Possibilities of geothermal energy utilization around Létavértes

A geotermikus energia hasznosításának lehetőségei Létavértes környezetében

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Abstract – A geothermal project led by the Faculty of Engineering, University of Debrecen (UD) studied the geothermal exploitation methods and utilization possibilities around the Hungarian-Romanian border, between Létavétes and Sacuieni. The research group of the Department of Mineralogy and Geology, UD determined the hydrogeothermal properties of the Hungarian part of the study area based on geological, seismic and well-log data. The variable tectono-morphology of the basement and the conditions of Pannonian sedimentation in the area allow almost all of the geothermal exploitation methods such as EGS, conventional wells, and closed shallow systems with heat pump.

The geothermal reservoirs of the area are large and separated vertically therefore at least 4 production wells and 4 injection wells can operate simultaneously below the shallow wells. The complex utilization of geothermal energy around Létavértes includes electricity generation, district and space heating, producing sanitary hot water, bathing, possible usage of agricultural and industrial purposes, and heat pump applications as well. The total amount of energy performance is estimated to be 36MW$_{th}$ and 5MW$_{e}$ that would cover a significant portion of the subregion's energy demand.

Összefoglalás – A Debreceni Egyetem Műszaki Karának vezetésével nemzetközi project keretében egy magyar-román határmenti térség földhőbányászatának és geotermikus energiahasznosításának lehetőségét vizsgáltuk Létavértes és Sacuieni (Székelyhíd) területén. A Debreceni Egyetem Ásvány- és Földtani Tanszékének kutatócsoportja a magyarországi rész hidrogeotermikus adottságait határozta meg geológiai, szeizmikus és mélyfúrási geofizikai adatok felhasználásával. A terület változatos tektonikájú aljzata és a pannóniai üledékfelhalmozódás adottságainak köszönhetően gyakorlatilag az összes geotermikus energiakinyerési mód alkalmazható a területen, mint például az EGS rendszerek, a hagyományos vízkutak és sekély hőszivattyús rendszerek.

A geotermikus rezervoárok kiterjedtek és vertikálisan elhatároltak, így legalább 4 kitermelő és 4 besajtoló kút működhet egyszerre a területen a sekély zónák ívóvizes és energetikai céllal létesített kútjai alatt. A geotermikus energia komplex hasznosítása Létevértesen kiterjedhet az áramtermelésre, távhőellátásra, egyedi fűtésre, használati melegvíz előállításra, valószínűsíthetően ipari és mezőgazdasági hasznosításra és természetesen a hőszivattyús alkalmazásokra is. A területre becsült hőteljesítmény 36 MW$_{th}$, az elektromos teljesítmény 5MW$_{e}$, melyek a térség energiaigényének jelentős hányadát biztosíthatják.

Key words – geothermal energy, Létavértes, EGS, thermal water, ground source heat pump system
Tárgyszavak – geotermikus energia, Létavértes, EGS, termálvíz, felszín alatti hőt hasznosító hőszivattyús rendszer

Introduction

In the framework of the HURO/0801/006 project entitled "Long-term utilization of geothermal energy with maximum efficiency in the area of Sacuieni-Létavértes" the research team of the Department of Mineralogy and Geology carries out the geological, hydrogeological and geothermal analysis of the study area (KOZÁK & BUDAY 2010; KOZÁK et al. 2010; PÜSPÖKI et al. 2010; BUDAY et al. 2011).

The studied area located in the eastern part of the Great Hungarian Plain, around the Hungarian-Romanian border extends over 272km^2 including a town and two villages. Létavértes has 7058 inhabitants with 2742 dwellings, while Kokad and Álmosd have further 2135 inhabitants with 1034 dwellings (KSH 2011). Two adjacent landscapes compose this area; the northern one is the Nyírség characterized by mostly inactive sand dunes and woodlands, however, the largest part of the region belongs to the arable land of the plains of the Érmellék.

In this paper the geothermal conditions of the study area are characterized based on chronostratigraphic and lithological correlations. Vertical zonation of heat utilization is established, alternative heat utilizations are described, in addition the amount of extractable energy is also estimated.

Geological setting

Basement

Due to hydrocarbon exploration near Álmosd, more than 20 boreholes were drilled in the study area (*Fig. 1*). Most of them reached the basement. They are located in the eastern part of the area, therefore surface geophysical surveys such as seismic reflection data and gravity maps are also analyzed in order to extrapolate borehole data.

Based on gravity measurements, a range of the basement arises east of Létavértes, while the depression of the Derecske Trough occurs in the western part of the study area. Seismic sections and well logs enabled the stratigrahic and lithological correlation of the Neogene sediments as well as the identification of the various ages of basement movements.

