COST ACTION CA18219 Geothermal-DHC

Coupling technologies to use low and medium depth hydrogeothermal energy

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in Thermogeology

in Slovenia and Croatia

9th to 16th July 2021

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- Geological Survey of Slovenia (GeoZS), Dimičeva ulica 14, 1000 Ljubljana, Slovenia;
- University of Ljubljana, Faculty of Natural Sciences and Engineering (NTF UL), Aškerčeva 12, 1000 Ljubljana, Slovenia;
- Faculty of Mining, Geology and Petroleum Engineering of University of Zagreb (UNIZG-RGNF), Pierottijeva 6., p.p. 390, 10 000 Zagreb, Croatia;
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Coupling technologies to use low and medium depth hydrogeothermal energy

FIELDTRIP GUIDEBOOK

9th to 10th July 2021

1. Fieldtrip schedule

DAY 1: Friday 9th July

8:30 – 8:45	Registration at NTF, Ljubljana
9:00 – 10:15	Bus transfer to Kostanjevica with explanation of general geological settings (M. Brenčič)
10:15 – 11:00	Geothermal potential and its use in Slovenia (D. Rajver)
11:00 – 12:30	Guided tour in Kostanjevica cave and regional groundwater flow systems in SE Slovenia (M. Brenčič)
12:30 – 13:00	Bus transfer
13:00 – 14:00	Light lunch
14:00 – 15:00	Geothermal features and cascade use of water in Terme Čatež Spa (D. Krulc, N. Rman, D. Rajver)
15:00 – 16:30	Training in science communication (M. Turnšek)
16:30 – 18:00	Fieldwork at Terme Čatež Spa (M. Brenčič, N. Rman, D. Rajver, S. Adrinek)
18:00 – 20:00	Accommodation and dinner at Terme Čatež Spa (individual payment)
20:00 – 21:00	Introduction to Geothermal-DHC (G. Goetzl) Wrap-up of the first field day (M. Brenčič, N. Rman)

DAY 2: Saturday 10th July

8:00 – 9:00	Bus transfer to Zagreb, Croatia (crossing the Schengen border)
9:00 – 10:00	Geology and geothermal potential and its use in Croatia (S. Borović)
10:00 – 11:00	Direct use of a geothermal doublet Mladost and clinical hospital Novi Zagreb in a fissured reservoir in Zagreb (S. Borović)
11:00 – 12:30	Bus transfer to Velika Ciglena
12:30 – 13:30	Light lunch
13:30 – 14:30	Guided tour at the geothermal power plant Velika Ciglena (I. Kolenković Močilac)
14:30 – 15:00	Geology of the Pannonian Basin and its petroleum resources in connection with geothermal potential (I. Kolenković Močilac)
15:00 – 18:00	Bus transfer back to Ljubljana

2. Geological settings of Slovenia

Matevž Novak

The Republic of Slovenia has been independent since 1991 and is an alpine coastal state in the south Central Europe, bordering Italy, Croatia, Hungary and Austria. It covers 20,273 km^2 and has about two million inhabitants. The country is one of the most water-rich in Europe, while over half of its territory covered by forest, making it one of the three most forested countries in Europe. More than a third of the country is included in the Natura 2000 protected areas. Our Karst underground has been on the UNESCO list since 1986.

Slovenia lies at the junction of the Eastern Alps, Southern Alps, Dinarides (Dinaric Alps) and the Pannonian Basin. Their rocks belong to the Adriatic Lithospheric Microplate, which detached from the African Plate during the Mesozoic Era. The microplate travelled north and collided with the Eurasian Plate during the Neogene, causing the uplift of the Alps which shaped our surface.

The oldest sedimentary rocks were formed in the Silurian and Devonian. Among these the Devonian reef limestone containing sponges and corals is the most interesting. The collision of Godwana with Laurussia at the end of the Devonian caused the uplifting of the Variscan Mountain chain and during this process, known as orogenesis, the rocks of the Precambrian and Early Paleozoic basement were folded and drastically changed. The metamorphic rocks which form today’s Pohorje, Strojna and Kozjak Mountains originate from these.

The territory was continuously drifting north. By the Middle Permian it had reached into a hot and arid climate zone. Meanwhile on the desert land, rivers occasionally filled their channels and deposited sediment from which colourful, violet-red and greenish quartzitic clastic rocks developed. The sea periodically flooded the salty tidal flats and gradually a vast shallow continental shelf formed called the Slovenian Carbonate Platform. In the Late Permian mainly dolomite was deposited in this area.

At the beginning of the Triassic, a major part was submerged below sea level where mixed clastic-carbonate sedimentary rocks formed due to the influx of debris from the nearby mainland. In the Middle Triassic, a new ocean called Meliata began to open up at the eastern edge of Pangea and a deep trench - Slovenian Basin formed. On both sides of it shallow carbonate platforms arose. The rocks of the Julian and Kamnik-Savinja Alps and the Karavanke Mountains developed on the northern (Julian) platform, while the rocks in south Slovenia formed on the Dinaric Carbonate Platform. The volcanic activity left volcanic rocks and tuffs indicating mainly undersea volcanic eruptions. The two biggest Slovenian mineral deposits – Mežica (lead) and Idrija (mercury) – are linked to this volcanism.

In the Late Triassic, limestone with fossil remains was formed in both shallow marine platforms, later altered into dolomite. These rocks are overlain by up to 1,200 meters of limestone and dolomite, which had been forming in the coastal zone for over 16 million years.

In the Cretaceous extensive areas of limestone formed in today's Kras region. At the end of the Cretaceous, the oceanic part of the northwards drifting Adriatic Plate collided with the continental part of the Eurasian Plate. The associated uplift of the territory resulted in the mobilization of large quantities of terrestrial and submarine sediments and various flysch rocks began to form. Flysch first filled the space of the Slovenian Basin and then gradually the territory in front of the rising Alps. Before the end of the Cretaceous, it covered the entire northern edge of the Adriatic-Dinaric Carbonate Platform. Its sedimentation continued from the Cretaceous to the Paleogene, with a shift of the flysch basin to the south and southwest.

In the Oligocene, the formation of the mountain ranges of the Alps, Dinarides and Carpathians led to the isolation of a new, smaller sea – the Paratethys – from the Atlantic and Tethys Oceans. The collision of plates led to the penetration of magma to the surface along the Periadriatic Fault Zone in the Oligocene. The Smrekovec volcanism came to life, erupting in the marine environment. Andesite and its tuff are most prevalent among the volcanic rocks, occurring between layers of marine sedimentary rocks in a broad zone along the Savinja Valley to Rogaška Slatina and in the surroundings of Radovljica.

In the Early Neogene (in the Miocene) an area of what is now north-eastern and eastern Slovenia began to subside rapidly. The result was a broad transboundary Pannonian Basin in which several kilometres of predominantly clastic sediments were deposited in thick succession.

In the Pliocene, the Pannonian Basin subsidence finally stopped. In central and eastern Slovenia, the Sava Folds began to form. Several small sedimentation basins formed along the faults and were filled by terrestrial sediments with layers of coal of various thicknesses (e.g. the Velenje Basin).

In the Late Pliocene, volcanoes erupted for the last time in our vicinity. The centre of volcanism was in the Austrian Styria. It started with the eruption of basaltic lava from a small volcanic cone followed later by explosive eruptions of gas from several small volcanic vents. The basaltic tuff at Goričko was formed then.

In the Quaternary, the current complex landscape of Slovenia has taken shape. A period of marked climatic fluctuations characterised by the expansion and contraction of glaciers commenced with the Pleistocene.

In the Pleistocene and later in Holocene, gravel, rubble, and lake and bog sediments were deposited on land. The subduction of the Adriatic Microplate under the Eurasian Plate has continued in the Holocene and therefore the Slovenian territory is now in a state of compression.

Atanackov, J., Bavec, M., Bavec, Š., Bedjanič, M., Brajkovič, R., Brenčič, M., Celarc, B., Gaberšek, M., Gale, L., Hitij, T., Ivančič, K., Jamšek Rupnik, P., Jeršek, M., Jež, J., Jurkovšek, B., Kolar-Jurkovšek, T., Kralj, P., Markič, M., Mezga, K., … Žvab Rožič, P. 2016. 70 geological wonders of Slovenia (N. Rman & M. Novak, Eds.). Geological Survey of Slovenia, GeoZS.

3. Geothermal energy and its use in Slovenia

Dušan Rajver

Water with outflow temperature at or above 20 °C is regarded as thermal water in Slovenia.

In the western part of Slovenia, a good correlation was found between the deeply lying Mohorovičić discontinuity, low heat flow density, low temperatures at depth and a large negative Bouguer anomaly. In the eastern part with the Pannonian Basin, the rising mantle-crust boundary is associated with high heat flow density, high temperatures at depth and a positive Bouguer anomaly (Ravnik et al., 1995).

Geothermal potential of Slovenia can be read out of the subsurface temperature distribution maps. Geoisotherms gradually increase from less than 20 °C in western to 80 °C in northeastern Slovenia at 1 km, and from 24 °C to about 115 °C at 2 km (Figure 1).

The use of »deep« geothermal energy in Slovenia is based only on direct use of thermal water which is extracted from 50 geothermal wells and four thermal springs (Figure 1). Most wells in NE Slovenia draw water from the transboundary Mura Formation in the Mura-Zala sedimentary basin (25-63 °C), but locally the Špilje Formation below produces up to 76 °C. Total thermal capacity and the annual energy consumption of all 31 users in 2020 (Figure 2) was 56.941 MWt or 456.921 TJ (= 126.1478 GWh), significantly less than the year before.

The use of shallow geothermal energy with heat pump technology is expanding. In 2020, there were a total of about 13,654 operational ground source heat pump (GSHP) units with a total capacity of 218.17 MWt. Of these, 48.1 % are open systems that have extracted about 671.36 TJ of underground heat, 36.4 % use horizontal closed heat exchangers (with 267.55 TJ of heat), and 15.5 % are vertical borehole heat exchangers (with 150.67 TJ of heat generated). Thus, a total of 1,089.582 TJ (= 302.662 GWh) of heat was used in 2020 (7.9 % more than in 2019), while our approximate estimate is that at least 240 TJ of heat was released into the underground in cooling mode.

The total capacity of deep and shallow geothermal resources and the underground energy used with them was estimated at 275.11 MWt and 1,546.50 TJ/year (= 428.81 GWh/year), respectively, in 2020. This is only 3.91 % less than in 2019, mainly due to the practically unstoppable growth of shallow geothermal sector, as the pandemic had the greatest impact on the significant reduction in the use of thermal water from deep wells.

Ravnik, D., Rajver, D., Poljak, M., Živčić, M., 1995. Overview of the geothermal field of Slovenia in the area between the Alps, the Dinarides and the Pannonian basin. Tectonophysics 250, 135-149.

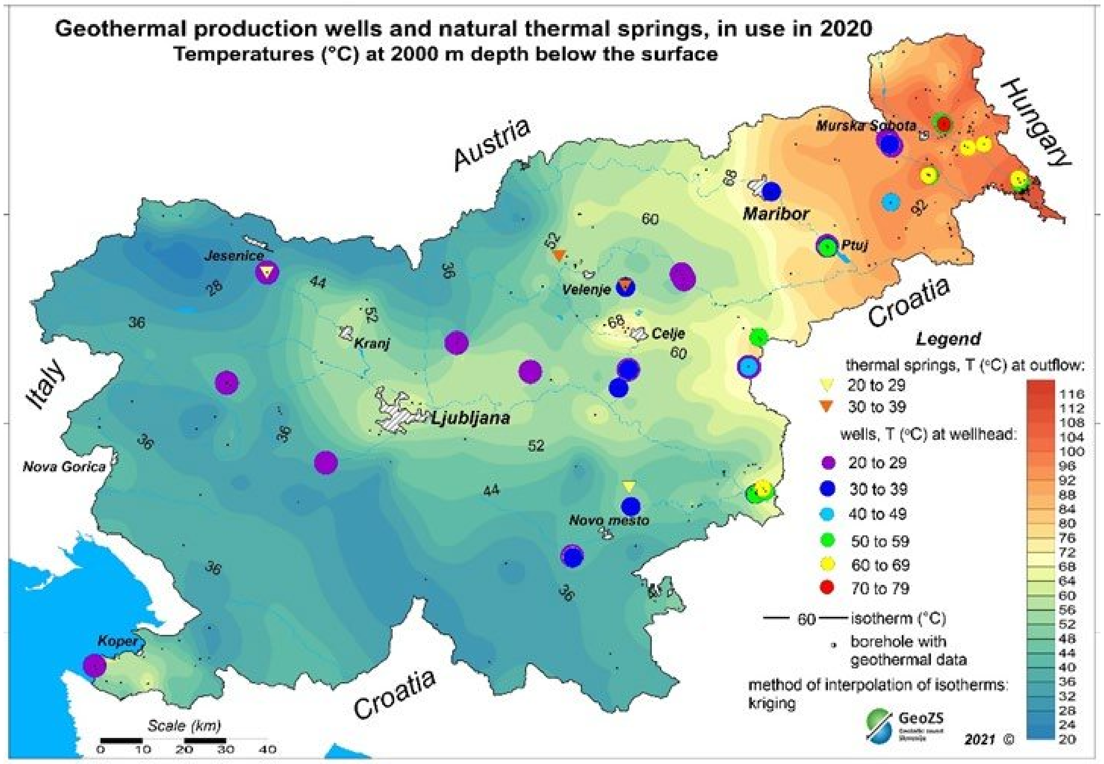

Figure 1: Geothermal production wells and natural thermal springs, in use in 2020, ranged by temperature of thermal fluids at the wellhead and at the discharge, respectively.

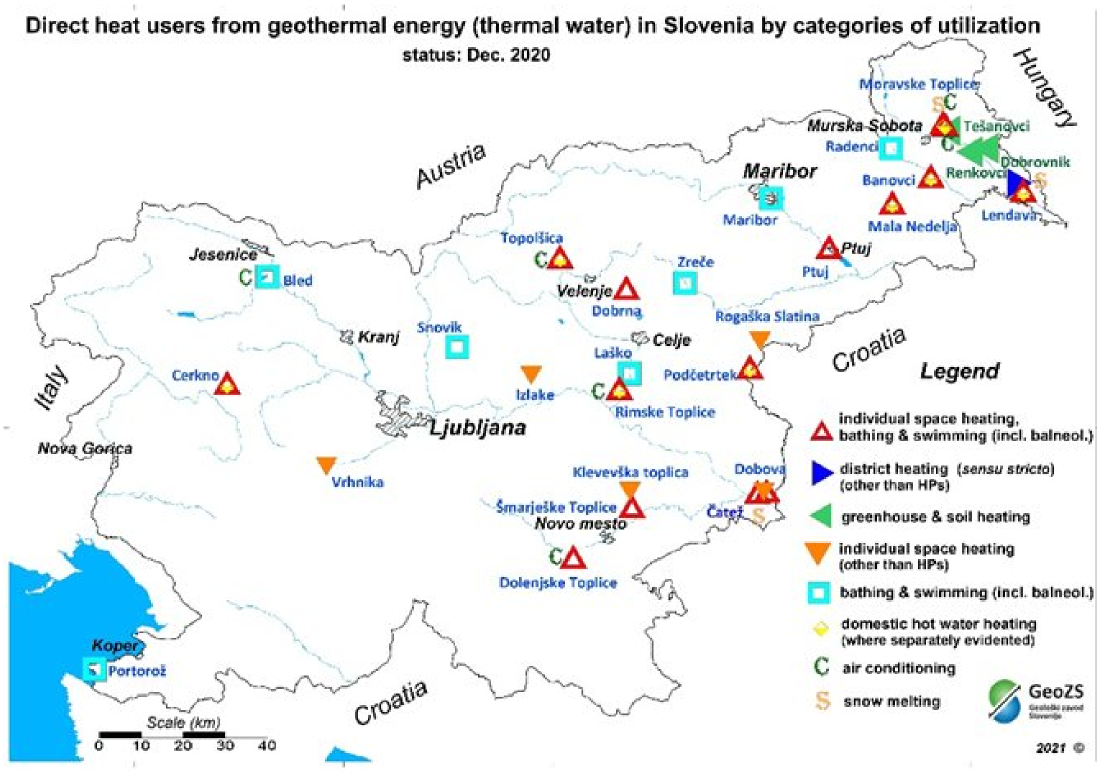

Figure 2: Direct heat users from geothermal energy (thermal water) in Slovenia by categories of use, as of Dec. 2020.

4. Karst and regional groundwater flow systems

Luka Serianz, Mihael Brenčič

In Slovenia, a significant groundwater flow can be found in carbonate rocks of the Mesozoic age, which covers approximately 12,500 km^2 of the nation's territory. Limestone aquifers with high karst porosity are located in large continuous areas in the west and south, from the Julian Alps to the Dinaric karst, and supply almost half of the Slovenian population with drinking water. The aquifers can reach thicknesses of several hundreds of meters, sometimes even kilometres.

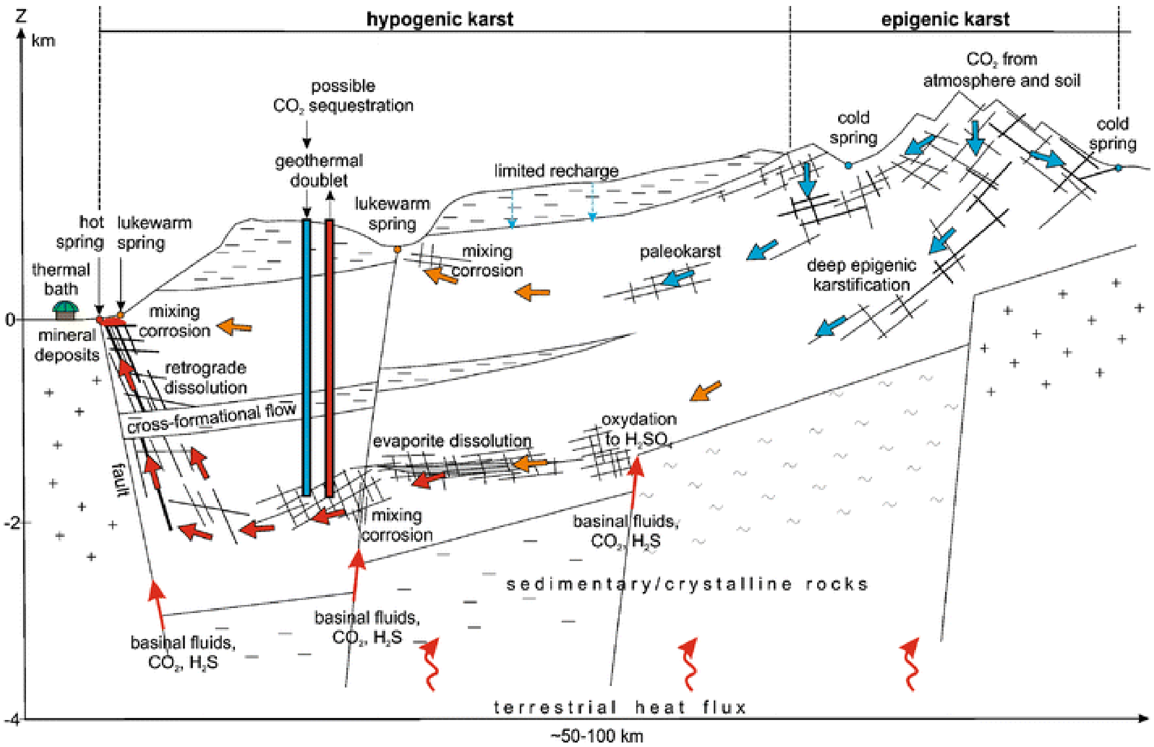

Figure 3: Concept of groundwater flow and karstification processes in a deep and mostly hypogenic inland-carbonate-rock system (Goldscheider et al., 2010).

Aquifers with karstic and fissured porosity are characterized by a heterogeneous structure and three types of porosity: micropores in rock matrix, small fissures or fractures, and larger fissures and conduits (karst). Groundwater recharge and discharge drive the flow through the aquifer, whereas the height of the base level establishes the pressure difference for flow within the aquifer (Scheidler et al., 2021). Slovenia is characterized by complex landforms and geological settings that produce multi-scale groundwater flow systems. The latter can be understood within a conceptual framework of hierarchical flow systems, consisting of local, intermediate, and regional flow systems (Figure 3) where the main driving force is gravity, named than gravity-driven regional groundwater flow (Toth, 1963, 1999). It is well known that the regional groundwater flow is mostly affected by local hydrogeological conditions, hydraulics, geology, geomorphology, topography and drainage area characteristics (Gleeson & Manning, 2008) which determine also the dynamic of the thermal flow regime (Garven, 1995; Cao et al, 2016). The convective process induces increased temperatures in the upper part of the circulation system and a corresponding lowering of temperature occurs in the lower part. Studying dynamics of the regional groundwater flow system from the recharge areas to the discharge zones is probably the most efficient way to answer some fundamental hydrogeological questions, namely: what the geometry of the groundwater circulation system is, where are the main flow paths, what is the natural temperature distribution in different geological formations and what is the intensity of the groundwater flow.

Deep carbonate rock aquifers, most of which are to some degree karstified, are probably the most important thermal water resources outside of volcanic areas (Goldscheider et al., 2010). In west and central Slovenia, predominately dolomitic carbonate aquifers provide many local geothermal reservoirs of warm water system type while we will visit also the regional basement geothermal aquifer in Čatež (Figure 4).

