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Geothermal Potentials and Current Status of Their Use and Development, Bosnia and Herzegovina

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ABSTRACT

Geothermal research and development in Bosnia and Herzegovina was initiated after World war II. Geothermal energy was used from hydrogeothermal systems only. The degree of research and utilization of geothermal energy was the greatest in period 1980 – 1992 and the smallest during the war 1992-95 in B&H. After 2005 it is evident slow increase of geothermal use comparing to period 1995-2005.

Geotectonic zones in Bosnia and Herzegovina are the following: 1) Sava-Vardar Zone (Active continental margin); 2) The Dinaride Ophiolite Zone; 3) The Bosnian Flysch Zone (Passive continental margin); 4) Allochtonous Paleozoic and Triassic formations from Mid-Bosnian Schist Mountains, Una – Sana Nappe, Durmitor Nappe and 5) Dinaric carbonate platform. A greater number of geothermal energy deposits of low enthalpy are encountered in Bosnia and Herzegovina in all geotectonic zones except zone 5).

There are 9 hydrogeothermal regions in Bosnia and Herzegovina. According to boreholes data in hydrogeothermal regions 1, 2, 3, 4, 5, 6 and 7 conductive geothermal gradients vary from G=28,2 - 49,6°C/km and heat flow values q = 60 – 88,7mW/m^2. Convective maximal values are G=66,6°C/km and q=134,9 mW/m^2 in Active continental margin, more less values are in Passive continental margin and Mid-Bosnian Schist Mountains. The smallest values are in Dinaric carbonate platform (drillhole Gla-1, 4,206 m depth - G=10,9 mK/m and q=38,2 mW/m^2).The highest measured temperatures are in Active continental margin (hydrogeothermal region 2) vary from 39-62°C at 1000 m, 78 – 101°C at 2000 m, 111 – 147°C at 3000 m and 176 – 209 °C at 5000 m below surface. Significantly lower values of gradients and heat flows are in Dinaric carbonate platform 10-20°C/km and 20-50 mW/m^2. The extreme lower temperature values (25-38°C at 1000 m) are supposed in Dinaric carbonate platform on the basis of only one drill hole in Bosnia and Herzegovina and ten drill holes in adjacent areas of Croatia and Montenegro.

The largest positive geothermal anomalies are in the Pannonian Basin (Active continental margin); minor potential is in area of Allochtonous Paleozoic and Triassic formations and practically without geothermal potentials in Outer Dinarides (Dinaric carbonate platform).

The main geothermal lower reservoirs in Pannonian Basin are situated in Middle and Upper Triassic and upper reservoirs of minor enthalpy are in Cretaceous and Tertiary marine sediments. Triassic aquifers occur deeper of 1500 m below surface of terrain. Thickness of Triassic reservoirs is supposed 500-800 m and its area is about 6500 km^2.

Numerous separate reservoirs of minor geothermal potentials are in Dinaric Ophiolite Zone, The Bosnian Flysch Zone, Allochtonous Paleozoic and Triassic formations from Mid-Bosnian Schist Mountains with main reservoirs in Triassic carbonate rocks.

Direct use of geothermal energy is mainly attributed to bathing and swimming (including balneology), space heating, less for geothermal heat pumps, greenhouses and industrial use. There are 22 thermal and thermomineral spas and recreations centers where swimming pools are heated by geothermal water directly or indirectly through heat exchangers and GHPs. Thermal spas and recreations centers are predominant thermal localities for direct heat use. At 3 thermal spas geothermal heat pumps are included, whereas the utilization included in 31 deposits only with total available power ca 200 MWt with referent temperature of 10 °C. As the temperature outputs are far higher than 10, the real power utilization is much lower.

During the last 8 years exploration and development have resulted in only 8 new wells with a total depth of about 3,5 km. One of them well GD-2-Slobomir in Semberija encountered water temperatures of 73°C, $Q_{pump.}$=45 l/s and depth 1,800 m and other in Slatina

near Banja Luka in Ophiolite Zone has t= 44°C; both wells drilled waters in Triassic limestones.

It is planned exploration and use of hydrogeothermal potentials in area of town Bijeljina in Triassic limestones (Pannonian Basin), which includes drilling 5 wells of single depth of 2500 m with water temperature t=130°C for district heating.

1. INTRODUCTION

There are some preliminary projects for utilization of wind, solar and biomass within renewable in the following period. Nowadays it is not expectations or projects for any production of electricity from geothermal. There are not supports from government toward direct use of geothermal energy through different projects and the various private investors and users in the terrain try in the frame of their activities and possibilities investigate and use this kind of energy.

Bosnia and Herzegovina, as the state within Alpine orogene, belongs to Dinaride geotectonic unit and have very complex geological structure. Various data indicate the geothermal potentiality of about 40% of the whole Bosnia and Herzegovina territory north of the line Bihać – Konjic – Foča in 9 hydrogeothermal regions: 1) Mesozoic massif of NW Bosnia, 2) Mesozoic and Tertiary artesian basins of northern Bosnia, 3) Una-Sana Paleozoic massif, 4) Ophiolitic massif, 5) Mesozoic Midbosnian massif, 6) Midbosnian Paleozoic massif, 7) Midbosnian Mesozoic basin, 8) Paleozoic massif of SE Bosnia and 9) Paleozoic and Neogene massif of E Bosnia (Fig.1). Geothermal conductive and convective parameters are calculated from the data of 40 wells in B&H for depths 486 – 3913 m and from countries of Pannonian basin as Croatia, Slovenia, Hungary, Slowakia and Romania (Jelić, 1979; Doevenyi et al., 1983; Franko, 1980). Details on geothermal data, connected to geology one can see in papers of Papeš (1988), Sikošek, Medwenitsch (1969), Hrvatović (2006), Miošić (1982, 1995, 2001, 2003a i 2003b).

Values of terrestrial heat flows in Inner Dinarides are higher than the average of continental Europe. Geothermal parameters grow from central to northern parts of country, isolines follow direction of stretching of geotectonic units; the greatest values of parameters are in hydrogeothermal regions 1, 2, 4 and 7 (Fig 2).

Potentials are characterized by their irregular distribution, concentration, specific locations, conditions and the possibilities of use. There are 87 active deposits of thermal and thermomineral waters with 175 springs and 130 artesian and pumping drillholes with total yield of 2921.1 l/s.

2. GEOLOGY BACKGROUND

The area of Bosnia and Herzegovina is included in the middle parts of the Dinaridic Mountain System. From the SW to the NE, the following geotectonic zones can be distinguished (Fig. 1).

1) The Dinaridic carbonate platform composed of:

a) The Upper Paleozoic sequence composing Late Carboniferous-Early Permian clastics and carbonates,

b) The Late Permian to Norian sequence of clastics and platform carbonates and associated synsedimentary igneous rocks deposited during the initial rifting stage of the Alpine cycle.

c) The Norian-Lutetian carbonate platform starts with the Norian-Rhaetian «Hauptdolomite» which only in some areas overlies the Raibl Beds.

2) The Bosnian Flysch (Blanchet et al. 1969) also referred to as the Sarajevo-Banja Luka Flysch (Mojičević, 1978), was deposited on the slope (margin) of the Dinaridic carbonate shelf (Pamić et al. 1998). In the Bosnian Flysch, which attains a total thickness of about 3000 m, two subunits can be distinguished;

a) The «Vranduk Subgroup» is characterized by an alternation of non-flysch, «paraflysch» and subordinate turbidity series composed mainly of micrites, arenites, and shales. This series ranges in age from Early Jurassic to Berriasian.

b) The «Ugar Subgroup» is a typical carbonate flysch series from the carbonate shelf margin. It ranges in age from the Albian to the Senonian.

3) The Dinaride Ophiolite Zone is composed of the following units:

a) Late Jurassic wildflysch or „ophiolitic melange“. The melange composed of shale-silty matrix embeding the fragment of greywacke, ultramafics, gabbros, diabase, basalt, tuff, amphibolites, chert, schist and limestones.

b) Ultramafic formations: tectonic peridotites cumulate gabbros and peridotites, diabases and dolerites, and basalts.

c) Overstep formations which are composed: Tithonian to Valangian reefal limestones and Berrisian to pre-Albian conglomerates, breccias and lithic sandstones.

4) The Active continental margin sequence of the Sava-Vardar Zone, the most internal unit of the Dinarides, comprises the following units (Pamić 1993, 2002; Pamić et al. 1998, 2002; Hrvatović 2006):

a) The «Cretaceous-Early Paleogene Flysch Sequence» composed of Early Cretaceous to Albian-Cenomanian formations (Dimitrijević & Dimitrijević 1985), which are disconformably overlain by Turonian-Maastrihtian-Early Paleogene turbidites (Jelaska, 1978; Obradović, 1985).

b) The «Progressive Metamorphic Sequence» is composed of slate and phyllites, as well as of greenschist, quartz-muscovite schist, gneisses (48-38 Ma), amphibolites and marbles, which originated under P-T conditions of very low-, low-and medium-grade metamorphism from the surrounding Cretaceous-Early Paleogene flysch formations

c) The «Tectonized Ophiolite Mélange» which differs from the Jurassic olistostrome mélange of Dinaride Ophiolite Zone by a higher degree of tectonization of its matrix by ophiolite fragments of Cretaceous/Early Paleogene age and coeval limestone exotics.

d) Granitoid rocks which are represented by collisional S-type, I-type and A-type granites (55-48 Ma), which intrude into Cretaceous/Paleogene flysch.

5) Paleozoic complexes which represented basement on which started Mesozoic-Paleogene evolution of the Dinaridic Tethys. The Paleozoic complexes, together with frequently accompanied Triassic formations are allochthonous and occur in the areas as follows: Ključ-Raduša Mt., Mid-Bosnian Schist Mts., Sana-Una, Southeastern Bosnia (Foča-Prača area-Durmitor Nappe) and East Bosnia.

In the area north of the uplifted Dinarides, a system of larger NNE-SSE and SSE-NNW oriented, larger shallow-to deep-water transtensional depressions came into evidence. Generation of these isolated basins was controlled by strong strike - slip faulting, predisposed generation of recent Drava and Sava depressions.

Deep refraction seismic data indicate the autochthonous basement is located at depths of 8 to 13 km beneath the external parts of the central Dinarides and at about 8-10 beneath the Bosnian Flysch and Dinaride Ophiolite Zone. By contrast, sediment thicknesses are of order of 3-5 km in the southern parts of the Pannonian Basin. Similarly, the crust-mantle boundary rises from about 40-45 beneath the External Dinarides to about 30 km beneath the Dinaride Ophiolite Zone and to less than 25 km beneath the South Pannonian Basin (Dragašević, 1978).

