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2.
EXPLORATION AND EXPLOITATION OF GEOTHERMAL WATERS IN THE ZAGREB AREA

Miron Kovacic
Institute of geology, Sachsova 2, 10000 Zagreb, Croatia

E- mail: miron.kovacic@zg.htnet.hr

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Abstract

In the sixty's of the last century in the Zagreb area was discover significant geothermal potential by drilling. Today is in use only a part of this geothermal energy potential. By drilling have been discovered some few geothermal aquifers in the depth from 300 to 1000 m. The temperatures in these aquifers are from 30 to 80 ^{0}C. Main aquifers are the Triassic dolomitic breccias, dolomite, and dolomite limestone, less important aquifers are the Miocene bioclastic limestone. Geothermal gradients on locations of single boreholes are very different, and the temperatures in the depth of 500 m vary from 27 to 52 ^{0}C. After the heat conductivity values, the Tertiary formations in that area represent the heat isolator, while the Triassic dolomite in their base represent the heat conductor. The mean value of the terrestrial heat-flow density is 83,6 mW/m^2. The lowest value is 58,6 mW/m^2 (well Jarun-1), while the highest amounts are up to 102 mW/m^2 (well KBNZ-1B). The most of the calculated terrestrial heat-flow density values in the Zagreb area in the central part of Europe represent the positive anomaly.

1. Introduction

In the area of capital of Republic of Croatia - Zagreb there are several springs of geothermal water. Because of low temperature that water has never been interesting for exploitation. Virtual geothermal potential in the Zagreb area has been discovered by deep drilling in the sixty's of last century. This paper shows a brief history of exploration and exploitation of geothermal water, and introduces of geology and geothermal characteristics in the area of Zagreb.

2. The brief history of utilization of geothermal waters in the area of Zagreb

In the Zagreb area there are two springs of subthermal water: Toplicica near Gornja Dubravica with temperature ranging from 17^{O} to 18^{O}C, and Sutinska Vrela with temperature of water ranging from 17 to 23^{O}C (Kovacic & Perica, 1998) (Fig. 1). Waters from these springs have never been utili-zed in an organized way. That there is a significant geothermal potential in the Zagreb area it was understood only by the year 1964. owing to discovery of geothermal water resources by the oil well Stupnik-1. Geothermal aquifer is situated in the depth greater than 740m and it is composed of Miocene lithotamnium limestones and Triassic dolomites.

By testing of the well during the year 1977. it turned up that natural discharge was 7 l/s while the temperature of water was 57^{O}C. Favourable results initiated complex investigations during the eighties of the last century. During that period 15 boreholes were drilled in the Zagreb area. Few of these pierced the geothermal aquifers with considerably high temperatures. For example: in the area of Blato with the upper limit of the aquifer of about 900m the temperature was 80^{O}C, on the surroundings of the sport center of Mladost the temperature was 65^{O}C, around Sveta Nedela in the depth of 1000m it was circa 65^{O}C, while in the area of Podsused in the depth of 300m it was 30^{O}C.

Geothermal energy has been utilized from this drill holes in the wider city region of Zagreb in for the past 20 years. At first geothermal water was directly discharged into swimming pools while later it was used for swimming pool heating and the heating of buildings with the aid of heat exchanger.

Application of thermal waters is today restricted to three locations: the sports center "Mladost" (pools, sports hall), the Factory for Special Equipment Ina and the University Hospital under construction (space heating and sanitary water heating). The geothermal energy consumed in this way is equivalent to approximately 800 tones of oil annually. The geothermal energy used is only a part of the energy potential of the positive geothermal anomaly in the wider region of Zagreb (Kovacic, 1995).

