D.5.3.1. Summary report on the evaluation case studies

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Contents

Introduction

Since one of the aims of the DARLINGe project is to encourage utilization of deep geothermal resources, 15 national case studies of utilisations and aquifer types were selected to emphasis the good practice, but also the bottlenecks (Fig. 1). The examples are from all 6 project countries: Hungary, Slovenia, Croatia, Serbia, Bosnia and Herzegovina and Romania and they were chosen from data gathered for the current status for thermal water uses (D 5.2.1) (Table 1.1). There are 5 case studies from Bosnia and Herzegovina (Domaljevac, Slatina, Kamuž, Gračanica and Gradačac), 2 from Croatia (Bošnjaci and Zagreb), 3 from Hungary (Szentlőrinc, Mórahalom and Szeged), 2 from Serbia (Bogatić and Banja Kanjiža), 2 from Slovenia (Lendava and Moravske Toplice) and 1 from Romania (Dorobanti). In all these national case studies BF (Basin Fill) and BM (Basement) geothermal aquifers were presented as well as different types of utilizations (such as agricultural – greenhouse heating; industrial applications; district heating-, individual space heating; balneological and recreation purposes; etc.). Nevertheless some bottlenecks can be also detected from these examples: lack of reinjection; release of thermal waste water into the surface recipient; amount of waste water is larger than natural minimum flow rate of the recipient; multiple users on one well.

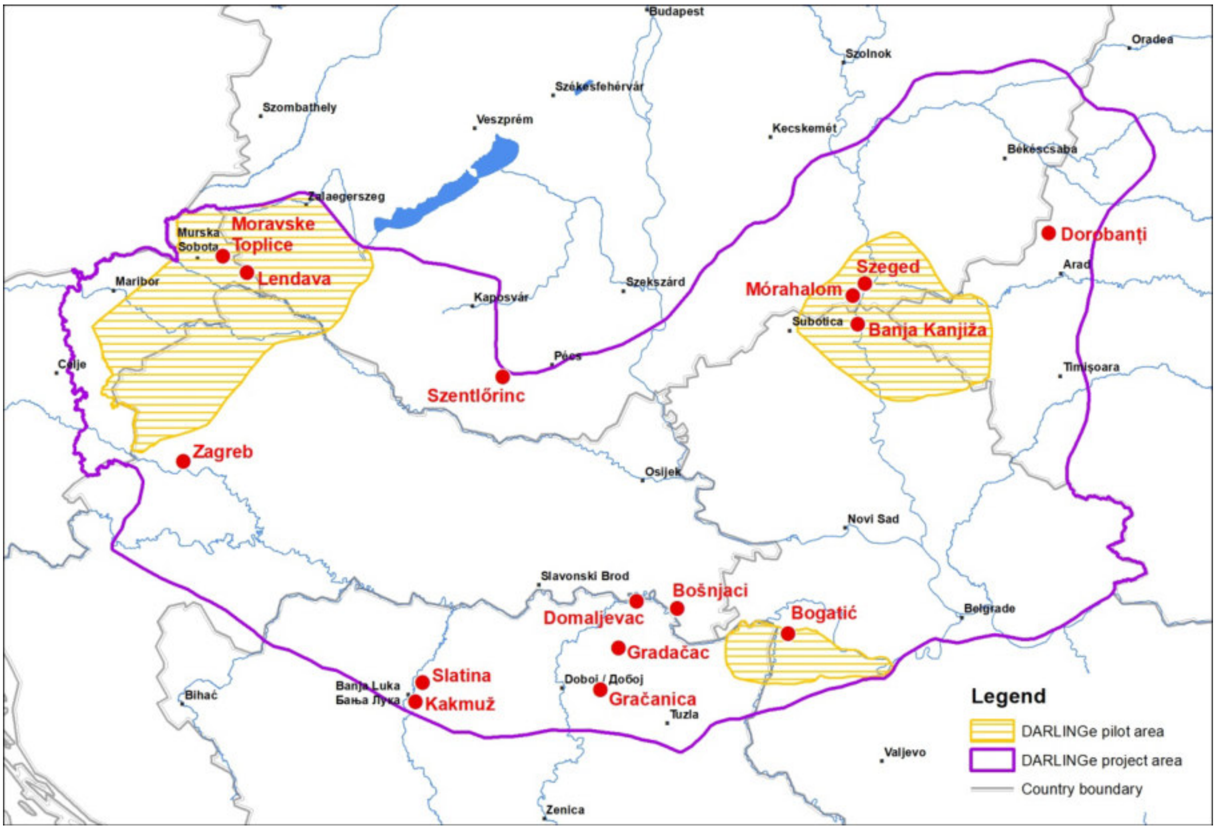


Fig. 1: Location of the case studies

Table 1.1 Summary of the national case studies

	Bosnia and Herzegovina (BiH)							Croatia (HR)		Hungary (HU)					Serbia (SRB)		Slovenia (SLO)		Romania (RO)	
Name of location	Domaljevac	Slatina	Kamuž	Gračanica	Gradačac			Bošnjaci	Zagreb	Szentlőrinc	Mórahalom town			Szeged town	Bogatić	Banja Kanjiža	Lendava	Moravske Toplice	Dorobanti locality, Arad County	
User		Zavod za fizikalnu medicinu i rehabilitaciju Dr Miroslav Zotović	TGP ad Kakmuž	Terme Gračanica & Messer BH gass	Spa Ilidža Gradačac	Mliječna industrija 99	Swity	Ruris d.o.o	Mladost sport center	entlőrinc to	The system of the Szent Erzsébet Spa of Mórahalom	The Geothermal District Heating system of Mórahalom	The Norwegian Geothermal Public Utility system	University of Szeged	Municipality of Bogatić	Banja Kanjiža spa	Petrol Geot	Terme 3000	Agricola Agrador; Operator: S.C. Ecologica Arser	„Gradina Termala"
Type of aquifer	BM: Triassic carbonate, Badenian and Sarmatian limestones	BM: Triassic limestone	BM: Triassic limestone	BM: Triassic limestone	Badenian and Sarmatian limestones			BF: Upper Panonian sand (Vera fm)	BM: Triassic carbonate, Badenian and Sarmatian limestones (Prečec fm)	BM: metamorphic rocks of Paleozoic age, mainly gneisse	BF: Upper Panonian sandstones			BF: Upper Panonian sandstones	BM: Triassic carbonate	BF: Upper Panonian sediments	BF: Upper Pannonian sandy aqufer (Mura-Ujfalu Fm.)	BF: Upper Pannonian sandy aqufer (Mura-Ujfalu Fm.); Badenian sandstone	BF: Upper Pannonian sandstone	
Production Well name	Do-1	SB-1, SB-4, SL-1	GB-6, TGP-1, TGP-2	PEB-4	B-6	BZ-1	EB-1	Boš-1	Mla-3	K-22	B-40, B-45	B-45	K-43	860, 1551, 1703, 1895, 1950, 2000	BB-1, BB-2	Kz-1/H, Kz-2/H, Kz-3/H	Le-2g	Mt-1, Mt-4, Mt-5, Mt-6, Mt-7	1655 and 1613 only in the winter time	1655
Water temperature (oC)	96	41-44	39	37,7	30	30	30	65	78-80	77-85	60-62	62	60-62	92-95	75-78	45-72	66	60-75	60	60
Type of utilization	heating of greehouses	Cascade system (heating, balneology, recreation)	extraction of CO2	for swiming pools and extraction of CO2	Balneology and space heating in spa	Industrial processes in dairy industry	Fruit and vegetable processing industry	Greenhouses (tomatoes)	cascade system (swiming pool, space heating, cooling)	for district heating of the town	heating – balneology	heating - domestic hot water	heating - domestic hot water	for district heating of the University	distric heating - project in development	balneology , space heating and cooling and as domestic warm water	cascade use: heating of public buildings, apartments and deicing of pavement, innovative heat pump	cascade system: space heating; indirect pool and sanitary water heating, air heating; tomato greenhous	heating of 6 ha of greenhouses and fish farm	swimming pools
Waste water treatment	released into surface recipient	released into surface recipient	released into surface recipient	released into surface recipient (Spreča river)	released into surface recipient	released into surface recipient	released into surface recipient	released into surface recipient (melioration channel)	rejection in	rejection in	rejection into B-46	rejection into VS-1	rejection into K-44	rejection into 1750, 1300, 1700	released into surface recipient	released into surface recipient	rejection in	released to channel; reinjection around 1993		The water released from the swimming pools is treated for adjusting the pH in order to be used at the fish farm

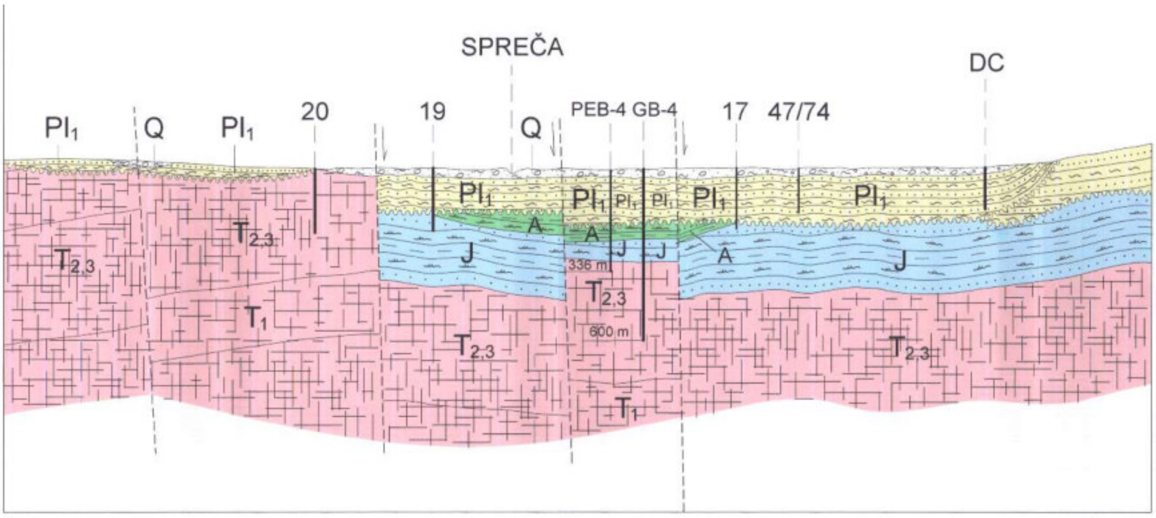
2. Bosnia and Herzegovina

2.1. Domaljevac

At the Domaljevac area vegetable production in greenhouses heated by geothermal energy occurred for a many years, but production stopped 5-6 years ago. Since than geothermal energy is not utilized. The highest temperature of the artesian water in Bosnia and Herzegovina is registered at this area at the borehole Do-1 (outflow temperature at wellhead is 96 °C). The depth of the well is 1275,4 m, and mineralization of water is 15.4 g/l. The borehole is drilled into karst aquifer – limestones (Badenian, Sarmatian and Triassic age). When the aquifer was utilized the water was not reinjected, but released into surface recipient.

2.2. Gračanica

At the Gračanica area the karstic (Triassic limestone) geothermal aquifer is utilized (Fig. 2). The aquifer is tapped by the well PEB-4, which is shared by two companies: Terme – Gračanica and Messer BH gas. The water temperature is 37.7 °C and water contains high amount of the CO_2 gas. In the last few years, during the summer periods the water from the well is utilized by a cascade system; swimming pools were completed in 2017 and since than it operates continuously. Firstly CO2 is extracted from the water (by Messer BH gas) (Fig. 3) and than water is used in swimming pools at Terme – Gračanica (Fig. 4). CO_2 is of high quality and it is exported to Germany for utilisation in Coca-Cola company (user: Messer BH gas). There are no reinjection wells.



Q - Quaternary, Pl_1 - sand, clay, A – amphibolite, J – sandstone, claystone, chert , volcanic-sedimentary series, $T_{2,3}$ – limestone, T_1- clastic rocks

Fig. 2: Geological cross section at the Gračanica area (Miošić 1984 and Jašarević et al., 2009)

Fig. 3: Company Messer BH gas d.o.o - subsidiary Sočkovac

Fig. 4: Swimming pool in Ćelahuša and water of well PEB-4

In addition to the use of PEB-4 well, this reservoir is also exploited by another 3-4 wells in the Republic of Srpska (well MS-1 Messer and wells of company Tehnogas) for extraction of CO_2. At this reservoir both good and bad practice of using of thermomineral waters is present at the same time. Good practice is that it is recognized wellbeing value of these waters, and that waters are intensively investigated and extensively used. The bad practice applied on this reservoir is that thermomineral water with temperature of 37 - 38 °C and quantity greater than 200 L/s discharges into the Spreča River. Greater output than input of waters resulted in a large drawdown and losing of natural outflows in wells and existing interference between wells, so now all wells are used by pumping. It is necessary to design the optimal use of water and include drilling reinjection wells.

