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Hydrogeothermal Potential of the Strumica Valley with a Special Review of the Bansko Locality

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ABSTRACT

The Strumica valley with its skirt board with reference so tectonic sense belong to two structural-tectonica units. Serbo-Macedonian massif and the Vardar zone. The valley itself presents a tectonic graben which has been lowered in relation to the Belasica na d Smrdes horst, filled with Pliocene lake sediments while the skirt – board is made of granite-gneisses.The investigation-exploration drillhole B-1 with its 254 m. depth in the village Bansko discovered a deposit with geothermal fluid at a depth of 150 – 103 m. in the granite-gneisses. Transmitters of the heart from the deeper depths are the waters from vadose origin which use large open fractures in the granite-gneisses and the fresh granite which are found at great depths of seismically-active Belasica fault, are likely to present a geating source.

The hydrogeothermal potential of the Strumica valley is made upon the base of the results obtained from the investigation in the village Bansko, i.e. upon the base of the understanding of the dynamic reserves where 51 l/sec. with temperature of 70°C and 30 l/sec. with a temperature of 40°C have been taken. The effective usage is 22,4°C, where a heating energy of 1,15x1011 KJ or 3,19x107 KWh is obtained.

Concerning the hydrogeothermal investigations, the drilling should be continued, because of the determination of the spacious location of the collector to the Strumica valley geothermal fluid.

1. INTRODUCTION

The Strumica valley and its wide surrounding (fig.1) were a subject of numerous geological, hydrogeological and geothermal explorations. They have been carried out within the regional hydrogeological explorations while making the Basic hydrogeological map of Macedonia, as well as the detailed explorations for solving various problems from the field of the watersupply, hydromeliorative systems, irrigation sites.In the period between 1982 – 91, a special attention was paid to the Bansko locality, where detailed geothermal explorations were carried out. Here, active geothermal springs and boreholes from the geothermal reservoir of Strumica are located. From the several previous geothermal exploration boreholes (B-1 in the Bansko village, B-2 in the region of Staro Baldovci, B-3 in the Saraj village and B-4 in the vicinity of the Banica village), only the geothermal borehole B-1 yielded a capacity with positive characteristics for the energetic exploitation. This borehole is actually a unit with the existing natural spring above the hotel "Car Sam oil" with about ten smaller springs round it. It has been drilled down to a depth of 254 m. From the surface of the terrain down to a depth of 143 m., the material in the borehole has been presented by various granular Proluvion sediments, composed of fragments of granites and gneiss. From 142 m. to the final depth of the borehole, the lithological structure is composed of granitogneiss with interbeds of amphibolites and amphibole schists.

2. A SHORT PRESENTATION OF THE GEOLOGICAL STRUCTURE AND STRUCTURAL GEOLOGICAL CHARACTERISTICS OF THE STRUMICA VALLEY AND ITS EDGE

The Strumica valley which is situated in the south-east part of the Republic of Macedonia and according to its spatial characteristics is a distinguished natural unit. There are several geological units on this terrain, different in the lithological characteristics, geological age and tectonic features (fig. 2).

The geological structure and its characteristics of the geothermal reservoir Bansko are a part of the very characteristic geological structure of the Strumica valley where the Precambrian metamorphites are the oldest, presented by various gneisses schists and magmatites. The gneisses are the basic rocks of the metamorphic complex while the remaining metamorphites are only facial transitions. This complex has been represented along the peripheral parts of the Strumica valley, which concerning the structural-tectonic aspect belongs to the Serbo-Macedonian mass, the schists have been represented in the Ograzden and Belasica mountain and they are presented by amphibolites, micaschists, leptinolites and amphibole schists. The magmatites has a local representation round the old Paleozoic granite intrusions in the gneisses which are feldspatized and silificated.

The old Paleozoic rocks are presented by metamorphites and magmatites. The magmatites are presented by various granites, Rhyolites as well as gabbro represented by several variants. They are tectonically rather cracked and somewhere hydrogeothermally altered.

The Tertiary manifestations have been presented by Upper Eocene sediments, dacites, andezites and Pliocene tuff, conglomerate, sandstone and limestone while the dacites and andezites occur as intrusions in the Paleozoic magmatites.

The Pliocene sediments are the most representative phenomena in the exploration surfaces. They have been discovered along the peripheral parts of the valley and identified in the exploration boreholes and under the Quaternary sediments in the valley, presented by different granular gravels, sands and clays.

