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History of Exploration and Exploitation of Geothermal Energy in the Zagreb Geothermal Area (Croatia)

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ABSTRACT

Zagreb Geothermal Area (ZGA) with its history of exploration and exploitation of geothermal waters, currently known geothermal energy potential and actual quantity of geothermal energy is presented in this work. The sixties of the last century saw the discovery of significant geothermal potential as a result of intense drilling in the area. In the course of over 40 years 17 exploration and exploitation boreholes have been drilled to the depths of 500 to 2200 m. Geothermal aquifers were drilled in many cases. A few geothermal aquifers have been discovered at the depth of 300 to 1000 m with temperature of 30 to 80 0C. There are two types of aquifers. The main type is represented by the Triassic dolomite breccias, dolomite and dolomite limestone while the less important type includes the Miocene bioclastic limestone. On some locations both types occur. Water from the boreholes is widely used for the purpose of heating, breeding fish as well as for greenhouses and warming the swimming pools. Currently, the geothermal waters are in use on four locations in ZGA but their geothermal potential is only partly utilized.

1. INTRODUCTION

In the area of the Croatian capital, Zagreb, there are several springs of geothermal waters. Because of its low temperature this water has never been considered for exploitation. Virtual geothermal potential in ZGA has been discovered by deep drilling in the sixties of the last century. This paper shows a brief history of exploration and exploitation of geothermal water, introducing geology, geothermal characteristics and geothermal waters potential in the area of Zagreb.