2.3. Gradačac

At the Gradačac area a karstic aquifer (Badenian and Sarmatian limestone) is utilized by several wells (B-6, BZ-1 and EB-1) and several users (Spa Ilidža Gradačac, Mliječna industrija 99 and Swity). The thermal water has a temperature of 30 oC, while some thermomineral waters with temperature between 28.3-29.8 °C also discharge.

At Spa Ilidža Gradačac the water is used from the well B-6 firstly for swimming pools and bathtub, and afterwards it is used for space heating in Spa Ilidža Gradačac. The well BZ-1 is utilized in dairy industry (Mliječna industrija 99) and the well EB-1 is utilized in fruit and vegetable processing industry (Swity).

At this location both good and bad practice of using of thermal and thermomineral waters is present at the same time. Good practice is that thermomineral water has been investigated for a long time (since 1886) and used in balneology, so the Spa Ilidža Gradačac is recognized as a good treatment centre, and nowadays works at full capacity using thermomineral water in balneology, recreation and for space heating. Bad practice is that recent investigations for water supply of industrial facilities are carried out without any projects; most users use the water without the necessary permits and adequate measures to protect the reservoir's quantity, which leads to a continuous drop in the level of thermal and thermomineral waters in the karst aquifer, and reservoirs become potentially threatened by anthropogenic pollution.

2.4. Slatina

The rehabilitation centre distanced just 8 km from the capital of the Republic of Srpska, Banja Luka is recognised as the one of the best regional centres for bone traumas. First wells were drilled in the earlier 80's, but the currently operating project has a full valorisation of the hydrothermal potential. The capacities of the centre increased significantly and heating based on thermal water is introduced in each building. The water is further used in balneology treatment and in one restricted area for recreation. There are also plans to use this water for the agriculture production and extension of the spa centre in the future. There are also plans for new boreholes. Currently, there are three active wells (SB-1, SB-4, SL-1). Each well is equipped with modern measurement devices and a successful monitoring program was established in 2017. Current pumping rate is about 60 L/s (all wells). The weakest point of the system is releasing of the used water into a nearby small surface stream. The management of the centre is very interested in the DARLINGe project, especially activities related to financial supporting mechanisms for geothermal projects.

2.5. Kakmuž

Three active wells (GB-6, TGP-1, TGP-2) are just used for the extraction of CO_2. There is no additional utilisation of water with temperature 39 °C and pumping of 20 - 30 L/s. In the past there was a small recreation centre based on thermal water from the above-mentioned boreholes, but today it is not active. In 2017, some initiatives of the additional utilisation of thermal water were triggered (swimming pool and other recreation activities). After extraction of the gas the water is released into a nearby small surface stream, already very polluted by chemical pollutants from upstream factories.

3. Croatia

3.1. Bošnjaci

The geothermal aquifer of Bošnjaci area is located in the SE part of the Pannonian Basin System, i.e., in the Slavonia-Srijem Depression. In this area very favorable geothermal gradient of 61 °C/km exists (Kolbach & Škrlec, 2012). The water from the well Boš-1 is used for heating greenhouses for the production of tomatoes by hydroponic cultivation (Fig. 5).

Fig. 5: Greenhouse production of tomatoes. (Photo: Ruris)

The main utilized aquifer is Upper Pannonian Županja sandstone (Vera Fm.) with primary porosity (Fig. 6). The well depth is up to 1165 m, a maximum yield is 20 L/s with water temperature 65 °C.

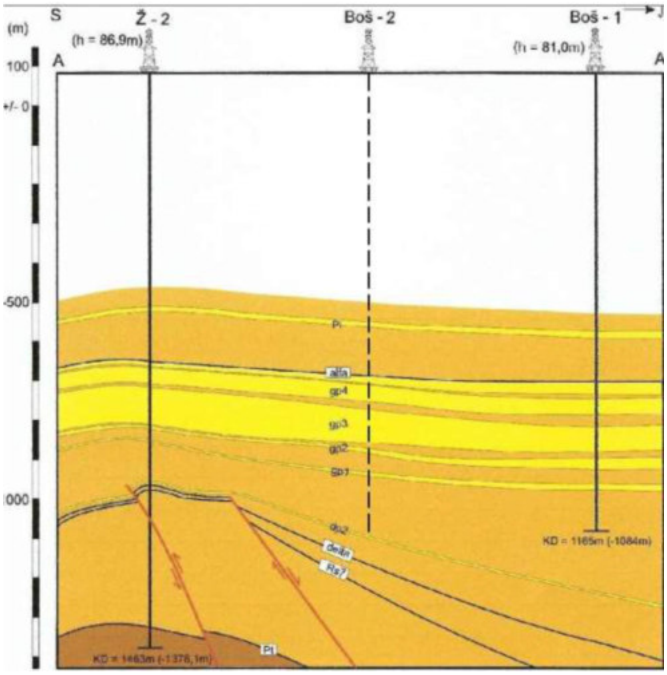


Fig. 6: Geological cross section at the well location based upon drilled boreholes Boš-1 and Ž-2 (Kolbach & Škrlec, 2012)

According to groundwater classification, the, geothermal water is classified as poorly mineralized water, dominated by bicarbonate, chloride and sodium, high quality, non-corrosive and does not contain a large amount of present gases. The cooled geothermal water (30 °C) is discharged into the melioration channel in the vicinity of the well (Fig. 7).

Fig. 7: The discharge of the cooled geothermal water at the vicinity of the well (Photo: T. Bilić)

It is planned in the future to drill another borehole Boš-2 which will be exploitation/rejection well.

3.2. Zagreb – Mladost sport centre (SRC Mladost)

At the Zagreb geothermal field utilization of geothermal energy begun in the 80's for heating purposes of swimming pools in SRC Mladost. Until 1986 sixteen more wells were drilled with the aim to heat various locations at SRC Mladost and University hospital under construction at that time. At SRC Mladost site closed loop technological process (production-injection) is established currently, but with production capability far more than current energy utilization.

SRC Mladost technological system consists of three wells: Mla-1 (monitoring), Mla-2 (injection) and Mla-3 (production) (Table 2). This closed system of production and injection wells satisfies the energy requirements of Sports Park Mladost including heating of swimming pool water and heating the complex building in the winter period.

Table 2: Basic information about wells Mla-1, Mla-2 and Mla-3

Well	Type of well	Depth of well (m)	Open interval (m)
Mla-1	Monitoring	1057.0	911.0 - 1047.0
Mla-2	Injection	911.7	881.4 - 911.7
Mla-3	Production	1362.2	1169.0 - 1362.0

The main aquifer is a massive Triassic dolomite with overlying Sarmatian and Badenian lithothamnium limestones. The water temperature at the wellhead of the borehole Mla-3 is around 78 oC (Fig. 8). High amount of CO2 is present in the water. The borehole Mla-2 at the moment is functioning as a reinjection well, but it can be used as production well (Fig. 9). The thermal water comes to a heat station located under the large winter swimming pool of the SRC Mladost. In this way all the heat losses in the heat station are indirectly used. The thermal water from the Mla-3 well is around 78 °C due to losses of the well about 2 °C at an average exploitation under specific winter conditions.

Fig. 8: Production well Mla-3 (Photo: T. Marković)

Fig. 9: Reinjection well Mla-2 (Photo: D. Šolaja)

Because of high CO2content the heating is conducted via heat exchangers (Fig. 10). The water from borehole Mla-3 is directed onto three lines which contains heat exchangers:

1. The first line goes to a 2 MW heat exchanger (uses 33 % of the total discharge) that transfers the heat to the so-called secondary circuit for heating outdoor facilities (volleyball, table tennis and changing rooms and restaurant). After the exchanger, the thermal water with temperature of 50 - 56 °C goes back to the injection pumps.

2. The second line goes to a 1 MW heat exchanger (uses 17 % of the total discharge) that transfers the heat to secondary circuit which warms the air in the area of the winter pool (ventilation). After the heat exchanger, the thermal water with the temperature of 50 °C goes to the injection pumps.

3. The third line takes about 50 % of the total discharge. This represents a cascaded system. First, a heat exchanger over 0.4 MW power the heat to a secondary circuit for radiators, located in all main and auxiliary winter pool areas (training room, sauna, office, changing rooms). Second, a heat exchanger over 0.4 MW power the heat for the heating water for daily consumption, following that on the 1.8 MW heat exchanger the water for the swimming pool is heated. Then goes to the third heat exchanger that powers the hot water (0.4 MW), fresh water for refilling a swimming pool (0.2 MW) and fresh air for ventilation (0.2 MW).

The utilized water is collected and is taken by pipelines towards the reinjection well. The system is in operation since 1987 (Universiade games).

Fig. 10: Heat exchanger inside the complex of SRC-a Mladost (photo: D. Šolaja).

4. Hungary

4.1. Szentlőrinc

Szentlőrinc geothermal field is located at SW Hungary along the South Mecsek line, which is an E-W to NE-SW oriented deformation zone, where metamorphic rocks of Paleozoic age and sequences of Permian and Mesozoic age juxtaposed to Late Miocene towards south direction (Figs 11, 12). The South Mecsek line has a complex tectonic development (Csontos et al., 2002), presumably the latest right-lateral shear during the late Pannonian gave an indispensable precondition to develop the geothermal field. The South Mecsek line is still active seismologically.

The aquifer is composed of medium grade metamorphic rocks of Paleozoic age, mainly gneisse. The pre-tertiary basement map of the area is shown on Fig. 13, the geological cross section is presented on Fig.14. The geothermal fluid is produced from the highly fractured part of the crystalline rocks.

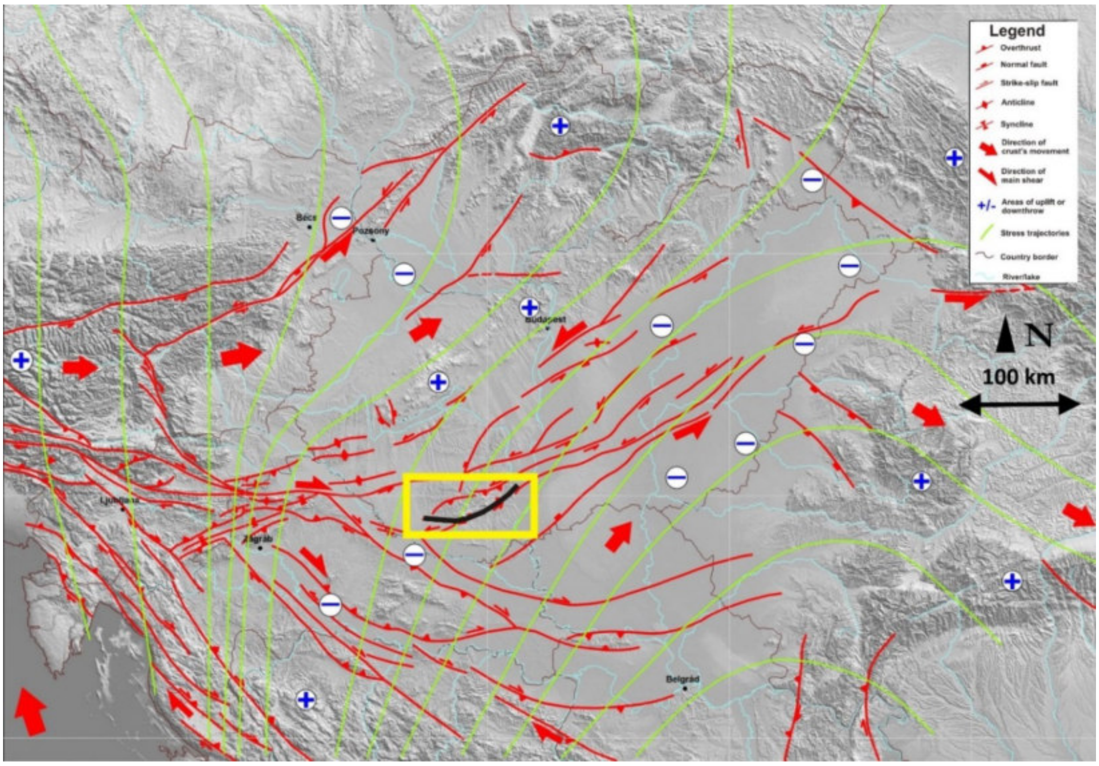


Fig. 11: Location of Szentlőrinc field. Background image is from „Atlas of the present-day geodynamics of the Pannonian basin" project, map called synthesis (Horváth et al., 2004).

