Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Formation of the Geothermal Resources of the North-Eastern Part of Turkey

Vadim K. Mamontov, Andrew G. Yakovlev, Salih M. Bayraktutan
19, ul. Podolskih kursantov, 117546, POB 104, Moscow, Russia
E-mail: libertad84@mtu-net.ru

Keywords: North-Eastern Turkey, geothermal resources, prospecting and development.

ABSTRACT

From the viewpoint of natural geothermal resources and a level of their development Turkey occupies one of the outstanding positions of the world. At the same time a significant part of the geothermal resources remains unused. First of all it concerns to a northeastern part of the country. Here geothermal resources can be applied not only for electric power generation, but also for other purposes, including for development of mounting skiing resorts, a municipal infrastructure and for delivery of greenhouse gardening.

In the report on the basis of the suggested principle of geothermal zoning as well on the basis of results of pre-feasibility investigations of Russian and Turkish experts is established, that the forming conditions of geothermal fields of Erzurum valley and its mountain frame are typical for all northeastern part of Turkey.

Authors substantiate the opportunity of geothermal resources development with binary geothermal power plants with capacity about 4 MWe for the different purposes. In the report authors have used materials of the Turkish, Russian and foreign researchers as well as legal published materials of bathymetric space surveys.

1. INTRODUCTION

Asia Minor is one of the richest regions in the World in its geothermal potential. According to 8-th Five Years Development Plan of Turkey generation of the geothermal electric power in country should increase from 45 MW_e in 2001 up to 500 MW_e in 2010 and up to 1000 MW_e by 2020 (Orhan et. al (2001)).

At the same time in a number of references are pointed other data on geothermal potential of Turkey. In particular Battocletti (1999) estimates the total energy potential of geothermal resources of Turkey at a rate of 368 MW_e, and geothermal potential for its direct use — at a rate of 1262,38 MW_t.

Such difference in an estimation of geothermal resources is typically and for other regions, for example for the countries of Latin America. In our opinion it is caused, besides other reasons, terminological discrepancy. Therefore below the questions of an estimation of geothermal resources are considered in the terms and the definitions accepted in practice of the Russian hydro-geological school.

Other factor influencing on the reliability of geothermal resources estimation is absence of typification of geothermal fields on the principle of their position relatively various types of lithosphere, tectonic and hydrogeological structures. It can result in acceptance of the incorrect decision at planning exploration, to an inexact estimation of conditions of geothermal resources formation, and also to an incorrect choice of the hydrodynamic simulation of geothermal field and technology of its development and operation. In this connection in the report the principle of zoning of geothermal fields on the basis of tectonic attribute is considered.

Application of the stated principles to studying of hydrogeological conditions Erzurum valley has allowed, in our opinion, not only to increase quality of survey but also to establish mechanism of formation of geothermal resources of all northern east Turkey and to prove probable variants of their development techniques.

2. RESOURCES AND OPERATIONAL RESERVES OF HEAT POWER UNDERGROUND WATERS

The Russian researchers distinguish natural and operational resources of underground waters in the following ways.

Under natural resources we understand the rate of the underground water alimentation in water balance of the given area. Natural resources quantitatively correspond to the rate of average annual underground water discharge and define an opportunity of renewal of underground water probable operational resources and operational reserves.

The operational resources are understood as the rate of underground waters of determine quality and a special-purpose using which can be received within the certain region. In essence operational resources reflect potential opportunities of water using.

Operational resources of underground waters are estimated on the basis of the common hydrogeological conceptions, regional researches, generalization and interpretation of available materials.

Operational reserves of underground waters are understood as their rate which can be get from the field with the help of the geologically and technically substantiated water-intakes under specified running regime and conditions, as well as the quality of water which is meeting the requirements of its purpose using during projected term of water consumption taking into account of environmental protection requirements.

Operational reserves are counted on the base of hydrogeological prospecting and exploration data or on the base of the using experience of developed or operated underground water fields.

Thus, natural resources are a component of probable operational resources and operational reserves, and their rate can vary during operation of underground water field. Distinction between resources and operational reserves consists, in essence, in a level of underground water field studying.

We shall use these concepts and definitions below.

3. TYPIFICATION OF GEOTHERMAL FIELDS

On the grounds of geothermal field position relatively the lithosphere plate boundaries it is possible to recognize the following types of fields: geothermal fields of divergent zones; geothermal fields of convergent zones; geothermal fields of "hot spots"; geothermal fields of transform regional fault zones; geothermal fields of artesian basins.

Let us consider the most typical features of the allocated types of deposits.

3.1 Geothermal fields of divergent zones

The geothermal fields located within continent and submarine spreading and rift zones are the fields of this type. The most typical example of such fields is Cerro Prieto which is located within a zone of San Andres Fault. Heat power waters of geothermal fields of this type are highly potential with temperature 240-270^{0}C though sometimes on the data of Torres-Rodriges (2000) lower temperatures are fixed: on Tulechek geothermal area — 165^{0}C, and on geothermal field Laguna Salada — 126^{0}C. The geothermal reservoir locates on the depths from first tens and hundreds meters in submarine zones up to several kilometers in continents.

The endogenous heat source of such fields is the rising mantle substance stream with significant strike extension. The reduced earth crust thickness in the range of divergent zones promotes intensive convective heat transmission.

Water component of the geothermal natural resources in divergent zones can be formed not only for account of atmospheric precipitation and superficial water infiltration, but also due to released from mantle substance. Markhinin (1985) has indicated, that at the rising of mantle substances from the depths of 11400 m up to 3700 m it is occur the release of juvenile waters in volume of 2,9% from the weight of mantle melt. Juvenile genesis of heat power waters and extensive area of their formation (the area of Cerro Prieto field is about 15 км^2) as well injection of the used heat-carrier form the provided alimentation and significant rate of the water component of operational reserves of geothermal fields of considered type. So, for example, on data of Quijano-León and Gutiérrez-Negrín (2003) in Cerro Prieto field the average annual steam rate in 2002 has reached 5430 t/h, not counting the discharge of thermal brines.