The Quaternary formations cover almost all the Strumica valley and are presented by sandy clay, gravel, sands and tufaceous sediments. The tufaceous sediments occur in the

Bansko village as a product of the deposition of the thermal springs as contemporary paleohydrogeothermal occurrence and a process at the Veljusa village where it comes from the karst springs that occur in the marble. During the drilling of the borehole B-1 (Bansko), at a depth of 30 m., a tufaceous plate was determined which points to the fact a long time ago thermomineral springs existed at this area.

Concerning the structural-tectonic aspect, the Strumica valley and its peripheral parts belongs to two tectonic units: The Serbo-Macedonian mass and the Vardar zone. The area of interest can be separated into four structural geological units: the Belasica horst, the Ograzden batholiths, the Smrdes horst and the Strumica graben. Significant structure of hydrogeothermal are the Svidovica – Zleovo fault as well as the Belasica one, the Bansko – Gabrovo and the Ilovica fault as well as hydrothermally altered zone Drvos – Canakli.

The Strumica trench was formed by subsidence of the terrain along the Belasica and the Ograzden fault during the Pliocene. The depth in all the valley hasn't been determined yet, but according to the geophysical explorations it is from 700 – 1200 m.

3.RESULTS OF THE APPLIED METHODS AND MAKING THE GEOTHERMAL EXPLORATION DRILLHOL B-1 AT BANSKO

In order to determine the geothermal potential of the Strumica valley before performing the exploration geothermal drilling, many geological methods have been applied whose final goal was to define the geothermal anomalies and to determine the microlocations of the exploration boreholes. The aerophotogeological, structural-geological, geophysical, hydrochemical and geothermic methods have been applied.

By the analyses of the applied methods for the Strumica valley, separation of the tectonic elements, morphostructures and faults was made and their geothermal significance gas been determined according to the existence of surface and hydrothermal manifestations by the correlation of the results obtained from all the applied methods.After the synthesis of the results obtained from all the applied methods, a selection of the promising localities for further detailed geothermal and the related hydrogeothermal explorations was done in order to discover the accumulation of the geothermal fluid, understanding of its spatial characteristics, calculation of the hot water reserves as well as understanding of the economical justification for its exploitation.

The most promising localities in the Strumica valley,according to the previous explorations, the following localities have been established: Canakli – Drvos; Banica – Vodoca – Veljusa; The area east of Ilovica – Stuka; Monospitovo-Dobrejci.

The exploration geothermal drilling commenced in the Bansko locality, which is very understandable, because there are geothermal springs and the water is used for balneological purposes. Here, on this locality, four boreholes were drilled: B-1, B-2, GDB-1, GDB-2, whose obtained results are rather significant. They will be presented and studied in details in this paper.

In the remaining localities, one borehole was distinguished: the region of the Staro Baldovci, village (down to a depth of 420 m., overflowing water of Q = 5 l/sec., temperature T = 290°C, the region of the Saraj village (the depth is 738 m., Q = 0,5 l/sec., T = 190°C), the locality Banica (hot water was not identified, and the temperature measured during the process of drilling is 28,4°C).