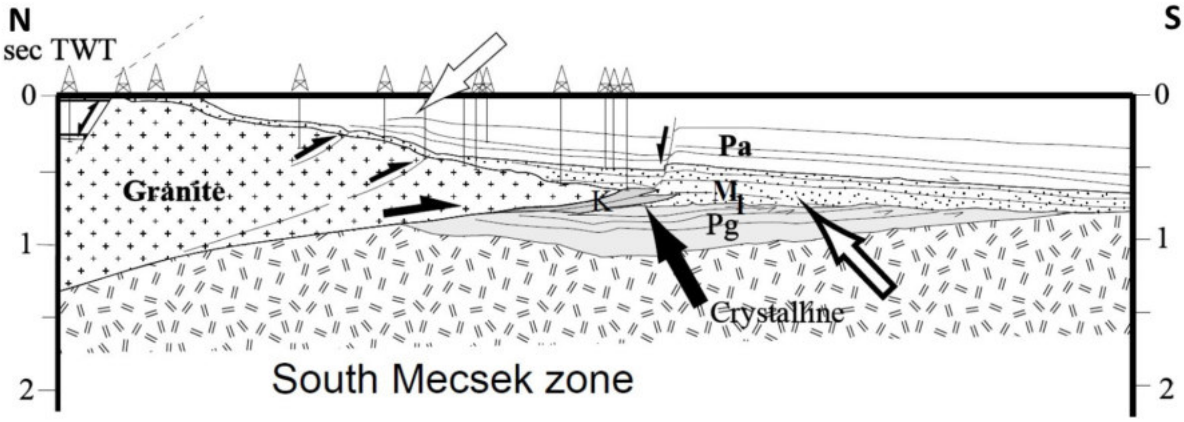


Fig. 12: The interpretation of South Mecsek line by Csontos et al., 2002

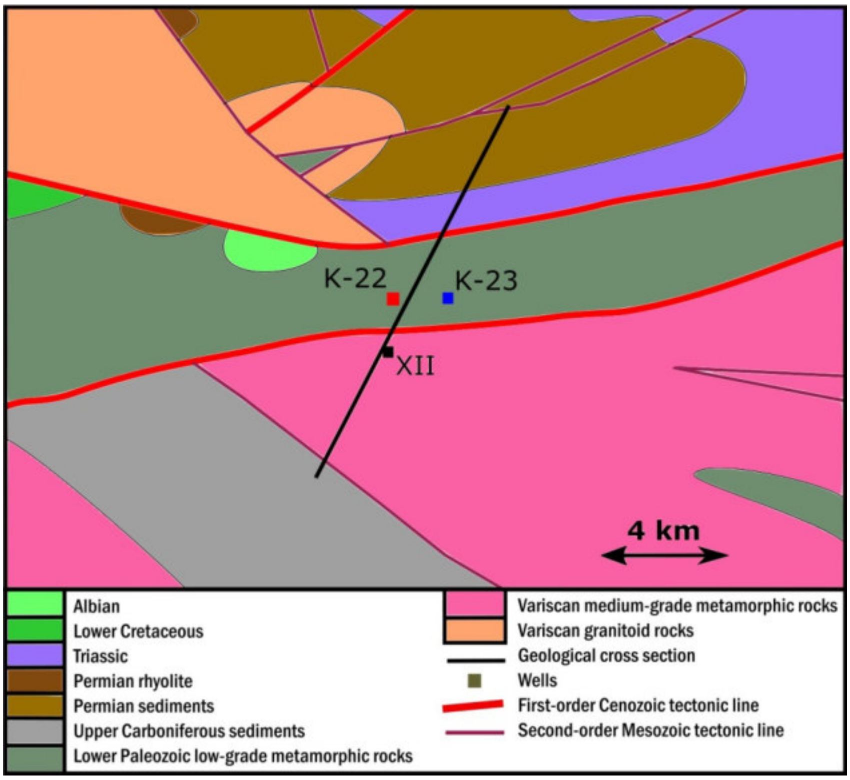


Fig. 13: Pre-tertiary basement map of surroundings of geothermal wells of Szentlőrinc field (Haas et al., 2010).

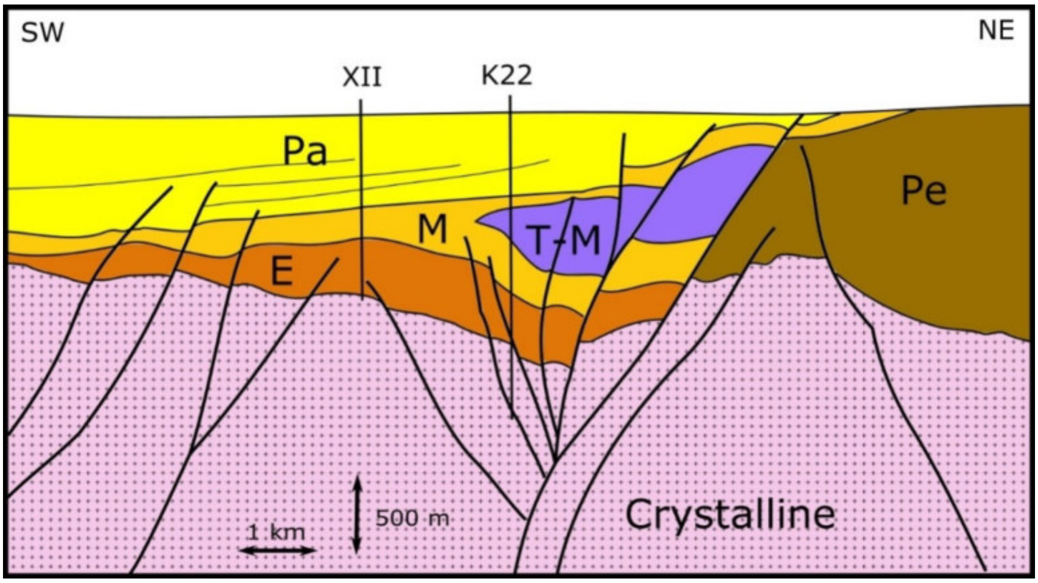


Fig. 14Geological cross section (from Fig.13.) along K-22 geothermal well. XII is a geological research well drilled in 1978, which indicated the presence of thermal water.

Numerous feed zones were identified in the K-22 production well; the most productive is located at 1760 m depth. The drilled sequences and the structure of the wells are depicted on Fig. 15. The main parameters of the wells are summarized in Table 3. The higher productivity index of K-23 is presumably due to the wider diameter, the longer drilled section and the use of bentonite free drilling mud.

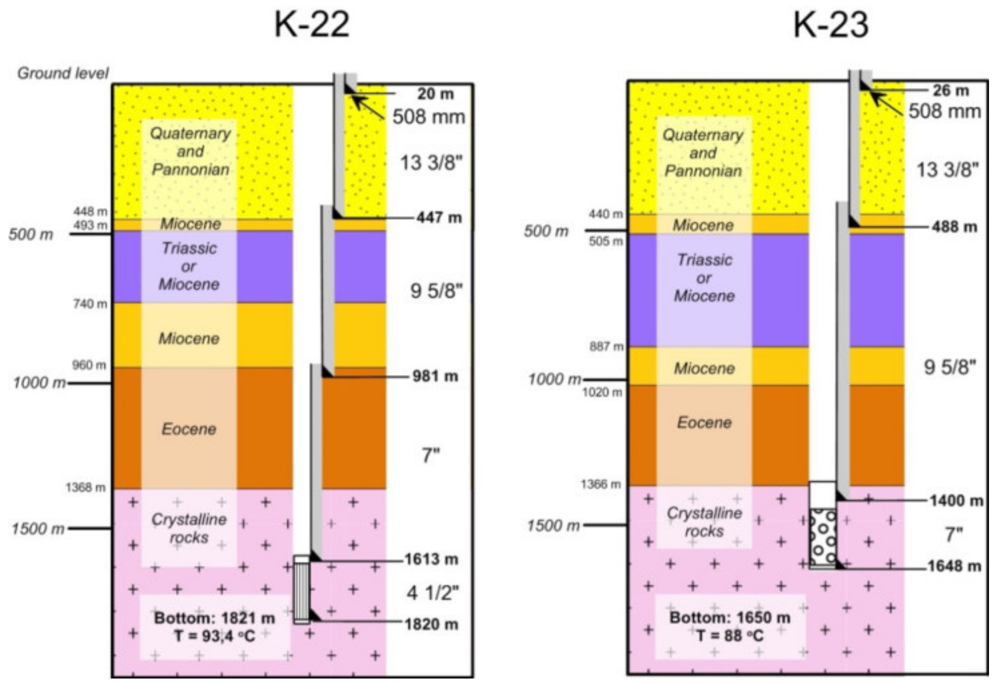


Fig. 15: Drilled sequences and well structure of K-22, production well and of K-23, injection well.

Table 3: Main parameters of geothermal wells

	Unit	K-22	K-23
Drilled depth	meter	1821	1650,5
Depth of screens	meter	1614,3-1809,1	1413-1630,5
Diameter of screen	"	4 1/2	7
Bottom temperature	°C	93,4	88
Outflow temperature	°C	85,4	77
Yield	l/s	18,8	35
Drawdown	bar	7,2	3,11
Productivity Index	l/s/bar	2,24	15,25

The geothermal resource is used for district heating of the town Szentlőrinc (approx. 450 flats) previously heated by natural gas. The heat plant was equipped with a heat exchanger (Fig. 16), where the heat of geothermal loop is transferred to the district heating system. The geothermal loop is more than 3 km long. The location of wells and pipelines of geothermal loop is shown on Fig.17, and the reinjection well (K–23) on Fig.18. There is no cascade-type use. Full amount of the produced geothermal fluid is reinjected into the same aquifer. The geothermal system works well, no scaling and reinjection problems are reported. There is no treatment of produced water.

Fig. 16: The heat exchanger with mechanical equipment

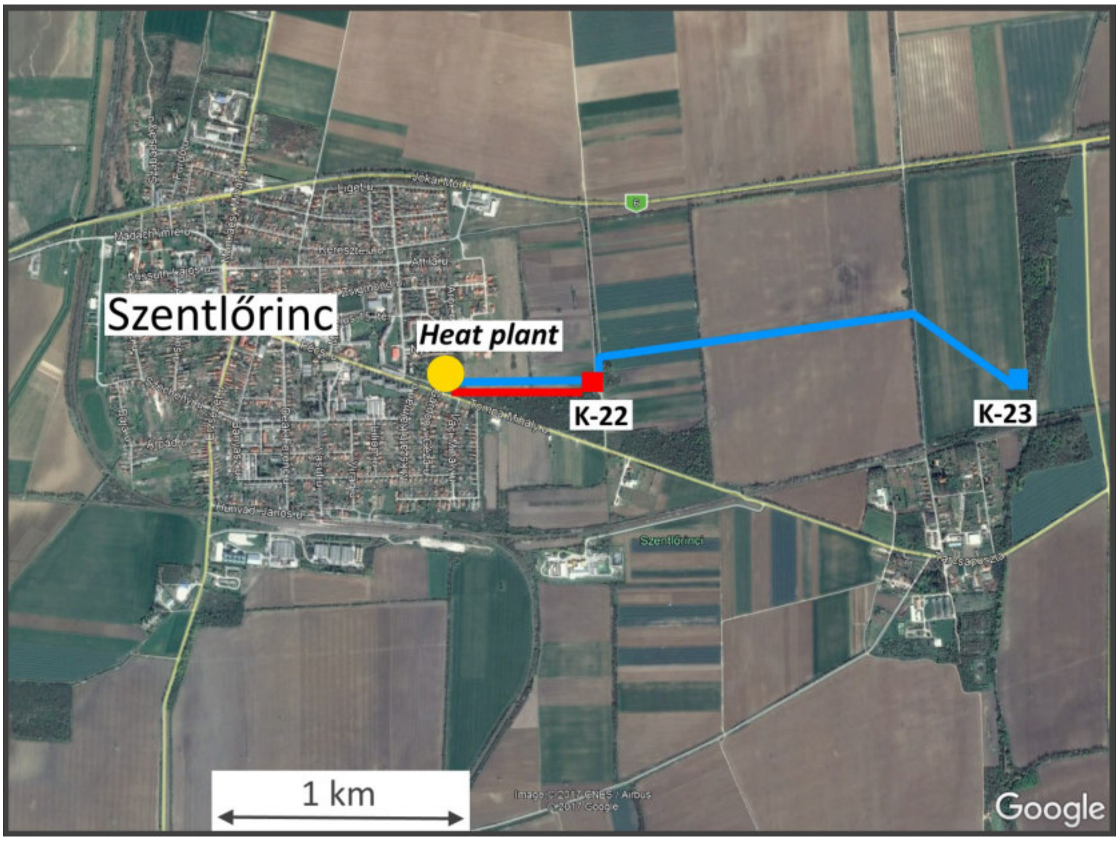


Figure 17: Map of geothermal loop at Szentlőrinc. The red square represents the production well (K-22), while the blue one is the reinjection well (K-23). The production pipeline is red, the reinjection pipeline is blue.

