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## Geothermal Evaluation in Hungary Using Integrated Interpretation of Well, Seismic and MT Data

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### ABSTRACT

Mannvit has for the last three years worked on evaluating geothermal energy in Hungary. Integrated approached using different datasets has been used with good success. Before the study stated huge amount of data existed in the country mainly acquired in an attempt to find oil and gas or for scientific purposed. An extensive AMT/MT and gravity survey was performed especially with the aim of finding geothermal energy in the Triassic basement. The first geothermal exploration well, was successfully completed, close to the small town Szentlőrinc in south Hungary, in September 2009 giving 20 l/s in airlifting of over 80°C hot water with 5 – 6 l/s of artesian flow.

### 1. INTRODUCTION

This geothermal evaluation project in Hungary has been ongoing since the fall of 2007 with the aim of locating possible well sites for geothermal utilization in Hungary. Mannvit (former VGK, then VGK-Hönnun) has undertaken this work for PannErgy (former Pannonplast). The first phase of the project was to outline the areas with promising geothermal interest in all of Hungary. The second phase was to concentrate on the potential geothermal areas in an attempt to locate smaller areas for geothermal drilling. The objective is to find geothermal reservoirs that can be used to produce electricity and/or for space heating. This work is based on existing and new geosciences data from Hungary. The new data are extensive AMT/MT and gravity surveys performed by KMS Technologies for Mannvit.

Hungary is one of the most promising countries in Europe for low temperature (< 150°C) utilization of geothermal energy because of its high temperature gradient of close to 50°C/km over most of the country. This high gradient is mainly due to the thin earth crust and partly due to the non permeable lower Pannonian sediment layer that covers big part of the country. These clay and marl sediments covered the bottom of Lake Pannonian.

The main target zones for geothermal utilization is the pre-Tertiary basement rock made of limestone/dolomite layers of Mesozoic age. This kind of layers is thought to have the highest permeability, and its thickness and its extent are also significant. The mentioned targeted reservoir is below the Tertiary sediments, (i.e. Oligocene marl, Miocene conglomerate/ silt, and Pannonian sediments). Several tens of thousands of wells exist in Hungary reaching maximum up to 5 km in depth. Many deep wells drilled for oil and gas exploration have given valuable information on geology and temperature in the areas of interest. Dens net of seismic lines, also for oil and gas exploration, is available and has been used extensively in this project along with the well

data and new AMT/MT and gravity data and other available data on geology and geophysics.

The most promising geothermal areas for space heating or electrical production in Hungary are characterized by faulting that induces secondary smaller fracturing of limestone and dolomite layers of Mesozoic age at a depth of 2 ~ 3 km. These fractures result in a higher permeability and porosity, and therefore higher flow rate of geothermal waters from the wells.

It has now been proved that the fractures play a major role in geothermal development in Hungary and the emphasis is not as strongly on limestone/dolomite as before, but also on crystalline rocks that are cut by major faults. The major deep fault system is also acting as the path for the deep heat source to reach the surface.

The law in Hungary requires all geothermal water to be reinjected into the same aquifer as it came from. The default intention is therefore to drill at least two wells (duplet) in each well site area, one production well and one injection well. The exact distance between the production well and the injection well will depend on the permeability and connection between the wells within the reservoir. In most cases the distance between the production and injection wells is expected to be between 1 and 3 km. This has to be confirmed by reservoir modeling in each case.

### 2. DATA INTERPRETATION

The data used for selecting the well site (WS) areas were taken from existing wells (age of layers, rock type, temperature, fluid chemistry and yield), existing seismic lines (tectonic features and geology), and new AMT/MT and gravity data (porosity and tectonic features), as well as geological and geophysical maps, databases and articles (Almási, 2001, Árpási and Unk, 1995, Árpási et al., 2000, Bobok et al, 1998, Bobok and Tóth, 2003, Dövényi 2007, ELGI, 2005, Geologischen Bundesanstalt, 2000, Geothermal Power Project, 2005, Hungarian Geological Survey, 2002, Liebe, 2001, Battocletti and Lawrence, 2000, Horváth, 2004, Fülöp and Dank, 1987, Lorberer, 2003, Royden, 1988, Royden et al, 1983, The Geological Institute of Hungary, 1997, Tari, 1994, Tulinius et al, 2008, Unk, 2004 and USC Sequence Stratigraphy Web, 2005).