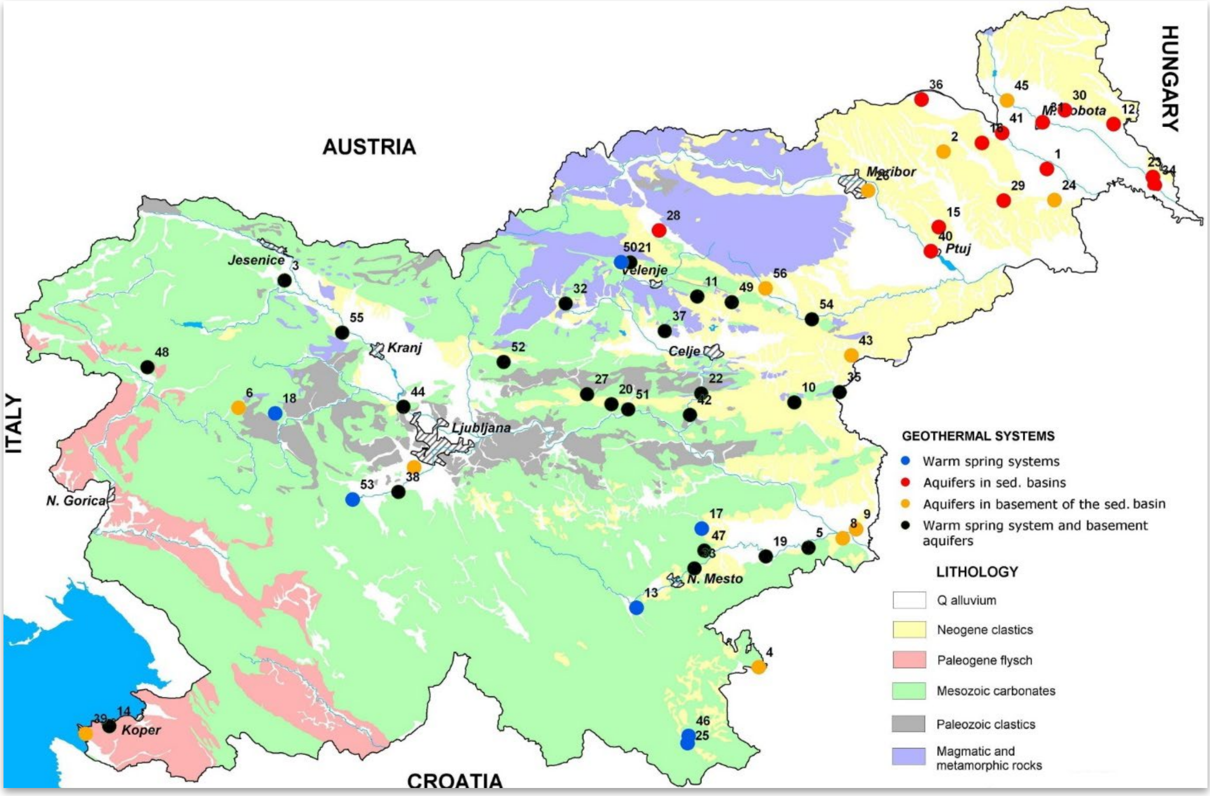

Figure 4: Types of geothermal systems in Slovenia according to Hochstein shown on simplified geological map.

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Gleeson, T. and Manning, A.H. 2008. Regional groundwater flow in mountainous terrain: three-dimensional simulations of topographic and hydrogeologic controls. *Water Resources Research*, 44, W10403.

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Scheidler, S., Huggenberger, P., Dresmann, H., Auckenthaler, A. and Epting, J. 2021. Regional groundwater flow and karst evolution–theoretical approach and example from Switzerland. *Environ Earth Sci* 80, 201.

Tóth, J. 1963. A theoretical analysis of groundwater flow in small drainage basins. Journal of *Geophysical Research*, 68 (16), pp. 4795-4812.

Tóth, J. 1999. Groundwater as a geologic agent: an overview of the causes, processes, and manifestations. Hydrogeol J 7:1–14

5. Geothermal potential of Kostanjevica in the southeastern Slovenia

Dušan Rajver

The Krško Basin, especially its southern part between the Šmarjeta Spa in the west and the Croatian border in the east, is one of the most geothermally explored areas in Slovenia. Investigations in the Krško Basin have so far been limited only to depths of less than 1 km. While the intention of geothermal research in northeastern Slovenia was conditioned by oil research, for the Krško Basin it was necessary to find the most successful methods based on common investigations and focused on geothermal energy. Besides geology and hydrogeology, mainly regional geophysical investigations (geoelectrics, seismics, gravimetry) were of great help. The Krško Basin forms part of the Sava folds and is located in the transition zone between the External and the Internal Dinarides (Placer, 1998; Rajver, 2001). The dinaric structures are characterized by folds, thrusts and successive longitudinal faults in NW-SE direction and have Cretaceous-Paleogene age. They are typical of the Mesozoic rocks of the Krško Hills and the Gorjanci Mountains. The base of Tertiary sediments in the basin is probably built in the same way.

The discharge of springs along the Krka River and the possibility of capturing thermal water has been the subject of quite extensive research in recent decades (Rajver et al., 2015). This indicated the possibility of capturing groundwater with increased temperature and the geological structure of the narrower area of springs. A regional picture of the geological and hydrogeological structure of the area was given during the research of the area of thermal springs in southeastern Slovenia. Research conducted between 1973 and 2001 in Kostanjevica resulted in some general conclusions (Rajver et al., 2015):

- northwest of Kostanjevica along the Krka River there are several thermal springs, the most productive are Topličnik (with temperatures between 14 and 23.5°C (as of 1972)) and Pod Jelšo (23.5°C),
- thermal water flows from formations under the Tertiary clastic rocks, which act as thermal insulators, probably from the north,
- bedrock of Tertiary sediments is represented at well site Si-1/86 by Jurassic (or Triassic-Jurassic) limestone and Upper Triassic dolomite, which are aquifers,
- along the riverbed of the Krka at Topličnik runs a fault along which the bedrock dips northwards by several tens of meters. Further north, the bedrock dips steeply and the Tertiary marl thickens,
- in all wells near Topličnik a temperature reversal with depth was observed, indicating that the thermal water at the contact with the Tertiary flows from north to south. Further south, the influence of cold groundwater predominates (probably this is true in the upper 200 to 300 meters, deeper the conditions are uncertain),
- numerous springs with increased temperature along the Krka riverbed, over a length of several hundred meters, also show this type of thermal water flow. The sites of occurrence of the springs coincide with the site of outcrops of the Tertiary sediments,

– besides a similar geological structure, numerous springs occur in the wider area of the Krško Basin, with the increased temperature of the Tertiary layer which acts as a thermal insulator (at Bušeča vas and at Čatež).

The Topličnik geothermal aquifer system or thermal "belt" near Kostanjevica (after Verbovšek, 1990) can be roughly considered as one of the geothermal aquifers in the southern part of the Krško Basin. This thermal aquifer consists of Jurassic limestones and dolomites (dolomitized limestones), among which there may be Upper Triassic dolomites. A more recent exploratory well, the 848 m deep PDt-1/03, near Brod pri Podbočju, confirmed the assumptions of narrow thermal zone(s) in the Kostanjevica area, mainly in the S-N direction, as a lower geothermal gradient was found in this well than in the 800 m deep well Si-1/86 (Rajver et al., 2015).

After measurements with the method of reflection seismics, it was found that the thickness of impermeable Tertiary sediments increased towards the north in the whole Krško Basin. The bedrock of the impermeable Tertiary sediments is most likely a Mesozoic carbonate formation. In accordance with this geological structure, thermal waters were assumed to occur due to the lower thermal conductivity of the impermeable Tertiary sediments. The thermal waters rise at the Tertiary-Mesozoic carbonate contact and mix with the cold groundwater along the southern periphery and occur as such in the thermal springs considered.

A complex investigation treated the whole discussed region in a period of 1973-1978 (Rajver & Ravnik, 2003). Later, regional geophysical, hydrogeological and tectonic investigations were also carried out (Verbovšek, 1990). In the late 1960s and in the 1970s, all existing thermal springs were inventoried, aquifer types were hydrogeologically classified, hydrogeochemical interpretation was performed, and the structure of the region was interpreted using geophysical methods and geotectonic studies.

The localities of Čatež Spa and Topličnik near Kostanjevica were investigated in more detail and described in numerous internal reports (Rajver, 2001). Many exploration and exploitation wells were drilled there. The Čatež field was investigated in more detail (Nosan, 1959; Ivanković & Nosan, 1973) because shallow thermal manifestations there showed possibilities for the existence of thermal water with higher temperature at greater depths. In both areas, research continued in 1985-87 with additional geophysical measurements (Rajver, 2001) and the drilling of three development wells with depths of 400 m (V-15/88) and 704 m (L-1/86) in the Čatež field and of 800 m (Si-1/86) at Kostanjevica. Geothermal research continued in 1995-96 with deep vertical geoelectrical research in a larger area between Krško, Globoko, Brežice and Kostanjevica and temperature gradient measurements in shallow boreholes in the area between Brežice and Krško (Rajver, 2001).

Another exploitation borehole was drilled in 1995 near Dobova with a depth of 700 m. The results, mainly from the Čatež field, show the temperature increase of thermal water from south to north, but in the same direction the Tertiary low-permeability sediments also gets thicker (Figure 5). A similar situation, although with lower temperatures, is observed north of

Kostanjevica. Under the Tertiary sediments, Mesozoic carbonates (mostly dolomites) form primary aquifers with thermal water.

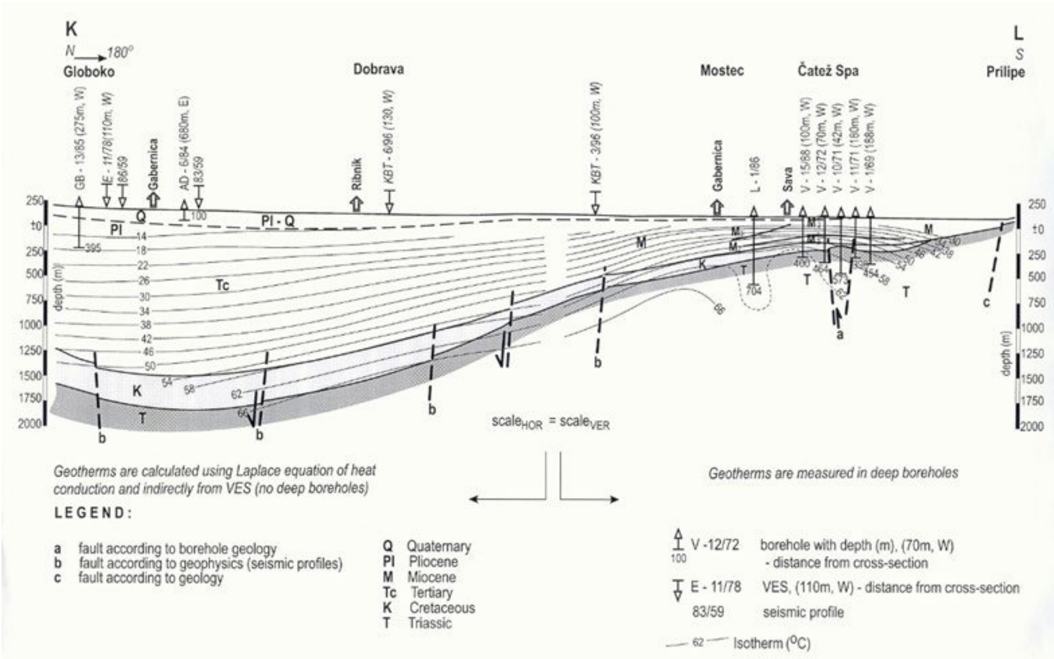

Figure 5: Geothermal cross-section from Globoko to the Čatež geothermal field (N-S direction) (Rajver & Ravnik, 2003).

The highest temperature (64 °C) was measured in a borehole in the middle of the Čatež field within the Čatež Spa. There is at least one deep water flow from the Gorjanci Mountains beneath the Čatež field area further north, which is heated at depths of 2 to 3 km and partially reverses somewhere at fault zones and flows south immediately beneath the Tertiary (Cretaceous) low-permeability cover. This flow must be quite intense, as evidenced by the high porosity, which is a consequence of chemical dissolution of the rock by thermal water at the Tertiary-Mesozoic contact (Verbovšek et al., 1986).

Ivanković, J., Nosan, A., 1973. Hydrogeology of the Čatež Thermal Springs. Geologija 16, 353-361 (in Slovene with English abstract).

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Placer, L., 1998. Structural meaning of the Sava folds. Geologija 41, Ljubljana, 191-221.

Rajver, D., 2001. Geothermal characteristics of the Krško basin with emphasis on geophysical investigations. M. Sc. Thesis, University of Ljubljana, Ljubljana, Slovenia, 203 pp. (in Slovene, with English abstr.).

Rajver, D., Ravnik, D., 2003. Geothermal characteristics of the Krško basin, Slovenia, based on geophysical research. Phys. Chem. Earth 28, 443-455, Pergamon.

Rajver, D., Lapanje, A., Rman, N., Poljak, M., Matoz, T., 2015. Hydrogeological professional bases for obtaining a concession for a thermal water source near Kostanjevica on the Krka (well SI-1/86 near the village of Sajevce). Geological Survey of Slovenia Report, Ljubljana, 45 p.

Verbovšek, R., 1990. Geothermal model for the Krško-Brežice field. Geologija 31, 32, 581-592 (in Slovene with English summary).

Verbovšek, R., Ločniškar, A., Nosan, A., 1986. Thermal water research in the Čatež field. Unpubl. Report, Geological Survey Ljubljana, 20 pp. (in Slovene).

6. Kostanjeviška jama (Cave of Kostanjevica)

Mihael Brenčič

Almost half of Slovenia is formed by carbonate rock in which karst has developed. As a result, groundater is an important source of drinking water. Karst is characterized by karst - channel porosity, in which the flow of groundwater is relatively fast. This also affects the distribution of water temperature within the karst rock, karstic groundwater is consequently relatively cold. Karst channels form in both saturated (phreatic zone) and unsaturated areas (vadoze zone). In the phreatic zone phreatic loops are formed, in the vadoze zone vertical channels in the form of potholes and chasms. Special channel shapes are also formed in the area of groundwater level fluctuations.

During the field trip, as an example of a karstic cave, we will visit Cave of Kostanjevica (in Slovenian Kostanjeviška jama) , which is part of the karst of Gorjanci Mountains. The cave was opened in 1937 after a violent storm. Since 1971, it has been equipped with electric lighting and has a length of about 300 m for tourist visits. The total length of the channels is 1871 m, the height difference between the highest and the lowest point is 47 m (Figure 6). Cave of Kostanjevica is developed in Cretaceous limestones formed in the area of the shelf. They are represented by light gray micritic and biosparitic limestones, in which there are remains of shells, algae and foramenifera. In places, dark gray to light gray limestone with thin layers of granular dolomitized limestone and limestone occur in the cave. The formation of the cave was influenced by brittle tectonics. In the cave the structures of the Dinaric direction NW-SE and the Balaton direction NE -SE predominate. As a result of tectonics, there are also many collapses in the cave, which were formed by the collapse of rocks and channels near the surface. The channels in Cave of Kostanjevica were formed in several phases. There are few channels that would be interpreted as true phreatic channels, nor are there any channels that would have formed only in the vadose area. Almost the entire cave is dominated by channels formed in the area of intense fluctuations of the groundwater level.

Brenčič, M., 2002: Geologija Kostanjeviške jame (Geology of Cave of Kostanjevica). In: Brenčič, M. et al.: Kostanjeviška jama. Novo mesto: Jamarski klub; Kostanjevica na Krki: Klub jamarjev (in Slovenian).

Gams, I., 2004: Kras. Ljubljana: Založba ZRC SAZU (in Slovenian).

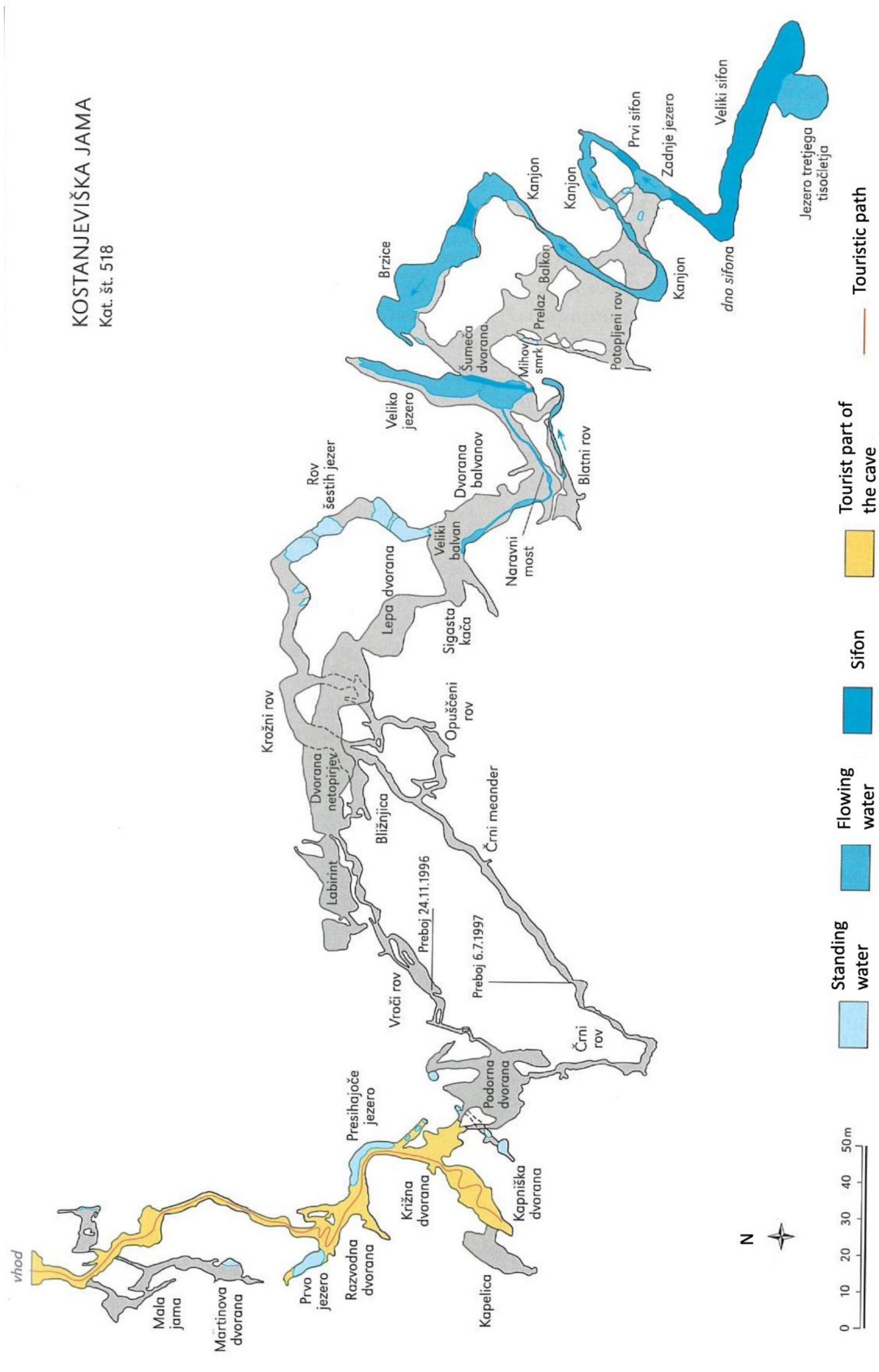

Figure 6: Ground plan of Cave of Kostanjevica (modified after Gams, 2004).

7. Geothermal features and cascade use of water in Terme Čatež Spa

Nina Rman

The fractured Upper Triassic and Triassic to Jurassic »Main« Dolomite, often covered by limestone, form a regional basement reservoir with a thickness of more than 1 km. The rocks dip to the N-NW into a syncline, reaching a depth of about 4 km. They also outcrop at Krško Hills and Orlica in the north, and Gorjanci in the south, allowing for recharge. We estimate that another, deeper geothermal aquifer is situated in the Dachstein limestone about 2 km below the first one, having a thickness of about 900 m (Figure 7). Its basement is formed by Triassic and Permian rocks which formed on top of the Middle Permian clastites of the Val Gardena formation. The latter outcrops form the southern boundary of the regional aquifer, and separate it from the adjacent Zagreb geothermal system. There are at least two separated geothermal systems: the easternmost between Čatež and Dobova with convection at 2-3 km depth and temperatures up to 80 °C, and the western between Bušeča vas and Velika vas with lower temperatures. At Kostanjevica na Krki and Šmarješke Toplice convection occurs at >1600 m and temperature can be 40 °C.

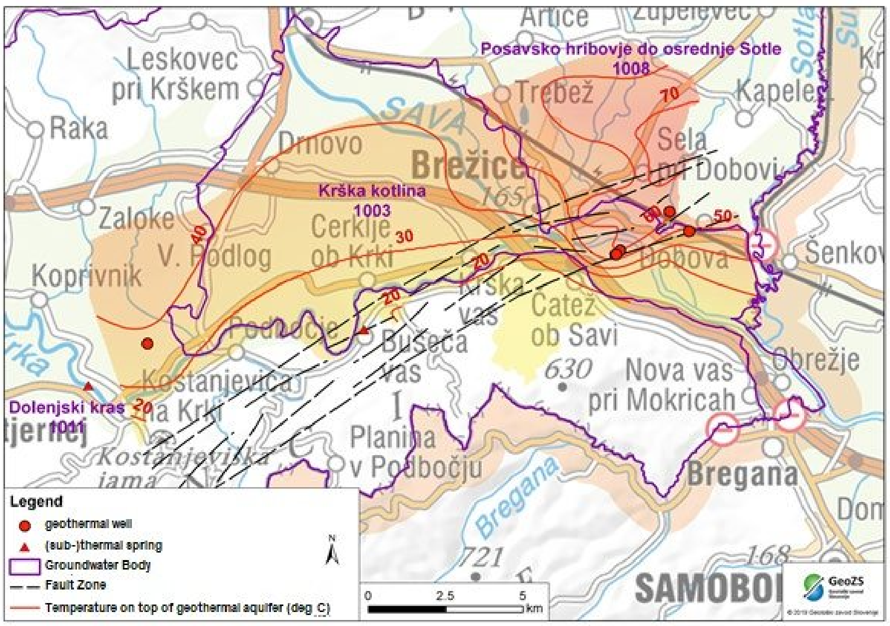

Figure 7: Extent of the geothermal aquifer in SE Slovenia with prognosed temperatures on top of it. Normal Earth heat flow prevails in the surroundings while convection is characteristic for the 2.5 km wide Čatež (reverse) Fault Zone.

The secondary geothermal aquifer is tapped with shallow boreholes at Čatež (also has a spring Perišče) and Bušeča vas (has a spring Klunove toplice). Jurassic, Cretaceous and Badennian rocks are fissured within the fault zone here. Thermal springs occur also at wider area, at Šmarješke Toplice, Klevevž and Kostanjevica na Krki.