3. INTERDISCIPLINAR INDICATIONS OF GEOTHERMAL POTENTIALITY

Elements of existence of positive geothermal anomalies are visible from the geological tectonic, geophysical, geomorphological, neotectonic, hydrogeological and seismological indications. These indications were obtained by correlating the data of various authors to conditions of terrain of Bosnia and Herzegovina (Miljuš, 1972, Papeš 1985, 1988, Kappelmayer, Haenel, 1974, Berman, 1978, Bowen, 1979, Čermak, Rybach, 1979, Rybach, Muffler, 1981, Doevenyi et al., 1983, Jelić, 1979, Miošić, 1986, Sikošek 1983, 1985, Vyskočil 1979 etc.).

Geological-tectonic indications are:

- crustal and lineament faults,
- deep old regional and repeatedly reactivated faults,
- existence of large overthrusts in which the aquifers are covered by insu,
- tensional and contractional – compressive structures,
- geotectonic division of terrain in numerous blocks,
- thinning of the epidermal part of the earthcrust,
- less distance from surface to the Mohorovičić discontinuity in the Pannonian basin to 25 km,
- presence of young plutonites and their effusive members,
- continual masses space connection of upper magmates with deep roots in zones of Conrad discountity.

Geophysical indications are:

- Thickening isogals – zones of strong anomalous gravity gradient, representing dislocation zones with enhanced convective flow,
- Zero isoanomals on the border of maxima and minima gravity, indicating the occurrence of a number springs of thermal and thermomineral waters in lines along major faults,
- Directions of strike of gravity maxima indicate the faults, and these zones are often compatible with geomagnetic positive anomalies and point out to the anticlinal structures with aquifers in the basement of the overlying roof insulators,
- Gravimetric minima (synclinal form) and a uniform fields of positive anomalies - Tertiary sediments, in whose basement underlie carbonate hydrogeothermal systems,
- Gravimetric maxima - insulators - Paleozoic sediments and ophiolites in whose footwalls probably lie hydrothermal with carbonate aquifers,
- Faults which are determined by the gravimetric and electrical data,
- Low apparent of specific rock electrical resistances make possible to contour the accumulations of thermominerala waters in space.

Neotectonic-geomorphologic indications are:

- The existence of depressions formed in the Pliocene and Quaternary,
- The speed of the vertical movements and contemporary and recent uplift and subsidence of the ground differential movements,
- Sinorogene horizontal and preneogene and Neogene gravity faults, multiphase reactivated in Neogene and Quaternary,
- The existence of young neotectonic movements and graben neotectonic structures,
- Horizontal and vertical block movements along fault contacts,
- Contrasting steep fault sections.

Seismic indications are:

- Remarkable seismic belts,

- The great number, depth and length of seismogene structures,
- High seismoenergetic potential of seismogene structures,
- Depth of seismoactive levels, density of earthquake epicenters, magnitudes and earthquake afterschock zones,
- Zones of highest seismic hazard,
- Genesis of the earthquake, which is tectonic origin and earthquake focal activation is related to modern tectonic movements,
- Areas of high heat flow values, which are directly proportional to the belts of maximum seismic activity.

Hydrogeological indications are:

- The existence of springs and wells of thermal and thermomineral waters,
- Water, drilled in shallow zones with increased values of convective temperature gradient,
- The existence of deep artesian basin – intramountains depressions with heating water reservoirs protected from cooling from groundsurface,
- Ascending convective zones of enhanced fluid flows along faults,
- High temperature spring water according to all chemical geothermometers,
- Proven mixing of hot and cold waters in fault communications, indicating higher temperatures in the deeper horizons,
- Slow water circulation and exchange indicates heating of infiltrational meteoric waters in the long periods of time,
- Constant temperature water springs and wells indicates their accumulation have higher thermoenergetic concentrations,
- Similar to the isotopic composition of the water with higher and lower temperatures may result in the similar temperature conditions of their origin,
- Exhalations of thermogenic CO_2 indicate young, deep and recent orogenic movements and faulting i.e. the origin of this gase at the higher temperatures.

All these factors condition the existence of numerous hydrogeothermal convective systems, which are proved by the existence of thermal and thermomineral springs and wells.

4. INDICATIVE DIRECT HYDROGEOTHERMAL FACTORS

Indicative proved direct quantified factors of hydrogeothermal potentiality in Bosnia and Herzegovina are the folowings:

- thermal spring with maximum yield is Toplica-Spreča with Q = 250 l/s,
- the spring with the highest temperature t=58°C is in Ilidža- Sarajevo,
- spring at the highest altitude of 750 m a. s. l. is Ilidža-Knežina,
- the highest temperature of artesian well is Do-1 – Domaljevac, depth of 1275 m, with Q = 25 l/s and outlet temperature of 96°C and the power of 9 $MW_{term.}$,
- the highest measured nonstationary and uncorrected temperature at maximum depth of 3913 m is in the borehole Br-1- Brvnik, 177°C with G=42,4 mK/m and q=93,3 mW/m^2,
- the highest extrapolated temperature at 5000 m depth from the ground surface at well Br-1 is 209°C,
- the maximum convective geothermal gradient of 66 C/km is in the drillhole Do-1- Domaljevac for depth of 1275 m,
- the maximum convective heat flow is 134.9 mW/m^2 (Sl-1),
- artesian well GB-1-Gracanica from 1979 with the depth of 68 m only has outlet temperature 39 C, initial eruptive yield was Q = 414 l/s, GWR= 2.5 of free 99% pure CO_2 - this cavernous Triassic limestones with large values of effective porosity and transmissivity have the same temperature of 39°C at 23 m and 600 m depth and the entire aquifer behaves as one isotherm,
- in Tičići by Kakanj, where the temperature of the source before drilling was 28°C, yield Q=2 l/s, artesian outflow in drillhole IT-1 was Q=35 l/s and 56°C at depth of 82 m only (Slisković, 1986, 1993),
- in Lješljani, well SB-1 depth 670 m with several inflows of water through depth has artesian outflow of 7 l/s, temperature 32°C, temperature at bottom of well was 34°C, and the spring before drilling, in distance of 30 m of the SB-1, had a temperature of 18°C and Q = 0.2 l/s (Miošić, 1991),
- in Fojnica well FB-2 has artesian outflow Q = 250 l/s, water temperature t = 22.6 °C and pressure of 5.8 bar at the mouth of the well, near FB-2 is Memića spring of the same chemistry and genesis, having t = 21°C and Q = 0.7 l/s (Slisković, 1993).

These data clearly show that there are proved hydrogeothermal exploitative potentials in Bosnia and Herzegovina in the relatively shallow depths. Due to the low level of geothermal research and complexity of geological structure, there are the possibilities of similar positive surprises.

5. GEOTHERMAL PARAMETERS

The most significant geothermal parameters - thermal conductivity of rocks, geothermal gradient and heat flow were obtained from the measured data from boreholes and data of neighboring countries as well as references, especially on thermal conductivity (Čermak, Rybach, 1979, Doevenyi et al. 1983, Franko et al., 1980, Hurtig et al., 1992, Jelić, 1979, Ravnik, Miošić et al., 1992).

5.1. Temperature

Highest temperatures are in regions 1, 2, 4 and 7. In hydrogeothermal regions 1, 2, 4 and 7 temperatures rise from the central to the northern parts of the country, the isotherms are oriented NW-SE and follow the strikes of geological formations. Average temperatures are: 1.000 m - 50°C (hg. region 1, 2, 4 and 7), 2.000 m - 92 C, 3.000 m – 130°C, 4.000 m 169°C and 5.000 m – 196°C (hg. hydrogeothermal region 2) (Table 1)**.** Temperatures are not often stabilized and calculated values of static equilibrium formation temperatures show an increase in temperature of 10 - 30% compared to temperatures measured at all wells.

Maximum depth of measured temperatures in hydrogeothermal regions are in Artesian basins of northern Bosnia. The maximum depth of measured temperature is on the drillhole Gla-1 – Glamoč in the Outer Dinarides at 4206 m below surface and temperature was 53°C only.

The highest temperatures are in the convection zones, where the Mesozoic limestone aquifers are overlain by thic Tertiary roof insulators, which have low thermal conductivity (wells Do-1, S-1, Bij-1) as it case also in Tertiary sediments, where there are artesian water outflows (wells Sl-1, III / B) and in areas of salt layers with high thermal conductivity (drillholes K-1, K-2, Tetima) and in serpentinites (V-3).

Convective cooling is the most in exposed outcrops of karst terrain, where exist the intensive and deep aeration and infiltration of meteoric waters and quick exchange of waters. Basin sediments as Sarajevo-Zenica and others have about 10 times less infiltration and cooling of karst terrain along the contact of the Tertiary and carbonate rocks of greater hypsometry and longitudinal faults at the edge of the plain. In the area of horsts and trenches of northern Bosnia cooling from the surface is very small.

At depths of 1,000 m the highest temperatures are in the hg. region 2 because of covering by Tertiary insulators as the roof barriers and in ophiolites (V-3) due to the high thermal conductivity of serpentinite in the basement of Tertiary sediments. The highest temperatures are at 1.000, 2000 and 3000 m depth in Semberija then in Bosnian Posavina and in Tuzla basin, which means that at these depths exist uniform isothermal stratification.

Temperatures measured by maximal thermometer and well-logging do not present actual representatives values of thermal properties of rock media, but the real temperatures are higher 10 - 25% in the measured ones. This shows the estimated static equilibrium temperature of formation calculated by Kehle (1971), which provides increased temperature of 10 - 30% of all wells in relation to the measured temperatures. Such is the case in Croatia too (Jelić, 1979), and we see that comparing logging data at different times on the same well (S-1) or comparing well-logging and outflow temperature (Do-1 and S-1).

5.2. Thermal conductivity, geothermal gradient and heat flow

Thermal conductivity of rocks is determined by the data of analogous chrono and lithostratigraphic media from Hungary, Slovakia, Romania and Croatia in which this parameter is determined experimentally. Gradients and heat flows of significant wells are given in Table 2. Increased temperature gradients and heat flows are in wells in which exist convective heating givng by circulation of hot waters (B-1, SB-1, So-1, S-1, Bij-1, SL-1, K-1, K-2 , III / B) or where there are rocks with high thermal conductivity - evaporites - Tuzla basin, serpentinites - V-3 - Vitanović (Miošić, 1986, Miošić, 1988, Miošić, 1989, Miošić, 1991, Miošić, 1995, Miošić, 1996 , Miošić, 2001, Miošić et al., 1987)**.**

Average temperature gradients are the lowest in the hg. region 1. with decreasing with depth, while the highest values are in the ophiolites for depths from 1.000 - 2.000 m, and in the hg. region 2 are the greatest for depths <1,000 m, and then remained almost the same for other deeper intervals. Temperature gradients generally decrease with depth. Average heat flows are highest in basins of northern Bosnia and basins in the Central Bosnia and ophiolitic zone, where there is one drillhole only.

