European Geothermal Congress 2013
Pisa, Italy, 3-7 June 2013

Possible simultaneous heat extraction from geothermal reservoirs at various depths in East Hungary, a case study of Létavértes

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Keywords: simultaneous heat extraction, GSHP, EGS, Upper Pannonian aquifers.

ABSTRACT

Increasing geothermal energy production is to be accomplished by the extraction from all aquifers simultaneously. If there is need for local energy sources, by adequate planning such individual complex systems can constitute the basis of a subregion's energy supply. Certain systems can lead to local overproduction since many of them aim to exploit from the same depth. As a result, extractable power lags behind the planned value. If extraction is carried out from different depths interference may occur, however, to a far less extent.

The purpose of the paper is to quantify the total available geothermal power of a specific area in East Hungary from each depth considering the local natural and regulatory environments. The conditions presented characterize east Hungary in general, only the depths of the reservoirs are different. Therefore the applied technologies are the same only the produced heat powers differ slightly.

1. INTRODUCTION

The amount of extracted geothermal energy around a settlement increase in case of simultaneous heat extraction at various depths. This process is somewhat different from the cascade geothermal energy utilization, since the energy used at different temperatures is derived from different depths. Consequently, the impacts of heat extraction (e.g. decreasing temperature or reservoir pressure) are less characteristic.

In the case of simultaneous heat extraction, the owners of the systems are generally different. The total investment is higher due to the higher number of drillings as well as the independent studies, plans and permissions. However, these systems are able to operate independent from each other, and smaller investments could be favourable even if the same owner operates systems producing from different depths provided the systems were installed at different times.

It might prove to be a significant problem, however, that systems installed separately can have interactions that cannot be considered at the time of installation. Furthermore, systems installed earlier may influence negatively heat extraction possibilities from other depths as well. Avoiding such mistakes can be based on surveying geothermal conditions and determining roughly the extraction possibilities at subregional level.

2. STUDIED HEAT EXTRACTION TECHNOLOGIES

Létavértes is a small town in East Hungary with a population of around 7000 people. Beside the private buildings numerous public buildings (e.g. town hall, schools, and nursery-school) and small companies require energy for heating and producing sanitary hot water (SHW).

Based on the possibilities described in the next chapter, geothermal energy extraction from each depth for heat energy utilization and electricity has been studied. Although in Hungary the most common methods are thermal water extraction and the utilization of ground source heat pump, other methods are also discussed such as enhanced geothermal system, GEOHIL system, and deep borehole heat exchangers.

This paper does not contain the details about the current and future heat demand of different buildings. These were described in different research reports (Csomós 2011, Halász 2011). The local government is committed to decrease the heat demand of public buildings as well as to develop the industrial and agricultural sector. All of the energy extraction methods could be applied in a few years provided the financial background is forthcoming.

3. GEOLOGICAL SETTING

3.1 Basement

Data of more than 20 boreholes and surface geophysical surveys (e.g. seismic sections, gravity maps) were studied to explore the geological conditions of the study area and to develop heat transport and hydrodynamic models in order to determine the electric and heat power of the potential production units (Fig. 1).

