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Nina Rman, Tamara Marković, Mihael Brenčič

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Nina Rman, Andrej Lapanje, Tamara Marković, Miloš Markič, Dušan Rajver, Dejan Šram, Mihael Brenčič, Katja Koren, Marjana Zajc, Evgen Torhač, Peter Junež, Dragana Šolaja, Ozren Larva, Željka Brkić, Branimir Suton, Martina Crljen, Radovan Avanić, Antun Šimunić, Zoran Peh

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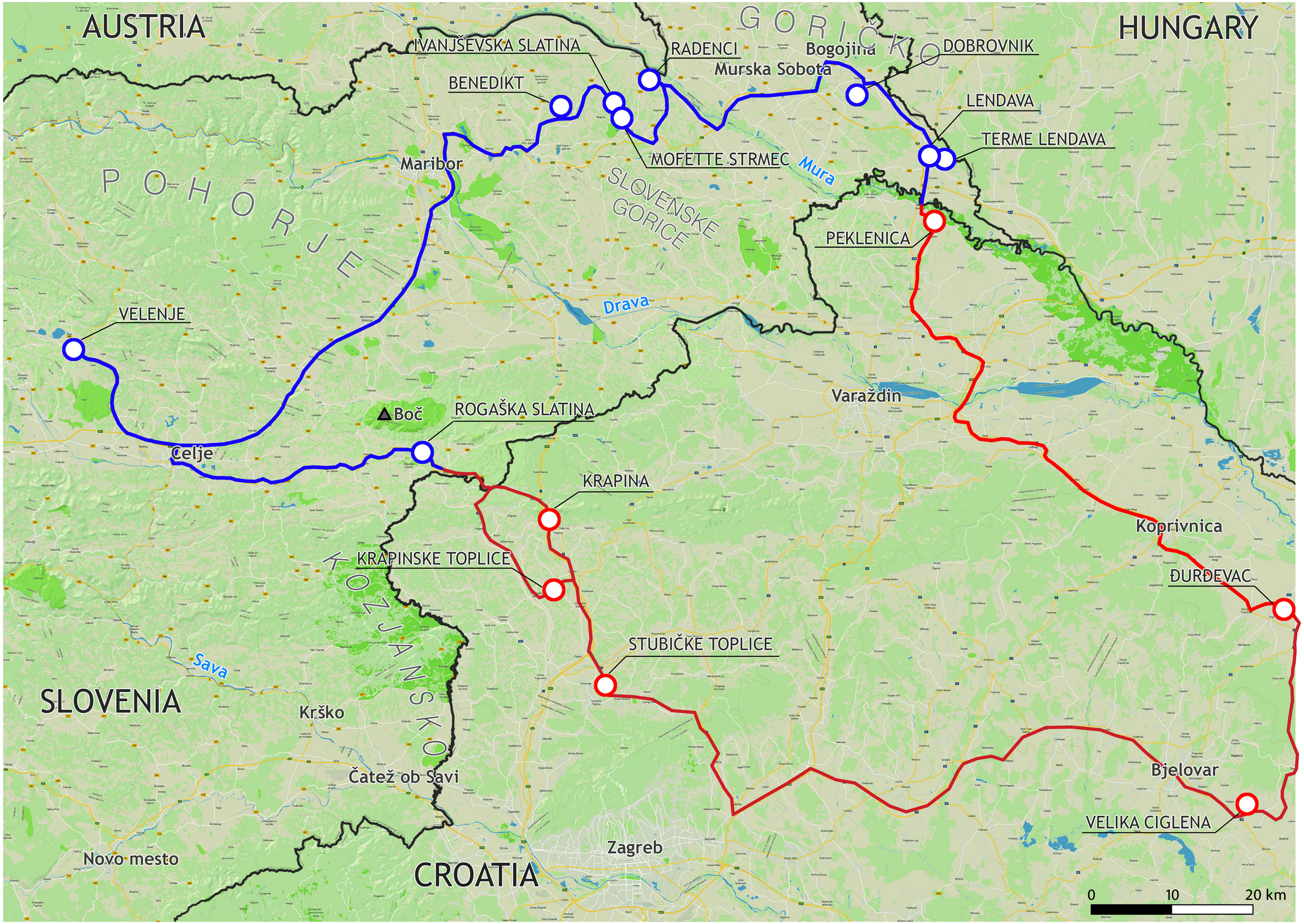
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Foreword

Nina Rman

The Slovenian Geological Congress offers our leading geologists a celebration of their research achievements in the last four years. It is a great opportunity to exchange experience internationally also, and this bilaterally organized field trip offers just that, an opportunity for many international informal contacts.

The field trip is organized as a collaboration of many institutions: the Slovenian Geological Society, the Geological Survey of Slovenia, the Faculty of Natural Sciences and Engineering of the University of Ljubljana, the Slovenian Committee of the International Association of Hydrogeologists, the Croatian Geological Society and the Croatian Geological Survey.

It also has the honnor to form a part of the annual assembly of the Commission on Mineral and Thermal Water of IAH of the International Association of Hydrogeologists (CMTW-IAH).

Most of the field trip is perfomed in the west part of the extensive Pannonian basin where in the past hydrocarbon industry used to play an important role. Nowadays, many of these sites are depleted, and thermal and mineral water production is economically and turistically important in both countries, Slovenia and Croatia.

Slovenia in depths – boreholes, deeper than 500 m

Nina Rman, Andrej Lapanje

It might be interesting to know that in Slovenia the well depth of 1000 m was first exceeded in 1942 by the well D-1/42 (1467 m) in Dolina near Lendava. Many boreholes with depths between 1000 m and 2000 m were drilled there, in Kog, Murska Sobota and Petišovci between 1942 and 1944, while the depth of 3000 m was exceeded in Gabrje near Lendava in 1955.

The first well on mineral water deeper than 500 m was drilled in Boračeva near Radenci in 1962, while on thermal water in Čatež in 1971.

All boreholes deeper than 3000 m were drilled for hydrocarbon exploration, also the deepest one, Ljut-1/88 at Ljutomer. The deepest rock core in Slovenia was collected at 4048 m there, consisting of gneiss. It also drilled through the thickest Neogene sedimentary rocks sequence, of 4010 m in total. We will learn more about the Croatian boreholes during the field trip.

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http://www.egeologija.si

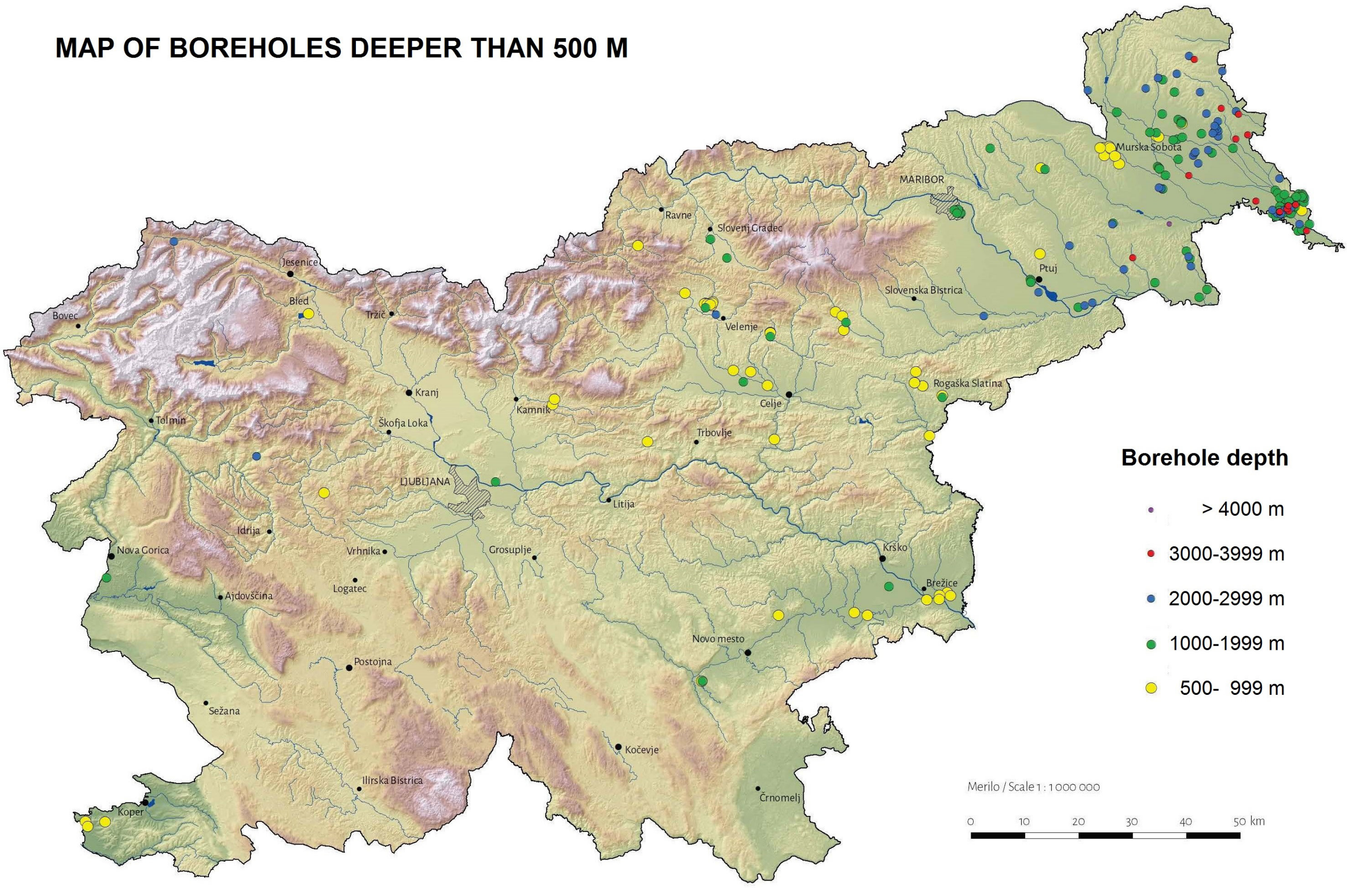

Figure 1: Eastern Slovenia is the most investigated part of the country in depth due to its richness of hydrocarbon, coal, mineral and thermal water resources (modified from the Geological Atlas of Slovenia)

On the road from Velenje to Slovenske gorice

Mihael Brenčič

Slovenia is predominantly composed of sedimentary rocks and sediments, other types of rocks are appearing only occasionally, therefore hydrogeology is typical for sediment rocks and sediment related phenomena. Starting in Velenje sedimentary basin where in the past thirty years extensive hydrogeological investigations were performed. They were intended to preventing groundwater inrush to the mine where productive layer of lignite is positioned bellow sandstone aquifer and the mine is also endangered with the groundwater inflow from the Triassic carbonates in the flanks of the basin.

Heading south to Velika Pirešica we are coming on the alluvial plain of Savinja River representing shallow aquifer (Lower Savinja Valley) with relatively high permeability and yield. In the central part near the river the aquifer is under unconfined conditions and on the edges, it is under confined conditions due to presence of clay deposits from the mountain hinterland which consists predominantly from clastic sediments and rocks. In its eastern part several wells for drinking water supply for Celje city are positioned, the oldest still operating from the World War II. The area is known for hops growing and intensive agriculture. In 70's groundwater was heavily polluted with nitrates and pesticides, today aquifer is still under the threat but with diminishing trend in concentrations. In part of its course over the aquifer the highway is positioned under the groundwater level. To prevent flooding special drainage system was constructed diverting groundwater to Savinja River.

Between cities of Celje and Slovenske Konjice we are crossing mountain range of Konjiška gora consisting predominantly of dolomites and limestones. In the area several important water resources suppling local settlements are present. There are some karstic springs. In dolomites several wells were developed. In other parts of Slovenia similar fissured dolomitic aquifers are also representing important drinking water resources. Northwest of Slovenske Konjice borough of Zreče is positioned. In the area Zreče Spa was developed where groundwater with the temperatures around 35 °C are exploited. Water is of Ca^{2+}-Mg^{2+}-HCO_3^- facies. Deeper groundwater circulation is connected with regional groundwater flow induced by higher relief in the surrounding of the valley. Spa is specialized in healing locomotor system injuries and disorders, sports injuries and orthopedic post operational rehabilitation.

In the area of Slovenske Bistrica we are coming on the larger Quaternary aquifer of Dravsko Ptujsko polje (Drava Ptuj plain). It is representing important drinking water resources for larger cities of Maribor and Ptuj as well as for small villages and boroughs in the wider area. Consequently, it is covered with extensive drinking water protection zones, the largest system of groundwater protection present in Slovenia; today with intensive development and agriculture seriously challenged. In large part aquifer is unconfined with permeabilities in the range between 10^{-3} and 10^{-2} m/s and with high yield. Thickness of saturated part is in the range of 15 to 25 m. Groundwater is flowing in the direction from west to east draining to several springs and Drava River. Aquifer is recharged through rainfall infiltration but important part of recharge in its western part is represented by exfiltration of surface water from beds of creeks coming from the Pohorje mountain. Such recharge influences dynamics of groundwater, on the western part of the aquifer groundwater fluctuation amplitude is of several meters and then diminish towards the east to the order of one meter. In central part of the plain, in the direction E-W is presented depression filled with Pliocene sediments. They are extended down to other formations pertinent to understanding hydrogeological conditions in NE Slovenia. This is the same set of formation where Ptuj Spa with lukewarm waters is positioned. Pliocene beds are also representing aquifer and where several deeper water supply wells up to 250 m are already developed. This aquifer is recharged through the regional groundwater flow from Slovenske gorice on the north and Haloze on the south. Due to the problems with groundwater quality in the upper Quaternary aquifer nowadays more and more deeper wells are drilled in this aquifer and drinking water supply is switched to them.

In the most northwestern part of the aquifer in the left bank of the Drava River near Maribor city is positioned groundwater pumping station Vrbanski plato where managed aquifer recharge system is emplaced. In the past aquifer dynamics of Dravsko Ptujsko polje was substantially altered with the construction of two hydropower plants; main reason was complete rearrangement of Drava River water course, construction of long drainage systems and deep diaphragm along the river's left bank. On the central part of the plain big aluminum industry is positioned with two big landfills influencing groundwater quality.

From Maribor to the direction of BenediKt we are crossing Slovenske gorice rolling hills where clastic rocks and sediments from Miocene on the west and Pliocene on the east are positioned. For the drinking water supply due to low permeability Miocene beds are not suitable but going to east direction more coarse sediments were deposited and consequently higher permeability is present. In that part several successful water supply wells were drilled.

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Slovenske Gorice – Geology of the Mura-Zala basin

Andrej Lapanje, Dejan Šram

The Pannonian basin is an Alpine-Carpathian fore-deep and intramontane basin which spreads from Austria to Ukraine. Its sub-basin, the Mura-Zala basin, developed as a result of Lower to Middle Miocene extension in the Central Paratethys. Regionally high heat flow of over 100 mW/m is attributed to thin lithosphere and can be locally reduced for 10-30% due to rapid Neogene sedimentation or cold water infiltration. Conductive heat transfer is predominant in the Neogene basin fill while convection occurs locally in fissured basement rocks, e.g. in Benedikt.

Metamorphic and carbonate basement rocks (I in Fig. 3) are cut into several structural units forming horst-graben-like structures, which controlled the Neogene sedimentation. Because the basin was filled mainly from north-west and north-east, the lithostratigraphical formations outcrop in the west, and deepen and thicken towards east, toward Hungary. The siliciclastic deposits contain many water-bearing layers, but the gravitationally driven regional groundwater flow system evolved only in Neogene sediments in the upper 2 km of the basin. The terrestrial Haloze Formation forms only local aquifers (II in Fig. 3). The Carpathian to Upper Pannonian Špilje (III-IV in Fig. 3) and Lendava (V-VI in Fig. 3) Formations geothermal aquifers are of local character due to low porosity and permeability of thin turbiditic sandstone sequences, and their stratigraphic and tectonic isolation.

Hydraulically connected coarse-grained lenses of the Upper Pannonian loose sandstone of the Mura Formation (VII-VIII in Fig. 3) were deposited between silt and clay, forming a 50-300 m thick sequence of delta front environment. They represent an important transboundary geothermal aquifer with active gravity induced regional groundwater flow regime. Thermal water was recharged in the Pleistocene and flows through sandstone with high intergranular porosity (up to 30%) and hydraulic conductivity (between 10^{-5} and 10^{-6} m/s) from Slovenia to Hungary. It discharges into the Lake Hévíz in Hungary with an estimated flow rate of 20 l/s, but a hidden underground discharge into shallow fresh water aquifers is assumed elsewhere. Its depth and thickness are the greatest in the Ptuj-Ljutomer-Budafa sub-basin, near the state borders. Extent of this aquifer is estimated to be 22.175 km^2 altogether in Austria, Croatia, Hungary, Slovakia and Slovenia, of which only 1.766 km^2 is located in Slovenia. Thermal water is of Na^+-HCO_3^- type with mineralization below 2000 mg/l and almost no free gas. Momentary yields from wells had reached 60 l/s and many hydraulically connected wells stopped overflowing in recent years. Thermal water outflows from wells at approximately 60 °C and is used for direct use.

The covering Mura Formation delta plain fine-grained sediments are not favorable for thermal water production due to low permeability.

The Pontian to Pliocene Ptuj-Grad Formation (IX in Fig. 3) sandy and gravely aquifer contains predominately fresh drinking water but some lukewarm thermal water is produced for spa in Ptuj. Layers outcrop or are in contact with the unconfined Quaternary gravely drinking water aquifers in the River Drava and Ptuj plains, where they receive some recharge, while in the Slovenske gorice hills overlying clays control the recharge.

A web-viewer of the 3-D flying-carpet geological model of 5 km depth and area of 5.400 km^2 is available at http://www.geomol.eu/3dexplorer. It consists of pre-Neogene basement and eight Neogene formations but shows no faults nor Quaternary sediments.