Traces of the movements along the active fault system of the subsided E-W striking basement belt appear on the surface. These resulted in shearing and dip oriented tilting of the aquifer sediments. Consequently, structural changes in the aquifers modified their temperature and pressure conditions.

The study area is located in the Tisza Megaunit, the southern part of the Pannonian Basin (FÜLÖP et al. 1987). Age of the lithological units is various and unknown in some cases due to the variable degree of metamorphism, however, the units joined together during the Palaeozoic, as the age of most of them were accepted as Palaeozoic (FÜLÖP 1989; CSÁSZÁR 2005).

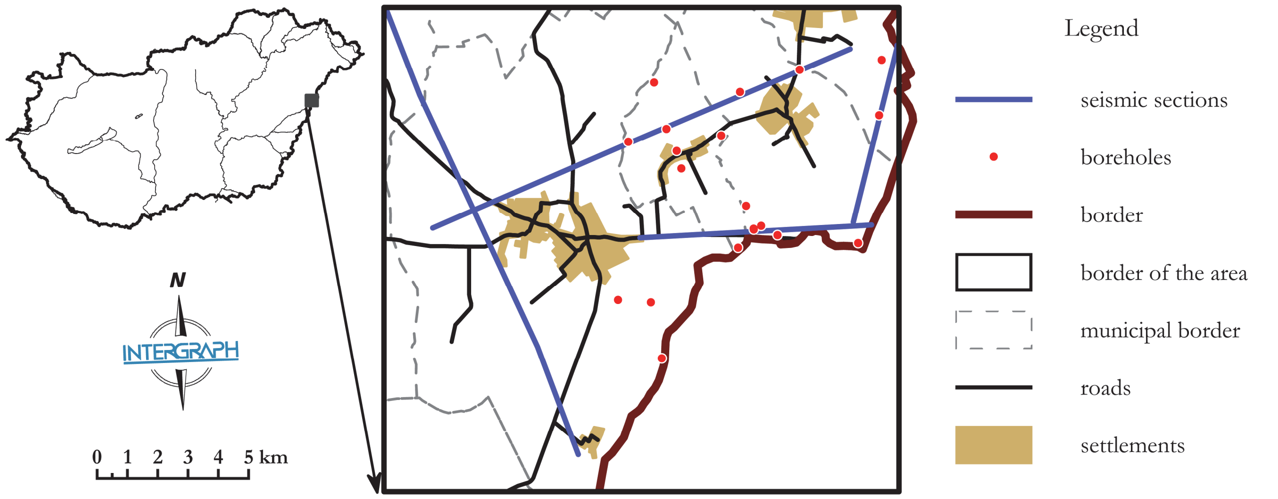

Figure 1: Model area with the seismic sections and boreholes interpreted in the lithology model
1. ábra: A modellezési terület és a litológiai modellben felhasznált fúrások, szeizmikus szelvények

The basement beneath Létavértes and Álmosd is part of the Körös Subunit of the Kunság Terrain in addition an upper cretaceous nappe is thrust over the rocks of the Körös Subunit. The Kunság Terrain and its subparts joined together during the Variscian (Hercynian) orogen cycle in the Carboniferous forming unit the development of which can be traced until the Alpine orogen starting in the Late Jurassic – Cretaceous (CSÁSZÁR 2005).

This tectonic phase resulted in a structural orientation different from the previous one, with structural lines active even today and with imbricated nappe structures in belts striking NE–SW. The study area within this is part of the Villány-Bihar Structural Belt according to the nomenclature accepted today. Thrusting of the crystalline complex onto Mesozoic formations can be detected in several boreholes in the eastern part of the unit as well (PAP 1990).

Considering the above, the basement of the study area is composed of rocks formed on and metamorphosed as enclosed in the Kunság Terrain and then re-metamorphosed in several phases in the course of the Alpine orogen. Some of the rocks can be found on the surface and exhibit structures formed mainly by the Alpine tectonic events. Seismic studies revealed that the crust is penetrated by deep faults as a result of major compression tectonics breaking into the upper mantle at places. Apart from these, the development of folding-like stacking can be observed in the section of the upper mantle directly underneath the crust suggesting quasi-plastic behaviour of the material.

The dominant rock type in the basement between Püspökladány and Álmosd is graphitizated and chloritizated biotitic type micaschist forming the Ebes Micaschist Formation (FÜLÖP 1994). This material is very close in composition to the material of the Álmosd Formation composed of strongly foliated, chloritizated, strongly sericitized two-mica schist with frequent pyrite scattering (SZILINÉ 1985, e.g Álmosd-3, Álmosd-7, Álmosd-13). Age of the Ebes Micaschist is not known, however, SZEDERKÉNYI (1998) considers in being the remnant of a nappe formed in the Upper Cretaceous as a result of Alpine tectonism.

