

Deep geothermal systems: a promising alternative energy source in Hungary

Máté Tóth, Viktor Hlavička, Annette E. Götz¹, Ingo Sass¹, Ákos Török² (1) *Institute of Applied Geosciences, Darmstadt University of Technology, Germany* (2) *Department of Construction Materials and Engineering Geology, Budapest University of Technology and Economics, Hungary*

INTRODUCTION

Recently, more attention is paid on renewable energy sources, since the conventional energy producing technologies have such an impact on the environment which is unacceptable. The required amount of energy can not be produced for the future based on coal-fired thermal, nuclear and combined-cycle gas-combustion plants according to the growing technical requirements of the entire population. The number of alternative methods is growing as well, plenty energy plants were established in the last years based on renewable resources such as wind, sun and hydropower. Moreover, the number of engineers and scientists is growing, with intention to replace the conservative systems to well-distributed renewable energy plants with acceptable life-expectancy and economical efficiency. Hungary is considered as a potential area for utilizing the heat of the Earth's crust, in accordance to the geothermal gradient of the Pannonian Basin. The average geothermal gradient is 0.042-0.066°C/m in Hungary compared to 0.020-0.033°C/m on the earth in general (Andristyák et al., 1995; Árpási, 1995).

Keywords: deep geothermal systems, outcrop analogue studies, thermal conductivity, permeability, reservoir, field tests, laboratory tests, geology of Hungary



Fig.1. Outcrop, Ittlinger Mühle, Simmelsdorf (DEU), photo: Mate Toth

1. OVERVIEW OF DEEP GEOTHERMAL SYSTEMS

Geothermal systems – including conventional hydrothermal systems and enhanced systems - are an option to diversify the portfolio of renewable energy sources and according to different surveys are able to produce electrical energy in commercial size, without taking numerous impacts on the environment. There are two major types of heat-mining from the earth. Hydrothermal systems have high thermal gradients, hot water stored in aquifer, the rocks have high interconnected porosity – permeability - and thermal conductivity, however it is usually a local property of an exact area. One of these mentioned conditions are always missing from EGS systems. Hungary is rich in these circumstances, for instance considering the number of well-known thermal spas such as Hévíz, Sárvár, Zalakaros, Budapest, Bük, Kehidakustány - the evidences of the absence of hot water coming upwards from numerous places from deep areas in the Central-European area, and also gives the opportunity to utilize the heat. Petrothermal system is considered as a continuum in several aspect, the grade of these systems based on a relationship between depth-temperature (geothermal gradient). Hot dry/wet rock gives the opportunity to utilize the heat, It can happen, that the rock reservoir may hot enough, but the permeability/connectivity, thermal conductivity and fracture system is not suited for water to be transported through the reservoir.

2. REQUIREMENTS FOR A DEEP GEOTHERMAL SYSTEM

Geothermal energy consists of the thermal energy stored in the Earth's crust. Thermal energy is stored in hot rock reservoirs and also in neutral fluids. In all cases, certain conditions must be met before one has a viable geothermal resource. The first requirement is accessibility with drilling, the second is sufficient reservoir productivity. 80 l/s flow rate is required for enhanced geothermal systems for sufficiency. For hydrothermal systems, rock need to be permeable, and porous to provide a long-term production at economically acceptable levels. The geothermal power plants concept is to extract the heat from the Earth's crust through wells, and the transportation fluid is the water – that may be found in the fractures in its neutral condition (Fig.2.)[1]. The geothermal reservoir operates like an underground heat exchanger. Injected water is circulated through the reservoir and is exposed to the surfaces of hot rock allowing it to remove heat. Finally, producing electricity with the usage of steam-turbines is a well-known procedure. The permeability/interconnected porosity, thermal conductivity and density measurements are required to being implemented in laboratory, but dealing only with these values are not enough to predict the whole behavior of the reservoir, structural data is required to add. If the reservoir is located in low-permeable material – dense limestone, granite etc.– the fracture system is probably not open enough for the water-flow and even the primary porosity of the rock mass is not eligible. In that case, stimulation is required to enhance the pores and fissures under pressure to make the conditions applicable.