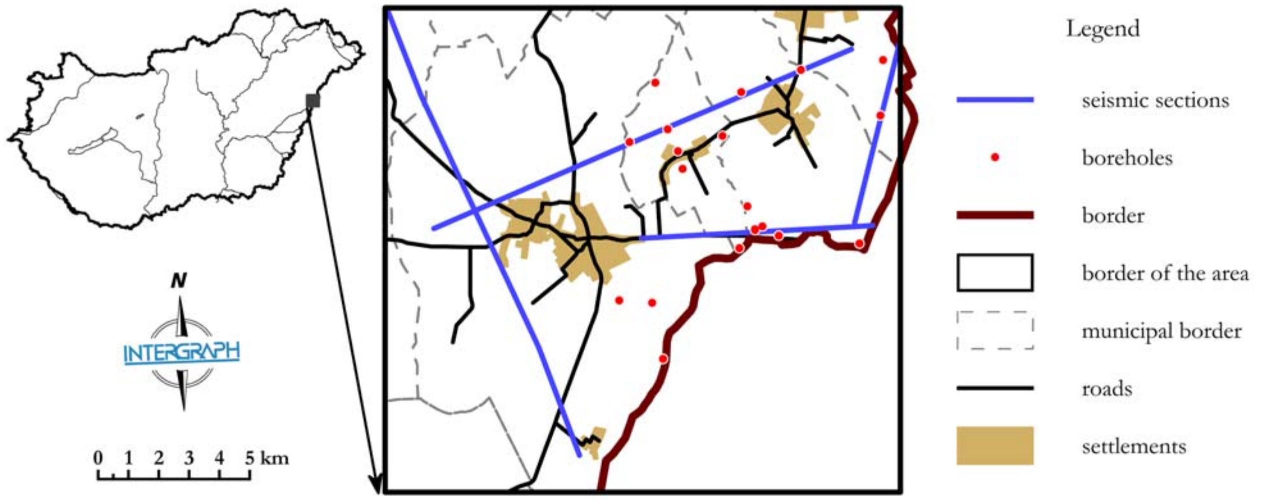

Figure 1: Model area with the seismic sections and boreholes interpreted in the lithology model

A characteristic feature for the basement composed mainly of Variscan middle grade metamorphic rocks is a trench striking SW-NE that can be interpreted as the continuation of the Derecske Trench.

Movements along the active fault system of the basement resulted in shearing and dip oriented tilting of aquifer sediments. Temperature and pressure conditions in the aquifers were modified by the structural changes.

The model area is located in the Tisza Mega-unit, and the basement of the area beneath Létavértes and Álmosd is part of the Körös Subunit of the Kunság Terrain. The Kunság terrain started to develop in the Carboniferous and this can be tracked until the Alpine orogen (Császár 2005).

This orogenesis formed mostly the structural pattern we know today. Imbricated nappes and variously active structural lines (thrusts mostly) form NE–SW striking belts. The model area is located in a belt like these called Villány-Bihar Structural Belt. Several boreholes expose thrusting of the crystalline complex onto Mesozoic rocks within the structural unit (Pap 1990).

Rocks formed and metamorphosed and then during the Alpine structural events, re-crystallized in the Kunság terrain compose the basement of the study area. Structural settings detectable today are formed mostly by Alpine tectonic events. Elements of multiple folding with double orientation are evidenced in geophysical sections, however, those with northern, northwestern vergence are dominant. Seismic studies also show that deep faults reaching at places as deep as the upper mantle penetrate the crust. Both ductile and brittle structural elements indicate major compression tectonics and significant shortening.

Material of the Ebes Micaschist Formation (Fülöp 1994) composed mostly of graphitized and chloritized biotitic micaschist is dominant in the basement in the surroundings of Létavértes. The other important formation in the area is the Álmosd Formation the material of which regarding composition is very close to the strongly foliated, chloritized, strongly sericitized two-mica schist with frequent pyrite scattering of the Ebes Micaschist (Sziliné 1985, e.g. Álmosd-3, Álmosd-7, Álmosd-13). According to Szederkényi (1998) the Ebes Micaschist is the remnant of a nappe formed by the Alpine tectonism presumably in the upper Cretaceous, however, its age is not known exactly.

Zones of strong ductile and brittle deformation (fold fronts, thrust planes with breccia zones at nappe systems or imbrications) may have a key role in the extraction of geothermal heat as rocks in these zones are in a fractured state naturally. In other areas presumable artificial fracturing would be necessary to achieve sufficient heat content.

3.2 Basin filling sediments

The basement is overlain by clay and clay marl sediments of the Pannonian Lake. Mesozoic rocks were eroded from the majority of the study area, only a small nappe remnant of Lower Cretaceous volcanites and their reworked sediments are found thrust onto older low grade metamorphic rocks (Haas et al. 2010). The Miocene volcanites and volcanosediments so widespread and immensely thick north of the Mid-Hungarian Structural Line (Széky-Fux et al. 2007) are practically missing in the study area. Large scale marine sedimentation resulted in the development of extended siliciclastic formations.

Due to intensive structural activity in the second half of the Miocene the subsidence of the northern vicinity of the study area became slower while the southern depression started a rapid subsidence. By the end of the Late Miocene marine depressions were filled and terrestrial sedimentation intensified resulting in the deposition of fluvial and wind-blown sand in the Great Hungarian Plain. Tectonic movements and climatic changes made sedimentation dynamism and facies variable resulting in diverse siliciclastic deposits with limited extension.