Basin filling sediments

Pannonian sediments are laid directly on basement rocks in the study area consequently the region was a dry land during the Palaeogene. Furthermore, Mesozoic rocks were eroded strongly in most parts of the basement of the study area. As can be seen on the Pre-Cenozoic geological map of HAAS et al. (2010) only a tiny klippe of a nappe composed of Lower Cretaceous volcanites and their reworked sediments remain thrust onto a slightly greater nappe of older low grade metamorphic rocks. This nappe remnant is also thrust onto the more extended Variscian middle grade metamorphic rocks.

In the Early Miocene the main location of sedimentation was north of the Mid-Hungarian Structural Line therefore the thickness of Miocene volcanites and volcanosediments is either small (<500m) or they are not present at all in the study area due to the significant distance from the centre of volcanism underneath the Nyírség (SZÉKY-FUX et al. 2007). The thickness of the crust and the position of structural lines enabled volcanism to occur in the Derecske and Békés Depressions, however, local remnants of volcanites and volcanosediments are eroded strongly, and their origin is unknown. During the volcanism large scale marine sedimentation began due to transgression that formed extended siliciclastic sediment layers.

Geodynamism in the foreland of the Flysch Zone changed in the Late Sarmatian. Subsidence of the northern depression slowed down, while that of the southern depression intensified after the Early Pannonian. The Nyírség uplifted and the southern areas subsided following the Late Pleistocene. The marine depressions were filled by the end of the Late Miocene, and fluvial and wind-blown sand were deposited in the Great Hungarian Plane subsequently. In this facies the dynamism of sedimentation changed rapidly regarding the geological timescale due to tectonic movements and changes in the climatic conditions, therefore siliciclastic deposits are diverse and have limited extension.

In the studied region Pannonian marine sedimentation began with calceoreous marl, marl, clay marl and clay

(Juhász 1992, *Fig. 2*). These rocks are classified into the Endrőd Formation and were formed in hemipelagic facies at a depth of approximately 800m. Some near-shore abrasion platform sediments (conglomerates, sandstones) were deposited locally (Békés Formation).

In the deepest zone of the sub-basins graded fine-grained sandstone, siltstone and marl were deposited cyclically in turbidite facies. These sediments compose the Szolnok Sandstone Formation that has a great thickness in the basins, decreasing toward the margins where it disappears.

Progradation of delta systems decreased the area of deep basins and resulted in the formation of thick clay marl and siltstone units with fine-grained sandstone intercalations in the delta slopes (Algyő Formation), together with coarse delta front material (Újfalu Sandstone Formation) in significant thickness. In the delta and the alluvial plains fluvial sediments (channel, riverbank, floodplain facies) alternate with lacustric fine-grained sediments (Zagyva Formation).

During the Pleistocene 6–8 cycles of fluvial, fluviolacustric sediments were deposited. At the margins gravel, gravelly sand and sand fan deposits are characteristic. Since the main river of the region, the Tisza flowed across the study area its right side tributraries built an extended fan, the Nyírség. Due to the subsidence of the northern part of the Great Hungarian Plain, the Tisza changed its flow direction and the Nyírség became dry. During the Late Pleistocene wind-blown sand accumulated in the Nyírség.

The delimitation of the facies is made by well-logs (*Fig. 2*) and seismic sections (*Fig. 3*). The silty Endrőd and Algyő Formations have similar prints: low resistivity and poor reflections while the sandy sediments (primarily the Újfalu Sandstone Formation) are characterized by high resistivity and strong reflection. Therefore the boundary between the Lower and Upper Pannonian of the classic chronostratigraphic divison is characteristic, however, this boundary is not isochronous.

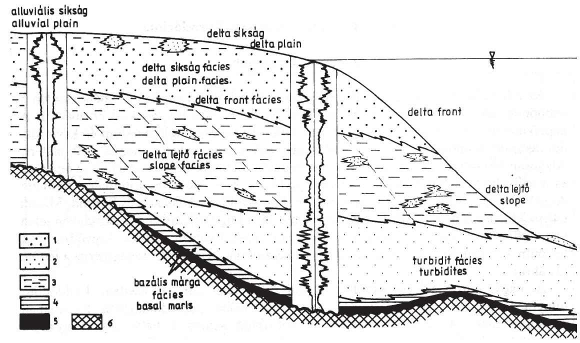

Figure 2: Schematic section of the sedimentation environment of the Pannonian s.l. basin lithofacies units and the characteristic well logs (Juhász & Magyar 1992)