Fig 18: The reinjection well (K-23) with mechanical equipment

4.2. Mórahalom and Szeged towns

4.2.1. Geology of the area

The S-SE-ern part of the Great Plain has got the most favourable geothermal conditions in Hungary. The two main depression of the South Great Plain were formed in the Miocene: The Makó-Hódmezővásárhely depression and the Békés Basin, these being divided by the Battonya-Pusztaföldvár ridge (Fig.19). A thick porous sedimentary succession can be found on this thinned, subsiding basement, deposited in the late Miocene-Pliocene "Pannonian" period. The Makó-Hódmezővásárhely depression was filled mainly by the deltaic systems arriving from the NW, while a subordinated sediment supply from the SE can be recognized in the Békés Basin. The sedimentary formation environments vary from deep basins through prodelta and delta fronts to delta plains (Juhász, 1989) (Fig. 20).

Due to the effect of marine transgression at the beginning of the Lower Pannonian period, a basalt conglomerate formed on the emerging higher territories, known as the Békés Conglomerate Formation. This is covered, in the deep basins, by the Endrőd Marl Formation, consisting of calcareous marl and clay marl. Fine and coarse layers of sand deposited in the deepest depressions of the Great Plain between the calcareous marl in the upper sections of the formation (Rónai, 1985). The average thickness of the formation is 100 - 200 m, but it can reach 700 m (Haas, 2001). This layer is covered by the fine sand turbidite set of the Szolnok Formation, reaching several hundreds of metres at some points. Above the turbidites, in the shallower basin areas, the hemipelagic marls are covered by the thick clayey-silty formations of the Algyő Formation with a prodelta facies (Fig. 21). The formation can reach a thickness of 900 m in the deeper basins, becoming thinner towards the edge of the depressions (Haas, 2001). The Algyő Formation is characterized by extremely high overpressure below it and everywhere within it. This is primarily caused by tectonic factors due to the thick layers with low permeability (Tóth & Almási, 2001). The sand content of the Algyő Formation increases in the areas with a shallower basement, thus the upper part of the formation can be regarded as water-bearing at some points. Generally, the Lower Pannonian formations have unfavourable aquifer conditions.

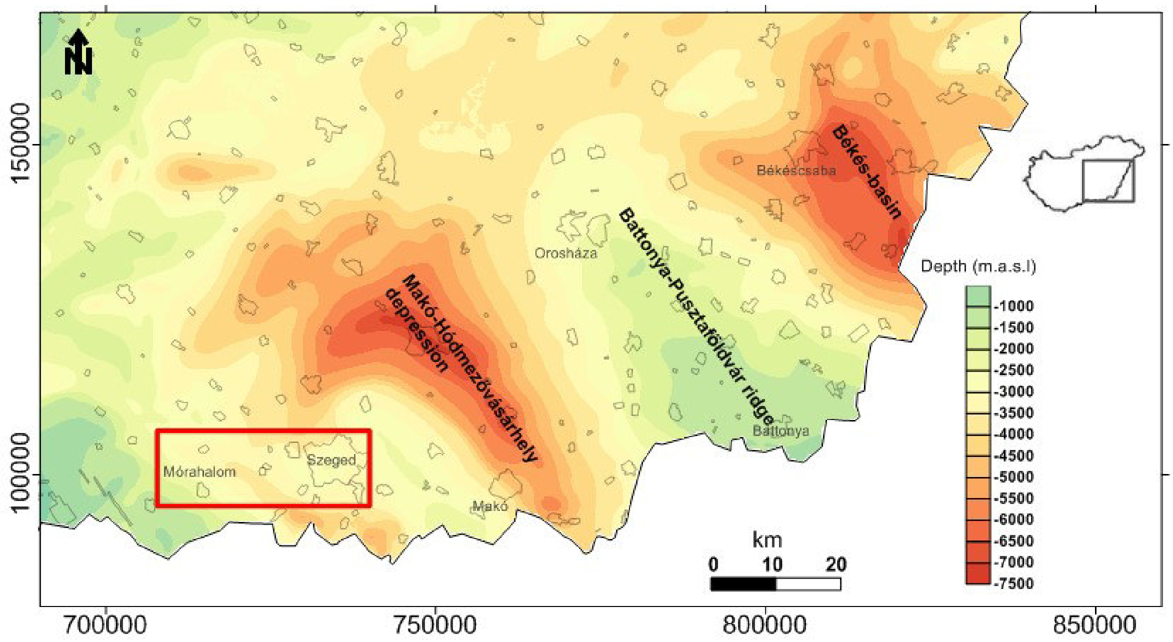


Fig.19: Depth of the pretertiary basement environment of the Makó-Hódmezővásárhely depression and the Békés Basin

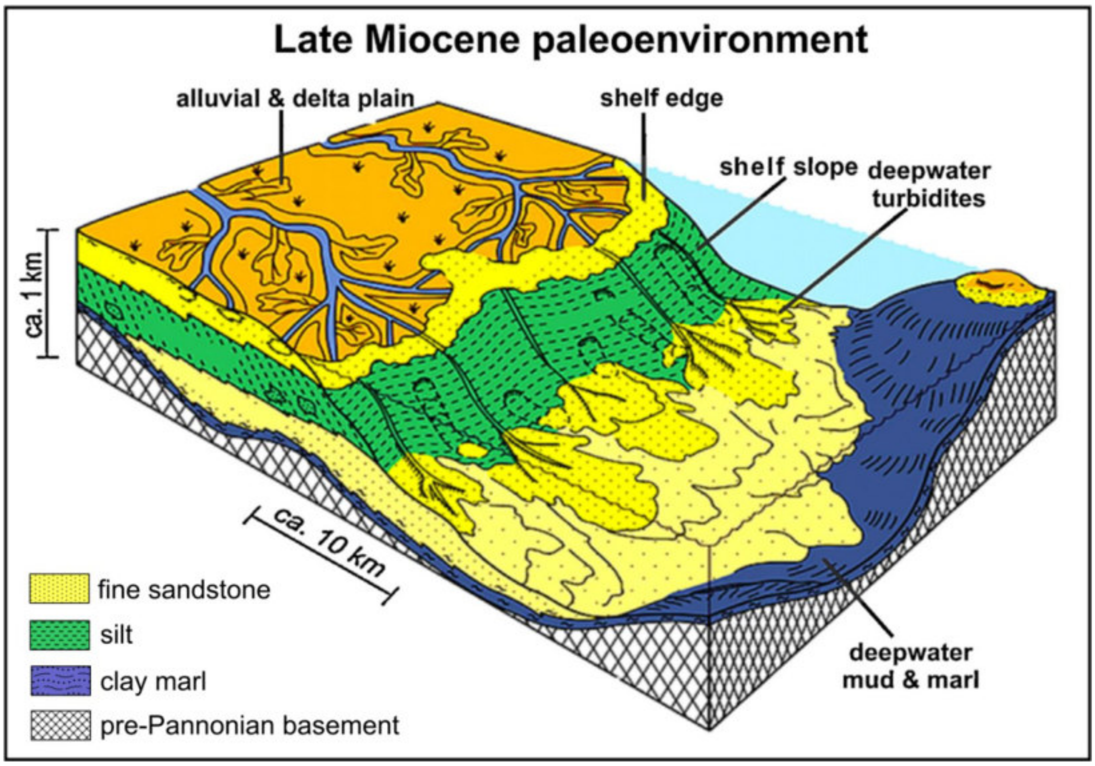


Fig.20: Idealized sediment accumulation model in the Great Plain (Juhász et al., 2006) 1 - fine sandstone, 2 – silt, 3 – clay marl, 4 – pre-Pannonian basement

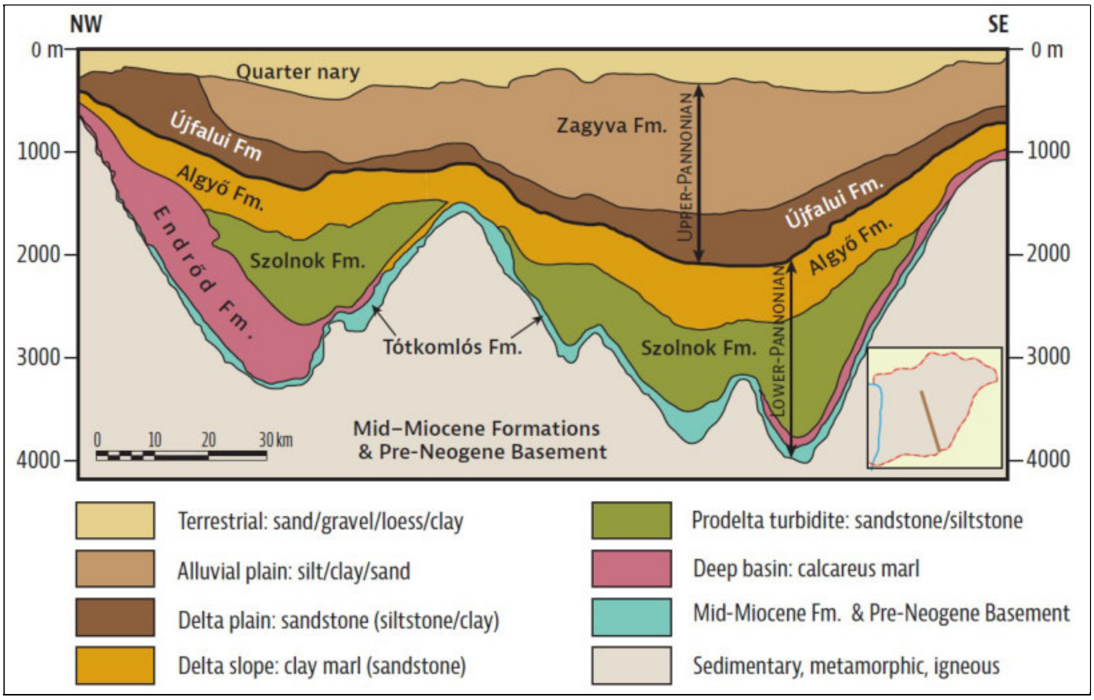


Fig. 21: Sedimentological and stratigraphical section of the Great Plain based on Almási, 2001

The Lower Pannonian layers are overlain by the Upper Pannonian Újfalu Formation, with a delta front and delta plain facies, which is the most important sediment from a hydrogeological point of view, and by the Zagyva Formation, with a deltaic background and alluvial plain facies (Fig. 22). The thickness of Upper Pannonian sediments in the South Great Plain can reach 1800 m in the Makó-Hódmezővásárhely depression, and can exceed 2000 m in the Békés Basin (Fig. 23). On the other hand, in the regions of the Battonya-Pusztaföldvár ridge, the Upper Pannonian sediments become thinner. Due to the variance of the layers, the water-bearing and yielding capacity of the Upper Pannonian sediments can be very different over relatively small areas. According to the literature and our measurements, the permeability of the Upper Pannonian reservoir, which has highly permeable sand layers, in the Szentes-Szegvár and the Hódmezővásárhely regions can reach 2000 mD; this corresponds to a filtration coefficient of 5 - 10 m/day.

The Újfalu Formation consists of sandstone, silt, and clay marl layers with dominating sandstone layers. The dominant sediments are bed-filling and bay-mouth bar sediments that have good water-bearing features and limited horizontal dimensions, but they are hydrodynamically connected due to multiple linear erosions and overlappings (Juhász, 1989). The Újfalu Formation is the most important thermal water reservoir, and a significant crude oil and natural gas reservoir, for example in the region of Algyő (Rónai, 1985).