Verbovšek (1990) assumed recharge from the south through deep infiltration in fractured zones from carbonates which crop out in the E and N part of Gorjanci Mts. Structurally, recharge from outcropping Upper Triassic carbonate rocks from the eastern part of the Krško hills and the western part of Orlica from the northern side of the Krško basin is also possible (Figure 8).

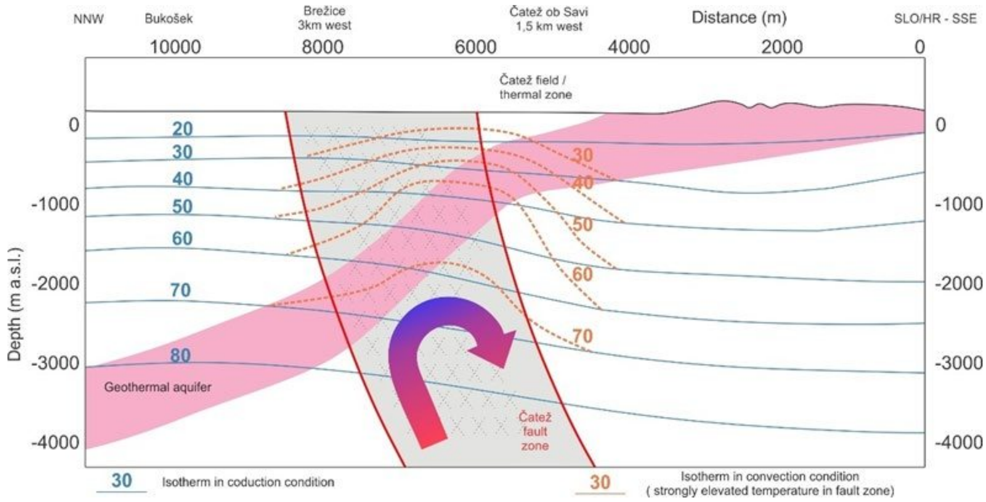

Figure 8: Prognosis of temperature distribution with depth (blue – conduction model, red – convection model within the Čatež Fault Zone which causes many increased temperatures in shallow depths)

Produced maximum water temperature is 60-64 °C at Čatež and Dobova, 35 °C at Kostanjevica na Krki, 32 °C at Šmarješke Toplice and at Bušeča vas 26,5 °C. Water is used for individual space heating, sanitary water heating, (agriculture), bathing and swimming with balneology, deicing and as monitoring wells. Wells tap water at depths between 200 and 400 m with max. pumping rate of 45 l/s. Water is of Ca-Mg-HCO_3 hydrogeochemical composition and does not cause any technological issues (Figure 9).

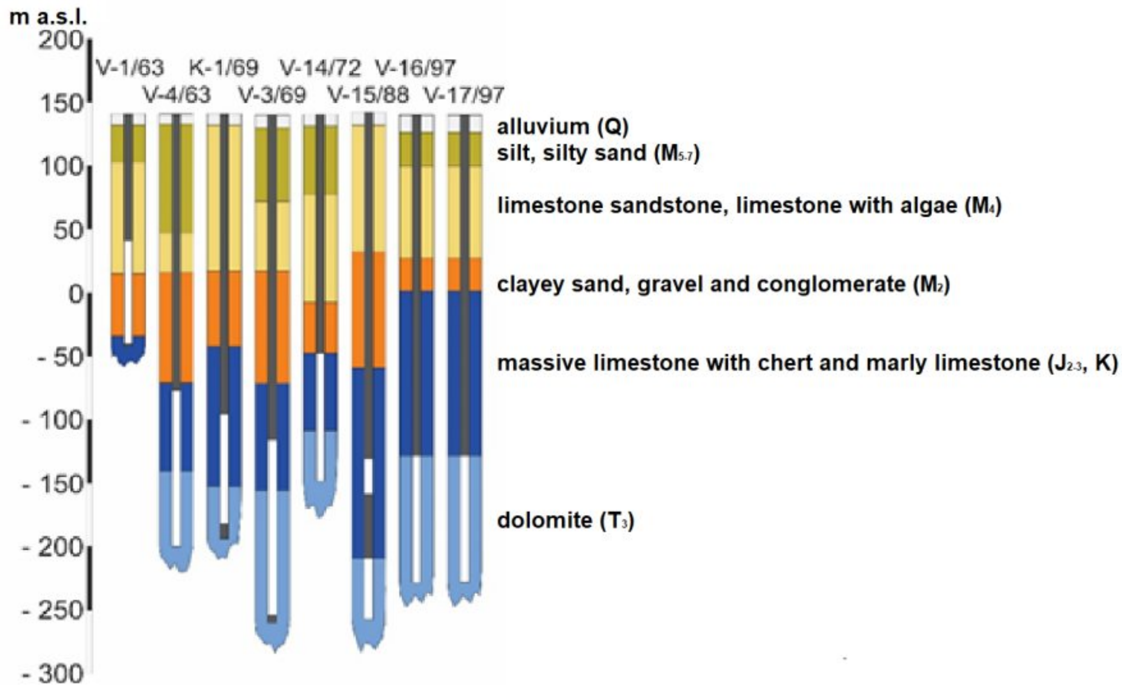

Figure 9: Simplified geological section of most geothermal wells in Terme Čatež Spa

Lapanje, A. 2006. Origin and chemical composition of thermal and thermomineral waters in Slovenia. Geologija, 49/2, 347-370.

Nosan, A. 1959. Hydrogeology of the Čatež Thermal Springs. Geologija, 5, 63-79.

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8. Fieldwork at Terme Čatež

8.1. Introduction to the thermal properties of the rocks and sediments

Simona Adrinek, Dušan Rajver

For dimensioning of geothermal systems the knowledge of the thermal properties of the studied area is crucial. The key thermal parameter is *thermal conductivity*. The thermal conductivity λ (W/m×K) of a material defines its ability to transfer heat. It is defined as the quantity of heat Q (W), transmitted through a unit thickness, L (m), in a direction normal to a surface of a unit area, A (m^2), due to a unit temperature gradient ΔT (K/m), under a steady-state condition. It is expressed by Fourier's law:

$$\lambda = \frac{QL}{A\Delta T}$$

As rock or sediment is a porous media consisting of their matrix, pores, and pore fluid, the resulting λ is regarded as an "effective" thermal conductivity λ_e, which is governed by rock matrix thermal conductivity λ_m, porosity n and the thermal conductivity of the fluid λ_f (Fuchs et al., 2013). Further, λ_e can be influenced by many factors such as water content, density, mineral content of the sediment, particle size and anisotropy (Woodside and Messmer, 1961; Fuchs et al., 2013).

The thermal response test is the most reliable method for determining thermal properties in the field (Gehlin, 2002), but its performance requires specialized equipment and evaluations. Therefore, this method can be expensive and time-consuming, even though it is the most correct. To evaluate the thermal properties of sediments more quickly and easily or if the direct measurement cannot be performed, thermal conductivity can be inferred indirectly, either from mineralogical composition and saturating fluids or from correlations with other physical properties. Such an approach is made with bulk thermal conductivity estimation models, some of them being mixing, analytical or numerical (Somerton, 1992). Also, thermal conductivity can be measured in the laboratory on samples, i. e. cores or cuttings or in moulds or in-situ either in boreholes or with shallow penetration probes. There are numerous steady-state and transient techniques available for measuring thermal conductivity, the most prominent being the "divided bar", "needle probe" (Figure 10), "optical scanning", and "(laser) flash". Among these techniques, the transient ones are also suitable for determining thermal diffusivity. As with most other petrophysical properties, in situ thermal conductivity may deviate significantly from laboratory values, even if the effects of temperature, pressure, and pore fluid are accounted for. This scale dependence involves different aspects: In situ measurements represent an average over a much larger rock volume than laboratory measurements performed on small samples, and cannot resolve small-scale variations. A subsequent upscaling may be necessary to identify the appropriate representative elementary volume (REV) for which reasonable transport parameters averages can be defined.

The other important parameter is *thermal diffusivity* α, which is defined as a ratio between the thermal conductivity λ and the volumetric heat capacity ρc of the material, described as:

$$\alpha = \frac{\lambda}{\rho c}$$

The relationship in the upper equation shows that, due to direct proportionality of thermal diffusivity to thermal conductivity, materials with high thermal diffusivity rapidly adjust their temperature to that of their surroundings, because they conduct heat quickly in comparison to their volumetric heat capacity. In many engineering applications, this property is important for the design of materials that constitute a substance or an object. For shallow geothermal systems, thermal diffusivity of the involved components, such as the U-tube, the circulating fluid and the grout, is an important measure for analyzing the conductivity and resistivity of the borehole heat exchanger. Also, all of the transient laboratory methods used to determine thermal conductivity are useful to determine thermal diffusivity as well.

The *specific heat capacity* (J/m^3·K) is defined as the amount of heat that can be stored in or extracted from a unit volume of rock per unit temperature increase or decrease. Knowledge of the specific heat capacity is of fundamental importance in geothermal calculations. It could be expressed as:

$$\rho c = \frac{\lambda}{\alpha}$$

The specific heat capacity varies with temperature. If the temperature interval is not too big, such as that in shallow geothermal systems, c can be treated as constant. For example, at constant atmospheric pressure, the specific heat of water varies by only 1 % for a temperature ranging between 0 °C and 100 °C (Al-Khoury, 2012).

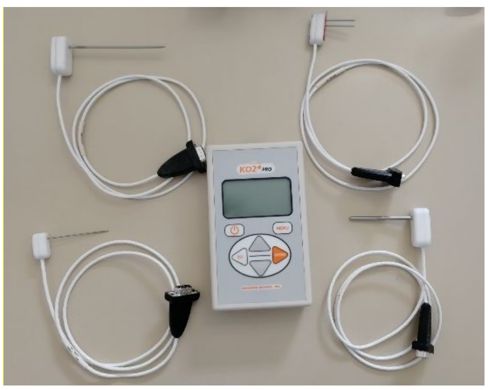


Figure 10: Example of a needle probe device (KD-2) used for sediment measurements.

Al-Khoury, R. 2012. Computational Modeling of Shallow Geothermal Systems. Delft, Netherlands. Taylor & Francis Group. 245 p.

Fuchs, S., Schütz, F., Förster, H.-J., Förster, A. 2013. Evaluation of common mixing models for calculating bulk thermal conductivity of sedimentary rocks: Correction charts and new conversion equations. Geothermics, 47, 40–52. https://doi.org/10.1016/j.geothermics.2013.02.002.

Gehlin, S. 2002. Thermal Response Test: Method Development and Evaluation. Lulea University of Technology.

Somerton, W. H. 1992. Thermal Properties and temperature related behaviour of rock/fluid systems, Amsterdam Elsevier.

Woodside, W., Messmer, J. H. 1961. Thermal Conductivity of Porous Media. I. Unconsolidated Sands. Journal of Applied Physics, 32, 12.

9. Thermal water chemistry and field sampling methods

Nina Rman

There will be a separate course on hydrogeochemisty of thermal waters in the Pannonian basin and its surroundings. In the Terme Čatež Spa we will demonstrate sampling of groundwater with a down-hole sampler and at an operating well for main parameters, stable isotopes and noble gases. We will discuss chemistry of water based on archive analyses (below) and observe which environmental issues may occur do to its use (Figure 11, Table 1).

Table 1: List of characteristic chemical parameters of fresh and thermal groundwaters in the SE of Slovenia.

Chemical parameter	SE fresh groundwater			SE thermal waters		
	N	Average	Me	N	Average	Me
pH	19	7.4±0.1	7.39	17	7.3±0.3	7.3
T (°C)	17	12.9±2.9	12.4	18	45.8±14.3	52.0
EC (µS/cm)	19	480±128	477	18	446±39	439
Na^+ (mg/l)	19	3.2±3.4	1.3	20	6.4±3.0	5.7
K^+ (mg/l)	19	0.9±0.6	0.7	20	2.7±1.1	2.9
Ca^{2+} (mg/l)	19	66.9±16.7	64	20	49.6±9.1	46.7
Mg^{2+} (mg/l)	19	25.1±12.2	25	20	25.6±5.4	26.3
Cl^- (mg/l)	19	6.4±6.7	3.42	20	5.3±3.9	4.2
SO_4^{2-} (mg/l)	19	9.1±5.8	7.6	20	26.3±10.9	32.6
NO_3^- (mg/l)	19	7.7±6.5	5.3	20	1.7±1.9	1.5
SiO_2 (mg/l)	15	6.3±2.4	6.5	20	24.3±13.4	30.6
HCO_3^- (mg/l)	19	330±63	350	20	264±45	250
Li (µg/l)	5	0.6±0.1	0.6	15	11.0±5.0	10
B (µg/l)	5	9.7±2.7	9	15	22.8±12.0	22.2
Sr (µg/l)	5	176±128	142	15	346±135	330
^3H (TU)	17	7.0±2.6	7.5	14	*<0.3, <0.6, 2-3	
δ^2H (‰)$_{vsmow}$	17	-65.8±3.1	-65.2	13	-71.4±2.6	-71.8
$\delta^{18}O$ (‰)$_{vsmow}$	17	-9.85±0.53	-9.91	13	-10.69±0.34	-10.71

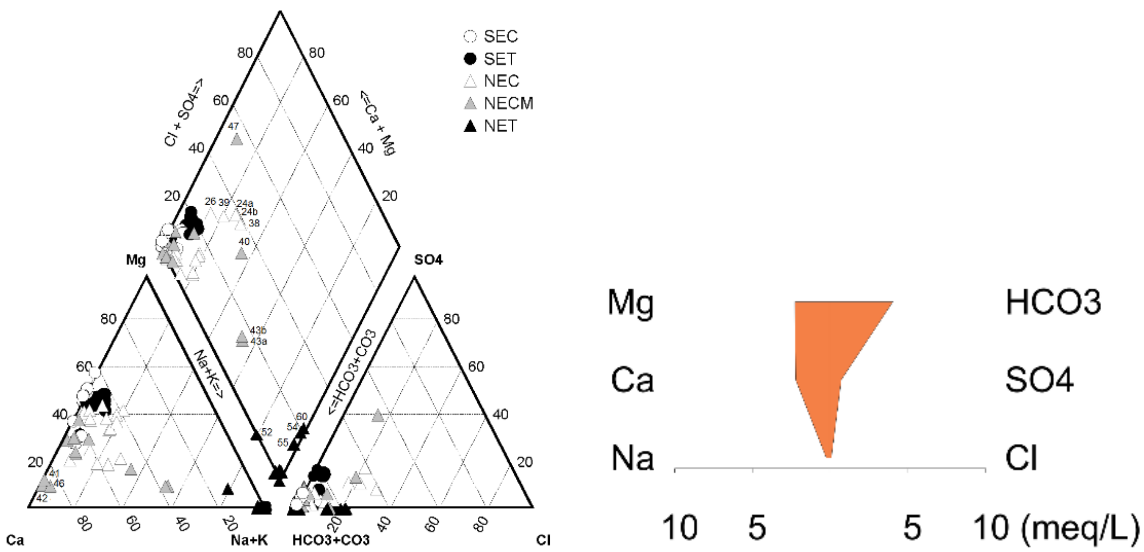


Figure 11: Piper plot (left) and Stiff diagram (right) showing the characteristic thermal water chemical composition.

10. Student worksheet for fieldwork

FIRST LOCATION: Measurements of chemical parameters and sampling techniques

We will measure field physical-chemical parameters in different freshwater and geothermal wells and compare the results. For data gathering we use WTW probes, alkalinity kit, water sampler, groundwater level meter and sampling equipment ($\delta^{18}O$, δD, tritium).

EXERCISE 1:

1. Comment differences among chemistry of groundwaters from archive analyses (Table *1*):

2. Based on the geochemical composition categorise the groundwater in a particular water types

3. After measuring all wells and recording it to the table below, are there any differences in observed parameters between wells? Why? What do they mean?

4. How did you sample for various parameters? Describe. Why do you need such resutls for from technological point of view?

GROUNDWATER SAMPLING RECORD SHEET

Reason for sampling (e.g. project):

Sampled by:

Measured by:

Date sampled:

Name of the sample site and object	Depth of the object (m)	GW level (m)	Start of the sampling (hour)	End of the sampling (hour)	T (°C)	Electrical conductivity (µS/cm)	pH	Redox (mV)	OXI (mg/l)	OXI (%)	Turbidity (NTU)	Notes	Analyses*			
													Chemical parameters	$\delta^{18}O$, $\delta^{2}H$	3H	Noble gases

* Basic fisical-chemical parameters (Nitrate, DOC, TOC,...), Stable and radioactive isotopes ($\delta^{18}O$, δD, tritium), microelements, pesticides, organic solvents, pasive samplers,...

Date/time of acceptance of the sample to the laboratory: ....

Accepted by: ....

SECOND LOCATION: Temperature and groundwater level measurements

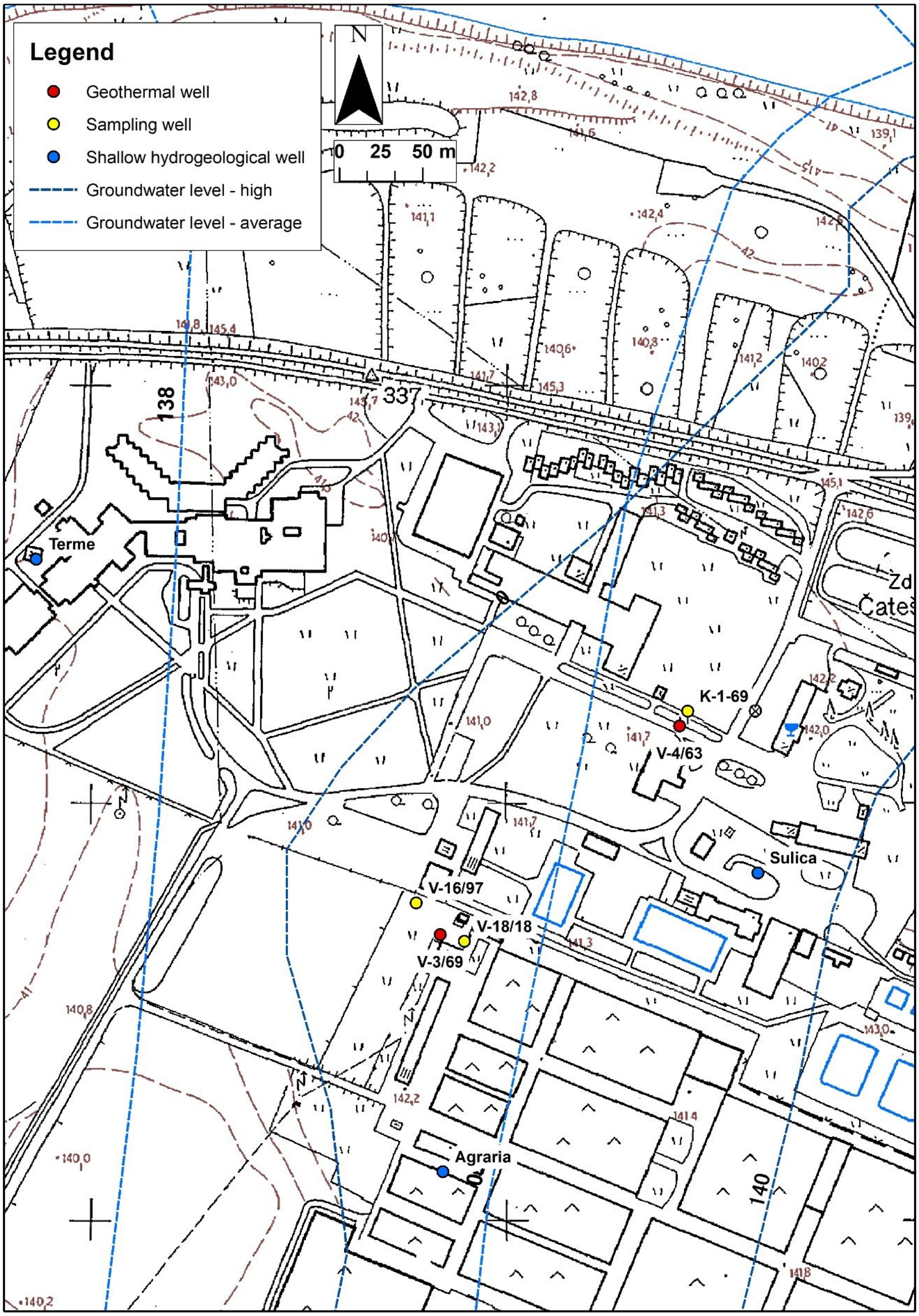
Measure the groundwater level in the selected wells. In one, you will also measure the groundwater temperature and electrical conductivity on a 10 m interval along the whole depth of the well.

EXERCISE 1: Draw a map of the groundwater level based on the obtained measurements in the selected wells.

1. To find the groundwater elevation, you need to subtract the depth to groundwater from the elevation of the top of the well.