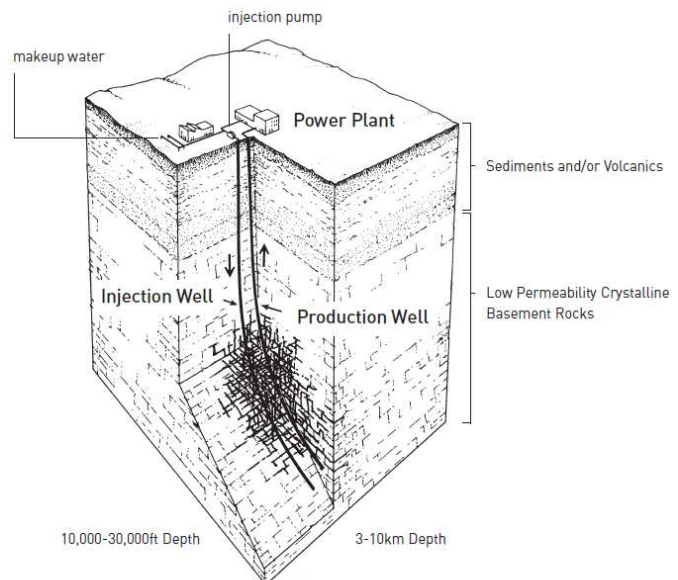


Fig.2. Schematic of a conceptual two-well Enhanced Geothermal System in hot rock in a low-permeability crystalline basement formation [1].

Injected water is circulated through the reservoir and is exposed to the surfaces of hot rock allowing it to remove heat. Finally, producing electricity with the usage of steam-turbines is a well-known procedure. The permeability/interconnected porosity, thermal conductivity and density measurements are required to being implemented in laboratory, but dealing only with these values are not enough to predict the whole behavior of the reservoir, structural data is required to add. If the reservoir is located in low-permeable material – dense limestone, granite etc.– the fracture system is probably not open enough for the water-flow and even the primary porosity of the rock mass is not eligible. In that case, stimulation is required to enhance the pores and fissures under pressure to make the conditions applicable.

3. TESTS - Description of test methods in general, through a German example

The field tests were implemented in Southern Germany, and the laboratory tests were carried out at TU Darmstadt. This procedure is even working in general, the following lines introducing a technology of estimating the suitable conditions and the common measurement methods for thermo-physical rock properties, and potential reservoir conditions.

3.1. Test methods in field

In order to analyse the potential reservoir conditions, structural tectonic data is required to assess. Outcrop analogue studies enable the determination and correlation of thermo-physical parameters and structural geology data with regional facies patterns [2]. This is a cost-efficient in-situ test method on the surface, which gives help to predict the fissure system in deeper areas. The main orientation - dip angle and dip direction - of fractures measured and these values may be later included into a 3D

structural model. The figure below (Fig.3.)[2] shows a trans-section of stratigraphic units of the Molasse Basin in South Germany, where the *Malm of the Upper Jurassic* is a promising stratigraphic horizon for the utilization of deep geothermal systems. In the corresponding outcrops located in the Swabian and Franconian Alb, nearly all lithological and stratigraphical information can be gained. The Upper Jurassic strata fit the most for deep geothermal systems, since the material is a well-fractured, porous limestone with the mean thermal conductivity value of 2-2.6 W/m/K. Other direct testing method is drilling, where exact temperature, and water-flow rates can be quantified with pump tests.