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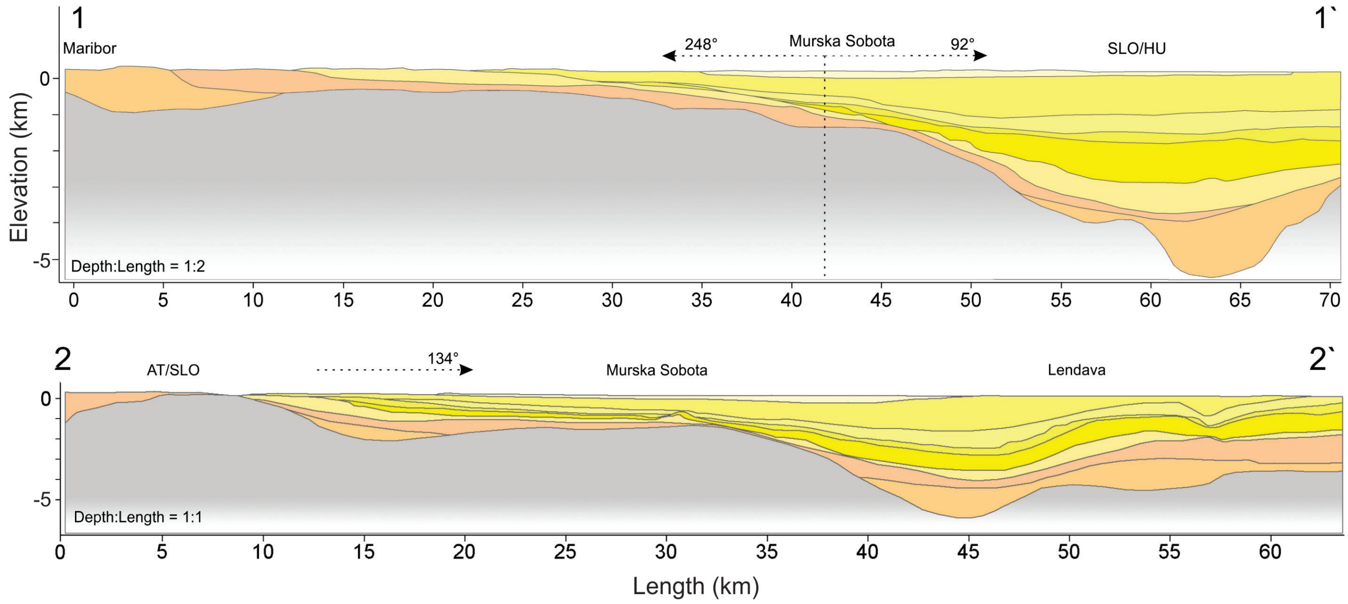

Figure 2: Simplified surface lithostratigraphic map of NE Slovenia (modified from Jelen and Rifelj (2011)) with locations of active geothermal wells open in the Neogene geothermal aquifers (Gabor & Rman, 2016). Thick black lines stand for cross sections shown below it (Šram et al., 2015).

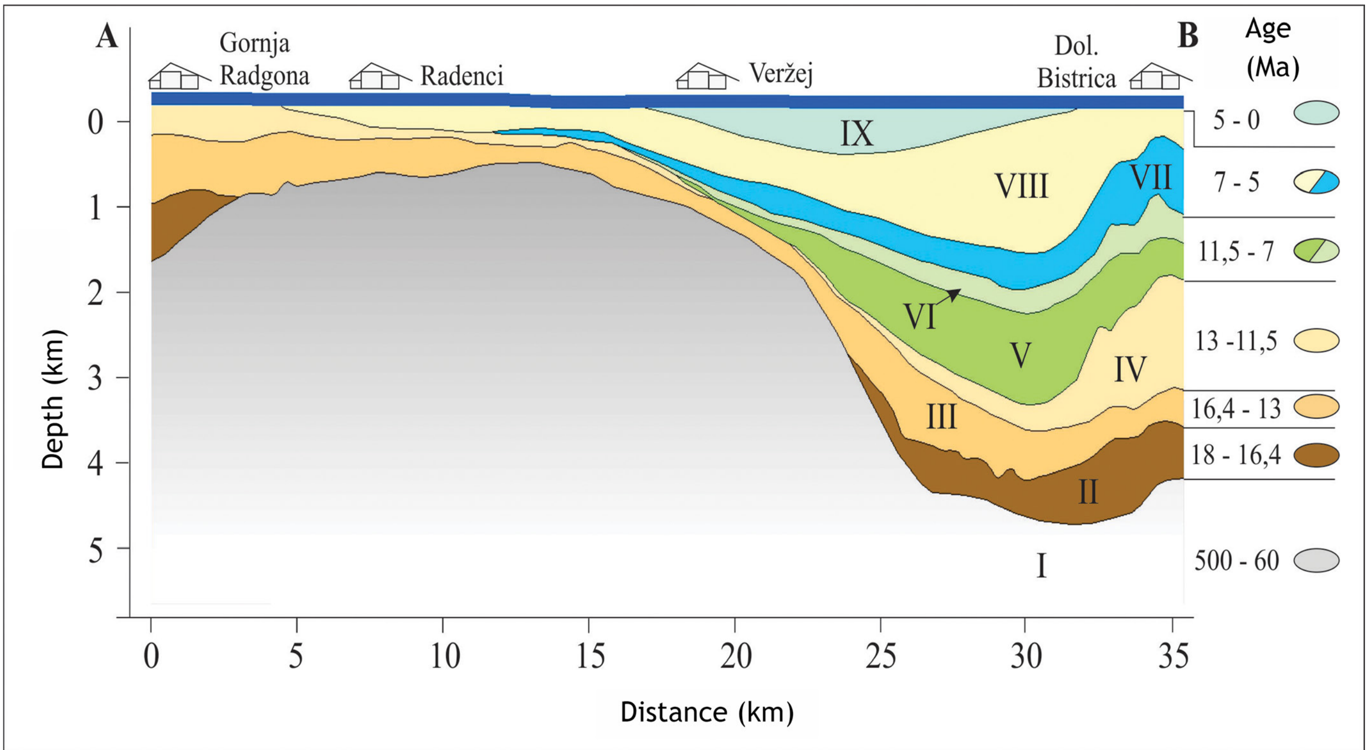

Figure 3: Stratigraphical model along the Mura River in NW to SE direction.

Benedikt – Utilization of thermal water in Slovenia

Dušan Rajver

Based on the measured high geothermal gradient (81 °C/km) in the Tertiary sedimentary section of the 788 m deep borehole BS-2/76, a thermal convection zone of at least 70°C was predicted in the metamorphic rocks at Benedikt. Therefore, a new well Be-2 was drilled in 2004 to a final depth of 1857 m. It could produce thermomineral water at about 72-74 °C from Paleozoic metamorphic rocks of mostly muscovite biotite schist with alternating dolomite marble and quartzite. Fissures prevail at 1492 m and 1848-1.857 m depth. The temperature at 1.000 m depth was as high as 80 °C but did not continue to rise further, reaching only 81.5 °C at 1.800 m. The well penetrated a geothermal convection cell within the Raba Fault zone. A similar phenomenon is also known in Čatež in the Posavska Region. The water was recharged as meteoric water in the Pleistocene. It is of Na^{+}-HCO_3- water type, high mineralised (7.4 g TDS/l) and rich in free CO_2, causing a carbonate scaling. The water was used in winter for district heating: school, school gym, kindergarten and business premises of the municipality. In 2016, the well was re-worked for testing as a deep borehole heat exchanger where temperatures of about 45 °C were expected to be produced. Today, however, the well is inactive.

To get a general overview of the use of geothermal energy in Slovenia, we can report that the total utilization of geothermal energy in 2017 was 1423.13 TJ (33.991 ktoe) with the corresponding installed capacity of 221.12 MWt. Thermal water with up to about 72 °C contributed about 41.7% of the utilized GE in the energy balance of Slovenia. Direct use took place at 32 users, where installed capacity and used geothermal energy amounted to 60.63 MWt and 593.54 TJ (14.176 ktoe), respectively. As much as 35.01 MWt appertained to 22 operational wells in NE Slovenia, producing from depths of 400-1,500 m. Thermal water is used predominantly for bathing and swimming including heat pumps (208.49 TJ), followed by individual space heating (175.11 TJ), heating of greenhouses and soils (108.38 TJ), domestic hot water heating (49.37 TJ), air conditioning (21.14 TJ), district heating (16.51 TJ) and snow melting (14.54 TJ).

Possibilities for geothermal electricity production in Slovenia have been poorly investigated in practice. However, hot pre-Neogene basement rocks in NE Slovenia may form potential reservoirs but their permeability will probably needed to be additionally enhanced by hydraulic stimulation to be able to produce sufficient flow of fluids.

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Figure 4: Producing well Be-2 in 2010 with a cooling pool (photo by N. Rman).

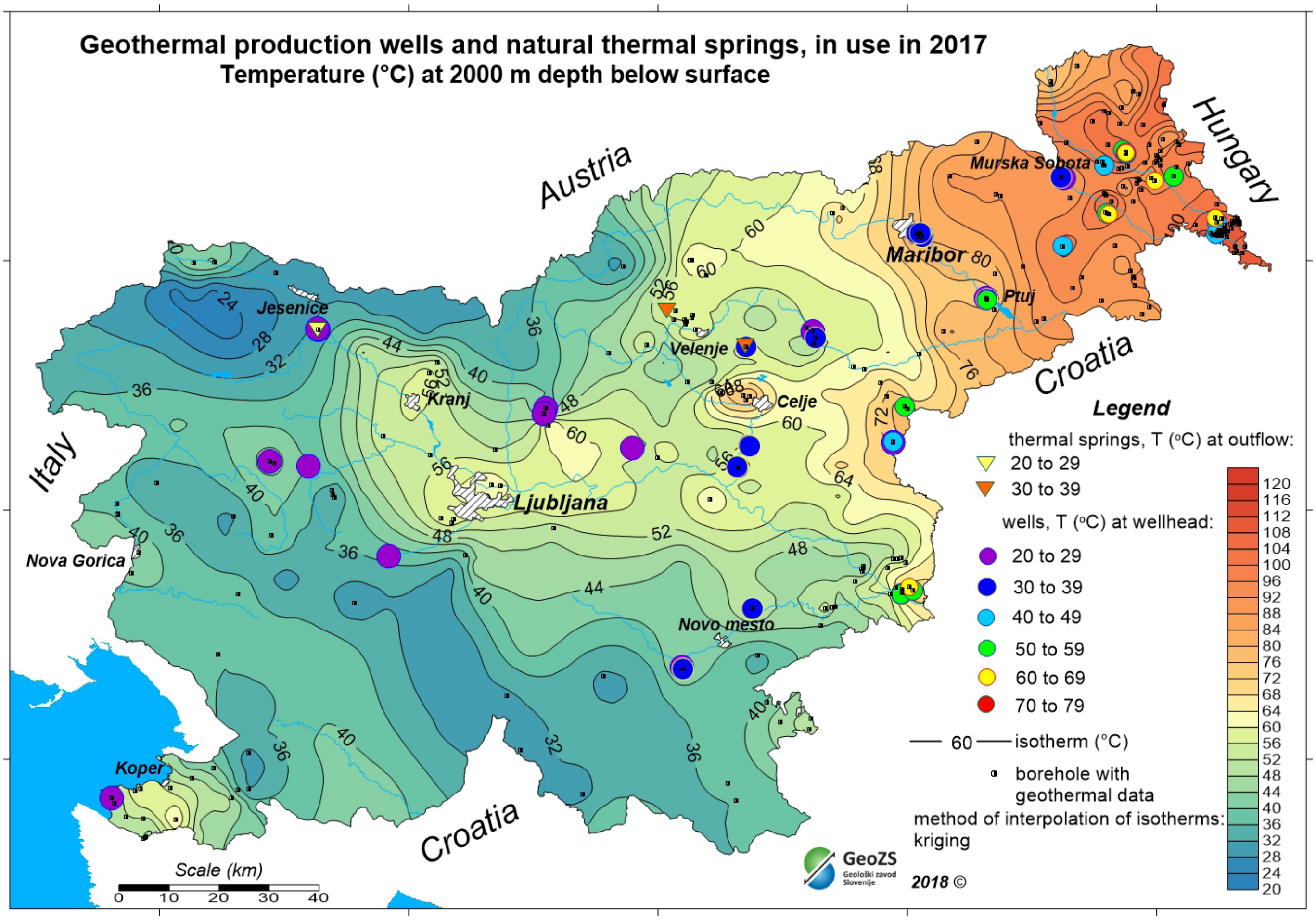

Figure 5: Geothermal wells and natural thermal springs in use in 2017 in Slovenia. The isotherms are expected formation temperatures at 2000 m depth.

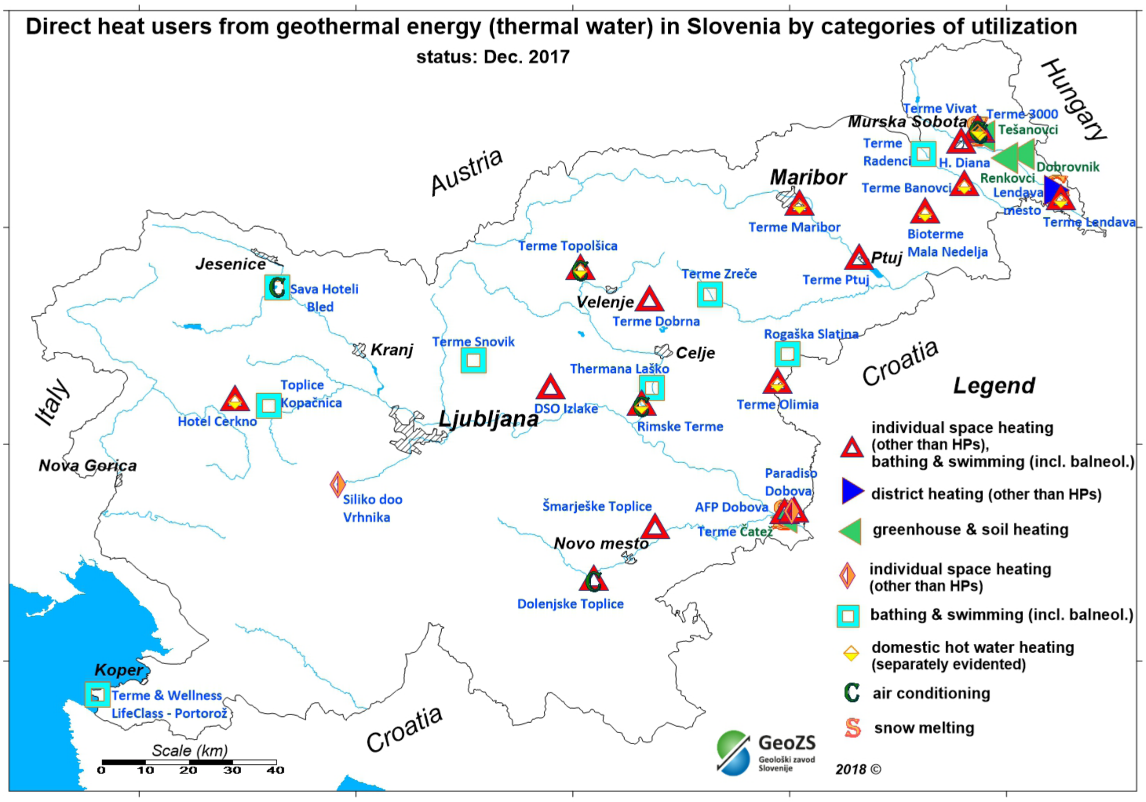

Figure 6: Main categories of direct use of geothermal energy from thermal water in Slovenia in 2017.

Ivanjševska slatina – Mineral waters in NE Slovenia

Nina Rman, Andrej Lapanje

The hydrogeological term *mineral water* usually denotes high mineralized groundwaters, often also rich in gases, and similar definitions are reported in balneology. However, when talking about bottled waters the term *natural mineral water* is commonly used, which refers not to the lowest concentrations of certain parameters but entails rather the addition of other demands or parameters, such as small variations in the chemical composition of the groundwater, a clear distinction from drinking waters and other. In Slovenia, we most ofter use the term *mineral water* for waters having more than 1 g/l of total dissolved solids and/or above 250 mg/l of naturally dissolved CO_2 $(CO_2)_{aq}$. A *slatina* is a Slovenian term that cannot be consistently or definitively translated. It usually denotes either high mineralized mineral waters, often rich in gases, or acid mineral waters. In balneology, the German "die Säuerlinge" has a similar meaning. The English terms "carbonated water, soda water, sparkling water, fizzy water" refer to bottled waters with a high CO_2 content, and are therefore not directly comparable. We propose to use the term *slatina* for waters with more than 250 mg/l of dissolved CO_2 $(CO_2)_{aq}$.

In Slovenia, there are 17 mineral water sites (No. 46-62 in Fig. 8) and three officially delineated mineral water spring areas with hydrogeologically connected springs. Waters with characteristics of thermal and mineral groups are thermomineral and known at 18 sites (No. 63-80). Mostly, the CO_2 gas emits along deep and well-permeable fault zones (in Jezersko, Rogaška Slatina, Ščavnica Valley, Radenci, Nuskova).

Lots of geogene CO_2 has also been proved, e.g. from 780 m deep borehole T-1 in Boračeva water stopped outflowing after three months and was replaced by dry CO_2 gas.

Within the fieldwork in 2014–2015 we investigated 11 special springs: Ihovska slatina, Ivanjševska slatina, Lokavska slatina, Polička slatina, Radvenska slatina, mofettes Rihtarovci, Slepice and Strmec, Ujterska slatina, Verjanska slatina and Žekš (Fig. 8). The diameter of five uncaptured springs can exceed 4 m, with depression depths of 2 m, but most are smaller. We elaborated bathymetric 3D models of these spring areas, marked degassing locations in a plan view, and evaluated the gas flux according to a subjective, visual five-level scale. Two are wet *mofettes* (Polička slatina and Slepice) and three dry *mofettes* (Rihtarovci, Strmec, at Lokavska slatina). These constantly emit cold CO_2, hold acid surface or meteoric water, and bare soil or changed vegetation may also be present. *Mineral water* which contains more than 1 g/l of total dissolved solids and is very rich in free CO_2 emeeges in Ihovska, Ivanjševska and Radvenska slatina, and Žekš. Verjanska slatina and Ujterska slatina are neither mofettes nor *mineral waters*. The first, like most others, may be *a slatina*, having more than 250 mg/l of dissolved CO_2 $(CO_2)_{aq}$. We found no connection between the depth of the spring and the intensity of gas emissions.

Ivanjševska slatina has temperature of water of 5.0-8.5 °C, pH 7.6-8.2, conductivity of approximately 3.100 μSi/cm and 1,44 g of free CO_2 per litre. Its hydrogeochemical water type is of Ca^{2+}-Mg^{2+}-HCO_3^- type and it microbiotically and chemically fits to the drinking water standards. Its characteristic taste can be attributed to approximately 8 mg/l of iron which also produces characteristic orange scale. The near-by house, which has been deserted for decades, used to be a bottiling plant prior to the st and to shortly after the 2nd World War. The slatina site is now protected as a local valuable natural feature No. 7520.

In the nearby channel of the River Ščavnica bubbles of free CO_2 gas are visible, and mineral water from an artesian well Ivanjševski vrelec can also be tasted near-by.