2. Contour the groundwater elevations using a contour interval of 1 meter. Label each contour line.

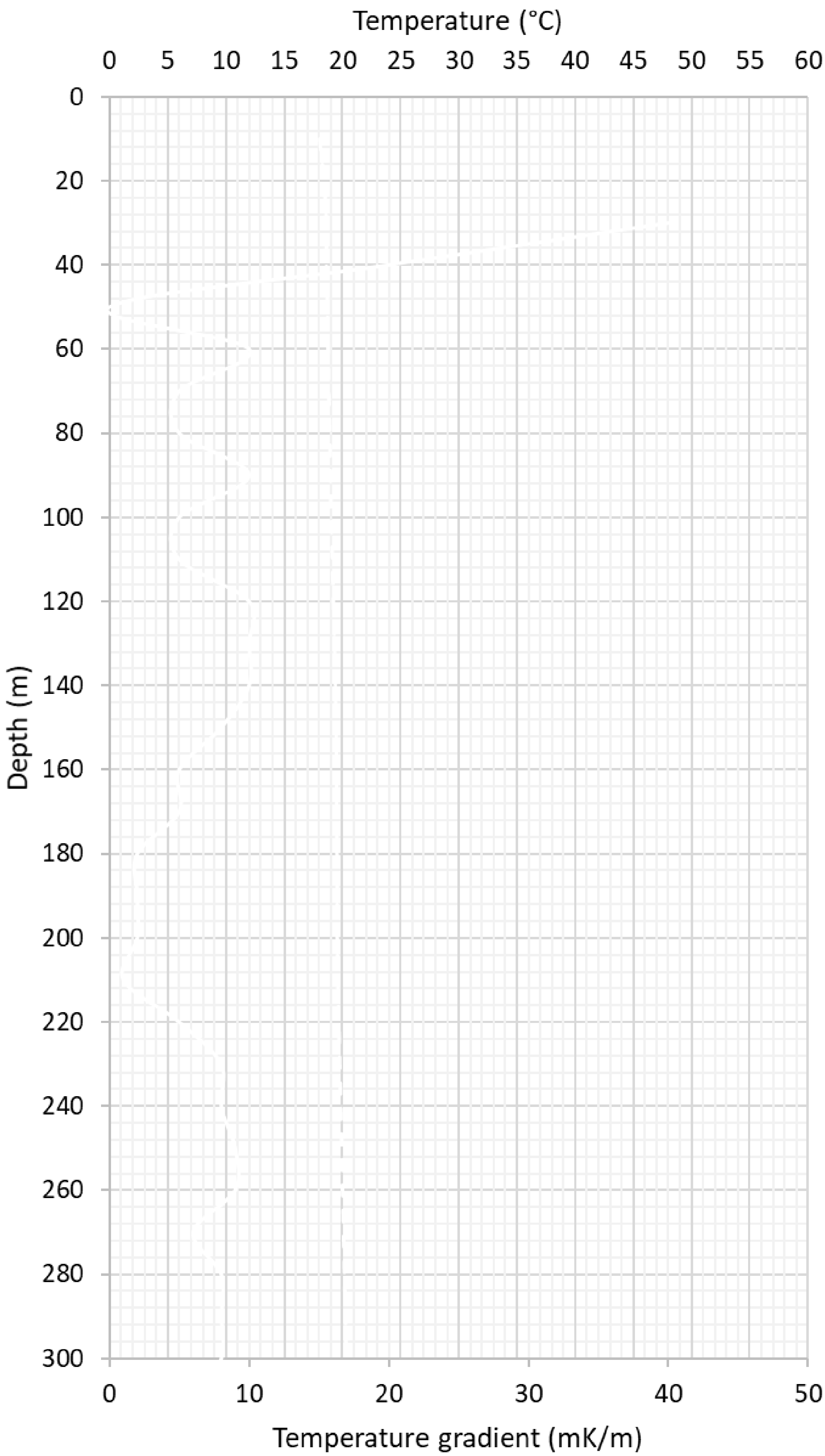
Well	**Wellhead elevation (m a.s.l.)**	**Depth to groundwater (m)**	**Groundwater level elevation (m a.s.l.)**
Terme			
Sulica			
Agraria			


Legend
Geothermal well
Sampling well
Shallow hydrogeological well
Groundwater level - high
Groundwater level - average
N
0 25 50 m
Terme
K-1-69
V-4/63
Sulica
V-16/97
V-18/18
V-3/69
Agraria
337
138
140

EXERCISE 2: Draw a temperature profile of a selected well and calculate its geothermal gradient.

Name of the well:___________________________

Depth	Temperature (°C)	Electrical conductivity (µS/cm)	Geotermal gradient (mK/m)


Temperature (°C)
0 5 10 15 20 25 30 35 40 45 50 55 60
Depth (m)
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300
0 10 20 30 40 50
Temperature gradient (mK/m)

THIRD LOCATION: Thermal property measurements of sediments

Measure the thermal parameters (thermal conductivity, thermal diffusivity, volumetric heat capacity) of nearby sediments with needle probe (KD-2, Decagon devices, Inc.). Also, measure the moisture content at selected location.

EXERCISE 1: Compare the obtaine thermal parameters of different sediments with the values that are recommended in the VDI guidelines. Are there any differences, why?

Location	**λ (W/m×K)**	**α (mm²/s)**	**c_v (mJ/m³×K)**

Rock	**Density *p*** 10^3 kg/m^3	**Thermal conductivity *K*** W/(m·K)	Typical values	**Volume-related specific heat capacity** $C_V = P\ C_p$ MJ/(m^3·K)
Magmatic rocks				
Basalt	2.6-3.2	1.3-2.3	(1.7)	2.3-2.6
Diorite	2.9-3.0	2.0-2.9	(2.6)	2.9
Gabbro	2.8-3.1	1.7-2.5	(1.9)	2.6
Granite	2.4-3.0	2.1-4.1	(3.4)	2.1-3.0
Peridotite	3.0	3.8-5.3	(4.0)	2.7
Rhyolite	approx. 2.6	3.1-3.4	(3.3)	2.1
Metamorphous rocks				
Gneiss	2.4-2.7	1.9-4.0	(2.9)	1.8-2.4
Marble	2.5-2.8	1.3-3.1	(2.1)	2.0
Metaquartzite	approx. 2.7	approx. 5.8	(5.8)	2.1
Micaschists	approx. 2.6	1.5-3.1	(2.0)	2.2
Argillaceous schists	2.7	1.5-2.6	(2.1)	2.2-2.5
Sedimentary rocks				
Limestone	2.6-2.7	2.5—4.0	(2.8)	2.1-2.4
Marl	2.5-2.6	1.5-3.5	(2.1)	2.2-2.3
Quartzite	approx. 2.7	3.6-6.6	(6.0)	2.1-2.2
Salt	2.1-2.2	5.3-6.4	(5.4)	1.2
Sandstone	2.2-2.7	1.3-5.1	(2.3)	1.6-2.8
Hard coal	n.a.	0.3-0.6	(0.3)	1.3-1.8
Claystone/siltstone	2.5-2.6	1.1-3.5	(2.2)	2.1-2.4
Unconsolidated rocks				
Gravel, dry	2.7-2.8	0.4-0.5	(0.4)	1.4-1.6
Gravel, watersaturated	approx. 2.7	approx. 1.8	(1.8)	approx. 2.4
Moraine	n.a.	1.0-2.5	(2.0)	1.5-2.5
Sand, dry	2.6-2.7	0.3-0.8	(0.4)	1.3-1.6
Sand, watersaturated	2.6-2.7	1.7-5.0	(2.4)	2.2-2.9
Clay/silt, dry	n.a.	0.4-1.0	(0.5)	1.5-1.6
Clay/silt, watersaturated	n.a.	0.9-2.3	(1.7)	1.6-3.4
Peat	n.a.	0.2-0.7	(0.4)	0.5-3.8

11. Geological settings of Croatia

Iva Koleković Močilac

Croatia is a Central-South-Eastern European country with a specific crescent shape that gives it its geographical and cultural diversity. It has an area of 56,594 km². The northern and north-eastern part is presented by the Pannonian plain, with the valleys of the Sava and Drava River, separated by the Medvednica and the Slavonian mountains. In the west and south of the Pannonian region, the central mountain belt of the Dinarides extends from Southern Calcareous Alps in Slovenia to the south. The mountain belt consists of carbonates and is intensively karstified with many interesting speleological objects. The third geographical region is the coastal area, which consists of Istria Peninsula in the north and extends to Croatian Littoral and Dalmatia in the south. The coastline is 1,800 km long with more than 1,200 islands and islets. The population was 4.076 million in 2019 and is decreasing due to economic migrations to other EU countries as well as unfavourable demographic development. The geographical regions of Croatia correspond to the geological regions. Croatian territory is usually divided into three large units, characterised by different geological settings – Pannonian Basin, the Dinarides and the Adriatic offshore.

Due to the complex geologic history of the SW part of Pannonian Basin (North Croatian Basin - NCB), the bedrock structure is complex. Elongated basement highs and narrow depressions formed during Mid-Miocene rifting (Royden & Horváth 1988) were transformed by several phases of basin inversion before, during and after the subsequent thermal subsidence (Prelogović et al. 1998), resulting in an increased geothermal gradient. Most of the sedimentary succession accumulated in the depressions separated by uplifted and partially eroded tectonic units. The mentioned structural depressions - the most northern Mura depression, the Drava depression, the Sava depression and the Slavonija-Srijem depression are filled with sediments (with some volcaniclastic and volcanic rocks) reaching a maximum thickness of 5,000 m in the Sava depression and more than 6,000 m in the Drava depression (Saftić et al., 2003). This thick sedimentary sequence was deposited in lacustrine-marine and lacustrine-fluvial environments. A generalized lithological column of Neogene basin fill of Sava and Drava depression is given in Chapter 16.

The Dinarides orogenic system can be divided into two main tectonostratigraphic units (after Vlahović et al., 2005): the Outer (Karst or External) Dinarides along the Adriatic Sea and the Inner (Internal) Dinarides, between the Outer Dinarides and the Pannonian Basin. External Dinarides are characterized by a thick carbonate succession of Adriatic Carbonate Platform (AdCP) deposited during the Jurassic and Cretaceous (Vlahović et al., 2005) with occurrences of pelitic sediments deposited in deep troughs. The area of the tectonostratigraphic unit Internal Dinarides comprise passive and active continental margin rocks including ophiolites (Pamić et al., 1998).

The oldest rocks drilled in the Adriatic offshore are of Permian age, and are characterized by a heterogeneous lithological composition, including clastic, carbonate and evaporitic rocks (Tišljar, 1992). The smilar heterogenous sedimentation continues into Lower Triassic, indicating a shallow-water depositional environment while Middle Triassic is characterized by widespread occurrence of effusive rocks (Vlahović et al., 2005). In general, carbonate sedimentation started under platform conditions in the Late Triassic, on a large Southern Tethyian Megaplatform (STM) (Vlahović et al., 2005). while tectonic disintegration of this megaplatform, leading to formation of several smaller carbonate platforms started by Early Jurassic rifting. In this way, the Adriatic Basin and the Adriatic Carbonate Platform, characterized by pelagic and platform carbonate sedimentation throughout the Jurassic and Cretaceous, were formed (Vlahović et al., 2005). Towards the end of the Cretaceous, the Adriatic Carbonate Platform gradually disintegrated and emerged, but carbonate sedimentation was locally restored by the Paleogene transgression with sedimentation of foraminiferous limestones during Early to Middle Eocene (Vlahović et al., 2005). The average thickness of the AdCP succession is about 5,000 m (Vlahović et al., 2005).

During the Middle-Late Eocene and lower Oligocene, the Adriatic offshore in Croatia was partly influenced by compressional tectonics and SW -directed propagation of overthrusts, which led to the formation of the External Dinarides fold thrust belt (Pamić et al., 1998), exposed along the Adriatic coast, but also occurring in the Adriatic offshore. The development of a SW -propagating thrust system gradually led to the formation of a foreland basin system characterized by the deposition of syntectonic flysch sediments mainly of Middle-Upper Eocene age (Vlahović et al., 2005). The continued SW -propagation of frontal overthrusts locally extended into the Adriatic basin, while inner foreland basins developed into piggy-back basins filled with syntectonic clastic-carbonate succession of Promina deposits (Vlahović et al., 2005).

The locally preserved Miocene in the coastal hinterland of the External Dinarides is associated with Dinaric Lake System and is exclusively of lacustrine origin (De Leeuw, 2010). On the other hand, the Miocene deposits in the contemporaneous offshore basins are represented by marine hemipelagic marls and turbidites. The transition from Miocene to Pliocene sediments in the Adriatic offshore area is characterized by transgression, so that the Pliocene sediments comprise clays, marls and sands. In most of the offshore area, there is a depositional continuity from Pliocene to Pleistocene sediments, consisting of fine- to medium-grained clastics with lignite interbeds.

De Leeuw, A., Mandic, O., Vranjković, A., Pavelić, D., Harzhauser, M., Krijgsman,W., Kuiper, K.F. (2010): Chronology and integrated stratigraphy of the Miocene Sinj Basin (Dinaride Lake System, Croatia). Palaeogeogr. Palaeoclimatol. Palaeoecol. 2010, 292, 155–167.

Pamić, J., Gušić, I., Jelaska, V. (1998): Geodynamic evolution of the Central Dinarides, Tectonophysics, 297, 251-268.

Prelogović, E., Saftić, B., Kuk, V., Velić, J., Dragaš, M., Lučić, D. (1998): Tectonic activity in the Croatian part of the Pannonian Basin, Tectonophysics 297, 283-293

Royden, L.H., Horváth, F. (eds.) (1988): The Pannonian Basin – A Study in Basin Evolution, AAPG Memoir 45, 394 p.

Saftić, B., Velić, J., Sztanó, O., Juhász, G., Ivković, Ž. (2003): Tertiary Subsurface Facies, Source Rocks and Hydrocrbon Resevoirs in the SW Part of the Pannonian Basin (Northern Croatia and South-Western Hungary). Geologia Croatica, 56/1, 101-122.

Tišljar, J. (1992): Origin and Depositional Environments of the Evaporite and Carbonate Complex (Upper Permian) from the Central Part of the Dinarides (Southern Croatia and Western Bosnia). Geologia Croatica, 45, 116–126.

Vlahović, I., Tišljar, J., Velić, I., Matičec, D. (2005): Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. Palaeogeogr. Palaeoclimatol. Palaeoecol., 220, 333–360.

12. Geothermal potential and energy use in Croatia

Staša Borović

Croatia can be divided into two parts with significantly different values of important geothermal parameters (Figure 12). The northeastern Pannonian part is characterized by a high average geothermal gradient (0.049 °C/m) and surface heat flow (76 mW/m^2). Conversely, the southwestern Dinaric part has a low average geothermal gradient (0.018 °C/m) and surface heat flow (29 mW/m^2).

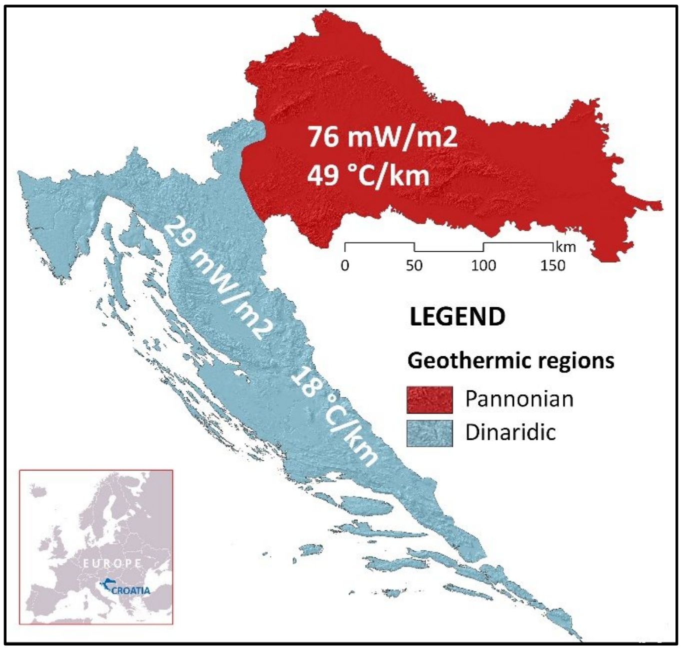


Figure 12: Heat flow density and geothermal gradient in geothermically different Croatian regions (adopted from Borović et al., 2016)

These different traits are the result of the regional tectonic setting. The seismic Mohorovičić/Moho discontinuity, is located at a depth of 50 km in the Dinarides, while in the Pannonian Basin it is only 28 km deep (Aljinović & Blašković, 1984). High values of geothermal parameters in the Pannonian Basin System (PBS) are the consequence of the Middle Miocene (≈ 16 - 11.6 Ma b. p.) back-arc extension of the basin, which thinned the lithosphere and allowed the hot asthenosphere to approach the surface (Horváth & Royden, 1981). In the Dinaric part, the situation is reversed: there is an ongoing collision of the Adriatic Carbonate Platform with the rest of the Eurasian continental plate, which is responsible for the thickening of the crust and the formation of the Dinarides, which are part of the Alpine-Himalayan orogenic belt. Moreover, the Dinaric carbonate rocks are highly karstified which allows large-scale infiltration of rainwater, further cooling it. Therefore, almost all sites where geothermal waters are used are located in the north-eastern part of Croatia (Figure 13).

Thermal springs and wells are being used. When larger quantities of thermal water were needed at locations of thermal springs, shallow wells were constructed sometimed causing their drying up. Opposite, during exploration and exploitation of hydrocarbons many deep wells found also thermal water.

The temperature range in which the waters are currently used is 17-170 °C. Waters were classified according to the modified balneological classification (Kovačić & Perica, 1998 from Iveković & Peroš, 1981). However, from the hydrogeological point of view, all groundwaters with temperatures higher than the mean annual temperature of the site are considered geothermal, although they cannot be used in balneology (Table 2).

Table 2: Categorization of geothermal localities in Croatia on the basis of water temperature (according to Kovačić & Perica, 1998).

Category	SUBTHERMAL	HYPOTHERMAL	HOMEOTHERMAL	HYPERTHERMAL
Temperature	13 - 20 °C	20 - 34 °C	34 - 38 °C	>38 °C
Natural spring	1	6	2	6
Deep borehole	0	4	0	7

The utilised waters considered range from subthermal to hyperthermal. The type of utilisation varies according to the temperatures, e.g. the waters with the lowest (17 - 20 °C) are used for fish farming, while the waters with the highest temperatures (68 - 170 °C) are used for space heating, domestic hot water preparation and electricity generation. In total, geothermal waters in Croatia are utilised in the following eleven activities: recreation, balneotherapy, water heating, space heating, greenhouse heating, fish farming, as sanitary water, public water supply water, bottled table and mineral water, and since 2018 also for electricity generation. The most common uses are recreational and balneotherapy, known from prehistoric and ancient times. This is followed by water and space heating and utilisation of thermal water for sanitary purposes. Other types of use are present only in one or two places.

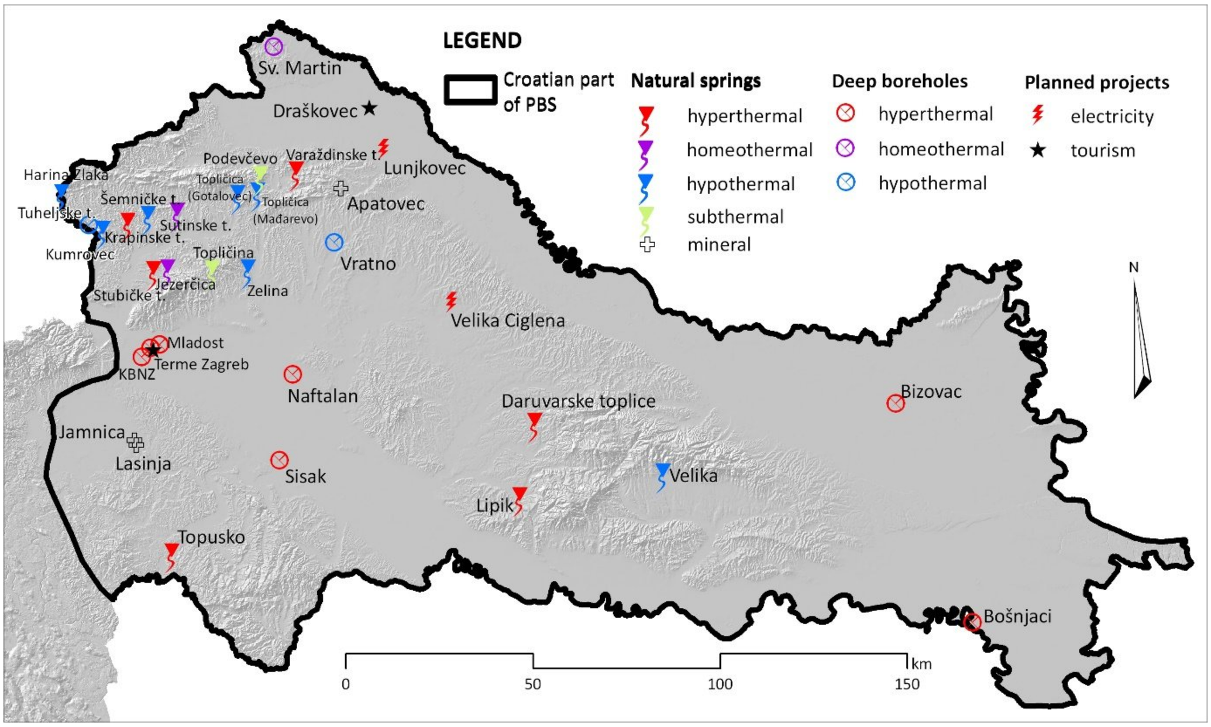


Figure 13: Locations of thermal and mineral water utilization in the Croatian part of the PBS (adopted from Borović et al., 2016)

Croatian geothermal resources were calculated within the framework of the national GEOEN - Programme of geothermal energy utilisation (EIHP, 1998), both for existing wells and taking into account the full development of existing geothermal fields (Table 3). Potential electricity production was calculated for a capacity factor of 90% and direct heat production for 70%, the maximum capacity factors given for these purposes (Fridleifsson, 2003).

Table 3: Annual energy production in Croatia – projections.

	Electricity (PJ)	%	Heating and cooling (PJ)	%
Total 2020 [a]	83.90	100	134.17	100
Geothermal 2020 [a]	0.26	0.31	0.66	0.49
Geothermal - existing boreholes [b]	0.21	0.25	4.20	3.13
Geothermal - full development [b]	1.30	1.77	16.53	12.32

Sources: [a] Ministry of Economy of the Republic of Croatia, 2013; [b] EIHP, 1998

Electricity generation is considered marginally profitable, depending on the project, as the available resources have temperatures up to 170 °C (Kristmannsdóttir & Ármannsson, 2003). On the other hand, if cascade use of water is considered, they become economical (Pravica et al., 2006). In 2020, the geothermal power plant in Velika Ciglena (using the same calculation method) will produce 0.28 PJ of electricity, which is slightly higher than the 2013 predictions. The Croatian heating and cooling sector could benefit from large-scale geothermal use, as the full development of existing fields could supply over 12% of energy demand, not including the use of geothermal heat pumps. It should be emphasised that these figures refer only to the geothermal fields already developed to some extent, not to all geothermal fields discovered in Croatia. In the Pannonian part of Croatia, there are a total of 3,500 boreholes left over from hydrocarbon exploration and exploitation, and many of them represent untapped energy micro-potential (Kolbah & Škrlec, 2010; Macenić, 2020). It has been established that there is significant energy potential in the water surrounding mature hydrocarbon reservoirs with deep wells, high temperatures and favourable permeability conditions, which could be retrofitted for geothermal water extraction during and after hydrocarbon exploitation (Čubrić, 1978; Kurevija & Vulin, 2011).