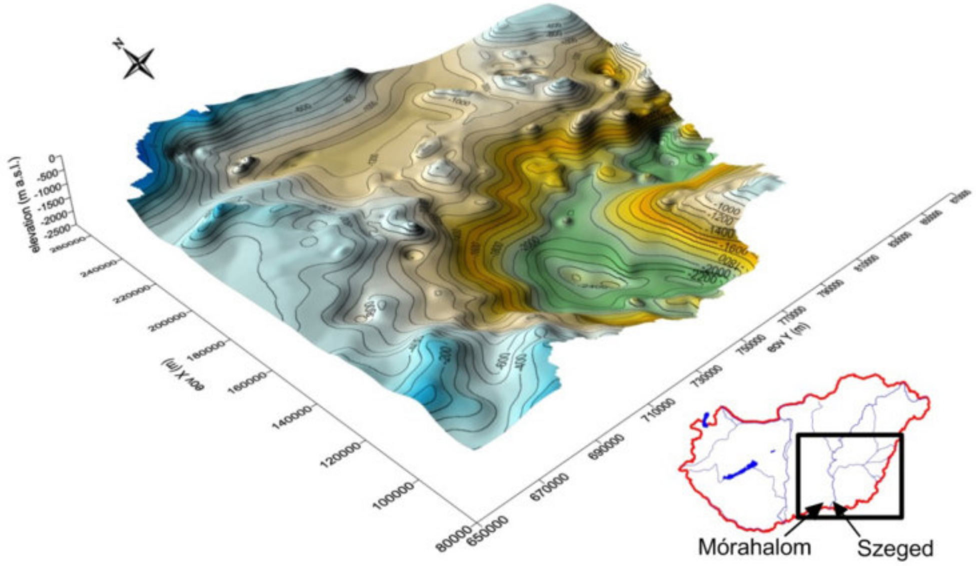


Fig.22: Depth of Upper Pannonian sediments in the South Great Plain, shown in local coordinates

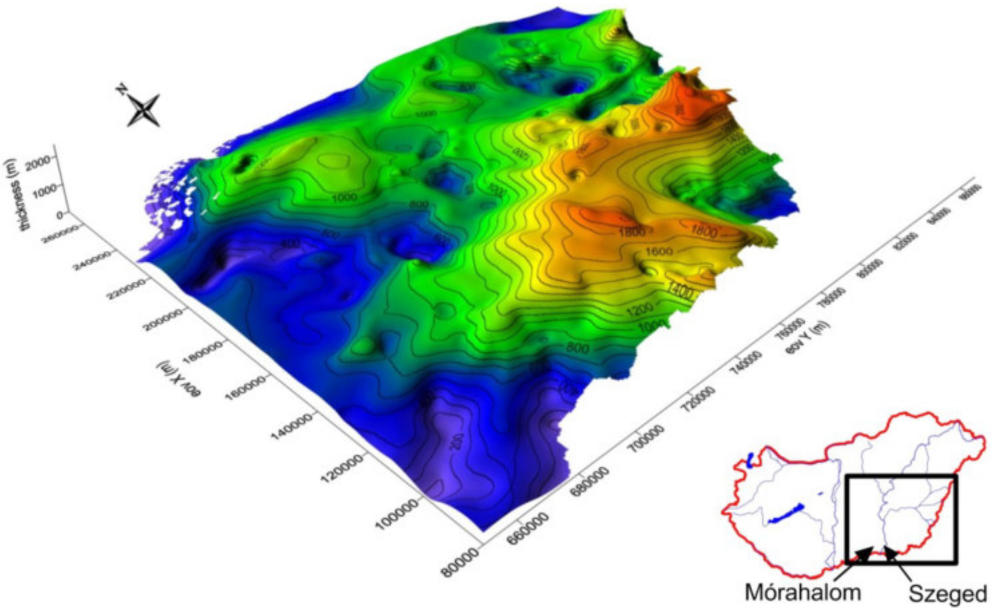


Fig.23: Thickness of Upper Pannonian sediments in the South Great Plain shown in local coordinates

The Zagyva Formation consists of sediments deposited in the deltaic background and alluvial plain environments. From a lithological point of view, the formation is extremely heterogeneous, mainly dominated by sandstone, silty sand, silty clay and clay layers. The size of the sandstones in the formation ranges from fine through small and medium-sized, with carbonate binders at places, and this can result in a significant local decrease of permeability. Bed filling and sandbank sediments are common in the alluvial plain formations (Juhász, 1989). These formations are not common on the Great Plain; they are limited to the depressing territories (Ágoston et al., 2008). Despite the fact that the formation is characterized by many thin layers on top of each other, there are thickening sand layers in some areas, resulting in excellent water-bearing formations.

The first layer of the Nagyalföld Tarkaagyag Formation covers the Zagyva Formation, which is a set of sediments consisting of uniform multicolour clay in the Great Plain. This formation, with a thickness of 300 - 500 m, has a low proportion of sand layers. It can be found in the Makó-Hódmezővásárhely ridge at a depth of 600 – 1000 m. In the Quaternary, fluvial sediments of different thickness deposited on the previous mentioned Neogene sediments.

4.2.2. The geothermal district heating system of University of Szeged

After considering environmental and energy saving aspects, the University of Szeged and the Local Government of Szeged have decided to use geothermal heat for their heating systems. The Department of Mineralogy, Petrology and Geochemistry of the University of Szeged applied successfully within the Interreg III programme of the European Regional Development Fund for the design and authorization of a complex system using thermal energy.

The use of geothermal energy has a long history in Szeged. The first researches related to thermal water were carried out in Szeged in the 1880's, and the first thermal well was drilled in 1927, but after that the geothermal energy utilization decreased.

The heat supply systems of the university institutions, public buildings and dwelling houses of Szeged are mainly based on natural gas. Approximately 75 % of the estates are supplied from district heating systems, while the remaining part uses gas convectors, or individual heating solutions. Heating with natural gas results in the pollution of the environment due to the emission of pollutants, the profitability depends significantly on the actual political situation and world market prices.

According to the concept, the thermal water to be produced from the 2000 m deep wells at two locations (downtown and in Új-Szeged) has a temperature of 92 - 95 °C, and it is reinjected into the subsurface through 2 reinjection wells at each location (Fig. 24). The plans were completed by 2008, but the project was not implemented due to the lack of money. A professional investment group was set up, which successfully applied for an assistance of 48 % of the total investment costs from the European Union. According to the updated concept, the two thermal circles supply 80 % of the heating of the buildings (clinics, department buildings, dormitories) of the University of Szeged and certain buildings of the Local Government (the Medical Clinic No. 1 and the Szeged Swimming Pool). The University of Szeged has approximately 30.000 students and is the town's largest thermal energy consumer, thus the largest emitter of pollutants. The construction of the system has been completed; six wells have been drilled, pipelines laid down, heating circuits in buildings as well as heating centres refurbished, and both systems started operation last years.

The two systems replace a quantity of natural gas of 2.900.000 m3/year with a capacity of 8.9 MWth, and reduce the emission of CO2 by approximately 5.900 t, representing a factor conducive to health in urban areas. The total costs of the project, including the six wells, pipelines, new heating stations, reach EUR 10.8 million. The expected operating costs of the system reach EUR 473.000 t/year. The project has a payback period of 13.5 years, which is reduced to 7 years due to the non-refundable grant (Fig. 25). Thanks to this investment, the university reached 19th place on the world ranking list of the "Green University".

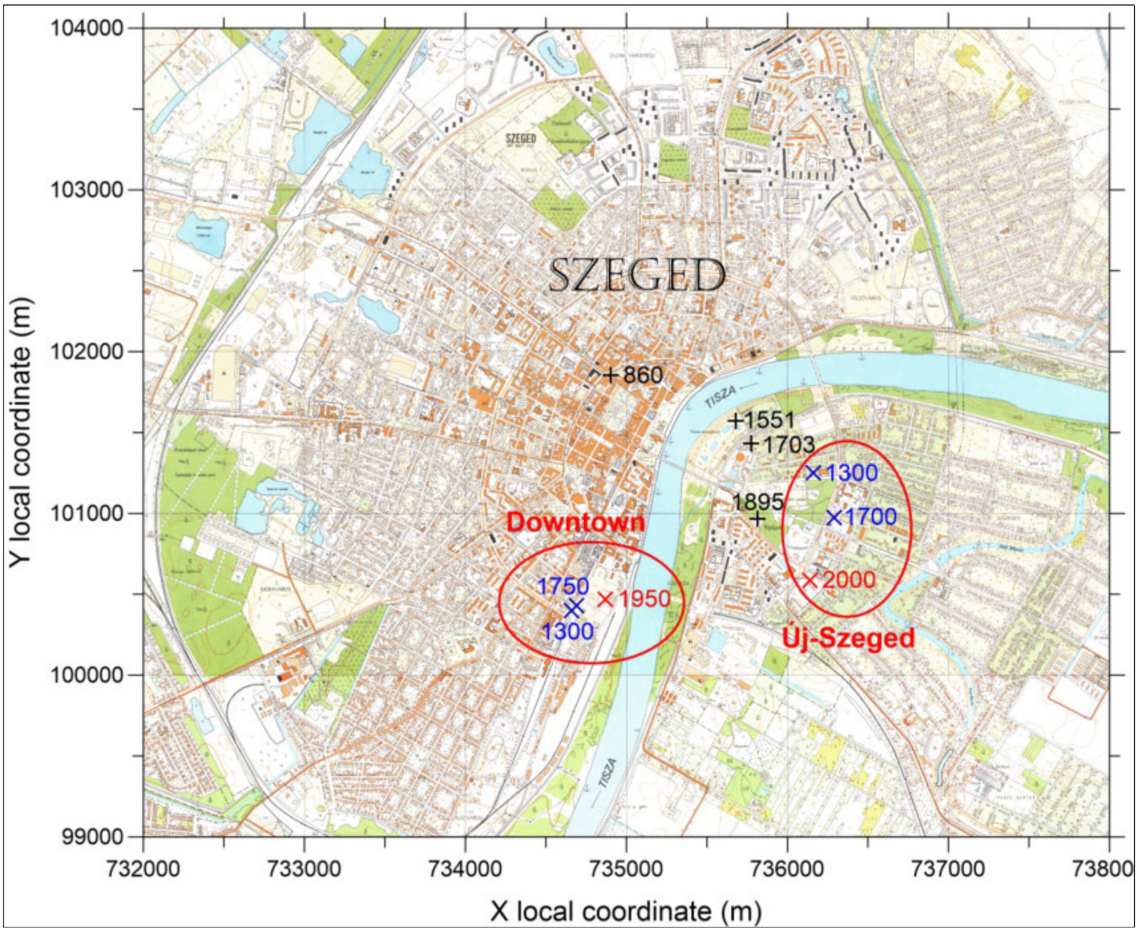


Fig. 24: Location of thermal wells in the center part of Szeged with their depth in m (black: old production wells, red: new production wells, blue: new reinjection wells)

The best innovations in Szeged:

- keeping the system overpressured, degasification directly before reinjection (reduced scaling, reduced maintenance cost, increase efficiency due to gas temperature)
- unique metal acid-proof wire filter before reinjection (easier operating, much less need to be replaced)
- applying unique pumps in the production well

Summarizing the advantages of geothermal energy use at the new systems in Szeged:

- 80 % decrease in gas consumption at the connected buildings.
- Running costs 70 % less than gas systems.
- The geothermal system serves as a demo site for higher education.
- Fits in the Green University idea.
- Good example for the cooperation of the University and the City.
- Sustainable system designed by researchers from the university staff.

Fig. 25: Geothermal cascade system in Downtown with heat centers marked with orange stars

4.2.3. The thermal systems in Mórahalom

The geothermal system in Mórahalom has three subsystems, two of which can be found in the inner area of the town, and the third of which is an independent heat supply system outside the town.

The three subsystems are

- The system of the Szent Erzsébet Spa of Mórahalom (heating – balneology)
- The Geothermal District Heating system of Mórahalom (heating - domestic hot water)
- The Norwegian Geothermal Public Utility system (heating - domestic hot water)

A series of projects were recently implemented with two objectives. One was the replacement of the heat supply system with natural gas boilers in the Szent Erzsébet Spa in Mórahalom to cool the thermal water to a temperature of approx. 40 °C, so it could be used in the fill-drain pools and showers of the Spa. The other objective was the replacement of the heat and domestic hot water supply with natural gas boilers in the institutions of the local government.

The geological features of the Mórahalom region compare unfavourably to the greater part of the South Great Plain. Upper Pannonian sandstones can be found at a depth range of 600 m to 1300 m, thus the temperature of the produced water varies "only" between 39 and 65 °C. The balneological system constructed in 2004 and successfully operating for 10 years was the first part of the complex thermal system. The projects were implemented in several stages. Production well B-40 in the spa was built in 2004, the production well B-45 (Fig. 26) in Hunyadi Park (T-1) in 2008, the reinjection well B-46 in Ady Square (VS-1) in 2009, the Norwegian production well K-43 in the Szent János area (T-2) in 2010 and the Norwegian K-44 reinjection well (T-2) in 2011. (These wells are referred to as Norwegian because their construction was funded by EEA sources.) They are operated as three independent systems.

Geothermal District Heating system and the system of the Szent Erzsébet Spa in Mórahalom

The system focussing on the downtown supplies heat for nine public institutions (Care Centre, School Sports Hall, Barmos School, Móra Ferenc Culture Centre, Day-Care-Kindergarten, New Town Hall, Events Hall, Youth House and the House of Sustainable Development and the Colosseum Hotel). The starting point of the heating system is the 1260 m deep thermal well in Hunyadi Park that produces thermal water with a temperature of 60 - 62 °C at 60 m^3/h in the winter and 25 - 30 m^3/h in the summer. The well's submersible pump is controlled according to the water level of the tank (100 m^3) and the heating demands. It pumps the water into the production tank based on signals of the telemonitoring system and at a rate determined by demand. Four degassing pumps transfer the water into the degasser based on signals from the automatic system. After degassing, one of the four network pumps sends the filtered water into the pipeline system connecting to the six heating stations, from which nine public institutions and the Colosseum Hotel are supplied with heat and domestic hot water.