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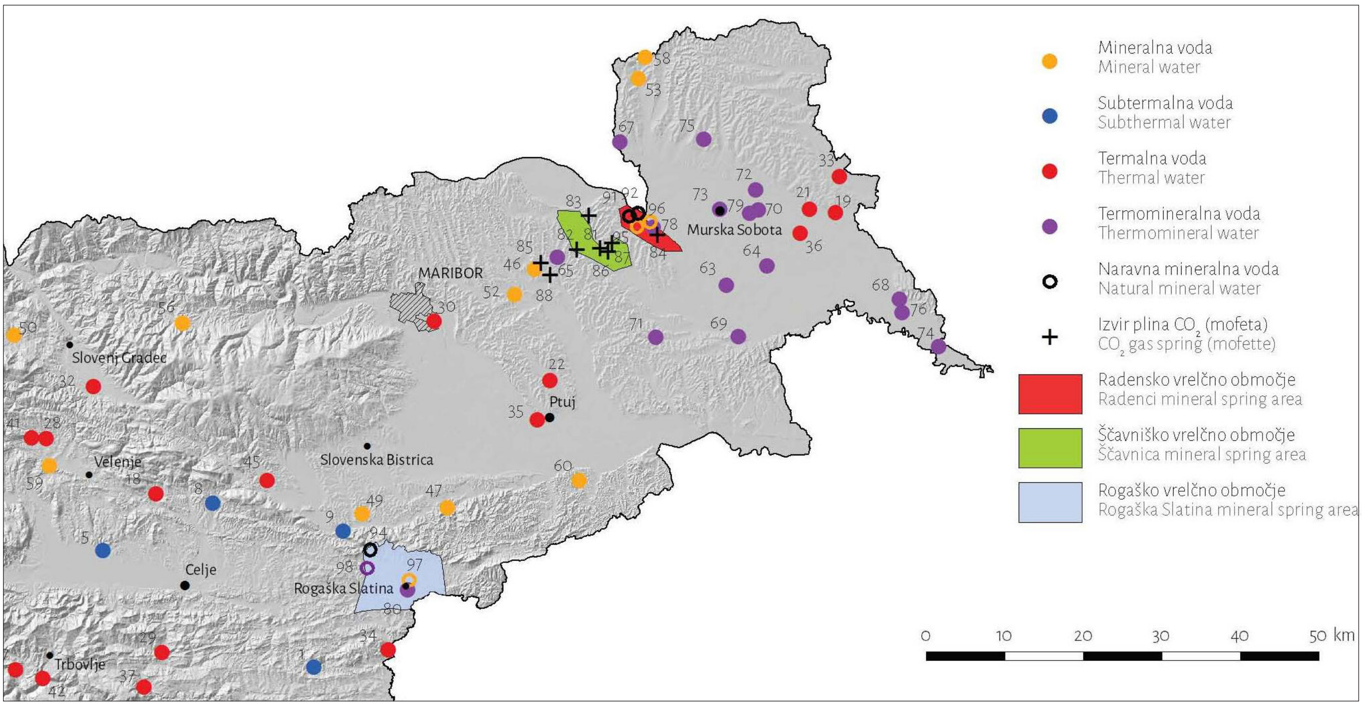

Figure 7: Mineral, thermal water sites and mofettes in NE Slovenia (modified from Rman & Lapanje, 2016).

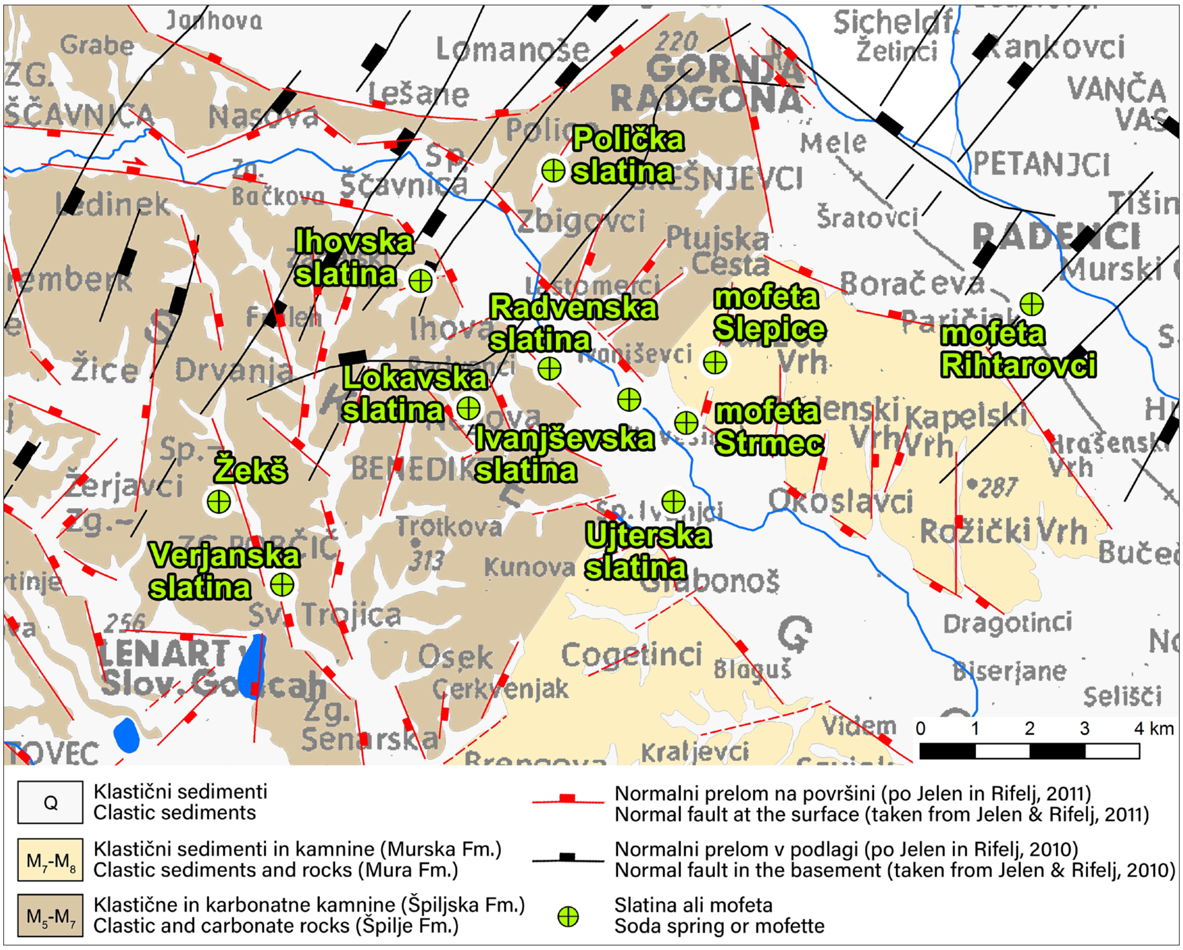

Figure 8: Simplified lithostratigraphic map of the investigated area and investigated slatinas and mofettes (Gabor & Rman, 2016).

Ivanjševska slatina – Microbiology of groundwaters

Nina Rman, Mashal Alawi

The GTZ Potsdam group sampled a broad variety of fluids from nine wells in the westernmost part of the Panonian basin in SE Austria and NE Slovenia in 2013-2014 to better understand the influence of different environmental parameters such as temperature (between 12 °C and 105 °C), depths (between 0-2843 m) and the hydrochemical composition of the sampled waters (between 2.39 and 10.78 mSi/cm) on the microbial communities.

The following information is not simple to understand by geologists but for microbiologists it is very interesting that the microbial abundances estimated through qPCR ranged from $1.91 \cdot 10^{1}$ gene copies L^{-1} to $1.27 \cdot 10^{6}$ gene copies L^{-1}. Surprisingly, archaea and bacteria were, in most cases, more abundant in the deep rather than in the shallow geothermal aquifers. Illumina MiSeq 16S rRNA amplicon sequencing revealed that 30 genera occurred in at least 75% of the investigated waters and form the core community of these fluids. Accordingly, to their respective environmental conditions, many waters showed a very distinct community composition. Salinity, pH, iron concentration, temperature and screen depth showed a strong impact on the population structures, and explained 27 % of the microbial distribution patterns. Therefore, not considered environmental characteristics and complex interactions within the microbial communities may contribute to a large extend to the distinct microbial population structures. Interestingly, the microbial diversity was for most sites higher in the deep aquifers than in the shallow ones. Presumably, more ecological niches in the deep than in the shallow aquifers are available.

In Ivanjševska slatina, 95% of OTUs was assigned as Bacteria (two orders represent together 71% of the community) and the rest to Archaea, which is little less than in other deeper mineral and thermal water wells. Unique features in Ivanjševci were the occurence of *Acetobaterium* (10%) as well as *Methanobacterium* (4%). In Radenci, in shallower well V-M, an uncultured organism of the family *Anaerolinaceae* (9%) was most abundant. *Nocardioides* and *Ferruginibacter* occurred with 5-6%. But in deeper T-4 well, a dominance of Archaea, an uncultured euryarchaeote (SM1K20) can be observed in 60%. The presence of sulfate reducing bacteria like *Desulfuvibrio* (8%) and *Desulfitobacterium* (7%) were also noticeable. *Thermoanaerobacterium* (2%) and *Thermodesulfobacterium* (2%) were only present in low abundances.

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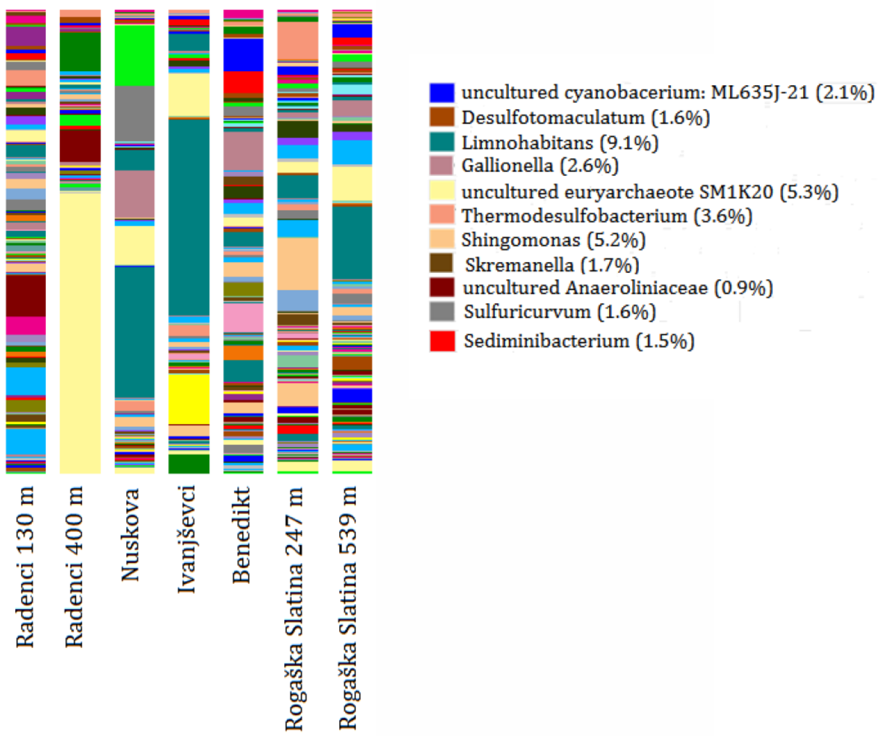

Figure 9: Taxonomic distribution on genus level in deep aquifers with 11 taxa indicated. The bars were labeled in accordance to the considered sample (modified from Börger, 2017).

Mofette Strmec – Natural CO_2 seeps

Nina Rman, Marjana Zajc

Natural CO_2 vents, i.e. mofettes, are usually found in volcanic environments; however, they can also occur in areas where deep fault and fracture systems allow natural gas to migrate from the mantle or crust and discharge at the surface.

Mofettes can easily be spotted in areas where surface indicators, e.g. reduced vegetation (dry mofette) and bubbles in water collected in gas vent (wet mofette), are present. However, in cases where the CO_2 concentration is not high or stable enough to impact the surrounding flora and gas vents do not contain water, it is much harder to define them. Due to the CO_2 concentration sometimes being higher than 99 vol% , dead animals (insects, birds or even roe deer) can be found nearby. The high CO_2 concentrations have been fatal for humans as well. Numerous studies have been conducted on the effect of natural gas vents on health, groundwater and soil quality as well as atmospheric CO_2 concentrations, however, few have tried spatially defining the subsurface extent of mofettes with geophysical methods.

Mofettes of non-volcanic origin emerge along the deep-seated Raba Fault Zone and can be found between Lenart in Slovenske gorice and Radenci (mofettes in Rihtarovci) and in the Ščavnica Valley: at Stavešinci, Lokavci, Police and elsewhere. The isotope signatures of the free gas phases indicate the subcontinental mantle to be the predominant origin of helium and CO_2 (highest $^3He/^4He$ ratios ~6.3 Ra, and $\delta^{13}C$ of -3.5‰).

Stavešinske mofette Strmec is located about one kilometre to the south on a meadow south of the local road between Ivanjševci and Stavešinci. It is a dry mofette and has a different appearance with distinctive or no vegetation at app. 2,500 m^2. When shallow holes fill with rainwater, it becomes muddy and its surface bubbles. Gas emission at 60 m^2 have shown 244.8 -964.8 mol of gas per h per m^2. The site is also protectied as valuable natural feature.

The Strmec mofette was investigated by the non-invasive ground penetrating radar (GPR) method in 2017 with three different antenna frequencies (250, 500 and 800 MHz). As can be seen in Profile 2 (Fig. 10 A, 500 MHz), strong anomalies are present in the last ten meters of the profile where a mofette is also visible at the surface (yellow star) and vegetation is damaged by high CO_2 concentrations. By enlarging this part of the profile, three distinct features can be observed (Fig. 10 B): a no reflection zone at the top of the profile (0.2 – 0.5 m, green area), a strong reflection zone beneath a concave feature (orange area) and narrow vertical high attenuation zones (blue areas between dashed lines). The latter could indicate the presence of fractures allowing the natural gas to migrate towards the surface.

By placing all five profiles recorded in a grid-like pattern (Fig. 10 C) into a 3D model (Fig. 10 D), it is obvious that these features appear only in the area closest to the mofette, whereas other parts of the profile contain hardly any reflections. The GPR method therefore proved to be useful for investigating subsurface features as well as spatial extents of mofettes and could also be applied in areas where no surface indicators are present.

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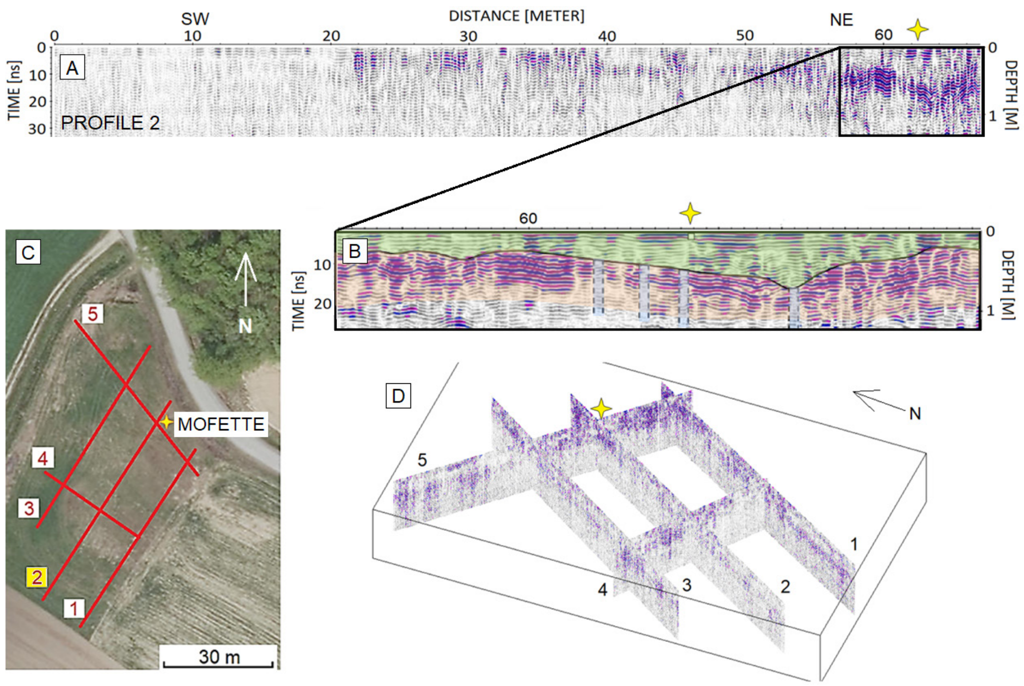

Figure 10: A – GPR Profile 2 recorded with 500 MHz antenna; B – enlarged part of Profile 2 around the mofette area; C – locations of recorded GPR profiles; D – 3D model of all GPR profiles

Radenci – Natural mineral waters

Nina Rman

In Radenci, natural springs of mineral water rich in CO_2 were not discovered until 1833, and the bottling of this water, initially in clay bottles, started in 1869. The brand Radenska was officially attributed to this natural mineral water in 1923. Extensive research for new mineral water sites in Ščavnica Valley and Radenci were performed in 1970's. Today, only focused research for Radenska d.o.o. bottling company and Radenci Health Spa Resort are performed. Mineral water emerges here mostly along faults where mixing of recent rainwater of Ca^{2+}-Mg^{2+}-HCO_3^- type occurs with older rainwater of Na^+-HCO_3^- type and diluted brine of Na^+-HCO_3^--Cl^- and Na^+-Cl^- type.

Today, the bottling company in Boračeva near Radenci produces a few types of such waters. They hold a certificate indicating that they have the same purity and chemical composition as at the spring and special nutritional-physiological effects. The waters are tapped from a few wells that are up to 200 m deep and produce water from the Upper Pannonian to Pliocene sands of the Mura Formation, which are protected from possible surface pollution by several beds of low permeable clay. The most well-known brand is Radenska Classic, high mineralised groundwater of the Na^+- Ca^{2+}-Mg^{2+}-HCO_3^- water type. At least 3,500 mg of its own free CO_2 gas is added into the litre of water before being bottled. The brand Radenska Light has the same chemical composition but contains less CO_2. Two of more than 200 wells, which were drilled for exploration of mineral waters here in the last century, are used for balneological treatment (drinking and bathing) in a nearby spa Zdravilišče Radenci. Moreover, the most interesting springs between Negova and Radenci are incorporated into the cycling and hiking interpretative trails named Med vrelci življenja (Among the Springs of Life).

Four wells are used also in spa Zdravilišče Radenci, producing thermomineral water of 8-11 g TDS/l and of Na^+-HCO_3^- type; two producing from the Mura Formation sandstone from wells V-M (196 m, filters 129-193 m, 20 °C) and V-50t (330 m, filters 281-308 m, 37 °C), and two from the Špilje Formation sandstone from wells T-4 (817 m, filters 400-542; 39 °C) and T-5 (830 m, filters 705-792 m).

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Materials of Radenska d.d. Company

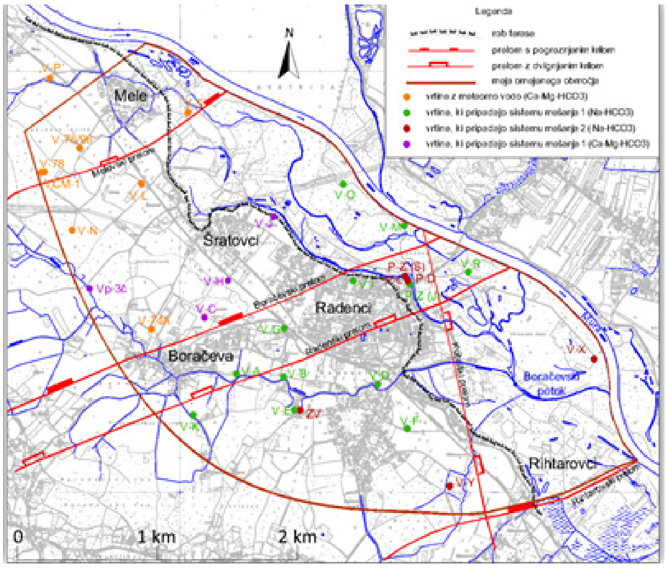

Figure 11: Mineral water wells and faults in Radenci: orange: meteoric water; green: mixing system 1; red: mixing system 2, and violet: mixing system 3 (taken from Vrzel 2012, fig. 27).