One of the obstacles for stronger integration of geothermal energy into the heating sector is the fact that the same region rich in geothermal potential also has a developed gas pipeline network. Natural gas heating is a strong competitor because it is readily available, while geothermal wells are often located several kilometres away from settlements, so it would be necessary to build isolated hot water pipelines (Čubrić, 1993). In this situation, even if there is awareness of the possible use of renewable resources, it gives way to economic interests. As Fridleifsson (2003) states, the potential for geothermal development also depends on the availability and prices of other energy sources in a specific location, as well as the compatibility between the available temperature level of the geothermal heat source and the demand of the particular user.

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13. Zagreb Geothermal Field

Staša Borović

13.1. Overview

Zagreb is the capital of the Republic of Croatia and by far the largest urban agglomeration in the country with 800,000 inhabitants (Croatian Bureau of Statistics, 2021), which means, among other things, that it has a high energy demand, about half of it for thermal energy, with an average of 220 heating days per year.

Zagreb Geothermal Field (ZGF) (Figure 14) extends under the Croatian capital and covers an area of 54 km2 according to existing research (Zelić et al., 1995). It was discovered in 1964 by hydrodynamic (HD) measurements on a negative hydrocarbon well. As the tests revealed significant amounts of thermal water, the area was developed as a geothermal field, which included the drilling additional 26 wells until 1988. The measurements revealed a sustainable pumping capacity of 77 l/s using geothermal doublets, while only 9 l/s were used on average in 2018 (only one doublet system is in operation) (Cazin & Jurilj, 2019).

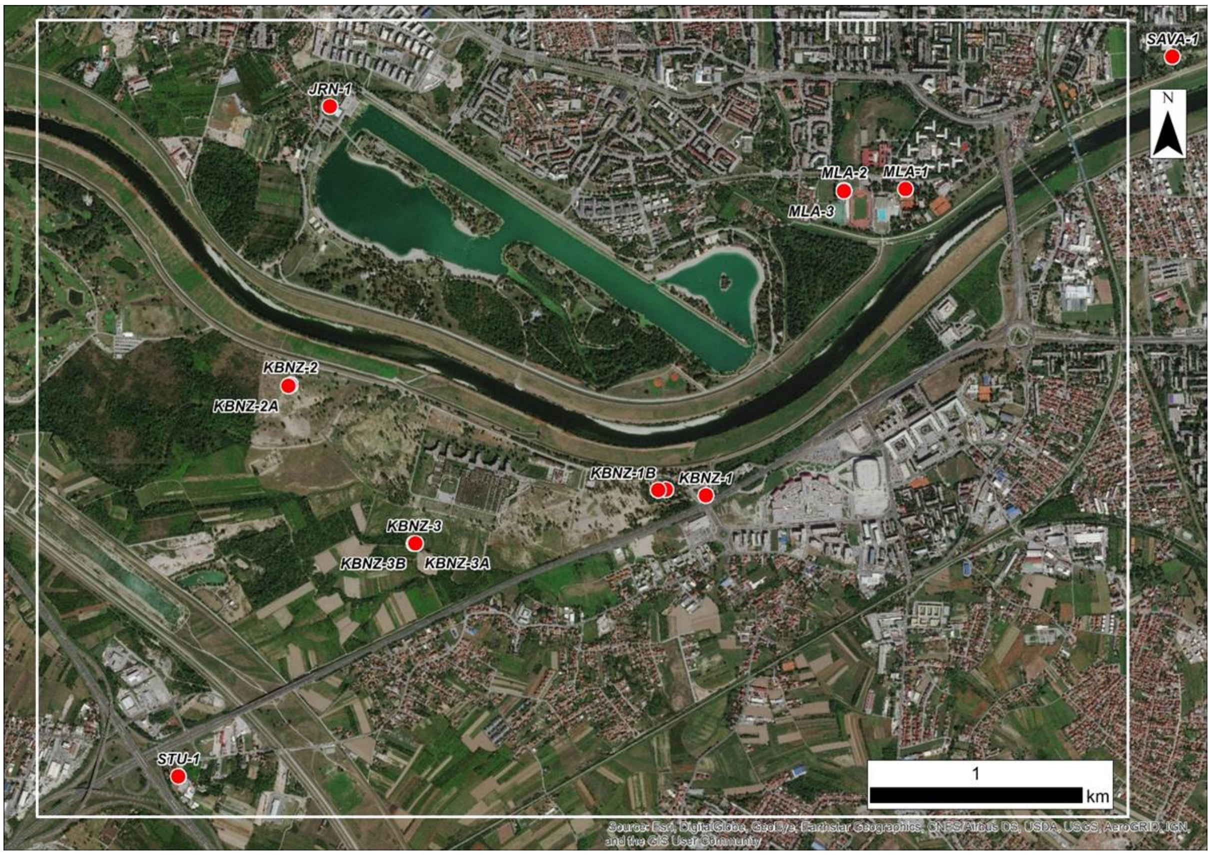

Figure 14: Central part of the ZGF. Red points indicate existing geothermal wells (satellite imagery in the background by Google Earth)

13.2. Geology, hydrogeology and geothermal setting

The ZGF comprises two distinct but interconnected carbonate thermal aquifers: Triassic dolostones, limestones and dolomitic limestones, and lower and Middle Miocene bioclastic

(*Lithotamnium*) limestones (Figure 15). The Triassic aquifer is highly fractured and can be classified predominantly as dolomitic breccias with high secondary porosity and good permeability. The thickness of the aquifer varies from 5 to 357 m. The Miocene aquifer has good primary porosity due to the bioclastic composition, but also good secondary porosity, occurring in some wells as breccia or breccia conglomerate. As a result, it has excellent permeability. The entire formation ranges in thickness from 35 to 1016+x m, but also contains marly sections with lower permeability and cannot be considered an aquifer in total thickness.

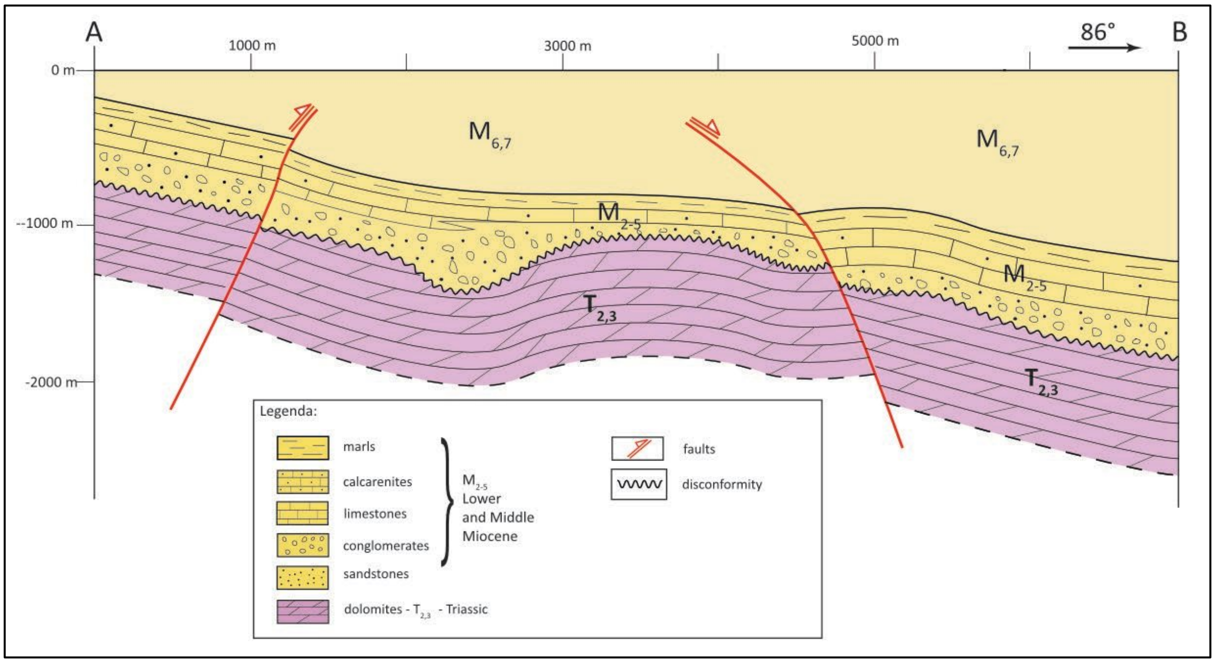

Figure 15: Characteristic geological cross-section in the productive part of the ZGF (HotLime WP2 Summary Report)

The geothermal aquifers are overlain by a thick succession of Neogene and Quaternary sedimentary rocks and sediments. Laboratory analyses of water samples from six wells in ZGF were carried out from 1984 to 1992. These data were also found in the well documentation. The principal anion and cation compositions are shown numerically and graphically in Figure 16. It can be seen from Figure 16a that the total mineralization is not especially high (around 2 mg/l). In comparison, the majority of hydrothermal systems in the Republic of Croatia are fed by fractured carbonate aquifers (Borović et al., 2016), and they have mineralization of less than 1 g/l, i.e. they are more similar to cold and potable groundwaters from carbonate aquifers (Borović, 2015; Marković et al., 2015; Šimunić, 2008). Although boreholes demonstrate beyond doubt that the water resides in dolostone and limestone aquifers, the water chemistry does not directly reflect this: the waters have a hydrochemical Na-HCO_3 facies, and in addition there is a high chloride anion content. Although counterintuitive, such water composition and hydrochemical stratification is known in other carbonate aquifers in the PBS and indicates a long residence time of the groundwater (Szőcs et al., 2013). This is a consequence of cation exchange of Ca^{2+} and Mg^{2+} cations with Na^{+} cations during prolonged periods (Hem, 1989).

Temperatures range from 27 to 52 °C at 500 m, and from 38 to 81 °C at 1,000 m. Two technological systems were established at the parts of the field where the highest temperatures were measured: Mladost (active) and KBNZ (inactive - shutdown).

a

	Mla-1	Mla-2	Mla-3	KBNZ-1A	KBNZ-1B	KBNZ-3A
Ca^{2+}	65	56	20	43	46	36
Mg^{2+}	12	9	8	28	16	11
Na^{+}	576	550	495	516	525	125
K^{+}	23	30	27	28	25	15
HCO_3^{-}	991	926	732	973	814	247
Cl^{-}	252	255	234	248	294	50
SO_4^{2-}	322	290	296	239	284	158
TDS	2248	2122	1822	2083	2013	645

b

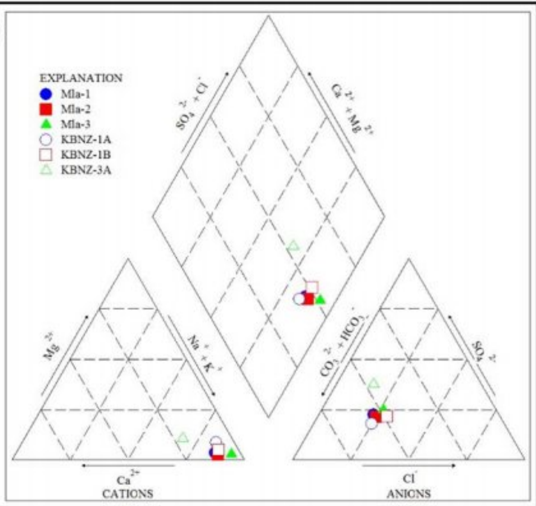

Figure 16: Major ion composition (a) and Piper diagram (b) of the waters from ZGF boreholes (Borović et al., 2020).

Estimates of surface heat flow estimates were performed based on geothermal gradients and thermal conductivities summarized in Kovačić (2002). Different deterministic interpolations were tested and the one with the lowest RMS error was considered optimal (in this case it was the "spline" interpolation in ESRI's ArcGIS tool). The result of the interpolation with the lowest RMS error is shown in Figure 17.

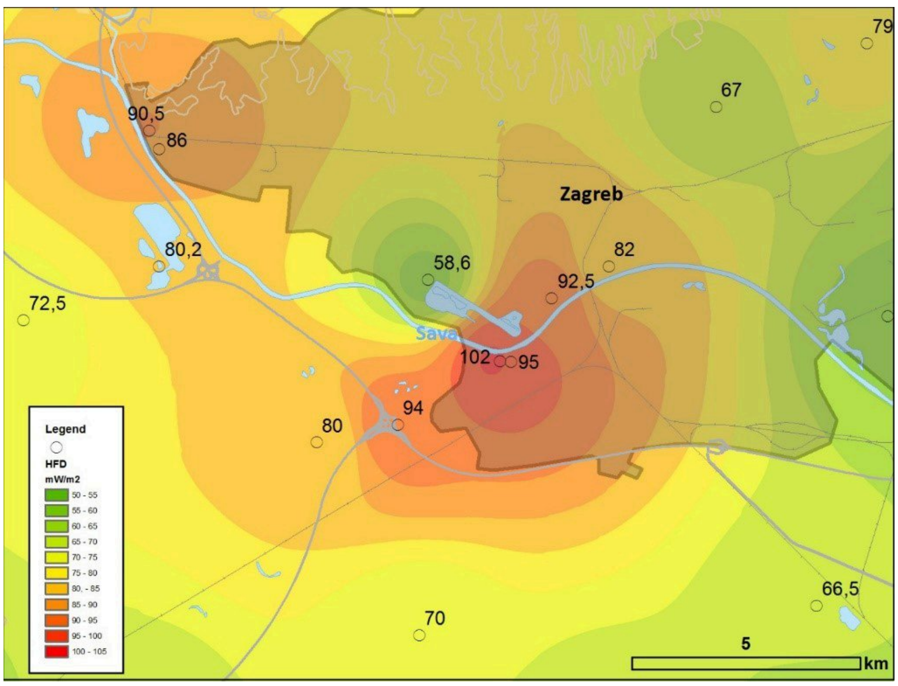

Figure 17: Interpolation of the heat flow density (HFD) in the ZGF (Borović et al., 2020).

13.3. Resource assessment and classification

The resource assessment and classification according to the modified UNFC-2009 for geothermal projects (Figure 18) was carried out as part of the HotLime project. This was possible due to the fact described in the introduction: ZGF is a developed geothermal field, so it is fully tested and the data was provided to us by the Croatian Hydrocarbon Agency (AZU).

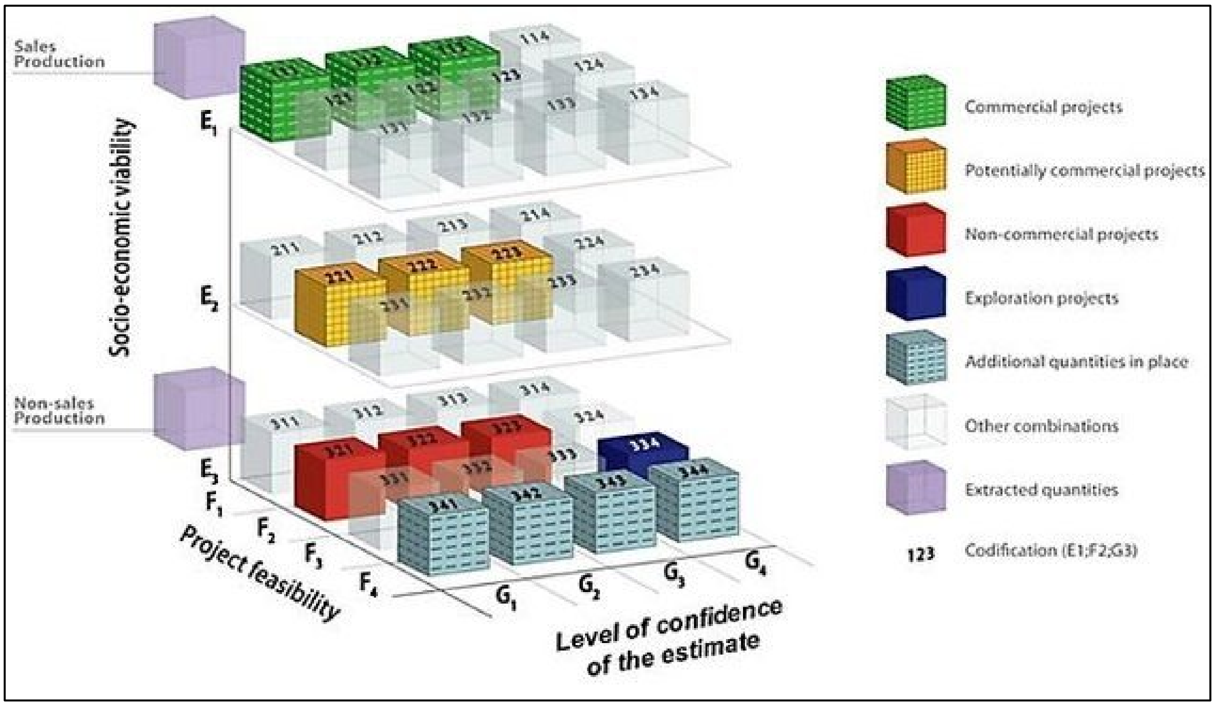

Figure 18: Modified UNFC-2009 for geothermal: classification axes and categories (UNECE & IGA, 2018).

Probabilistic estimates (P10, P50 and P90) of the potential power output were calculated for two technological systems of the ZGF mentioned in the previous subsection: Mladost and KBNZ, based on the ZGF main mine planning and design data (Zelić et al., 1995), using the DoubletCalc 1.4.3 software (TNO, 2014), designed for issuing permits for geothermal energy exploitation in the Netherlands.

Mladost is a doublet plant that has been operating successfully and continuously since 1987, so it is clearly feasible and socio-economically accepted. Mladost is a sports park and the thermal energy is used for space and water heating. Due to its longevity, it is known that it is in operation for an average of 335 days a year, so this figure was used to calculate the energy output. The calculation was made for a period of 50 years.

The **KBNZ** system is located approximately 1 km from Mladost on the site SW. Three wells were drilled, all with side-tracks. The system was planned for heating the University Hospital (Croatian: Klinička bolnica Novi Zagreb, KBNZ), which was under construction at the time. The hospital was never completed and the boreholes are not used. The predicted energy output for both systems is summarized graphically in Figure 19.

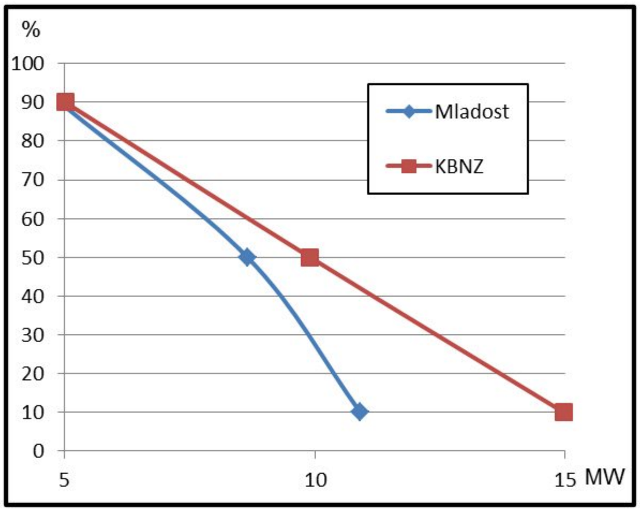

Figure 19: Probability plot for Mladost and KBNZ systems power outputs (Borović et al., 2020).

As the UNFC-2009 classification is project-based, it was necessary to ensure the comparable level of quantification. Most of the HotLime case studies were investigations on large areas, therefore classification was not applicable, i.e. all regional examples would be classified as E.3; F3; G4, based on national 'standard' projects, as for the Pannonian Basin System (PBS) under the DARLINGe project (Nador, 2018). The technological systems in place in the ZGF: Mladost (in operation) and KBNZ (decommissioned) were classified. Looking at the whole theoretical 'Zagreb Basin' (sub-basin of the PBS), the DARLINGe project classified the resource as mentioned above.

When analysed at the project level, the Mladost system classified 7 PJ E1.1; F1.1; G1 + 5 PJ E1.1; F1.1; G2 + 3 PJ E1.1; F1.1; G3 - in complete contrast to the sub-basin scale classification. This system has been successfully in continuous operation since 1987, so is clearly feasible and socio-economically accepted. On the contrary, the adjacent KBNZ is classified as 7 PJ E3; F1.3; G1 +7 PJ E3; F1.3; G2 + 7 PJ E3; F1.3; G3 because - although all wells have been in place since 1987, they have been tested, the concession has been granted, etc. - the system has never been put into operation. The KBNZ case is a typical example of legislative, administrative and political obstacles to project implementation leading to an E3 classification of a project that could have been in operation for decades.

The Mladost system has been in operation for 34 years, so its thermal output can be compared to the theoretical (and planned by the main mining project). According to the latest published data (Cazin & Jurilj, 2019), the annual utilization is 3 MW in capacity. Compared to Figure 19, it is visible that it is 60 % of the P90 estimate, i.e. exploitation should be organized much more efficiently. The KBNZ system is not in operation, so none of the available energy is used in a useful function. Considering that the ZGF is located in the national capital with a number of potential users, it can be considered as an example of a resource abandoned for decades due to socio-economic circumstances.

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14. Hydrothermal systems in Croatia

Staša Borović

Natural thermal springs in Croatia can be traced via the occurrence of the toponyms toplica/e, meaning hot water spring/s, and topličica, meaning warm water spring/s. In some localities of present-day Croatia the springs were utilised since prehistoric times. As the understanding of the structural setting of the Croatian part of the PBS had been advancing, it was showen that the majority of natural thermal springs are located within the hinge zones of anticlines, faulted by transversely oriented faults and whose core zones are mostly composed of Mesozoic carbonates (Šimunić & Hećimović, 1999). Due to the multiphase tectonic evolution of the PBS, folded and faulted Mesozoic carbonates are usually highly fractured, and this strong permeability contrast with the surroundings enables the upwelling of heated water from deeper subsurface to the surface, creating thermal springs.

The existence of hydrothermal systems is generally the result of a delicate balance between flow rates, dissolution/precipitation processes, and local to regional structural frameworks. In order to sustainably exploit thermal spring resources, the functioning of the entire fluid flow and heat transport systems, from recharge to discharge areas, needs to be investigated in a multidisciplinary study.