The ARC GIS software is used in the integrated interpretation of all the existing data along with other software like Grapher, CorelDraw and Surfer.

Mannvit has information on over 7000 wells in its database, but in this study the well data is the most valuable data for locating the reservoirs as well as constraining the depth and possible temperature of the geothermal reservoirs. The seismic data is used to trace the lateral extent of these rock types and to locate fault zones within these layers.

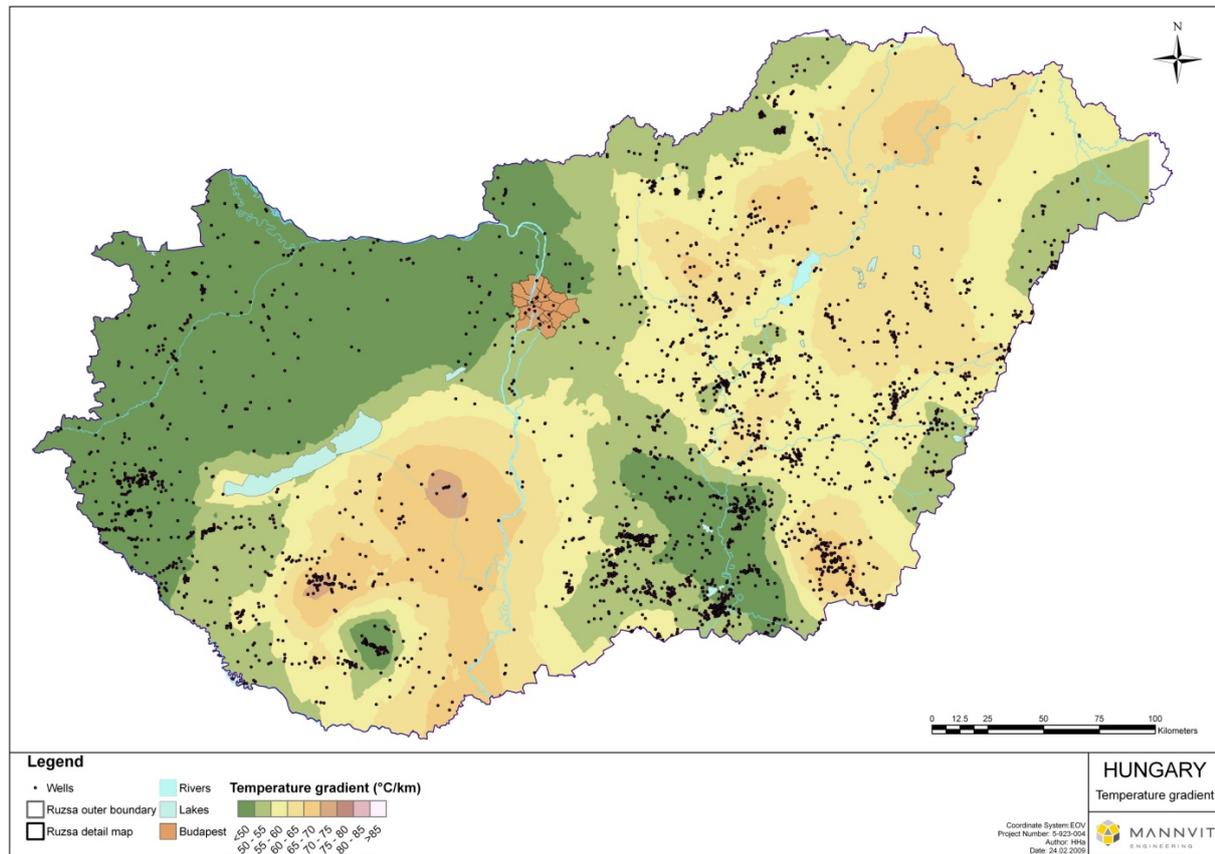


Figure 1. Temperature gradient map of Hungary made by Mannvit 2009.

Furthermore areas, where low resistivity and low gravity anomalies, outlined by AMT/MT and gravity data interpretation, also included promising structural and stratigraphical features, i.e. both fault zones (seismic) and dolomite/limestone (well data), are considered to be the most promising geothermal reservoirs. The conclusion of this work is used to evaluate the geothermal potential of the areas and to select possible drilling sites within the areas.

### 2.1 Temperature in wells

The temperature of the geothermal reservoir is one of the most important factors in geothermal utilization. Geothermal aquifers with temperature lower than 120°C are considered to have potential as aquifers for direct use (i.e. district heating). Fluid with temperature 120°C and higher is considered to be suitable for both electricity production and district (space) heating.