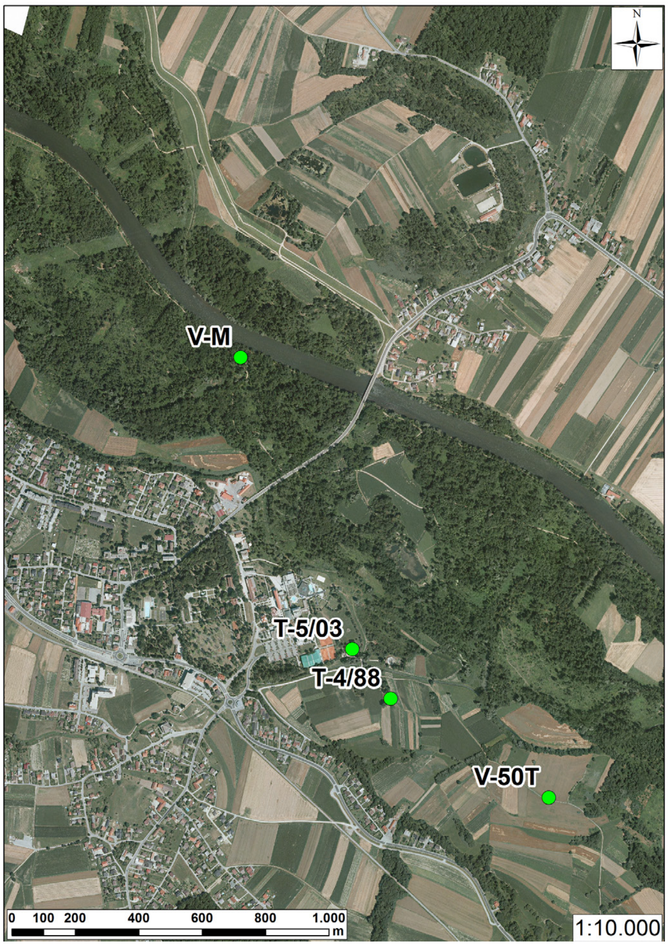

Figure 12: Locations of mineral and thermomineral water wells used in spa Zdravilišče Radenci and Radenska d.d..

Mura River – Various use of the Quaternary aquifer

Katja Koren

Unconfined Quaternary Mura River aquifer extends from the Slovenian state border with Austria to the state border with Croatia. In the south, the aquifer is bounded by the Slovenske gorice hills and in the north by the Goričko hills.

The contact between Prekmursko polje and Goričko is geomorphological and is represented by a system of low pleistocene terrace due to accumulation and erosion of Mura. The terrace of gravel and sand has more thick grained sediments towards the central area.

From the aquifer 10 milion m^3 per year for drinking water supply is exploited. Precipitation is one of the major sources of local recharge but also rivers or streams contribute some water. The basis consists of lower permeable Pliocene sediments (clay, silt, marl) at depths of approximately 10 m. Depth to groundwater is more than 2 m.

Direction of groundwater flow in the central part is from NW to SE, as the pre-Quaternary basis sinks in the same direction as the regulated River Mura bed. To the north towards Goričko transition area, groundwater flow direction changes from north to southeast. The Mura River exfiltrate into groundwater and vice versa. Before regulation of the river, it shifted the riverbed and created side sleeves. Today, area is home to many plant and animal species.

Due to only a few meters thick and well permeable covering layer, the aquifer is very vulnerable to pollution. Agriculture is widespread and often reflected in increased concentrations of pesticides and nitrates. In drinking water increased concentrations of iron or manganese, mainly of geogenic origin, are often present. Since water is mostly used for private water supply (blue dots in the figure) and public utility services (blue squares), water protection areas are delineated at many latter sites in the area. Many gravel pit ponds (yeloow dots) were also created due to gravel and sand exploitation.

Since groundwater is very shallow and the aquifer is highly productive, the use of shallow geothermal energy is very favourable, especially with open loop systems (red dots – water use – heating). As the aquifer has an unconfined character in its western part, the the water is rich in dissolved oxygen (often >8 mg/l) and almost no operational problems occur since the iron oxidizes already in the aquifer. Still, at oxidation of Fe^{2+} to Fe^{3+} (insoluble), rust can be formed. Where lenses of low-permeable sediments are present (mostly on top of the surface) oxygen concentration decreases and more operational problems may occur.

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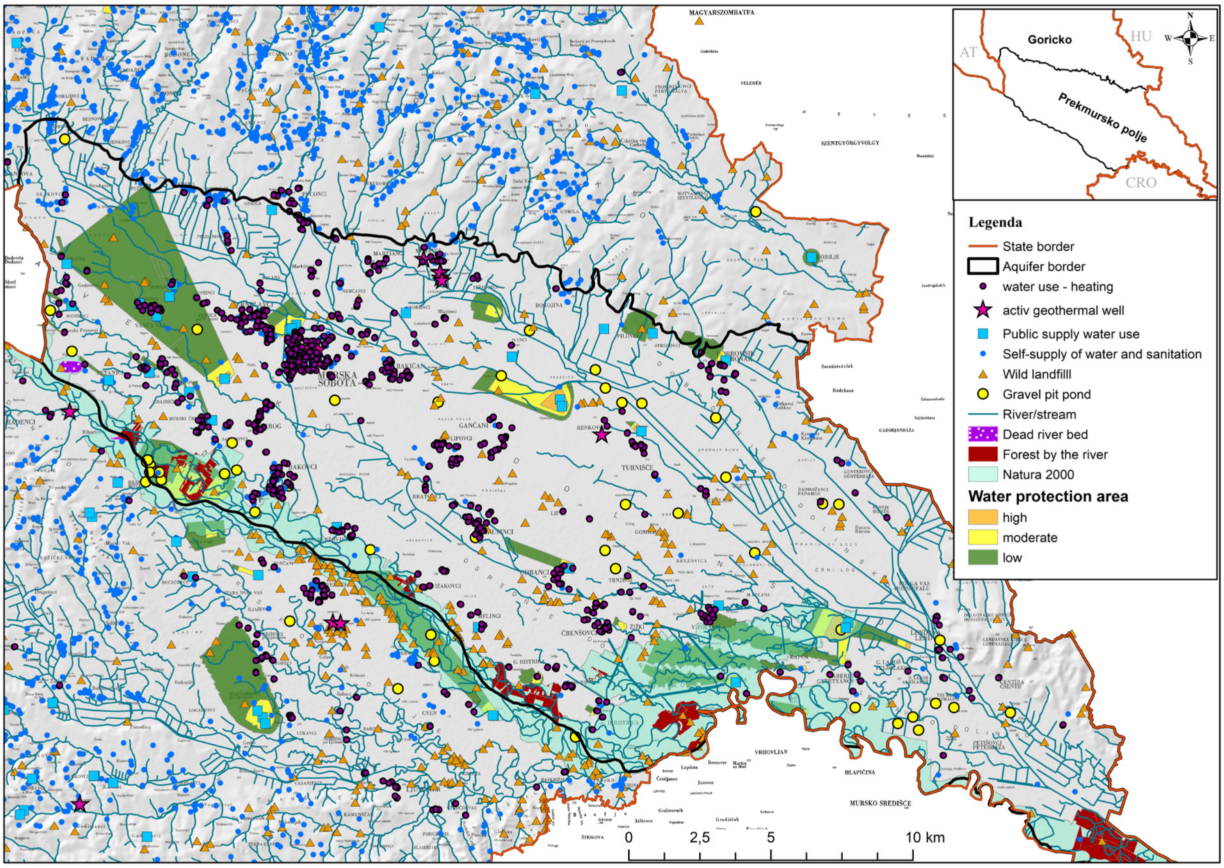

Figure 13: Land use and groundwater use along the Mura River

Murska Sobota – Shallow and deep geothermal applications

Dušan Rajver

Shallow geothermal energy (GSHPs) contributed about 58.3% of the utilized geothermal energy (GE) in the energy balance of Slovenia in 2017. This energy was exploited by approximately 10,830 units of GSHPs and exceeded the direct use. The GSHPs contributed 829.59 TJ (19.814 ktoe) from the installed capacity of 160.49 MWt. Approximately 10,335 GSHP units of low rated power were installed, typically 12 kW, and 495 units of high power with over 20 kW. Approximately 48% of units are water-water systems, and produced 495.74 TJ. Approximately 42% of units are closed-loop horizontal systems, obtained 247.74 TJ, while almost 10% of units are closed-loop vertical systems (BHEs, baskets etc.), and produced 86.1 TJ. All three types returned to the ground 56.17 TJ of heat in the cooling mode, mostly through BHEs and shallow water reinjection wells. In public and other buildings, at least 495 units are known to have larger capacities (> 20 kW), of which 379 are water-water, 84 with BHEs, and 32 with horizontal collectors.

The greatest potential for shallow geothermal occurs in NE Slovenia just as for direct use. There, the formation temperature at 250 m depth exceeds 17 °C while elsewhere is 9-16 ° C and less in the mountainous areas.

Shallow groundwater in Murska Sobota is very favourable for open-loop heat pumps but beside these, four geothermal wells are also situated in the town. Sob-1/87 and Sob-2/88 (0.5-0.9 km depth, Fig. 14) can produce 50 °C water with mineralization of 5 g/l and lots of free CO_2. The town used to have a geothermal district heating system and heating of open pools in summer, but currently only spa in a hotel operate on this thermal water. In 2012-2013, a geothermal doublet with wells Sob-3g and Sob-4g was drilled but the wells have not yet been properly tested.

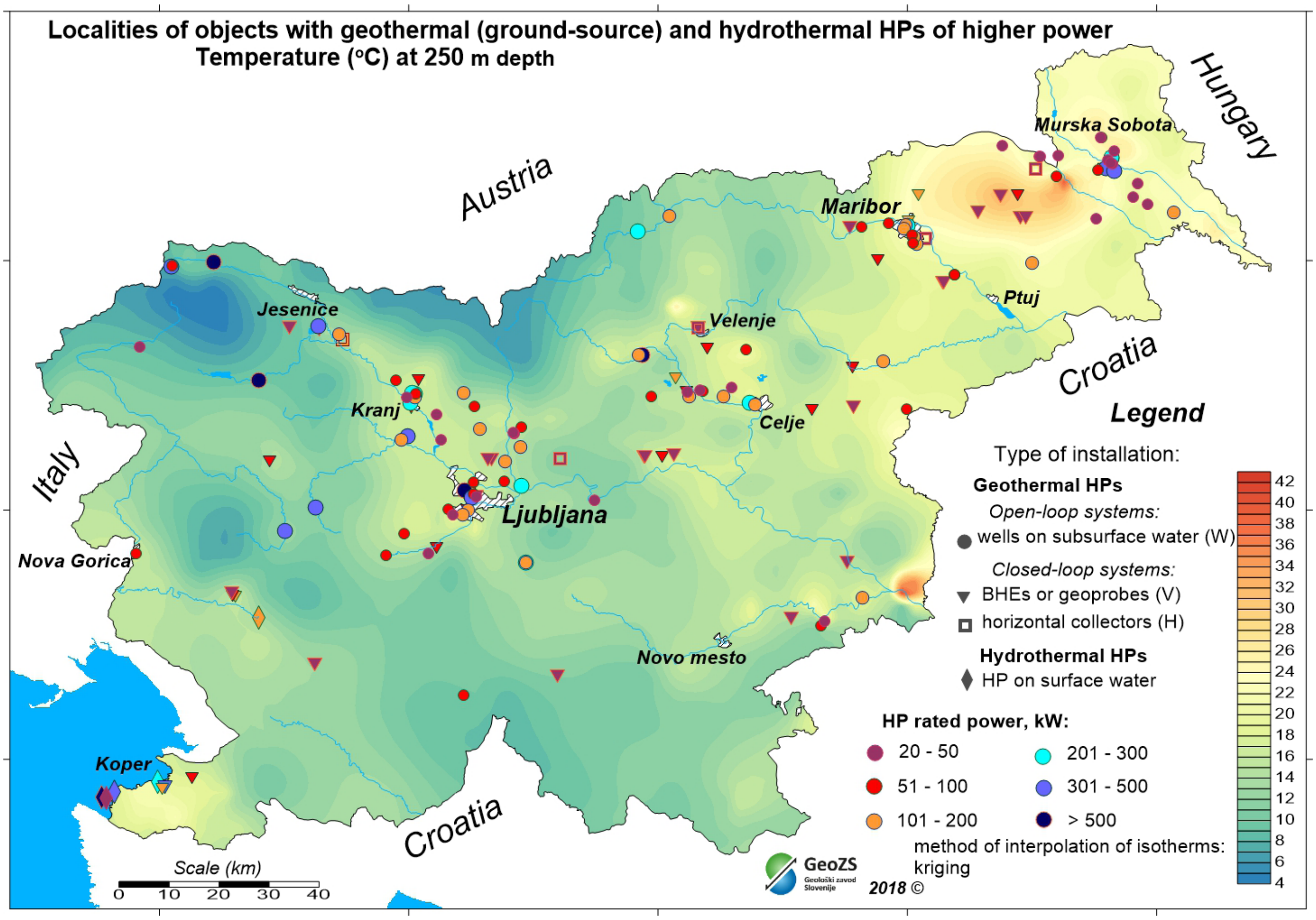

Figure 14: Distribution and type of 149 facilities with a GSHP system with detailed data and a rated power of 20 kW or more, and 6 facilities with a hydrothermal HP unit on surface water. The data is reported on a voluntary basis. The isotherms show expected formation temperatures at a depth of 250 m below the surface.

Dobrovnik – Greenhouse heating system

Nina Rman, Andrej Lapanje

There are three greenhouse heeting systems in NE Slovenia. The one in Tešanovci uses waste thermal water from a spa resot in Moravske Toplice, the tomatoes greenhouse is situated in Renkovci, while the orchids greenhouse operates in Dobrovnik. The geothermal well Do-3g for Ocean Orchids was drilled in 2005 and supplies thermal water of 62 °C for heating the greenhouse to enable growth of tropical plants and especially orchids. The business plan allows that 85% of the greenhouse heating needs come from geothermal energy, using plate heat exchangers. The well Do-3g is drilled up to app. 1,585 m depth in the Upper Pannonian aquifer of the Mura Formation. The production layers consist from fine to medium grained loose sandstone and have very good production properties.

On the north side of the village Dobrovnik an older well Do-1g is located, which was primarily drilled for oil and gas prospection. It was not successful; however, shallower layers were open in it later and thermal water was found in depths approximately 930–1,875 m. Both wells tap the same aquifer, therefore having similar level of mineralization of thermal water and quite good hydraulic permeability. The well is currently used as an observation well but in future it is expected to provide water for space heating in the municipality of Dobrovnik.

The regional static groundwater level in the aforementioned transboundary Upper Pannonian loose sandstone geothermal aquifer in NE Slovenia has been declining at a rate of approximately -0.67 m per year since 2009. Besides, water composition was noticed to have changed over the years locally. We believe that increased production of geothermal energy in the region is only possible by establishing many more reinjection wells and geothermal doublets.

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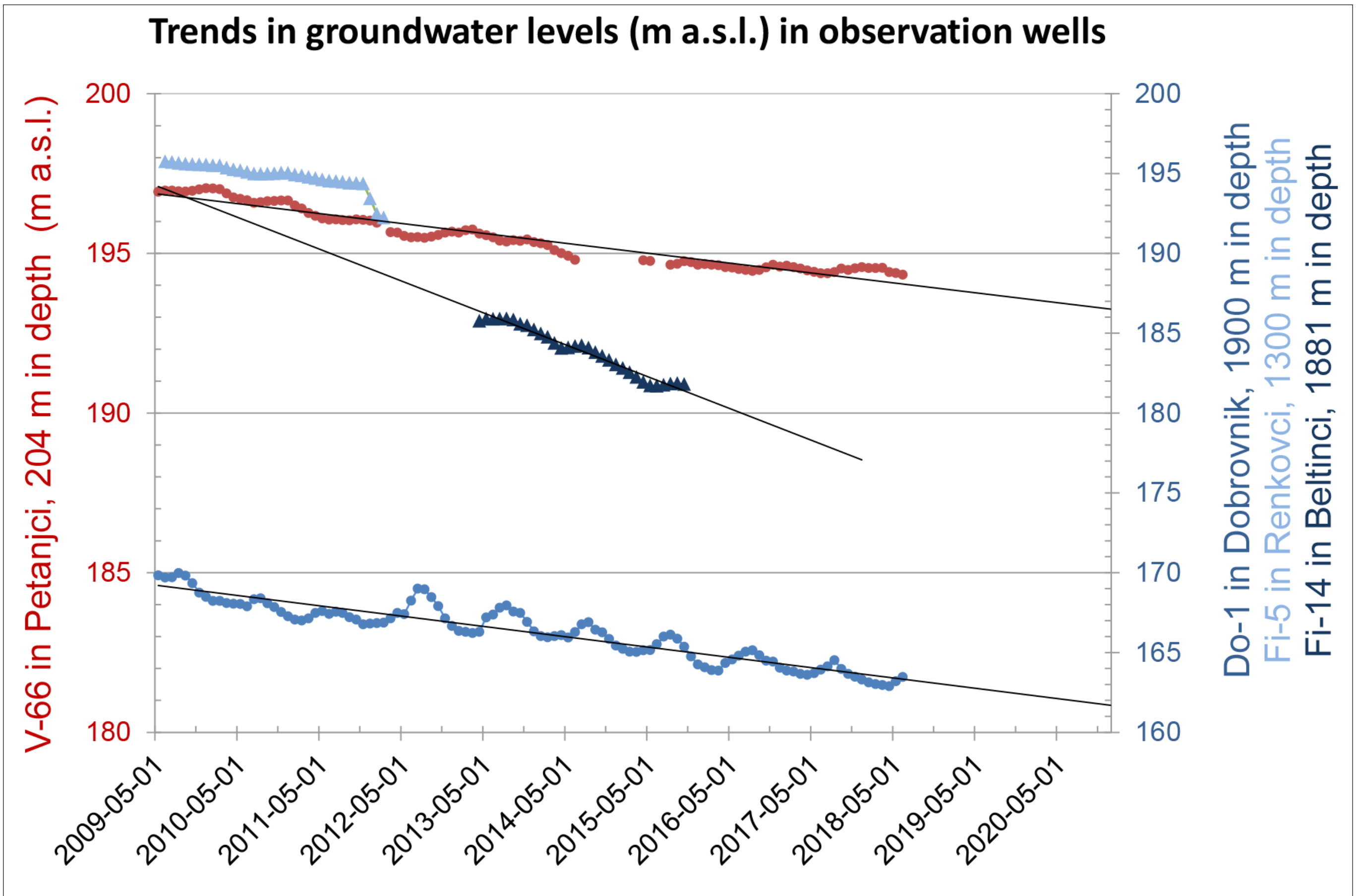

Figure 15: Piezometric groundwater levels in four observation wells in the regional Mura Formation geothermal aquifer in the period 2009-2018.

Lendava – Thermal waters from Neogene sediments

Nina Rman

In Slovenia, subthermal water is defined with temperatures between medium annual air temperature increased for 4 °C and 20 °C. Thermal waters have a temperature of 20 °C or more. There are 10 sites with subthermal (No. 1-10 in Fig. 7) and 35 with thermal waters (No. 11-45 in Fig. 7) in Slovenia. In NE Slovenia, ground temperature rises with depth, while the velocity of groundwater flow decreases. This causes a longer residence time of groundwater; therefore, the amount of total dissolved solids (and sometimes of gas) also often rises.