Finally, the partially-used water directly supplies thermal energy for pools in the Spa and additional water for the pools. The used water from the pools is realised into the Madarász Lake, which is monitored in every 3 months (measured temperature and TDS). The remaining water quantity (in the winter 40 m^3/h, in the summer 25 m^3/h) is pumped into reinjection well B-46 in Ady Square through the reinjection buffer tank in Hunyadi Park after a 20/10-micron filtering.

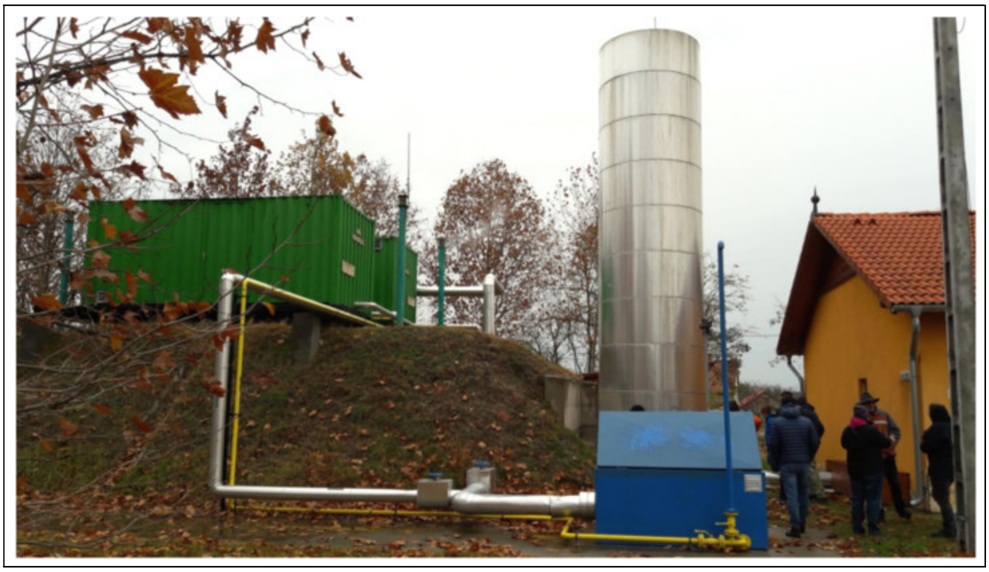


Fig. 26 The production well (B–45) and the gas separator in the Hunyadi Park, Mórahalom

The Norwegian Geothermal Public Utility system

The other thermal network supplies thermal water from production well K-43 for three Renewable Model Farms (Community, Residential and Farming), for the Bathing House and for the greenhouse. The starting point of the heating system is the 1270 m deep thermal well, which produces 14 - 15 m^3/h of thermal water with a temperature of 60 - 62 °C in the winter. In the summer, it is unnecessary to operate the thermal system, since the solar collectors installed on the roofs can supply heat for the production of domestic hot water. The well's submersible pump is controlled according to the water level of the tank (100 m^3) and heating demands. After degassing, it pumps water to consumers based on the signals of the telemonitoring system and at a rate determined by demands. Finally, the cooled thermal water reaches the reinjection well K-44 behind the greenhouse after a 20/10 micron filtering. However, since there was no storage tank installed for the reception of the cooled thermal water, a separate reinjection pump system was not built. The network pumps also function as reinjection pumps, and their control is separate from the previous system. The telemonitoring system modifies the activity of the network pumps very slowly in order to protect the reinjection well and to avoid creating damaging positive or negative pressure waves.

Automatic computer control of the two separate geothermal public utility systems and the spa system is carried out from the dispatcher centre in the Spa. Every production, transmission and reinjection pump can be controlled with a frequency changer, which can be used to alter the reservoir level and maintain pressure and temperature, which is economical for water production and operational energy utilization and guarantees a dynamics- and fluctuation-free well operation.

CHP gas engine systems in Mórahalom

50 kW CHP power plant in the Hunyadi Park

The utilization of the gas from thermal well B-45 (the gas-water ratio is 1:1 approximately) began in 2011, and was ended and decommissioned in October 2012. The electricity produced in the 50-kw gas engine CHP plant (Fig. 27) is used for the machinery of the thermal well, the surplus is forwarded into the public network and the heat produced by the gas engine is used to heat the thermal water. The payback period of construction the gas engine was 3 years.

Fig. 27: The 50 KW gas engine CHP plant

Production well B-45 (T-1)
Total depth: 1260 m
Yield: 55.2 m^3/h with submersible pump, 132 m^3/h with compressor
Outflow temperature: 62.1 °C
Dissolved gas content (GVV): 664.7 l/m^3
Free gas: Similar to well B-40, but not measured
Gas quantity: 608 l/min (810 l/min by production rate)
Gas composition: Methane 83.8 %, CO_2 9.3 %, N2 6.9 %
Heat demand: 60 m^3/h in winter, 15 m^3/h in summer

30 kW CHP power plant of the Szent Erzsébet Spa in Mórahalom

The utilization of the accompanying gas of thermal well B-40 began in 2013, and was ended and decommissioned in March 2013. The electricity produced in the 30-kw gas engine CHP plant is used in the spa, and the heat produced by the gas engine is used to further heating the thermal water. A heat pump system to use the waste heat of the Spa has been designed; its implementation is in progress.

Thermal well B-40
Total depth: 1270 m
Water-yielding capacity: 30 m^3/h with submersible pump
Outflow temperature: 69 °C
Gas content (GVV): 544 litre/m^3
Production of dissolved gas: 9.73 m^3/h
Production of free gas (casing-head gas): 3.87 m^3/h
Total production of gas: 13.6 m^3/h
Methane 83.8 %, carbon dioxide 9.3 %, nitrogen dioxide 6.9 %

Operational parameters of the systems

- The quantity of the thermal water produced and supplied by the Geothermal Cascade Systems is approx. 230.000 m^3/year;
- The quantity of the reinjected water is approx. 68.000 m^3/year;
- The quantity of heat for thermal heating is approx. 22.100 GJ/year,
- The primary cost of producing thermal energy for heating and domestic hot water (with reinjection) is approx. 0.003 EUR/MJ (with traditional, natural gas technology currently approx. 0.01 EUR/MJ);
- The quantity of natural gas replaced by heating and thermal DHW is approx. 630.000 m^3/year;
- The quantity of methane gas produced with the thermal water is approx. 104.000 m^3/year (98.000 m^3/year is used in the gas engine),
- Generated electricity (gas engine) 245.446 kWh/year; its value is 22.117 EUR/year;
- Produced thermal energy (gas engine) approx. 392.376 MJ/year;
- Equivalent of replaced greenhouse gas emission 1.352,4 tonnes/year;

Project results

One of the most important results of the project was the creation of a complex system based on renewable energies (geothermal and solar energy) and the utilization of methane gas for heating and electricity production. This system represents a significant savings compared to traditional public electricity and natural gas systems.

- Gross revenue of the projects is approx. 37.377 EUR/year;
- The simplified return period of the projects, based on current purchase costs, is approx. 6.36 years with assistance, 3.18 years without assistance;
- More than 95 % of the primary electricity demand of the thermal wells is provided from the methane gas produced together with geothermal energy.

The utilization of the local energy source – independent from external political and economic factors – replaces an annual quantity of approx. 163.924 m^3 of imported natural gas and 427.388 kWh of electricity, and reduces CO_2 emission by 2.467,5 t annually.

Analysis of reinjection

Continuous monitoring enables the permanent and economical reinjection of waters into Pannonian sandstone. The software monitoring the station of the reinjection well records characteristic operational data, which allows the well's requirements for maintenance to be monitored. According to operational experience, if the wellhead pressure reaches 3 bars, compressor cleaning and regeneration activities are suggested. Based on the data of the previous 3 years, these were necessary only three times.

5. Romania

5.1. Dorobanti locality, Arad County

At the Dorobanti area the Upper Pannonian sandstone geothermal aquifer is utilized by two wells (1655 and 1613), at depths between 932 m and 1100 m below ground. At the well 1655 the main aquifer occurs between 950 and 1100 m; the yield of the well is Q=20 L/s and the water temperature is T=60˚C. At the well 1613 the main aquifer occurs between 932 and 1078 m; the yield of the well is Q=15 L/s and the water temperature is T= 60 ˚C (Fig. 28).

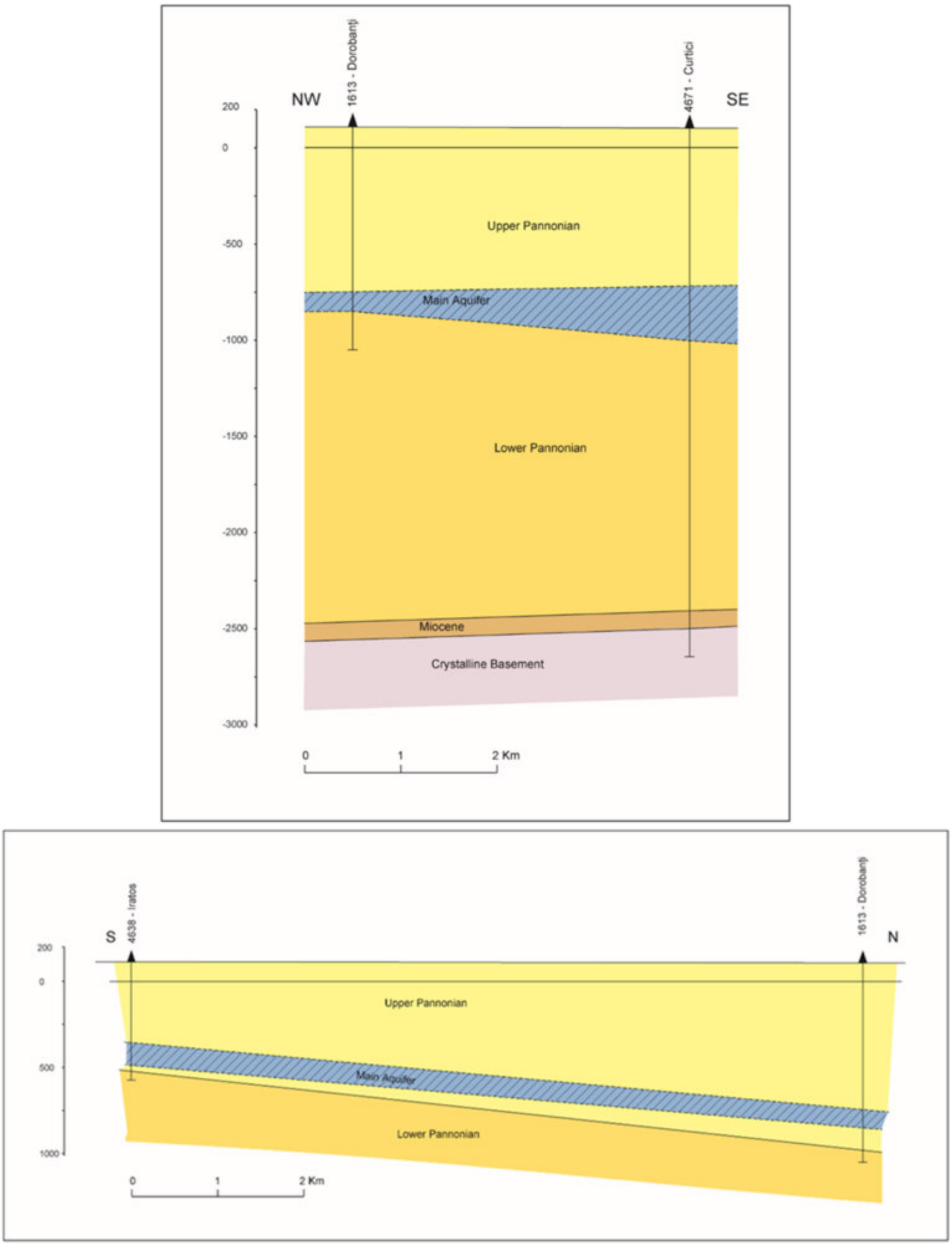


Fig. 28: Cross sections showing the Upper Pannonian thermal aquifer in Dorobanti area

The aquifer is utilized for:

a. Agricultural production - 6 ha of greenhouses belonging to Dorobanti village (Owner: Soc. Agricola Agrador; Operator: S.C. Ecologica Arser) are heated. The well 1655 is permanently used (during summer for a fish farm, during winter, from September to May for heating greenhouses). The well 1613 operates only in the cold season.

b. Recreation and balneology proposes – at the 1.5 ha thermal park named „Gradina Termala" the well 1655 is used only in the warm season (from June to August) for pools water. The water temperature in the pool for adults has temperature between 36 – 40 ˚C, wail the pool for the children has the water temperature between 32 - 36 ˚C. Also there is another 30 m long swimming pool with lower temperature (Fig.29).