A temperature gradient map for all of Hungary was made by Mannvit based on available temperature data (Figure 1).

The conditions of the wells during temperature measurements are unknown. In many cases the temperature was measured shortly after drilling of the wells and is therefore likely to underestimate the true value. Only one temperature value was selected from each well to calculate the temperature gradient map. Where more than one temperature measurement was available in each well the temperature at the greatest depth was usually chosen. In a few cases a value at shallower depth was chosen, especially in cases when the temperature gradient at the greatest depth was considerably lower than at shallower depths. In general

this temperature map represents the temperature gradient from the surface down to about 2,000 m depth.

The same dataset that was used to make the temperature gradient map (Figure 1) is shown on Figure 2 as temperature versus depth. The average temperature gradient is 50 °C/km. This gradient is considerable higher than in other countries around Hungary and is mainly due to the thin earth crust and partly due to the non permeable (aquiclude) lower Pannonian sediment layer that covers big part of the country. These clay and marl sediments covered the bottom of Lake Pannonian.

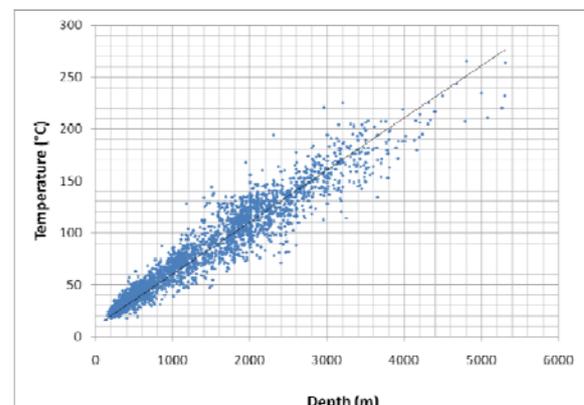


Figure 2. Temperature vs. depth for wells in Hungary.