The calcareous marl and clay marl and clay of the Endrőd Formation (Juhász 1992) were deposited in the Pannonian sea at a depth of around 800 m. Local near-shore conglomerates and sandstones compose the Békés Formation. Turbidite facies, cyclic deposits of marl, siltstone and graded fine-grained sandstone formed in the deepest zones compose the Szolnok Sandstone Formation that is thick in the basins but thins out at the margins. Thick clay marl and siltstone intercalated by fine-grained sandstone of the Algyő Formation and the thick coarse delta front deposits of the Újfalu Sandstone Formation indicate the progradation of delta systems and the reduction of deep basins. Fluvial sediments and lacustrine fine-grained sediments alternate in the delta and alluvial plains (Zagyva Formation).

The Pleistocene is represented by fluvial and fluviolacustrine sediments in an extended alluvial fan. In the drier periods the fine material of the alluvial fan was blown-out by wind and wind-blown sand mixed to fluvial sediments were accumulated.

The above formations all have their characteristic seismic attributes based on which their delimitation is possible using well-logs and seismic sections.

Thermal water supply together with the geothermal gradient are influenced by the extension and setting, the porosity and grain-size of the above formations. The area around Létavértes seems to have good conditions also regarding nearby enclosing mountains as adequate sources of groundwater both near the surface and in deep zones.

Borehole data revealed that the thin Miocene volcanosediment horizon or the basement rocks are found at depths between 1885 m and 2650 m. The Upper Pannonian is found somewhere between 650–1000 m and 1500–1750 m. Pleistocene sediments are located at depths between (185–) 250 m and 350 m. It is interesting to note that each surface between the stratigraphic units of the Derecske Trench has its deepest point at the line of the BB’ seismic section (Fig. 2) due to the shape of the trench.

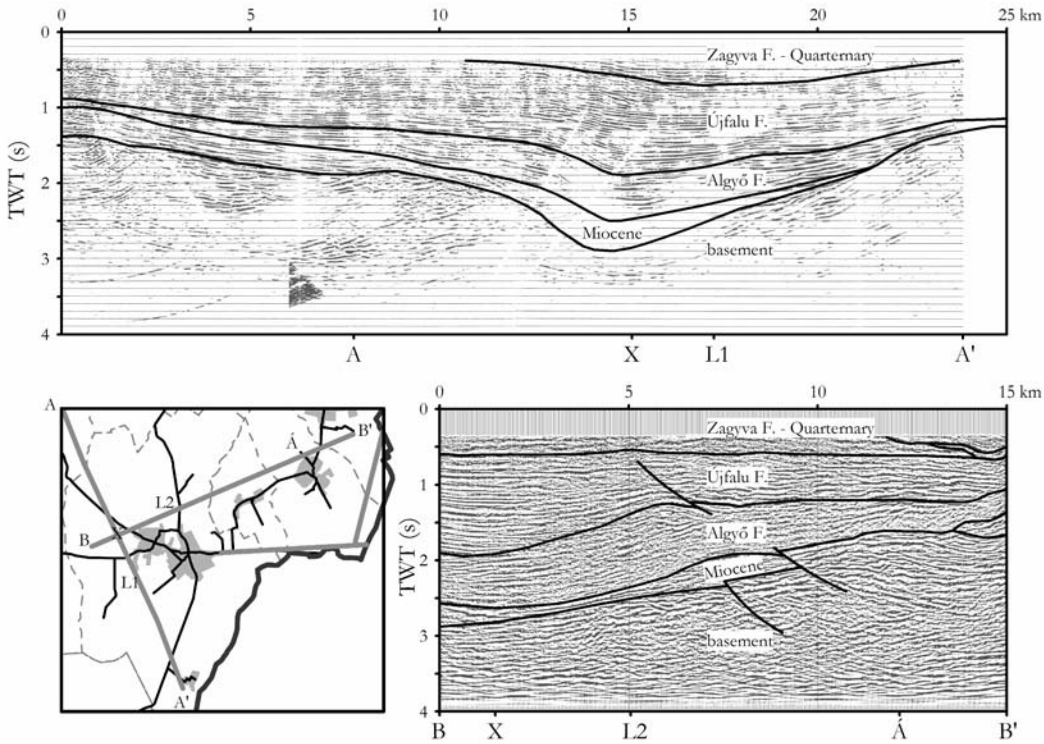

Figure 2: Characteristic seismic sections of the study area (Buday et al. 2011, Püspöki et al. 2010)

3.3 Hydrogeological and thermal properties

Despite their differences in consistency the aquiclude layers of Miocene volcanosediments and the basement rocks are similar regarding hydrogeothermal characteristics according to lithological studies, therefore the following statements apply for both.