The highest individual temperature gradients in the region of horsts and trenches of northern Bosnia are from G = 28.2 mK / m (Br-1, 1205 m) to G = 49.6 mK /m (S-1, 1055 m), and they correspond to the those in the Pannonian basin in Croatia, Vojvodina, Hungary, Romania and Slovakia (Jelić, 1979, Kolbah, 1978, Doevenyi et al., 1983, Franko, 1980, Čermak, Rybach, 1979).

In Tuzla Tertiary basin average conductive temperature gradients is 29.3 - 42.3 mK/m. The border zone between ophiolites and Mesozoic limestones has only 1 data (Var-1) with 25.8 mK / m for the depth of 1.201 m. Triassic limestones in the Sarajevo-Zenica Tertiary basin has also only one datum (Knj-1) with 33.4 mK/m in the Tertiary sediments.

Conductive individual terrestrial heat flows to all depths in geothermal wells vary in regions 1, 2, 4 and 7 from 60.0 mW/m^2 (RT-4, 1.444 m) to 88.7 mW/m^2 (Ob-1, 2.330 m). Similar to gradients increased conductive heat flows in hg. regions 4 (82.4 mW/m^2) and 7 (92.8 mW/m^2) exist. Adjusted average conductive heat flow ranges from 72.7 mW/m^2 (Po-2), 87.7 mW/m^2 (St-1).

In Tuzla Tertiary basin average conductive heat flow is 73.2 mW/m^2, and in Sarajevo-Zenica Tertiary basin conductive heat flow is increased and is 92.8 mW/m^2. In relation to the European continental average of 63 mW/m^2, it can see that exists increased heat flow in all hg. regions and at all depths in Bosnia and Herzegovina, which is an argument for the successful exploration of geothermal resources.

6. HYDROGEOTHERMAL SYSTEMS

Hydrogeothermal systems, petrogeothermal dry potentials and thermogeopressured zones exist in Bosnia and Herzegovina.

Hydrogeothermal systems are formed in porous and permeable rocks of various chronostratigraphic age and lithology in different depths from the surface in 87 proven deposits of thermal and thermomineral waters.

These waters are of different genesis, predominantly meteoric origin and with a large variety of physical and chemical composition of ingredients, often of high mineralization.and free and dissolved gases. Renewable resources potentials are formed in the open, semiopened, semiclosed and closed structures at various depths in a numerous areas as well as in the deeper horizons of registered reservoirs. Most of hydrogeothermal systems are investigated and utilized, they are closest to the surface of the terrain and they are the most perspective for exploration and use now and in the future.

Various geological, geophysical, geomorphological-neotectonic, seismological and hydrogeological indications, hydrogeological, petroleum-geological exploration data and thermal and thermomineral springs of waters suggest existence of hydrogeothermal potentials in Bosnia and Herzegovina in the regions north of the irregular line connecting the towns of Bihac- Gornji Vakuf/Uskoplje - Foča on about 50% of the territory of the country in 9 hydrogeothermal regions (Table 3). Geothermal resources are presented to a depth of 5.000 m from the surface, which are located in the following nine hydrogeothermal regions. Hydrogeothermal convective systems exist in all regions except 5. and 9., closed systems exist in regions 2, 3, 4, 6, 7 and closed systems are supposed in regions 5 and 9 (Čičić, Miošić, 1986). Waters are registered by drillings for petroleum too, which boreholes are not active now.

Limestones are the main aquifers in all geological periods and among them the most significant are Triassic limestones with the highest thermoenergetic potential in all regions. Collectors are characterized by vertical and horizontal discontinuity. Depth and thickness of collectors and their hydrogeological and geothermal parameters are mainly in the phase of prognoses, especially for deep hydrogeothermal systems.

Geothermal potentials are characterized by irregular distribution, discontinual expanses, concentration, specific locations, the variety of quality and quantity, conditions and a wide range of possibilities of use.

According to reinterpreted geological, geophysical, neotectonic, geochemical, geomorphological, seismic, oil-geological and hydrogeological parameters and the geothermal indications in Bosnia and Herzegovina exist different types of hydrogeothermal systems. Lithology and stratigraphy of collectors of hydrogeothermal region is given in Table 3. Hydrogeotherms have large range of mineralization from 0.15 g/l only to as much as 300 g/l with a variety of condensable and non condensable combustible and noncombustible gases.

Promising of research areas are:

- a) open, semi-open and semi-closed structures and
- b) closed structures.

Open, semi-open and semi-closed structures are: Busovača fault zone, fault-Vogošća Lašva, Spreča fault zone, faults Banja Luka-Slatina-Laktaši, faults of Bihać – Velika Kladuša-zone, faults Teslic, Kulasi, Trebovac, Priboj, Praca, Drinjača, Visegrad, Vares - Olovo- Knežina, Bugojno-Lepenica-Kreševo-Fojnica.

Closed systems are: Artesian basins of Posavina and Semberija, Middle Bosnian basin, Banja Luka basin, Bihac – Cazin basin, Jurassic-Cretaceous flysch trough Sarajevo-Banja Luka, Prijedor depression, Paleozoic Una massif, Sana, Mid Bosnian schist massif, Palaeozoic massifs of east and southeastern Bosnia.

7. BASIC DATA OF SPRINGS AND WELLS OF HIDROGEOTERMS

In Bosnia and Herzegovina are registered 57 deposits of thermal and 30 thermomineral waters with a total of 175 springs and 127 drillholes with total yield of 2,921.1 l/s (Table 4). These resources are proven in the exploring oil wells too, which are not active now.

There are 40 deposits with springs, 34 with springs and drillholes and 13 deposits (mainly in the Pannonian Basin) with wells only. Temperatures of waters of 36 deposits are <20°C and 44 deposits have single yield <10 l/s. There are 45 occurrences in Ophiolites, 7 in the Pannonian Basin, 10 in Midbosnian Paleozoic 10, 10 in Midbosnian Basin, 8 in Bihac-Kladuša Basin, 6 in Una-Sana Paleozoic and 1 in Paleozoic of SE Bosnia.

Thermal waters with springs only (31) are more numerous than the thermomineral (9), which means thermomineral waters are more investigated by drilling. At 49 deposits of thermal waters there are 101 spring, and at 25 deposits of thermomineral waters there are 74 springs (Miošić, Slišković, 1982, Slišković, Plavkić, Miošić, 1985).

Drilling was carried out at 26 deposits of thermal waters, from this number in 13 deposits one well and in 21 deposit of thermomineral waters was drilled, in 9 deposits was drilled one borehole. Thermomineral waters with temperatures less than 40 °C are in higher level of investigation than ones above 40 C. Waters of higher temperature were investigated at oil drillings before 50 years and this is the reason for their lower degree of exploration.

18 deposits of thermal and 16 deposits thermomineral waters have springs and wells, while the 8 deposits of thermal and 5 of thermomineral waters have only wells. The number of thermal wells is 56 and thermomineral 71. Deposits with springs and wells of thermal waters have 45 wells and thermomineral have 55 wells.

Deposits with wells only of thermal waters have 11 wells and thermomineral waters 16 wells. At 12 deposits of thermal waters and 13 thermomineral waters was drilled more wells. In 31 deposit of thermal and 8 deposits of thermomineral waters was not any drillings.

Depths of all 127 active wells range from <100 m to 1345.5 m (S-1-Dvorovi), they give low enthalpy hydrogeothermal resources t<20°C to 96 °C at the surface trerrain.

It can see without drillings there is no effective use of these waters.

Yields of thermal waters are greater than thermomineral, while their powers are lower, which means the temperatures of thermal waters are lower. Ascending discharge comunications to thermomineral springs have lower transmissivities and springs are with lower yields and temperatures than it case with drillholes. It means by drillholes are got the new inflows, higher temperatures and higher wellhead pressures too of waters through its profile i.e. drillholes have fast circulation paths and springs are with less velocities.

Maximum temperatures of drillholes in all thermal waters are at the wellhead lower or the same to maximal temperatures of springs with the exception in Šumatac and Barake, where they are higher.

In all 31 deposits of thermal and thermomineral waters in which was drilled where got greater yields in wells then they exist in springs and in most of thermomineral deposits (11) where got higher temperatures in wells.

Based on the above facts it can assume that it get additional amounts of waters in other deposits by drilling, but higher temperatures are of minor probability.

A higher percentage of artesian wells of thermomineral (58%) compared to the thermal waters (50%) exists in deposits in use. There are 36 wells of thermal and 55 wells of thermomineral waters in these deposits.

There is a low degree of investigation of both waters, but thermomineral waters are at a higher level of research.

Drillings were made in zones of natural springs mainly, to small depths with technical problems and environmental difficulties, which lead to impossibility of deeper drilling and even to colapses of wells. Drillings were often performed at a venture without studies about site and characteristics of primary aquifers and especially new programmes on the basis of chemical and isotopic indicators. Complexity of geology and existence of evident different irregularities point out to the justifiability of deeper drillings in the aim to get additional capacities and the higher temperatures of waters.

8. HYDROGEOTHERMAL REGIONS

Geothermal resources are developed in the central and northern part of Bosnia and Herzegovina in 9 hydrogeothermal regions in about 50% territory of the country (Fig. 1). The names of regions are presented in introduction. Depths and temperatures of aquifers in regions are given in Table 5.

Mesozoic carbonate massif of NW Bosnia region (1) includes Triassic collectors with hydrothermal systems in 8 deposits, which appear in fault and thrust zones. Significant occurrences are Barake, Mala Kladuša and Šumatac with impressive Q=420 l/s by pumping and t= 22-28 C, Gata (the only thermomineral water in the Outer Dinarides of BiH), Tržačka Raštela and Racic with temperatures from 17 to 38 °C and $Q_{tot.}$= 60 l/s.

Linear temperature increase along depth exists in Barake, while in Grabovac and Šumatac temperature inversion in wells, causing by thrusting of the Triassic over Cretaceous layers; in Triassic shallow waters in zone of thrusting have higher temperature and these waters are deeper and Cretaceous collectors have lower temperatures. It would obtain by deeper drilling in normal stratigraphic sequence – after Cretaceous repeatdly in the Triassic aquifers warmer waters compared with present state of well. Waters in Cretaceous collectors are shallower and have lower temperatures and they have recharge from different areas, while the waters in the Triassic are deeper. Because of that the both waters are hydraulically separated.

Mesozoic and Tertiary artesian basins of northern Bosnia (2) are located north of Doboj- Laktaši-Zvornik line on the southern part of Pannonian hyperthermal basin (Jelić, 1979). There are a some separate basins in this region, which are characterized by special thermal characteristics - the highest temperature are in Semberija in $T_{2,3}$ limestones then less values in Posavina, and the lowest values are in Tertiary sediments of Tuzla basin (Table 6).