Geothermal fields of divergent zones are characterized by the following distinctive features: origin of the water component of the natural geothermal resources can be completely juvenile; areas of a the alimentation of water and heat power components of geothermal resources coincide as with each other, and with the geothermal reservoir position; the geothermal fields of the given type, apparently, is limited in space because its external borders are geochemical barrier where calmatation of filtration medium is occurred with the association of hydrothermal minerals.

3.2 Geothermal fields of convergent zones

This kind of geothermal fields includes that ones, which are located in areas of volcanic structures and disjunctive tectonic disturbances of the subduction zones in the ocean regions and in thrust zones of continent areas. Typical examples of fields of this type are such geothermal fields as Mutnovskoe (Kamchatka, Russia), Los Azufres (México), geothermal fields of Central America and Lesser Antilles. Heat power waters of convergent zone fields are high-grade heat potential with temperature that on the data of Quijano-León and Gutiérrez-Negrín (2003) can reach 400^{0}C (geothermal field Los Humeros, México). The geothermal reservoir locates on depths from hundreds meters down to the first kilometers.

Source of endogenous heat of such fields are magma chambers of young and modern volcanoes. The formation of water natural geothermal resources component is carried out, as, for account of juvenile, and due to meteoric waters. Hydrogeological researches of the Russian experts in the region of geothermal area of San Jacinto (Nicaragua) have shown (Mamontov et. al (1993)), that the rate of atmospheric precipitation alimentation of aquifers which are lain at the depths beneath of 300-500 m, are about 1-3 % from their total annual volume. Therefore alimentation of the heat power waters lying at the depths of 2000 m and more for account of meteoric waters is the subordinated. At the same time juvenile water-alimentation component within subduction zones has significant resources. Markhinin (1985) cites the data that the total volume of juvenile waters, which are annually brought out by solfataras and thermal springs of Kuril Islands exceeds $5*10^6$ t. However, in many cases, natural features create favorable conditions for formation of a water resources component of geothermal fields due to meteoric waters. Such conditions exist in the range of Mutnovskoe field (Kamchatka, Russia) where the alimentation of heat power waters in concordance with Kiryukhin (2002) occurs, basically, due to thawing of the glacier located in a crater of volcano Mutnovskiy, as well at the number of geothermal fields of Central America and Lesser Antilles.

In the range of considered field type underground waters carry out heat transmission. Thus the area of the geothermal resources formation may be not coincided with spatial position of heat power water accumulation area. In this connection, and also in view of distinction of a nature of processes of water yield and water-saturation of aquifers, renewal of water resources due to a injection of used heat carrier into the geothermal reservoir not always gives expected effect.

3.3 Geothermal fields of the "hot spots"

The typical example of "hot spots" geothermal fields is Yellowstone. On the basis of existing now conception on processes of "hot spots" formation and development it is possible to assume, that conditions of formation of the geothermal fields related with them have attributes both types described above. It is necessary to note, that the geothermal deposits related with "hot spots" can be the important sources of the electric power in such regions, as Africa, and a number of the island states.

3.4 Deposits of transform and regional fault zones

Substantiation for separation of such type of geothermal fields is that fact, that within zones of transform and other kinds of regional active faults the heat stream can exceed its average vale at 10-12 times (Markhinin (1985)).

The examples of such geothermal field type are next ones: El Pilar, Los Baños, San Diego (Venezuela), which are located in a southeast part of Oca-Ancon fault systems, Piedras de Lumbre (Mexico), connected with regional fault zone of Sierra Tarahumara. In Turkey similar fields are situated at the of Northern Anatolian fault zone along line Istanbul-Izmit-Havsa-Erzincan, at crossing zone of Eastern and North-Eastern Anatolian faults: Erzurum-Pasinler, Erzurum-Dumli-Ilica and others.

Geothermal fields of the given type are least of all investigated that is connected, first of all, to comparatively small natural resources of heat power waters. Complexity of research of geothermal fields of this type is defined also by essential heterogeneity of internal structure of transform and regional fault zones.

Geothermal resources in of active tectonic zones form under influence of located in space convective thermal stream. Here geothermal waters according to their thermal potential change from low potential with temperature up to 70^0C up to high potential with temperature of the heat-carrier up to 120-150^0C and higher. The depths of occurrence, operational reserves of heat power waters, as well capability of operational wells are within wide ranges.

The high degree of heterogeneity of a geological and tectonic structure of transform and regional fault zones causes complex conditions of formation of heat power underground waters. These conditions are characterized by the following features: relatively small value of endogenous convective thermal stream; the alimentation of water component for account of atmospheric precipitation and superficial waters infiltration an outside area of their accumulation; the small area of heat power water discharge; and also low filtration properties of water bearing rocks. These factors determine lower potential of geothermal fields of transform and regional fault zones in comparison with operational resources of fields of divergent and convergent zones.

3.5 Deposits of artesian basins

As examples of artesian basin geothermal fields are such ones as the field near the town Svetlyi (Kaliningrad district, Russia), a geothermal field in area of town of Labinsk (Krasnodar Territory, Russia), the geothermal fields, located in the range of the seaside plains of Florida (USA), and many other ones.

Geothermal resources of artesian basins are formed in deep-seated aquifers in a zone of the slowed water flowing under influence of unconcentrated on the area conductive and convective endogenous thermal streams. Fields of artesian basins are, as a rule, middle potential, rarely high potential with temperature of the heat-carrier 65-120^0C, lie on depths of 2000-3000 m. They are characterized by significant operational reserves (tens thousand cubic meters of the heat-carrier per day), high efficiency of wells (100-160 m^3/hour) and can be used for development of the electric power, heating and for other purposes.

