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HYDROGEOTHERMAL CONVECTIVE SYSTEMS OF ILIDŽA AREA NEAR SARAJEVO, BOSNIA AND HERZEGOVINA

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ABSTRACT

The wider area of place Ilidža is characterized by a variety of lithology, tectonic complexity and remarkable geomorphological phenomena, from which result complexity of hydrogeological relations and the existence of many surface flows and accumulations of various types of groundwaters. Drinking, mineral, thermal and thermomineral waters in karstic Triassic carbonate rocks and alluvium are concentrated at a distance of 3 km only from Ilidža to Blažuj. All waters have high capacities, verified indications of quality with a broad range of applications. The Roman Emperor Diocletian had been treated here for ischialgia and name of Ilidža derives from Ottoman rule in Bosnia and Herzegovina comes from the Turkish word ilaç (= drug), which is clearly associated with healing thermomineral waters of Ilidža.

Thermomineral waters of Ilidža are the most important. There are 5 types of CO_2 –H_2S and CO_2 waters with temperature of water from t = 20–58°C. H_2S–CO_2 water in the center of Ilidža are surrounded by CO_2 and thermal waters in the form of incomplete belts and around these the large zones of cold waters exist in Triassic karst and alluvium media. The total yield of artesian flow of wells with CO_2–H_2S water with t =58° is about Q=260 l/s and a power of 50 MW_{therm}, referent to 10°C. The waters are of meteoric origin, prenuclear age and very slow circulation and water exchange, CO_2 is of hydrothermometamorphic genesis. IB-10 well, made in 2004, 500 m only from the zone of CO_2–H_2S waters, with thermomineral CO_2–waters, depth of 1100 m, only one of all wells has separated different waters horizons with great temperature inversion (t=38°C at 550 m, interval 1002-1100 m, t=20°C, Q_{pump}=86 l/s) and substantially reduced mineralization and the content of CO_2 along the depth.

The more it was explored in the past, hydrogeothermal model of Ilidža waters is the more complex today. The new data of well IB-10 are even more unknown and becomes puzzling, especially in the development of plausible deep geological and geothermal profile of terrain and the possibility of determination of the aquifer with the temperature more than 58°C, which is the most important task in future research. Many indications point to the existence of water temperature more than 58°C in the primary aquifer and proven seismoactive levels of over 5 km depth give the same possibility of descendence of meteoric waters and their heating in that depth.

INTRODUCTION

Ilidža area represents one of the richest zone of different types of mineral, thermal and thermomineral waters, potable groundwaters and surface water flows in Bosnia and Herzegovina. Ilidža is located in the central part of Bosnia and Herzegovina, 8 km west of Sarajevo with which it makes an urban whole, situated in Sarajevo field, which is in the south and west surrounded by the high mountains Treskavica, Bjelašnica and Igman and in the east Trebević, while to the southwest lies in the Middle Bosnian basin.

River Bosnia flows through Ilidža with the main tributaries Zujevina and Željeznica and several smaller tributaries.

In the area of thermomineral springs in Ilidza existed a Roman colony under the name Aquae S ..., as evidenced by the mosaics and original stone plaque. Inhabitants of Ilidža have erected a monument to their emperor Diocletian, apparently severe rheumatist, which is kept in the National Museum in Sarajevo, where it writes: "Imperatori Caesari Gaio Valerio Diocletiano, Pio, Felici, Invicto Augusto Aquae S...." ("To Emperor Caesar Gaius Valerius Diocletianus, Pious, Happy, Invincible Augustus Aquae S....."). Absence of letters probably means Sulphurae (=sulphuric). According to the archaeological findings water were used over 2400 years B. C.

Terrain of Ilidža is characterized by diversity of lithological composition, complexity of tectonic processes, a hallmark of geomorphological phenomena and the variability of hydrometeorological factors, resulting in a complex hydrogeological relations and the existence of accumulations of cold drinking, thermal and thermomineral waters.

Hydrogeoterms of Ilidža are formed in strongly tectonized and karstified Triassic carbonate fracture-karst rocks which make many tectonic bocks.

Thermomineralal waters as the most important resource among hydrotermal resources were formed in different tectonic blocks from which in the Ilidza area and Blažuj outflows in the alluvium in the small surface and have different temperature, mineralization, yield and hydraulic characteristics.

GEOLOGICAL CHARACTERISTICS

Terrain of Ilidža belongs to geotectonic unit of Paleozoic schists and Mesozoic limestone of Interior Dinarides. The terrain is built of Triassic, Jurassic-Cretaceous, Tertiary and Quaternary rocks in which are expressed plicative and disjunctive tectonics. Busovačka fault zone is the most important tectonic element and other smaller faults, which have been morph tectonically marked, reactivated in multiphase and they have expressed neotectonic activity today.

Stratigraphy

Lower Triassic (T_1^1 and T_1^2)

Lower Triassic deposits are spread over a wider area of Hadžići, Trebević, Kasindol and Vojkovići. Lower Triassic layers are built of sandstones, schists, marls and limestones with the thickness as a whole about 600 m.

Middle Triassic (T_2^1 and T_2^2)

South and southeast of Ilidza Middle Triassic carbonate deposits lie over the Lower Triassic sediments.

Anisian (T_2^1) is built of massive and rarely dolomite and limestone in banks. The thickness of them is about 200 m. Anisian layers in the Sarajevo are covered by Neogene and Quaternary sediments, which are cut by numerous faults.

Ladinian deposits (T_2^2) were found in the area Krupac, Igman and Trebević. They consist of a variety of sediments and are characterized by stratification. Ladinian thickness is about 400 m.

Middle - Upper Triassic ($T_{2,3}$)

These deposits are widespread on Igman and Bjelašnica, consist of massive and thick bedded limestone and dolomite. The thickness of this unit is 300 - 500 m.

Upper Triassic (T_3)

These layers cover considerable area on Igman and Bjelasnica, where they situated in the roof of the middle-upper Triassic ($T_{2,3}$). Upper Triassic is represented by limestones, occasionally with dolomite. The thickness of this member is about 700 m.

Jurassic-Cretaceous sediments (J, K)

The sediments of this age have a local character only and appear in the Presjenica, Vojkovići and even less on Bjelašnica and Igman mountains. They are mainly found wedged between rocks of Triassic age.

Upper Cretaceous (K_2)

It stretches from Blažuj to Rakovica in the form of flysch. It lies discordantly over Anisian limestones and dolomites. The thickness of these layers is up to 400 m.