2. ábra: Az alföldi medencebeli pannóniai s.l. litofáciesek felhalmozódási környezetének elvi szelvénye, a jellemző karotázsalkokkal (Juhász & Magyar 1992)

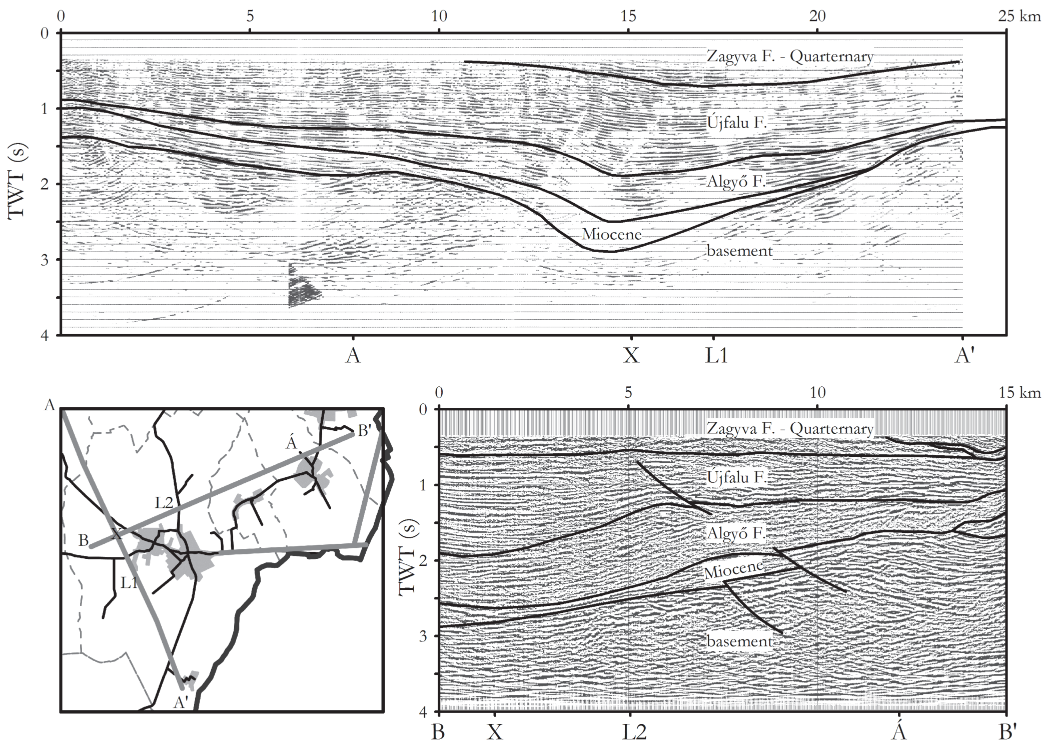

Figure 3: Characteristic seismic sections of the study area

3. ábra: A vizsgálati terület jellemző szeizmikus szelvényei

The porosity, grain-size, extension and situation of the formations determine the drilling process, the hydraulic potential of the reservoirs; therefore these features are important for the drinking and thermal water supply as well as the value of the geothermal gradient. Closeness of the enclosing mountains in the east may have importance considering the supply of groundwater near the surface and in the deep zones as well. Érmellék has good conditions in this respect as basement protrusions are relatively close, however, not close enough for the cooling effect of these supplies to be effective in the short-term.

Based on borehole data, the footwall of the Pleistocene sediments is between (185–) 250 and 350m below the surface, the top of the Upper Pannonian is between 650 and 1000m, while the base of this unit is between 1500 and 1750m. The base of the Lower Pannonian between 1885 and 2650m is thin Miocen volcanosediment layer or the metamorphic basement. According to the shape of the Derecske Trough, each surface between the stratigraphic units reaches its deepest point at the line of the BB' seismic section (*Fig. 3*).

Hydrogeological and geothermal conditions of the area

Hydrogeological consequences of the geological conditions

Lithological studies proved that the aquiclude layers of Miocene volcanosediments and the compact basement are similar from hydrogeothermic point of view in spite of differences in consistency, since the following statements describe both of them.

Porosity measurements on the cores from the deep zone (2000–2500m) show 5–15% porosity in sandstones, tuffs, tufites, however, in the borehole Álmosd EK-1 porosity exceeds 20% and compact metamorphites usually have porosity values lower than 1% (e.g. Álmosd-5). Therefore in the Pre-Pannonian sediments significant proportion (6–20%) of the energy is stored in the fluids, while in the metamorphites less than 1% of the energy is related to the fluids, the other part of the energy is stored in the solid phase. Consequently, closed heat extraction technologies can produce mainly permanent heat power, or enhanced geothermal systems shall be engineered.