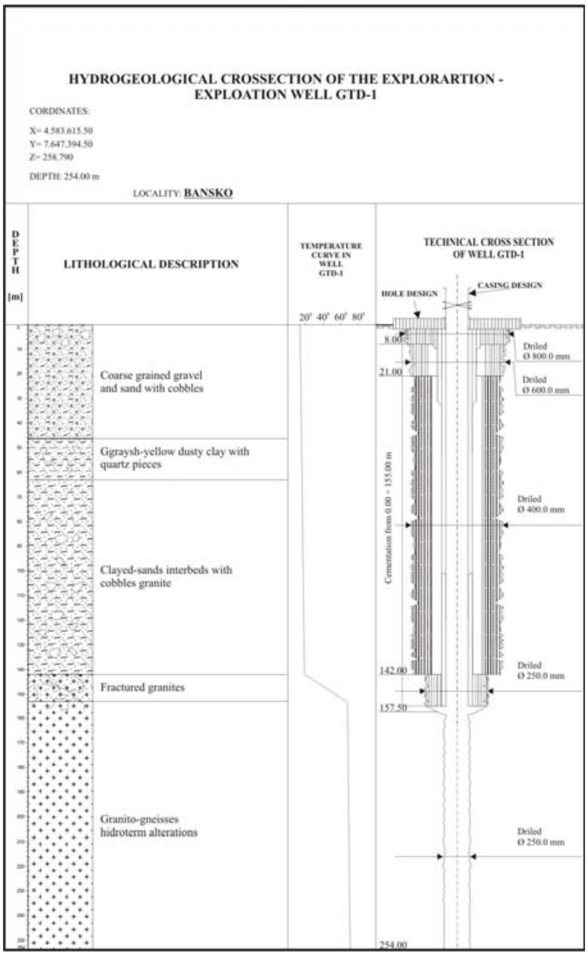

Fig. 3: Lithological profile and results from the measurement of th temperature in the borehole B-1, Bansko

The microlocation of the exploration geothermal boreholes B-1, B-2, GDB-1, GDB-2 is in the Bansko village and its surrounding (fig. 2). The borehole B-1 is located in the centre of the Bansko village at a distance of about 50 m. and the hotel "Car Samoil", while B-2 is situated at about 700 m. in the direction of the Monospitovo village at a determined fault structure according to the geophysical explorations of that terrain, carried out in 1986.

The other two boreholes GDB-1 and GDB-2 are located in the east side of the Bansko village, following the Belasica fault towards the villages Gabrovo – Mokrievo – Smolari. The determination of the microlocation of all these boreholes has been done according to the previously performed geophysical explorations in 1988 – 1989.

The exploration borehole B-1, was drilled down to a depth of 254 m. (fig. 2), from the surface of the terrain down to a depth of 142 m., the material in the borehole is presented by different granular Proluvial sediments, composed of fragments of granites and gneiss. From the depth of 142 m. to the final depth of the borehole, the lithological profile is composed of granite-gneiss with interbeds of amphibolites and amphibole schists.

In order to examine the Bansko locality until 1986, within the program for further exploration, the borehole B-2 commenced to be drilled. This borehole has been drilled down to a depth of 600 m. According to the previous explorations, the borehole intersected the Upper-Pliocene materials presented by different granular sands, gravels, clays and muddy material down to a depth of 554 m., and down to 600 m. it entered the Upper zone of the granite-gneiss. The granite-gneisses are rather mechanically crushed with many fractures which are filled with calcite a. In the borehole B-2, thermal water was registered in the Proluvial sediments at a depth of 34 m. as well as artesian water occurred at the distance of 153 – 185 m. in the sandy-gravel sediments presented in the profile of the borehole end quartz veins of 0,5 cm.

At the moment, the borehole is conserved, i.e. filled with dense bentonite drilling fluid. As hot water was not determined down to a depth of 600 m', but having the previous understanding from the explorations of this locality, we should continue with the drilling, 100 m. more, so as to go deeper in the granite-gneiss in order to get hot water with a temperature higher than 70^{o}C.

In order to examine this locality in details beside finishing the borehole B-2, the people continued with further expected exploration in the direction towards the Gabrovo village by drilling the boreholes GDB-1 and GDB-2, whose results achieved the expected goal by shallow sondage boreholes, to do monitoring of the fault zone and record the geothermal anomalies in that direction. The geothermal borehole GTD-1 has been drilled down to a depth of 220 m', recorded temperature of 28,3^{o}C, while the borehole GDB-2 has been drilled down to a depth of 120 m', and a quality of overflowing water Q = 6 l/sec. and a temperature T = 22^{o}C. The results of these two exploration boreholes point to the fact that in the fault rapture in the surface zone, geothermal anomalies have been registered..

3.1 Hydrogeothermal characteristics of the terrain round the exploration boreholes

According to the performed hydrogeological explorations, during the drilling of the borehole B-1, two horizons with subartesian water were registered at a depth of 30 – 35 m. and at 88 m., while at a depth of 108 m., a horizon with artesian water was registered. The largest flow of thermal water was registered at a depth of 164 m. with a discharge of 60,3 l/sec. and a temperature of 72^{o}C. In the process of drilling the discharge increases to 85 l/sec., while the discharge in the main captage spring decreases to only 10 l/sec.(Fig3)