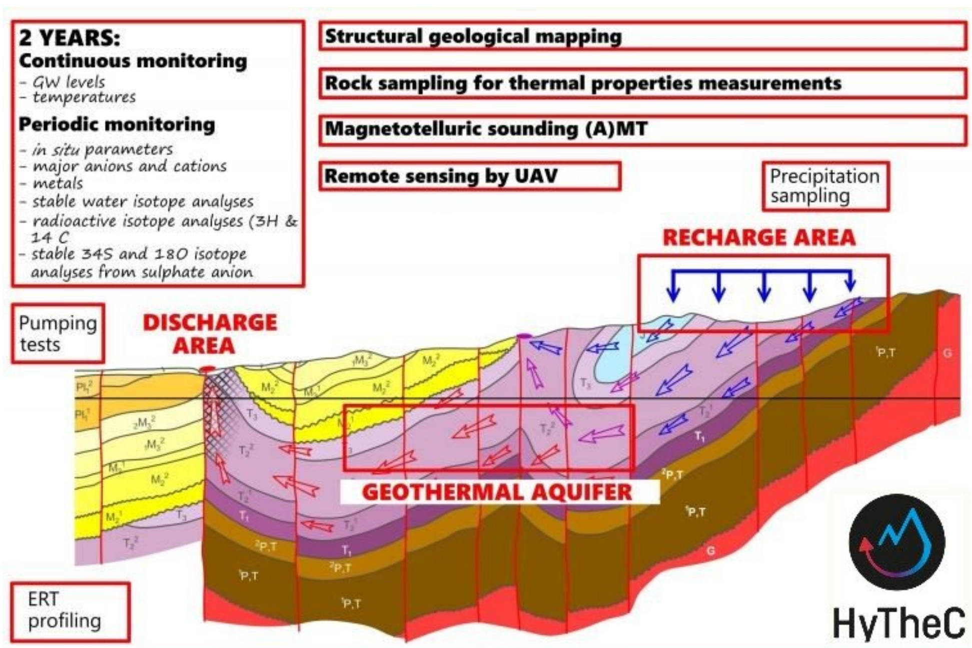

Figure 20: Schematic of the current multidisciplinary research of hydrothermal systems in the scope of the HyTheC project, funded by the Croatian Science Foundation

The schematic of one of the hydrothermal systems currently under five years of multidisciplinary investigation, is shown in Figure 20. It shows the Daruvar hydrothermal system closest to our stop at Velika Ciglena (60 km in the direction of SE). More data on the ongoing research of hydrothermal systems in Croatia can be found on the project website: https://hythec.wordpress.com.

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15. The geothermal power plant Velika Ciglena

Iva Kolenković Močilac

The geothermal power plant Velika Ciglena was commissioned in December 2018 and has been operating at full capacity since March 2019 with an installed capacity of 15 MWe with the largest ORC (Organic Rankine Cycle) turbine in Europe. The core technology of the power plant was developed by Italian Truboden. The working fluid is isobutane and the cooling system is Air Cooled Condenser. Taking into account the expansion of Non-Condensable Gases (NCGs), an additional 1.5 MWe is produced that would otherwise simply be discharged to the atmosphere, which is common for most geothermal binary power plants in operation (Guercio & Bonafin, 2016). Velika Ciglena has an electricity supply contract with Croatian Energy Market Operator (HROTE) for 10 MW of the installed capacity, which is equivalent to the average consumption of 29,000 Croatian households.

The geothermal reservoir was discovered in 1990 by the well VC -1 during hydrocarbon exploration carried out by INA. Hydrocarbons were not found, but promising geothermal potential was identified. At the depth of 2,585 m, an unusually high temperature (172 °C) was recorded and drilling fluid losses occurred, indicating increased permeability within the Tertiary carbonate breccias underlying the Neogene sedimentary basin-fill sequence. Further drilling through the Triassic carbonate complex (to 3,835 m) continued with total drilling fluid losses. The well was drilled with a water-nitrogen mixture. At a depth of 3,200 m, a short blowout of hot water and CO_2 occurred. Logging revealed several fracture zones. Two of these, located at depths 3,210 - 3,220 m and 3,590 - 3,630 m and later interpreted as reverse faults, absorbed most of the drilling fluid. A temperature anomaly was also recorded in the lowermost part of the Triassic carbonate complex at depths of 3,821 - 3,831 m, accompanied by increased permeability, which was recognised as a favourable setting that should prevent rapid breakthrough of re-injected water into the production well, provided the production well penetrates only the upper part of the reservoir (VC -1a in Figure 21).

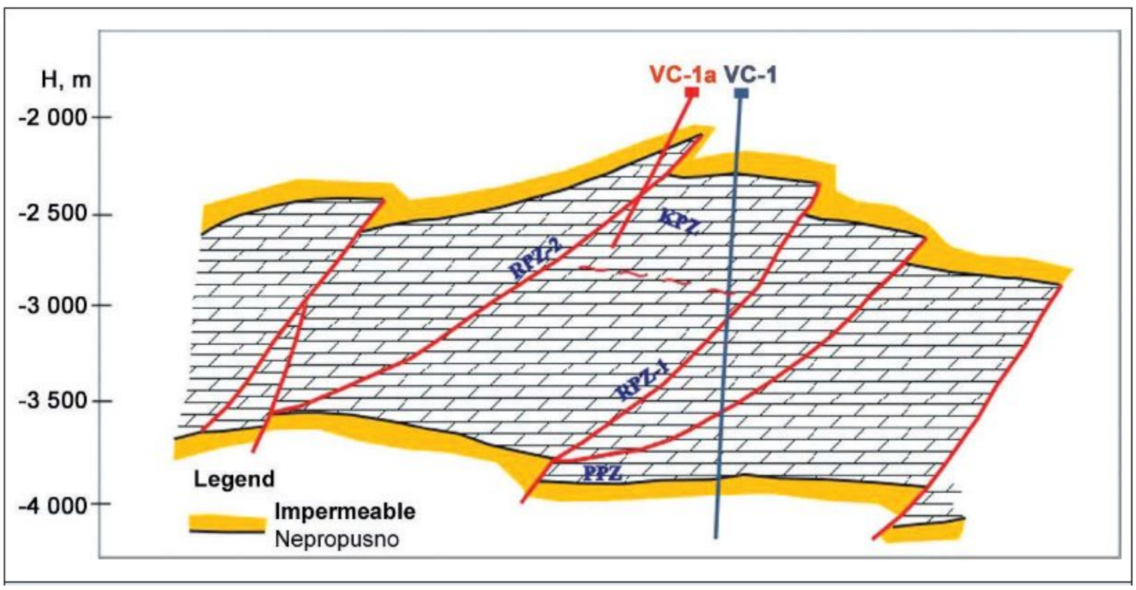

Figure 21: Longitudinal cross-section across the Velika Ciglena geothermal reservoir (from Čubrić, 2012).

The schematic structural model (Figure 21) of the geothermal reservoir Velika Ciglena was developed based on the seismic surveys and data from the wells VC -1 and VC -1a and two (dry) exploration oil wells (VC -2, Ptk-1). Based on knowledge of local stresses, it was inferred that normal faults (not shown in cross-section) are likely boundaries of hydraulic units such that the new wells are not connected to the VC -1 and VC -1a wells. The hypothesis was then proven by an interference test.

The interference test indicated the presence of a high permeability fracture zone intersected by both wells (representing a potential risk for rapid breakthrough of reinjected water). Moreover, low values of the interporosity flow coefficient (ratio of matrix permeability to fracture permeability) and storativity ratio indicate that the flow is limited to the fractures, with negligible influence of matrix porosity, leading to the development of the so-called "Z-model" of flow shown in Figure 21.

According to Čubrić (2012), several hydraulic units can be distinguished:

– base rock permeable zone (PPZ) with the volume of reservoir fluid of 7 ×10^6 m^3;
– faulted permeable zone-1 (RPZ-1) with volume of reservoir fluid of 2 × 10^6 m^3;
– top rock permeable zone, block 1 (KPZ-1), situated at depth of 2,585 to 2,940 m, with the volume of reservoir fluid of 34 × 106 m^3, effective thickness of the zone is 174 m;
– top rock permeable zone, block 2 (KPZ-2) with volume of reservoir fluid of 14 × 10^6 m^3;
– faulted permeable zone -2 (RPZ-2) with the volume of reservoir fluid of 4 × 10^6 m^3.

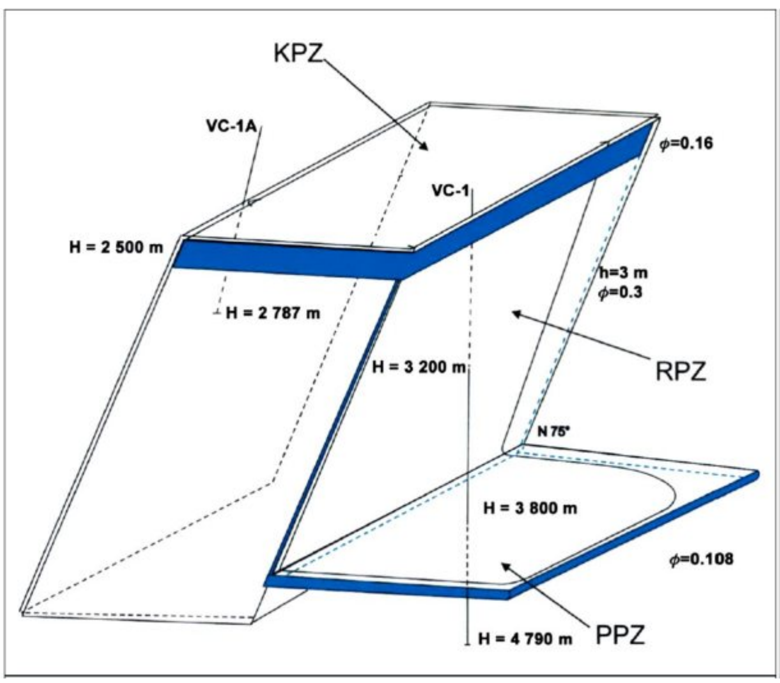

Figure 22: Flow model of the Velika Ciglena geothermal reservoir (from Čubrić, 2012).

Calculated time of constant temperature of 170˚C at the outlet is 24.2 years.

16. The petroleum geological settings in Croatia and its relation to geothermal resources

Iva Kolenković Močilac

The petroleum- geological provinces in Croatia correspond to geological regions, each of which has characteristic petroleum geological settings. Oil and natural gas have been exploited in the Croatian part of Pannonian Basin for 80 years, while the exploitation of natural gas in the Adriatic offshore area started in the 1990s.

16.1. Pannonian petroleum system

Sedimentation of source rocks occurred primarily during the Middle and Upper Miocene under the influence of several factors, including intense tectonic movements that created deep-water environments favourable for the accumulation of large amounts of organic matter, especially during Badenian and older Pannonian. Thermal subsidence led to an increased geothermal gradient that allowed the maturation of source rocks.

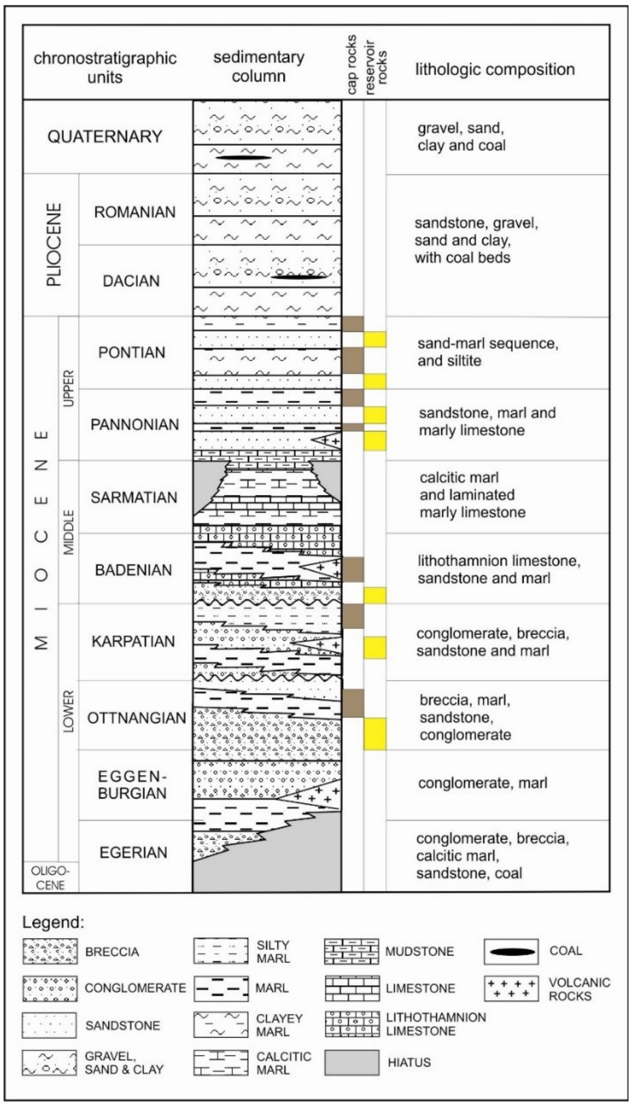

Figure 23: Generalized stratigraphic column of Neogene basin fill in Drava and Sava depressions (SW part of Pannonian Basin, from Saftić & Kolenković, 2011)

On the other hand, the presence of a variety of reservoir rocks (Figure 23) resulted in different types of reservoirs in terms of trap type and lithology. Reservoirs can therefore be found in basement rocks (igneous and metamorphic rocks with fracture porosity), Mesozoic dolomites and dolomite breccias and Early/ Middle Miocene carbonates, but most reservoirs are found in Upper Miocene sandstones of turbiditic origin (Velić, 2007).

In the Drava Depression, a total of 30 oil and/or gas fields have been in exploitation, including the largest gas fields Molve, Kalinovac and Stari Gradac, whose combined production accounts for more than 50% of the total gas production of all gas fields in Croatia. In the Sava Depression, 20 oil and gas fields have been in operation since the beginning of modern petroleum exploitation that started in 1941, and most of the reservoirs are nearly depleted with two CO_2 EOR projects (Enhanced Oil Recovery using CO_2 as injection fluid) underway in operation on the reservoirs of the Ivanić and Žutica oil fields. Nine hydrocarbon fields in the Mura Depression in the northernmost part of Croatia have produced oil and, to a lesser extent, gas, while in the Slavonija-Srijem Depression in the eastern part of North Croatian Basin only three oil fields were in operation.

16.2. Adriatic and Dinaric hydrocarbon provinces

Two key tectonic phases marked the development of External Dinarides -the Early Jurassic extension, which accompnaied the formation of the Adriatic Carbonate Platform; and disintegration of the platform in the Late Cretaceous. These phases set the boundaries of depositional megasequences identified by Velić et al. (2015), corresponding to "petroleum geological units" (PGUs) in the Croatian part of the Adriatic and the Dinaric areas:

1. Upper Carboniferous to Lower Jurassic - time before the formation of the platform
2. Lower Jurassic to Upper Cretaceous - formation of the Adriatic carbonate platform
3. Paleogene to Neogene - time after the formation of the carbonate platform
4. Pliocene - Holocene megasequence Within the Croatian part of the Adriatic Basin

Fig. 24 shows source rocks, reservoirs and seals in composite stratigraphic columns for the northern, central and southern parts of the offshore Adriatic Basin. The columns are based on data from wells within the different regions and do not include data from onshore wells.

1st PGU contains overmatured source rocks of terrogenous origin. Potential reservoir rock intervals include sandstones and the Main Dolomites with secondary porosity. Potential seals include shales and evaporites of Permian and Triassic age (Velić et al., 2015).

Within the 2nd PGU reservoir rocks include Lower Jurassic to Upper Cretaceous limestones with secondary porosity and offshore talus breccias derived from Adriatic Carbonate Platform. Altogether four source-rocks horizons are registered onshore and oil shows were recorded in wells Kate-1 and J-13. Commercial accumulations of biogenic methane have been found in Upper Cretaceous fractured carbonates (Ika gasfield).

In 3rd PGU oil shows are recorded in reservoir rocks of unfavourable petrophysical properties in Kate-1 offshore well were related to Lower Cretaceous source rocks. Biogenic methane found in Irma field was generated by biodegradation of kerogen type II and III.

Biogenic gas is commercially produced from Pleistocene sands of 4th PGU from ten gas fields in Northern Adriatic (Po Plain – Adriatic foredeep). Traps are structural and stratigraphic. Structural traps include anticlines and brachy-anticlines (Velić et al., 2015). Stratigraphic traps result from lateral change of facies, from permeable into impermeable. The source rocks are thermally immature organic-rich shales of Pliocene age.

Saftić, B. & Kolenković, I. (2011): CCS Actions and Storage Options in Croatia.- Geophysical Transactions, 45, 4, 193-206.

Velić, J. (2007): Geology of Oil and Gas reservoirs [in Croatian, Geologija ležišta nafte i plina]. University of Zagreb – Faculty of Mining, Geology and Petroleum Engineering, Zagreb, 342 p.

Velić, J., Malvić, T., Cvetković, M., Velić, I. (2015): Stratigraphy and petroleum geology of the Croatian part of the Adriatic basin. Journal of Petroleum Geology, 38, 3, 281-300.

TRAINING OUTLINE

17. Introduction of Geothermal-DHC project

Gregor Goetzl

The EU COST Action CA18219 "Geothermal-DHC" is an open research network on the integration of geothermal energy into decarbonized heating and cooling networks across Europe.

Why talk about geothermal energy in heating and cooling networks?

Geothermal energy is a reliable energy source literally available anywhere and anytime across the globe. It is able to cover heating and cooling demand between less than 20°C and up to above 150°C (Figure 24). District heating and cooling networks are important hubs to boost the share of renewable energy sources on the one hand and allow for social justice on the other but their share is rather low (around 10% according to Eurostat). Studies like the "Heat Roadmap Europe" project (https://heatroadmap.eu/) recommend to increase it to 50% of the overall heat supply in Europe. For the decarbonization and further deployment of new networks concepts have to be established to allow for harvesting locally available, climate friendly heating sources and sinks, combined with heat storage for efficiency reasons. Geothermal energy has the potential to play an important twofold role. Firstly, it may provide reliable base load supply at reasonable operational costs for saving valuable high enthalpy energy carriers for peak load and backup supply. Secondly, underground thermal energy storage puts an added value to fluctuating heat and energy sources, such as solar, air or waste heat for medium to long term (seasonal) storage.

A Geothermal-DHC district heating and cooling network represents a decarbonized, highly efficient low temperature heating and cooling supply option offering a "market place for heat and cold" to local residents.

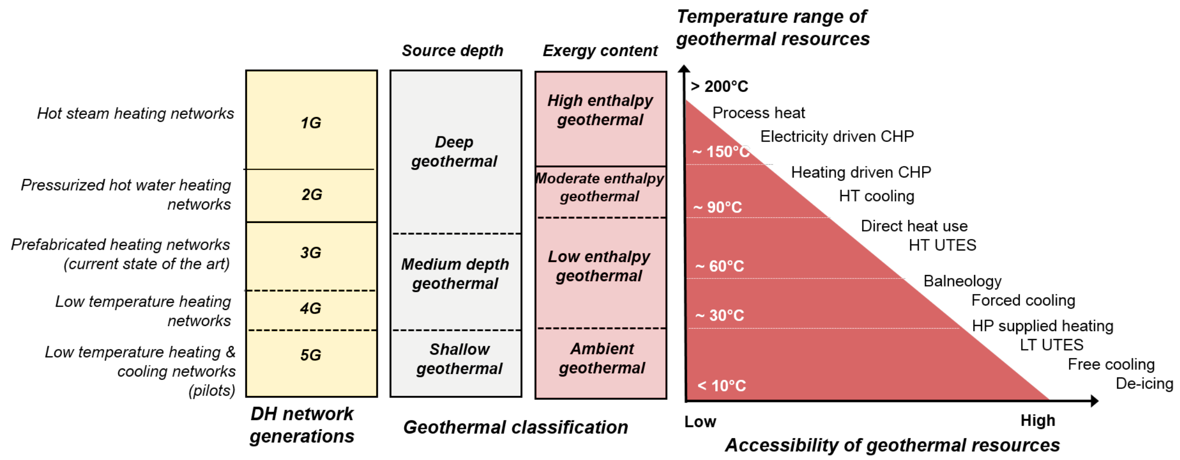

Figure 24: The interlink between different geothermal sources, applications and generations of district heating and cooling systems.

A COST Action is not a research project!

In contrast to typical EU funded research funds, COST (European Cooperation in Science and Technology) is a funding agency for research and innovation networks. COST Actions help to connect research initiatives across Europe and enable scientists to grow their ideas by sharing them with their peers. In that sense, Geothermal-DHC is an open access research network, which does not offer direct staff cost funding, but instead various services for networking and promoting careers based on a joint vision and common goals.

As shown in the figure below, Geothermal-DHC is structured in four *Permanent Working Groups (PWG)*, complemented by a flexible number of so called *Ad Hoc Working Groups*, which address specific topics inside our network (Figure 25).

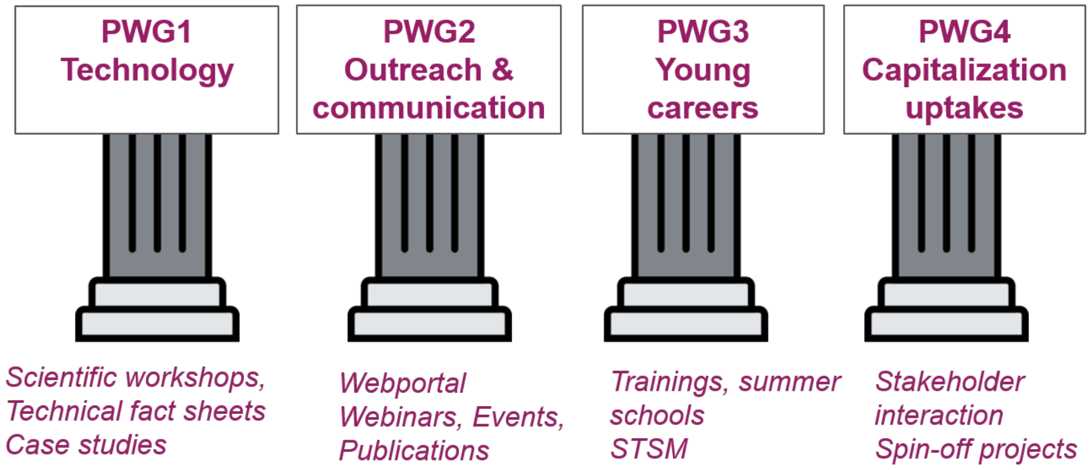

Figure 25: The Permanent Working Groups of the COST Action CA18219 Geothermal-DHC

The PWG3 Young careers is most important for young people interested in geothermal. Inclusion of PhD students and early career researchers, especially from Inclusiveness Target Countries (for more info on this see the COST *Vademecum* guidelines) is strongly supported as well as the gender equality. Within these activities we organize trainings, e.g. this summer schools and the next one on “Design and operation of shallow geothermal energy systems with reference to low temperature heating and cooling grids” between September 20 and 24, 2021 in Cyprus. There are also several calls on Short-Term Scientific Missions (STSM) opened each period which support individual mobility and foster collaboration among individuals from various organizations and countries. We also offer ITC Conference Grants that are aimed at supporting PhD students and Early Career Investigators from ITC to attend international conferences on the topic of ‘Geothermal Energy for Heating and Cooling’ that are not organised by this COST Action CA18219.