Aquifers with greatest yields are located in Semberija, less yields are in Posavina and the lowest productivity is in Tuzla basin.

Collectors of these region are Triassic limestones and dolomites, Cretaceous and Neogene (M_2^2, M_3^1, Pl_1^2) limestones and clastites and have the area of 6500 km2. Possible reserves down to depth of 3 km amount impressive 107.5 x106 TJ with a maximum resource per unit area of 113 GJ/m^2, temperature of 136°C, the middle depth of 2500 m and net aquifer thickness of

400 m. Aquifers were proved with some drillholes for petroleum from which 5 wells were productive but without possibilities of use in the present conditions (S-2, DV-1, Bij - 1, Do-3, Sl-1) and in exploitation are only 2 (S-1 – Q= 7 l/s, t=75°C and Do-1 – Q= 20 l/s, t=96 °C).

Region 2 has the following subregions: Semberija, Bosnian Posavina and Tuzla basin. Semberija is more productive than Bosnian Posavina and Tuzla basin.

The most significant aquifers of the region 2 are T_3 carbonates with depths from 1290-3900 m. Artesian basins of mid potentiality without drilled of Cretaceous and Triassic aquifers occur west of Domaljevac. Tuzla basin has lower productivity in Miocene collectors compared to Cretaceous and Triassic aquifers in Posavina and Semberija.

Triassic aquifers in Semberija at depths from 1290 to 2410 m have temperatures 64-119°C, Upper Cretaceous aquifers are at depths of 780-1465 m with t=42–93°C, Baden 625-710 m, t=37–47°C, the Sarmatian 490-667 m, t=31–43 °C and Pliocene 250-252 m, t= 21–26 °C.

Temperatures of 120°C are at depths of 2420 m in Triassic aquifers (Bij-1) to 3250 m (Tertiary and Upper Cretaceous of Tuzla basin, well Tu-1), while in the well Br-1 are at 2650 m, and Ob-1 at 2900 m depth from the ground surface in the Mesozoic sediments.

There are springs and wells in fault zones in the area of Gradačac, Slavinovići and Priboj (t =19–30°C, $Q_{tot.}$=50 l/s), whereas in Tuzla basin reservoirs exist with water brines with temperatures up to 27°C and mineralization of 280 g/l in Miocene sediments in which occur salt deposits (Miošić, 1982, 2003a).

Una - Sana Paleozoic massif (3) is characterized by thrusting of Paleozoic over Triassic rock masses and these last on Cretaceous sediments (Jurić, 1971), what enable the existence of hanging wall Paleozoic barriers over Triassic hydrogeothermal systems. The intensity of thrusting is greater than 15 km, which provides an hanging wall barriere of Cretaceous and Triassic aquifers and the existence of closed and semi-closed hydrogeological structures.

Here there are a numerous regional and local faults, and they are marked on the surface by morphotectonic. These faults were created in some phases and regenerated also and there exist neotectonic and seismotectonic activity (well known Banja Luka earthquke in 1969.).

There are great regional faults and thrusts Mrkonjić - Ključ and Kozica-Budimlić Japra in this zone with ascension of thermomineral waters in Balkana (Q = 3 l/s, t = 17 °C), Kozica (Q = 6 l/s, t = 25.3 °C), Sanska Ilidza (Q = 40 l/s, t = 32 °C) and Budimlić Japra (Q = 15 l/s and t = 18 °C).

Massif of Ophiolites (4) is characterized by covering of Triassic carbonate aquifers by intrusive, effusive and metamorphic rocks as roof barriers. The whole massif is discontinuous because of tectonics and it has separate occurrences of mineral, thermal, thermomineral carbon acid and hyperalkaline waters.

Thermomineral CO_2 waters in Spreča fault zone Živinice - Doboj are in Triassic carbonates rocks, waters are of meteoric origin, CO_2 is of deep - thermogenic origin, which ascends through insulator basement in Triassic aquifers along the fault paraclases. Aquifers of thermomineral waters have the same temperature throughout the thickness of the composite, which indicates irregular but large cavernous and effective porosity, but also the fact that in the basement of the aquifers does not have aquifers with active circulation of the ascending waters and carbonate aquifers are heating conductively from circulation base - insulator foot-wall, which are probably ultramafic lithology. Absence of sulfate ion and H_2S in waters indicates the water does not circulate through P-T_1 evaporite sediments.

Higher temperature in wells related to springs (Slatina Ilidža, Teslić, Gračanica) are the result of low yields in themselves.

There are only two wells SB-1 - Lješljani in serpentinites with strong convection, therefore exists an increased gradient and the thermal conductivity and therefore value of heat flow and V-3 - Vitanović, which was completed in serpentinites (drilled to 1132 m) and also shows a high temperature of 67.5°C at 1.110 m depth and the high gradient and heat flow. Although V-3 geographically belongs to geotectonic zone of horsts and trenches of northern Bosnia (hg. region 2), here is developed geological and hydrogeological horst of ophiolites covered by Cretaceous and Tertiary sediments.

The most significant deposits are: Lješljani (Q=7 l/s, t= 32°C), Gornji Šeher (Q=150 l/s, t=35°C), Slatina (Q=100 l/s, t= 44°C), Laktaši (Q = 100 l/s, t= 30°C), Teslić (Q=20 l/s, t= 38°C), Gračanica (Q=250 l/s, t= 39°C) and Toplica-Spreča (Q= 230 l/s, t= 25°C). All these deposits have great yields thanks too exclusively the drillholes. There are large number of hydrothermal systems in numerous fault zones in the area of Vares, Olovo, Knežina, Drinjaca, Zepce, Rogatica and Visegrad ($Q_{tot.}$= 190 l/s, t=15, 5–34°C).

Hyperalcalic thermal waters exist in 5 locations with the most important spa Kulaši (Q = 20 l/s, t=30°C) near Prnjavor.

Mesozoic Central Bosnia Massif (5) is spread as the belt from Banja Luka to Sarajevo between Mid-Bosnian Paleozoic Schist Mountains in the SW and Ophiolitic zone in the NE as a deep trough in which Triassic carbonates with hydrogeothermal closed systems are overlain by Cretaceous flysch sediments of great thickness.

In this deep trough thick Cretaceous flysch sediments lie on older Mesozoic carbonates, which are closed hydrogeothermal systems. Here occur deep faults as Busovača fault zone and regional fault Mrkonjic grad - Ključ along which ascend the thermal waters and termogenic CO_2 of deep origin. These faults originate are from the geosinclinal period and are related to the initial tectonic movements (Vidović, 1974).

Mid-Bosnian Paleozoic Massif (6) is presented by Paleozoic schists as roof barriers, which are interrupted by intrusive and effusive acid plutonic and volcanic rocks. Collectors are limestones, dolomites, marbles, quartzporphyres and quarzites of Paleozoic and Mesozoic ages in fault and thrust structures. Hydrogeothermal deposits are located in the dinaric direction of NW-SE stretching from Bugojno over Kruščica, Fojnica, Kreševo to Lepenica (Q=270 l/s, t=16.5–30°C). There are two theories about the position of rock masses for Mid Bosnian Schist Mountains: a) according to an earlier thesis Paleozoic sediments are present the horsts, while the newer thesis they are the end parts of a large thrust, which lies on the younger Triassic carbonate rocks –this opinion was done Pilger (1941), Miholić (1956) and especially from Papeš (1988). Therefore, there are the large accumulations of thermal waters as above mentioned. Geological picture is complicated due to the exceptional complex tektonicks and intrusions and effusions of acid plutonic and volcanic rocks.

Mid-Bosnian Mesozoic basin (7) presents intermountain artesian depression between units of the Mid-Bosnian Paleozoic Flysch trough and Banja Luka - Sarajevo with Triassic collectors covered by Tertiary roof insulators in NE and Mid Bosnian Paleozoic massif in the SW. Contacts of these geotectonic units are marked by regional dinaric faults Sarajevo - Busovaca and Vogošća – Lašva. Along these structures ascend thermal waters of great yields and higher temperatures as it case in the SE in Ilidža with thermogenic CO_2 (Q=300 l/s, t=58°C) and Kakanj (Q=60 l/s, t=56°C) in the NE. Thermal properties were explored with two drillhole only in the Tertiary in which the measured depths of 708 m (Knj-1) and 568 m (III/B) proved increased geothermal gradient (33.4 and 42.2 mK/m) and heat flow (92.8 and 94.4 mW/m2). This correlates with elevated convective water temperature in borehole IT-1 - Tičići of 56°C and artesian flow Q=35 l/s in the depth of 82 m, while nearby spring had t=28°C and Q=2 l/s.

This positive surprise is a promising and stimulating for similar geological situations.

On the other hand in Ilidža the maximum temperature (t=58°C) of the spring waters prior to drillings with Q_{tot}=12 l/s was the same as at wellhead of drillhole, so the aquifer presents an isothermal convective ascending path of fast and strong water circulation.

Paleozoic Massif of South-East Bosnia (8), often called the Prača Paleozoic, build Silurian, Devonian, Carboniferous and Permian rocks. It has hydrogeothermal systems in Devonian limestones, which are interstratified between older and younger Paleozoic insulators. Carbon roof barriers condition occurrence of spring waters in hypothermal deposit Čeljadinići (Q=100 l/s, t=15°C). Numerous occurrences with exhhalations of CO_2 occurrences point out to deep faultings, but the genesis of this gas is not yet solved, is it thermogenic from great depths or chemogene origin.

Normal development of sedimentation from Silurian to Permian is probable what is reversely to Palaeozoic Mid Bosnian massif and therefore aquifers here are with lower water yields.

Paleozoic and clastites metamorphites and massif of Neogene effusives east of Bosnia (9) contain probably hydrogeothermal closed systems in deeper zones because of increased thermal conductivity and young, probably not yet entirely cooled, volcanic rocks. Mineral springs occur in hydrothermally altered Neogene volcanic effusives in the oxidation conditions. These mineralized rocks contain minerals, non-ferrous metals, which vaulted create specific very acid ionic solution chemistry with pH=2-4. Accumulations occur in open structures and now active electrochemical processes. Exothermic reaction of many waters in the area of Srebrenica give hypothermal or nonthermal springs. Otherwise these mineral waters are very rare in the world (Levico, Italy) and this is the only one deposit of such type in the former Yugoslavia, and are important in therapeutics and balneology with many medicinal indications proved long ago by Austrian – Hungarian scientists in XIX century.