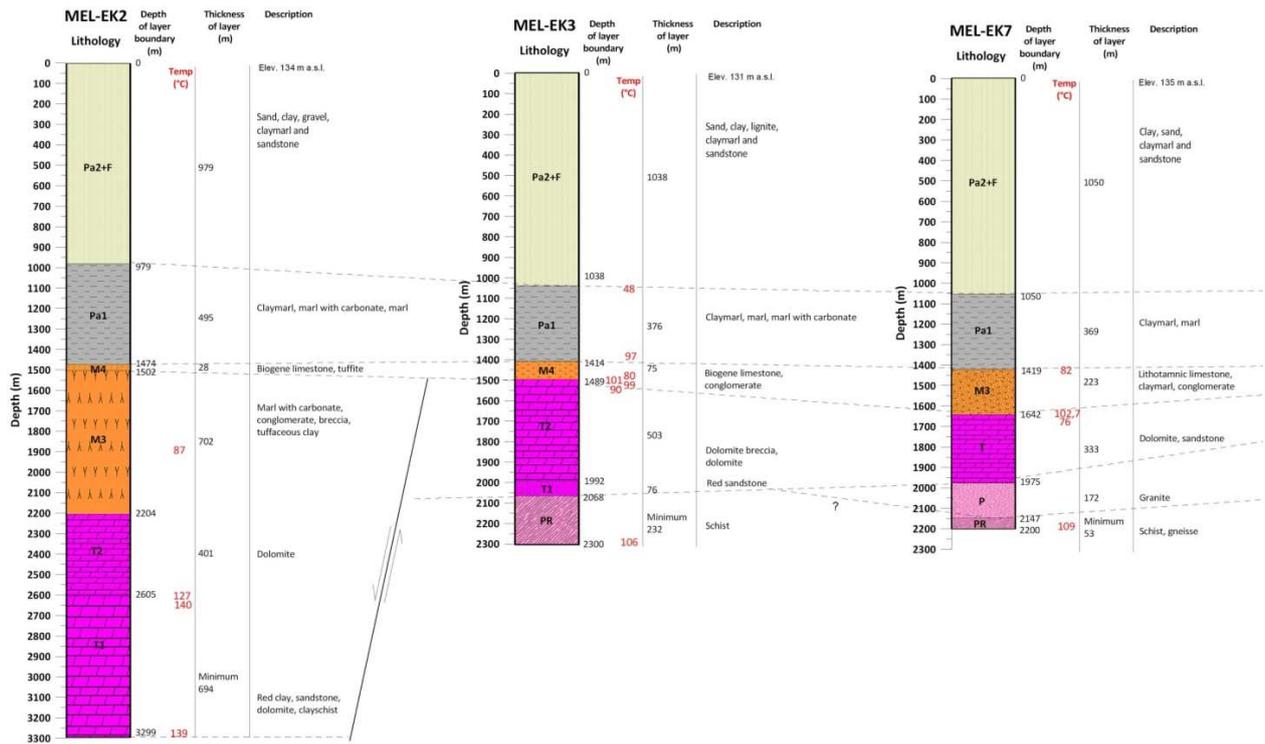


Figure 3. Lithological correlation between wells MEL-EK2, MEL-EK3 and MEL-EK7 from west to east.

### 2.2 Geological information from wells

When locating the well sites the occurrence of several types of features was considered to be of greatest importance from geological point of view. The goal was to find promising geothermal reservoir with high permeability and temperature indicated and proved by well data in karstified and fractured dolomite/limestone of Mesozoic age, fractured crystalline basement, fractured limestone of Miocene age, and coarse-grained layers of Pannonian and Miocene age.

Mannvit has information on over 7000 wells in its database. These information is of different type; eg. lithology (rock type and age), temperature, yield, chemistry and design of the wells. In Figure 3 examples are shown for some of the information that is available on wells to the project.

The available well geological data were analyzed in relation to available geological maps, and literature describing the basic lithostratigraphic units of Hungary (The Geological Institute of Hungary, 1997) among other relevant data.

### 2.3 Seismic interpretation

Close to 600 seismic lines with total length of more than 10,000 km has been available in this study. They are used together with the available well data to locate layer boundaries, fault zones and to trace interesting geological features throughout each potential geothermal region.

The quality of the seismic lines available for the different areas during this study depends on the features of interest (Figure 4 and Figure 5). The quality of the studied seismic lines can be ranked as good, medium or poor. Good quality is reflected by the observed continuity, or easy identification, of Tertiary layers and of tectonic features. Poor quality is attributed to seismic lines where Tertiary layers and tectonic features are hard or impossible to identify. Medium quality indicates that the identification of

the above mentioned features is partly possible (around 50% along the seismic profile).

The seismic data from Hungary was acquired in an attempt to find oil and gas at target depths that are shallower than the geothermal reservoirs. Therefore, it has been

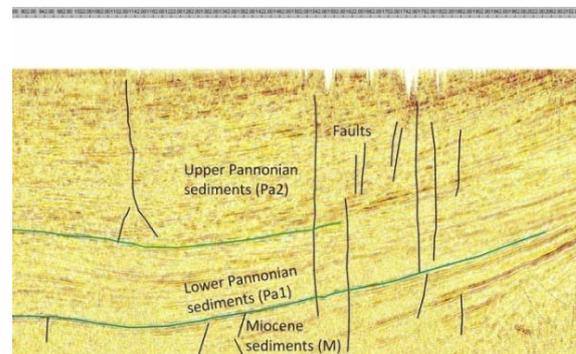


Figure 4. Example of a medium quality seismic section.

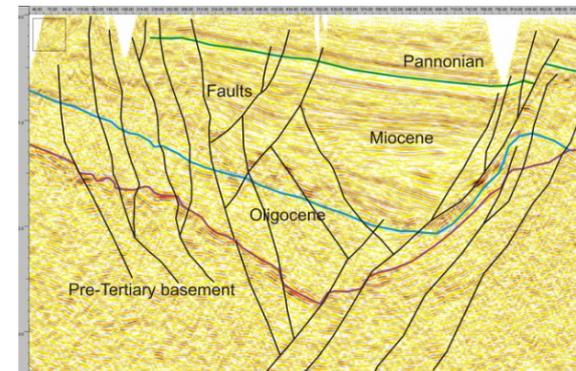
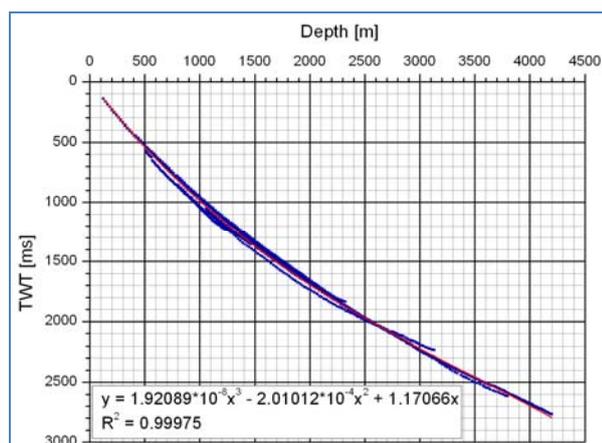


Figure 5. Example of good quality seismic section.

recommended to reprocess several seismic lines in an attempt to get better image on the basement and the tectonic features (faults) controlling the permeability and flow patterns. Reprocessing of seismic lines has improved the imaging of faults and layer boundaries.