Artesian thermomineral water in the Mura-Zala basin was discovered during oil and gas exploration in the village of Moravci in the 1960s. This oily water has been produced from the Middle Miocene turbiditic sandstone (Lendava and, mostly, Špilje Formations) for space heating and balneology for over 50 years and was officially declared medicinal in 1964. The village was renamed exclusively because of the occurrence of this water to Moravske Toplice (toplice translates to spa). It is tapped by four wells at depths below 1,200 m. Two of them are inclined which is extremely rare in Slovenia. Thermomineral water reaches up to 75 °C and is one of Slovenian's hottest thermal waters. It is an old diluted brine of Na^+-Cl^--HCO_3^- water type, with as much as 15,000 mg/L of total dissolved solids and a high content of organic compounds. At the surface, CH_4, CO_2 and H_2S degases from water. Carbonate incrustations precipitate in wells and pipes due to the degassing of CO_2 if not mitigated properly. Distinctive flocculation particles of iron sulphide are formed in bathing pools after the water is oxidised in the air, giving it a typical black colour.

The same aquifer is exploited in Radenci with well T-4 but with only very little organic substances in the water.

On the opposite, most wells tap the delta front sands of the Mura Formation at depths from 500 m to 1.5 km km where it is heated to about 80 °C. Thermal water of Na^+-HCO_3^- type is produced by submersible pumps, having app. 60 °C at the wellheads and just little over 1 g/l of TDS. It is used for space heating, balneology and bathing in Banovci, Lendava, Moravci, Moravske Toplice, Murska Sobota and Ptuj; for greenhouse heating in Dobrovnik, Moravske Toplice and Renkovci; and for district heating in Lendava (Fig. 6).

In Lendava, five wells have concession for thermal water production: Le-1g (1571 m, filters 735-1458 m, 61 °C), Pt-20 (1119 m, filters 817-909 m, 55 °C) and Pt-74 (1000 m, filters 700-833 m, observation well) for heating and bathing in Terme Lendava, and Le-2g and Le-3g as a geothermal doublet with total reinjection in the latter (Fig. 17). Water is of Na^+-HCO_3^- type with mineralization 1-3 g/l, while noble gases arise from crust and do not indicate open deep faults.

As oil and gas fields occur in Petišovci, water from wells Pt-20 and Pt-74 is enriched with organic substances and metane. The first attributes to their 'parafine' healing effect while the methane increases the risk of explosion, especially at the wellheads. All wells have been fully equipped for continuously hourly operational monitoring since 2018.

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Figure 16: Site of the well Pt-20 with a degassing unit and ex-zone signs (photo by N. Rman).

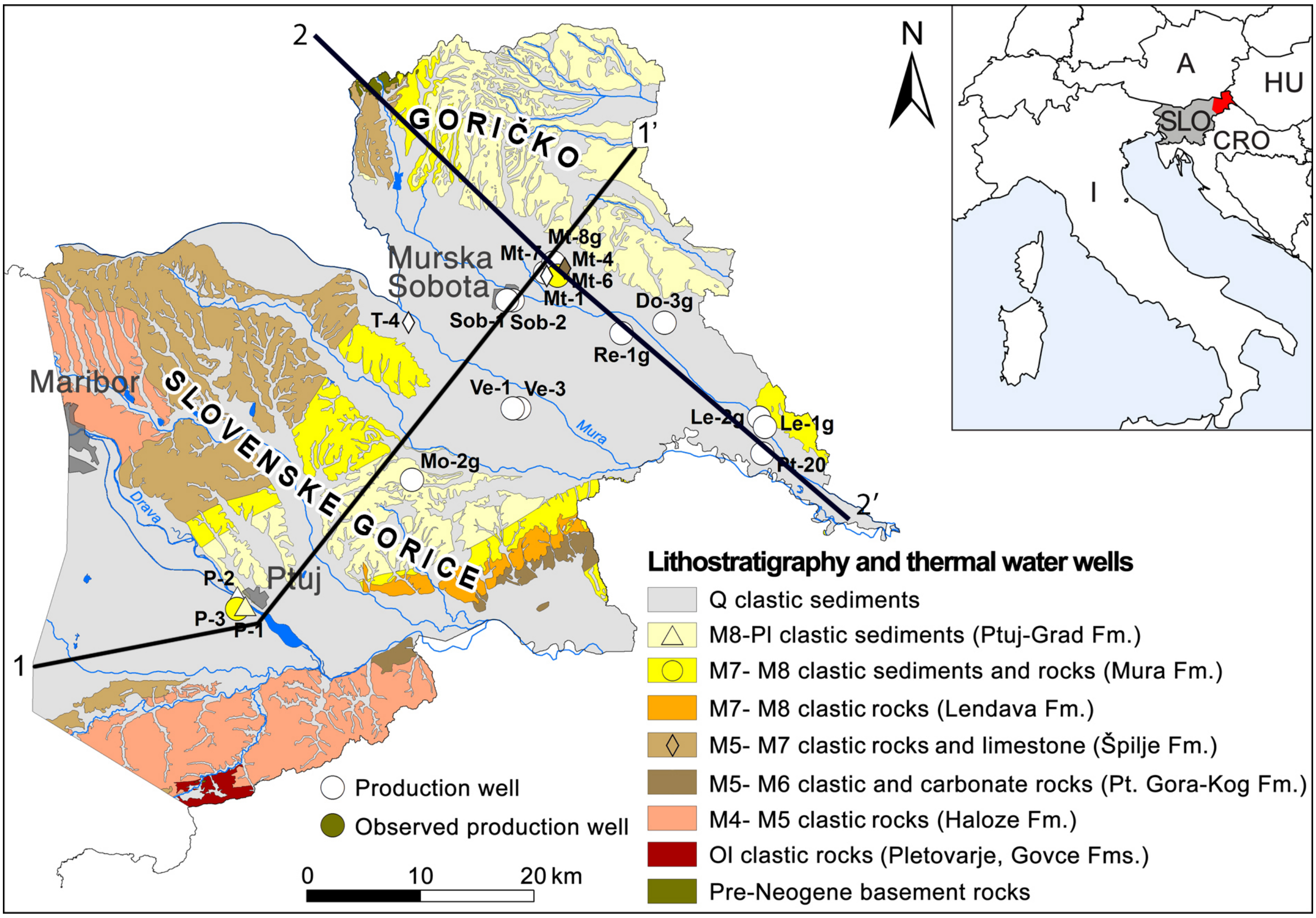

Figure 17: Simplified surface lithostratigraphic map of NE Slovenia with locations of active geothermal wells open in the Neogene geothermal aquifers (taken from Rman, 2016). Thick black lines stand for cross sections shown in Figure 2.

Lendava – District heating system with reinjection

Evgen Torhač

In Lendava, the geothermal doublet consists of a 1.5 km deep production well Le-2g and a 1.2 km deep reinjection well Le-3g, both are vertical and hydraulically connected. Thermal water with outflow temperature 66 °C from both, the sandy Mura Formation and to a lesser extent from the sandstone of Lendava Formation, is first used in a district heating system of the town of Lendava (50,000 m^2 of surface), which is managed by the Petrol Geoterm Co. If the available heat in the primary circuit plate heat exchanger is not sufficient, the high-temperature heat pump (HTH project Eureka Pump) and gas boilers provide additional heat in the secondary circuit. Yearly consumption of geothermal heat is approximately 5,000 MWh.

Cooled water of approximately 45 °C is injected back into the aquifer (of approximately 80–85 °C at reinjection depth) at a rate below 25 l/s and at wellhead pressure of approximately 4 bars. Three-stage mechanical filtering of suspended solids is performed prior to injection, using sand and two microfiber filters for removal of particles with a diameter of above 10 µm. If the injection pressure increases, the flow through sand filters is reversed and the 20 and 10 µm microfiber filters are changed. Additionally, cleaning of the well is performed once or twice per year. The flow direction is reversed and the well is activated to produce thermal water by a 20-bars compressor (backwashing). Produced thermal water was dated to be a Pleistocene rainwater of the Na^+-HCO_3^- hydrogeochemical type and contains 1,130 mg/l of total dissolved solids, 31 mg/l of silica, and has low calcium, magnesium and chloride concentrations. No major scaling or corrosion processes are observed in the utilization system.

Nearby, well Le-1g/97 penetrates the same aquifer as well as two previously hydrocarbon wells in Petišovci. Parafin-rich thermal water in Terme Lendava is used in cascades, for sanitary water heating, space heating, and finally, for bathing and balneology in pools.

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Figure 18: Filtering system with microfibers at the reinjection well Le-3g (photo by T. Fuks).

Petišovci-Dolina – Oil and gas fields

Miloš Markič

In NE Slovenia, the Neogene strata of the Petišovci–Dolina area near Lendava have the most outstanding potential for oil and gas, which was discovered there in 1942 as a continuation of a known Lovászi field in Hungary. In Croatia, oil and gas fields in Selnica and Peklenica were also known, already in exploitation in the mid of 19th century and so representing one of the oldest oil and gas fields in Europe! Several oil and gas outcrops or in shallow coal shafts were also known in the wider area.

In the Petišovci–Dolina field (ca 7 × 2 km), 122 wells were drilled between 1942 and 1954 (in time of the peak oil production – 75.000 tons per year in 1951). Oil and gas were pumped-out from a depth interval between 1,300 and 1,700 m, from 10–40 m thick sandstones known as the Petišovci, Lovászi, Ratka, and Paka sandstones, embedded within similarly thick marls belonging to the Lendava Formation of the Upper Miocene (Pannonian to Pontian) age.

A decisive step in the oil exploration of the Petišovci–Dolina field was made in 1960, when the Pg-1 well was drilled almost 3,000 m deep, and detected especially gas in numerous but somewhat less permeable sandstone strata. The wells Pg-2, 3 and 4 were then drilled in the 1960s and Pg-5, 6, 7, 8 and 9 in the 1980s. All these wells were between 3,000 and 3,500 m deep. Seven "Pg" wells and four "D" wells are gas-producing wells in recent years.

After an extensive geophysical 3-D seismic exploration programme after year 2000 (ca. 40 mio € investment by a British company Ascent Resources), the most recent two "Pg" wells – Pg-10 (3,545 m) and Pg-11A (3,500 m) were drilled. The wells penetrated so called "Petišovci-deep" tight gas-bearing strata A-Q (> 15 layers) of the Lower to Middle Miocene age. Five hydraulic fracturing campaigns were carried out in 2011 in a depth greater than 3000 m. A testing production runs at the time. In-place resources are estimated to ca 13 × 10^9 Sm^3.

The present structural form of the hydrocarbons-bearing sandstone strata is an antiform termed as the Ormož–Selnica Antiform. It arose due to regional compressive regime during the Upper Miocene-Pliocene times. The Lendava Formation of the Mura–Zala basin is correlated with the Ivanić grad and the Kloštar–Ivanić Fms. in the Sava and Drava Depressions in Croatia. The maturity of organic matter was high enough to generate hydrocarbons especially in the area of the Ormož–Selnica Antiform.

In the wider area of the Mura–Zala basin oil and gas exploration ran as well. 41 wells were drilled in the 1950s, and 16 in later years. The deepest well in Slovenia is the Ljutomer-1 (Ljut-1) well from 1988 which is 4,048 m deep (Fig. 1). The most perspective area became known as the Filovci structure, but no commercial production has been achieved.

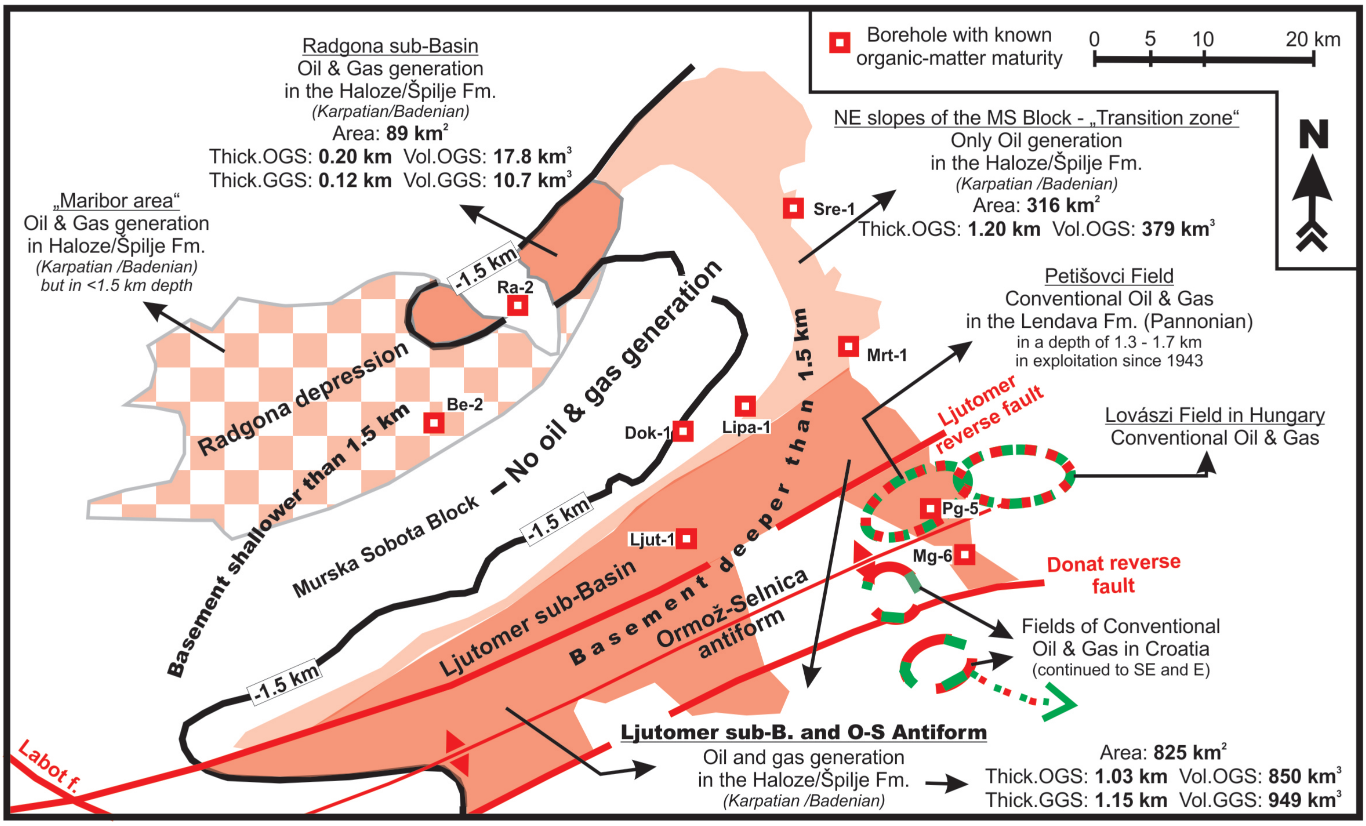

Figure 19: Areas of oil generating strata (OGS) and gas generating strata (GGS). Listed are thicknesses (Thick.) and volumes (Vol.) of OGS and GGS (from Markič et al., 2016). Marked are wells with measured organic matter maturity (Hasenhüttl et al., 2001).

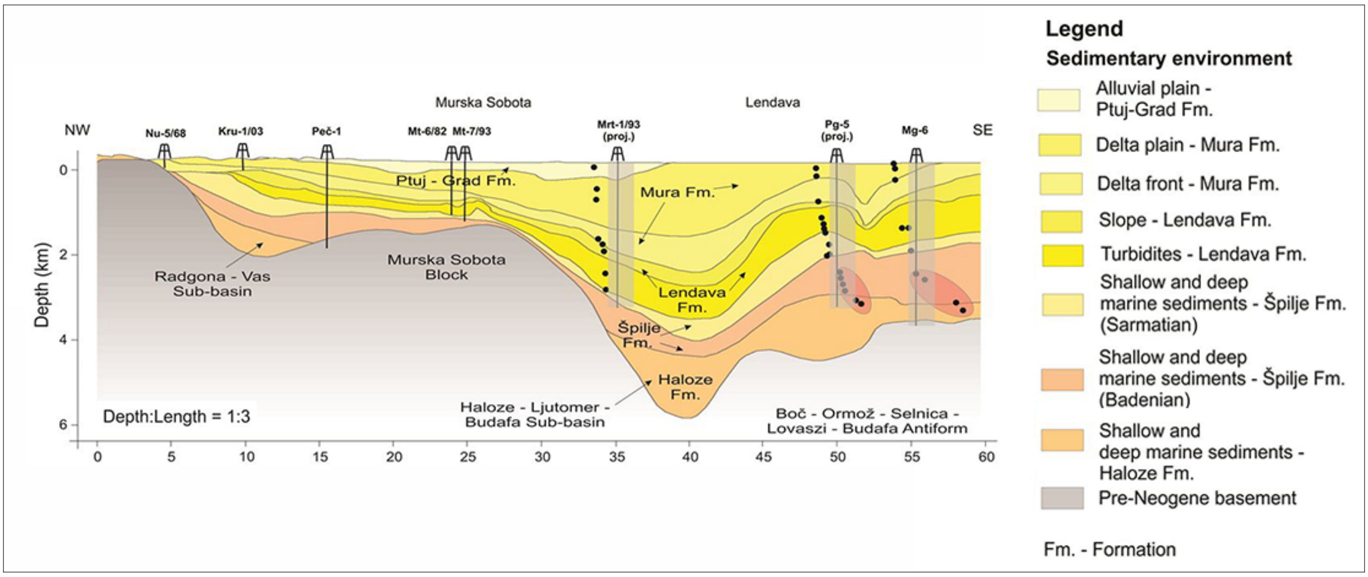

Figure 20: Cross-section from Goričko (NW) to Lendava (SE) (modified from Šram et al., 2015) showing the most perspective structure for the oil and gas generation within the Haloze and Špilje Formations (Fms.) (formerly Murska Sobota Fm.) in realm of the Ormož–Selnica Antiform. Black spots along the wells indicate maturity of organic matter (by vitrinite reflectance data from Hasenhüttl et al., 2001). The highest maturity is visible for the Pg-5 and Mg-6 wells.

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Lendava-Mursko Središće – Coals in the Mura Formation

Miloš Markič

The coal-bearing lower part of the Pontian Mura Formation in the Mura-Zala basin in NE Slovenia is >1000 m thick. It consists of marls, silts, sands, and numerous (10–30) but thin paralic brown coal seams. The coal-bearing sequence, coal quality and reserves are well ascertained by core-wells and mine workings only in the area between Lendava – Petišovci – Benica (SI) and Mursko Središće (HR) (ca 60 km^2). The whole coal-bearing bed-set in the Lendava area is ca. 130 m thick but contains only three coal seams >1 m thick (1.1, 2.1 and 2. 2 m). The net calorific value (NCV) of the Lendava coal is ca. 14.5 MJ/kg (at 25-30 % moisture and 15-20 % ash). The Mursko Središće coal is of a similar quality. An average total sulphur content of both coals is about 2.1 %. Such sulfur content and outstanding gelification of coal is a consequence of relatively alkaline brackish waters soaking the paleo-peaty biomass and enhancing intensive bacterial activity.