Kosevo layers (${}^1M_3$)

Koševo layers are stretched north of Blažuj and river Rakovica and in surrounding of Vogošća. Most of them are made of sandy marl, clay, and clay or siltstones, alevrolites and limy sandstones. Koševo series has thickness of about 400 m.

"Orlac" conglomerates (${}^2M_3$)

These rocks occur in Sarajevo and along the right side of the river Miljacka. This series is a depth of 100 - 200 m built of conglomerates, sandstones, marls and friable limestones.

Quaternary (Q)

These layers are presented mainly by alluvial streams and river deposits (al) and terraces (t_1, t_2, t_3,) and are built mostly of gravel and sand with clay.

Tectonics

Rock masses are characterized by multiphase tectonic activity with plicative and more expressed disjunctive tectonics. The most significant element is Busovača fault zone and numerous other minor faults. the following tectonic units are featured: Igman, Bjelasnica and Sarajevo-Zenica depression. An anticline is let down at the foot of the Igman down to Busovača zone and the Sarajevo field represents the unit, where Triassic carbonates are gradually lowered deep in the form of fault blocks and over them are deposited transgressive and discordant Tertiary and Quaternary sediments.

The wider area of Ilidža consists from several structural-facial units: Bosnian schist mountains, Bjelašnica – Igman and Mid Bosnian depression i.e. Sarajevo-Zenica basin.

Area of Ilidza belongs to Sarajevo-Zenica basin. The sediments of this basin are faulted with sin and anti forms. Southwestern part of the basin is let down along the "Busovača fault zone."

The minor tectonic unit Hadžići belongs to highest horizons of Mid Bosnian Schist Mountains. The formations of these units are due to tectonic pressures folded especially from the southeast, broken into blocks as independent structural units. Through this unit is partly drawn tectonic Igman unit. Tectonic unit Igman syncline is flattened at the southwest and its northeast flank goes over in the anticline with the Lower Triassic sediments in the its core. Northeastern boundary of tectonic units Igman makes Busovača fault zone. Tectonic units Bjelasnica has expressed plicative forms, generally this unit is pulled through the Jurassic-Cretaceous flysch in the southwest.

From Sarajevo across Busovaca to Travnik is situated a large tectonic zone called by F. Katzer "Busovača fault zone." This tectonic zone, followed by a series of faults that intersect with the main, which is called "crossed folding of" Bosnian Schist Mountains.

Along "Busovača fault zone", in addition to vertical movement (>2500 m), comes to the horizontal displacement, which point out the diagonal folding in Sarajevo – Zenica basin.

The main product of the neotectonics is Neogene and Quaternary Basin located in Sarajevo field and elevated mountain ranges Igman and Bjelasnica. Regional vertical movements and uneven descending are marked along numerous faults. Neotectonic activity – uplift of mountains and descending of Basin of Sarajevo field and tectonic activity with depth of seism active levels of more than 5 km from the surface in Ilidža suggest the possibility of karstification in deeper zones and descending of meteoric waters and their heating in the base of water circulation (Katzer, 1926, Miošić, Hrvatović, 1999).

HYDROGEOTHERMAL RESOURCES

Thermomineral and thermal waters of Ilidža occur in highly tectonized rocks in the extreme SE part of the well known Busovača fault zone. Contact of Palaeozoic massif of acid eruptive and schists in central Bosnian Paleozoic and Triassic carbonates with Tertiary depression Sarajevo-Zenica basin is marked by Busovača fault zone in which are formed accumulations and springs of thermomineral waters with exhalations of CO_2 and H_2S.

Accumulations of great yields of thermomineral waters in Ilidža are formed in the contact section of three hydrogeological structures: intermountain depression Sarajevo-Zenica Tertiary basin, carbonate hydrogeological massif Bjelašnica and eruptive massif of plutonic rocks and Paleozoic schists of Middle Bosnia. These structures are in mutual fault contact, and genesis of the water is complex. West of Blažuj until Busovača there is not any spring of thermomineral waters but only carbon-acid mineral springs, with CO_2, indicates the deep descending and ascension of waters in Ilidža only.

CO_2-H_2S thermoineral waters exist in Ilidza only in B&H and they are the spring waters with highest temperature in whole country also.

There are 6 types of groundwaters in the area of Ilidža:

- Thermal waters, 14-22 °C in Triassic karst environment,
- Thermomineral CO_2 - H_2S water, 58 °C in Triassic karst environment and alluvium,
- Thermomineral CO_2 waters, 16-38 °C in Triassic karst environment,
- Thermomineral CO_2 waters to 30 ° C in the alluvium,
- Cold drinking water in the alluvium,
- Cold drinking water in karst Triassic rocks (Encl. 1 and 2).

Physical and chemical characteristics of thermal and thermomineral waters are presented in Encl. 3.

Thermal waters 14-22°C in the Triassic karst environment

Deposits of thermal waters in the wells IB-4 Sokolovići and IB-7 Butmir are formed in Middle Triassic limestones and dolomites.

These sediments were drilled in depth of 188.6 m (IB-4) and 76.8 m (IB-7). The roof of the aquifer is clays and marl clays of Miocene age. Recharge area of this deposit is from the mountains Trebević or Treskavica (Miosić and Hrvatović, 1999).

Table 1: Characteristics of thermal waters

Drillhole	Depth (m)	Q (l/s)	t (°C)	W.L. (m)
IB-4	293,6	6	14	+7,5
IB-7	174	14	22	+8

Q-Artesian yield, W. L.-Artesian static level of groundwaters above surface of terrain

IB-7 well is finished in diabases Ladinian 161-174 m (Miošić and Hrvatović, 1999).

Thermal waters of well IB-4 were HCO_3-Ca-Mg-type, N_2 gaseous type, mineralization of 424.22 mg/l and from well IB-7 HCO_3-Ca-Mg type, with a temperature of 22°C and mineralization of 294.92 mg/l.

Thermomineral CO_2 - H_2S water, 58°C in Triassic karst environment and alluvium

Thermomineral CO_2-H_2S waters exist in a small area near Ilidza spa only, at about only 20 hectares. Prior to drillings of wells in 1893. in Ilidža there were springs of thermomineral H_2S - CO_2 waters, t = 57°C and Q_{tot}=12 l/s. The water from the Triassic carbonates ascends in alluvium, which lies directly on Triassic aquifers which have great yields as evidenced high productive wells. Recharge is from the mountain karst massifs Bjelašnica, Igman and Treskavica with very slow circulation and deep water descending and thus its heating from the base flow and deep ascension along faults, which intersect tectonic blocks.