The seismic lines all came with Two-Way-Time (TWT) in ms as a depth reference. TWT refers to the time it takes the seismic waves to travel down from the surface to the reflector and up again to the surface. To be able to convert the TWT to depth in meters information on the velocities for the different layers is necessary. In most case a VSP (vertical seismic profiles) is available close to or inside the areas of interest. Figure 6 shows an example of a TWT to depth conversion curve.



**Figure 6. TWT (ms) as a function of depth (m). Datum is 50 m a.s.l.**

#### 2.4 AMT/MT and gravity measurements

AMT/MT measurements are used to estimate the resistivity with depth. If done properly it is possible to get the resistivity in a 2 dimensional sections along a line or lines. Uniform rock formation saturated with water, has in general lower resistivity if the temperature of the fluid is higher. The formation most likely to give enough fluid for geothermal utilization is below the Pannonian formations, and the temperature is in general higher in the water bearing layer if the thickness of the Pannonian is greater. For the study here it has been assumed that the optimal temperature for electrical productions or space heating is between 90° and 170°C or at a depth between 2,000 m ~ 3,000 m.

In other words the temperature is most likely known in the layers that will be drilled into. But the permeability is not known. It is assumed that the permeability, or the ability of the formation to have water flowing through it, is rather low. It is therefore essential to look for some tectonic features that could mean more permeability. If there are some water bearing fissures it is very likely that the hot water rises up the fissure and that can be detected by the AMT/MT measurements.

To increase the chances of finding a good reservoir in Hungary an extensive AMT/MT survey was performed in several locations all around the country. To get better constrains a gravity survey was also performed along the same AMT/MT profiles with much denser spacing (250 m).

The survey was set out in such a way that the AMT/MT could be interpreted as 2 dimensional (2D) lines with the help of the gravity data measured on the same line. To help in the interpretation of the AMT/MT and gravity data

Geological cross sections were made at the same location as the survey lines (Figure 7). The geological cross sections were based on available well data, seismic data and other sources of geological information. These geological cross sections were used to constrain the 2D interpretation of the AMT/MT (Figure 9 and Figure 10) and gravity data (Figure 10).

Four components were measured in the AMT/MT surveys in Hungary, i.e. the X and Y components of both the magnetic and electrical fields. In order to identify the responses for electric currents flowing along the structure or the transverse electric (TE) and currents crossing structures or the transverse magnetic (TM) modes, the geoelectric strike was calculated for a set of sites in the frequency range between 10,000 Hz ~ 0.001 Hz in each survey area

Total of 468 AMT/MT sites and close to 1900 gravity stations were measured along 45 lines in 27 areas. The locations of the survey lines were chosen in the most promising areas after phase one. The location of railroad track, road and building had to be taken into account when selection the location of the AMT/MT sites. Protected areas (drinking water, Natura 2000 and other protected area) were avoided. The data quality was in general good, but few sites close to Budapest had too much noise for definite interpretation. The AMT/MT and gravity data has given valuable information when locating well sites in Hungary.

#### 2.5 Integration of geological and geophysical data

By the integration of well data, seismic data, AMT/MT and gravity data a clearer and more transparent interpretation result evolves. Figure 8, Figure 9 and Figure 10 show the different dataset along a cross section.

During this phase the emphasis was to outline potential geothermal reservoirs (eg. Triassic, Miocene, or Upper Pannonian aquifer) and to select well sites indicating the target depth, the expected outflow temperature and yield of the expected reservoir.