4. CONDITIONS OF GEOTHERMAL RESOURCES FORMATION OF NORTHEAST PART OF TURKEY

4.1 Tectonic conditions

Turkey and contiguous regions are at collision place of several lithosphere plates and in the tectonic relation is one of the most complex regions of the world. In opinion of McKenzie (1972) and Dewey et al (1973) in area of East Mediterranean - Caucasus - Arabia it can be selected till 10-11 lithosphere plates of the different orders. In the given paper the model developed by Bird (2003) taking into account of data's Barka (1992), Stein et al (1999), Kahle (1999), and other researchers was used as the initial tectonic scheme. This model was added with results of decoding of space images and field researches of authors in a northeastern part of Turkey (Figure 1). On the scheme as the basic tectonic elements are selected: The Eurasian plate (EU), the African plate (AF), the Arabian plate (AR), Anatolian plate (AN), Aegean plate (AG), Northern Anatolian fault zone (NAF), Eastern Anatolian fault zone (EAF) and Zagros fold-thrust belt zone (ZFTB). Besides these structures Northeastern Anatolian fault zone (NEAF) and Central Anatolian fault zone (CAF) influence on formation of natural geothermal resources of the northeastern parts of Turkey.

4.2 Geothermal resources and operational reserves of region

Locations of geothermal fields of the region relatively the basic tectonic elements on the data of Battocletti (1999) are shown on a figure 1. The given data show, that according to above-mentioned typification, in territory of Turkey it is possible to allocate a province of deposits of divergent zones and a province of deposits of transform and regional fault zones. Allocation of provinces convergent zones in area of volcanic files Van, Nemrut and Zagros fold-thrust belt zone demands a special substantiation. On a on account of some of attributes we also can assume, that in northwest of Turkey heat power underground waters can contain in the range of Ergene Nehri intermountain flowing basin.

In this paper we consider only the formation conditions of geothermal resources solely the northeastern part of Turkey. The considered territory is limited with coast of Black Sea on north in the range of Samsun-Sarp; in a southwest and the south – with line Havsa-Tokat-Erzincan-Erzurum (including northern part of Palandöken ridge)-Pasinler, in a southeast – with Kargapazari and Yalnizçam ridges.

How it is seen on a figure 1 geothermal deposits in the western part of the indicated region are attached to transform Northern Anatolian fault zone and to fault zones of less order which are jointed to it. The brief characteristic of these geothermal fields is given in table 1.

Table 1. Characteristics of geothermal fields of the western part of the concerned region, after Battocletti (1999) and Mertoglu et al (2001).

Location	Type	Capacity /Potential, MWt	t^0C
Samsun-Havsa	Space heating, bathing	0,07/0,07	54
Kuzuluk-Sakarya	Space heating, bathing	20/-	up to 120
Gözlek-Amasaya	Space heating, bathing	2/-	42-50
Tokat-Niskar	Greenhouse heating	0,14/-	up to 54
Tokat-Resadiye	Space heating, bathing	0,1/-7,16	-

From the given data follows, first, that geothermal fields in the western part of considered area are located or along border Eurasian and Anatolian plates, or on northern margin of Anatolian plate at the zones of active fault. Secondly, in the top part of a hydro-geological section down to depths about 240-400 m heat power waters are, as a rule, low potential, and operational reserves are insignificant and are used in the municipal purposes. At the same time at Kuzuluk-Sakarya geothermal field on depth of 160-250 m were met underground waters with encountered temperature 80^{0}C and estimated temperature 120^{0}C. That is operational resources of the given part of area can appear more essential as in quantitative, and in a qualitative sense.

At the eastern part of the region geothermal fields are attached to North Anatolian, North-Eastern Anatolian and Central Anatolian fault zones. The brief characteristic of the basic fields is given in table 2.

Table 2. Characteristics of geothermal fields of the eastern part of the concerned region, after Battocletti (1999) and Mertoglu et al (2001).

Location	Type	Capacity/Potential, MWt	t^{0}C
Erzurum-Illica-Pasinler	Bathing	-/-	38-80
Erzurum- Dumlu	Bathing	-/-	37

Some time ago the group of the Russian and Turkish experts investigated natural geothermal resources around town of Erzurum in a zone of crossing East Anatolian and Northeastern Anatolian faults. During these works hydrogeological survey of northern slope of Polandöken ridge was executed, as well as earlier known both again revealed thermal and mineral springs and gas showings are examined. Simultaneously the geophysical work package was carried out to display of the most perspective sites for exploration and development of geothermal resources. The structure of geophysical researches included magneto-telluric sounding (MTS), vertical electric sounding (VES), TEM sounding, researches of potentials of a natural electric field and magnetic investigations.

Some aspects of joint Russian-Turkish works were set out at an exhibition "Export Opportunities of Russia 2000" which was an autumn of 2000 in Istanbul. The further development of this problem is found in the given report.

4.3 Natural conditions of Erzurum valley

In the orographical relation the area of works of Russian-Turkish researches is located at the crossing of Erzurum and Karasu valley. There are two basic types of relief within the territory: valley part where erosion-accumulative type of a relief is developed, and a mountain part with volcanic type of a relief.

The erosion- accumulative type of a relief represents alluvial-proluvial the plain lightly cutting by ravine-gully net, with characteristic morphology of debris cone. Mountain frame of the Erzurum valley and the northeast part of a Karasu valley is formed with volcanic relief of Palandöken, Mescit and Kargapazari ridges of extinct volcano massifs Büyükelder (3176 м), Akbaba Daği (3080 м), Dumludaği (3169 м) and others. The relief of this mountain ridges is constituted by typical cone-shaped forms merging with each other stratovolcanoes which are complicated with parasitic volcanoes, explosive cones and are cut by numerous narrow river valleys and barrancos.