If you would like to learn more on Geothermal-DHC and enter our network, please visit our website: www.geothermal-dhc.eu.

18. Programme outline

Venue: NTF, Aškerčeva 11, Ljubljana but on DAY 5 Tuesday 13th July also GeoZS, Dimičeva ulica 14, Ljubljana

DAY 3 Sunday 11th July : Student conference

9:00 – 9:20	Welcome talks prof. dr. Boštjan Markoli, dean of NTF dr. Gregor Goetzl, Geothermal-DHC project leader dr. Nina Rman, Head of hydrogeology department at GeoZS dr. Boštjan Petelinc, Ministry of Agriculture, Foresty and Food Alenka Loose, City of Ljubljana Energy Manager at City administration
9:20 – 10:30	Session 1 – Student presentations
10:30 – 10:40	Coffe break
10:40 – 12:00	Session 2 – Student presentations
12:00 – 13:00	*Light lunch*
13:00 – 14:15	Session 3 – Student presentations
14:15 – 14:30	Coffe break
14:30 – 15:30	Session 4 – Student presentations
15:30 – 16:00	Best presentation selection and awards
18:00 – 19:30	Hydrocultural trip through Ljubljana – Water from deep history to nowadays (M. Brenčič)
19:30 on	Welcome party

DAY 4 Monday 12th July: Geothermal concepts & Exploration methods

9:00 – 10:30	Groundwater flow concepts (M. Brenčič)
10:30 – 10:40	Coffe break
10:40 – 12:00	Heat flow concepts (I. Kolenković Močilac / S. Borović)
12:00 – 13:00	Light lunch
13:00 – 14:00	Hydraulic measurements and tests (M. Brenčič)
14:00 – 15:00	Thermal measurements and tests (I. Kolenković Močilac / S. Borović)
15:00 – 15:15	Coffe break
15:15 – 16:20	Geothermal plays (I. Kolenković Močilac)
16:20 – 17:20	Hydrogeochemistry (N. Rman)

DAY 5 Tuesday 13th July: Drilling, utilization technologies and integration of heating and cooling networks

9:00 – 10:00	Drilling and completion works for shallow geothermal (T. Kurevija)
10:00 – 11:00	Technologies: Shallow geothermal providing for heating and cooling (T. Kurevija)
11:00 – 12:30	Travel to GeoZS and light lunch at GeoZS

12:30 – 14:30	Field and lab exercises at GeoZS (N. Rman, D. Rajver, M. Brenčič, K. Koren, S. Mozetič)
14:30 – 15:30	Drilling of thermal wells and re-working of abandoned oil and gas wells (M. Macenić)
15:30 – 15:40	Coffe break
15:40 – 17:40	District heating and cooling grid and power-heating market (H. Dorotić)

DAY 6 Wednesday 14th July: Reservoir engineering and Student projects

9:00 – 10:00	Thermo-Hydro-Mechanical reservoir processes (P. Vardon)
10:00 – 10:50	Reservoir modeling and uncertainties (P. Vardon)
10:50 – 11:00	Coffe break
11:00 – 12:00	Introduction to Geothermal economics (P. Vardon / T. Compernolle)
12:00 – 13:00	*Light lunch*
13:00 – 14:15	Advanced geothermal economics and decision making (T. Compernolle)
14:15 – 14:30	Coffe break
14:30 – 16:30	Environmental Life Cycle Assessment (T. Compernolle)
16:30 – 18:30	Student projects development

Day 7 Thursday 15th July: Management of geothermal projects and Student projects

9:00 – 10:15	European policies and legal aspects of using hydrogeothermal for direct heat supply (P. Dumas)
10:20 – 10:50	Geothermal legislation engineering approach – case studies from participating countries (Slovenia and Croatia (N. Rman / S. Borović)
10:50 – 11:00	Coffe break
11:00 – 12:30	Environmental issues trends and optimization of exploitation (N. Rman)
12:30 – 13:30	*Light lunch*
13:30 – 15:00	Student projects
15:00 – 15:15	Coffe break
15:15 – 18:15	Student projects

Day 8 Friday 16th July: Wrap-up day

8:30 – 10:50	Student projects
10:50 – 11:00	Coffe breaks
11:00 – 12:30	Presentation of student projects
12:30 – 13:30	*Light lunch*
13:30 – 14:30	Exams
14:30 – 15:00	Coffe break
15:00 – 16:00	Granting certificates of attendance
16:00 – 17:00	Closing event and farewell speech mag. Martina Gračner, Ministry of Infrastructure

19. Trainers of the summer school

dr. Staša Borovic, Croatian Geological Survey; sborovic@hgi-cgs.hr

Dr. Staša Borovic is the Senior Research Associate at the Department of Hydrogeology and Engineering geology of the Croatian Geological Survey. Her scientific interests include different topics in geothermal and applied geophysical research, as well as coastal karst aquifers research. She was a collaborator, coordinator and principal investigator of numerous projects funded by the Croatian Ministry of Science, EU Horizon2020 and Interreg programs, and the Croatian Science Foundation. She is the Croatian representative in the Panel of Experts on Geothermal energy of the European Federation of Geologists and the GeoEnergy Expert Group of the EuroGeoSurveys.

Prof. dr. Mihael Brencic, Faculty of Natural Sciences and Engineering of University of Ljubljana, Geological Survey of Slovenia; mihael.brencic@geo.ntf.uni-lj.si

Mihael Brencic full professor at the Department of Geology, University of Ljubljana and part time member of Geological Survey of Slovenia. He is hydrogeologist focused on several topics of groundwater; groundwater resources development, contaminant studies, groundwater dynamics, regional hydrogeology, karst hydrogeology and its evolution. He is currently serving as a president of Slovenian Committee of International Association of Hydrogeologists.

Assist. prof. **Tine Compernolle,** University of Antwerp, Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium; tine.compernolle@uantwerpen.be

Tine Compernolle is assistant professor Environmental Economics at the University of Antwerp and the Geological Survey of Belgium (Royal Belgian Institute of Natural Sciences). Her main interest is in analyzing the sustainable management of geological resources, by adopting an interdisciplinary approach. Her expertise is on techno-economic and environmental impact assessment of subsurface activities like geothermal projects, carbon capture and storage, and CO2 enhanced oil recovery. More specifically, she focusses on the integration of uncertainties and the value of flexibility within these assessments, through the adoption of a real options approach.

Hrvoje Dorotic, MSc., Faculty of Mechanical Engineering and Naval Architecture of University of Zagreb; hrvoje.dorotic@fsb.hr

Hrvoje Dorotic is enrolled in a Phd programme and since 2017 employed at the Department of Energy and Power Engineering, as a Research Assistant. His research deals with the optimization and analysis of energy systems and the integration of renewable energy sources, with the emphasis on district heating systems. The topic of his doctoral thesis is a multi-criteria method for comparison of district heating and cooling systems in relation to individual ones. He also deals with techno-economic analysis of cogeneration, solar photovoltaics and biogas plants and is currently involved in the consultancy dealing with post-earthquake recovery for the City of Zagreb, while focusing on the heating sector and energy efficiency.

Philippe Dumas, European Geothermal Energy Council; p.dumas@egec.org

Since September 2008, Philippe is the EGEC Secretary general in Brussels managing the association The European Geothermal Energy Council (EGEC). EGEC is an international association, founded in May 1998 and based in Brussels, Belgium. EGEC unites more than 120 companies and organizations, representing 500+ entities from 22 European countries, working in the geothermal field in Europe. The main goal of EGEC is to foster market development for geothermal energy and to work for the improvement of business conditions in Europe.

Gregor Goetzl, MSc, Geological Survey of Austria; Gregor.Goetzl@geologie.ac.at

Gregor Goetzl coordinates the geothermal energy research group at the Geological Survey of Austria. He holds an MSc degree in geophysics and is involved in numerous national as well as international research projects on the use of shallow and deep geothermal energy. Currently, he is chair of the EU COST Action CA18219 Geothermal-DHC as well as co-chair on geothermal energy inside the GeoEnergy Expert Group of EuroGeosurveys.

Assist. prof. dr. **Iva Kolenkovic Mocilac**, Faculty of Mining, Geology and Petroleum Engineering of University of Zagreb; iva.kolenkovic@oblak.rgn.hr

Iva is an assistant professor at the University of Zagreb – Faculty of Mining, geology and geological engineering. She graduated Hydrogeology (2006) and holds a PhD degree in Geology (2012), from the University of Zagreb. She is involved in research aiming for the characterization of deep geological systems for the assessment of geoenergy potential. Her primary focus is on CO2 geological storage and characterization of petroleum systems, as well as deep geothermal reservoirs and subsurface energy storage.

Assoc. prof dr. **Tomislav Kurevija**, Faculty of Mining, Geology and Petroleum Engineering of University of Zagreb; tomislav.kurevija@rgn.unizg.hr

Tomislav Kurevija is an Associate Professor at the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Croatia. His research interests include geothermal energy, thermogeology, energy management and reservoir engineering of oil, gas and groundwater. His expertise is on applied thermogeology, especially with thermal response test analysis and application of results to borehole heat exchanger design, heat pump design.

dr. **Marija Macenic**, Faculty of Mining, Geology and Petroleum Engineering of University of Zagreb; mmacenic@rgn.hr

Marija Macenic works as a postdoctoral researcher at the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Croatia. She completed her Master studies in Mining (2011) and doctoral studies in Petroleum Engineering (2020) at the same Faculty. Her research interests include geothermal energy, shallow geothermal energy, and energy management. Her main interest is a revitalization of abandoned oil and gas wells, as well as dry wells for exploitation of geothermal energy.

Assist. dr. **Nina Rman**, Geological Survey of Slovenia; nina.rman@geo-zs.si

Nina Rman is Senior Researcher and Head of the Department of Groundwaters-Hydrogeology at GeoZS. She is also an assistant at the Faculty of Natural Sciences and Engineering in Ljubljana for the Hydrogeology course. Her main interest is exploration and optimization of the use of low enthalpy geothermal systems, mineral and thermal waters, and CO_2 springs. Her expertise includes regional flow dynamics, geochemistry and monitoring systems installation, evaluation of aquifer's state and environmental impacts of geothermal resources. She supports the Slovenian Water Management Plan, bilateral water commissions and concession granting processes regarding thermal waters.

Assoc. prof. dr. **Maja Turnšek**, Faculty of Tourism of University of Maribor; maja.turnsek@um.si

Maja Turnšek is associate professor and vice dean for research at the Faculty of Tourism of the University of Maribor. Her background is in media and communication science and her research interests cover amongst other marketing of sustainable innovations, with a special focus on the role of visual communication, creativity and storytelling. She is the national coordinator of the Geofood project which is supported through the ERANET Cofund GEOTHERMICA project (Project no. 731117). The project aims to provide innovative concepts illustrating how to increase the economic viability of geothermal heat infrastructure using circular food production systems.

Assoc. prof. dr. **Phil Vardon**, Faculty of Civil Engineering and Geosciences, TU Delft; P.J.Vardon@tudelft.nl

Phil is an associate professor in the Department of Geoscience and Engineering and leads the Theme in Geothermal Science and Engineering. Phil's research is on the impacts on geomaterials of various processes including heat, moisture and contaminant movement, including practical applications such as geothermal energy, heat storage and radioactive waste disposal. He is the TU Delft PI on the 2 km deep campus geothermal well, the nationally funded Energy Piles in the Netherlands project and the ATES Triplet project. He was a chair of the Energy Geotechnics conference held in Delft in 2019, and a co-chair of Interpore 2017.

STUDENT CONFERENCE

Book of abstracts

Ljubljana, 11th July 2021

Organizational & scientific board:
prof. dr. Mihael Brenčič, dr. Nina Rman, dr. Gregor Goetzl, assist. prof. dr. Iva Kolenković Močilac

20. List of abstracts

1. Integrating geothermal energy into fifth-generation district heating and cooling

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Keywords: District heating, District cooling, Geothermal energy, Heat pumps, Modeling.

Abstract

The technology behind fifth-generation district heating and cooling offers the ability to supply simultaneous heating and cooling to buildings connected to a low-temperature pipe network. Heat pumps and chillers in each building adjust the low network temperature to the desired building supply temperatures. The simultaneous demands for heating and cooling across the network enable sharing energy flows between connected buildings. When the shared energy is not sufficient to maintain network energy balance, an external energy system referred to as a balancing unit injects or extracts heat from the network according to the demand type. The fifth-generation offers an increased potential to integrate low-enthalpy geothermal energy into the balancing unit since the network operates at temperatures close to the ground temperature. Ongoing research aims at developing a model for sizing a shallow geothermal energy system for applications related to fifth-generation district heating and cooling. By participating in the summer school for coupling technologies to use low and medium-depth hydro-geothermal, deeper insights into different geothermal concepts, policies, and design guidelines will be offered. The model can therefore be developed to support the decarbonization of the heating sector by integrating renewable geothermal energy.

2. Impact of physical parameters on the thermal properties of sediments

Authors: Simona Adrinek[1], Mitja Janža[1]

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Keywords: geothermal potential, thermal conductivity, non-cohesive sediment, cohesive sediment, estimation model.

Abstract

I investigate the relationship between the physical parameters and thermal properties of sediments which influences the potential for the use of low-temperature geothermal resources. I study the variation of thermal properties comprising thermal conductivity, thermal diffusivity and volumetric heat capacity of sediments depending on physical parameters that can be measured in the laboratory (mineral composition, porosity, saturation, density, and granularity) and, in the natural environment (influence of groundwater). The influence and relationship of the mentioned physical parameters on the thermal properties of sediments will be analyzed using thermal conductivity estimation models. By setting up a network of measurements of groundwater temperature and water table in the area of Murska Sobota, it will be possible to determine the influence of hydrogeological conditions on heat transfer. In addition to the models used to estimate thermal conductivity, analytical and numerical models of groundwater flow and heat transfer will be investigated for a selected shallow intergranular aquifer. The obtained results will enable to define a unified approach to determine the thermal properties of sediments depending on different physical parameters under different hydrogeological conditions. A systematic methodology will make it easier to define a low-temperature geothermal potential in the considered area as well as in other shallow intergranular aquifers in Slovenia and beyond.

Acknowledgement

The study presented here was financially supported by the Slovenian Research Agency (ARRS) under the Young Researchers Programme and under the Groundwater and Geochemistry Research Programme (P1-0020).

3. Improved imaging of Late Miocene (Messinian) to Plio-Quaternary salt structures in the central Algerian basin

Authors: Simon Blondel[1,2], Massimo Bellucci[3,4,2], Sian Evans[5], Anna Del Ben[2], Angelo Camerlenghi[1]

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Keywords: Messinian, salt tectonic, Algerian Basin, Seismic, contractional salt tectonic system.

Abstract

The western Algerian basin is a deep-water under-explored basin generally considered as a Miocene oceanic back-arc basin. It is underlain by a young (16–30 Ma) and warm lithosphere (average heat flow of 94 ± 13 mW/m2) and filled-up with up to 3 kilometres of Miocene to recent sediments including a thick layer of mobile Messinian evaporites. Heat flow data collected during the MedSalt and WestMedFlux cruises in 2015 and 2016 show an important heat flow variability on the basin-scale, but also locally on the margins. This high variability is thought to be caused by (i) an active fluid circulation in the sediments associated to the widespread Plio-Pleistocene volcanism and (ii) local "chimney effect" above salt structures that are draining upward the heat because of the high thermal conductivity of the salt. Mapping the geometry of salt and basement structures and understand their kinematics can lower uncertainties of heat flow distribution models. Salt structures of the Algerian basin have been previously interpreted as gravity-driven, with salt detachment and downslope basinward translation as a consequence of margin uplift and tilting. However, the southern margin of the basin is actively being inverting, with an estimated shortening of 1.6-2.7 mm/yr accommodated by the Algerian basin induced by the northwestward motion of the African plate, which should have influenced the salt deformation. Yet, only studies of the southern margin, where tectonic is already thick-skinned, have evidenced contractional salt-tectonic. In this study, we use newly re-processed 2D multichannel seismic data to identify, classify and map salt structures throughout the whole western Algerian basin. Based on our results, we describe a basinward evolution of salt structures, with salt pillows and anticlines along the proximal Balearic ramp, versus salt stocks and walls, and even allochtonous salt sheets at the distal part of the basin near the Algerian margin. We describe most structures as resulting from active shortening and diapirism, with locally passive and reactive diapirism along the Balearic margin. We re-interpret the western Algerian salt system as contractional, deforming by response to the N-NW regional shortening induced by the motion of the African plate. More locally the salt structures can be strongly influenced by the overburden thickness and the base relief, which could be quickly steepening on the Balearic side as a result of the basin subsidence, and rising topographic highs.

Acknowledgement

Shearwater Geoservices for providing the REVEAL software and Schlumberger for providing the Petrel software.

4. A new approach to the evaluation of contact thermal resistance at soil-structure interfaces

Authors: João Diogo Figueira[1], Peter Bourne-Webb[2], Teresa Bodas Freitas[2]

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Keywords: Shallow Geothermal Energy, Energy Geostructure, Contact Thermal Resistance, Heat Transfer, Laboratory Testing.

Abstract

Considering the need to reduce our dependence on unsustainable energy sources and reducing the carbon footprint associated with building climate control, shallow geothermal energy represents an attractive sustainable technology for providing renewable heating and cooling. The temperature field generated around ground-coupled heat exchangers, and thus their energy efficiency, fundamentally depends on the heat transfer mechanism and the thermal properties of the materials involved. While the thermal properties of materials that make up the system can be defined with some certainty, little is known about the impact of contact thermal resistance at the soil-structure interface. Contact thermal resistance (CTR) will reduce heat exchange efficiency and increase mechanical impacts associated with temperature changes within energy geo-structures. This paper describes a laboratory test method to quantify the CTR of soil-concrete interfaces. The methodology is first evaluated using numerical analysis, and then validated against a test using a limestone aggregate concrete and fine, silica sand at differing levels of compaction. This method recognizes that lateral heat losses are inevitable and demonstrates numerically that a better evaluation of the geo-CTR can be made if the heat flow is measured directly on the interface. The results show that the geo-CTR is sensitive to the density of the soil but its value is lower than the values suggested in other studies.

Acknowledgement

This work was initially developed within the scope of the research grant UID/ECI/04625/2013 financed by CERIS (Civil Engineering Research and Innovation for Sustainability), and continued under the PhD program of the first author (SFRH/BD/128845/2017) and the DEEPCOOL research project (PTDC/ECI-EGC/29083/2017) both funded by the Foundation for Science and Technology (FCT). The authors are grateful for the financial support of the two institutions.

5. Interaction between surface water and groundwater

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Keywords: surface water-groundwater interaction, flow measurements, ADCP StreamPro.

Abstract

When and how water exchange occurs between a river and an aquifer is still poorly understood and researched in many areas around the world, especially in complex karst areas. The relationship between surface water and groundwater is important for the proper management of water resources and their effective protection.

In general, the interaction between a river and an aquifer can take place in three ways (1) the river obtains water from groundwater, (2) the river loses water into groundwater, or (3) the river obtains water in certain parts, and in some it loses or the same part loses and gains at different times. The direction of water flow between surface and groundwater depends on: (1) the distribution and magnitude of permeability in the river channel and riparian sediments, (2) the relationship between river water level and groundwater level, and (3) the geometry and location of the river channel.

As part of our research, we will determine the amount of surface water infiltration into groundwater based on multiple flow measurements on several sections of the river. The StreamPro Acoustic Doppler Current Profiler (ADCP) with associated WinRiver II software will be used for flow measurements. Flow measurements are carried out by placing two ropes on which the ADCP is attached on selected measuring sections, from one bank of the river to the other. When the ADCP moves slowly, evenly across the river in both directions, it records the exact velocity flow profile from the surface to the bottom of the profile at regular time intervals. During the measurement, the collected data is transmitted to a laptop, where WinRiver II processes, displays and stores it. Data on the measured flow, the distribution of the velocity in the cross-section and the shape of the measuring cross-section are already available during the measurements.

6. Chemical geothermometers and geothermometrical modelling applied to hydrothermal systems

Authors: Jon Jiménez[1], Luis Francisco Auqué[1], María José Gimeno[1]

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Keywords: Chemical geothermometers, geothermometrical modelling, geothermal exploration, hydrothermal solutions.

Abstract

Chemical geothermometers together with geothermometrical modelling are widely used in geothermal exploration to determine the temperature, pH and mineral equilibrium conditions in groundwater reservoirs, throughout the analytical data of water samples from springs or wells. Classical chemical geothermometers consist of experimentally calibrated equations that enable to determine the temperature in the reservoir throughout the concentrations measured in the springs. These geothermometers are based on the assumption that the concentrations involved have not changed significantly during the ascent of water. However, in certain geological settings, re-equilibrium can occur, and processes such as CO_2 input or degassing can drastically affect the reactivity of hydrothermal solutions. Under these conditions, some of the chemical geothermometers are not applicable, so that the use of geothermometrical modelling is essential, since it enables to consider and quantify these secondary processes. Besides, the prior characterization of the geological conditions is necessary to foresee the incidence of the processes determining the applicability of geothermometers. In this work, we apply the explained geothermometrical techniques to two hydrothermal systems, Luchon (France) and Lanjarón (Spain), affected by processes such as water mixing, re-equilibrium with calcite and kaolinite, and CO_2 exchange. The temperatures obtained were 113 ± 4 °C and 116 ± 6 °C, respectively.