### 3. THE FIRST DRILLING AT SZENTLŐRINC

The first geothermal well was drilled in a small town in south Hungary called Szentlőrinc in 2009 (Figure 7). Two AMT/MT and gravity lines were carried out there and data from 4 seismic lines were available in the area. Information on several wells was also available, but non deeper than 1,000 m. The temperature gradient was calculated from temperature measurements in these wells. The AMT/MT and gravity data integrated interpretation indicated potential geothermal zone close to stations 11 and 12 (Figure 7 and Figure 10). A seismic line GÖ-3 (Figure 8) runs almost parallel to the AMT/MT survey line and was used to locate faults in the vicinity of the resistivity anomaly.

From the above data a well site was decided, the next step was then to buy land and apply for permits to drill and test a well. When the land was acquired the seismic data was used to design the well. The drilling started in February 2009 and was supposed to take 70 days. Because of some technical difficulties it took over 200 days to complete the well down to 1,820 m. The crystalline basement was reached at 1,330 m depth. From there and down to the bottom of the well several feed points can be seen in the temperature, caliper and sonic logs. The well is cased down to 1,600 m depth and slotted liner is from there to the bottom. The biggest feed point is from 1,700 m ~ 1,760 m depth, but several other feed points can be seen in the well.

In the end of September 2009 the maximum temperature measured in the well was 95°C at 1,820 m, and is still increasing. The well is artesian with 5 ~ 10 l/s water flow. With airlifting more than 20 l/s was produced from the well with over 80°C hot water. The expected outflow

temperature is estimated to be over 90°C and from the airlifting period it is estimated that 20 l/s can be produced from the well in the future for space heating in the town of Szentlőrinc.

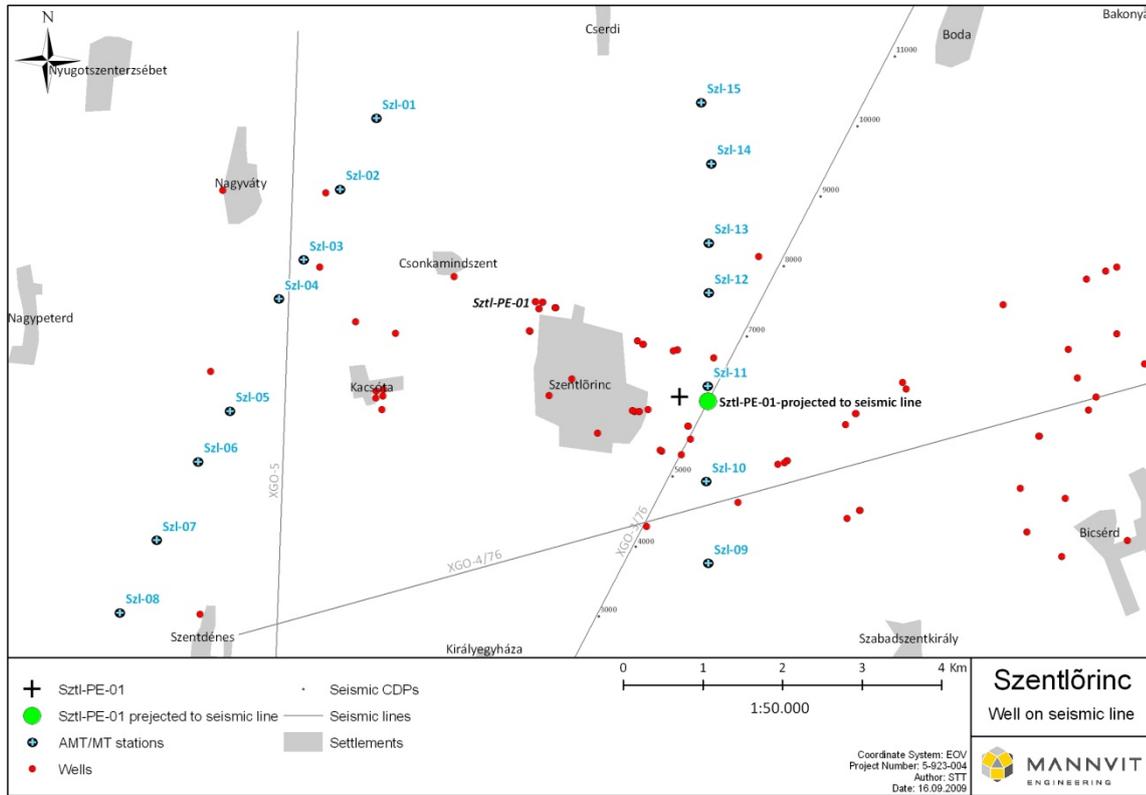


Figure 7. Location of the AMT/MT and gravity survey, seismic lines and the well in Szentlőrinc.