In the climatic relation the area of works is located in a zone of sharply continental semiarid climate. The climate of the plain territory is characterized with annual precipitation rate of 200-400 mm and with predominates of evaporation and transpiration above precipitations. At the same time in a mountain part of territory the annual value of an atmospheric precipitation exceeds 1000 mm. The hydrographic network belong to river basin of Euphrates. Channels of all rivers are connected with zones of tectonic faults and in a mountain part form V-shaped valleys. At the plain territory the riverbeds lose clearness of their outlines, but thus river valleys always keep a general rectilinear direction that confirms them приуроченность to linear tectonic zones. River alimentation is seasonal, and carried out, mainly, for the account of melting of snow and atmospheric precipitation in the spring period, alimentation due to underground waters has the subordinated value.

The history of geological development Erzurum valley is caused by features of interaction Eurasian, Anatolian and the Arabian plates, and also active development of numerous regional deep faults.

Crossing East Anatolian and Northeast Anatolian faults with adjoining disjunctive disturbances results in essential reconstruction of bottom of Erzurum and Karasu valleys. Tectonic features of area are defined by block structure of volcanic ridges-raisings, and two-stage graben-shaped structure both of valleys. Geological section of the valleys – depressions is formed with limestones, marls, sandstones and effusive rocks of cretaceous age and Neogene-Quaternary deposits. Basic and average lavas and tuffs, agglomerates, marls, clays, and also sandy-gravel sediments present Lithologic composition of the rocks. Block structure of valleys is determined with a complex network of tectonic faults with northwest and northeast strike.

The carried out hydrogeological researches are summarized as a hydrogeological map (Figure 2) and given the following results.

The region under the study is located in the range of Karasu mountain-valley underground flowing basin, which framed by hydrogeological massifs of Palandöken, Mescit and Kargapazari. In territory of work alluvial-proluvial Middle Pleistocene-Holocene aquifer (apQ_{II-IV}), Pliocene-Lower Pleistocene aquifer (N_2-Q_I) and neogenic aquifer (N) are extended.

Middle Pleistocene-Holocene aquifer (apQ_{II-IV}) is extended on the bottom of valleys and along the lower parts of their slopes. Thickness of given aquifer can exceed 200 m. It is the first from a surface and is bedded with Pliocene-Lower Pleistocene and neogenic aquifers. Due to similar composition of water bearing rocks the border between these aquifers in a section is not clear. Water bearing rocks of the aquifer are presented with alluvial and proluvial sand, gravel, a pebble interlaid in a section with strata of clay. The coefficient of filtration of water bearing rock is on averages 5-10 m/day, coefficient of gravitational capacity (specific yield) is 0.1-02. Alimentation of underground waters occurs for account of infiltration of atmospheric precipitations and snowmelt water. Underground water discharge is carried out in Karasu river, due to evaporation and transpiration and also due to water intakes for economical and potable supplying. The underground water regime is defined by seasonal irregularity of atmospheric precipitation. The amplitude of fluctuations of underground water level can reach 5-10 and more meters. Waters of aquifer fresh hydrocarbonate, value of total dissolved solids is not higher than 0.5 g/kg. Operating resources of the Middle Pleistocene-Holocene aquifer are characterized by specific capacities of wells from 80 up to 1380 m^2/day. Middle Pleistocene-Holocene aquifer is hydraulical connected with adjacent aquifers.

Pliocene-Lower Pleistocene aquifer (N_2-Q_I) is extended in the range of hydrogeological massifs of Palandöken, Mescit and Kargapazari. In territory of the of slope parts of valleys the aquifer is encountered by wells number 5451 and 4390 and surveyed by geophysical methods (TEM, VES). In central part of valleys given aquifer is not encountred.

The aquifer contains fractured and vein-fractured waters, which are belonged with open fractured zones tectonic faults. Water bearing rocks are effusives, agglomerates, seldom slag. Alimentation of underground waters is carried out in territory of volcanogenic massifs forming a mountain frame of valleys. Underground water discharge occurs mainly in aquifers that are lain in the bottoms of Erzurum and Karasu valleys and, in much smaller degree, as a spring run-off in territory of hydro-geological files. Depth of occurrence underground waters is controlled by a seasonal atmospheric precipitation regime and snow melting intensity as well as by erosion cutting deepness. High watersheds are drained. Waters of Pliocene-Lower Pleistocene aquifer are mainly fresh with a value of total dissolved solids up to 0,5 г/л, non-gaseous. However in the range of hydrogeological massif of Palandöken are encountered mineral hydrocarbonate calcium barbatic springs with total dissolved solids from 0,1 g/kg up to 2-4 g/kg. Geophysical researches reveal zones of containing thermal waters which are connected with fault zones extended along the basement of volcanic massifs as well as with deep active faults crossing those and forming the valleys of such mountain rivers, as Deliveli, Çaltak, Kurupinar and others. Natural water resources of the aquifer are estimated by analogy with adjacent territories of Georgia, Armenia and Azerbaijan at the rate of 5-10 % from average annual value of the atmospheric precipitations which fall in the mountain areas (not less than 1000 mm) and make (1.4-2.7)*10^{-4} m^3 /day per square meter of the area of the aquifer alimentation. Average values of coefficient of filtration of effusive rocks do not exceed of 0.5-1.0 m/day, coefficient of gravitational capacity — 0.03, the coefficient of elastic capacity of water bearing rocks lie between 10^{-5}-10^{-6} $м^{-1}$.

Neogenic aquifer (N) is extended on the bottom of Erzurum and Karasu valleys. It lies second from the surface under Pliocene-Lower Pleistocene aquifer, and in slope parts of a valley it is the first from a surface. Water bearing rocks are submitted by sand, gravel with clay layers; in the top parts of a section limestones and sandstones are uncounted. Given aquifer is insufficiently investigated because along the slope parts of the valleys, it is, as a rule, weak watered, and in the central parts of valleys it, apparently, forms common hydraulic system with Middle Pleistocene-Holocene aquifer.