Acknowledgements

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7. Geothermal potentiality of the teritory of the Republic of Srpska

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Keywords: geothermal potential, hydrogeothermal systems, Republic of Srpska.

Abstract

One of the most use renewable energy sources worldwide is geothermal energy. It represents heat, originated by natural processes happen in the Earth interior. The hot springs phenomena are the most frequent natural manifestation of geothermal activity. During the last few decades, significant attention has been directed to production of the geothermal energy, especially for electricity production, as a kind of the relatively clear and renewable energy. It is the reason why The International Energy Agency (IEA) insists on enhancement of this one type of the energy resource. The focus is on the hydrogeothermal systems.

The knowledge obtained during researches in the last forty years of the 20th Century and during the 21st Century obviously indicates the justification of the further investments in the research of this kind of energy resource. The territory of the Republic of Srpska is characterised with very complex geological and tectonic setting. Its territory comprises the central part of the Dinarides orogene system and in the north the smaller part of the south edge of the Pannonian Basin.

In the hydrogeological sense it is possible to define a few different regions. Each of these regions characterises with specific geothermal characteristics. The geothermal gradient, as one of the main geothermal parameters, generally increases from the south to the north of the territory of the Republic of Srpska. The biggest value of geothermal gradient is registered north of Bijeljina. The maximum convective value is higher. The heat flow shows similar spatial distribution like the geothermal gradient. Most important proved hydrothermal resources are situated within the large artesian basins in the north part of the Republic of Srpska. The results of the deep drillings in Semberija and Posavina indicate that rocks of the Mesozoic age (the Cretaceous and the Triassic limestones) represent very important aquifers of thermal (Semberija) and thermo mineral water (Domaljevac, the Federation of Bosnia and Herzegovina, near the entity border).

Currently use of thermal and thermo-mineral water is modest in comparison with available reserves. This kind of renewable energy resource, highly ecologically recommended, must be considered more seriously in the future in the Republic of Srpska. Furthermore, it must be in appropriate manner put into the energy strategic documents.

8. Suitable site selection for geothermal energy power plants by using GIS-AHP under physical, environmental and technical impacts in Turkey

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Keywords: Suitable Site Selection, Geothermal Energy, Geographical Information Systems, Analytic Hierarchy Method.

Abstract

Renewable energy systems gain reputation due to their environmentally friendly, profitable and sustainability aspects. Geothermal energy has major benefits providing for an increasing energy demand while tackling climate change problems. Detailed planning processes such as physical, environmental, technical are critical and essential for the development of geothermal energy installed capacity. To obtain the detail analysis results, the combination of geographical information systems (GIS) and analytic hierarchy method (AHP) are used intensively. The objective of present study is to determine the most appropriate site with comprehensive feasibility map layers of a desired geothermal power plants in Turkey which has 1.7 GW installed capacity. To obtain the visual analysis results, Copernicus land monitoring (CLC), earth data, Kandilli earthquake center (KOERI) were employed for data acquisition. For determination suitable regions with the combination method, 3 main criteria physical (C1), environmental (C2), technical (C3) and 12 sub-criteria have determined until now. Furthermore, the buffer zones of criterion were determined based on literature. In the scope of present study, the number of criteria and data sources can be expanded according to experts who study on geothermal energy. Also, to calculate the importance value of determined criterion, experts' opinions will take, and analytic hierarchy method will be performed. Finally, the most appropriate regions will determine in study area and the most effective criteria will calculated. Results will be compared with the existing geothermal power plants. The proposed method in present study will provide information to energy planners, investors, and policy makers about installation of geothermal power plants.

9. Occurrence of mineral and thermal waters in the Kłodzko area, SW Poland

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Keywords: Kłodzko area, thermal waters, mineral waters, groundwater temperature, groundwater chemistry.

Abstract

The Kłodzko area is located in the Lower Silesian in the Sudety Mts. which gelogy is complex and consists mainly of the Variscan granitoids. In the central part of the region a graben filled with the Cretaceous deposits occurs. Hydrogeological conditions strongly reflect local geology. The complicated system of faults significantly facilitates water flow towards the surface. The deep fractures fostered the intensive volcanism and the influx of CO_2. For those reasons the region is well known for numerous mineral, medicinal and thermal waters and resorts, such as: Długopole, Duszniki, Kudowa, Lądek, Polanica and the smaller ones. At some locations mixing of fresh and mineral waters happens. In the region the following major chemical types of groundwater appear:

- Lądek Spa: HCO_3-F-Na, Rn, H_2S; TDS 0,16 – 0,27 (g/dm^3)
- Polanica Spa : HCO_3-Ca, Fe, CO_2; TDS 0,9 – 2,7 (g/dm^3)
- Długopole Spa: HCO_3-Ca-Mg-Na, Fe, CO_2, Rn; TDS 0,9 – 1,5 (g/dm^3)
- Duszniki Spa: HCO_3-Ca-Mg, HCO_3-Ca-Na-(Mg), Fe, CO_2, Rn; TDS 0,2 – 2,7 (g/dm^3)
- Kudowa Spa: HCO_3-Na-Ca, Fe, CO_2, Rn, H_2S, B; TDS 1,3 – 6,0 (g/dm^3).

The thermal groundwaters are known from Lądek and Duszniki Spas, however those are used in Lądek Spa only and for present their application is limited to balneology. For the L-2 borehole water temperature at the outflow reaches up to 45°C, while for the LZT-1 borehole it is 37.4°C. In addition several natural springs in the area show temperature as high as 28°C as well.

Acknowledgement

I am really grateful to Karol Zawistowski, the Director of Lower Silesian Branch PGI-NRI, for opportunity of participation in the Geothermal-DHC summer school.

I would also like to extend my gratitude to Maciej R. Kłonowski, the hydrogeologist at PGI-NRI, for valuable advice and unparalleled support in preparing myself for that event.

10. Women in Geothermal: the Importance of Gender Equity in the Geothermal Industry

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Keywords: geothermal, women, men, gender, WING

Abstract

The mission of the non-profit organization Women in Geothermal (WING) is to promote the education, professional development, and advancement of women in the geothermal community. Its long-term vision is to eventually be unnecessary organization, when special groups are no longer needed to advocate for gender equity. There is a growing appreciation for the quantifyable advantages to gender diversity in the workplace, both financial and innovation. Historically, women in the geothermal industry and academia are greatly under represented both as board members, at conferences, and as published authors. During the pandemic, WING has adapted through virtual events and increased social media presence and online events , such as monthly presentations by each country ambassador to provide updates and share ideas.

Acknowledgement

Karen Christopherson, Bridget Ayling, Kelly Blake

11. Use of the geothermal energy in households and its impact on the environment

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Keywords: geothermal, household, heating, cooling, groundwater.

Abstract

Geothermal energy is not a new discovery, although it is still not used as much as wind, solar, biomass and hydropower. Some countries such as Germany, have been already using geothermal installations and heating pumps, which had a total installed thermal capacity of about 2500 MW in 2010. Nowadays, due to seeking of better energy efficiency for financial benefit and environmentally friendly life, homeowners from all over the world are trying to use all the possible sources of energy from their surroundings. It also promises its users a certain independence from energy imports, mainly consisted of oil and gas. As the geothermal technology is exponentially developing, it is already possible to use the low enthalpy geothermal energy from the fossil resources with temperatures ranging from 40 °C to 60 °C. However, the use of geothermal energy is not flawless. Firstly, it mostly depends on the subterranean geology, therefore it cannot be used everywhere. Moreover, although it is an inexpensive source of energy once when the well is drilled and the pump installed, the drilling process can cause an increase in predicted costs due to unforeseen geological conditions. Secondly, increasing use of the geothermal energy in everyday life has risen questions about its impact on the groundwater temperature. However, geothermal energy doubtlessly plays a major role in the energy supply of countries with favourable geological setting, such as Iceland. The emphasis on the geothermal energy is also given in parts of the world with abandoned flooded mines that could provide enough heat for local households.

12. Ultra-deep geothermics in po plain: Geological model of exploitation in the Malossa area (BG, Italy)

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Keywords: Geothermal energy, hydrocarbons, 3D model, subsurface.

Abstract

Ultra-deep geothermal energy is increasingly an interesting and innovative possibility, as it is considered a sustainable source for electricity production. This geological study is developed by using the public subsurface data derived from the hydrocarbon exploration. We created a 3D subsurface model of an area in the northern area of the Po Plain, using the well dataset of Malossa Field (Bergamo, Italy) finalized to evaluate the deep medium-high enthalpy geothermal potential.The best indication is the high temperature (> 165°C) at 5 km in depth. The formation targets for aquifer exploitation are: Maiolica Fm, Medolo Fm, Zandobbio Fm and Dolomia Principale Fm. The porosity was computed from resistivity logs by using Archie equation. We also estimated the Kh, including fracture permeability by using production tests, averaged to 4 mD for the entire open-hole section. The peculiarity of this old oil field is a strong overpressure, that in the order 15000 psi to the surface at 5000 meters of depth, while the beginning of abnormal geobaric gradient is after 4000 meters. Production test showed very good productivity, but the important data is 943 m^3/d of water (well #2). These data have been modeled by assuming a Geothermal Doublet System by Doublet Caculator 1D (TNO). The computed results show a potential of 3,5 MW of geothermal energy. Finally, thanks to the 3D model, we have identified the best area for exploiting the aquifer with a Doublet System.

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13. Multidisciplinary Approach to Conceptual Modelling of Hydrothermal Systems in Croatia

Authors: Mirja Pavić[1], Staša Borović[1], Marco Pola[1], Maja Briški[1], Ivan Kosović[1], Tihomir Frangen[1], Kosta Urumović[1], Bojan Matoš[2], Ivica Pavičić[2]

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Keywords: hydrothermal system, natural thermal spring, multidisciplinary research, Croatia.

Abstract

With temperatures up to 65 °C, natural thermal water springs emerge at two dozen localities in the Pannonian part of Croatia, which has favourable geothermal characteristics. These waters have been used for millennia, and in the past fifty years they were a basis for the development of tourism and health care centres. The increase in thermal water utilisation is foreseen by many European and Croatian strategic documents regulating energetics, tourism and environmental protection. Thus, Croatian geological survey wishes to establish a multidisciplinary group for hydrothermal systems (HTS) research, contributing to responsible geothermal development in our country through a 5-year research project HyTheC. Thermal springs are generally part of intermediate scale hydrothermal systems, including recharge areas in the mountainous hinterlands and geothermal aquifers mostly hosted in Mesozoic carbonate rocks. A system-level understanding of the factors controlling these resources is necessary for their sustainable utilization. A multidisciplinary approach is used to characterize Daruvar, Hrvatsko zagorje, and Topusko HTSs in NE Croatia. Structural, hydrogeological, geothermal, hydrogeochemical, geophysical investigations, and remote sensing will be used to construct conceptual models. Their physical validity will be tested through numerical simulations supported by 3D geological reconstructions and local hydrogeological and thermal parameterisation of the hydrostratigraphic units.

Acknowledgment

Croatian Science Foundation is funding the Installation Research project HyTheC (UIP-2019-04-1218).

14. An Introduction to Geothermal Energy Geostructures

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Keywords: Geothermal Energy Pile, Thermal Pile, Energy Geostructures, Shallow Geothermal Energy.

Abstract

Although the first use of geothermal energy dates back to centuries ago, it has gained popularity in many countries in recent years. Geothermal energy has three main applications, including high, medium, and low-temperature applications. The low-temperature application is used for heating and cooling residential buildings using the stable ground temperature of the ground in shallow depths, which is no more than 10-20 ℃. Energy geostructures and borehole heat exchangers are utilized as a novel method of extracting heat from shallow ground energy sources. Energy geostructures technology links the structural role of underground structures such as pile foundations, tunnels, and walls with the energy supply. This technology can be used in urban or rural zones and provide cheap and renewable energy for the heating and cooling of residential buildings. The energy geostructure system consists of closed or open loops of liquid circulating through polyethylene pipes installed inside concrete or steel energy piles, energy tunnels, and energy walls. The circulating liquid in the tubes is either water or a water-based liquid that has antifreeze ingredients. In this presentation, a brief introduction to Geothermal Energy Geostructures is presented.

15. Hydrogeological analysis of a low temperature geothermal system in the Julian Alps, Slovenia

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Keywords: thermal spring, low temperature, carbonates, regional groundwater flow, hydrogeochemistry.

Abstract

This study is focused on the low temperature geothermal system in the karstic-fissured aquifer located in the eastern Julian Alps, in the vicinity of Bled Lake (Slovenia). The occurrence of such systems is common in the Alps and is defined by a number of specific hydrogeological boundary conditions such as: large vertical component of fluid flow, relatively large elevation differences between thermal water recharge and discharge areas, and, concentrated ascending of heated water to the surface. Such systems are directly dependent on topography and differences in hydraulic potential and are most commonly found in mountain ranges. The main driving force in topography-driven circulation is gravity, referred to as gravity-driven regional groundwater flow. In Bled, thermal water with a temperature between 19 and 23 ^{o}C from a thermal spring and two wells has been used for many years. Based on application of field methods, laboratory methods, statistical methods and mathematical modeling of groundwater flow and heat transfer, some specific questions are answered, such as: where thermal water recharge area is located, through which rocks and permeable zones the water percolates and how deep it is, which is the heat source, how long the water flows from the infiltration area to a thermal well or spring and whether it is mixed with other components during that travel, what is the available amount of thermal water and how the water resource is protected from pollution.

Acknowledgement

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16. Modeling borehole heat exchangers fields under uncertainty

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Keywords: ground source heat pump system, borehole heat exchangers, heat transport, shallow geothermal energy.

Abstract

Ground source heat pump (GSHP) systems are standard applications of low-enthalpy geothermal energy utilization. For supply of greater energy demands, large-scale systems with multiple borehole heat exchangers (BHEs) are applied to access substantial volumes of the shallow ground. As these technologies are operated for decades, and ground heat transport processes are very slow, extra caution has to be taken for avoiding long-term degradation of both the ground and of system performance, which can hardly be restored in the short-run.

In this presentation, the main concept of GSHP and BHE as the most common approach in shallow geothermal systems will be explained. Afterward, some of the prominent analytical models and their considered input parameters will be reviewed to demonstrate how complex underground heterogeneity, shallow groundwater flow, and temperature conditions can influence BHE design and operation.

Furthermore, the descriptive uncertainty regarding the conditions in the ground is accompanied by the predictive uncertainty in the energy demands that are often only roughly known and highly variable in time will be discussed to emphasize the necessity of further researches to look for efficient tools to quantify these uncertainties.

In the final stage, we will go one step further and try to propose the idea that how to find optimal system solutions for long-term operation even when relevant conditions are insecure.

17. Funding opportunities for the deployment of geothermal energy in Croatia

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Keywords: geothermal, deep, shallow, database, capacities, documentation, funding opportunities, financial mechanisms, grants

Abstract

Within the Republic of Croatia, the geothermal potential was indicated by more than 25 natural thermal springs and by more than 4,000 deep wells drilled during oil and gas explorations undertaken in the second part of the 20th century. With the development of renewable energy technologies, this potential is increasingly becoming more interesting, and there are fewer and no justifiable reasons not to harness it. Lack of funding opportunities was the main barrier for further development of geothermal energy sector in Croatia.

The new funding opportunities for the deployment of the geothermal energy resources are being offered by the Energy and Climate Change Programme (EACC) co-funded by the European Economic Area financial mechanism. At the moment four calls for proposals are being prepared in the field of geothermal energy: development of technical documentation for geothermal energy, increased geothermal energy production capacities, development of shallow geothermal energy database and deep geothermal energy database.

The first call for proposals that is just about to be published is the call that shall support projects which are planning to develop the technical documentation for geothermal energy. Applicants may apply for funding for studies and technical documentation such as concept, pre-feasibility, feasibility and front-end-engineering and design (FEED) required to mature projects necessary to prepare a potential future investment decision.

18. Satellite based geothermal potential determination

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Keywords: satellite, remote sensing, geothermal potential.

Abstract

Different geothermal resources accross the world are increasingly being used for meeting energy demands of various societal sectors. Exploitation of these resources has led to increased research focus on prospecting, detection, and analysis techniques for scientific and engineering purposes. Among them, remote sensing based on Earth observing satellite records presents an example of tools for initial reconnaissance stage of exploration of a geothermal system or reservoir which can support the traditional exploration composed of hydrogeological, geochemical, geophysical and modelling methods, particularly in the large-scale classification of areas by their geothermal potential exploitation in order to target the regions of interest with subsequent research stages.

The reasons for the current lack of widespread use of these methods are mainly due to the common disadvantages of most remote sensing methods which may suffer from spectral, temporal and spatial resolution limitations as well as the low signal-to-noise ratios and the lack of adequate correction techniques used for removing the noise from the data. Nonetheless, so far measurements of surface temperature anomalies and variations, surface deformations connected to geothermal activity, surface features, such as hot springs, and mineralogical mapping to identify areas containing minerals connected to geothermal activity have all been performed by using either thermal infrared radiation, optical sensors, multispectral or hyperspectral remote sensing, SAR interferometry and even vegetation coverage detection.

Recent decades have also seen large improvements in Earth observing systems of measurements as far as their collection and availability of their data go. Additionally, data analyses are being performed with novel machine learning techniques which can offer more objective and economical alternatives to previously used approaches. Time series analyses based on the cyclical satellite measurements present an upgrade of the point-in-time geospatial observations and a research prospect to measure and monitor the natural and developed geothermal resources and their inherent dynamic components.

19. Thermal effects on the geomechanical properties of the fine-grained soil

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Keywords: thermal conductivity, heat capacity, thermal diffusivity, geomechanical properties, fine-grained soils.

Abstract

Since dewatering of the fine-grained soils with very high moisture due their low bearing capacity is still a major challenge in geotechnique, the selection of an appropriate method for their improvement is required. From geotechnical and also environmental perspectives, utilization of these sediments namely entails issues related to handling and storage before they can be used for a specific purpose. In geomechanics we are developing an accelerate dewatering of fine-grained soils with a method which basis on established electric field. The current injected results also in soil heating, which can cause changes in the engineering properties of the soil.

For better understanding the soil behaviour under the heat, it is crucial to get a better prospect about the interaction between heat and flow fields in the subsurface and a prospect of which methods would be appropriate to measure thermal properties of soil (thermal conductivity, heat capacity, specific heat and thermal diffusivity). Because soils as well as the slurry sediment consist of different minerals, the influence of the contained minerals to thermal properties would also lead to better understanding of induced heat flow and its influence to the soil. With a systematic testing of different types of pure clay minerals it will be possible to define the effect of dewatering under the established electric field and the effect of caused heating. Regarding to the results, the soil types that can be effectively improved with a method which basis on established electric field, will be define.

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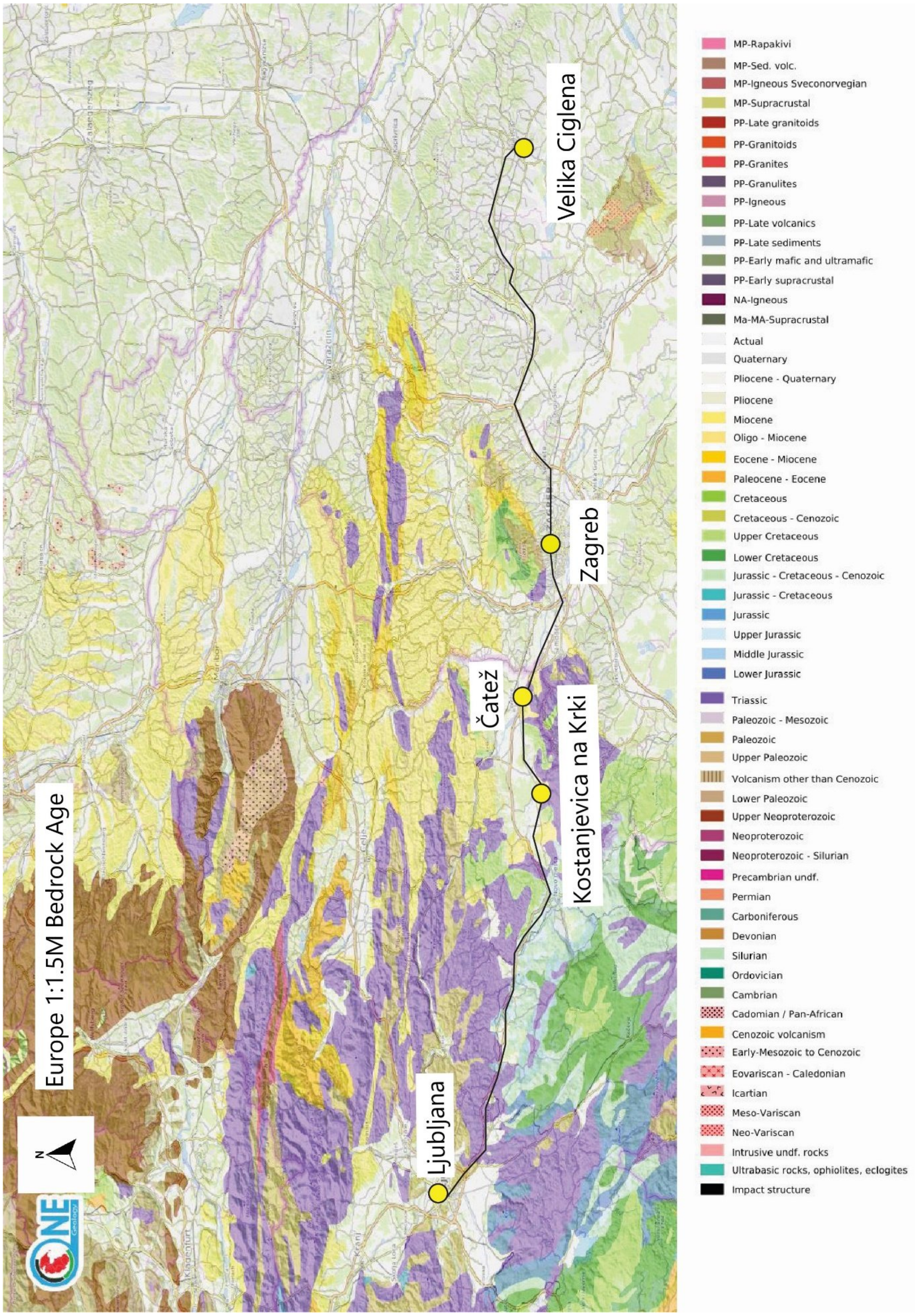
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