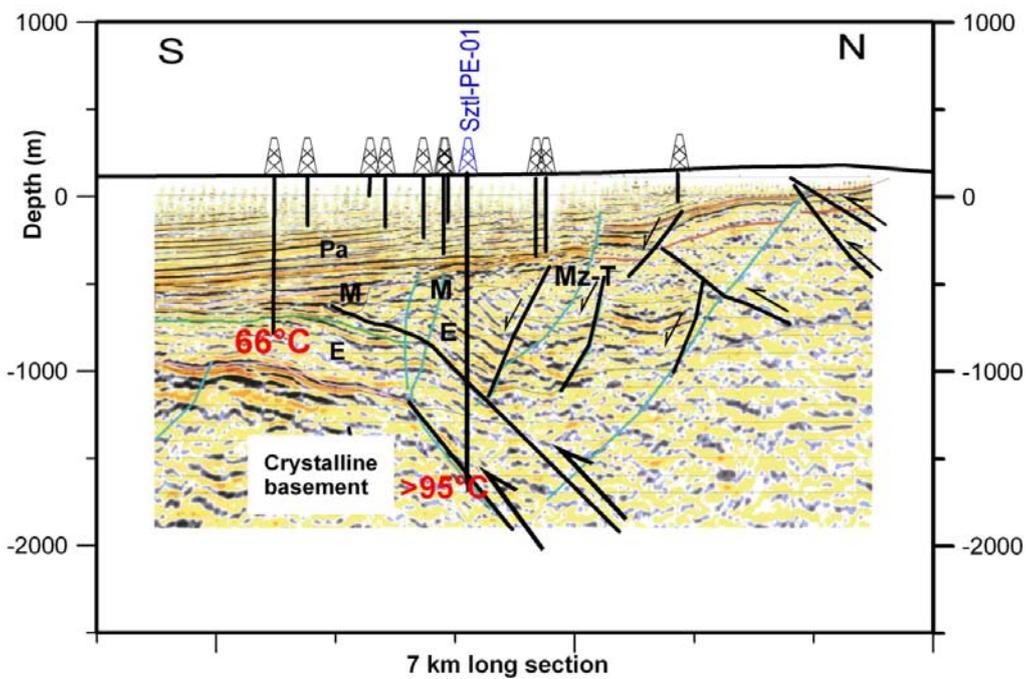


Figure 8. Seismic section with interpretation and the well site in Szentlőrinc. Seismic section from Waterplan Kft. (2006).

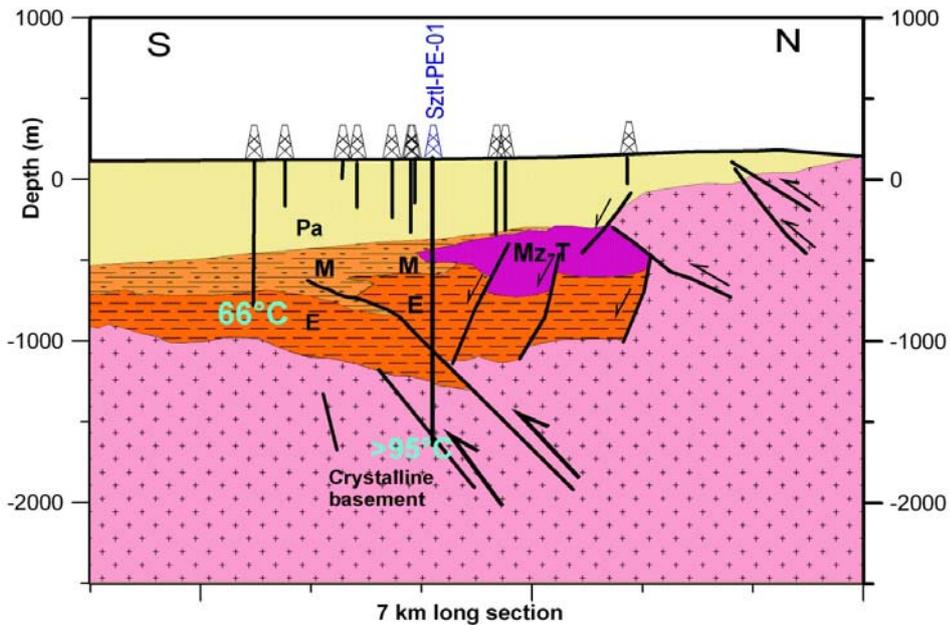


Figure 9. Geological cross section parallel to AMT/MT line 2 in Szentlőrinc.