Tectonic structure of coal seams in the Lendava – Mursko Središće area is simple. Strata inclination is <15° and their extent follows gentle flanks of the Ormož–Selnica Antiform down to a depth of cca 400 m. Several very small collieries were in operation in the area of the mentioned antiform since the mid of the 19th century, but the only relatively large was the Mursko Središće coal mine with the highest production of 170.000 t in 1965. It was closed in 1972.

Coals in the broader area of NE Slovenia are not explored enough. They were encountered in almost all deep oil, gas, geothermal and hydrogeological wells but the data on coal seams are based only on masterlogs and geophysical logs, not on well coring. Existing data indicate quite thick coal seams in the Mura Formation, up to 4 m and even more, down to depths of 2000–2500 m below the surface. Deep coals may be regarded as potentially interesting for underground gasification and/or sequestration of CO_2. Rank of coal is too low for coal-bed methane production.

Total potential of coal resources in NE Slovenia (ca 1000 km^2) in seams >1 m, together 5 m thick (black lines indicating coal seams in the Mura Formation), is estimated to ca. 6500 Mt. At the coal's net calorific value (NCV) of 14.5 MJ/kg it represents nearly 10^{14} MJ of energy stored.

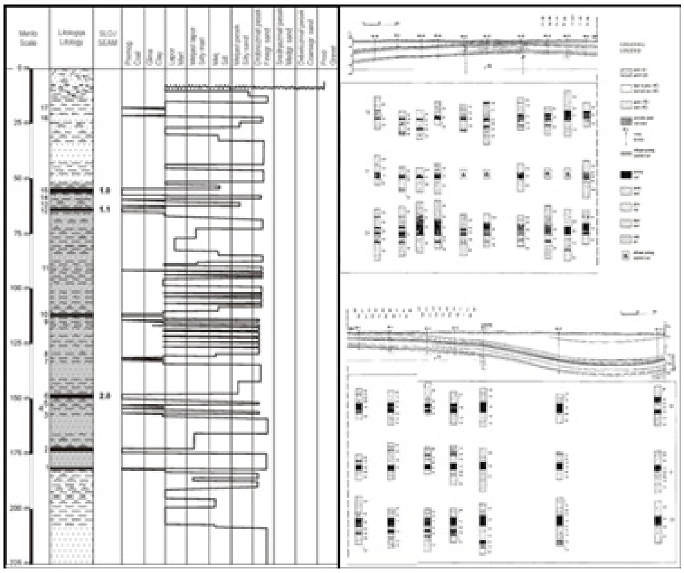

Figure 21: Coal-bearing sequence and a typical cross-section of coal seams in the Mura Formation in the area of Lendava – Petišovci – Benica (Slovenia) – Mursko Središće (Croatia).

Figure 22: Brown coal from the exploration mine workings at Benica – Petišovci carried out in 1986–1988. A similar coal was excavated in the Mursko Središće coal mine and several small collieries in the region (photo by M. Markič).

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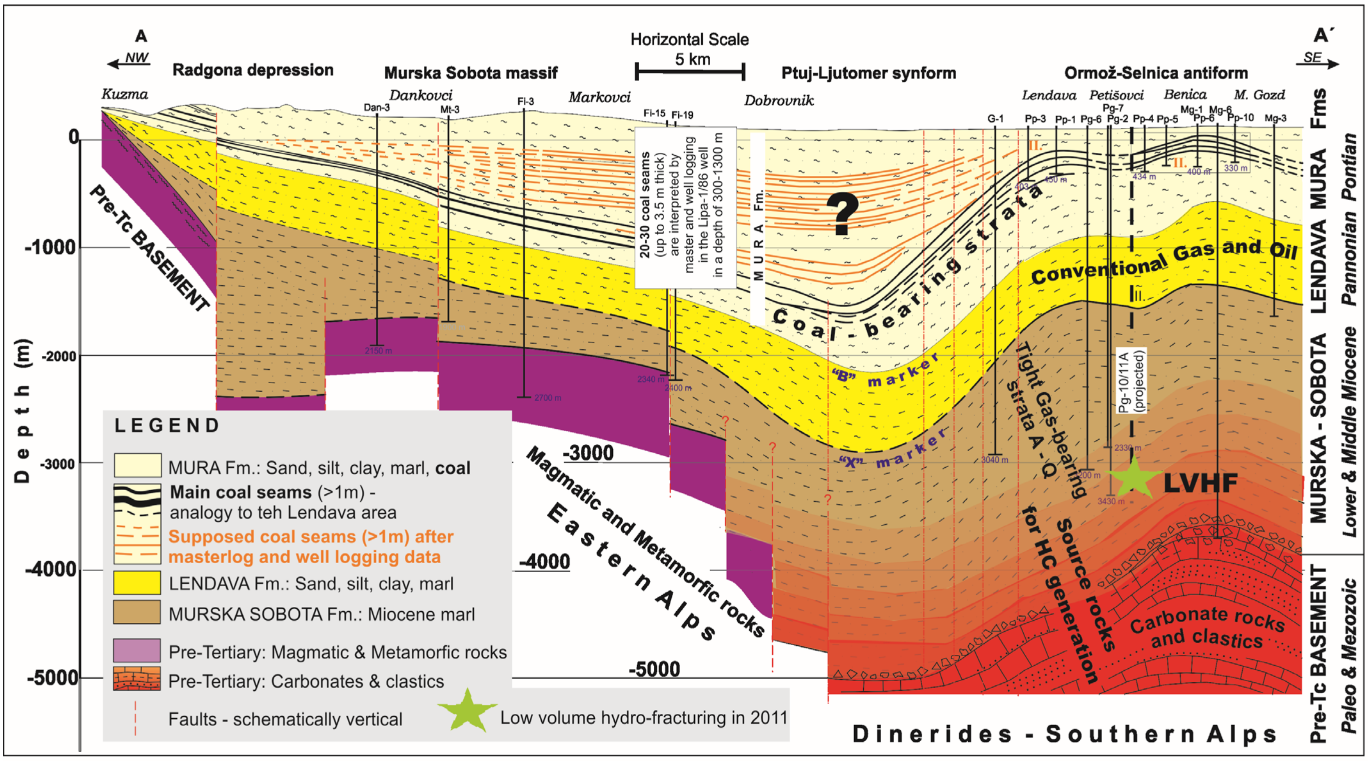

Figure 23: General cross-section from Kuzma – Goričko (NW) to Lendava (SE). A question mark shows coal layers detected in deep wells of which thickness is not ascertained. Well proved are only coals in the area of the Ormož-Selnica antiform. In the Lendava and Murska Sobota Fms. shown are gas and oil bearing strata and presumable source rocks.

Sveti Martin na Muri – Utilization of thermal waters in Croatia

Tamara Marković, Dragana Šolaja

Geologically, Croatia is situated at the intersection of major European regions: Alps to the north-west, Pannonian basin to the north-east, and Dinarides to the south-west. The majority of Croatia's geothermal potential is concentrated in the Croatian's part of Pannonian basin System (PBS) which represents the south-western margin of the PBS. With regard to geothermal characteristics, Croatia can be divided into two regions: the Pannonian basin area to the north and Dinarides to the south. The area of Pannonian basin has a significant geothermal potential where the average geothermal gradient is 0.049 °C/m and in places reaches values of more than 0.07 °C/m. The terrestrial heat-flow density is also high - 76 mW/m^2. Compared to the Dinarides area where the average geothermal gradient is 0.018 °C/m and the terrestrial heat-flow density flow is 29 mW/m^2. The average geothermal gradient of Europe is 0.03 °C/m.

Previous research of thermal waters in the Pannonian basin proved that the thermal springs are situated in the tops of anticlines that are in different directions fractured by transverse faults and cracks that usually represent fractured environment with high permeability which in this chase enables the upwelling of heated water from depth to the surface. The most aquifers in the Pannonian part are made of the Triassic dolomite and limestone and Badenian breccia and limestone.

Thermal water in Croatia is mainly used for rehabilitation, balneology, recreation, space and individual heating, greenhouse heating, sanitary water, bottling water and fish farming. The water temperatures vary from 25 to 85 °C. New projects, one ongoing, involve the production of electrical energy (Velika Ciglena – water temperature 170 °C), others in working progress Kotoriba, Legrad-1, Ferdinandovac-1, Lunjkovec-Kutnjak, Slatina, Babina Greda, Križevci, Karlovac, Draškovec-1 also for production of electrical energy, direct heating, individual heating, industrial use – cascade systems etc, whail the water temperatures are in the range 70-150 °C.

In 23 locations with a developed direct use of geothermal energy, a total direct heat capacity is placed slightly above 75 MWt. Annual utilisation of thermal energy from all localities, calculated on the basis of the average capacity factor of 0.27, could reach nearly 650 TJ/yr.

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Figure 24: Schematic division of Croatian territory according to geothermal features (taken from Borović & Marković, 2015)

Peklenica – Natural oil spring

Tamara Marković

Peklenica is the oldest and most famous oil spring site. The oil is stored in the Upper Pontian sediments. The record of oil from Peklenica dates from the earlier oral deliveries, but according to the Turkish traveler Evlija Ćelebi, the city of Szigetvár in 1566 was burned with oil from Peklenica.

In 1778, Jakob Winterl from Budapest made chemical analysis of the oil spring. In 1838, Peklenica was visited by Karoly Nedvitch, who described the oil spring on the estate of count Festetich and the spring was rented to a pharmacist from Graz who made a purified distillate from the oil. Count Feštetić was the first one who reported oil exploration on his estate in Peklenica on August 20th, 1856, and restored it on August 10th, 1860. He is the first person in Croatia to obtain a concession for the exploitation of a resin or oil. For a number of years, oil was removed manually from shallow depths of 4 to 12 m, up to 32 L per day.

The Viennese entrepreneur Wilhelm Singer drilled three wells in the period from 1884 to 1890. From the two forests, bitumen was obtained, and from the third, the deepest well, oil. These wells later produced as much as 7169 liters of oil per day. From 1900 to 1905, Singer built up to 31 wells, and only six were negative. Singer was the largest oil trader and he established company Medjimursko petrolejsko d.d. in the period from 1919 till 1944, the oil fields in Međimurje were under the jursidition of the German-Hungarian company.

Between 1919 and 1944, 138 shallow and 12 deep wells were drilled in Međimurje, 55% positive on oil.

After the Second World War, exploitation of oil was managed by the Lendava oil company (SI) which stopped in 1967 due to low amounts of produced oil.

In 2001, an initiative by Koloman Cigut, Milan Oreški, Jerko Tarandek / old navy Ivan Mikulić - president of the Touristic Asssociation of Mursko Središće, Željko Matiša - INA (Oil Industry Co.) and Srečko Kramar was initiated to make a memorial park in Peklenica based on Hungary's model. The conceptual model and field work was done and they applied to EU funds to preserve the place.

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Figure 25: The oil spring in Peklenica (photo by T. Marković)

Đurđevac – Drinking water supply

Ozren Larva, Željka Brkić

The Drava aquifer is a part of the Drava basin structural unit that is characterized by a thick sequence of coarse sediments. The aquifer itself is composed of gravel and sand with silt-clay interlayers. As a consequence of climate conditions in Quaternary, sediments of different grain size were being deposited in the lowered Drava basin. During warm periods in Pleistocene, coarse-grained particles were brought by the Drava River and deposited in lowlands as the river lost its strength. On the contrary, fine-grained particles were transported by wind during cold and dry periods in Quaternary and deposited in swamps forming marsh loess. Consequently, the entire cross-section of Quaternary sediments is characterized by interchange of aquitards composed of sand, silt, clay and interlayers of peat, and aquifer layers made predominately of gravel and sand.

The Quaternary aquifer system is stretched along the Drava River. In the west, the aquifer thickness reaches 150 m near Prelog. Further to the east, it is reduced to only 25 m at "Legrad uplift". East of Legrad, the thickness of the Drava basin in the whole gradually increases which also reflected on the thickness of the aquifer, e.g. it reaches 300 m near Donji Miholjac. Gravel and sand dominate the granulometric composition of the aquifer. However, the grain size gradually decreases in southeast direction. In Đurđevac area the maximum size of gravel particles ranges from 50 to 100 mm.

The covering layer of the aquifer is usually several meters thick, rarely exceeding 10 m, and mostly composed of silt and sand with various shares of clay. Generally, its thickness increases towards the southern aquifer boundary with Kalnik and Bilogora.

The groundwater flows in east-southeast direction. The aquifer is recharged by precipitation and inflows of groundwater from Bilogora. In most hydrological conditions Drava drains the aquifer. Hydraulic conductivity of the Drava aquifer between Koprivnica and Đurđevac varies from 100 m/day in central part to 50 m/day in marginal part along the boundary with Kalnik and Bilogora.

As a consequence of favourable hydrogeological conditions the aquifer represents the main source of drinking water. There are several pumping sites in the area: Ivanšćak, Delovi, Molve, Đurđevac. At Đurđevac pumping site, located south of the town and owned by INA, 20 L/s of groundwater on average is being abstracted currently by two wells in order to meet drinking water needs of Đurđevac and surrounding settlements. Groundwater being abstracted from the remaining four wells at the pumping site is used for industrial processes in INA d.d. A new pumping site named Đurđevac II, which is situated northwest of the town and developed for the future water needs of the region, consists of five wells, has a total capacity of 500 L/s and has not been connected to the water supply network yet.

Despite elevated and high aquifer vulnerability, natural quality of groundwater is mostly good and meets requirements for drinking water due to the relatively small number of pressures.

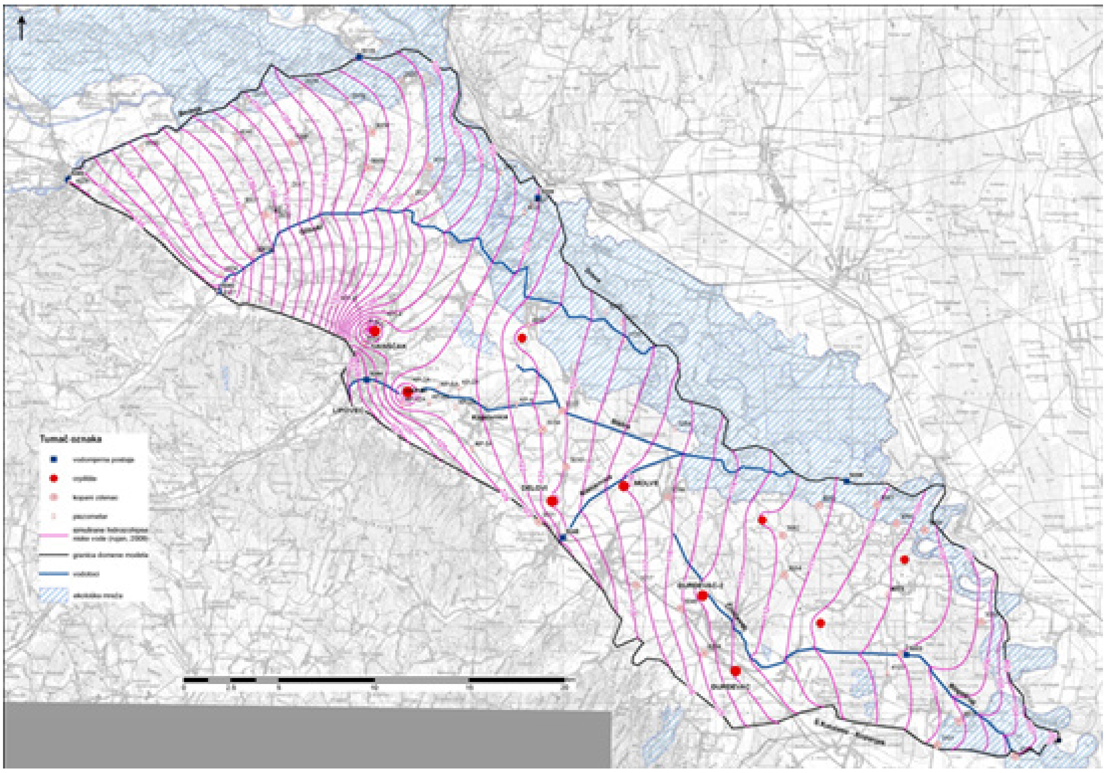

Figure 26: Flow net with major groundwater pumping sites

Đurđevac – Quaternary sands "Đurđevački peski"

Tamara Marković

The "Đurđevački peski" is located in the eastern part of the town of Đurđevac was proclaimed in 1963 a special geo-botanical reservat and it is unique place in Croatia. It occupies an area of 19.5 ha and covers section 11a part of the Đurđevacka lowland forestry unit managed by Croatian forests, Šumarija Đurđevac. It is characterized by sand dunes at a height of 4-6 m. Dunes were deposited through combinated processes fluvial and eolian during Quaternary period (Plestocene and Holocene). They could be considering as southern extension of the great sand dessert in Hungary in the Somogy area.

Sands have gray, brownish and brownish-brown colour and very different grain sizes - with medium-grained, fine-grained or silt fraction. They are medium to well sorted and grains up to round. The main mineral constituents are quartz (35-41%), rock particles (21-27%), muscovite (18-20%), feldspar (35-41%) and heavy fraction minerals (16.5-24%), among which are the most common garnet, then amphibole, and in small amounts staurolit, tourmaline, rutil and others.

The specificity of the relief is also reflected in the specificity of the vegetation. In the area exsist the combination of the plants of Eastern and Western-European origin with endemic plants of the Panonian plane. Plants which can be found are: *Corynephorus canescnes*, *Festuca vaginatae*, *Thymus serpyllum*, *Plantago indica*, *Artrenisia campestris* etc.

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Figure 27: Đurđevačke dunes (photo by T. Marković)

Velika Ciglena – Geothermal power plant

Tamara Marković

The first geothermal power plant in ex-Yugoslavia named "Velika -1" is being built near Bjelovar town in the municipality of Velika Ciglena. The project has started 10 years ago, first the INA Co. and afterwards GEOEN together with Turkish MB Holding with the investment of 35 million euros for finishing the project. The power plant should be operating by the end of 2018. It will produce the equivalent of 10MWt of electrical energy for 2300 households and the energy will be sold to HEP (Croatian Electrical Operator). In the future, the water is planned also for heating of greenhouses and fish farms.

The geothermal aquifer is situated in the Bjelovar sub-depression which is a separate regional geotectonic unit and it is geologically and geographically separated from the Drava Depression because of uplift of Bilogora Mt. in the Pliocene and Quaternary.

The palaeorelief map of e-log border "Pt/Tg" of 16.4 Ma shows Palaeozoic and Mesozoic top forms with a maximum of number of structures reflected across basement top. The transverse fault system strikes approximately N/NE-S/SW, and the diagonal fault system NW-SE. Normal faults are dominant in the transverse system, and faults with longer strikes in the diagonal system. Here can be observed the Western Bjelovar (Rovišće) syncline (>3100 m), the Pavljani anticline (1200 m), the Eastern Bjelovar (Velika Ciglena) syncline (>3700 m), the Šandrovac structural nose (3000 m), the Grubišno Polje anticline (<900 m) and the Dežanovec anticline (<1000 m).