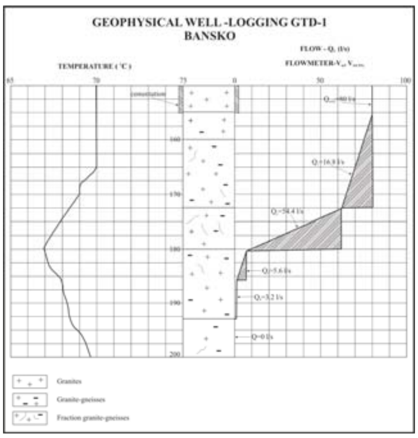

Fig. 4 Geophysical well - logging B -1 Bansko

The occurrence of geothermal water with a temperature of 72oC in the borehole B-1 and at a depth of 156 – 163 m. is rather significant geothermal anomaly. After finishing the drilling, geothermal logging was performed including the thermologging. In accordance with the measured temperatures in the borehole B-1, the geothermal gradient was measured to be a basic parameter for characterizing the geothermal reservoir. The following values were determined:

- -in the distance between 179,2 and 203,7 m., the greatest mean value of the geothermal degree was obtained, it was 68,85 m/^{o}C;
- in the distance from 184 to 185 m., the greatest anomaly with a geothermal gradient was considered in the granite-gneiss was determined to be from 250^{o}C/100 m., i.e. geothermal degree of 6,4 m/^{o}C;
- average geothermal gradient down to a depth of 254 m. is dT – 19,71^{o}C/100 m., i.e. the geothermal gradient is 5,07 m/^{o}C.

Such value of the geothermal degree is approximately 6 times greater than the value of that parameter for the continental part of Europe (the average value for Europe is 33 m/^{o}C). The heat flow was not directly measured, but according to the average heat conductivity of the granites and the gneisses, is has been considered to be 100 to 110 mW/m^2 (average value of the heat flow for the continental part of Europe is 60 mW/m^2).

3.2 Hydrochemical content of the water

For the determination of the chemical structure of the water from the drillhole B-1, have been made several analyses by Geological Institute-Skopje and Geological Institute-Ljubljana, whose results are presented on the table 1, no full chemistry of the water samples from the well are presented on the table 2.

Table 1: Content of the chemical structure to the thermal water from the borehole B-1 (mg/l) – Bansko

Na	K	Cl	Ca	B	F	Na/K	Na/Cl	Cl/B	Cl/F	total
210	8,5	20,5	4,95	0,37	5,9	41,93	15,8	16,89	1,86	1157,2 mg/l

The chemical content of the water has been determined by several analyses and has been defined as potassium – sulphate type of water with total mineralization of 1157,2 mg/l and with high content of boron and fluoride. It points to the fact that the water originates from great depths. The relation of potassium and sodium is greater than 1 and indicates to the fact that the water is vadose, i.e. the reservoir is feeded from the atmospheric water.

By the application of the hydrogeothermometres for estimation of the temperature in the primary reservoir, in the case of chemical equilibrium of the surranding rocks are used equations for chemical geothermometres (Arnorsson, Fournier & Truesdell), whose values are presented on the table 3. The quartz and the Na-K geothetmometer give allmost the same result, 117 and 118^{o}C, respectively. The sample is saturated with calcite at measured temperature but supersaturated at higher temperatures. Equilibrium with all ions is reach at 115 - 120^{o}C which is the predicted temperature.

4. THE IMPORTANCE OF THE HYDRO-GEOTHEMAL CHARACTERICS OF THE TERREN OF VICENTY OF BANSKO FOR ESTAMITION OF THE HYDROGEOTHEMAL POTENTIAL OF THE STRUMICA VALLY

The discovered geothermal anomaly in Bansko and other presentented results that were obtained by the former explorations (have a great importance), are of a great importance for estimation of the hydrothermal resources potential not only on the territory of Bansko, but more widely. Since in the Strumica valley till now, it has been discovered thermomineral water deposit only in Bansko, the geothermal potential of this valley will be treated only on this locality. It doesn't mean that we should not expect hot water with the further explorations and the remaining perspective localities.

The hydrogeothemal water potential in Bansko has been calculated on the base of the understanding of the dynamic reserves and their temperature, because the static reserves have not been known yet, i..e. not knowing the spacious location and dimensions of the collctors and geothermal waters accumulations in it.

The estimation is orientational as the values are taken from 50 l/sec. with a temperature of 69,5 ^{o}C and 30 l/sec., with a temperature of 40^{o}C, i.e. the total quantities that are registered in the locality of Bansko. The estimation has taken the temperature range of utilization to 10 ^{o}C and the fictitious utilization of 22,5^{o}C. So, according to these estimations, hydrogeothermal resources of the locality Bansko may be considered to be 115 x 10^{9} k j or about 32 x 10^{6} Kwh heat energy, i. e. the total thermal water yield would be 2,5 x 10^{6} m^{3}/year (table 4).Taking the temperature of efluent of 25 ^{o}C.as economicaly feasible for the existing composition of users, maximal geothermal heat power on disposal in 10.3 MW.