Fig. 29: The swimming pool in Gradina termala, Dorobanti, Arad County

The water from the well 1655, after being used in the thermal and swimming pools, is used at the fish farm. Prior the usage, the water which is released from the swimming pools is treated for adjusting the pH in order to be used at the fish farm. There is no rejection and the water is realised in the surface recipient.

The thermal water is used since 1988's in treating various diseases (rheumatism, arthritis, paresis, paresthesia, and inflammatory gynecological or respiratory system diseases).

6. Serbia

6.1. Bogatić - geothermal district heating system

Bogatić is located in the northwest part of Serbia and belongs to the Mačva region, which is known as one of the greatest geothermal anomaly. Mačva is part of the transboundary geothermal system characterized by very high values of geothermal gradient (70 °C/km) and heat flow (112 mW/m^2 to 120 mW/m^2). Geothermal reservoir is formed within karstified limestones and dolomites of Triassic age. On the reservoir surface temperature ranges from 75 up to 78 °C. Using the schematic models and hydrogeothermometers methods, the highest expected temperature is around 100 °C.

Eleven geothermal boreholes in wider area of Bogatić are confirming the great geothermal potential. Boreholes depth ranges from 178 m up to 1500 m. The highest temperatures were achieved on geothermal well BB-1 (75 °C) and well BB-2 (78 °C*).* Depth of well BB-1 is 470 m and yield is 25 L/s of free flow. Well BB-2 tapped 35 L/s geothermal fluid, 78 °C reaching 618 m depth (Figs 30, 31).

Although, this geothermal energy resource is available over thirty years, wells have been out of use until now. Last year Municipality of Bogatić with Faculty of Mining and Geology, Belgrade University has started developing a project for geothermal district heating of the public city buildings, which is now in final stage. Project solution is based on indirect-open geothermal district heating concept. For that purposes well BB-1 will be put in the operation. Ten public buildings have been chosen for fossil fuel substitution with geothermal energy. Expected installed capacity of district heating system is 2.1 MW_{th}. System will operate as cascade. At the first stage geothermal fluid providing energy for buildings and cooling down from 75 to 55 °C. At the second stage geothermal energy will be used for heating an open space area (city square and pedestrian zones) and on the third stage future user along the disposal pipe will use resource for multipurpose as green housing, production heating for housing in combination with heat pumps, sport and recreation.

Favourable chemical composition and three stages of cascade system allow disposing geothermal water into surface stream near to location of utilization. Project realization is ongoing, expected to be finished in 2018.

Fig. 30: Hydrogeothermal well BB-1, Bogatić (on the left) BB-2, Bogatić (on the right)

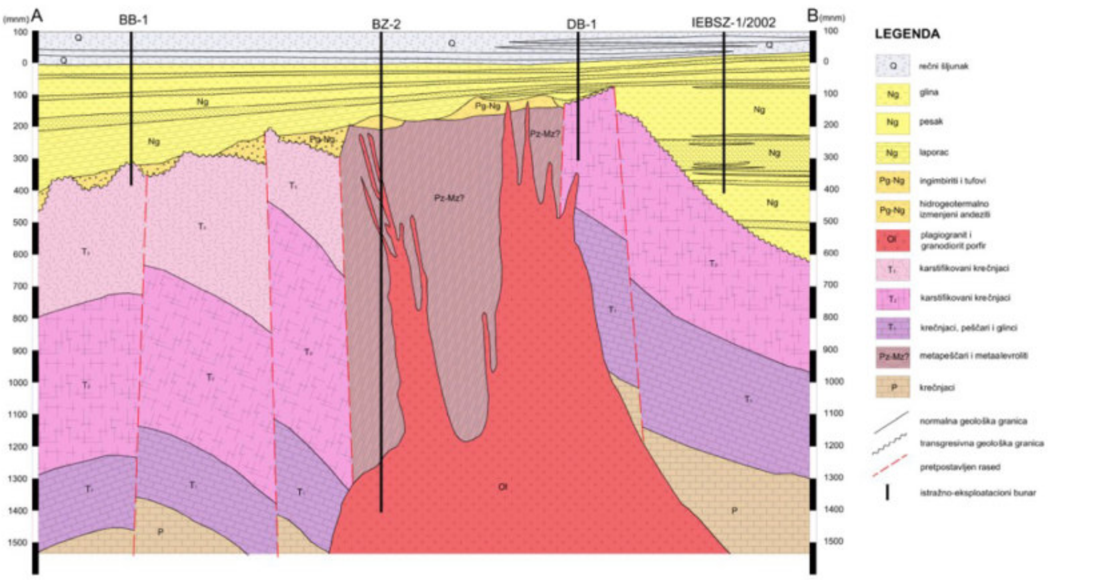


Fig.31: Geological cross-section (Djokic 2006, after FMG 1996)

6.2. Banja Kanjiža Spa - geothermal cascade system

Banja Kanjiža Spa is situated in the northern part of Serbia, on the territory of AP Vojvodina, which belongs to Pannonian basin. Three wells yield water from the sand and sandstone aquifers, Upper Miocene and Lower Pliocene age. Flow rates by well differ from 2.5 to 17.5 L/s with outflow temperatures in range of 45 to 72 °C. Geothermal water is used in balneology (sodium, bicarbonate, iodine, bromine, sulfurous, alkali and hyperthermic water), for space heating and cooling and as domestic warm water (Figs 32, 33). Geothermal energy is also used for space heating of a greenhouse (0.5 ha) in winter time. Total installed capacity is approximate 3.2 MW. There is no injection well, water is outlet into a surface stream.

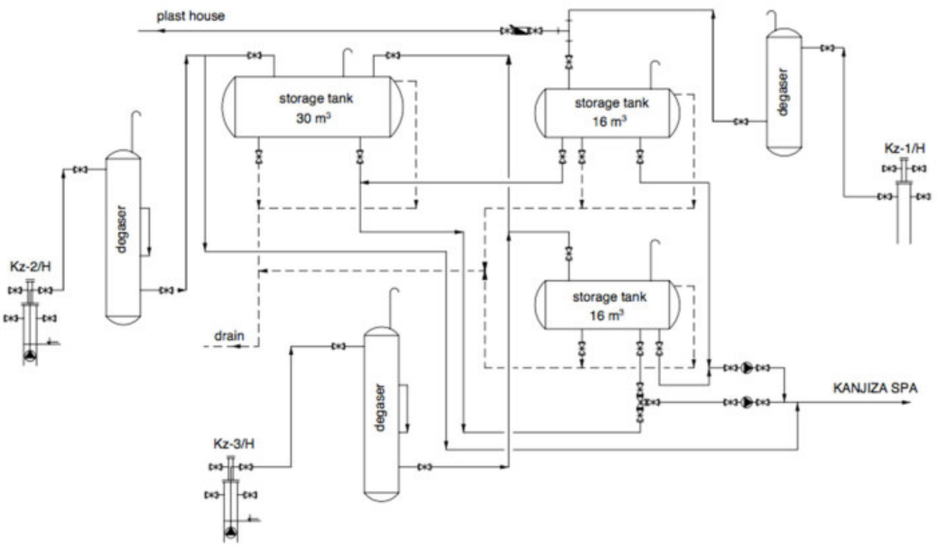


Fig. 32: Hydrothermal system for thermal water treatment at the Kanjiza Spa (Vidovic, Varga, 2005)

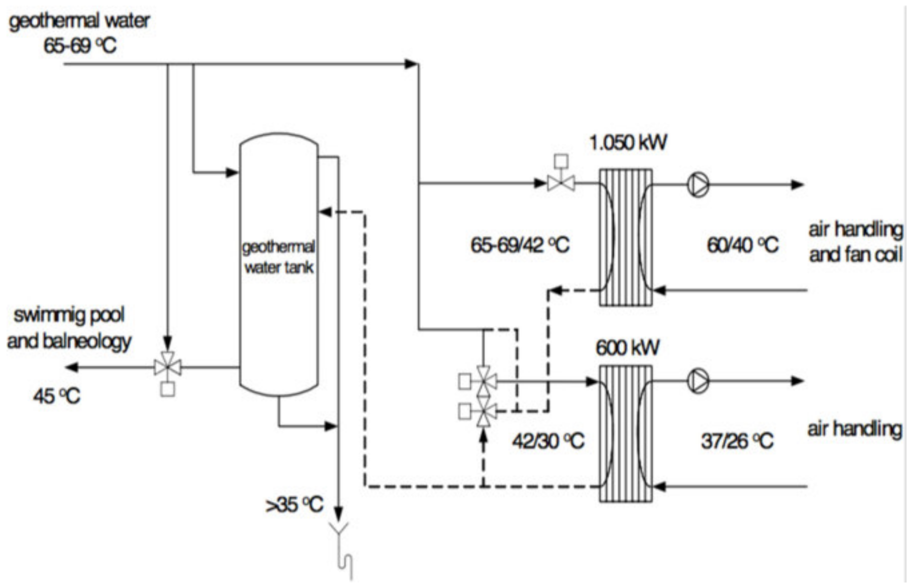


Fig 33: The present state of geothermal water utilization at the Kanjiza Spa (Demic, Vukicevic, 2005)

7. Slovenia

7.1. Geology of the area

The three most productive geothermal aquifers in the north-eastern Slovenia are:

a) The Upper Pontian to Pliocene fluvial Ptuj-Grad Formation with lukewarm paleo-meteoric water with retention time of up to a few thousand years. Mineralization of this Na-HCO_3 water is below 0.5 g/L and is produced by two wells up to 1100 m deep in Ptuj.

b) Active regional and transboundary groundwater flow systems have evolved in the lower and hydraulically connected lenses of the Pannonian to Pontian quartz sand and loose sandstone of the Mura Formation deposited in the delta front environment. This porous (n up to 30 %) sequence some hundreds of meters thick is exploited by about 14 geothermal wells open at depths between approximately 600 and 1600 m, which discharge water at temperatures between 50 and 66 °C. The users are situated in Banovci, Dobrovnik, Lendava, Moravci in Slovenske gorice, Moravske Toplice, Murska Sobota, Petišovci, Ptuj and Renkovci. This Pleistocene paleo-meteoric water of Na-HCO_3 type and with mineralization below 1.2 mg/L and little free gas was probably recharged during the last interglacial period.

c) The Badenian to Lower Pannonian limestone and turbiditic sandstone of the Špilje Formation are not part of the active flow system and hold minor aquifers of fissure porosity. Here, probably the oldest water in the basin, a diluted brine of Na-Cl and Na-HCO_3-Cl has been modified by evaporative conditions during its recharge and shows very strong water-carbonates-CO_2 interaction, as large amounts of CO_2 gas are emitted along the Raba fault zone. Thermomineral waters with temperatures between 34 and 75 °C are produced from open sections of three wells approximately 400 to 1300 m deep in Radenci and Moravske Toplice, which also contain lots of hydrocarbons at the latter site, where acid has to be constantly injected to prevent calcite scaling. For more information on settings the reader is invited to read articles of Rman (2016), Rman et al. (2016) and Šram et al. (2015) (Figs 34, 35).

Two cases which predominately exploit thermal water from the Pannonian to Pontian quartz sand and loose sandstone of the Mura Formation are presented in this report.