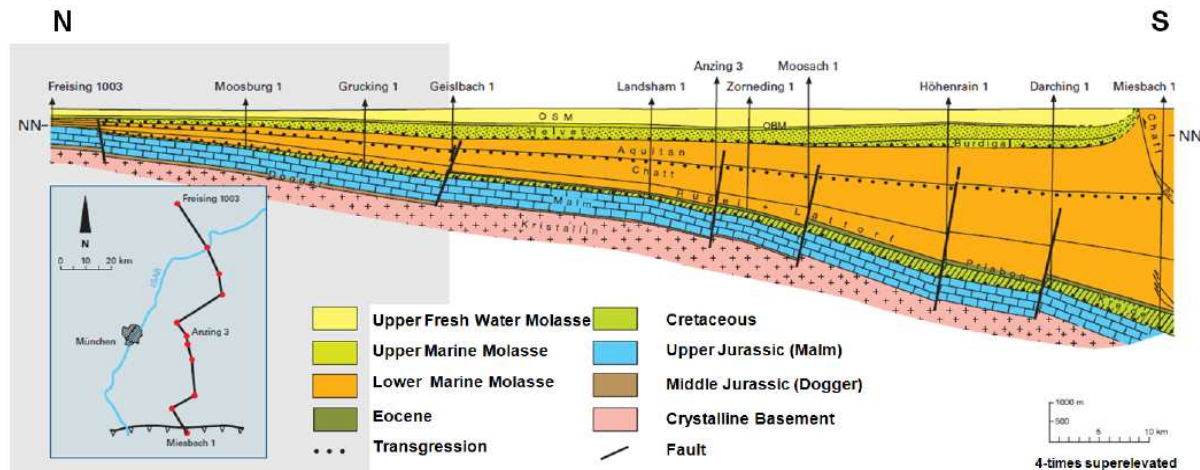


Fig.3. Cross section German Molasse Basin, Geothermal Atlas of Bavaria 2010

3.2. Test methods in laboratory

Density – Porosity: Firstly, the specimens need to be dried in oven at the temperature level of 105°C, until constant weight. The second step is to measure the weight of samples, than the gas displacement density analyzer – micrometrics AccuPyc 1330 (Fig.6.) – provide a very fast, reliable, high-precision volume measurements and density calculations. The porosity of earth materials is the percentage of the rock that is void of material [3]. In laboratory conditions, only the primary porosity can be measured, however the fractures create secondary porosity in the rock. The tests used to being implemented with Micrometrics GeoPyc 1360 (Fig.7).

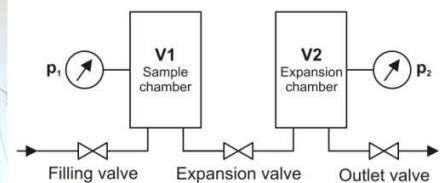


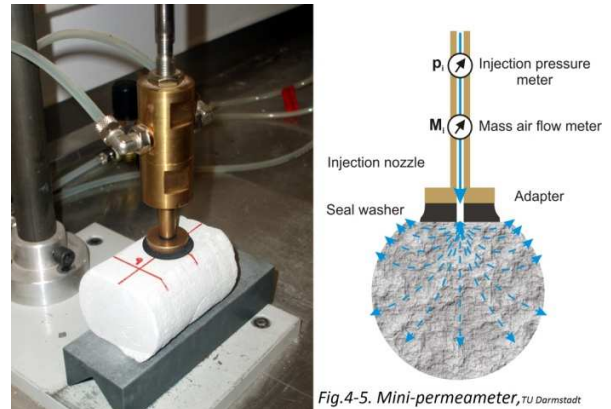
Fig.6. Gas Displ. Density Meter, TU Darmstadt



Fig.7. GeoPyc

Permeability: The intrinsic permeability of rocks due to primary openings formed with the rock and secondary openings created after the rock was formed[3]. The size of openings, the degree of interconnection, and the amount of open space – porosity – are all significant. Primary permeability can

be measured in laboratory with gas-permeameter. Secondary permeability can develop in rocks through fracturing, so the overall permeability can increase in accordance to the openings. Chemically participated rocks (limestone, dolomite, halite) are most susceptible to solution enlargement, although even ingenous rocks may also be enlarged by solution. Permeameters all have some type of chamber to hold the rock sample. The pointing device - so called “mini-permeameter”(Fig.4-5) – applies air pressure on an exact point on the specimen’s surface. The device measures how fast the pressure decreases in time, the procedure ends when the pressure converges to a certain number. Thus, the permeability for waterflow can be quantified by using a transversion factor from air to water.



Thermal conductivity/diffusivity: In physics, thermal conductivity is the property of a material's ability to conduct heat. Heat transfer across materials of high thermal conductivity occurs at a faster rate than across materials of low thermal conductivity. In the International System of Units (SI), thermal conductivity is measured in watts per meter Kelvin ($W/(m \cdot K)$).