4.3.1 Conditions of the geothermal field forming in the range of Erzurum valley

Characteristic feature of the area is thermal underground waters. Outcrops of geothermal flow are observed along the basic slopes of Erzurum and Karasu valleys (figure 2) as rising lightly bubble springs with discharge up to several liters per second. Despite of dilution of thermal waters by cold underground waters the temperature of thermal springs at the moment of researches reached 30-35^{0}C at temperature of air 12-18^{0}C, and a total dissolved solids — 1.5-2 g/kg. In territory of Palandöken ridge along the faults cutting this massif outcrops of carbonic gas are fixed by the bubble springs.

On the one hand, formation of geothermal conditions of area is determined by active deep East Anatolian Northeast Anatolian faults along which Erzurum and Karasu valley develop. On the other hand, geothermal conditions of area are affected with neogenic-quaternary volcanic massifs which are formed the mountain frame of these valleys.

The executed researches have shown, that in the range of the bottom of the valleys and in territory of framing them volcanic mountain massifs the continuous on the strike thermal aquifer is extended. The roof of the thermal aquifer is mapped by MTS and TEM as low-resistance layer with specific resistance 6-15 ohmm.

Depth of occurrence of thermal aquifer roof is not a constant and changes depending on geological-tectonic features of morphological structures of the area. On data of MTS hypsometric position of a roof of geothermal layer retraces a relief of valleys (figure 3). Absolute altitudes of the aquifer's roof decrease from mountain massifs to the center of the valleys: in the range of the mountain frame background absolute altitudes are 1000-1500 m, and in the central parts of the valleys decrease below zero mark.

Simultaneously, more detailed researches by TEM have shown, that the roof of geothermal aquifer in the range of mountain constructions has sharply shaped relief, which is completely controlled by plan and hypsometric position of narrow river valleys. Valleys of such rivers as Deliveli, Çalhac, Kurupinar and others which are placed along deep, active faults cutting volcanic massifs. Within such fault zones absolute altitudes of geothermal aquifer' roof sharply raise almost up to marks of a surface of the earth and also sharply fall behind their boundaries up to background values. Within the limits of the indicated mountain valleys the values of specific electric resistance have are 6-12 ohmm. Just the same values of specific resistance were fixed during researches of the thermal water outcrop sites.

It is interesting to note, that background depths залегания a roof of a geothermal layer, both in the central parts of valleys, and within the limits of the unbroken blocks of mountain massifs (but not in fault zones of mountain valleys!) are approximately equal on average 1350-1500 m, reaching in the most lowered places of 1900-2000 m. At the same time, the carried out investigations have shown, that internal structure of Erzurum and Karasu valley is very complex and characterized by presence of deep faults, which pass along the basis of their mountain frame. On a figure 3 position of such type of a fault conform to points of observation number 13, 12 and 18. In these points of depth of the geothermal aquifer occurrence sharply decreases up to 800 m. On a hydrogeological map of the area under researches (figure 2) it can see, that outcrops of thermal waters are located along such fault zones.

During field works the geothermal gradient was not determined. Therefore its value was accepted on the data for adjacent territories of Georgia, Armenia and Azerbaijan where average values of a geothermal gradient are equal 4-6^{0}C per 100 m. Extrapolating these data on geological-structural features of Erzurum and Karasu valleys, it is possible to come to a conclusion, that the geothermal gradient in zones of the faults, which are extended along the bases of volcanic ridges, can reaches 6-9^{0}C per 100 m.

At temperature of thermal springs 30^{0}C the temperature of heat power waters on average depth of occurrence of the a geothermal aquifer 1400 m will make of 110-150^{0}C in the area of spent works. At the most perspective sites the geothermal aquifer with temperature 110-150^{0}C can be encountered and on smaller depths in an interval of 800-1200 m.

The alimentation of water component of heat power waters is realized for the account of infiltration of atmospheric precipitation and snow melting in the territory of volcanic mountain massifs. As it was indicate above, natural resources of the underground waters lain on the depths more 500-700 m in conditions of flow basin of mountain–valley type can be estimated in volume of 1 % from the average annual sum of the atmospheric precipitation which fall at the area of the alimentation. In this case the annual volume of atmospheric precipitation in the range of mountain structures is accepted as 1000 mm/year. Then the discharge of a natural stream of the underground waters participating in formation of the heat-carrier, makes $2.7*10^{-5}$ m^3/day from square meter of area of the alimentation. At the total area of the alimentation that is more than 1500 square kilometers, the volume water component of heat power water natural resources will be more than thirty thousand cubic meters per day.

Thus, the carried out researches have shown, that geothermal resources of Erzurum and Karasu valleys are formed due to the increased value of endogenous heat stream along East Anatolian and Northeast Anatolian fault zones and transverse them active regional disjunctive dislocations. Heat transmission has convective character and it is carried out, mainly, along the faults, which are extended along the basis of the mountain frame of the valleys as well as along valleys of the rivers, crossing volcanic mountain massifs. At these sites fracturing and permeability of water bearing rocks increase that is created optimum conditions for operation of geothermal resources.

During operation of heat power waters in operational aquifer will be an additional alimentation for e account of water leakage from overlying and adjacent aquifers. At that the rate of in addition involved water resources can reach half of operational reserves of the field and are significant source of the operational reserve renewing.

All these and other questions connected to definition of operational reserves of heat power waters of area under researches should be solved at a stage of exploration of geothermal fields and drawing up of the feasibility report on its operation.

4.3.1. Opportunity of the use of geothermal resources of Erzurum valley

One of the most important questions of operation of low temperature (below 150^0C) geothermal fields is the opportunity of their use for electric power generation by binary geothermal power stations (BPS).

The first over the World Paratunskaya BPS was designed and put into operation in Russia on Kamchatka in 1967 and it is successfully exploited till now. Now in Russia by employees of Joint-Stock Company "NAUKA" are developed environmentally appropriate, completely automated modular BPS, allowing generating 4 MWh the electric power at the operational discharge of the heat-carrier 4000 t/hour and initial temperature 110-120^0C. From the point of view of authors of the report, the rates of natural geothermal resources of Erzurum and Karasu valleys (more than thirty thousand cubic meters per day of heat power waters with temperature 110-150^0C) allow to use data BPS for their development.