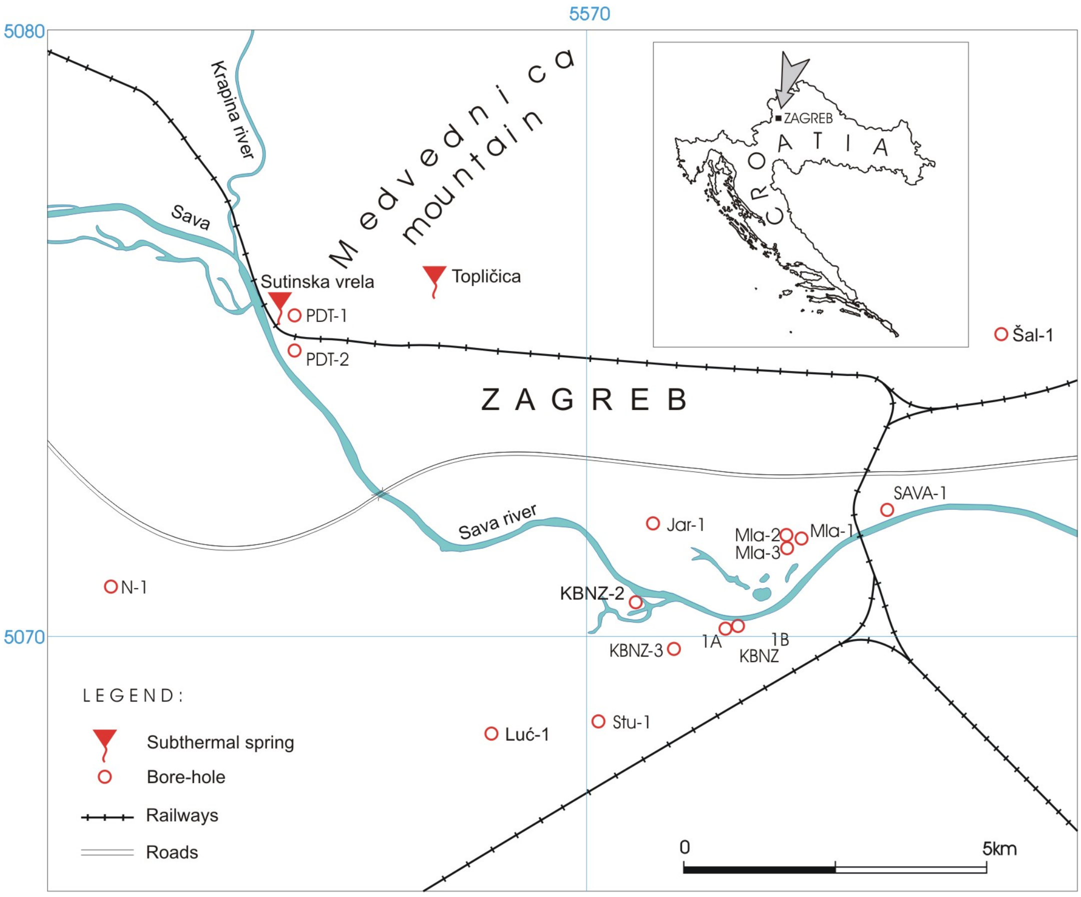

Figure 1. Position map of the Zagreb geothermal area

2. THE BRIEF HISTORY OF UTILIZATION OF GEOTHERMAL WATERS IN THE AREA OF ZAGREB

Two springs of subthermal water can be found in ZGA: Topličica near Gornja Dubravica with temperature ranging from 17^0 to 18^0C, and Sutinska Vrela with temperature of water ranging from 17 to 23^OC (Kovačić & Perica, 1998) (Fig. 1). Waters from these springs have never been utilized in an organized way. A significant geothermal potential in the Zagreb area was understood only by the year 1964 owing to the 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 the well during the year 1977 it turned up that natural discharge was 7 l/s while the temperature of water was 57^0C. Favorable results initiated complex investigations during the eighties of the last century. During that period 16 boreholes were drilled in ZGA. Few of these pierced through the geothermal aquifers of considerably high temperatures. For example: in the area of "Blato" with the upper limit of the aquifer of about 900m the temperature was 80^0C, in the surroundings of the sport center of "Mladost" the temperature was 65^0C, around Sveta Nedela at the depth of 1000m it was circa 65^0C, while in the area of Podsused at the depth of 300m it was 30^0C.

Figure 2. The geothermal borehole in Lučko

Geothermal energy has been utilized from the mentioned boreholes in a wider region of Zagreb for the past 20 years. At first, geothermal water was directly discharged into the swimming pools but afterwards it was exploited for heating of the swimming pools and buildings using the heat exchanger. Today, the use of ZGA thermal waters is restricted to only four locations: the sports center "Mladost" (pools, sports hall), the "Factory for Special Equipment INA" (Fig 2), Sveta Nedjelja (Greenhouse) and the "University Hospital" currently under construction (space heating and sanitary water heating). But that is only a part of the energy potential of the positive geothermal anomaly in a wider region of Zagreb.

3. GEOLOGICAL SETTING

ZGA is situated in the southwest part of the Panonian Basin and represents a part of the smaller Sava Basin with the Medvednica Mt. on the north and the river Sava to the south. The Mt. Medvednica area is represented by a variety of chrono-stratigraphic units spanning from the Paleozoic to the Quaternary (Šikić et al., 1972, Basch, 1980). To the south of Mt. Medvednica the area is covered by Pliocene-Quaternary and Quaternary sediments. It was determined by exploration drilling that underlying rocks are equivalent to those found on Mt. Medvednica. Lithology and average thickness of bedrock are displayed in the geologic column (Fig 3).

3.1 Mesozoic

In the investigated area the only Mesozoic rocks determined in the boreholes belong to the Middle and Upper Triassic. These are dolomite breccia, dolomites, and dolomite limestone, which were determined in the following boreholes; 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).

3.2 Tertiary and Quaternary

Tertiary and Quaternary deposits were found in each boreholes in the investigated area. Their thickness differs considerably in individual boreholes. Precise chrono-stratigraphic position between 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 units are developed in all drill holes.

3.3 Lower and Middle Miocene - M_{1-5}

The Lower and Middle Miocene deposits are represented by the following chrono-stratigraphic units: Egerian, Eggenburgian, Ottnangian, Carpathian, Badenian and Sarmatian. Contact with underlying rocks is discordant. The lithology varies considerably and consists of marls, sandy marls, sandstone, breccia, breccia-conglomerates and lithothamnium limestone. The thickness of the whole 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. Also, in some places they represent reservoirs for thermal water in the investigated area.

3.4 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.

3.5 Pontian M_7

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

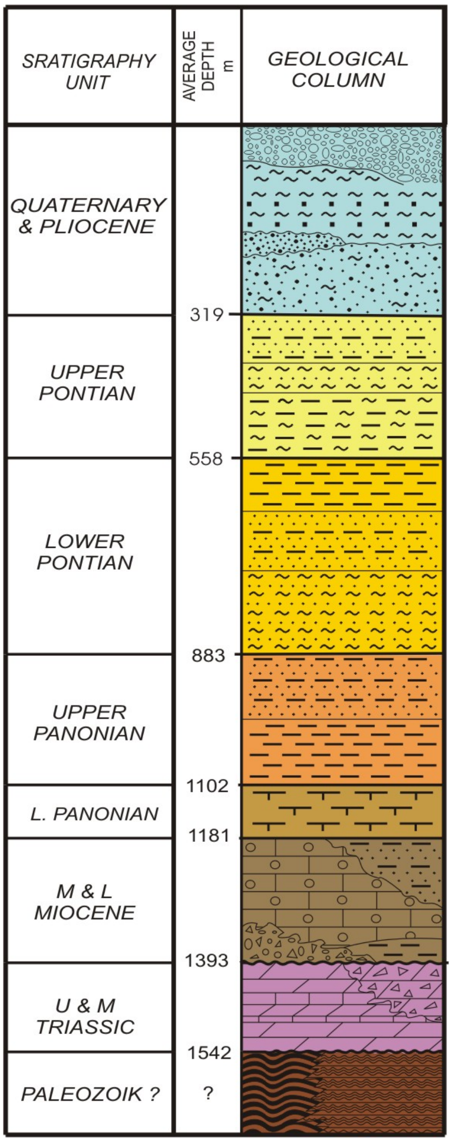

Figure 3. The geologic column of the Zagreb geothermal area

3.6 Pliocene and Quaternary -Pl+Q

The Pliocene and Quaternary deposits consist of various types of sediments. The lower, Pliocene part, consists of predominantly limy clays with intercalation of coal, sand and marl. In the Quaternary 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 boreholes 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, which 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 it is manifested by numerous earthquakes that have been recorded through history and in the near past. Faults that incise through even the youngest deposits to the surface, are a consequence of this tectonic activity (Prelogović, et al., 1997).