In heat transfer analysis, thermal diffusivity (symbol: α , but note that the symbols κ , D , and k are all commonly used) is the thermal conductivity divided by the volumetric heat capacity. It has the SI unit of m^2/s . The device (Fig. 8-9.) consist of a pointing heat source with three sensors moving alongside the specimen and are able to measure at once, and plot the TC and TD values immediately. Two standards required for the procedure with known TC/TD values – made from different materials- , and are located before and behind the sample.

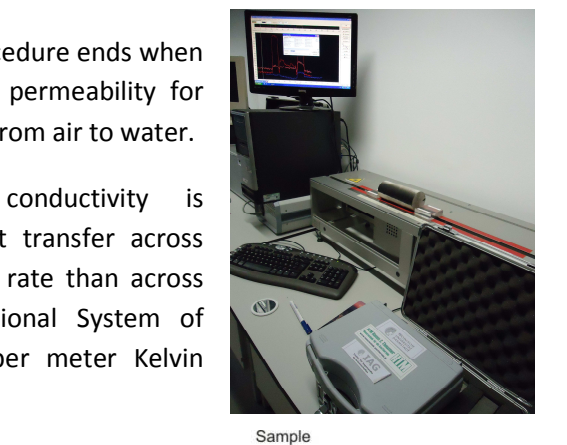


Fig.8-9. Overall and schematic view of thermal cond. scanner, TU Darmstadt

Thermo-triax cell: The concept with this device is to ensure the realistic rock circumstances in laboratory as well as axial (lithostatic) and lateral (surrounding) stress, and even the temperature can be adjusted (Fig.10.). Both fluid and rock can be individually tempered, thus allowing a wide range of testing setups to simulate reservoir conditions. In addition, aggressive water also can be circulated through the specimen in order to measure the permeability in various reservoir conditions, therefore the pressure rams made by premium steel.

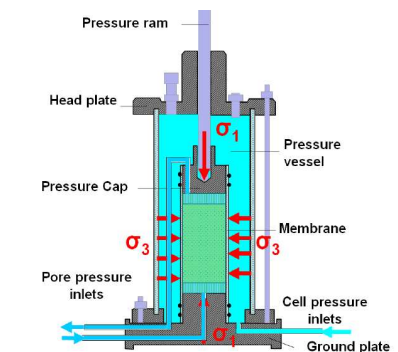


Fig.10. Schematic illustration of thermo-triax cell

4. GEOTHERMAL POTENTIAL OF HUNGARY, LOCAL ROCK PROPERTIES

4.1. Overview of Hungarian Energy Sources

Presently, Hungary depends mostly on conventional, non-renewable energy sources, all power plants are either fossil fuel or nuclear, with the exception of three small hydroelectric plants on the Tisza River in eastern Hungary. Moreover, nearly all power plants produce heat as well, providing the two-third of the heat demand. As of January 2000, Hungary had an installed capacity of 7,903 MWe (up from 7,845 MWe in 1999). Approximately 7,300 MWe is generated by public power plants; the remainder by industrial power plants. Oil and gas accounted for 48% of total installed capacity, coal for 25%, nuclear for 24%, autoproducers for 2%, and hydro for a scant 1% [4]. The significant impact on environment caused by these technologies is indisputable, and therefore other resources are needed for long-term usage. Approximately 44% of the Hungarian population lives in areas that do not comply with national air quality standards, so CO₂ emission need to be controlled in the future. However, the Pannonian Basin is still unexploited with respect to its geothermal potential, the current energy prices serve as limiting factors in the further development of geothermal power plants. The following maps and measurements deliver some scientific background of geothermal utilization and thermo-physical rock properties.