Experience of use of BPS also is described in work Sánchelez-Velasco et al (2003) on an example of testing operation of Piedras de Lumbre geothermal field, which is located within a zone of active deep faults in territory of mountain massif Tarahumara Sierra in Chihuahua state, México. Results of the project have shown, that a design of the power block of the binary type using isopentane as working fluid, can provide generation 300 kW the electric power at the operational flow rate of the heat-carrier 150 t/h with temperature 120-135^0C for brine inlet pressure. The results received by our Mexican colleagues, undoubtedly, cause the large practical interest especially for supply of the small settlements located in mountain districts of northeast Turkey with heat and electric power.

The similar project was realized in Germany — in November 2003 the binary power plant by capacity 200 kW was started up in operation.

Thus, there is a real technical opportunity of the practical use of geothermal resources of Erzurum and Karasu valleys for generation electric power with the help of environmentally appropriate binary power stations. It is necessary to take into account, that besides the electric power development of geothermal fields will provide with thermal energy in the volume allowing successfully to decide a multi purpose problem of thermal and power maintenance of the regions, including development of working mounting skiing resorts Palandöken, a municipal infrastructure, development of a green housing. The use of geothermal energy will achieve also essential improving of the environment due to reduction of the gas and solid component emission, which are formed at burning of hydrocarbon energy carriers.

4.3.2. Factors of geothermal resources formation within northeastern part of Turkey

To major factors, which define the general mechanism of conditions of the natural geothermal resources formation in the region of northeastern part of Turkey, concern: geological-tectonic, geothermal and hydrodynamic.

As geothermal fields of northeastern Turkey are connected with transform and regional fault zones, the geological-tectonic factor of of of heat power water natural resources formation is general for all region as it can see at the figure 1. Really, decoding of the space images has shown, that there are numerous regional faults of northwest strike the specified area. The most significant from them are Northeastern Anatolian and Central Anatolian faults. At that Northeastern Anatolian fault are traced in range of Adzharian-Trialetian fold zone.

Presence of the volcanogenic massifs of Pliocene – Lower Pleistocene age also is typical of all territory of northeast of Turkey. Numerous extinct stratovolcanoes are well traced at the place and are fixed by space surveys.

At that lithologic-facial features of various geological-genetic associations do not essential influence on formation of the thermal potential of the natural heat-carrier as the value of conductive component in the processes of heat transmission is insignificant for region as a whole.

The geothermal factor is caused by potential of endogenous heat energy, which is characterized by average value of a geothermal gradient 4-60C per 100 m within all area of a northeast Turkey. In the same time, in zones of active breaks and on sites of their crossing preconditions for formation of higher geothermal gradients with size up to 6-90C per 100 m are created. As a source эндогенного a thermal stream serves mantle matter and cooling down magma chamber of young volcanoes. That is, similar geological-tectonic features of region define close geothermal conditions of the area. Heat transmission has convective character.

The hydrodynamic factor defines uniform conditions of formation water geothermal resources component. Conditions of formation of underground waters are determined by the common regularities, characteristic for all mountain-folded hydrogeological regions. Alternation of the hydrogeological massifs connected with mountain structures and jointed with them underground water flow basin belong to these regularities. The largest hydrogeological massifs are connected with Geresun, Doğu Karadeniz ridges. Among underground water flow basins of the mountain – valley type such as Aras Nehri, Çoruh Nehri, Kelkit Çayi and others can be pointed. The main features of these underground water flow basins are those all of them are genetically connected to regional, active faults, filled with sufficiently thick sedimentary formations and can accumulate significant natural resources of geothermal waters. By estimate water component of natural geothermal resources for the specified flow basins can be about 1 % from the value of annual precipitations.

Thus, on the basis of the carried out analysis it is possible to draw a conclusion, that conditions of formation of heat power waters are similar for all territory of northeast Turkey. The results received during research of geothermal conditions of Erzurum and Karasu valleys, can be used at planning prospecting and exploration geothermal fields over all indicated region. The binary power stations with capacity of 4 MW, which are designed in Russia for operation of heat power waters with temperature 110-120^{0}C can become the basis for large-scale use of geothermal resources not only in Erzurum and Karasu valleys, but also in other areas of northeast Turkey.

5. CONCLUSION

The northeastern part of Turkey has significant natural and operational resources of geothermal waters. Their development and use can influence on the decision of many economic and social problems of the region. So, for example, realization of Maguarichic Project on the basis of testing operation of geothermal field Piedras de Lumbre (México), even in spite of insignificant volume of the generated electric power, has caused social impacts and has increased a living standard of rural population in this district.

High economic efficiency (specific capital investments make about 800-2000 US dollars on kWh) and environmentally appropriate technology define investment appeal of geothermal projects. In comparison with other kinds of alternative power (wind, solar) geothermal power stations provide the highest capacity factor.

The use of high-technology modular binary power stations effectively allows using low- and middle-potential geothermal resources. The design of modern BPS can provide their reliable operation in completely autonomous behavior under hard climatic conditions. In particular, satellite telecommunication system is developed and successfully applied in industry by the Russian firm "GEOTHERM".

Realization of geothermal projects has special appeal from the point of view of development of mechanisms of Kyoto Protocol of the and the Framework convention of the United Nations on reduction of pollution emissions in an atmosphere as enables receptions of gratuitous advance monetary payments under the future reduction of emissions of greenhouse gases.

In end we express hope, that submitted for participants of the World Geothermal Congress 2005 cooperation of Russian and Turkish experts, will allow to start realization of the joint projects of development and operation of geothermal resources of Turkey and Russia.

REFERENCES

Barka, A. A.: The North Anatolian Fault Zone. Annales Tectonicae, Special Issue, Supplement to Vol. VI, 1992.

Battocletti L.: Geothermal Resources in Turkey. Bob Lawrence& Associates Inc., 1999.