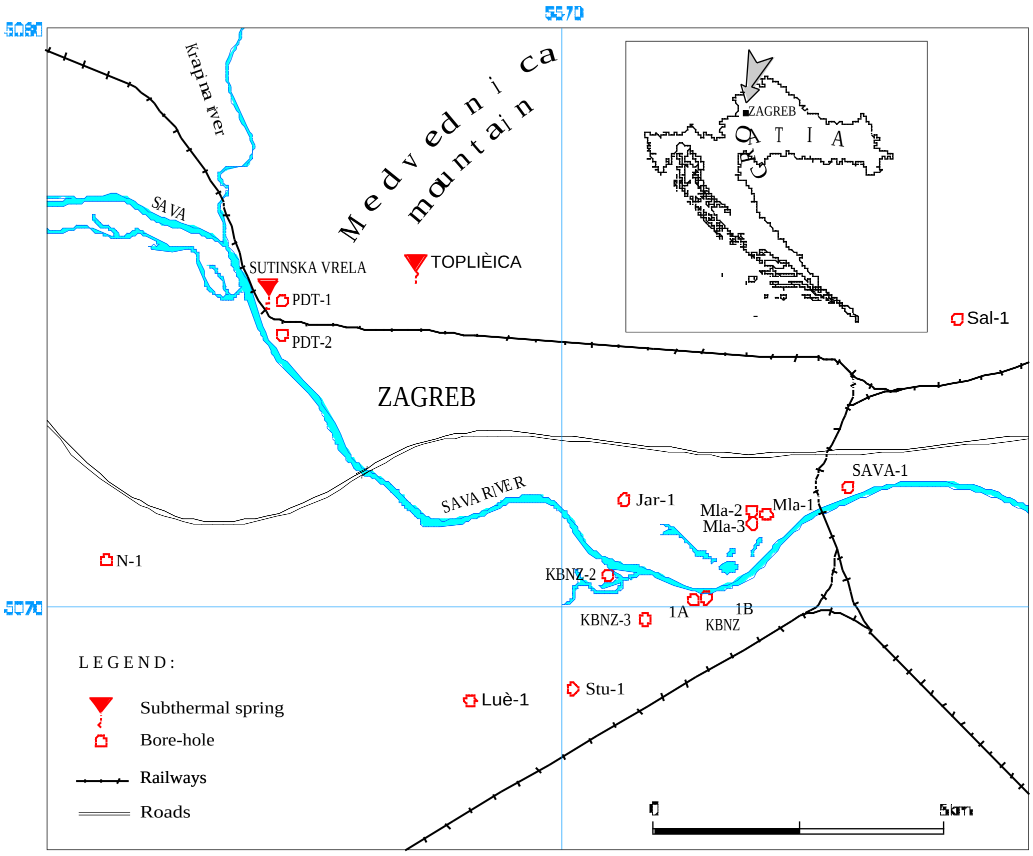

Figure 1. Position map of the Zagreb geothermal area

3. Geological Setting

The Zagreb geothermal area is in southwest part of Panonian basin. This area is a part of the Sava basin. In the northern part Mt. Medvednica rises, while in the southern part spread the plains of the river Sava. The Mt. Medvednica area is represented by a wide range of chrono-stratigraphic units dating from the Paleozoic to the Quaternary (_iki_ et al., 1972, Basch, 1980). To the south of Mt. Med-vednica the area is covered by Pliocene-Quarternary and Quaternary rocks. By exploration drillling it was determined that rocks that underlie beneath these rocks are equivalent to those found on Mt. Medvednica.

Mesozoic

In the investigated area the only Mesozoic rocks determined in drill holes belong to Middle and Upper Triassic. These are dolomite breccias, dolomites, and dolomite limestone. These rocks where determined in the following drill holes; The Clinical Hospital New Zagreb - 1A, 1B and 2 (KBNZ-1A, -1B and 2), Mladost-2 and 3, (Mla-2, -3), Nedelja-1 (N-1), Podsusesed termalna -1 and -2 (PDT-1,-2) and Stupnik-1 (Stu-1). The rocks of this age are characterized by secondary porosity and have high thermal water retention. The thickness of these rocks in the drill holes varies from 5 m (KBNZ-1B) to 357 m (PDT-1).

Tertiary and Quaternary

Tertiary and Quaternary deposits were encountered in every drill hole in the investigated area. The thickness of these deposits differs considerably in each individual drill hole. Their precise chrono-stratigraphic position within the temporal range from Egerian to Sarmatian is not possible to determine due to the lack of drill cores and fossil remnants. There are indications that not all the chrono-stratigraphic are developed in all drill holes.

Lower and Middle Miocene - M_{1-5}

The Lower and Middle Miocene deposits are represented by the following chrono-stratigraphic units Egerian, Eggenburgian, Ottnangian, Carpatian, Badenian and Sarmatian. The contact with underlying older rocks is discordant. The lithology of this formation varies considerably and consists of marls, sandy marls, sandstone, breccias, breccias-conglomerates and lithothamnium limestone. The thickness of the formation ranges from 35 m (Stu-1) to 1016+x m (Jarun-1). The beds are characterized by primary and secondary porosity, and in places have very good permeability, and also in some places act as reservoirs for thermal water in the investigated area.

Pannonian M_6

The lower part of this unit consists of marl beds characterized by an elevated content of the lime component as well as clayey limestone. These deposits are impermeable and their thickness varies from 35 to 121 m. In its upper section, these beds composed of marls, which are in places silty, are also impermeable without primary porosity.