During the 90-ties, INA drilled four boreholes in the area (Ptk-1, VC-2, VC-1, VC-1A) due to oil and gas exploration. All reached the Mesozoic carbonates (dolomite, dolomite breccia) at the depth from -2390 to -2314 m a.s.l. The water temperature at wellhead is 170 °C and cca 180 °C at the bottom with flow rate of 83 L/s. Thermal water contains dissolved gas (30 m^3/m^3) comprising 99.5% CO_2, and about 59 ppm H_2S. Study on reserves was confirmed in 2007, and the amount of stored water is about 167 million m^3. To optimize the production, the used water (which will be used from VC-1A) will be reinjected into wells VC-1 and Ptk-1.

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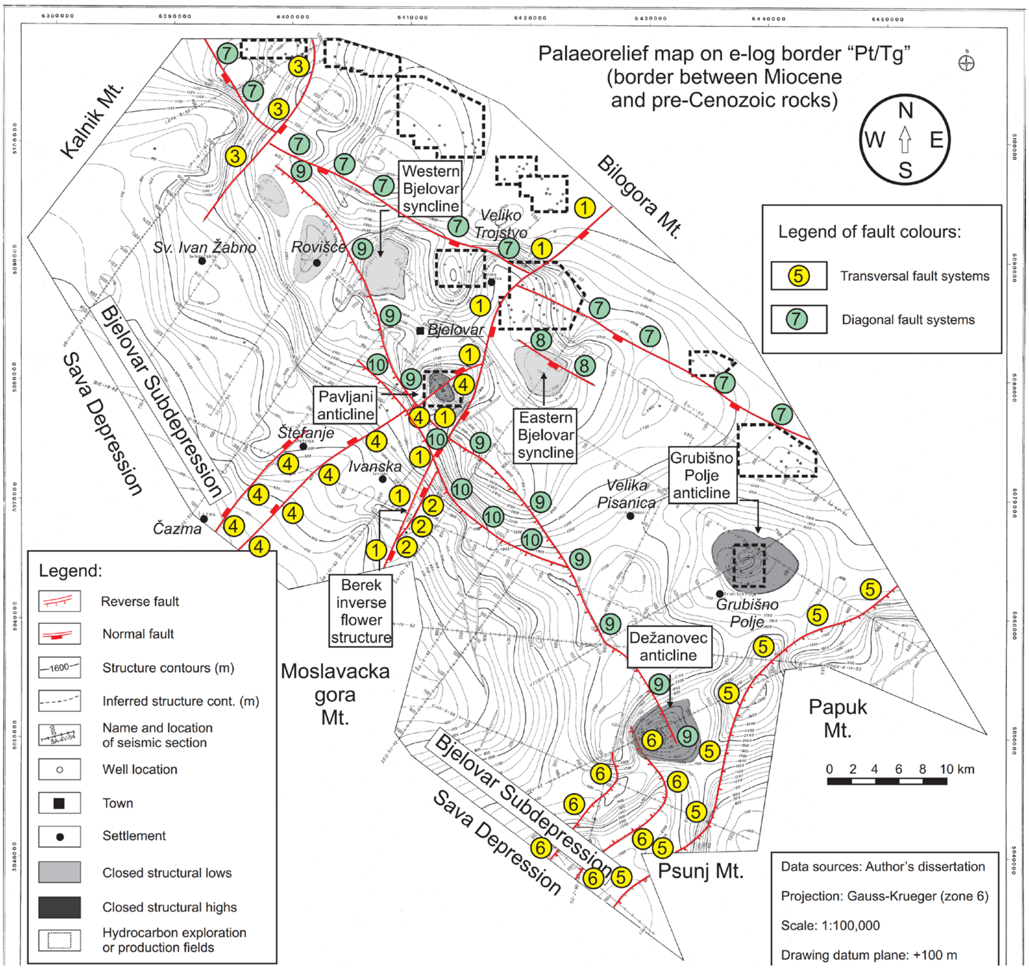

Figure 28: The palaeorelief map of e-log border "Pt/Tg" (Malvić, 2011).

Krapinske Toplice – Hydrogeology and use of thermal waters

Tamara Marković, Ozren Larva

Thermal springs of Krapinske Toplice occur in a narrow valley of stream Topličica with three main springs and a few springs of lower yield. The main occurrence is in the area of Pučke and Jakobove kupelji.

Total yield of all springs ranges from 69 to 81 L/s according to Bać & Herak (1962). The majority of springs occur along the boundary between dolomite and limestone.

In 1985, a 861 m deep well was drilled about 250 m north from the springs which passed through carbonates before it ended up in calcarenites and shale. It was tested with a yield of 30 L/s and water temperature of 45 °C. The most recent measurements have determined the yield of Pučka kupelj to 38 L/s and of Jakobova kupelj to 10.4 L/s. Thus, the total amount of natural leakage of thermal water is 48 L/s and does not differ significantly from previous results.

Spring water belongs to Ca^{2+}-Mg^{2+}-HCO_3^- type of water. Hydrochemical facies is a result of dissolution of carbonate minerals in the geothermal aquifer and has not changed over the years.

Today, the water in Krapinske Toplice is used at four sites: Special Hospital for Medical Rehabilitation Krapinske Toplice (therapeutic treatments and heat pump), Clinic Magdalena (space heating), Waterpark Aquae vivae (swimming pools and space heating), and Villa Magdalena hotel (whirlpools and hot water). Thermal water is used in water supply distribution system connecting 271 households.

Krapinske Toplice – Special Hospital for Medical Rehabilitation

Branimir Suton

In 1998, the government of the Republic of Croatia awarded a concession for extraction of thermo-mineral water to the Special Hospital for Medical Rehabilitation. So, the Special Hospital has the right to harvest thermomineral water from springs "Pučka kupelj", "Jakobova kupelj", and the KRT-1 well in the total amount of 534.500 m^3/y (for water supply up to 183,950 m^3/y, for technological needs up to 287,300 m^3/y, for health and recreational needs up to 63,250 m^3/y) or at most 51.0 L/s for heat and up to 23.0 L/s from the well.

Currently, 227 users are connected to the water supply system (total consumption approx. 4000 m^3/ month). The facility has thermal water heat pumps GEA HAPPEL type EUWH 240FSD from 1992 with COP 3.6 and are used only for space heating and only at night in the period of lower electricity tariffs.

The Hospital has four indoor pools. The famous "Jakob" swimming pool was built at the very source of thermal water and is one of the few such examples in the world.

Krapinske Toplice – AQUAE VIVAE Waterpark

Martina Crljen

It is equipped with the highest standards in technology, pool water preparation, energy usage and waste management. Thermal water is used in swimming pools and is the sole energy source for heating of the premises in the winter months. The surface lay out of 18.000 m^2 has 6 pools, a restaurant, sunbathing areas, dressing lockers, and a coffee bar. The water inlet temperature for the water park is 40.5 °C and outlet 28 °C, producing the difference of 12.5 °C. For this, it takes up to 100 m^3 of water for normal operation in the winter. Water used in swimming pools first goes to the hottest one, then to warmer and finally to the coolest.

The water in the water center also warms the air. The air is vented out when it becomes denser with special recuperators (mechanical) so that the warm air through the inside of the tube goes out into the surrounding area, and around these pipes fresh air enters into the center. Recuperators have 80% efficiency. In addition to them, heat pumps work at night when no room ventilation is required, while heating the water will heat the floors to a temperature of 32-33 °C. The system works in such a way that the heating condensators (accumulators) use the bottom plate of the water park in which 50 km of pipes were built-in for under-floor heating. The bottom plate is made of concrete, and has a mass of 5000 tons and a volume of 2700 m^3. It is heated during the night (cheap electricity) to 33 °C, and during the day it cools to 30°C. This way the thermal energy is stored at the lowest part of the premises, which ensures natural circulation of hot air from the floor to the ceiling, where the air conditioning chambers suck in it and transport to recuperators.

The roof and wall thermal insulation reduces mechanical and static losses to a minimum. The insulation of the outer walls is to achieve a high very coefficient (0.26 W/m²K). On the vertical walls there are 60 mm thick glass bricks with a coefficient of 0.9 W/m²K. The roofs are made up of a laminated wood construction and are insulated to have 0.2 W/m²K. The glazed areas of the roof are designed with triple-glazing so that the coefficienct of the passing of heat 1.1 W/m²K.

Used thermal water of 28 °C can be cooled by 8 °C to 20 °C, thus providing additional 2.2 MWh.

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Figure 29: Waterpark "Aquae vivae"
(taken from www.villa-magdalena.net)

Stubičke Toplice – Geology of the Croatian Zagorje Region

Radovan Avanić, Antun Šimunić, Zoran Peh

Hrvatsko Zagorje is located in NW part of Croatia occupying of about 1,900 km^2. It is a hilly terrain surrounded by the Medvednica and Kalnik Mts to the south, the Varaždin-Toplica Mts, the Ravna Gora and Macelj Mts to the north, and the Sutla and Drava Rivers to the west and east, respectively.

The Lower Palaeozoic includes ortometamorphites originated by alteration of basalts, andesite and tuffs, shales and quartzite together with marbles formed by alteration of sedimentary rocks. They appear at the Medvednica, Ivanščica and Strahinščica Mts and are building the basement of all the younger rocks. The Upper Paleozoic includes non-metamorphosed rocks, the Carboniferous and Permian limestones. At the end of the Permian, concurrently with the "Gröden sediments" (gravels, sands and shales) dolomites, salt and gypsum were deposited.

Triassic rocks build the core of almost all Zagorje mountains. During the Early Triassic, fine-grained sandstones, siltstones, marls and clays of the Ludvić Formation were deposited in the shallow sea. In the Middle Triassic, limestones and dolomites of the Belski Dol and Ruškovlje Formations were deposited continuing with stromatolite dolomites in the Late Triassic. At the end of the Middle Triassic, deposition of sandstones, shales, tuffs and andesite-basalts of the Gregorić Brijeg Formation occurred. The new cycle of sedimentation occurred at the end of the Upper Jurassic when the sea bottom was uplifted at the depth of about 2000 masl and limestones with pelagic silicates have been formed after that period deep-sea conditions. In Cretaceous, the deposition of fine-grained sandstones and shales of the flysch series accompanied with diabase, spilite and basalt along the deep faults or lava flows on the sea bottom occurred. In the same time, the blocks of Triassic and Jurassic limestones collapsed into the basin, resulting in the combination of rocks of different origin and age under the name of "diabase-chert formation", igneous-sedimentary complex" and "ophiolite melange". At the end of the Turonian formation of the rudist reefs and "scaglia" limestones together with sandstones and marls of the "flysch" formation occurred.

Deposition of flysch continued from the Cretaceous into the Palaeocene. At the end of the Palaeocene, and in some parts of Hrvatsko Zagorje even earlier, emersion began characterized by the Middle and Late Eocene deposition of the shallow-sea marine sediments of the Keglević Formation. Littoral limestones and calcarenites and shelf marls of the Meljan Formation were deposited in the Kiscelian. Continual sedimentation with prograding a tendency is present in deposition of sands and marls with occurrences of coal of prodelta and nearshore areas of the Golubovec Formation in the Upper Egerian. Associated to Donat and Rogaška fault systems, synsedimentary volcanism in the Egerian (andesite and pyroclastic rocks of the Golubovec Formation) and Eggenburgian (tuffs of the Macelj Formation) occurred. The Eggenburgian was marked by deposition of nearshore glauconite sands and pyroclastics (Vučji Jarek Member), clayey-sandy silts of the transition zone (Čemernica Member), sandstones and conglomerates (Lipni Vrh Member) in the nearshore and delta environments, and sands with intercalations of silts and clays of the tidal channels and planes (Vrbno Member) of the Macelj Formation After the calcareous silts and tuffs had been deposited on the shelf during the Ottnangian (Bednja Formation) and in the Carpathian, it was followed by by sands and gravels of the nearshore (Crkovec Formation). Marine sedimentation from the Late Eocene to the Carpathian was characteristic only for the northern part of Hrvatsko Zagorje (Hrvatsko Zagorje Basin).

In the southern part of Hrvatsko Zagorje (North-Croatian basin), the first sedimentation after Eocene-Egenburgian emersion was aluvial sedimentation in Ottnangian (Daranovac Formation). From the Late Ottnangian to the Karpathian a lake existed (the Glavnica Formation), composed of the littoral congeria limestones with coal intercalations (Vukov Dol Member), the lake basin and prodelta marls with intercalations of sands, sandstones and tuffs (Koščević Member) and prodelta and delta front conglomerates with intercalations of sandstones and siltites of the Franci Member. Due to the Early Badenian transgression in the Central Paratethys, the Hrvatsko Zagorje basin and the North Croatian basin joined so that marls of the Vejanica Formation sedimented in the marine offshore and coarse-grained material of the Trstenik Member in the soreface. The Middle and Late badenian is characteristic with marls of the Vejalnica Formation in the shelf, and biocalcirudites and biocalcarenites of the Vrapče Formation in the shoreface environment. In the Sarmatian, deposition of the conglomerates, calcarenites and limestones (Pećinka Formation) of the shallower area and laminated pelites (Dolje Formation) in the deeper environment of reduced marine salinity occurred.

During the Pannonian, in the newly formed brackish Pannonian Lake, shallow water bedded clayey limestones (Croatica Formation) deposited which were gradually replaced by the deep water marls of the Medvedski Breg Formation. Because of the progradation of the river clastic system after marls accumulated the sandy silteous sediments of the prodelta (Andraševac Formation) and sands of the delta front (Nova Gradiška Formation) together with the sediments of the alluvial plain of the Pluska Formation. During the Pliocene, the region represented the alluvial plain with minor freshwater lakes and marshes of the Vrbova Formation.

In Quaternary, deposition of gravels, sands, silts and clays of the Bistra Formation occurred in the alluvial fans as well as the sediments characteristic for floodplains, marshes and stream deposits environments.

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Stubičke Toplice – Thermal waters from carbonates

Tamara Marković

Stubičke toplice springs are located on the northern side of Medvednica Mt. They had consisted of two major and several smaller springs but they dried up when deep wells were drilled and put into operation. The yield of the springs was 18 L/s (Bać & Herak, 1962). The only spring which did not dry up is a spring near the hospital, but this spring is a mixture of thermal and cold water and the water temperature is 35 °C. The water temperature in the wells varies from 56 to 65 °C.

The surrounding area of the Stubičke toplice springs comprises clastic carbonate sediments, dolomite, alluvial, proluvial-deluvial deposits and siliciclastic rocks. Geothermal aquifer consists of dolomite and limestone.

Today, thermal water is utilized by the Special Hospital for Medical Rehabilitation, Stubičke Toplice and the hotel Matija Gubec. The Special Hospital for Medical Rehabilitation uses the well B-1, which was drilled in 1963. The operational depth of the well is only 51 m althought the drilled depth was 201.73 m (Glavinić, 1963). Its average yield is 2.7 l/s. The water is used for recreation, balneotherapy, water and space heating and sanitary water. The hotel Matija Gubec is using the second well ST-2 and the water is used for recreation.

The termal water belongs belong to a Ca^{2+}-Mg^{2+}-Na^{+}-HCO_3^{-}-SO_4^{2-} mixed type. The high content of CO_2 is observed – 101.49 mg/L (Hospital Stubičke Toplice, 2014)

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Krapina – Krapina Neanderthal Museum

Materials of Krapina Neanderthal Museum

Scientifically known as Homo sapiens Neanderthalensis, the Krapina prehistoric man was discovered all the way back in 1899, when geological and paleontological research started on Hušnjakovo hill in Krapina. Excavations, supervised by professor Dragutin Gorjanović-Kramberger, a well-known Croatian geologist, palaeontologist and paleoanthropologist, lasted six years (1899 – 1905). His works significantly contributed to European and global science of the fossil man.

Some nine hundred human fossil bones were found in the cave's sandstone deposits, which were 8 meters high. This is the largest and most abundant collection of Neanderthal people collected at a single locality. The bones belong to the fossil remains of several dozen individuals, both male and female, from 2 to 40 years of age. Numerous fossils remains of cave bear, wolf, elk, giant deer, woolly rhinoceros, wild buffalo, and many other animals were found. Over a thousand pieces of stone tools from the Palaeolithic age, or Early Stone Age, discovered at the site, speak of the material culture of Krapina Neanderthals. The age of this rich paleontological locality corresponds to the period of about 125,000 years ago. The site is protected as the first paleontological natural monument in the Republic of Croatia, and is listed as one of the richest Palaeolithic habitats of Neanderthals in Croatia and Europe.

Ever since it's opening on February 27, 2010, the „Kraneamus“ Krapina Neanderthal Museum has been attracting attention of visitors due to its specific ways of presenting the topic. Authors, paleontologist Jakov Radovčić and architect Željko Kovačić, gave a better understanding of the people of Krapina from the Stone Age, who lived in this area 125,000 years ago. The exhibition is set up as a time machine through the history of the Universe, the Earth and Man, leading up to the present day, and lays special emphasis on the Neanderthal period.

Figure 30: Excavation site – Hušnjakovo hill
(taken from http://mkn.mhz.hr)

Rogaška Slatina – Geothermal borehole RT-1/92

Andrej Lapanje, Nina Rman

Thermomineral water is also found in Rogaška Slatina, being very different from the mineral one. The 1,700 m deep geothermal borehole RT-1/92 was drilled in 1992 based on geoelectrial survey and thermometric borehole TR-3/90. Here, the Pre-Tertiary relief drops steeply to south and exceeds the depth of 2,000 m at the border river Sotla.

Natural mineral water aquifer in the Miocene andesite and andesitic tuff is separated from the geothermal reservoir by Oligocene to Miocene clayely silt with lenses of tuff material and sandstones, reaching depths of 1.4 km. The thermomineral water is stored in complex of Ladinian Psevdozilian Series of Formation. Below discordance, the Ladinian the dark gray to black clay slate with diagenetic dolomitization is encountered to 1.6 km. The bottom at 1.7 km ends in Carboniferous black clayey siltstone. The rocks are poorly permeable; geophysical measurements marked section between 1,506-1,570 m in dolomitized clayey slate as water-bearing while the major thermal water inflows occur only in a few narrow cracks between 1,507 and 1,518 m.

The artesian water has thermo- and gas-lift with dynamic wellhead pressure of 3.2 bar. Hydrogeochemical type of water is Na^+-HCO_3^--SO_4^{2-}-(Cl^-), mineralisation is 5.4 g/l, electrical conductivity is 5760 µSi/cm and it contains 1.3 g/l of dissolved CO_2. Dinamic reserves are estimated to 6 l/s. Stable isotopes of oxygen and deuterium are rather heavy and similar to freshwaters from the dolomite. Carbon-14 indicates the retention time of about 14.000 years by some interpretations. Noble gases show characteristic distinction from the mineral waters. Rt-1/92 has only 16% of mantle helium while the mineral waters more than 75%. Due to CO_2 degassing it is not possible to calculate the infiltration temperatures.

Thermomineral water is used in thermal pools of Grand Hotel Sava and SLKI Co. 800 m away from the well, reaching an average discharge below 2 l/s and average temperature of 57.2 °C. Prior to utilization, the iron has to be removed in sandy filters and the water cooled. Waste thermal water from pool complexes is dechloritized and discharged into the public sewage system, which is connected to the waste water treatment plant in Rogaška Slatina.