Based on measurements on cores porosity in sandstones, tuffs and tufites is 5–15% in the deep zone except for the borehole Álmosd EK-1 where porosity exceeds 20%. Compact metamorphites generally show porosities lower than 1% (e.g. in Álmosd-5).

Based on core descriptions the metamorphic rocks are characterized by frequent sub-vertical fractures parallel to imbrication thrust planes that are frequently brecciated and weathered with traces of water movement. These could be natural routes for water flow.

Although the extent of carbonate rocks is not significant they could have been preserved as remnants of Mesozoic nappes along fault planes between imbricated basement blocks like the Ebes imbrication on the map of Haas et al. (2010). These carbonate rocks are presumably also densely fractured with palaeokarst features.

Although karstic rocks are in hydraulic connection with the siliciclastic sediments on top of them such connection is precluded in the model area. Therefore the geothermal potential of siliciclastic sediments with sufficient hydraulic connections is probably much higher than that of the isolated Mesozoic basement remnants. It is possible to extract energy from hot karstic rocks with re-injection but decreasing reservoir temperature in this way is a potential risk.

Depositional characteristics determine fundamentally the hydrogeological conditions of Pannonian sediments. Marl, calcareous marl and clay sediments of the Endrőd Formation are aquiclude, the hydraulic conductivity of the Szolnok Formation is moderate, the hydraulic connection between sand layers is sub-regional. The clay marl and siltstone of the Algyő Formation deposited on delta slopes are aquiclude as well as the rocks of the Endrőd Formation. The conductive and horizontally connected sand layers of the Újfalu and Zagyva Formations compose the Nagyalföld Aquifer in hydrogeological terms (Tóth and Almási 2001) and they can have an important role in geothermal energy extraction.

The diverse siliciclastic sediments of shallow layers have similar thickness including gravelly sand, clay and loess. Pleistocene sediments and reservoirs of drinking water are connected. Decreased hydraulic head is apparent already in Létavértes as a result of water extraction in Debrecen (Marton 2009).

One of the highest geothermal gradients in Hungary is found in the Derecske trench as borehole temperature data suggest with values as high as 60°C/km (Dövényi and Horváth 1988). Temperatures for different heat utilizations appear at smaller depths than the average in Hungary. For example, 200 °C is found between 3500 m and 4000m below sea level representing Cenozoic formations in the west and basement rocks in other parts of the area (according to map in Dövényi et al. 2005).

Regional values are partially proved by temperatures measured during pumping tests and well-logging yielding a geothermal gradient of 48°C/km (Fig. 3). Produced fluids have temperatures higher than those measured in the course of well-logging at the same depths by around 10–15 °C. Temperature at the bottom of the Upper Pannonian thermal reservoirs the depth of which depends basically on the location of the well is approximately 65–85 °C.

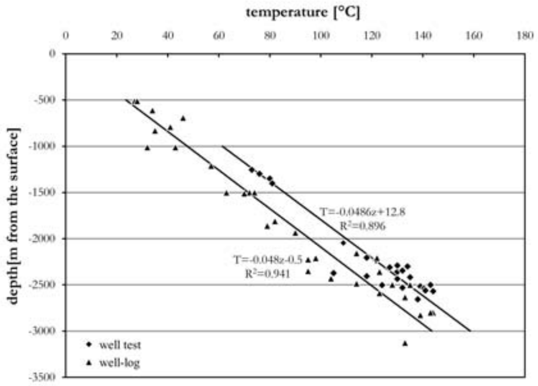

Figure 3: Connection between underground temperatures and depth in the study area

As the area is rapidly subsiding and compaction hinders the pore water present in clays and marls to migrate upward the effect of lithostatic pressure increases. Furthermore, tectonic movements also change normal pressure conditions. As a result, overpressure characterizes the central and southern parts of the Great Hungarian Plain.