Table 2: Characteristics of thermomineral CO_2-H_2S waters

Drillhole	Q (l/s)	d (m)	t (°C)	Static level (m)	Depth of hole (m)
IB-1	75	14	58	+14	43,7
IB-2	78	14	58	+18	246
B-3A	10		57		21,6
PP-1	50		58		90

Q – artesian yield, d - drawdown

CO_2-H_2S thermomineral waters of Ilidža are characterized by mineralization of 2733-4140 mg/l, temperature in wells and springs are 57-58°C, CO_2 content in water 3057 mg/l, H_2S = 18 mg/l, Ra =0.14 - 0.28 Bq/l, Rn = 0.2 - 22 Bq/l U= 0.2 - 1 mg/l. The dominant gas is free CO_2, which is represent by 98.1 - 99.3 vol%, and as dissolved has 95.2 - 98.4 vol%.

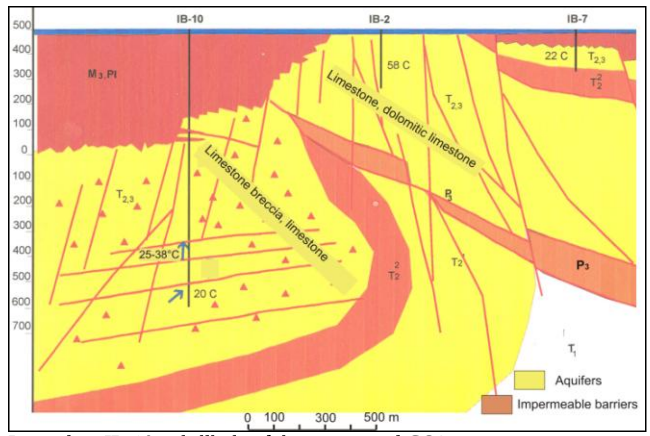
Thermomineral CO_2 waters, 16-36°C in Triassic karst media

Springs of these waters existed in Blažuj only before drillings, while these waters are determined in Ilidza in derillhole IB-10 and Fs-10a. The roof of Triassic aquifers are Tertiary isolators of Sarajevo - Zenica basin with thickness from 330-350 m, whereas in the Blažuj Triassic is only 5-10 m depth below the alluvial deposits. The deposit extends in more tectonic blocks, so that the depths to Triassic carbonates are very different.

Table 3: Characteristics of CO_2 thermomineral waters

Drillhole	Q (l/s)	d (m)	t (°C)	Static level (m)	Depth of drillhole (m)
IB-10	40	5,25	30-31		771-856
	44	5,25	31		940
	25	6,5	20	+11,3	1002-1100
	86	22,4	20	+11,3	1002-1100
Fs-10a			26		388
B-1 Blažuj	11,5	1,72	24,1	–0 ,37	105

At borehole IB-10 there are 3 types of CO_2 thermomineral waters: 1) 350-550 m - water t= 38 °C proven by well-logging only, 2) 853-902 m - water t= 30-31 °C, mineralization 1.5 to 1.6 g/l, HCO3-Ca type and CO_2 = 440 mg/l and 3) deeper than 1002 m - water t= 19-21 °C with mineralization 1,1 g/l, HCO_3-Ca-Mg type, CO_2= 352 mg/l. Here is a proven thermal inversion, reduction of mineralization and CO_2 content and greater water yield in greater depth of well. All reservoirs are hydraulically independent (Fig 1) and there is not mixing among any waters.



Legend: IB-10 – drillhole of thermomineral CO2 waters,
IB-2 – drillhole of thermomineral CO2-H2S waters
IB-7 – drillhole of thermal waters
M_3,Pl – Upper Miocene and Pliocene marl, clay, sandstone
$T_{2,3}$ – limestone, dolomitic limestone
$T_{2,3}$ - limestone breccia, limestone
T_2^2 – sandstone, marl, claystone, spilite
T_2^1 – limestone
T_1 – schist, sandstone, limestone
P_3 – schist, sandstone, evaporite

Figure 1: Hydrogeological profile of thermomineral and thermal waters in Ilidža

Thermomineral waters in Blažuj are carbon acid with mineralization 1.1-2.5 mg/l, CO_2 =616 -1125.2 mg/l, t=19-24.1°C, HCO_3-SO_4-Na-Ca-Mg-type, Rn-222 =2.3 ± 0.4 Bq/ kg.

Thermomineral CO_2 waters to 30°C in the alluvium

Thermomineral CO_2 waters temperature from 24.4 to 29°C were obtained in wells B-10A at a distance of 100 m only from IB-1. Wells B-10A drilled alluvial sediments. These waters circulate upwards from Triassic carbonates along fault paraclases to thick alluvial gravels, sands and conglomerates.

Table 4: Characteristics of thermal mineral water CO_2

	Depth of	Q (l/s)	t (°C)	Static

Drillhole	drillhole (m)			level (m)
B-10A	77,1	10-15	24,4-29	+7

These waters are similar to waters of IB-10 and Blažuj with mineralization 1.0 to 1.37 g/l, HCO_3-Ca type of macrocomponent compozition and CO_2 content of 396 to 680 mg/l.

Cold drinking water in the alluvium

On a large surface area of the Sarajevo field, as well as in Ilidza widespread Quaternary deposits over 70 m thickness.

Accumulation in alluvial sediments recharge from the infiltration of rain and snow, surface water flows of rivers Bosnia and Tilava and other minor surface watercourses and in some places from Triassic karst-fractured aquifers in the base of alluvial aquifers. Established the artificial recharge of aquifers through infiltration channels, which are waters of the river Bosnia, serve for additional recharge of exploitative potable water wells in Bačevo from which water supply for Sarajevo is performed in amount of 80% of all sources.

Ground drinking waters in the alluvium at Bačevo area are Ca-HCO_3 type, with a total mineralization of about 430 mg/l and temperature of 8 - 10°C.

Cold drinking water in Triassic karst media

Triassic carbonate sediments are characterized by distinctive karst-fracture porosity. Within them is formed accumulation of great yields of drinking waters in the mountain massifs of range Igman-Bjelasnica, Treskavica which discharge is performed in numerous springs along the very rim of Sarajevo field and directly in alluvium in places where the same lies directly on the karst sediments. Tracing of sinkholes in Igman and Bjelasnica showed groundwater connections toward springs along the perimeter of Sarajevo plain characterized with fictive velocity of circulation of groundwaters from 0.8 to 2.3 cm/s.