4.2. Geological maps

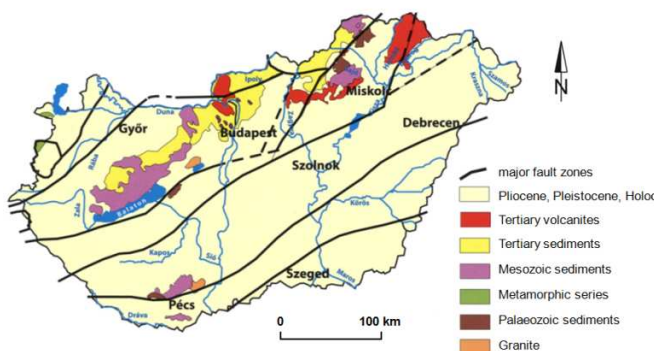
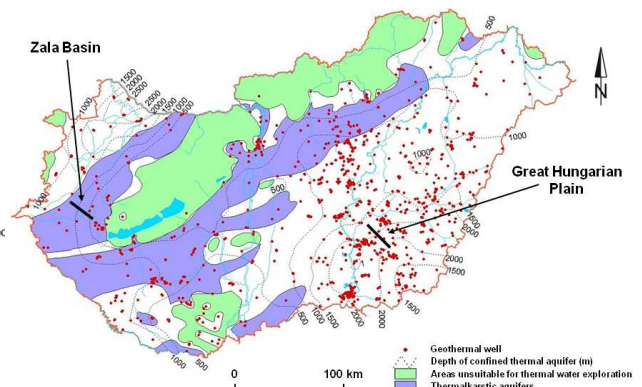


Fig.11. Geology of Hungary [6]



South. The North German Basin, where Permian, Triassic sandstone can be found. Finally, the South Molasse Basin with Upper Jurassic limestone. In Hungary, the Pannonian Basin is suitable for low-enthalpy systems. The Great Hungarian Plain is situated on a faulted impermeable basement, covered by Miocene sandstone. Zala Basin is also located on a low-permeable basement, covered by Triassic limestones and Miocene sandstones, but the strata is well-fractured and may have eligible secondary porosity and permeability for water-flow.