Pontian M_7

In their lower part these deposit consist of lime clays and marls with sporadic intercalation of sandstone. Limy, sometimes sandy clays and marls with rare intercalation of fine-grained sandstone and coal dominate the upper part of these deposits. The deposits are impermeable with developed primary porosity and contain no significant aquifers. Their thickness is different in each drill hole.

Pliocene and Quaternary -Pl+Q

The Pliocene and Quaternary deposits consist of various types of sediments. The lower, Pliocene section consists of predominantly limy clays with intercalation of coal, sand and marl. In the Quarternary part of the section alternations of gravel with sand and clay prevail. The Pliocene section of the deposits does not contain any significant aquifer, while in the Quaternary part, which is characterized by high primary porosity and permeability, contains a significant potable water aquifer. The thickness of these deposits ranges from 10 to 319 m.

The occurrence of discordant boundaries and the wide range of thickness of individual lithostratigraphic units in the drill holes is a consequence of intensive tectonic dynamics during the Tertiary. During sediment deposition the whole area was ruptured into a series of blocks of different size that depressed at different relative velocities and formed the paleorelief. These movements caused the formation of different deposition environments, with different thickness and in places different lithological compositions of Tertiary lithostratigraphic units. The tectonic activity is still active and numerous earthquakes that have been recorded through history and in the near past manifest it. Faults that incise through even the youngest deposits to the surface are a consequence of this tectonic activity (Prelogovic et al., 1997).

4. Geothermal characteristics of the Zagreb geothermal area

The following characteristics of the Zagreb geothermal area are defined by recent investigations (Kovacic, 1997, 2002):

1. The temperatures of the geological formations, as measured in the boreholes spaced closely to each other, vary considerably. To illustrate, in the appended table one can consider the temperatures in the boreholes at depths of 500 and 1000m with large range of their values. At the depth of 500m, the lowest temperature is 27^{O}C (_alata-1), and the highest 52^{O}C (Mladost-1), which represents the range of 25 ^{O}C. At the depth of 1000m the range is still higher having the value of 31,2 ^{O}C and 43,2 ^{O}C, respectively, if the extrapolated values are taken into account. The lowest temperature is 49 ^{O}C (_alata-1) (37,5 ^{O}C, PDT-2, extrapolated temperature), while the highest is 80,7 ^{O}C (KBNZ-1B).
2. Geothermal gradients on the locations of single boreholes are very different, which is particularly evident with interval geothermal gradients. The lowest value of interval geothermal gradient amounts to 3 mK/m (Mladost-1), and the highest amounts to 125 mK/m (KBNZ-1B)
3. The heat conductivity of individual geological formations pierced by the represented boreholes in the Zagreb geothermal area is varying. According to it we can classify the geological formations into two groups: Tertiary formations and formations in the base of Tertiary. Average heat conductivity of the former is about 1,89 W/mK, while for the latter amounts to 4,72 W/mK. With regard to the common relationship of the heat conductivity values, the Tertiary formations represent in this case the heat isolator, while the Triassic dolomites in their base represent the heat conductor.
4. Terrestrial heat-flow density values on the well locations in the investigated area vary. The lowest value is 58,6 m W/m^2 (Jarun-1), while the highest amounts to 102 m W/m^2 (KBNZ-1B). The mean value is 83,6 m W/m^2, with range of 43,4 m W/m^2.
5. According to investigations in Slovenia (Ravnik, 1991) and Italy (Cataldi, et al., 1995) as well as according to the Map of Terrestrial Heat Flow of Europe (Cermak & Rybach, 1979), and Geothermal Atlas of Europe (Hurtig et al., 1992), the values higher than 80 mW/m^2 in the central part of Europe represent the positive anomaly of terrestrial

heat-flow density. According to this criterion the majority of terrestrial heat-flow density values, 6. which are obtained by investigations in the Zagreb area, characterize the positive geothermal anomaly.

Table 1. The temperatures in the boreholes at depths of 500 and 1000m (*the extrapolated values)

Drill hole	Temperature °C z - 500 m	Temperature °C z - 1000 m	Terrestrial heat-flow density mWm^{-2}
Jarun-1	38,1	53,3	58,6
KBNZ-1A	47,5	77	95
KBNZ-1B	48,4	80,7	102
Lu_-1	37,5	59,2*	80
Mladost-1	52	77	92,5
Ned-1	39,6	59,9	72,5
PDT-1	32,4	40,9*	90,5
PDT-2	29,5	37,5*	86
Sava-1	40	61	82
Stu-1	41	64,6*	94
_al-1	27	49,5	67
Average	39,4	60* 64,7	83,6
Spread	28,5	31,2 43,2*	43,4

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