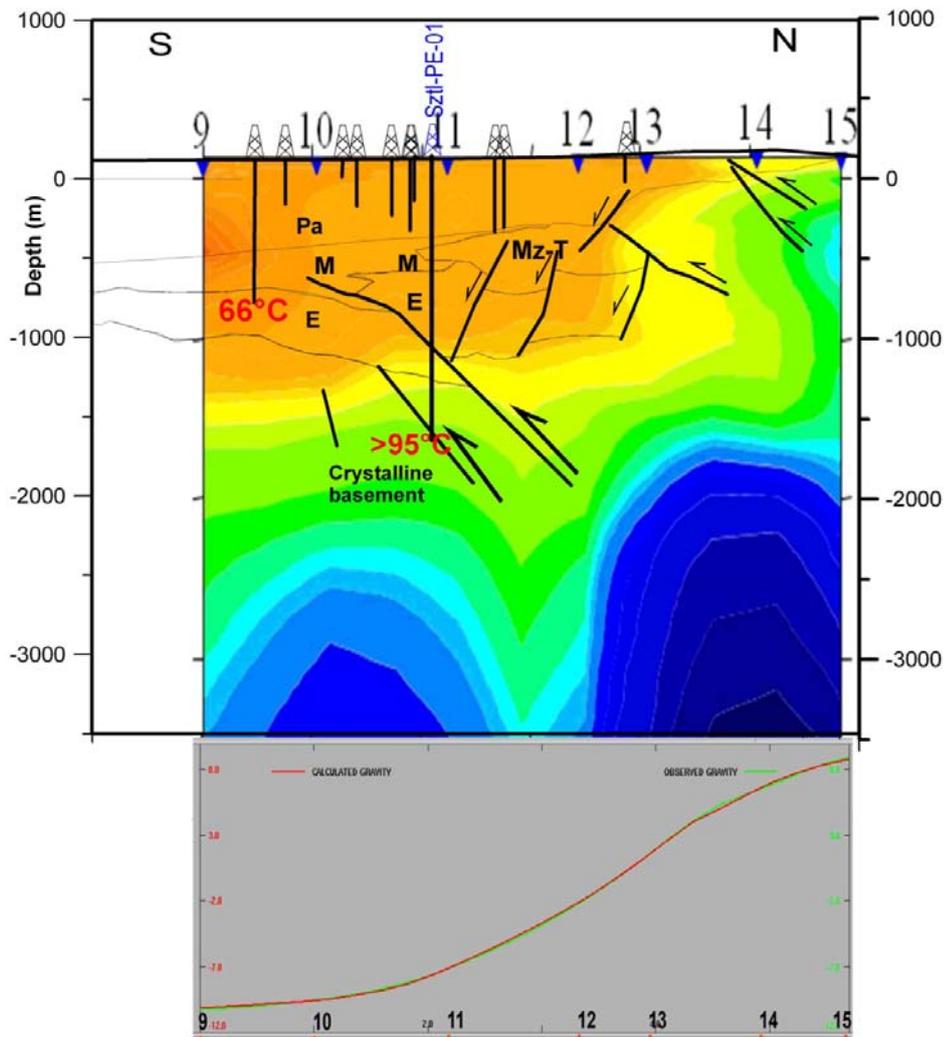


Figure 10. AMT/MT inversion and gravity data with geological cross section and the well site SZTL-PE-01.

#### 4. CONCLUSIONS

Twenty seven areas in Hungary have been investigated for geothermal evaluation with integrated approach using well, seismic and AMT/MT data along with numerous maps and information from articles and books. In most areas well sites have been outlined. Land has been bought and the license process has started.

The integrated approach using different dataset has proven to be very effective way of locating the most promising areas for geothermal utilization in Hungary and the goal of supplying 700 000 homes with geothermal energy within the next decade is quite possible.

The first well drilled close to the small town Szentlőrinc in south Hungary reached 1,820 m in early September (see Thorbergsdóttir, et al., 2010). The well is artesian with 5 ~ 10 l/s of up to 90°C hot water. During airlifting the well gave over 20 l/s. The well has not been tasted yet, but it produces mainly from a fault zone at 1,700 m ~ 1,760 m depth in a crystalline basement. The next well will be drilled later in 2009.

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