9. HYDROGEOTHERMAL POTENTIAL

9.1.Thermoenergetic potential of active springs and drillholes

All 87 active deposits have total power of 251 MW_{therm} referent to 10°C and the energy of 3,965.47 TJ/year. Deposits with springs (40) have available power of 15 MW_{therm} only, but deposits with springs and wells (47) have 236 MW_{therm}., from which one can see there is no effective utilization of waters without drillholes (Miošić, 2003a). There are 218 MW_{therm} in 34 deposits with single powers greater than 1 MW and 53 other deposits have only 33 MWtherm with single power <1 MW_{therm} (Miosić, 2003a). Possible - prognose powers of these systems by reconstruction of wells and drilling new wells in 87 cited deposits are estimated to 795 MW_{therm} and 12,539.33 TJ/yr. (Miošić, 2003a).

Power of springs and wells of thermal waters is 106.8 MWterm and thermomineral 144.6 MW_{term}. Available power in the individual deposits have range from 0.0004 to 30,341 MW_{term}.

Deposits of thermomineral waters are the most frequent with powers <0.1 MW, those with powers > 10 MW are three times more frequent than thermal deposits.

It is apparent nonuniformity in the distribution of energy and power of waters, as well as low level of research i.e. small number of drilled wells.

Possible powers and energies were argumentated by the following facts:

- over the past 30 years have been intensified polidisciplinar and phase research in numerous deposits of mineral, thermal and thermomineral waters and obtained great capacities with high quality and effectiveness; their indications were defined in wide range of applications (Miošić, 1980, 1982, 1984, 1987, 1994),
- In each of the 34 deposits of these waters with springs in which were performed drillings were obtained the multiple yields in drillholes in relation to the springs. Manifold drillings in deposits were given additional capacities of waters (Miošić, 2001),
- Waters were obtained at 13 locations (8 thermal and 5 thermomineral), where there were not any springs,
- Great yields were obtained by drilling, 20 to over 200 times greater than existing springs. In each deposit were obtained greater yields by drilling related to nearby spring which means that each borehole intersected more inflows of waters in different depths than it is the case with springsi.e.in each deposit was justified drilling.

We can see that no drilling, no effective water use.

Higher water temperature in wells were obtained where the springs have low yields (Barake, Šumatac). Springs with higher yields have higher temperatures and the wells with maximal temperatures have the maximal yields. 4 deposits only have not artesian outflows.

This means that the deeper waters mainly are warmer and they have larger yields ie deeper drilling will give higher yields and higher temperatures, although in the 6 deposits in greater depths were registered somewhat lower temperatures (Mala Kladuša – Ilidža, Šumatac, Gornji Šeher, Slatina-acid waters, Laktaši, R-1-Ribnica).

All performed drillings were relatively shallow. Drilling in greater depths, with minor exceptions, would give certainly increased temperatures as it was registered in all deep drillholes. Minor and shalow irregularities were registered and even thermal inversions in a small number of deposits.

Possible powers are over three times higher compared to the available powers of active springs and wells. Yields of thermal waters are more than thermomineral, while powers are lower, what means the temperature of thermal waters are lower.

Thermoenergetic potential of springs and wells of thermal waters is 106.8 MW_{therm} and thermomineral waters is 144.6 MW_{therm}. Deposits of thermomineral waters are the most common with powers <0.1 MW, compared to thermal waters, thermomineral deposits with powers > 10 MW_{therm} are three times more frequent than thermal waters.

9.2 Thermoenergetic potential of deep hydrogeotermal systems

Hydrogeothermal potentials are formed in nine hydrogeothermal regions of different extent, depths, types of structures, energetic potential, water quality and application. Various assessments and computations of geothermal potential are performed as exploitable unrenewable, minimal unrenewable, electric and renewable potential for depths of 3.000 and 3.000 to 5.000 m below surface.

Renewable potential of hydrogeothermal systems as the most representative was calculated for doublet (production and reinjection) well systems and includes the area of 26.200 km^2 of Bosnia and Herzegovina as follows in Table 7 and 8:

- Heat in place (HIP), HIP= Ctx (T-T0), where Ct = total heat capacity in the reservoir, T= mean temperature in the reservoir, T0 = mean annual ground temperature.
- Identified Resources (IR) are equal RHWxHIP, RHW = 0.33 x (T – 25°C) / (T – 11°C). Identified Reserves (IRS) are equal IRS = 0.5 x IR.
- Possible Reserves (PR) are equal 0.65 x IRS.

Possible Reserves represent the basis for calculation of geothermal powers, which amount 4.3x104 $MW_{century}$.

The heat in the collector and probable reserves of 9 hidrogeotermalnih regions are given in Table 8 Powers of hydrogeothermal systems can be much higher or lower, but however in the last case they can be in the future of significant importance as new, nonconventional, alternative and renewable energetic resource.

Economic and technical justification of polyvalent complex exploration and exploitation of hydrogeothermal resources is self evident. Therefore, it is necessary to intensify exploration of hydrogeotherms and synchronize it with oil and gas exploration, while continuously, transferring world know-how and technology and applying it to the geological conditions in Bosnia and Herzegovina.

Computed potentials may be higher or less of the evaluated ones, what is determined by the different values of reservoir thickness, temperature, porosity and coefficient of recovery. As the increasing factors we should mention: heat convection from deeper into the more shallow horizons, meaning less deeper wells, higher renewability much so that in some areas reinjection wells will not be necessary, water steam systems with prevalent steam have higher enthalpy than the waters of the same temperature, the heat capacity of fuel gases may be found and used as energents.

Without particular explanation it is clear the enormous calculated high energetic potential can be used in very small scale because of natural and technical reasons and the degree of substitution of conventional energents by alternatives geothermal resources depends on numerous factors at present and particularly in the future.

Without specific explanation it was clear that enormous geothermal potential of Bosnia and Herzegovina may be captured and used in a very small extent. If there is not this limit, we could solve forever the energy needs of the country i.e. many factors have influence on the level of substitution of conventional energents by geothermal energetic resources.

10. GEOTHERMAL UTILIZATION

For 80 locations and boreholes in B&H can be used without further explorations 170 MW-thermal with individual power of 0.1 to 15 MW thermal. For 20 locations or zones can be used 140 MWtherm and the remaining 60, only 30 MWtherm of thermal power with a single less than 1 MWtherm. From this it is apparent unevenness of distribution of geothermal resources (Fig. 3 and 4).

Waters from springs and wells are used from 31 deposits with available power 206.3 MWtherm and a temperature of 14 - 96 °C. Water temperature of 36 deposits were <20 °C and 44 reservoirs have a single yield <10 l/s.

Of the 33 deposits in use are 15 thermal and 13 thermomineral waters with wells and 5 with springs only.

Direct use of geothermal energy is implemented at 23 localities. Spas and recreation centers are the main users of hydrigeothermal energy (20), then individual space heating (6), green houses (1) and one fish farming. Geothermal heat pumps are used in 3 localities; there are no heating of waters in swimming pools with GHPs.

Utilization of geothermal energy for direct heat is the following:

1) individual space heating and sanitary waters (44.9 %),
2) bathing and swimming including balneology (39.2 %),
3) greenhouses (15.5 %) and
4) fish farming (0.4 %).

10.1. Bathing and Swimming

There are 20 spas of thermal and thermomineral waters and recreation centers with swimming pools, which are heated by geothermal waters directly or indirectly through heat exchangers.

Between these 20 spas there are also 9 public recreational centers where geothermal water is used only in open-air swimming pools during the summer season. There are 4 spas with open-air swimming pools active in the summer and in the same time in these spas indoor pools with accompanying facilities work all time of the year. Water temperatures in thermal spas range from 17, 4 to 58°C. The total geothermal energy used for bathing and swimming is estimated at 27.67 GWh_{th}/yr.

Thermal waters are used in 6 spas from which one radioactive (Fojnica) and one hyperalkaline – pH=12 (Kulaši) and 2 recreation centers (Toplica - Lepenica and Mala Kladuša). Thermomineral waters are used in 13 locations: 6 spas, 4 recreation centers from which one is for fish farming in cold season (Sedra Breza) and 1 greenhouse. Between 4 recreation centers of these waters one has hyperalkaline water – pH=11.75 (Lješljani). Extreme high yields are in five thermal spas with single Q>80 l/s and in 9 thermomineral spas with single Q>100 l/s but this capacities are partially in use only.

In the end of 2012 spa Kulaši Prnjavor finished with work because of great depts.

10.2. Individual Space Heating and Sanitary Waters

The second most important type of direct use of heat is mainly at thermal spas for space heating (6). Individual space heating with heat exchangers is performed in 5 localities (Ilidža Terme, Ilidža Termalna rivijera, Slatex-Slatina, Slatina and Dvorovi). In Kulaši Prnjavor spa water after balneological use is heated by coal burning and serves for heating closed space of this spa. This type of heating is used for 6 month a year. Total geothermal energy used for individual space heating is 31.69 GWh_{th}/yr.

10.3. Agriculture

10.3.1. Greenhouses

The heating of greenhouses with geothermal water began in 1970s at Domaljevac (north Bosnia) for production of flowers and vegetables for domestic market and export to Croatia. The total geothermal energy used in the greenhouses is about 10,94 GWh_{th}/yr. Active period of work is during ten months of the year.

Problems are in decreasing of yields of wells, even with outflows stopping, in 3 wells, which are very close each to other, scaling of high mineralized waters cause diminishes of capacities. The problems is also in high GWR of free noncombustible and combustible gases with CH_4 and its higher homologues and there is also interference between productive wells and it can use in the same time one well only. Some of wells are probably damaged in lower part of casing.

10.3.2. Fish farming

Fish farming exists in swimming-pool in one locality (Sedra Breza) during cold period, which serves as recreation bathing and swimming basin in warm season. Total geothermal energy used for fish farming is 0.31 GWh_{th}/yr.

10.5. Geothermal heat pumps

The GHPs are used in an open loop water - water system at 3 localities of thermal spas only (Fojnica FB-2, Višegrad, Gata), where water temperature is low for raising the thermal water temperature for space heating. The geothermal energy used for GHPs amounts to about 3,7 GWh_{th}/yr. Three GHPs were used in Laktaši spa, which are now out of work because of technical difficulties. Closed loop geothermal or ground source heat pumps are proposed for some individual objects from good promotion of producers of equipment and open loop systems with groundwater sources of inlet temperature of 13°C are planning especially for greenhouses (Klokun – Herzegovina).

11. DISCUSSION

Low enthalpy geothermal resources are utilized in B&H and high temperature (<100°C) geothermal systems with and without waters were proved in Mesozoic masses, overlain by Tertiary sediments, of Artesian basins of northern Bosnia (the part of Pannonian basin); these resources are still not in use.

Primary application of direct heat in spas is balneology and space heating.

Possibility of energy growing utilization of waters is in space heating, agricultural activities and expanding of use in balneology, recreation and sports.

The manner of using of waters is not adequate to their verified quality and quantity and we can see the utilization of waters falls behind to their level of investigation as well as in different application as in available capacities too.