The possibilities of utilisation of hydrogeothemal resources in the mentioned granite- gneisses at Bansko regardless this our first estimation, are great and well known and according the quality and qvantitiest that may be exploited give very great possibilitiest for a great restricted utilization of the geothermal energy.

5. OPTIMAL USE OF THE PRESENT CAPACITY OF THE HYDROGEOTHERMAL SYSTEM BANSKO

The determination of the discharge of the geothermal resource in the region of Bansko in the Strumica valley has been based on several years measurements and monitoring of the geothermal water flow, of the previous natural spring (captage), as well as according to the flow through the present existing borehole B-1.

The exploration – exploitation borehole B-1 is 254 m. deep and the casing was done down to a depth of 157 m. The diameter of the borehole is 156 mm. Immediately after finishing the technological works, as water flow within 75 – 80 l/sec. was measured., with a temperature of 70oC. The drawing experiment, the hydraulic characteristics of the borehole were determined, its hydraulic relation with the close thermal springs was determined and according to the results of these examinations, the sizes of the possible capacities were determined as well as the maximal capacity for a short period of time, maximal permanent discharge, the discharge of the resource during several years exploitation. The experimental explorations for the determination of the discharge of the geothermal fluid from the hydrogeothermal system Bansko, have been carried out the Geological Institute from Skopje and Ljubljana. First, when the drawing commenced in the borehole, the water level was measured and it was 26.532 m. above the opening of the borehole. Decreasing of the water flow during the time indicates that its size is decreasing from the starting 76,3 l/sec. to 64,6 l/sec., in a period of 8 days.

In the period from October – December 1991, the Geohydroproject carried out additional measurements of the discharges of all the springs, captage and boreholes. According to all these explorations, whose results are presented in graphic form (because of their legibility), we may draw the following necessary conclusions:

- The direct hydraulic relation of the borehole B-1 with the remaining springs of thermal water was determined. The main captage becomes dry immediately after several hours from the commencement of drawing from the borehole B-1;

- During the exploitation of the borehole B-1, we must consider the fact that almost all surrounding springs will become dry (maybe only the spring at an elevation of 269,8 m. will remain the same, i.e. the old Turkish health spa Salanci);

- It was determined that the aquifer is rather large. The minimal identified natural feeding of the aquifer is more than 30 l/sec.

- During large flows, hydraulic resistances occur. The installation of the pump for drawing geothermal water we do not expect significant increasing of the flow.

- According to the diagrams of water flow in the function of the time, by the extrapolation of the results, it can be prognosed for a longer period that:

- the maximal permanent water quantity which can be continuously exploited is 50 l/sec.;

- the maximal water quantity which can be temporary used from time to time (to 12 hours daily and seasonally) is 55 l/sec.;

- water quantity which can be used for a longer period of time in an open borehole is 52 l/sec. in the course of 2 years and 45,5 l/sec. in the course of 19 years.

6. CONCLUSIONS

According to the type of hydrogeothermal system, the Strumica valley belongs to the group of fracture systems whose reservoir has been composed of granites. The granites originate from the Paleozoic and have been altered and are mostly transited into granite gneiss. Across the granites which form the valley tertiary sediments lie, 1200 to 1300 m. thick. The reservoir of this system is being drained through a group of several natural springs with different temperatures from 60 to 73^{o}C and the exploration exploitation boreholes B-1 in the Bansko village with a discharge of 50 l/sec and a temperature of 70^{o}C,

According to the chemical structure of the thermal waters from Bansko, they belong to the group of sodium – sulphate type with a total mineralization of 1157 mg/l, while the quartz and Na–K geotehrmometers yield prognosis temperatures from 115– 120^{o}C.

Concerning the hydrogeothermal investigations, the drilling should be continued, because of the determination of the spacious location of the collector to the Strumica valley geothermal fluid.