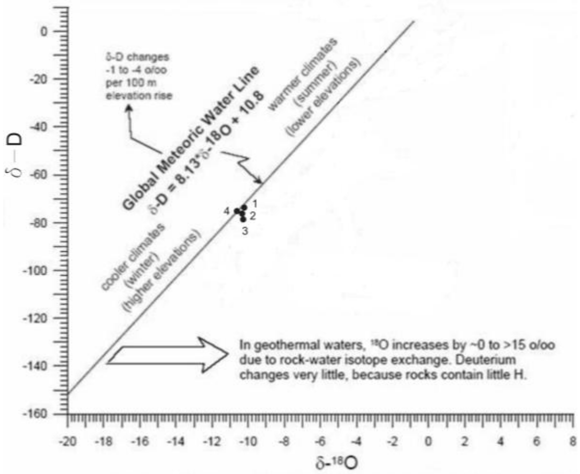
The basement rocks of the Triassic karstic are the insulator of Ladinian volcanogenic-sedimentary complex, which represents the footwall barriers for descendence of waters.

These waters are HCO_3-Ca (Mg) type, mineralization 400 mg/l, pH = 7 to 8.5 and t=8-10 °C.

GENETIC CHARACTERISTICS OF WATERS

Isotopes of oxygen and hydrogen indicate thermomineral waters of Ilidža and Blažuj are of meteoric origin and the same is expected for thermal waters in Ilidža. δ^{18}O and δD values for Ilidža and Blažuj are shown in Fig. 2. This diagram shows these waters fall near the middle line of meteoric waters.

All waters of Ilidža fall below the meteoric line except B-1 Blažuj. Waters were condensed in the cooler period in the past or at a higher hypsometry of Ilidza. Analyzed waters present mixture of waters condensed in different climatic conditions.



Legend: 1) IB-1 Ilidža, 2) Spring Fontana – Ilidža, 3) IB-2 Ilidža, 4) B-1 Blažuj

Figure 2: Correlation diagram of δ^{18}O (‰) - δD (‰) for thermomineral waters Ilidža and Blažuj (partly after Klein, 2006)

Isotopic composition of oxygen and hydrogen indicates condensation of water vapor at lower temperatures than are today in Ilidža, indicating the effect of recharge of the accumulation of thermomineral waters from the zones of higher hypsometric levels, in this case those are mountains Trskavica, Bjelašnica and Igman.

Data δ^{13}C in CO_2 compared with data from the world show CO_2 is thermogenic originated by thermometamorphism of marine carbonates or their termohydrolisis at higher temperature. Changes in the δ^{13}C in CO_2 and in total carbonate are very small at the time, indicating that the enrichment with CO_2 and hydrocarbons is permanent under the same conditions.

δ^{13}C content in CO_2 in water of Blažuj is from –3.7 ‰, falls in the range of +4 to –5 ‰ (Hunt, 1996) indicating CO_2 is formed in thermal destruction of carbonates, this value is close to the range of 0 ± 3 ‰ showing thermometamorphnc origin (Dai et al., 1996).

Data δ^{34}S in SO_4 indicate waters circulate through the sulphate evaporite deposits of Permo-Lower Triassic systems, which means primary aquifer is deeper than the P,T layers.

^{14}C data indicate thermomineral waters are of meteoric origin and in center of ascendant convection are almost three times older (IB-1) than of those on the edge of a tectonic block (IB-2) which requires a complex regimen of circulation. This fact is a result of possible accelerated recharge of younger waters from other zones. The age of H_2S-CO_2 waters ranges from 13500 to 33000 years (Obelić, 1984, 1986 and 1987) but this dating is not reliable because of the questionable applicability of this method for waters in Ilidza by the opinion from Heidinger (2000). In any case waters are much older than ^{3}H analysis shows.
All waters in Ilidža are inactive to tritium content and are "dead" waters, which mean they did not have a connection with meteoric and any other waters after 1953. Tritium content in water wells B-1 Blažuj was 1.8 ± 0.7 T.U. and is constant in different times. This indicates a mixture of predominantly older groundwater and a small component of the younger water than 40 years. In the same time there is a constant recharge, as it is today too, of accumulations thermomineral waters of Ilidža and Blažuj by meteoric waters from higher elevations zones of mountains Treskavica, Bjelašnica and Igman, and that no waters from the Pleistocene cold age, what supposed Heidinger in 2000.

Isotopic analyses of thermal and thermomineral waters are presented in Encl. 4.

Table 6 Analysis of results of radioactive isotopes ^{14}C and ^{3}H in waters and tuff sediments

Drillhole	^{14}C, years	^{3}H, T.U.	Date of analysis	Analyst
B-3A Ilidža	32. 937 ± 3000	< 1,7	15.02.1984.	Institute "Ruđer Bošković", Zagreb
IB-2 Ilidža (tuff)	25. 091 ± 1414	< 1,7	12.12.1986.	Institute "Ruđer Bošković", Zagreb
IB-2 Ilidža	13. 593 ± 359	< 1,7	12.12.1986.	Institute "Ruđer Bošković", Zagreb
Spring Ilidža	14000 ± 400	< 0,19 Bq/l	17.02.1987	Institute "Ruđer Bošković", Zagreb
Spring Ilidža (tuff)	>40 000		17.02.1987	Institute "Ruđer Bošković", Zagreb
B-1 Blažuj		1,8 ± 0,7	24.05.2000.	HYDROISOTOP GmbH, Schweitenkirchen
IB-4 Sokolovići		< 1,7	17.11.1987.	Institute "Ruđer Bošković", Zagreb
IB-7 Butmir		< 1,6	22.08.1987.	Institute "Ruđer Bošković", Zagreb

PROGNOSTIC HYDROGEOTHERMAL MODEL

At the current stage of investigation of resources is open a several questions regarding the mutual interaction between waters, their genesis, the spatial position of water, whose solution allows the intensification of the use and capturing of new quantities of waters and waters of higher enthalpy, what is the most significant task. These are the folowing:

- Solution of plausible geological and hydrogeological model recharge, heating, forming of thermal and thermomineral waters,
- Defining the existence of hydrothermal zones in the wider area of Ilidža vertically and horizontally,
- Determining of depth of water formation and lithostratigraphy of primary aquifers, spatial location of the temperature zone and waters yield,
- Identification and verification of prospective structures with geothermal resources,
- Zoning of spaces for further research, particularly for locating productive and reinjection wells.

High temperature of waters in Ilidža is the result of rapid ascending convection along a vertical paraclases of high transmissivity from greater depths, about 2-3 km, heating of waters is done in the base of circulation of descendent waters from the rocks with higher values of thermal conductivity, probably in the media of normal values of geothermal gradient and heat flow.