At some localities flow rates decrease during exploitations (Gračanica, Gradačac, Fojnica, Sanska Ilidža) because of interference (caused by too much mutual nearness of wells) of the surrounding wells, inadequate building of screens, scaling (Ilidža, Gračanica, Domaljevac), probably damaged wells and what is the most important reason - incorrect worked wells (Tičići – outflow through annular space, Dvorovi – impossibility of deeper drilling, Gračanica – inadequate screens, Ilidža, Domaljevac - scaling. In the same time there is not decrease of waters temperatures. The greater yields of active wells can be got by cleaning and deeper drilling.

The distribution pipes from eruption trees through heat exchanger give great resistence to water flow and make possible the use of 1/3 of available yield only which exist in the mouth of wells.

Inevitable task in all further investigation is to perform production wells technical correctly, because the greatest number of active wells needs necessary rehabilitation, reconstruction and deeper drilling in the aim of optimal utilization (IB-1, Tičići, Fojnica, Dvorovi, Gračanica, Domaljevac).

During last 8 years were drilled wells in Gradačac-4, Kakmuž-1, Garovci-1, Slatina-1 and Slobomir-1 (Milivojević et al., 2012). Drilling was performed in investigated exploitation fields, none new occurrence is discovered during this period.

There are 10 localities of thermal waters for water-supply from which Toplica Spreča is one of the greatest thermal springs in Europe, one for bottling (3 localities are planned for bottling) and 2 thermomineral waters for bottling also. Extraction of free CO_2 is performed in 2 localities: 1) for industrial use (2 wells in Kakmuž) and 1 for balneological purposes as baths with CO_2 (Teslić).

Effective work of spas is possible after drilling of wells, because the natural springs had low yields. For illustration in 9 deposits of thermomineral waters with low yields of springs were got by drilling great quantities of waters, even 400 times greater (FB-2 Fojnica) and in 6 thermal spas also from which one can conclude there are not the effective utilization of these waters without drilling wells.

Difference between inlet and outlet temperatures in most localities is very small from which result low capacity factor (0.37).

Small capacity factor is a clear evidence of an inadequate use of the installed geothermal capacities. The fact which indicates this is in nonsteady energy demand. In all facilities the amount of energy used in certain period varies significantly. In most cases capacities of waters available are much higher than those needed to satisfy the actual demand, a large part of installed capacities remains unused over a long period of time.

There is need to make reinjection wells to prevent decreasing yields of productive wells and pollution of surficial waters by high mineralized and waters of higher temperatures (Domaljevac, Gradačac, Gračanica, Laktaši, Ilidža, Kakanj, Teslić).

Enlargement of utilization in quantitative sense is possible in almost all hydrogeothermal deposits. Influence of new wells in Gradačac area act to greater drawdown and pollution of wells in Ilidža spa, because of that it needs the urgent measures to make protection projects and their implementation. It is important task to project and drill new reinjection wells.

There are not the shallow drillings for resources (horizontal loops, borehole heat exchangers with heat pumps – BHE/HP, driven ground systems), the use of deep borehole heat exchangers and doublet ptoduction - reinjection wells.

12. FUTURE DEVELOPMENT AND INSTALLATIONS

There is not any government funding or participation for geothermal energy exploration – exploratory and productive drillings and use after 1992. Because of this fact the drilling activities are significantly diminished compared with earlier period.

Initial investments in geothermal heating in BiH are higher than they are in conventional heating systems and because of that stimulative measures from the governement are needed for utilization of geothermal energy.

Significant growth of utilization of geothermal resources can be expected in individual and district heating, greenhouses and enlargement in spas, recreation centers and sports connected with winter sports and relaxation.

The growth of utilization of geothermal resources should be based in the followings:

- increase the use of GHPs and heat exchangers,
- enlargement of capacity factor of existing installations,
- optimize and intensify the exploitation of production wells,
- introduce the cascade systems of use of geothermal waters,
- use hte thermoenergy from negative petroleum drillholes,
- development and enlargement of present and a new geothermal fields with performing of new deeper wells,
- use of heat pumps from alluvial aquifers along numerous rivers and
- introducing and implementation of a new technologies.

Determination of exploitation of geothermal fields of high enthalpy for electric power generation employing binary process with high temperatures are proved by drilling and possible at present in Semberija (>120°C, depth 2500 m) and in the area Domaljevac – Obudovac (<100°C, depth 1500 m). Other potential zones of such energetic levels can not be proposed for safe productive drilling in present degree of exploration and knowledge of deep hydrogeothermal systems.

Priorities of investigation according to temperatures – energetic levels and safety to obtain the geothermal resources are the followings: 70 – 100°C - Middle Bosnian basin, 50 – 70°C – Banja Luka basin, Spreča fault zone, 30 – 50°C – Ophiolites, Bihać basin and Una-Sana Paleozoic massif and ca 30°C – Mid and South-east Bosnian Paleozoic massif. More and less promising geothermal zones and proved important resources for investigation and utilization of hydrogeothermal systems are presented in Fig. 1, 2 and 3.

Jadran Nafta-gas company got consession in 2011. for investigation and exploitation oil and gas in territory of Republic of Srpska (entity of B&H). It is planing workout 2 deep exploratory wells in 2013. for hydrocarbons in areas of Posavina and Semberija in Republic of Srpska. Large number of seismical 2D investigations was performed in belt Novi Grad-Doboj in 2011 and 2012 and deconservation of wells Dv-1 (Dvorovi -1) and Sv-1 (Svinjarevac-1) in Semberija was done; both wells show negative results in connection to oil and gas.

Shell company got consession for investigation and exploatation of hydrocarbons in Federation of Bosnia and Herzegovina (entity of B&H) and nowadays are not yet planned drillings but interpretation of data are carried out now.

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Table 1. Range and mean temperatures of hydrogeothermal regions 1, 2, 4 i 7 for depths 500 to 5,000 m below surface

Depths, m		500			1,000				2,000	3,000	4,000	5,000
Regions		**1**	**2**	**7**	**1**	**2**	**4**	**7**	**2**	**2**	**2**	**2**
Temp. °C	minimal	19	25	30	29	39	46	42	82	111	158	176
	maximal	21	39	30	32	62	62	42	101	147	182	209
	middle	20	31	30	30.5	50	56	42	92	130	169	196

Table 2. Average temperature gradients and heat flows of significant drillholes of hydrogeothermal regions (Miošić, 1998)

Parameters⇒ Drillholes ⇓	Depth of drillholes (m)	Average temperature gradients (mK/m)	Average heat flow (mW/m^2)
VKT-1	1500	16.0	75.1
B-1*	964	22.1	99.9
Š-1	587	17.0	78.5
SB-1*	672	36.2	111.4
Kor-1	2481,2	34.0	77.2
Po-2	1585,4	40.6	72.7
Do-2	1187	46.1	79.0
Do-1*	1275	55.2	100.8
Br-1	3913	37.3	80.8
M-1	1280	33.5	61.0
Ob-1	3296	39.2	85.3
V-1	1461,2	43.0	86.8
V-2	1426	40.2	72.4
V-3*	1160	50.9	97.2

Parameters⇒ Drillholes ⇓	Depth of drillholes (m)	Average temperature gradients (mK/m)	Average heat flow (mW/m^2)
Po-3	1516,5	47.5	85.5
S-2	1591,5	41.4	80.8
S-1*	1345,5	51.7	113.7
Sv-1	1746	46.6	87.7
Bij-1*	2479	47.8	101.4
Tu-1	3531	36.9	79.2
Rt-4	1551	29.1	60.0
K-1*	745,5	40.7	108.7
K-2*	655,2	42.7	112.5
Sl-1*	2025	56.3	134.9
Var-1	1202	25.8	82.4
Knj-1	1315	33.4	92.8
III/B*	590,1	42.2	94.4
Gla-1	4206	13.0	46,4

* Drillhole with convective geothermal parameters

Table 3. The age and lithology of collectors of hydrogeotermal regions

Periods of collectors	Hydrogeotermal regions⇒ Lithology of collectors ⇓	1	2	3	4	5	6	7	8	9
Silurian	Marble, Quartzite, limestone, dolomite	–	*(?) +	+	+(?)**	+(?)	+	(?)+	+	+
Devonian	Limestone, marble, dolomite, quartzporphirite	–	(?)+	+	+(?)	+(?)	+	(?)+	+	+
Carboni-ferous	Limestone, klastiti, dolomiti	–	(?)+	+	+ (?)	+(?)	+	(?)+	+	+
Permian	Limestone, dolomite, Quartzite, Marble	–	(?)+	+	+(?)	+(?)	+	(?)+	+	+
Triassic	Limestone, clastite, dolomite, chert	+	+	+	+	+	–	+	–	–
Jurassic	Limestone, dolomite, chert, clastite	+	+	+	–	+	–	+	–	–
Cretaceous	Limestone, dolomite, chert, breccia, clastite	+	+	+	–	–	–	+	–	–
Tertiary	Limestone, clastite	–	+	–	–	–	–	–	–	–

* There is no evidence of Paleozoic but it is assumed (?)+
** There is Paleozoic, but it is no certainty it is situated here +(?)

Tabela 4. Basic data on springs and drillholes of hydroterms

Type of waters	Deposits with springs only (number of deposits/ springs)	Deposits with springs and drillholes (number of deposits/ springs and drillholes)	Deposits with drillholes only (number of deposits/ drillholes)	Number of drilholes	Deposits with drillholes only	Number of deposits	Yield of drillholes and springs of all deposits (l/s)	Available power of springs and drillholes of all deposits ($MW_{therm.}$)	Possible power of springs and drillholes of all deposits ($MW_{therm.}$)
Thermal	31 101	18 45	8 11	56	26	57	1827.9	106.815	315.44
Thermomineral	9 74	16 55	5 16	71	21	30	1093.2	144.6	479.80
Total	**40** **175**	**50** **100**	**13** **27**	**127**	**47**	**87**	**2921.1**	**251.415**	**795.24**

Table 5. Measured and prognostic depths and temperatures at the top of aquifers of hydrogeotermal regions

Regions ⇒ System ⇓	1	2	3	4	5	6	7	8
Silurian – S					1,000 m 35°C	1,000 m 35°C		2,000 m 60°C
Devonian – D			1,500 m 55°C		600 m 25°C	600 m 25°C		1,500 m 47°C
Permian – P	1,500 m 52°C				600 m 25°C	400 m 20°C		
Triassic – T_3	1,000 m 30°C	1,290-3,900 m 64 - 177°C		2,000 m 80°C	3,000 m 85°C		2,500 m 95°C	
Cretaceous – K_2		780 - 1,530 m 42 - 93°C					1,000 m 50°C	
Baden – M_2^2		625 - 1227 m 37 - 63°C						
Sarmatian – M_3^1		262 - 1185 m 20 - 63°C						
Panonian – Pl_1^2		250-565 m 21- 38°C						