Core descriptions indicate that the cored metamorphic rocks are densely jointed, slightly weathered with signs of water movement. Sub-vertical fractures often parallel to the thrust planes of basement imbrications are frequent. Brecciated character of these thrust planes is also frequent therefore they can present natural routes for water flow. In our opinion, the secondary porosity of the already present breccia zones could be further widened by artificial effects resulting in water flow in these zones faster by one magnitude than in other directions.

As a result the surface for heat exchange would develop in a wide, easily definable zone so that the hydraulic connection between the production and the injection wells could be optimised. In case these natural zones are utilised the location of the wells to be drilled has to be adjusted to these zones. Identification of the well locations can be helped by new superficial geophysical measurements and by the re-interpretation of previous geophysical data.

Carbonate rocks were explored in some cases in the basement, these rocks are probable densely fractured by tectonic movements and are full of palaeokarst features. Their extension and permeability are unknown in this state of the research. As it was mentioned before, these are the klippes of the denuded Mesozoic nappes that could have been preserved in more extended areas wedged between imbricated basement blocks along fault planes. However, their horizontal area on top of the basement is not significant even in these cases. One fine example was detected on the southern edge of the Ebes imbrication extending further towards the study area on the top of the basement according to recent investigations (HAAS et al. 2010).

These karstic rocks have hydraulic connections with the overlying siliciclastic sediments, however, in the study area the direct connection with the carbonate outcrops is precluded even in the direction of the strike of the basement. Consequently, the geothetmal potential of isolated Mesozoic basement remnants is unknown or significantly less than the geothermal potential of siliciclastic sediments with good hydraulic connections. In the case of utilization for energy purposes, the cooled water has to be re-injected into the reservoir, in addition karstic rocks sink water efficiently. Consequently, the energy of hot karstic rocks can be extracted with applying re-injection, however, in this way the temperature of the reservoir may be decreased.

Reservoirs can be formed in less porous but fractured metamorphic rocks. For example the drilling of the borehole Álmosd-13 was finished due to drilling problems at 3280m. From this zone 360m^3/d of brine water with a temperature of 93°C together with 2990m^3/d of steam and 24100m^3/d of mixed gas was produced via a 7.4mm valve. These values could be enough to operate a power plant (LORBERER & LORBERER 2010). Re-injection to a metamorphic reservoir characterized by low porosity and/or high overpressure could be uneconomical therefore the producer is not able to follow the legislation.

Hydrogeological character of Pannonian sediments depends on the conditions of deposition. Marl, calcareous marl and clay layers of the Endrőd Formation are aquiclude, the hydraulic conductivity of the Szolnok Formation is moderate, the hydraulic connection between the sand layers is subregional. On delta slopes the clay marl and siltstone of the Algyő Formation were deposited and they are aquiclude similarly to the rocks of the Endrőd Formation.

The Újfalu Sandstone Formation and Zagyva Formation consisting of conductive and horizontally connected sand layers are important for geothermal energy extraction. In hydrogeology these formations are merged into the Nagyalföld Aquifer (TÓTH & ALMÁSI 2001).

The lithology of shallow layers is diverse, each siliciclastic sediment type from gravelly sand to clay and loess occure in similar thickness. The Pleistocene sediments are connected with the drinking water reservoir. In addition the decreasing hydraulic head resulted by the water extraction of Debrecen appeared already in Létavértes (MARTON 2009).

Temperature and pressure variations by depth

Based on borehole temperature data the area of the Derecske Trough has one of the highest geothermal gradient in Hungary, its value reaches 60°C/km (DÖVÉNYI & HORVÁTH 1988). Consequently, the temperature of different heat utilizations occurs in less shallow depth than the Hungarian average. Temparature of 200°C is found between the depths of 3500m and 4000m below sea level. This value represents Cenozoic sediments in the western part of the area and basement rocks in other parts (based on map in DÖVÉNYI et al. 2005).

Temperatures measured during pumping tests and well-logging partially confirm the regional values. The geothermal gradient of 48°C/km is derived (*Fig. 4*). Temperatures of the produced fluid are higher than those measured during well-logging at similar depths by approximately 10–15°C. At the depth of the bottom of the Upper Pannonian thermal reservoirs that depends significantly on the location of the well, the temperature is approximately 65–85°C.