The waters are old meteoric waters, very slow circulation which descend in deep zones of underground with high water residence times in the aquifer. Condensation of water vapor is carried out at lower temperatures than today, indicating the effect of recharge of accumulation of thermomineral waters from the higher elevations than they are in the zone of Ilidža, namely Igman, Bjelasnica, Treskavica mountains. There is no mixing of any hot waters with other surficial or groundwaters.

The basic questions are: is there a higher water temperature of 58°C in the primary aquifer and defining of their depth, if the waters are of mixed origin from various aquifers and is the CO_2 of thermohidrolitic origin or created as dry gas.

Assumptions about the existence of waters with higher temperatures than 58 ° C, as the most important issue in Ilidza, are the following:

1) If the CO_2 is created with water we can predict the temperature of the water is far more than 58°C in the primary reservoirs. Exploring of the genesis of hydrogeothermal convective systems H_2O - CO_2 in Bosnia, Miosić (1987) came to the following conclusions: waters with higher temperatures have higher CO_2 gas content, which indicates the primary thermal generation of CO_2 in the presence of water

i.e. hotter and deeper reservoirs have larger amounts of CO_2, the greeter water yield gives the higher gas content, waters with higher temperatures correspond to a higher percentage of free and dissolved CO_2, cleaner free gas and the higher levels of CO_2 correspond the higher water temperatures.

From these hypotheses result the CO_2 is created with water in Ilidza i.e. there is higher water temperatures in the primary reservoirs of 58°C. However, one indirect indication saying the opposite, namely, greater and lesser amounts of waters and higher and lower water temperatures do not change values of $\delta^{13}C$ in CO_2, what means the gas is thermogenic and did not originate from reaction with water. In the same time CO_2 can come from greater depths of water and equilibrate with water in its horizon, and we have therefore the illusion of thermohydrolitic origin of CO_2.

One can see, however, there is no absolute certainty the CO_2 created with water, i.e. the question of a common primordial generating system H_2O - CO_2 is not clear, because of the possible of existence of primary, secondary and transit aquifers and also potential CO_2 of deeper origin as dry without water and with water.

2) Protection of cooling of thermomineral aquifers in the basement as roof insulator of Tertiary and Jurassic-Cretaceous flysch,

3) The existence of the convective zone and the conductive heating in horizons deeper than 2000 m from the ground surface,

4) High ratio N_2/Ar (120) in free gas indicates high collector temperatures (Truesdell, Nehring, 1978, Potter et al., 1977), the relationship N_2/Ar is different than in the air, thus the part of Ar is of endogenous origin,

5) Content of the He $20.49x10^{-6}$ ml/g probably indicates that there is no direct connection with the deeper ground water collectors. Absolute helium content indicates a clear nonmeteoric excess of 4 He related to the water saturated air. This nonmeteoric helium component may originate from: a) accumulation of helium, which is produced by radioactive decay of U and Th from natural deposits in the deeper layers of the ground and releases into groundwater and b) may originate from the "mantle helium," despite the low content of ^4He. In water B-1 - Blažuj the $^3He/^4He$ ratio ($0.329\ x10^{-6}$) is relatively high. The share component of the helium layer is only 2-3% and can be explained by the relationship with deep tectonic activity. Content ^4He and $^3He/^4He$ ratio is an indicator of very old ground water, and indicates that the ground water in the aquifer is several thousand years old.

Another important question is whether the water of Ilidža is mixed origin and presumptions for that are as follows:

1) The relationship between the primary reservoir temperatures calculated by SiO_2 and cation concentrations, which fall under the uniform temperature line (Young, Lewis, 1982.), indicating the water are mixing of 2 types of waters without enough time to equilibrate with surrounding rocks,

2) Calculated temperature with SiO_2 geothermometers is lower than with cations - water is a mixture of hot and cold water, which did not equilibrate after mixing (Sorey, 1978).

3) Changing of values of $\delta^{18}O$ and δH_2 in different times,
- A wide range of deuterium in water samples between -139 to -130‰ indicates the mixing of water from at least two sources,
- A wide range of deuterium (- 72 ‰ to - 78 ‰) in the samples (in unmixed waters by Truesdell 1975 the amount of deuterium is very similar, because there is no mechanism for deuterium exchange during deep circulation through the system),

4) Content of $\delta^{34}S$‰ (+ 7.38, + 11.2, + 12.49) shows the primary collector in Ilidža is deeper than $P\text{-}T_1$, therefore with high temperature (this would have a higher water temperature than those in the Triassic in which ascends and move upwards as the mixed water),

5) Calculated of the reservoir temperature is significantly higher than measured, which means the portion of the heat conductive water lost when moving through the aquifer, and the temperatures are lower than those in the aquifer.

From this it can see there are many indications of the existence of higher temperatures of 58°C in the deeper horizons in Ilidza. However, further research is required to prove that it is: 1) CO_2 of thermohydrolitic and 2) water is mixed origin; the both potentially positive responses show that there are in the deeper parts of the terrain higher temperatures of 58°C. There are several indications for the case ad 1) and ad 2) and can be with great certainty that exist the fluids of higher enthalpy in the primary reservoir far more than 58°C.

If waters are of mixed origin (from different reservoirs), we can also expect a higher temperature in greater depths than they are springs (58°C).

Meanwhile, if there is no mixing of the waters, but the water temperature of 58°C ascends from the primary reservoir, then the water temperature at 4000 m depth will be the same 58°C as it is in the surface, if the vertical fault zone has yield of 15 l/s (Sammel, Craig, 1981), similar yield of all springs was in Ilidža before drilling.

Determined depth of seismoactive levels of more than 5000 m below the surface indicate the probability of the water temperature more than 58°C, but the thermal inversion of the drillhole IB-10 does not provide total security to the above supposition.

Numerous indications suggest mixing of waters in Ilidza and recharge from two separate reservoirs, thermohidrolitic origin of CO_2, sulfur isotope characteristics, etc., and it is realistic to expect deeper drilling can draw waters of higher temperature, and the amounts of additional capacities of waters.

WATER RELATIONS

The fact that both hydrothermal and cold waters drilled in analogous lithostratigraphic media refers to the question of the relationship of these waters - whether it comes to their mixing and in which conditions. This is an important and urgent applicative issue, which clarification provides the definition of the optimal regime of use for all types of waters without threatening their quality. All thermomineral CO_2-H_2S waters are in mutual hydraulic connection with each other. Testing has established a strong hydraulic connection between boreholes IB-1 and IB-2, which indicated the accumulated water in the alluvium (IB-1) and water in the Triassic aquifers (IB-2) represent one deposit. This it can see clearly from Encl. 2.