Bird, P.: An updated digital model of plate boundaries, Geochemistry Geophysics Geosystems, 4(3), 1027, doi: 10.1029/2001GC000252, 2003.

Erdik M., Alpay Biro Y., Onur T., Sesetyan K., Birgoren G.: Assessment of earthquake hazard in Turkey and neighboring regions. The Global Seismic Hazard Assessment Program (GSHAP). Annali di Geofisica, vol. 36, 3-4, 1999.

Kiryukhin A.V.: Modeling of Exploitation Geothermal Resources. Vladivostok, "Dalnauka", 2002.

Mamontov V.K., Matveev N.A., Stepanov V.N.: Estimación de las reservas operaciónas del aguas subterraneos en lugar de la estación geotérmica San Jacinto, Nicaragua. Ros Proect Ltd. Managua, 1993.

Markhinin E.K.: Volcanism. Moscow, "Nedra", 1985.

Sánchelez-Velasco R., Lópes-Díaz M.; Mendoza H, Tello'Hinojosa R.: Magic at Maguarichic.Geothermal Resources Council Bulletin, March-April 2003, pp.67-70.

Stein Ross S., Barka Aykut A., Dieterich James H.: Progressive failure on the North Anatolian fault since 1939 by earthquake stress triggering. Geophysical Journal International, 1997, vol. 128, pp 594-604.

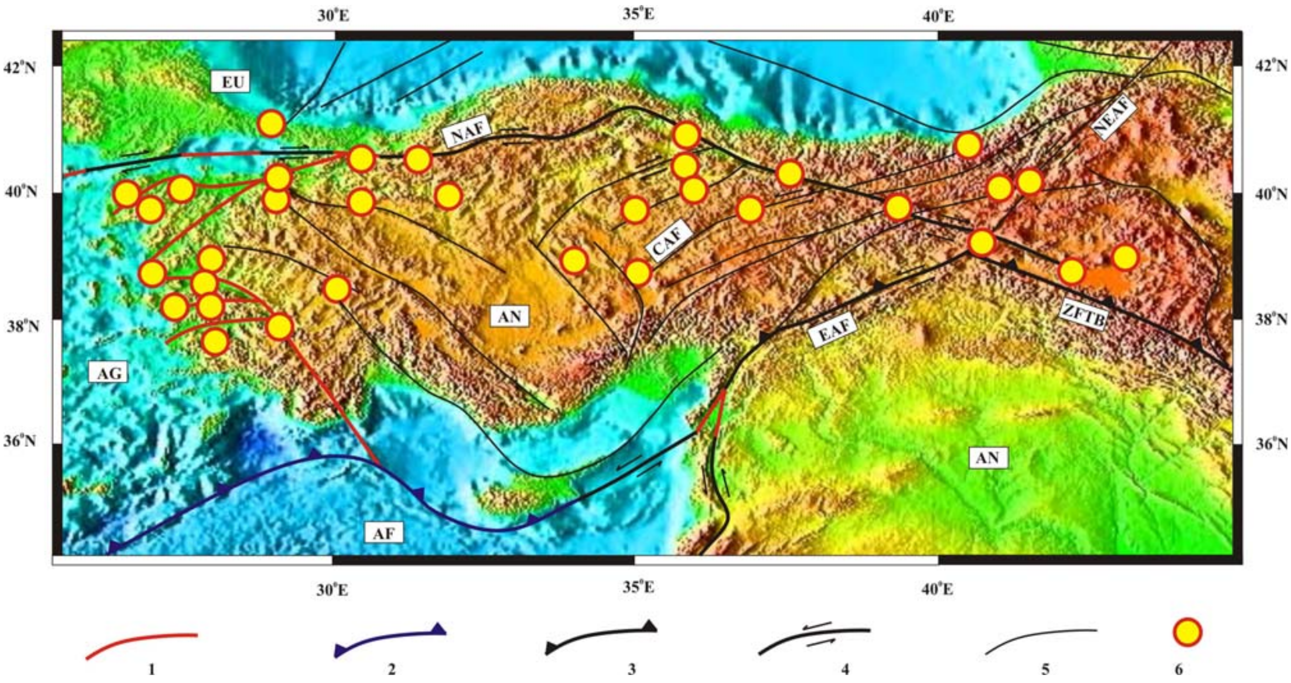

Figure 1: Relationship the geothermal fields and main tectonic elements: 1- divergent zones; 2- subduction zones; 3- convergent continental zones; 4- transform fault zones; 5- zones of other active regional faults; 6- locations of the geothermal fields.