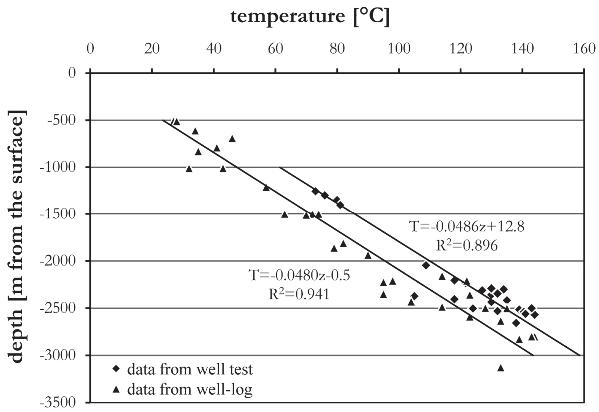

Figure 4: Connection between underground temperatures and depth in the study area

4. ábra: A kutatási területen mért hőmérsékletértékek kapcsolata a mélységgel

In the study area as well as in the central and southern part of the Great Hungarian Plain overpressure has an important role in addition to temperature. It is caused by the rapid subsidence of the area and the presence of clays and marls. Compaction hinders the pore water to migrate upward, and the effect of lithostatic pressure increases. Beside this, tectonic movements can also change normal pressure conditions.

Overpressure increases the extractable volumetric energy performance leading to efficient electricity generation. On the other hand, drilling and establishing wells are more expensive and have much risk, the isolation of reservoirs and the finite amount of extractable water cause strongly limited extractable energy with fluid production. In the exploration wells some pressure values were measured in the depth of 1100–1400m and in 2000–2500m. Completing the database with pressures derived from shallow wells, it seems that hydrostatic conditions characterize the upper 1400m, while in the depths of Pre-Pannonian rocks the pressure values exceed the hydrostatic values significantly. In some cases the extra pressure reaches 15–20MPa. Pressure conditions around the base of Upper Pannonian thermal reservoirs are unknown.

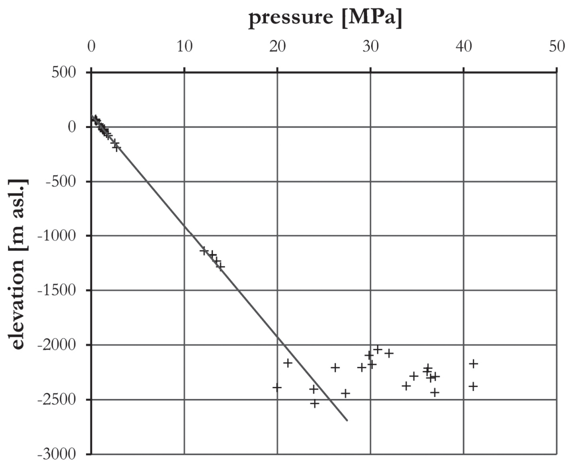

Figure 5: Connection between underground pressures and depth in the study area (values of hydrostatic pressure are marked with a continuous line)

5. ábra: A nyomás és a mélység összefüggése a modellezési területen (a hidrosztatikus nyomáshoz tartozó értékek a folytonos vonallal jelölve)

Alternative geothermal energy extraction methods in the study area

Basically, heat extraction has two main methods which are independent of the depth of the heat reservoir. Thermal water utilization is a long-established way of obtaining energy, while in a more recent method a fluid is circulated in a closed pipe system and the pipes function as underground heat exchanger. Nowadays new patents combine the open and closed systems, however, they are only pilot projects with some exceptions.

Traditional utilizations of thermal water are balneology and heating. Although water production is relatively simple from siliciclastic sediments and the cooling of the produced fluid is negligible if the reservoir is not situated too deep and the discharge rate is high enough, in some cases this method is not suitable for widespread utilization.

Establishment of a bath in the central part of the town is present in the development plans of Létavértes. Considering the significant thickness of the Nagyalföld Aquifer in the region, the amount of extractable thermal water warmer than 70°C is enough for the bath for space heating, heating sanitary hot water as well as to fill and temper the pools.

An increased water extraction can supply heat for public buildings and in addition the industrial and private sector can utilize the extra heat content of the fluids. The energetically utilized thermal water has to be re-injected into the reservoir therefore when the bath does not use all of the extracted water a re-injection well has to be drilled.

In the rural area geothermal energy is utilized by some potential agricultural users. They require lower temperature and one or several re-injection wells. Based on the Lindal-diagram, potential utilization includes greenhouse heating, drying, and breeding. Estimated heat performance of a well producing water from the above geological setting is $1.5MW_{th}$/well.