There was no any influence of thermomineral to thermal waters and vice versa or to drinking waters in karst and alluvium. Separated horizons of thermomineral CO_2 waters are proven in B-1 (Blažuj), B-10A and IB-10 (Ilidža), where exist various independent water bodies through depth of the last drillhole with different physical and chemical characteristics of waters.

Although the cold water are pumped continuously from the alluvium Ilidža ca 700 m away west from IB-1 for water-supply, it is not registered the influence of thermomineral CO_2-H_2S waters to drinking waters.

These complex hydraulic relations without mixing of various types of waters are determined by discontinuous zoning related to divide of karst aquifers in tectonic blocks in which dominate vertical flow component, disposed by faults indicating the deep hydrothermal ascendent convection of hot waters.

CONCLUSION

The wider area of Ilidža is characterized by diversity of lithological composition, complexity of tectonic processes, particularity of geomorphological phenomena and the variability of hydrometeorological factors, resulting in a complex hydrogeological relations and the existence of accumulations of drinking - cold, thermomineral and thermal waters.

This terrain consists of sedimentary rocks starting with the lower Triassic continuously until the Quaternary in normal stratigraphic column, while the mountains in the vicinity of Sarajevo are built mainly from Triassic sediments. Large thrusts point out to possible reduplications through vertical geological profile and the existence of great thickness of Triassic rock aquifer composite.

There are the following tectonic units: Igman, Bjelašnica and Sarajevo – Zenica depression. There are significant plicative, especially disjunctive tectonic products, which condition the existence of various types of waters. Remarkable neotectonic products such as depression of Sarajevo plain and elevation of the mountains in the edges of the field, old and repeatedly regenerated faults condition the complexity of hydrogeological characteristics.

This area is one of the richest in the narrow space at a distance of 4 km only of various karst, alluvial drinking, thermal and thermomineral waters of different constituents and genesis, which is a unique example, not only in Bosnia but also in the wider region. All types of groundwaters are formed in analogous karstic Triassic carbonate rocks and Quaternary sediments. Thermomineral CO_2-H_2S waters of Ilidza are the most important among hydrothermal resources; they have the greatest yields and highest temperatures. Their aquifers are Triassic limestones and dolomites in different tectonic blocks from which exist upflow in the area Ilidza and in Blazuj in alluvium. Thermomineral CO_2 waters have the same aquifers and different temperature, mineralization, yields and hydraulic characteristics.

Water from karst massif Bjelašnica and Igman slowly circulate along the deep fault and fissure systems to unidentified depth, warming up and mineralize in the Permian-Triassic, Central and Upper Triassic limestones and dolomites. In the area of Ilidza and Blažuj exists ascending convective fast flow of waters and gases along the faults, which results springs of thermomineral waters.

CO_2-H_2S waters from thick karst horizons flow along the fault blocks in alluvium in area of about 0.4 km2 only they are surrounded by CO_2 warm and cold potable groundwaters in karst and intergranular media. In other parts of Sarajevo plain thermomineral and thermal waters in karstic aquifers have the roof barriers of Jurassic-Cretaceous and Tertiary impermeable sediments.

Thermomineral waters of Ilidža have the highest spring temperature in Bosnia and Herzegovina with different mineralization in individual wells from 1.4 to 4.1 g/l, carbon acid , enriched with 95 - 98% CO_2 with GWR= 1 – 2 and H_2S, temperature varies from 26 – 58°C, waters are "dead" by the content of ^3H and ^{14}C -14000-33000 years – cosmogenic -meteoric origin, $\delta^{13}C$ in CO_2 (+ 0.18 to – 2.36 ‰) originated from thermometarphism of marine sedimentary carbonates or their thermohydrolysis, $\delta^{18}O$ – 10.2 to – 10.35 ‰, δD – 72 to – 78 ‰ (meteoric origin) and quite mildly radioactive (Rn = 0.9 – 2.1 Bq/l). Condensation of water vapor is carried out at lower temperatures and higher hypsometry (Treskavica, Bjelašnica and Igman mountains) from which heights is occurred the recharge of aquifers.

Thermal water Butmir (IB-7) and Sokolovići (IB-4) have mineralization of 0.3 - 0.5 g/l and temperature 14 – 22°C.

Numerous geological, seismotectonic, hydrogeological, physical – chemical indications suggest the higher temperatures in the primary aquifers of 58°C, and the waters are mixed from at least two reservoirs. The question of the existence of deep waters of higher enthalpy is open, but the depth seismoactive levels of more than 5 km provide approximate location of the primary aquifers.

It is necessary to perform more isotopic analyzes and implement works of Giggenbach and other authors, programs as "WATCH", "CAT_TEMP", PHREEQC" etc. to assess the mixing waters, calculation of temperatures in primary aquifers, determination recharge zones and definition of genesis of waters and gases.