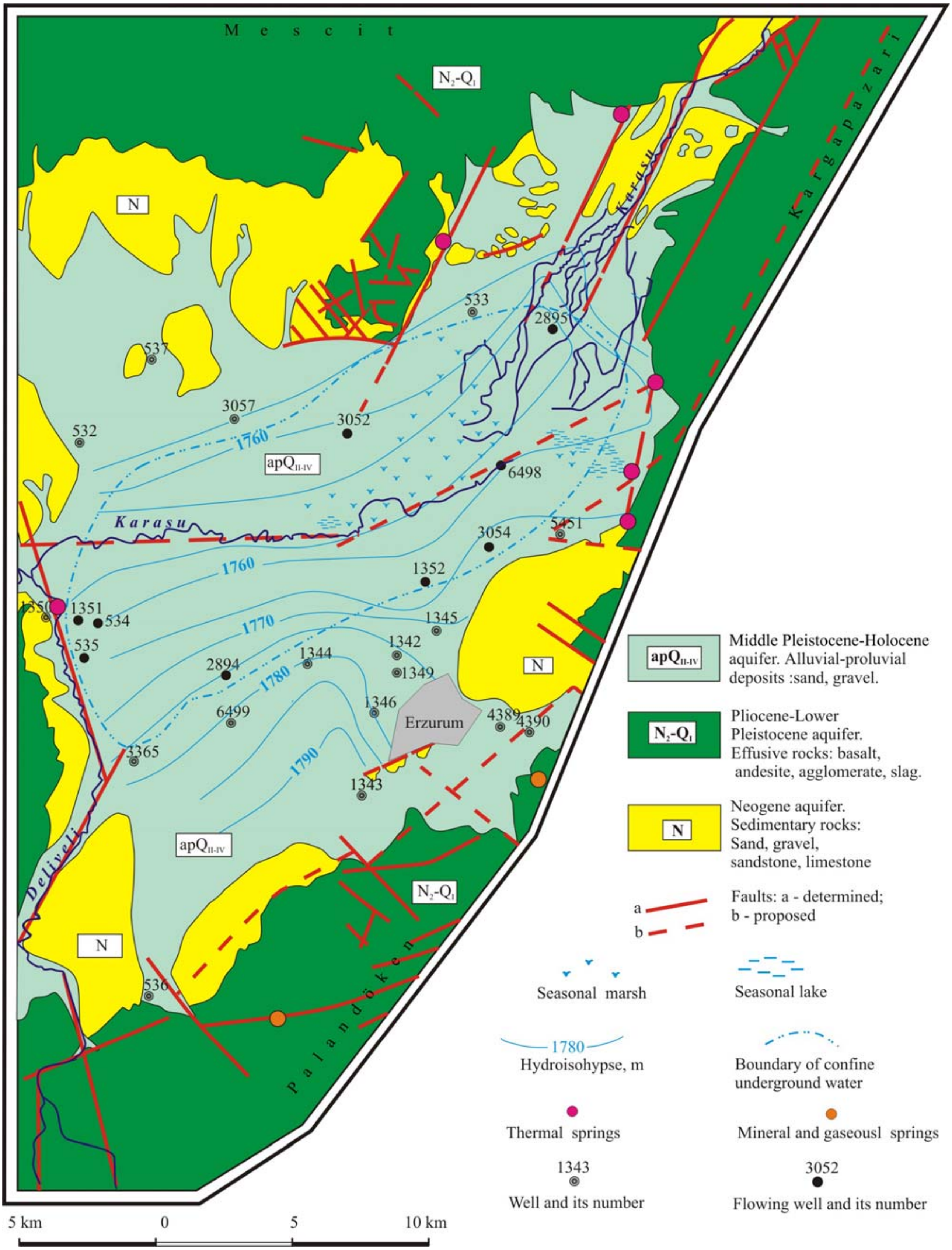

Figure 2: Simplified hydrogeological map of Erzurum valley (after Turkish and Russian investigations)

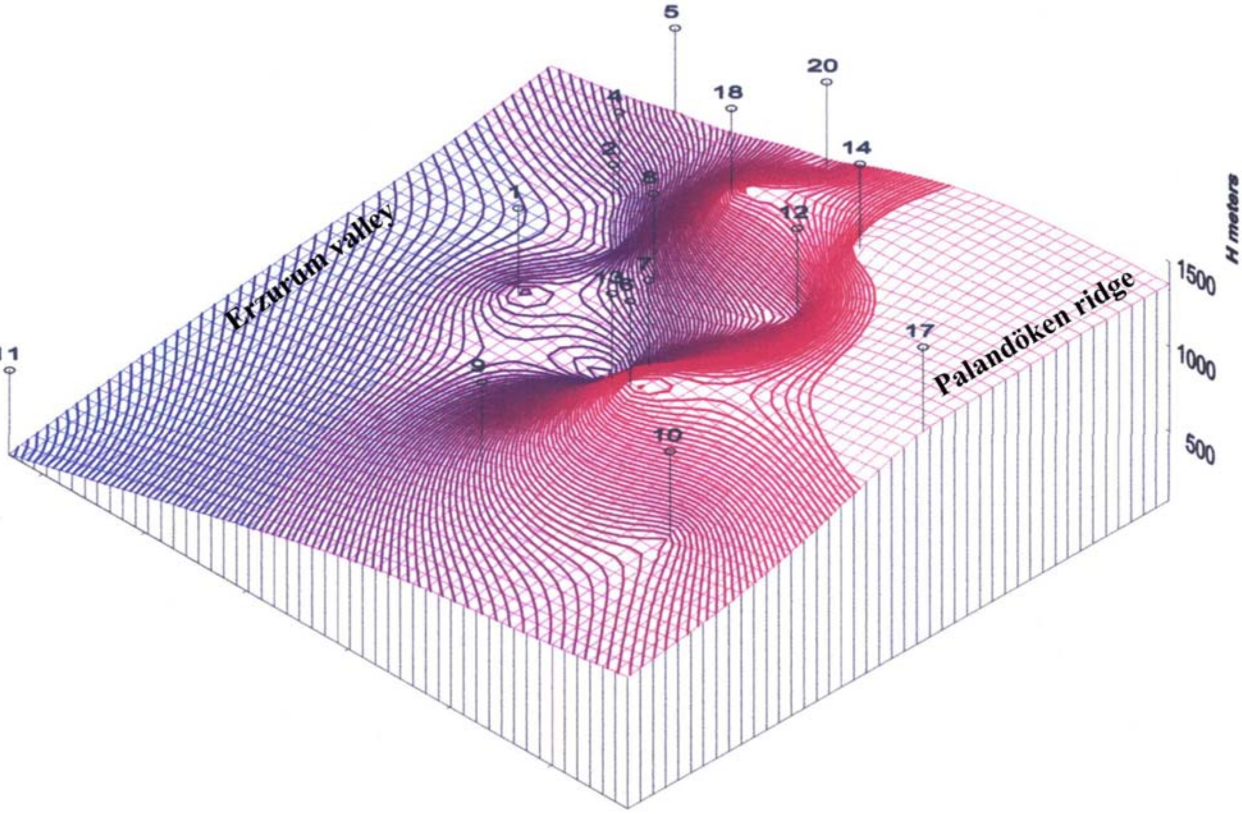

Figure 3: Fragment of the roof hydrothermal aquifer relief in the range of Palandöken slope of Erzurum valley, MTS data.