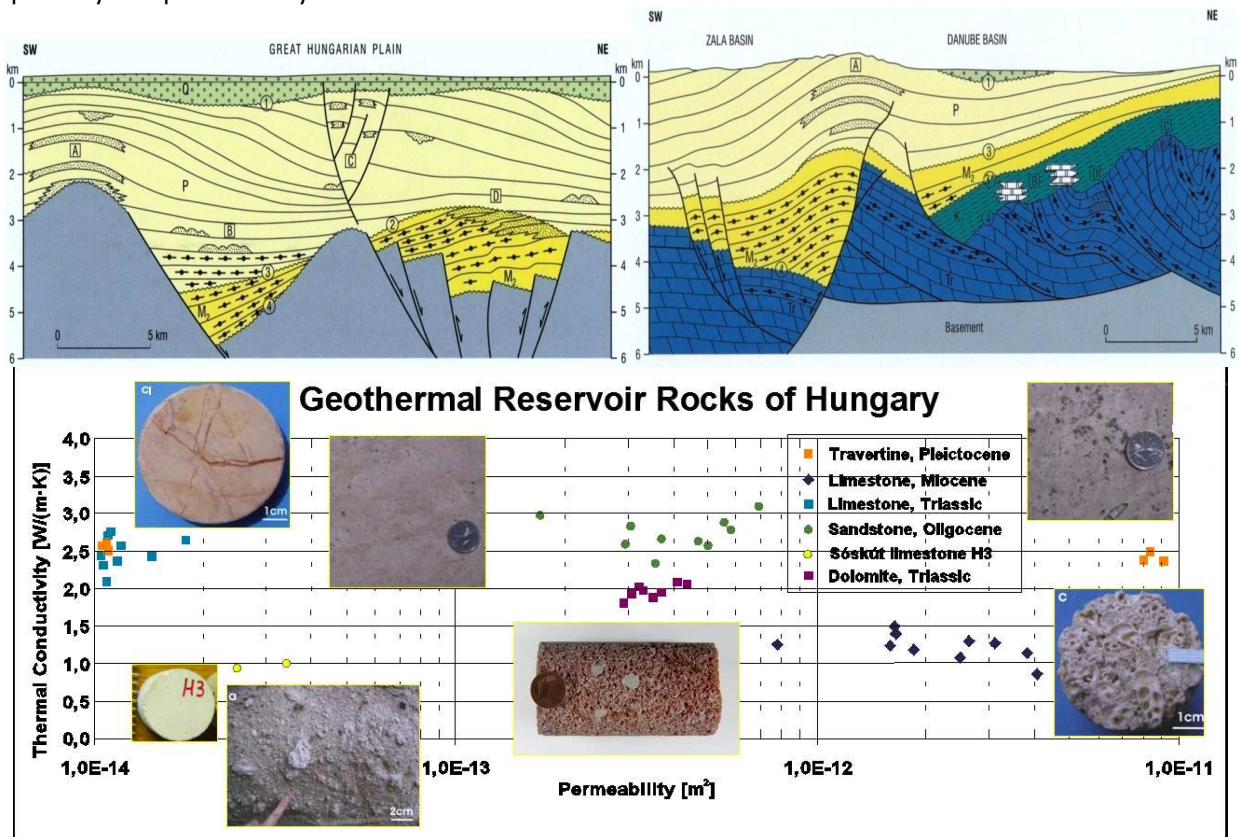


Fig. 13. Geothermal Reservoir Rocks of Hungary[5]

Hungarian limestones with higher permeability with the same thermal conductivity.

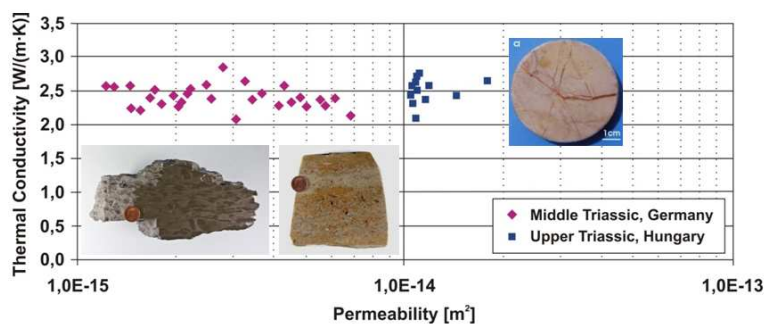


Fig.14. Comparison of limestones (Muschelkalk, Upper Rhine Graben/Main Dolomite, Buda Hills)

5. CONCLUSION

Hungary has the largest underground thermal water reserves and geothermal energy potential of low and medium-enthalpy in Europe (Boldizsár, 1967; Bobok, 1988). Thus, Hungary is a promising area for geothermal utilization due to its environmental circumstances, the Pannonian Basin is considered as a “geothermal hot-spot” according to its unique geological conditions. The earth’s crust in this region is thinner than average, because of subcrustal erosion, explaining the high thermal gradient values. The average ground flow in Hungary – 80-100 mW/m² - is also two times higher than the continental average.

The proportion of geothermal energy utilization in the energy balance of Hungary, despite the significant proven resources, is low (0.16%) (Árpási and Szabó, 2000). However, the financial matters in Hungary not makes it possible to invest for geothermal plants, extract heat and generate electricity in commercial size. Exploiting geothermal energy facilities due to the previously shown circumstances is the future of environmental friendly energy producing method in the Pannonian Basin area.

REFERENCES

- [1] *The future of geothermal energy*, Massachusetts Institute of Technology, 2006.
- [2] *Outcrop Analogue Studies for Reservoir Characterization of Deep Geothermal Systems in Upper Jurassic Limestone Formations (South Germany)* Sebastian Homuth¹; Annette Götz¹; Ingo Sass¹ (1) Institute of Applied Geosciences, Technische Universität Darmstadt, Darmstadt, Germany, 2011.
- [3] *Applied Hydrogeology* – C.W.Fetter (Third Edition), PRENTICE HALL, New Jersey 07458
- [4] *Geothermal resources in Hungary*, Liz Battocletti, Bob Lawrence & Associates, Inc.
- [5] *Geothermal Potential of Subsurface Carbonate Rocks in the Municipal Area of Budapest*, A.Götz, A.Torok, I.Sass, 26th IAS Meeting of Sedimentology – Bochum, Germany
- [6] *Geológia mérnököknek*, Török Ákos (Műegyetem Kiadó) Budapest, 2007
- [7] *Geology of Hungary*, Janos Haas, ELTE Eötvös Kiadó Kft., 2001