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Figure 33: Wellhead of RT-1 well (photo by N. Rman)

Rogaška Slatina – Natural mineral waters

Peter Junež, Andrej Lapanje, Mihael Brenčič

Landscape near Rogaška Slatina is hilly with with altitudes 220-350 m and composed of sandy marl which quickly weathers producing favorable soil for agriculture. Vineyards predominate in the southern parts where andezitic tuff and marls outcrop. On the northern edge, the slopes steeply rise and reach heights 400-550 m. The Boč mountain range (the eastern extension of the Karavanke Mts.) reaches even 978 m.

The oldest known written sources on mineral water in the area of Rogaška Slatina date in the 12th Century. Initially, mineral waters named Tempel and Styria were exploited from natural sources and shallow wells. In 1908, the mineral water was captured in 10 m deep drainage Knetteum, in which highly mineralised mineral water of the new Donat type was caputured for the first time. After 1950, under the leadership of Josip Bać and Anton Nosan, the period of capturing mineral waters from boreholes began in Rogaška. The research was extended eastwards to Rogatec and west to Gabernik. The Donat mineral water was captured in deep wells V-6/67 in Rogaška Slatina, V-3/66-70 in Podplat and K-2/75 in Spodnja Kostrivnica. Due to the high content of magnesium (over 1 g/l), the brand was officially supplemented with Mg to Donat Mg in 1976.

The geological structure Rogaška Slatina area is very complex. The oldest rocks are claystones, quartz sandstones and conglomerates of Carboniferous age (C) which were encountered in the RT-1/92 geothermal well under a mixed carbonate-clastic-volcanic Pseudogailltal series of formations ($T_{2,3}$). In the area of Boč and Dreveniška gora, and along the Donat fault zone from Kostrivnica to Zg. Negonje (the northern andesite belt), rocks of Middle Permian age outcrop. These are massive limestone (Pa), sandstone, conglomerate, claystone (Pk), and Tarviso breccia (TB). The Middle Permian rocks are overlained by black marly limestone of the Lower Triassic age (T_1), massive limestone (T_2^1a) and the massive dolomite (T_2^1d) of the Middle Triassic age in the Boč Mts. In fault zones, erosion resiudes of the Upper Eocene numulitic limestone (E_3) are found. The Donat Mg mineral water aquifer consists of pyroclastic rock series - andesite tuffs, tuff breccias and tuff sandstones ($^2Ol_1$), in which a thick layer of andesite (α) is deposited.

Diverse geological settings, deep-seated faults, different retention time of groundwaters and other settings result in chemically various waters. Groundwaters from the northern carbonate massive are of Ca^{2+}-Mg^{2+}-HCO_3^- type with mineralization of 0.5 g/l. Mineral water tapped in the northern and central part of the andesitic tuffs are of Na^+-Ca^{2+}-Mg^{2+}-HCO_3^--SO_4^{2-} type and with mineralization of 6-9 g/l (wells G-10/95, K-1/71, Kraljevi vrelec). Mineral waters from the southern part of the andesitic tuffs, holding a brand Donat Mg, have a characteristic water type of Mg^{2+}-Na^+-HCO_3^--SO_4^{2-} with mineralization about 14 g/l (wells V-3/66-70, K-2/75, RgS-2/88). South of the Šoštanj Fault, thermomineral water of Na^+-HCO_3^--SO_4^{2-}-Cl^- type and mineralization of 6 g/l is captured in the deepest well in the region, RT-1/92.

Stable isotopes of oxygen and deuterium in mineral waters are lighter than the recent precipitation and show a distinctive left-shift due to CO_2 effect.

Carbon-14 indicates the retention time of several thousand years but a reliable determination is difficult due to CO_2 gas and dissolution of carbonates.

Noble gases prove deep-seated permeable fault system with huge contribution of mantle helium, having very similar composition to the Radenci area waters.

Tritium activity in these wells is very low, mostly below 0.02 TU.

Carbon-13 indicates that all mineral waters dissolve carbonates, while this effect is not so evident in RT-1/92.

Strontium and boron isotopes were also measured and show differences not only between mineral waters but also from the thermomineral one.

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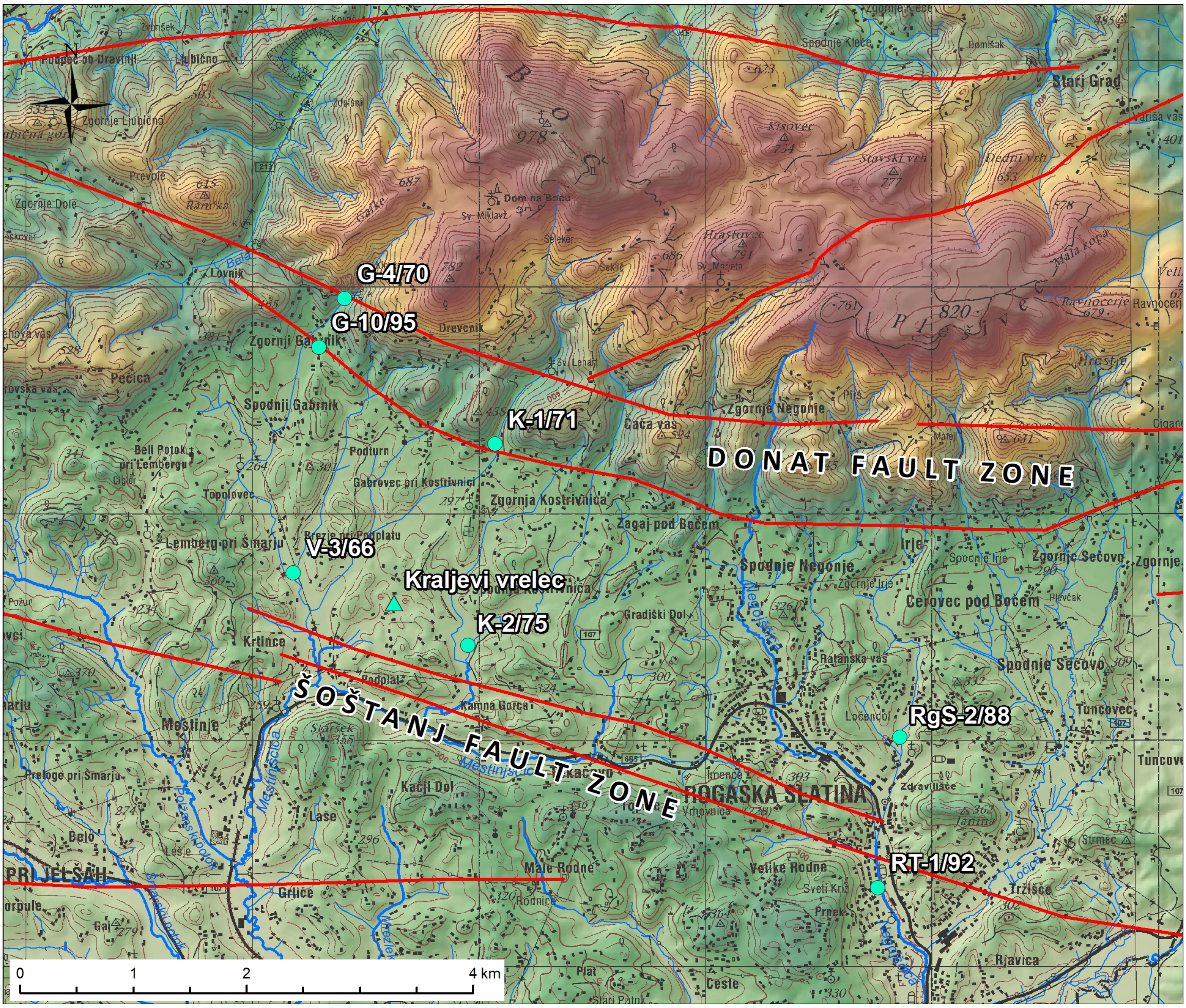

Figure 31: Main fault zones in Rogaška Slatina area and locations of mineral water wells.

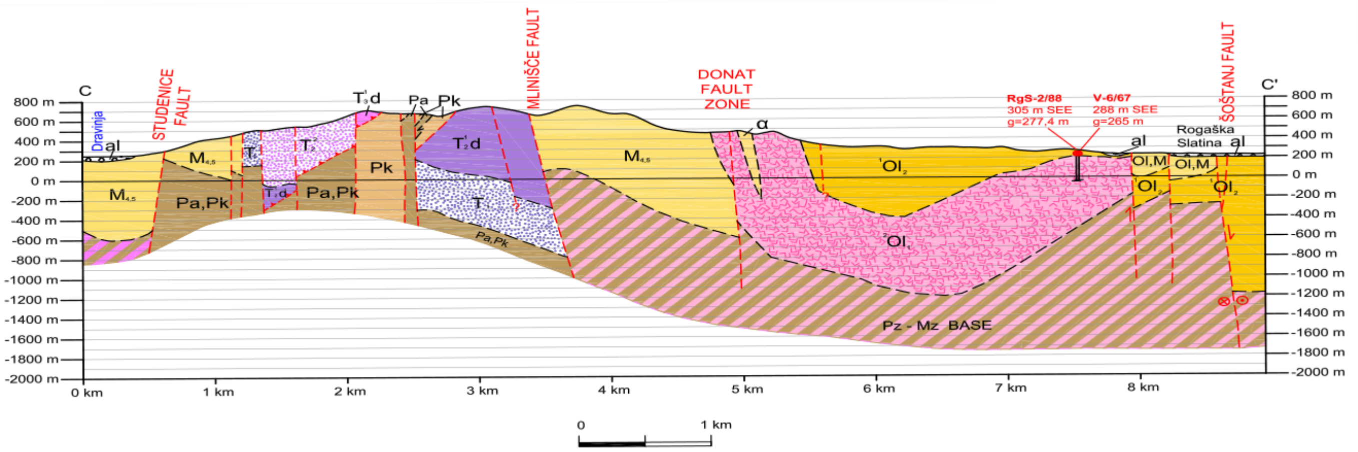

Figure 32: Geological cross-section of the mineral water area (modified from Novak & Celarc, 2010).

Commission on Mineral and Thermal Waters (CMTW-IAH)

Jim LaMoreaux, Adam Porowski

The Commission on Mineral and Thermal Water of IAH (CMTW-IAH) was established in August 1968 in Prague, Czechoslovakia, during the 23rd session of the International Geological Congress (IGC), and is one of the two the oldest IAH working groups. The Commission consists of IAH members who work and are specialized in the wide field of mineral and thermal waters. Up to date, the sustained activities of the Commission reach 50 years with more than 45 annual meetings organized by its members independently out of the large international conferences or together with IAH congresses. The CMTW meetings are comprised of scientific sessions, field trips and business meetings. During scientific sessions members and invited speakers present results of various researches in the field of mineral and thermal waters, legislative issues, hydrogeology in general and technical field work. Updated information is also presented concerning exploration and utilization of mineral and thermal waters primarily in the country hosting the meeting. The field trips usually cover important areas of thermal and mineral waters in the host country. At the business meetings, members of the Commission decide organizational issues, future plans and publication and educational projects. The objective of the Commission is to bring together scientists, engineers and other professionals dealing with mineral and thermal waters. The CMTW is open also on young beginners in hydrogeology and thermal waters. We always support scientific collaboration and exchange of knowledge and experience among members. Nowadays, the members of the CMTW are mostly hydrogeologists working in various governmental agencies and private organizations.

The Commission is honored to have among its members such internationally recognized professionals: Ambassador Professor Jan Dowgiałło, expert hydrogeologist and former member and honorable chairman of the Commission, honorable member of the IAH; Professor Ladislaus Rybach, internationally recognized professional in the field of geothermics and former President of International Geothermal Association (IGA); dr Jim LaMoreaux, CEO of the PELA Geoenvironment, Chairman of the US National Chapter of the IAH, internationally recognized Chief Editor of Environmental Earth Sciences Journal and actual Chairman of the CMTW.

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Slovene Committee of the IAH (SKIAH)

Mihael Brenčič

Society of Slovenian Committee of International Association of Hydrogeologist (SKIAH) is independent and nonprofit organization of Slovenian hydrogeologist and other professionals related to groundwater. SKIAH strives to increase the reputation and visibility of the hydrogeological profession in Slovenia and internationally and for high professional standards in hydrogeology and in all activities related to groundwater. SKIAH organizes public lectures, professional excursions and consultations, scientific meetings, workshops and conferences, participates in efforts to protect the environment, also by preparation of drafting legal acts and norms in the field of hydrogeology.

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Slovenian Geological Society (SGD)

Matevž Novak

Slovenian Geological Society (SGD) is a professional association of Slovenian geologists that brings together researchers, professional and educational workers and amateur geologists. The overall objective of SGD is contributing to the advancement of science and practice in the field of all branches of geology and related disciplines. To meet this goal, SGD performs the following activities: a) Organization of public lectures, field trips, and scientific meetings; b) Popularization of geology and integration of geological sciences in primary and secondary school curricula through popular scientific lectures, papers, brochures, exhibitions and excursions; c) Cooperation with universities, research organizations, public institutions and institutes, companies and persons whose areas of expertise involve different branches of geological sciences; d) Contribution in efforts to protect the environment; e) Contributing to the preparation of legislative acts in the field of geology; f) Cooperation with other professional associations in Slovenia and abroad.

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Projects IGGP

Nina Rman

Slovenian National Comission for UNESCO supports the sustainable development at all fields, national policy to mitigate climate changes, world heritage sites with special attention on geoparks, education activities and intercultural dialogue. IGGP supports several geological projets in Slovenia and within the project 636 - Characterization and sustainable exploitation of geothermal resources, we continue investigating the effects of geothermal energy production on status of geothermal aquifers in Slovenia. Type and extent of impacts on quality and quantity state of geothermal resources is presented to professional, scientific and general public to successfully address its mitigation in future.

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Project DARLINGe

Andrej Lapanje

This field trip falls not only within the DARLINGe project area but even in its pilot area. The DARLINGe runs witih the Interreg Danube Region 2014-2020 programme in the period 2017-2019. It aims at presenting the use of geothermal heat as a smart and sustainable solution supporting diversification and safer use of renewable energy resources. By developing the open access DRGIP portal, where the latest knowledge on known and potential geothermal reservoirs and their use will be presented interactively, increased investments in geothermal energy for district heating and cascade uses is fostered. The Slovenian-Croatian-Hungarian pilot area covers the Mura-Zala sedimentary basin and its vicinity where porous and fissured geothermal aquifers have been exploited for decades. The 3D transboundary geological model will be elaborated and renewable amount of thermal water evaluated by a numerical model of flow and heat transfer.

DARLINGe project is co-funded by the European Regional Development Fund (1,612,249.99 €) and by the Instrument for Pre-Accession Assistance II (534,646.60 €) under Grant Agreement no DTP1-099-3.2.

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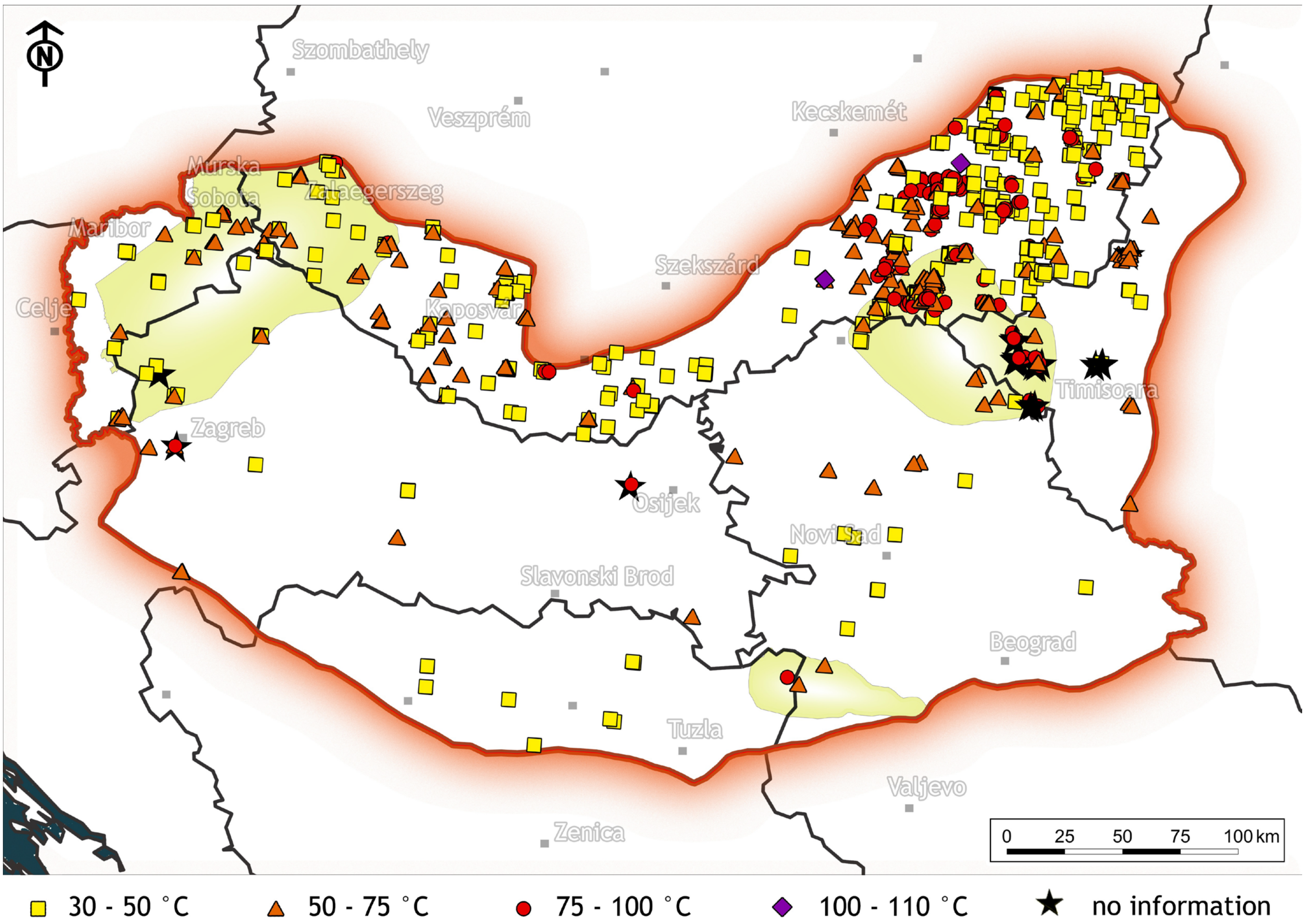
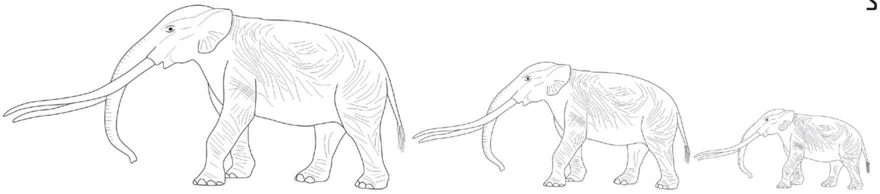


Figure 30: Thermal water temperatures in the DARLINGe project area

Notes



Se vidimo čez štiri leta.
SREČNO!

See you in four years.
SREČNO!
(Good luck!)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5. SLOVENSKI GEOLOŠKI KONGRES
Do 5 milijard let z družbo 5.0
Velenje, 3.– 5. 10. 2018