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KEY MAP

Fig. 1: Location map

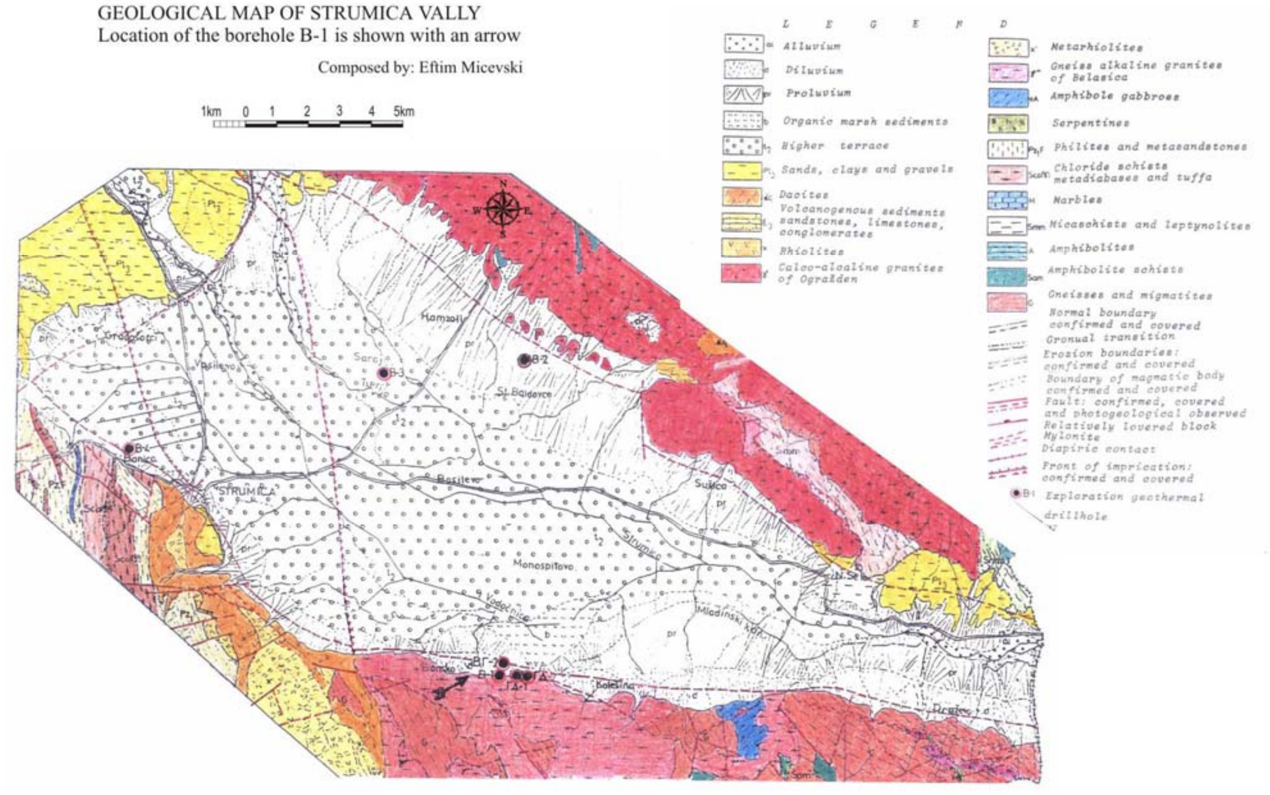

Fig. 2: Geological map of Strumica valley - Location of the borehole B-1 is shown with an arrow

Table 2 Chemical composition of thermal water from the borehole B-1(mg/l)

Sample	Tme °c	Flow l/s	S_iO_2	N_a	K	C_a	Mg	CO_2	SO_4	Cl	Fl	Dis.solid
1	70,0	55,0	68,0	210,0	8,5	74,8	2,60	105,7	491,0	20,5	5,9	1157,2
2	70,0	55,0	54,0	209,7	9,0	89,6	6,2	112,9	551,6	30,2	5,0	1048,7
3	69,5	50,0	72,0	196,9	9,82	83,1	3,45	102,3	407,6	23,0	2,0	1017,2

Table 4 Energetic potential of the thermal waters appearance in Bansko

Ord. Num	Object	Temperature °C	Jield m^3/year	Temperture °C	Total Potential		Effective Potential	
					KJ/y	kWh/y*	KJ/y	kWh/y*
1	BoreHole B-1	69,5	1.576.800	59,5	393 $x10^9$	109 $x10^6$	88 $x10^9$	24 $x10^6$
2	Spring	40	946.080	30	119 $x10^9$	$33x10^6$	27 $x10^9$	$8x10^6$

* - thermal equivalent