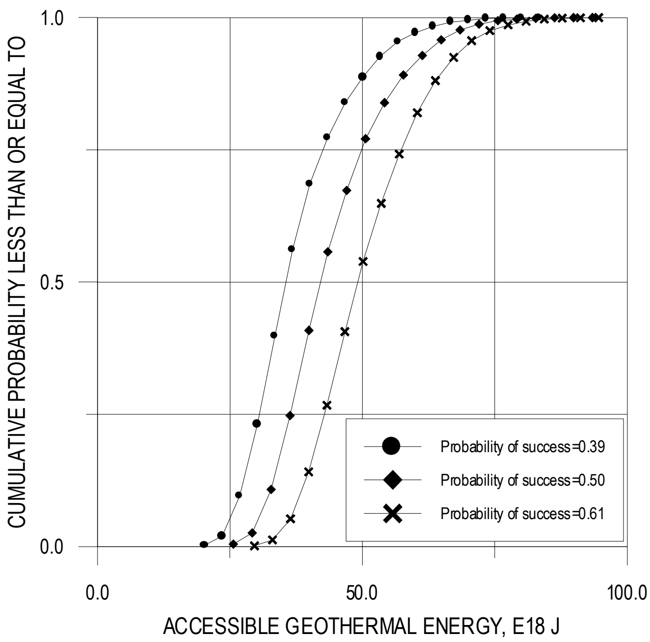

Figure 5. Cumulative accessible geothermal energy probability distribution of B. Menderes region with assigned success probabilities.

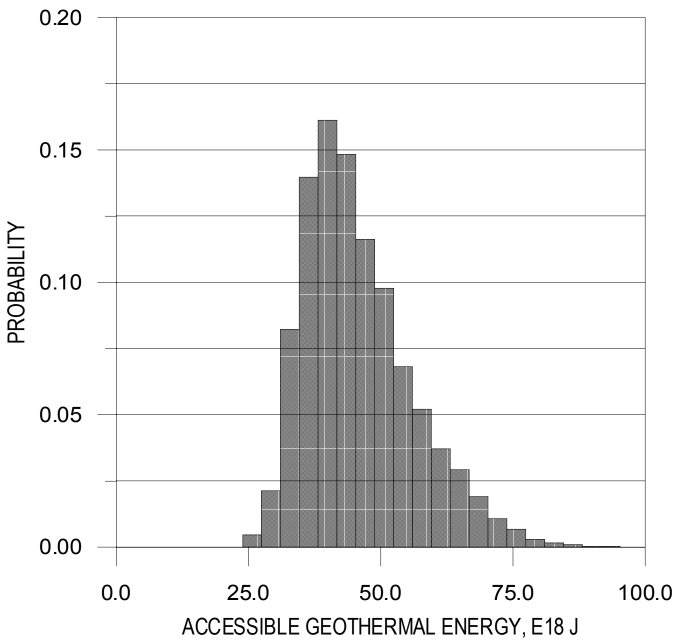

Figure 6. Accessible geothermal energy probability distribution of B. Menderes region (p=0.5).

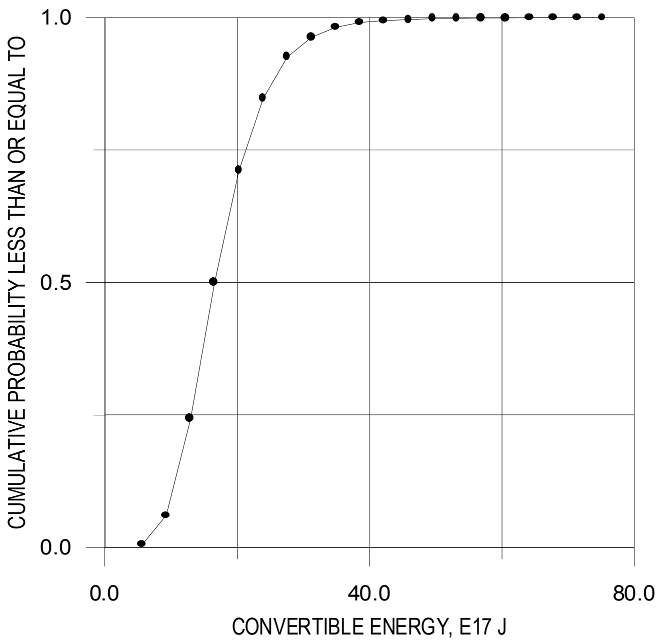

Figure 7. Cumulative convertible energy (electricity) probability distribution of B. Menderes region (p= 0.28).

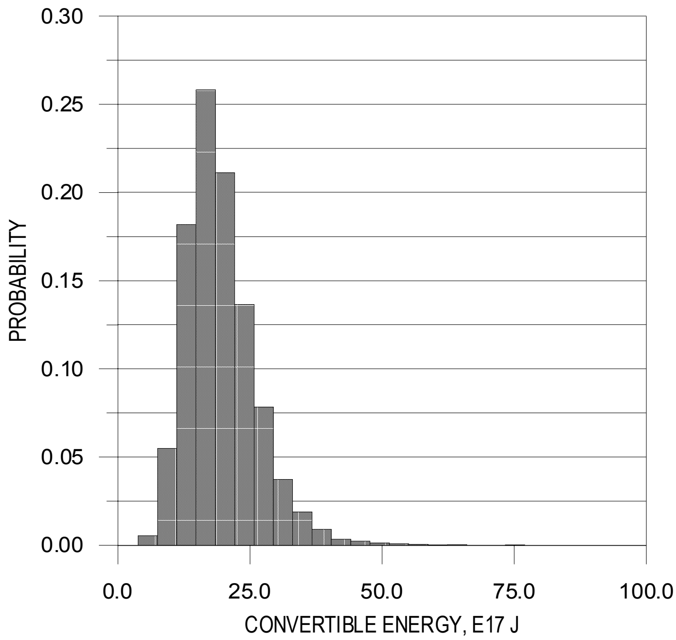

Figure 8. Convertible energy (electricity) probability distribution of B. Menderes region (p= 0.28).