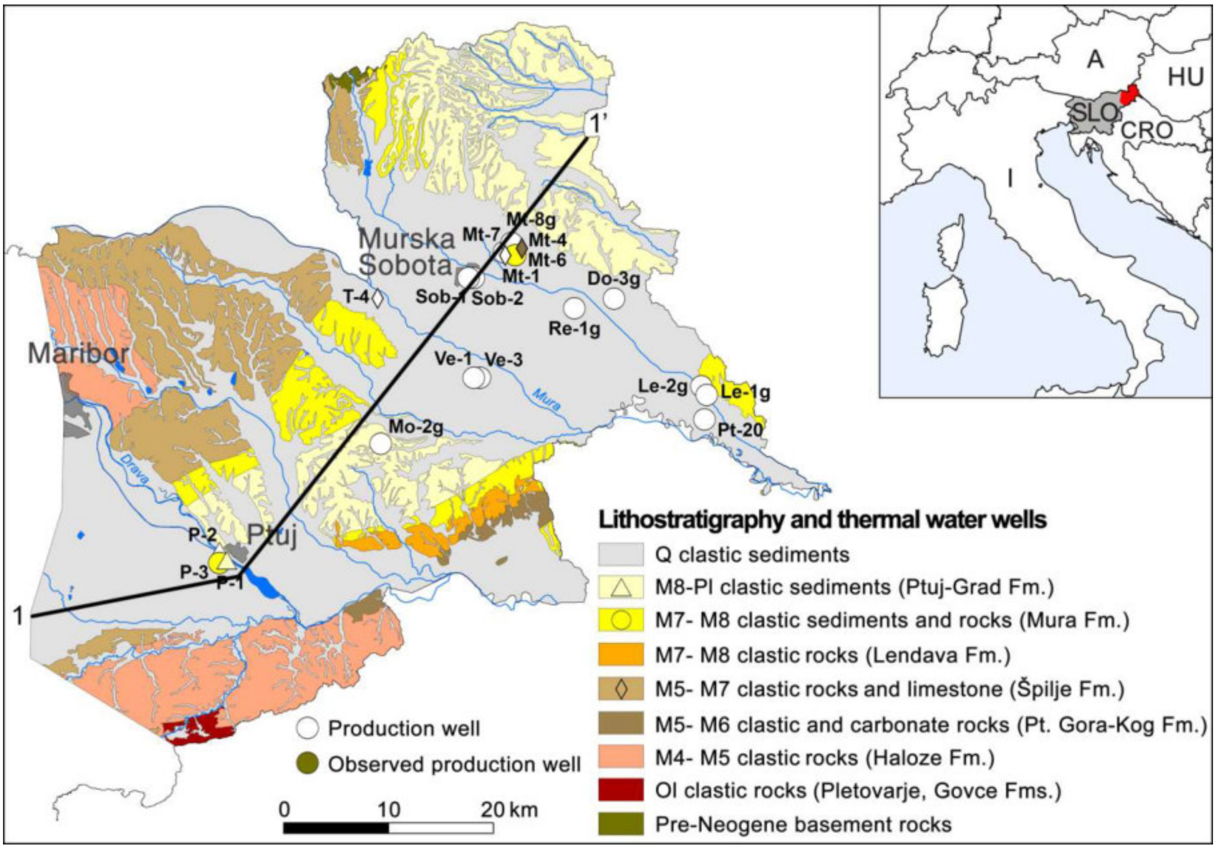


Fig. 34: Geothermal wells and aquifers in NE Slovenia (Rman, 2016)

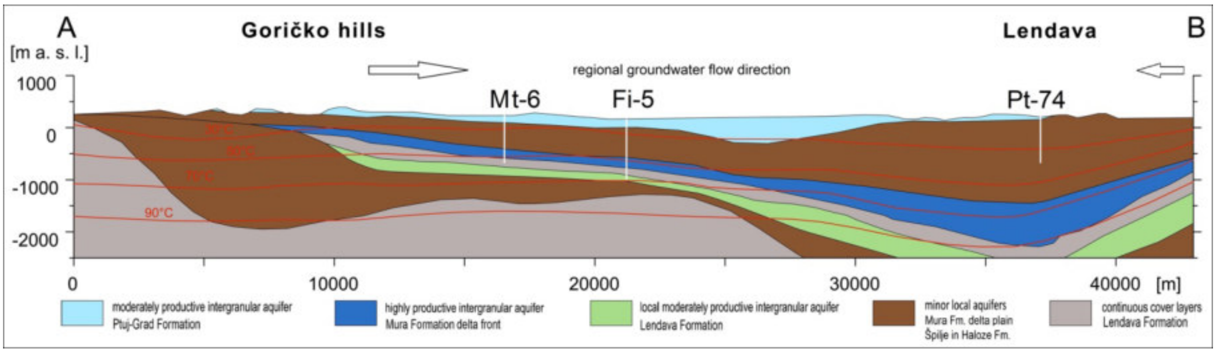


Fig. 35: Hydrogeological cross-section of the Slovene part of the Mura-Zala basin, approximate direction NW-SE. Mt-6 stands at Moravske Toplice location while Pt-74 near the Lendava wells (Rman et al. 2016).

7.2. Lendava

In Lendava, the geothermal doublet consists of a 1500 m deep production well Le-2g and a 1200 m deep reinjection well Le-3g, both are vertical and hydraulically connected. Thermal water with outflow temperature 66 °C from both the sandy Mura Formation and to a lesser extent from the sandstone of Lendava Formation is first used in a district heating system of the town of Lendava (50.000 m^2 of surface), which is managed by the Petrol Geoterm Co. If the available heat in the primary circuit plate heat exchanger is not sufficient, the high-temperature heat pump (HTH project Eureka Pump) and gas boilers provide additional heat in the secondary circuit (Figs 36, 37). Yearly consumption of geothermal heat is approximately 5.000 MWh.

Fig. 36: Location of geothermal wells in Lendava. All five wells tap the Mura formation aquifer but Le-1g, Pt-20 and Pt-74 are used by Terme Lendava while Le-2g in and Le-3g form a geothermal doublet of the Petrol Geoterm Co.

Fig. 37: Hight emperature heat pump in the Lendava district heating system (Petrol Geoterm website).

Cooled water of approximately 45 °C is injected back into the aquifer (of approximately 80 – 85 °C at reinjection depth) at a rate below 25 L/s and at wellhead pressure of approximately 4 bars (Fig. 39). Three-stage mechanical filtering of suspended solids is performed prior to injection, using sand and two microfiber filters for removal of particles with a diameter of above 10 µm (E. Torhač, personal information). If the injection pressure increases, the flow through sand filters is reversed and the 20 and 10 µm microfiber filters are changed. Additionally, cleaning of the well is performed once or twice per year. The flow direction is reversed and the well is activated to produce thermal water by a 20 bars compressor (backwashing). Produced thermal water is very old rainwater of the Na-HCO_3 type contains 1.130 mg/l of total dissolved solids (TDS) and 31 mg/l of silica, and has low calcium, magnesium and chloride concentrations. No major scaling or corrosion is observed and no additional geochemical treatment of water is known to be performed.

In Lendava the cooled geothermal water is also used for de-icing (Fig. 39).

Nearby, in the same geothermal aquifer, also well Le-1g/97 exists, which is used for bathing and balneology in Terme Lendava.

Fig.38: Nafte Geoterm object - fibre filters for waste thermal water before being reinjected into Le-3g well in Lendava

Fig. 39: Lendava de-icing: De-icing of pavements in Lendava as a part of a district heating system with geothermal energy

7.3. Moravske Toplice

Thermal water from Mt-1 well heats the facilities, sanitary and pool water of the complex Natural Park Terme 3000. Wells Mt-1/60, Mt-4/74 and Mt-5/82 with a free outflow produce from a max depth of 1300 m. Up to 5 L/s of high mineralized water (up to 16 g/l of TDS) at a temperature <75 °C can be obtained from the sandstone of Špilje Formation (Figs 40, 41). Due to the proximity of hydrocarbons, this very old brine that has been exposed to a strong evaporation is enriched with organic matter. As such, it is recognized as a natural healing remedy. Water contains methane and CO_2, causing a flow pulsation, corrosion, and carbonate scaling in walls of wells and pipes. To avoid it, chemical inhibitor is injected. Despite the relatively low flow rate, high water temperature allows heating of the tourist complex with plate heat exchangers, and part of the water is used for balneology.

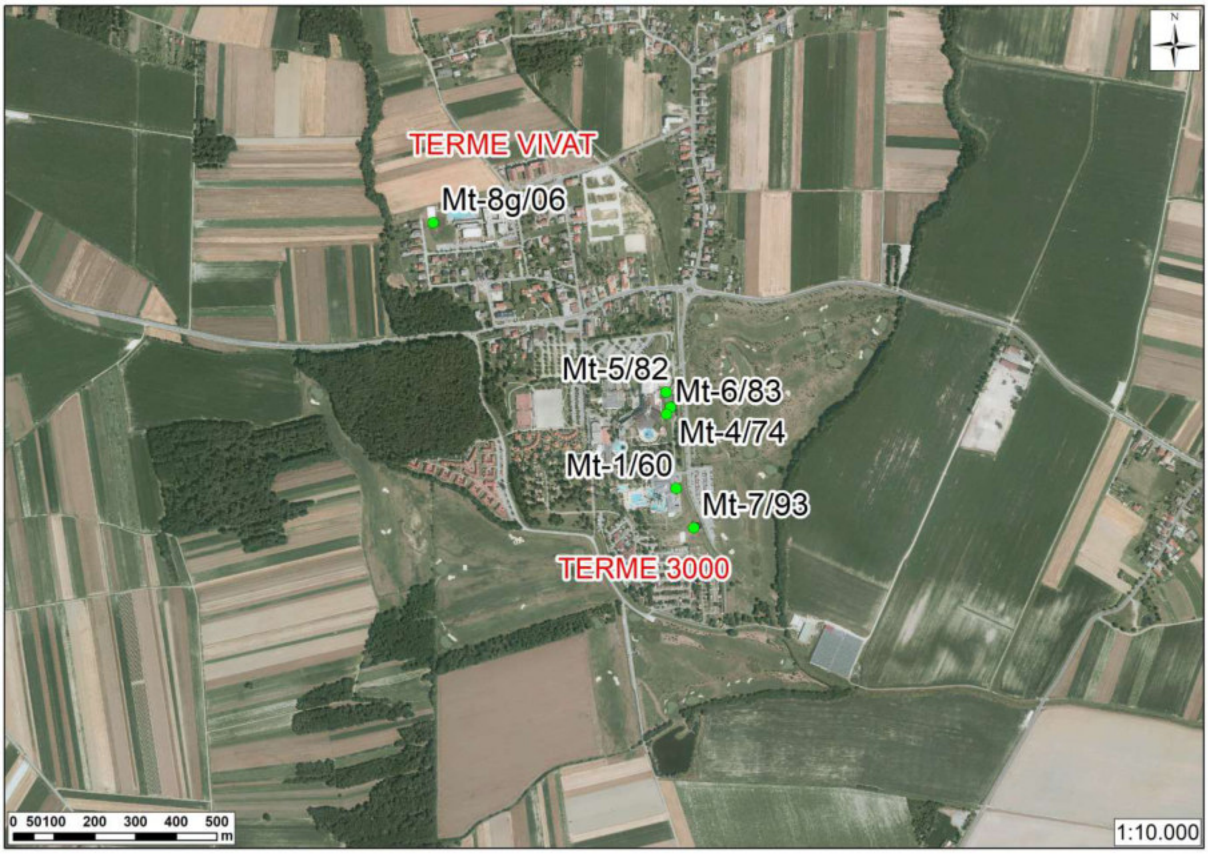


Fig. 40: Location of geothermal wells in Moravske Toplice. Mt-1, Mt-4 and Mt-5 tap the Špilje formation water while the Mt-6, Mt-7 and Mt-8g the Mura formation water

Fig. 41: Geothermal well Mt-1 with gas separator in Terme 3000 Moravske Toplice (foto: S. Mozetič)

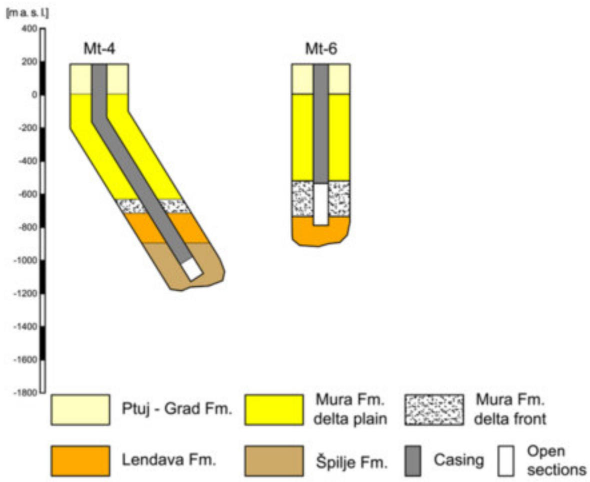


Fig. 42: Tapped aquifers in Moravske Toplice (Rman, 2016)

Thermal water from sandy Mura Formation is pumped from 700 to 1000 m depths. The initial rate reached 60 L/s but now it is up to 30 l/s. Thermal water of Na-HCO_3 type reaches 60 °C and contains 1.200 mg/l TDS (Fig. 6.2.2). In the 1990's two wells that are hydraulically connected, Mt-6 and Mt-7, respectively, worked as a geothermal doublet for some time (Fig. 42). Thereby up to app. 30 % of produced waste water from Mt-6 (at 40 – 54 °C) was returned to the aquifer through Mt-7. Injection rate was 1.0 – 5.4 L/s and the wellhead pressure 1.8 – 2.7 bars. Mt-7 was changed to production in year 2000 due to increased need for hot water. The water is used for heating the spa complex and filling swimming pools. Most of waste thermal water is discharged into a stream Ledava, and some is additionally used for heating 1 ha large greenhouse of tomatoes in the nearby Tešanovci.

In the same town, thermal water from both described aquifers is also obtained from Mt-8g/06. It is used for space heating, bathing and balneology in a near-by Vivat Spa.

Since May 2009 monitoring of the Upper Pannonian sandy geothermal aquifer is established (Fig. 43). Hourly measurements of temperature, groundwater level and abstraction rate show daily and seasonal fluctuations plus long-term trends, indicating a steady decrease in groundwater level.

Fig. 43: Gas sampling in Terme 3000 Moravske Toplice (foto: N. Rman)

8. References

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