Table 6. Average geothermal gradients, heat flows, temperatures of basins of Northern Bosnia

Basins ⇒	**Semberija subregion**		**Bosnian Posavina subregion**		**Tuzla basin**	
Parameter ⇓	Range	The average	Range	The average	Range	The average
Geotherm. gradient (mK/m)	41.4 – 53.9*	46.8*	28.2 – 66.6*	42.5	29.1 – 56.3*	36.6
Heat flow (mW/m^2)	82.8 – 116.6*	95.9*	61.0 – 100.8*	81.7	60 – 134.9*	84.6
Temp. at 1,000 m (°C)	53 - 62	59	40 - 62	51.4	39 - 53	44.7
Temp. at 2,000 m (°C)	93 - 101	97.3	78 - 92	87.5		82.0
Temp. at 3000 m (°C)	141 - 147	144	122 - 128	125		111
Temp. at 4,000 m (°C)			168 - 182	175		158
Temp. at			203 - 209	206		176

5,000 m (°C)						
Depth of 120°C (m)		2,420	2,625 – 2,900	2,762		3,250

* Convective parameters

Table 7. Total energetic potential and power of hydrogeothermalnih regions

Type of potential ⇒ Depth, m ⇓	Heat in place (10^6 TJ)	Identified resources (10^6 TJ)	Identified reserves (10^6 TJ)	Possible reserves (10^6 TJ)	Power ($MW_{therm.century}$)
To 3,000	1428.1	385.5	191.75	125	$3.9x10^4$
3,000 – 5,000	1707.2	500.0	250.0	162.5	$5.2x10^4$
Total	**3135.3**	**885.5**	**441.75**	**287.5**	**$9.1x10^4$**

Table 8. Heat in place (HIP) and possible reserves (PR) of hydrogeothermal regions (Čičić, Miošić, 1986)

Region ⇒ **Energy ⇓**	1 Mz massif of NW Bosnia	2 Mz i Tc artesian basins of north Bosnia	3 Una-Sana Pz massif	4 Ofiolite massif	5 Mz Mid Bosnian massif	6 Mid Bosnian Pz massif	7 Mid Bosnian Mz basin	8 Pz massif of SE Bosnia	9 Pz and Ng massif of E Bosnia	**Total**
HIP to 3000 m **x 10^6 TJ**	50,4	780	21,1	288	132,5	33,6	105,6	8,1	8,8	**1428,1**
HIP 3000-5000 m **x 10^6 TJ**	46	717,6	79,7	483	111,1	69	121,4	37,3	42,1	**1707,2**
HIP Total x 10^6 TJ	96,4	1497,6	100,8	771	243,6	102.6	227,0	45,4	50,9	**3135,3**
PR to 3000 m **x 10^6 TJ**	6,5	113	3	30	18	4,5	15	0,75	1	**191,75**
PR 3000-5000 **x 10^6 TJ**	6,5	107,5	11,5	70	16	9,5	18	5	6	**250,0**
PR TOTAL x 10^6 TJ	13	220,5	14,5	100	34	14,0	33	5,75	7	**441,75**
HEAT ENERGY TJ/km^2 to 3000 m	6500	13000	3000	30000	18000	4500	15000	750	1000	
HEAT ENERGY TJ/km^2 3000 – 5000 m	6500	107500	11500	70000	16000	9500	18000	5000	6000	
HEAT ENERGY TJ/km^2 TOTAL TO 5000 m	13000	220500	14500	100000	34000	14000	33000	5750	7000	

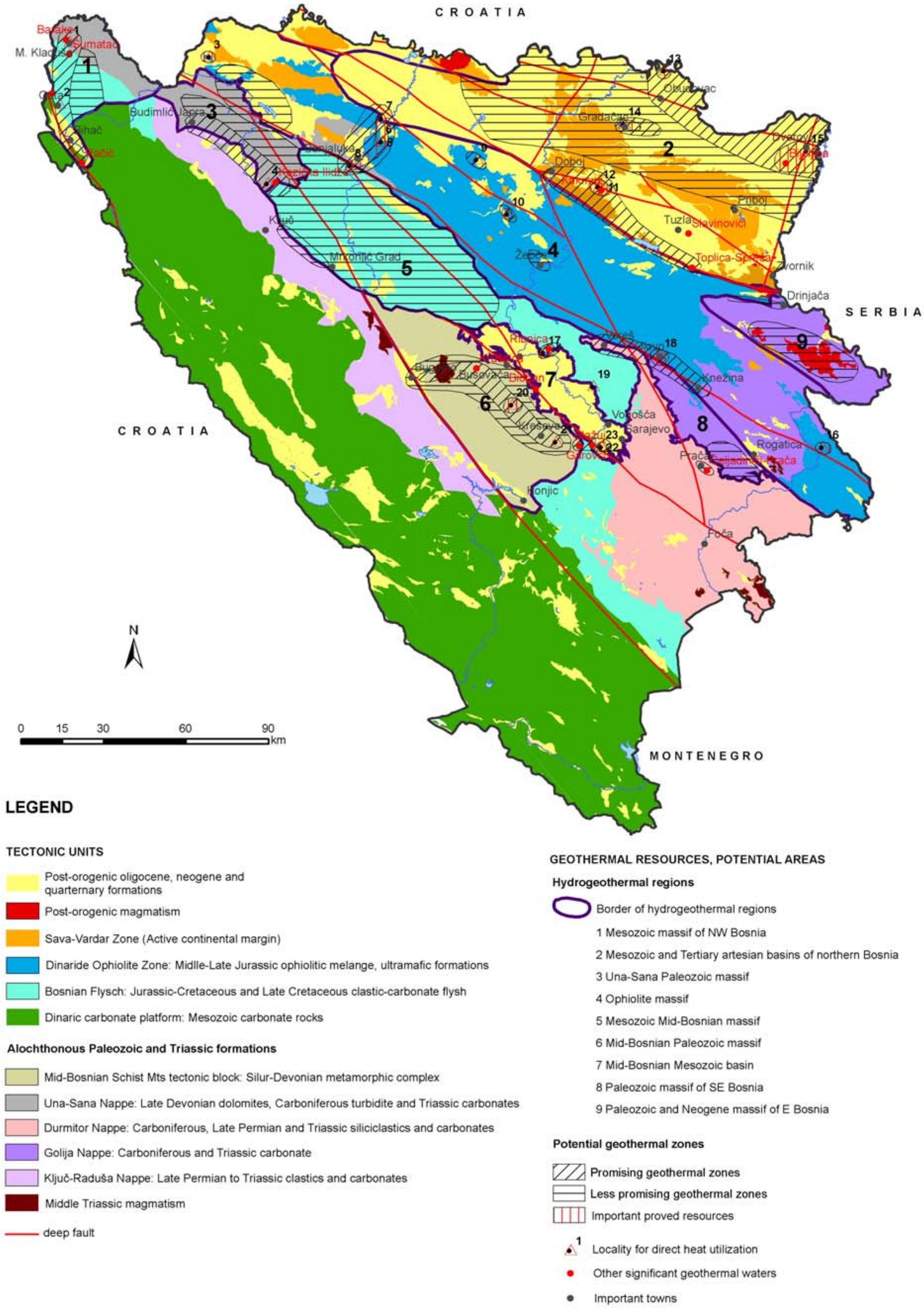
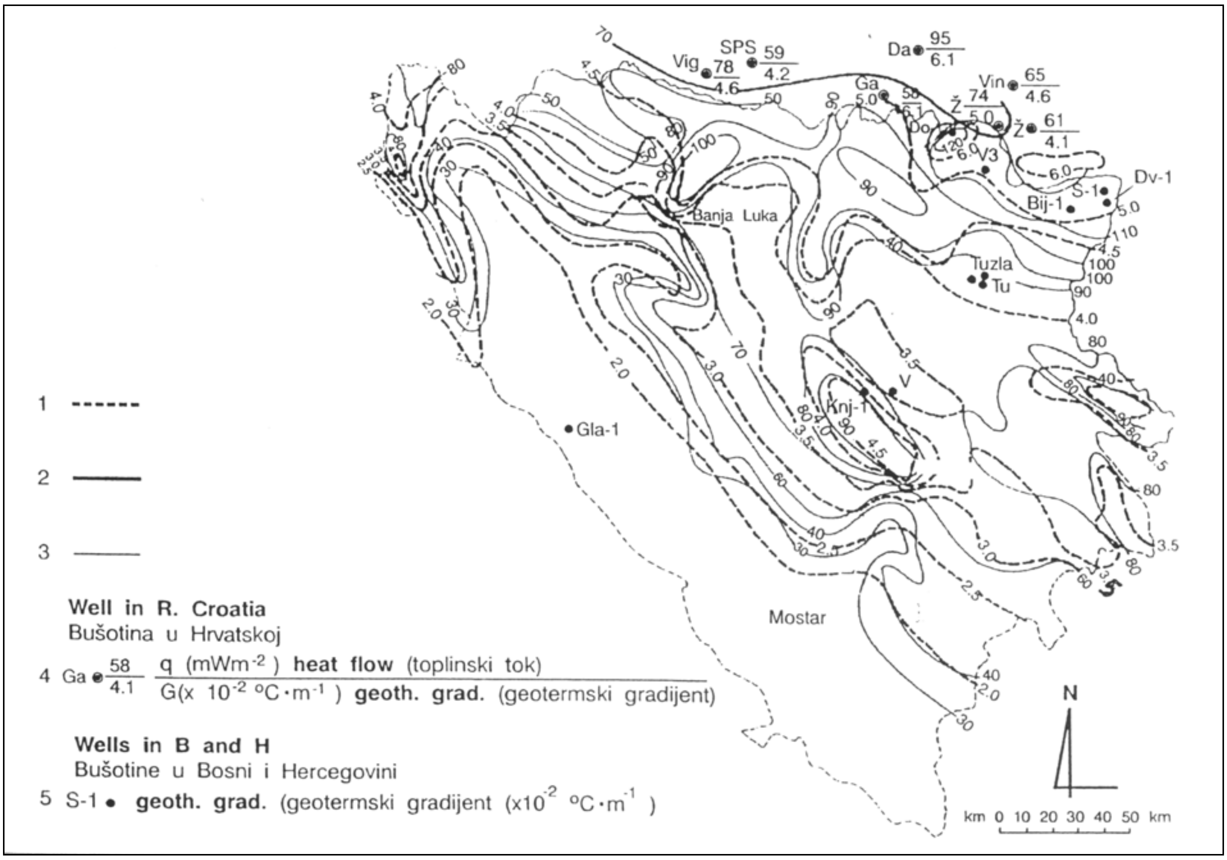