Heat content of the groundwater near the surface can be extracted by heat pumps (water/water systems). The sediments in shallow depths are usually sand, consequently water production and re-injection will operate appropriately. The most important problems with installing these systems are the time and financial relations of administration. Based on the temperature data of existing wells and the position of the drinking water reservoir, the water/water heat pump systems will not be established in the town centre, however, the dug wells out of use in the outskirts of Létavértes could be used for heating and producing sanitary hot water with permits.

Hot Dry Rock (HDR) systems and Enhanced/Engineered Geothermal Systems (EGS) use high temperature crystalline rocks as heat reservoir. The injected water warms up as it overflows the fractures and a well produces the heat with brine water. These methods can be used in porous rocks with specific conditions, however, injection may increase the hydraulic conductivity of the sediments. A large heat exchange surface formed since the cooling of the solid rocks is rapid, thus the extractable energy is relatively high, in addition the increasing injection pressure increases the performance of heat extraction. Injection induced seismicity and the high amount of solved solids cause environmental problems, while in the planning process it is important to know the temperature-depth profile and the stress field of the potential reservoir. Unexpected conditions (e.g. decreasing geothermal gradient) increase the cost and risk of investment, in addition they decrease the acceptance of the technology.

The Pannonian Basin is one of the most promising potential areas of a European EGS investigation (GENTER et al. 2003). The EGS report on Hungary (DÖVÉNYI et al. 2005) states that the Álmosd nappe and the Derecske Trough located near our study area have appropriate conditions to engineer a reservoir. Based on operating and under-construction EGSs, the expected electricity performance is 4–11MW_e/unit, which is realistic in Hungary as well. Apart from temperature, the good fracturability of rocks together with the appropriate direction of the present stress field are also important conditions. Orientation of secondary porosity forming during artificial cracking depends on the lineation and folitation conditions of the rocks, their tectonic position and on the definitive pressure directions of the stress field anisotropies prevailing in the geological block.

Considering deep heat mining suitable for electricity production, the most important factor is the optimal geological condition. In the case of multipurpose (cascade) thermal water utilization, companies concerned should be located near the well and utilization may be placed out of town. The estimated electricity and heat performance of a system is approximately 5MW_e and 10MW_{th} respectively. Plans of a geothermal power plant and a thermal water utilization system based on hydrocarbon exploring wells in which the predicted performace is of similar magnitude exist (TANCZENBERGER 2003).

A closed system extracts lower heat performance, however, its sensitivity to geological conditions is lower than that of an open system. Utilization does not require re-injection wells, hydrogeological modelling, heat transport modelling of re-injection and hydrological permits.

Vertical closed systems of Borehole Heat Exchangers (BHE) can be placed at any depth zones. Material of the pipes depends on this depth. It also determines the temperature of the geological environment. This temperature decides whether the installation of a heat pump is necessary or the temperature of the fluid heated by the geological environment is enough to utilize energy by a traditional heat exchanger. Due to the heat exchange processes underground and on the surface, the utilizable temperature is significantly lower than the reservoir temperature.

The most rapidly advancing geothermal utilization applies a BHE or horizontal collector with heat pump (soil/water systems). During heating operation the temperature of the fluid flowing back to the heat pump is lower than the original soil temperature. The amount of extracted heat depends on the parameters of the heat pump and the yield of the circulated fluid. Intensive heat extraction causes overcooling, the temperature of the fluid and the backfill in the borehole decreases below 0°C (BUDAY 2009). Therefore the COP and SPF values are decreased, energy extraction becomes more expensive. To avoid the damage caused by freezing the ground coupled loop is filled with antifreeze fluid that can contaminate the environment in case a pipe is broken. The typical heat performance of a system is in the magnitude of 10kW/unit.

In the case of private buildings in the town centre and urban built-up areas (*Fig. 6.*), application of horizontal collectors is not suitable, due to the thin lots and high areal building-to-land ratio. Vertical BHE systems for a house with normal heat demand that have enough space around require 1 or 2 boreholes. In the suburbs and the rural built-up areas the plotsize is enough for the setting of the system, however, agricultural machines deform soil structure at the depth of collectors therefore the area of collectors cannot be used in the household.