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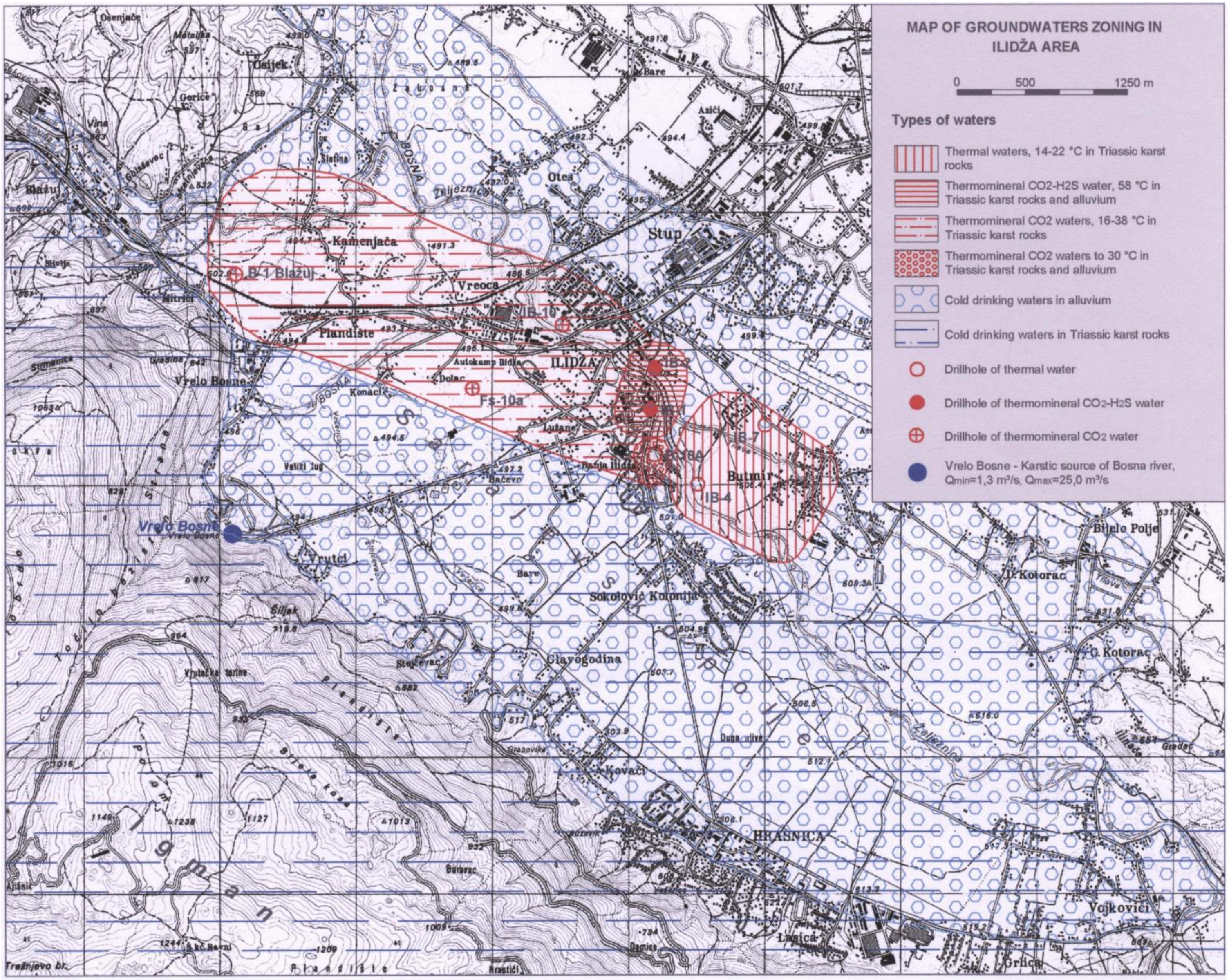
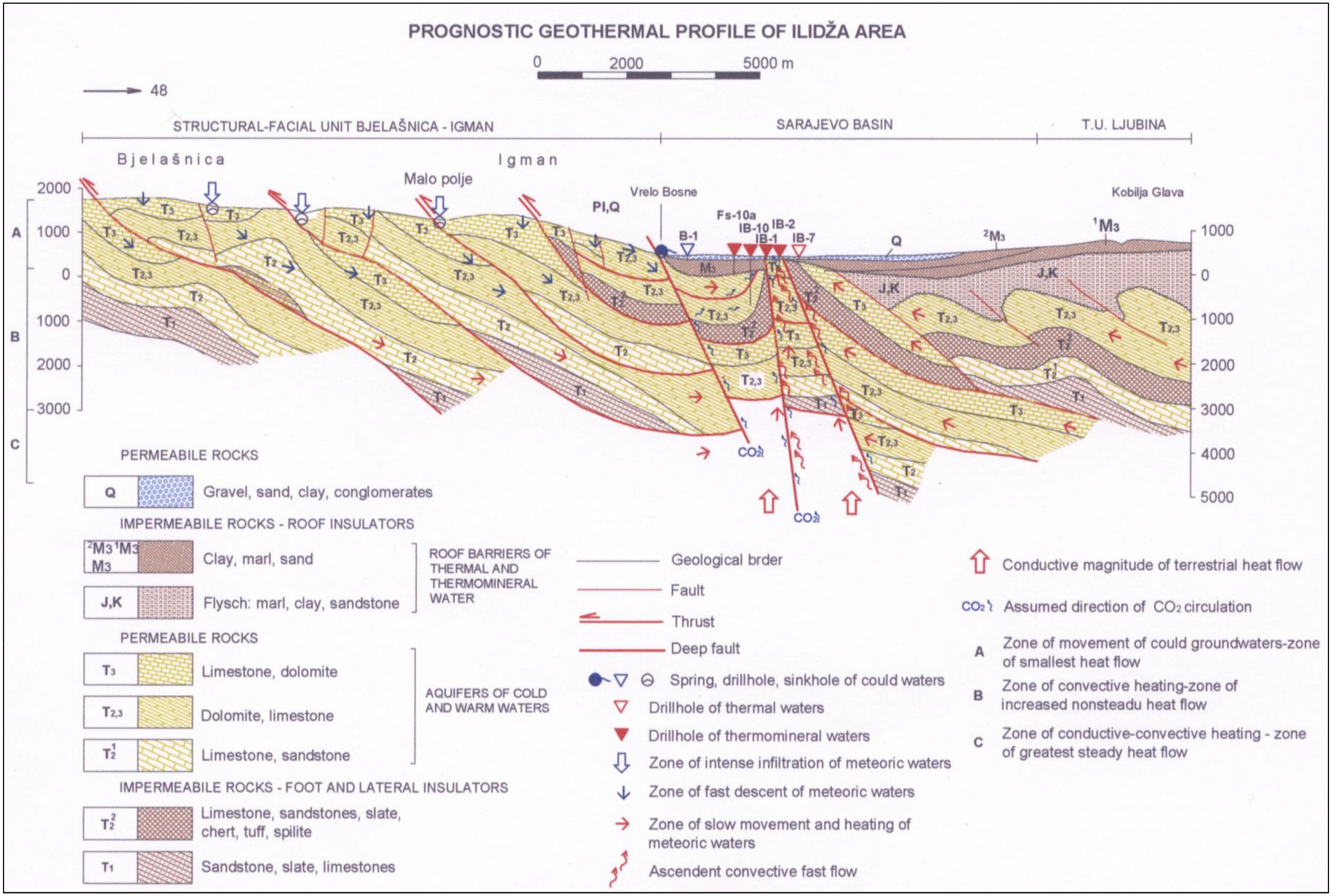
ENCL. 1. MAP OF GROUNDWATERS ZONING IN ILIDŽA AREA