Figure 1. The main tectonic units of Bosnia and Herzegovina with their lithological composition and geothermal resources with potential areas (Miošić, Samardžić and Hrvatović, 2010)



Legend: 1 - Isolines of geothermal gradient ($x10^{-2}$ °C m^{-1}) in Bosnia and Herzegovina
2 - Isolines of heat flow (mWm^{-2}) in Croatia, Jelić (1979)
3 - Isolines of heat flow (mWm^{-2}) in Bosnia and Herzegovina
4 - Well in Croatia
5 - Well in Bosnia and Herzegovina

Figure 2. Map of geothermal gradients and heat flows in Bosnia and Herzegovina (Miošić, 1986)

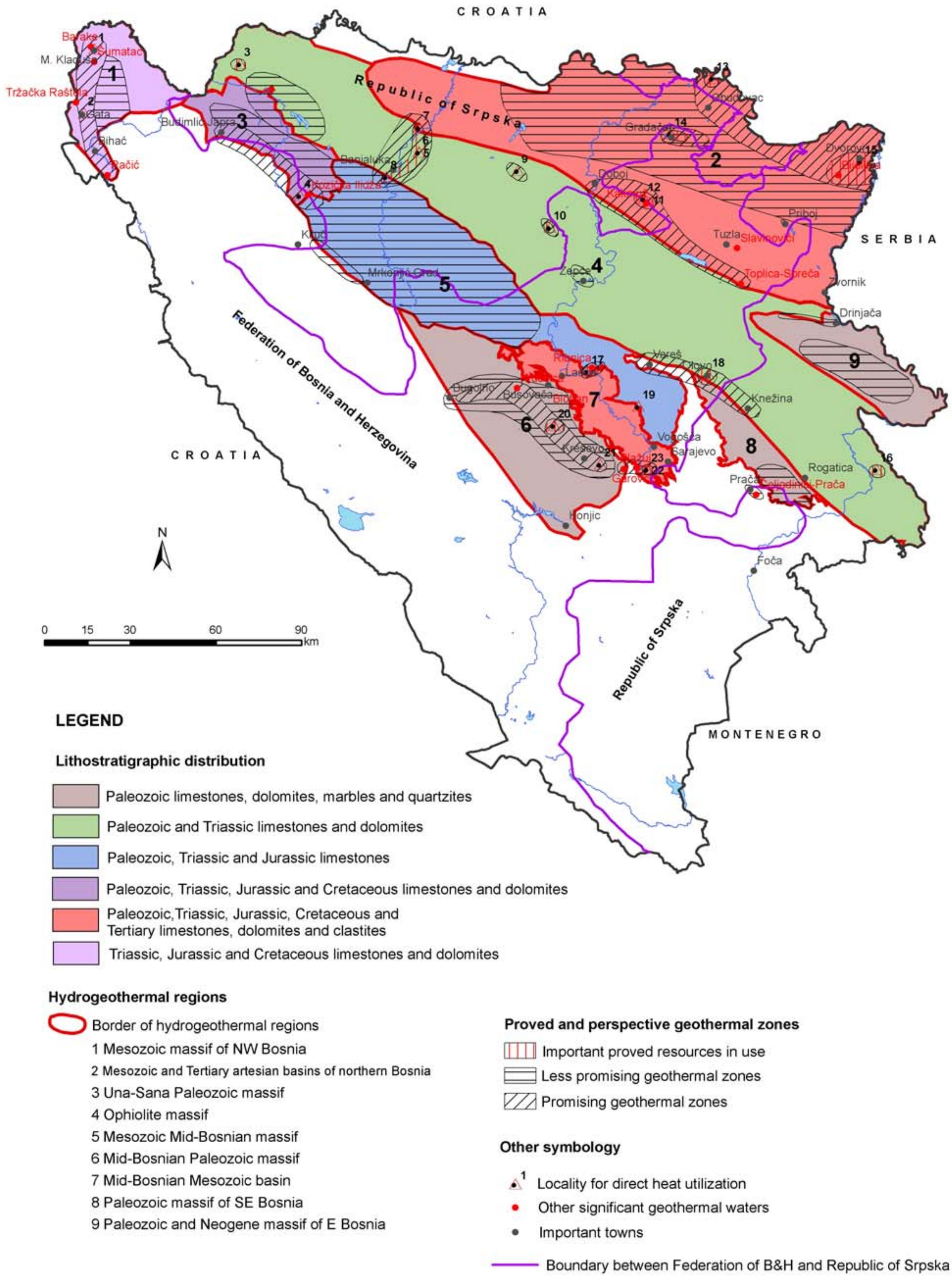


Figure 3. Lithostratigraphic distribution, hydrogeothermal regions and perspective geothermal zones of Bosnia and Herzegovina

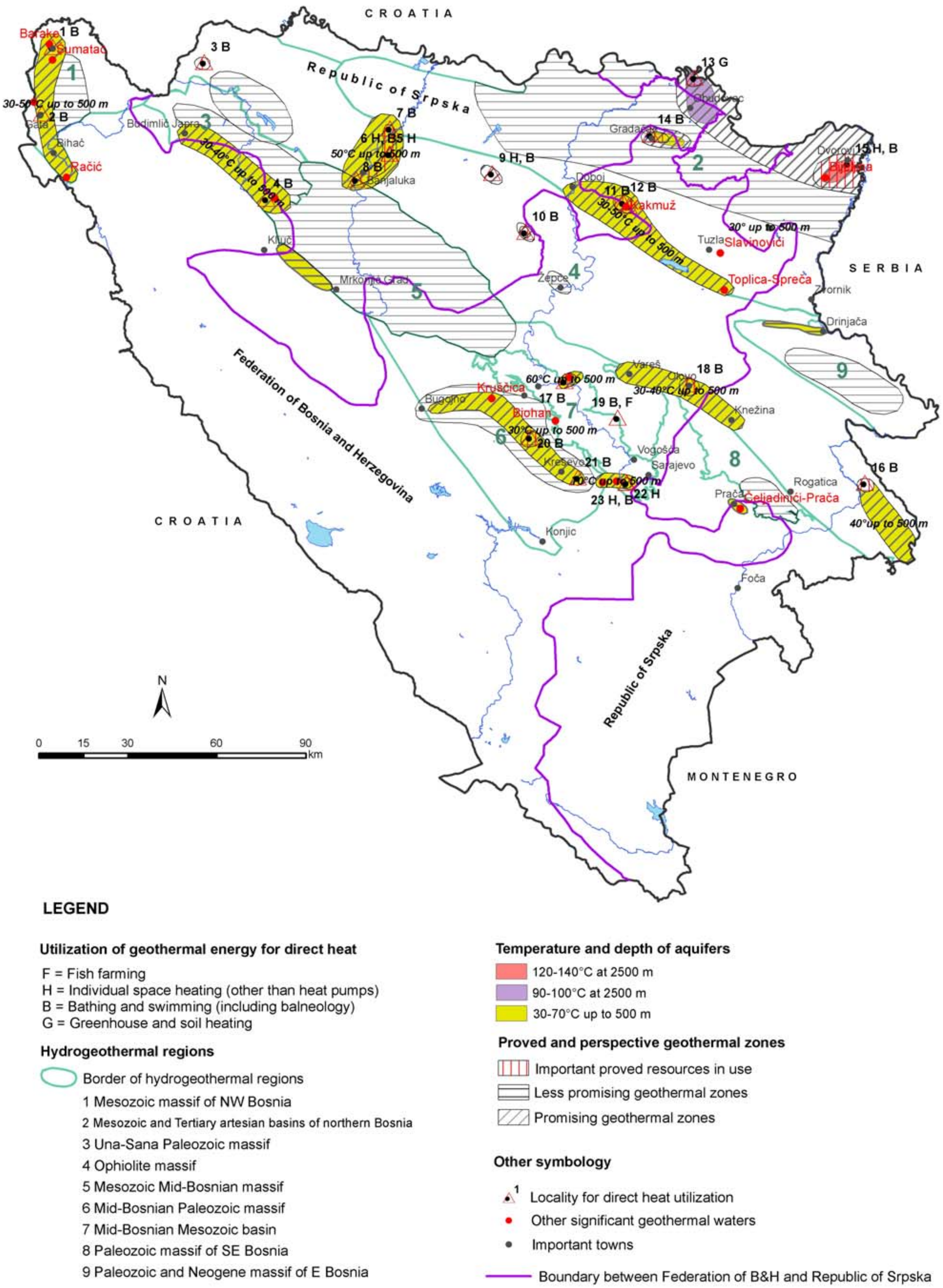


Figure 4. Priority of drillings according to temperatures of aquifers to depth <500 m and 2500 m below surface

Tables A-G

Table A: Present and planned geothermal power plants, total numbers*

*Geothermal power plants are not available in the country.

Table B: Existing geothermal power plants, individual sites*

*Geothermal power plants are not available in the country.

Table C: Present and planned geothermal district heating (DH) plants and other direct uses, total numbers

	Geothermal DH Plants		Geothermal heat in agriculture and industry		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2012	0	0	1.6	11.25	19.94	59.36
Under construction end of 2012						
Total projected by 2015						

Table D: Existing geothermal plants for district heating (DH) and other direct uses, individual sites

Locality	Installed geotherm. capacity (MWth)	Total installed capacity (MW_{th})	2012 geo-thermal heat prod. (GWhth/y)	Geother. share in total prod. (%)
1 Mala Kladuša Ilidža	2.51	2.51	0.18	100
2 Gata	0.025	0.025	0.11	100
3 Lješljani	0.15	0.15	0.99	100
4 Sanska Ilidža	0.12	0.12	0.34	100
5 Slatex-Slatina	0.53		1.54	60
6 Slatina	2.3		12.09	60
7 Laktaši	0.25	0.25	1.1	100
8 Gornji Šeher	0.21	0.21	1.1	100
9 Kulaši Prnjavor	0.35		1.32	45
10 Vrućica	0.09	0.09	0.51	100
11 Terme Ozren	0.67	0.67	1.96	100
12 Gračanica PEB-4	2.58	2.58	7.62	100
13 Domaljevac	1.51	1.51	10.95	100
14 Gradačac	0.005		0.025	85
15 Dvorovi	1.32	1.32	7.69	100
16 Višegradska Banja	0.09	0.09	0.51	100
17 Tičići-Kakanj	3.68	3.68	0.81	100
18 Olovo	0.13	0.13	0.84	100
19 Sedra Breza	0.19	0.19	0.61	100
20 Fojnica FB-1	0.13	0.13	0.37	100
21 Toplica Lepenica	0.24	0.24	0.7	100
22 Ilidža Termalna rivijera	3.22		14.84	95
23 Ilidža Terme	1.34		4.4	95
total	**21.64**		**70.61**	

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New GSHP in 2012		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2012	3	0.1555	3.7	0	0	0
Projected by 2015	1					