Due to overpressure the extractable volumetric energy performance is increased providing efficient electricity generation. Drilling and well construction, however, become more expensive with higher risk, while the isolation of reservoirs and the limited amount of extractable water reduces significantly the energy extractable with fluid production. Some pressure values are available measured in the depth of 1100–1400 m and in 2000–2500 m in the exploration wells. Together with pressures derived from shallow wells, it seems probable that the upper 1400 m is characterized by hydrostatic conditions, while significantly higher pressure prevails in the depths of Pre-Pannonian rocks (Fig. 4). The extra pressure in some cases is 15–20 MPa while pressure conditions regarding the base of Upper Pannonian thermal reservoirs are unknown.

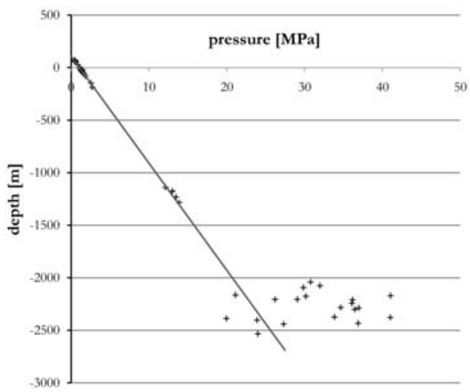

Figure 4: Connection between underground pressures and depth in the study area (values of hydrostatic pressure are marked with a continuous line)

4. RESULTS

Less than 1% of the energy is stored in fluids in the basement, the rest of the energy is related to the solid phase. Consequently, closed heat extraction technologies or EGSs are the most suitable for the deepest areas.

The Pannonian Basin is one of the most perspective areas of a European EGS investigation (Genter et al. 2003). The EGS report on Hungary (Dövényi et al. 2005) considers the Álmosd nappe and the Derecske Trench located near Létavértes to show adequate conditions for EGS technology. On the basis of EGS pilot projects the performance of 4–11 MWe/unit can be expected in Hungary as well.

Good fracturability of rocks as well as appropriate direction of the present stress field are also important. Already existing lineation and foliation in rocks, their tectonic position and the definitive pressure directions of stress field anisotropies prevailing in the geological block determine the orientation of secondary porosity formed during artificial fracturing,

Optimal geological conditions are the most important in deep heat mining suitable for electricity production. In the case of multipurpose (cascade) thermal water utilization, companies and buildings involved should be located near the well and utilization may be placed out of town. Electricity and heat performance of a system is estimated to be approximately 5MWe and 10MWth respectively. Geothermal power plant and a thermal water utilization system with similar magnitude have already been planned on the basis of hydrocarbon exploring wells (Tanczenberger 2003).

Although closed system extracts lower heat performance it is less sensitive to geological conditions than an open system. No re-injection wells, hydrogeological modelling, heat transport modelling of re-injection and hydrological permits are required for utilization

Reservoirs can be formed in less porous, however, fractured metamorphic rocks. For example drilling problems stopped the drilling of the borehole Álmosd-13 at 3280 m. Via a 7.4 mm valve 360 m^3/d of brine water with a temperature of 93°C and 2990 m^3/d of steam and 24100 m^3/d of mixed gas were produced from this zone. The operation of a power plant could be based on these values (Lorberer and Lorberer 2010). It is possible that re-injection to a metamorphic reservoir characterized by low porosity and/or high overpressure is uneconomic therefore the producer is not able to follow the legislation.

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

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. If the bath does not use all of the extracted water a re-injection well has to be drilled because the energetically utilized thermal water has to be re-injected into the reservoir.

Potential agricultural users can utilize geothermal energy in the rural area. For them lower temperature for the fluid and one or several re-injection wells are required. According to 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 1.5 MWth/well.

Regarding private buildings in the town centre and urban built-up areas (Fig. 5.), horizontal collectors cannot be applied, due to the thin lots and high areal building-to-land ratio. Vertical BHE systems for a house with average heat demand having enough space around require 1 or 2 boreholes. Plot-size is enough for the setting of the system in the suburbs and the rural residential areas, however, soil structure at the depth of collectors is deformed by agricultural machines therefore the area of collectors cannot be used in the household.