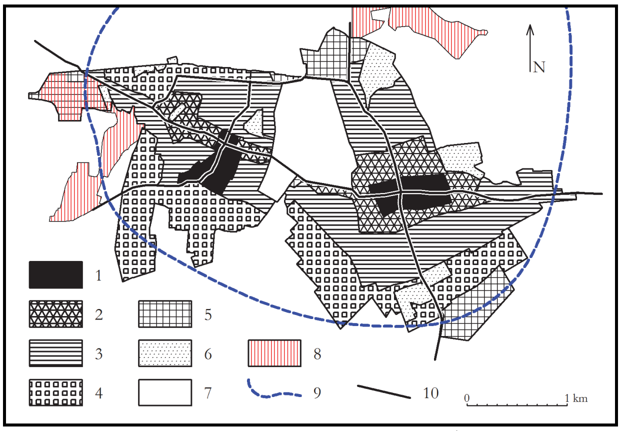

Figure 6: Simplified lay-out plan of Létavértes (CÍVISTERV 2007)
Legend: 1, town centre; 2, small-town residential area; 3, suburb; 4, rural residential area; 5, industrial area; 6, other; 7, planned open-air bath and spa; 8, area of Natura 2000 network; 9, contour line of drinking water source protection zone; 10, road

6. ábra: Létavértes egyszerűsített szabályozási terve (CÍVISTERV 2007)
Jelmagyarázat: 1, településközpont; 2, kisvárosias lakóterület; 3, kertvárosias lakóterület; 4, falusias lakóterület; 5, gazdasági terület; 6, egyéb; 7, tervezett strand és gyógyfürdő idegenforgalmi központ; 8, Natura 2000-es terület; 9, az ivóvízbázis védőterülete; 10, utak

Despite higher heat demand, placing horizontal or vertical collectors around public institutions (e.g. schools) is possible due to the size of the lot. Considering the fact, that the location of such institutes is in the town centre, where the potential district heating will operate, the portion of the two systems should be determined in the framework of a complex utilization plan.

Within the water source protection area of Létavértes deeper boreholes can be drilled only following an Environmental Impact Assessment. Therefore the construction of groundwater and BHE systems is now more complex, more expensive and takes longer time than before. There are two areas designated as Natura 2000 network of protected areas north and west of Létavértes that make the installation of BHE systems at the margin of the model area more difficult.

Although BHEs in deeper zones are promising, their construction has not started yet due to the high cost of investment and long payback period. The deepest systems have two other problems: increasing heat advection and decreasing cooling through the casing in the shallow zone. Numerous patents try to solve these problems (e.g. KOVÁCS & KOZÁK 2007), however, instalment of such systems increases costs significantly and their effectiveness is yet to be proven in practice.

Conclusions

For widespread geothermal utilization in a given geological setting it is important to compare the alternative heat extraction methods to each other, since the demand of the users, the return of the investment, sustainability and environmental protection considerations may require different methods, which can disturb the operation of the other extraction. To exploit the heat of the complete levels, the ratio between the different methods should be optimized based on the local conditions and demands.

In Létavértes the temperature of the deep Palaeozoic-Precambrian basement and that of the filling sediments in its subbasins exceed 150–200°C which is appropriate for electricity generation. In addition, this zone is accessible with low drilling costs even in international comparisons. In the rocks with relatively high secondary porosity, especially along the tectonically active breccia zones significant fluid movement can be induced, consequently, the area is suitable for EGS. Closed BHE systems could also be installed due to the relatively favourable drilling conditions. Based on recent knowledge, permanent water production from these zones is impossible. The total amount of extracted energy in the area from the deepeset zone is approximately $20MW_{th}$ and $5MW_e$. Based on the size and geothermal conditions of the area another smaller system could be operated with an approximate extracted energy value of 10 MW_{th}.

The thermal water reservoir can supply two or three wells in different subreservoirs. The deepest part of the Újfalu Sandstone Formation is located below Létavértes, and the temperature of the water produced from this formation is enough for district heating and industrial processes. Moreover, the heat and water supply can sustain a thermal spa. Another well will be placed east or south of Létavértes, depending on the location of the systems mentioned in the previous paragraph. Although there is agricultural heat demand in the whole area, space heating can be imagined also near Kokad and Álmosd, however, in case of excess energy new industrial works will be established. Possibilities of thermal water utilization in the project area are detailed by CSOMÓS (2011) and KULCSÁR (2011), while possible systems are showed by HALÁSZ (2010). The total performance of heat energy from thermal water will be able to reach approximately $5MW_{th}$.

Létavértes has good conditions for the extraction of low temperature energy as a consequence of the presence of sandy layers and upward migrating groundwater. The advancement of heat pumps depends on the financial position and attitude of the investors apart from the planning and permission processes. Thus, the geothermal potential of heat pump systems in individual houses is $2MW_{th}$, the real performance value in the future may increase by $0.5MW_{th}$ in Létavértes and by an additional $0.5MW_{th}$ in other parts of the area (Kokad, Álmosd and rural parts).

In summary, the total amount of energy power obtained by the full geothermal utilization of this subregion is estimated to be $36MW_{th}$ and $5MW_e$, however, the annual energy consumption depends on the state of the buildings and existing building services devices.

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