ENCL. 2. PROGNOSTIC GEOTHERMAL PROFILE OF ILIDŽA AREA



ENCL. 3. PHYSICAL AND CHEMICAL ANALYSES OF THERMAL AND THERMOMINERAL WATERS IN ILIDŽA AREA

Drillhole	t °C	Ec, µS/cm	pH	E mV	Mineral. mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	$Fe_{tot.}$ mg/l	HCO_3 mg/l	SO_4 mg/l	Cl mg/l	SiO_2 mg/l	Date of analyzing	Ionic composition	Analyst
IB-4 Sokolovići	14		7,4		424,22	72,14	23,23	3,01			268,84	51	6		10.11.1987.	$\frac{HCO_3^- 78}{Ca^{2+} 64\ Mg^{2+} 34}$	Institute for health protection of B&H, Sarajevo
IB-7 Butmir	22				294,92	57,64	9,73	1,29	1,35		170,8	24,69	14,2		25.8.1987.	$\frac{HCO_3^- 75}{Ca^{2+} 76\ Mg^{2+} 32}$	Geoinženjering, Sarajevo
B-1 Blažuj	24,1	2600	6,3	447	2439	390	92	100	6,5		1400	310	140		25.5.1999.	$\frac{HCO_3^- 69\ SO_4^{2-} 20}{Ca^{2+} 62\ Mg^{2+} 24}$	INSTITUT FRESENIUS, Taunusstein
B-10A		1400	6,4	-10	1377	240	36,6	66,6	5,2		854	70	88,8	12	6.8.1982.	$\frac{HCO_3^- 78}{Ca^{2+} 67}$	Geoinstitut, Beograd
B-10A	24	1176	6,4		1011,05	176,35	48,6	13,8	1,56	0,28	683,2	28,98	58,22		3.10.2007.	$\frac{HCO_3^- 83}{Ca^{2+} 66\ Mg^{2+} 30}$	Institute for public health of FB&H, Sarajevo
IB-10 Ilidža (771-856 m)	30	1750	6,5		1541,88	260,52	48,6	69	11,73	5,2	878,4	180	86,62		21.9.2004.	$\frac{HCO_3^- 70}{Ca^{2+} 62\ Mg^{2+} 21}$	Institute for public health of FB&H, Sarajevo
IB-10 Ilidža (771-902 m)	31	1560	6,92		1608,1	260,52	41,31	92	19,55		939,4	160	93,72		21.9.2004.	$\frac{HCO_3^- 72}{Ca^{2+} 62}$	Institute for public health of FB&H, Sarajevo
IB-10 Ilidža (1002-1028 m)	21	912	7,43		953,3	164,32	23,33	46	3,91	2,75	611,22	70	27,69		9.11.2004.	$\frac{HCO_3^- 82}{Ca^{2+} 67}$	Institute for public health of FB&H, Sarajevo
IB-10 Ilidža (1002-1100 m)	19	829	6,76		872,94	153,1	28,18	27,6	3,52	0,01	572,18	62	24,67		16.5.2005.	$\frac{HCO_3^- 83}{Ca^{2+} 68\ Mg^{2+} 21}$	Institute for public health of FB&H, Sarajevo
IB-10 Ilidža (1002-1100 m)	21	1382	6,31		1302,77	236,47	38,88	46,96	0,78	0,02	866,2	43,5	68,87		3.10.2007.	$\frac{HCO_3^- 83}{Ca^{2+} 69}$	Institute for public health of FB&H, Sarajevo
IB-10 Ilidža (1002-1100 m)		1100	6,67			192,38	38,88	46	0	0,01	707,6	80	68,87		28.1.2008.	$\frac{HCO_3^- 97}{Ca^{2+} 65\ Mg^{2+} 22}$	Institute for public health of FB&H, Sarajevo
IB-1	58	2100	6,6		3057	470	79,3	260	14		1342	500	320	50	27.3.1985.	$\frac{HCO_3^- 53\ SO_4^{2-} 25\ Cl^- 22}{Ca^{2+} 56\ Na^+ 27}$	Geoinstitut, Beograd
IB-2	58,5	3500	7,1		3095,69	468,93	111,78	253	7,82	0,03	1366,4	540	344,35		2.4.2002.	$\frac{HCO_3^- 52\ SO_4^{2-} 26\ Cl^- 22}{Ca^{2+} 53\ Na^+ 25\ Mg^{2+} 21}$	Institute for public health of FB&H, Sarajevo
B-3A	57	3500	6,5	+60	4140	440	109,8	300	18,2		1293,2	750	284	42	25.1.1984.	$\frac{HCO_3^- 47\ SO_4^{2-} 35}{Ca^{2+} 49\ Na^+ 29\ Mg^{2+} 20}$	Geoinstitut, Beograd
PP-1	58	2800	6,5	-20	2733	355	73,2	285,7	17,4		1372,5	250	326,6	47	6.8.1982.	$\frac{HCO_3^- 61\ SO_4^{2-} 25}{Ca^{2+} 48\ Na^+ 34}$	Geoinstitut, Beograd

ENCL. 4. ISOTOPIC ANALYSES OF THERMAL AND THERMOMINERAL WATERS IN ILIDŽA AREA

Drillhole/spring	Analyst	$\delta^{18}O_{SMOW}$ (‰)	δD_{SMOW} (‰)	$\delta^{18}O_{PDB}$ in total carbonate (‰)	$\delta^{13}C_{PDB}$ in total carbonate (‰)	$CaCO_3$ g/l	$\delta^{13}C_{PDB}$ in CO_2 (‰)	$\delta^{18}O_{PDB}$ in CO_2 (‰)	$\delta^{34}S_{CD}$ in SO_4 (‰)	$\delta\ ^{18}O_{SMOW}$ in SO_4 (‰)	$^{32}S/^{34}S$ (‰)	$BaSO_4$ g/l	δ^2H_{SMOW} in CH_4 (‰)	Temp. Of wat. °C	Temperature of condensation of water		Date of analyzing
															T°C ^{18}O	T°C$_D$	
B-1 Blažuj	HYDROISOTOP GmbH, Schweitenkirchen	-10,55			-1,5		-3,7		+23,2	10,8			-74,4				24.5.2000.
Spring –Banja Ilidža	Institut Jožef Stefan, Ljubljana	-10,35	-76,5		+0,96		-2,36	-12,21	+12,49		21,945	1,435		57	3,4	4,2	23.03.1984.
B-3A	Institut Ruđer Bošković, Zagreb																15.02.1984.
IB-1	Institut Jožef Stefan, Ljubljana	-10,2	-72,3		+2,44		-0,18		+11,2		21,974	1,5		56	3,5	4,9	april,1985.
IB-2	Institut Jožef Stefan, Ljubljana	-10,31	-78	-12,17	+1,14	4	-1,75	-14,85	+7,38		22,057			58	3,4	3,9	23.4.1987