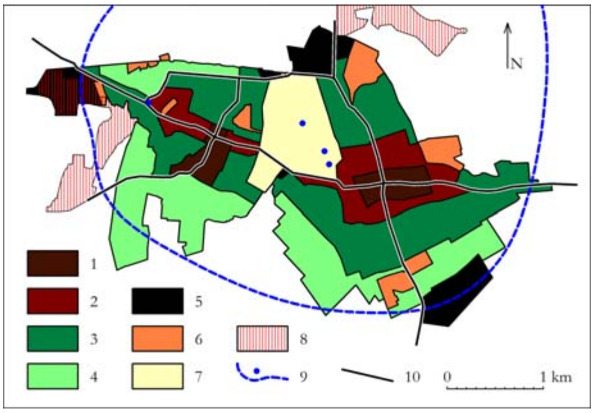

Figure 5: Simplified lay-out plan of Létavértes (Cívisterv 2007) Legend: 1. town centre, 2. small-town residential area, 3. suburb, 4. rural residential area, 5. industrial area, 6. other, 7. planned open-air bath and spa, 8. area of Natura 2000 network, 9. wells and contour line of drinking water protection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

Despite higher heat demand, installing horizontal or vertical collectors around public institutions (e.g. schools) is possible regarding the size of the lot. Since 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.

Water resource protection area was defined in the case of Létavértes as well within which establishment of wells can be permitted only on the basis of an Environmental Impact Assessment making the construction of groundwater and ground source heat pump systems more difficult. North and west of Létavértes two Natura 2000 network of protected areas at the edge of the study area make the installation of heat pump systems difficult.

Thick sediments of the Endrőd and Algyő Formations form a hydraulic barrier between the basement and the Pannonian thermal water reservoirs thus production from the different depths does not reduce the efficiency of each other. Porosity and hydraulic conductivity of the sand bodies developed in the Algyő Formation are moderate therefore their utilization for water production is limited. EGS system could be established in it with applying artificial fracturing with high pressure making it appropriate for seasonal heat storage as well.

Due to the smaller depth of the basement in the eastern part of the area the sand bodies in the Algyő Formation are in hydraulic connection with the Upper Pannonian reservoirs therefore the establishment of open systems can be recommended mainly in the western part of the study area where temperature values are higher.

Hydraulic connections between the Upper Pannonian layers and the drinking water reservoir and also between the drinking water reservoir and the shallow groundwater layers are proved. Production from all of the systems would be concentrated in the immediate surroundings of the settlement. Considering the three systems, the utilization of the shallow reservoirs is the least important from the complex utilization point of view. In addition their energy has to be produced primarily by closed subsurface heat exchangers.

5. CONCLUSIONS

Each explored geological formations can be targeted to produce geothermal energy. The geothermal gradient is about 45 °C/km thus the surface temperature of the basement is estimated to be 100-120 °C. The thrust and folded structure of the basement's upper zone has a directional stress field that enables the adoption of EGS technology, however, due to the low temperature the expected power is 4 MWe.

The geothermal energy of the deeper parts of the basement is extractable by well-designed closed systems (e.g. borehole exchangers with appropriate insulation of tubing) as the presence of limestone blocks of uncertain size and fragmentation is expected in the basement. Exposition and production of zones deeper than 2500 m in Hungary are regulated by concession agreements according to the mining law.

Temperature of the Upper Pannonian sand bodies can be as high as 70 °C and two production–re-injection systems could produce the power of 1.5 MWth each from them. In the case of a potential spa utilization the water extracted by one of the doublets would not be re-injected. Considering shallow systems the closeness of the heat utilizing constructions and spatial limitations on the surface (development plan, areas of water protection, areas of nature protection, etc.) present their primary limits as geological conditions are evenly moderate-good in the entire area.

In the case of Létavértes greatest problem is presented by water production thus the implementation of BHEs at depths less than 50 m and vertical collectors is only possible. Based on the conditions of the settlement the total estimated power of the BHE systems is 2 MWth.

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Acknowledgement

The paper was supported by the TÁMOP-4.2.2/B-10/1-2010-0024 project.