4. GEOTHERMAL CHARACTERISTICS OF THE ZAGREB GEOTHERMAL AREA

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 (Šalata-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 (Šalata-1) (37,5 ^{O}C, PDT-2, extrapolated temperature), while the highest is 80,7 ^{O}C (KBNZ-1B).

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

Drill hole	Temperature ^{o}C z - 500 m	Temperature ^{o}C z - 1000 m
Jarun-1	38,1	53,3
KBNZ-1A	47,5	77
KBNZ-1B	48,4	80,7
Luč-1	37,5	59,2*
Mladost-1	52	77
Ned-1	39,6	59,9
PDT-1	32,4	40,9*
PDT-2	29,5	37,5*
Sava-1	40	61
Stu-1	41	64,6*
Šal-1	27	49,5
Average	39,4	60* 64,7
Spread	28,5	31,2 43,2*

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)

The heat conductivity of individual geological formations pierced by the represented boreholes in ZGA is varying.

According to it we can classify the geological formations into two groups: Tertiary formations and formations in the base of the Teritary. Average heat conductivity of the former is about 1.89 W/mK, while for the latter amounts to 4.72W/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 (Kovačić, 2007).

Terrestrial heat-flow density values on the borehole locations in ZGA 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 (Kovačić, 1995).

5. GEOTHERMAL WATERS POTENTIAL IN ZGA

Geothermal water is currently exploited from only a few boreholes. No central, updated database on use of geothermal water in ZGA exists so far, so that all data presented here are collected from the literature, or are based on author's observations on various locations and on his contacts with users. At several locations water is used in different way, but everywhere with various intensity during the year. No consistent data exist on this matter. Due to the limitations in data quality the true quantities of produced energy can deviate from values represented in Table 2.

Energy capacity of geothermal waters is calculated after their currently known quantities and inlet/outlet temperatures. Total available quantity of water is 114,5 kg/s, but only 26,5 kg/s is currently in use. Energy capacity is 23,7 MWt. Of this, only about 25 % is used. Since geothermal water from majority of boreholes is intact, the total energy potential of geothermal waters in ZGA is considerably greater from that in use.

6. CONCLUSION

It is well known since the close of eighties of the last century, as a result of exploration drilling, that in a wider area of Croatian capital there exist considerable quantities of geothermal water. A few geothermal aquifers have been discovered at the depth of 300 to 1000 m with temperature of 30 to 82 ^{0}C. There are two types of aquifers. The main type is represented by the Triassic dolomite breccias, dolomite and dolomite limestone while the less important type includes the Miocene bioclastic limestone. The temperatures of the geological formations, as measured in the boreholes spaced closely to each other, vary considerably. At the depth of 500 m, the lowest temperature is 27^{0}C and the highest 52^{0}C. At the depth of 1000 m, the lowest temperature is 37,5^{0}C (the extrapolated values) and the highest is 80,7^{0}C. Terrestrial heat-flow density values on the well locations in the Zagreb geothermal area vary. The lowest value is 58 m W/m^2 while the highest amounts to 102 m W/m^2. Energy capacity of geothermal waters currently under exploitation in ZGA is 23,7 MWt, but only 25 % % is effectively used. Since geothermal water from majority of boreholes is intact, the total energy potential of geothermal waters in ZGA is considerably greater from that in use.

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Table 2. Utilization Of Geothermal Energy In The Zagreb Geothermal Area

		Maximum Utilization				Annual Utilization		
Locality	Type[1]	Flow Rate	Temperature (°C)		Capacity[2]	Ave. Flow	Energy[3]	Capacity
		(kg/s)	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[4]
Factory - Lučko	H	5,5	55,0	30,0	0,575	1,5	4,964	0,273
Mladost SC	HB	50,0	80,0	24,0	11,715	20,0	147,728	0,400
University Hospital	H	55,0	82,0	35,0	10,816	3,0	18,598	0,055
Sveta Nedjelja	G	4,0	65,0	25,0	0,669	2,0	10,552	0,500
TOTAL		**114,5**			**23,776**	**26,5**	**181,824**	**0,243**

1) H = Individual space heating
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
2) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
3) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154
4) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171

Figure 4. The geothermal greenhouse in Sveta Nedjelja