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Geothermal Exploration Using Integrated 2-D MT and Gravity Surveys in Hungary

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SUMMARY

All available data were used to outline the most prospective areas for geothermal electrical production and space heating in Hungary. Before locating wells to be drilled for geothermal utilization more data was needed. It was decided to use integrated MT and gravity survey in additional to the existing data in an attempt to further strengthen the possibility of drilling successful wells. Survey lines were proposed on the geosciences data and optimized for the clients concerns. The spacing for the 2-D MT lines was 1000 m, but 250 m for the gravity points. When the surveying was finished for a given line the geological cross section is derived and used for constraints on the MT and gravity interpretation.

Introduction

Hungary, in the Central Europe, it is located in the middle of the Pannonian Basin. The Pannonian basin is a Neogene extensional setting formed between the Carpathian and Dinaride thrust belts within the mega-suture zone of the African and European plates with a relatively thin crust; 25 to 35 km thick. The basement of the basin consists of higher thermal conductivity Precambrian-Paleozoic-Mesozoic rocks. The basin is filled with lower thermal conductivity Cenozoic sediments, the thickest sequences formed during the upper Miocene, Pannonian age. The Pannonian sediments are multilayered and composed of sand, shale, and silt beds. While the lower Pannonian sediments (e.g. clay, silt, marl) are impermeable, the upper Pannonian and Quaternary formations contain vast porous, permeable sand and sandstone beds formed by the upper Pannonian aquifer (Bobok, et al., 1998).

According to thermo-tectonic models the initial crustal thinning or rifting of the Pannonian basin occurred in the Middle Miocene and the subsequent thermal subsidence or post-rift phase extended up to the present (Royden, et al. 1983a and b, Royden, 1988). During the history of the basin significant tectonic events happened mostly in the Miocene. Along the main tectonic lines (like Mid-Hungarian line, Balaton line, Vatta-Maklár line) significant strike slip movements happened. These movements broke the basement rocks causing high secondary porosity. Along some tectonic lines high pressure geothermal conditions experienced (Árpási, et al., 2000, Tóth and Almási, 2001).

As a result of the Earth's thin crust, Hungary's geothermal gradient is higher than the world average. At the depth of 2,000 meters, rock (and water in the porous rock) temperature often exceeds 100°C (Hungarian Geological Survey, 2002).

Concerning the geothermal energy utilization there are vast areas of unexploited geothermal options within Hungary. Considerable amount of information and data on the various fields are available and many wells have already been drilled, either for oil or for thermal water. The oil wells are usually deeper than 3 km, but the thermal wells are most commonly less than 1 km deep. The objective is to find geothermal water for power generation at depth in-between 1 km and perhaps down to 4 or 5 km.

Methodology

As electromagnetic methods allow the imaging of the resistivity structure**,** we selected magnetotellurics as the method of choice for reconnaissance. In combination with gravity we anticipate to find zones of increased fluids and higher temperature.

MT: The magnetotelluric method comprises a frequency domain electromagnetic tool that utilizes natural variations in the Earth's magnetic field as a source. Variations in the Earth's natural magnetic field supply frequencies ranging from nearly DC (direct current) to many kilohertz.

For the AMT/MT application on hand, we use a broad band (7 decades) to study of the electric substructure of the Earth from near surface to great depth. The large frequency range also means that the method is not hampered by the presence of a conductive overburden or sampling frequencies that do not allow for deep penetration. A major advantage of the MT method is that it measures simultaneously the electric and magnetic fields in two perpendicular directions. This provides useful information about electrical structure in an area. It is also considerably cheaper (approximately 10 times) than reflection seismic surveys. The high frequency portion of MT is named the audio magnetotellurics (AMT) method. It is an extension of the MT sounding technique into audio-frequencies from 1 Hz to 20 kHz, which permits achieving moderate exploration depths to about 2,000 m depending on the terrene conductivity. AMT surveys carried out in about 40 known geothermal areas in the western United States generally show low restivities, which in many cases appear to correlate with hydrothermal convection systems of high temperature and large stored heat capacity.

MT-measurements are extensively used to estimate the resistivity with depth. If implemented properly it is possible to obtain the resistivity in two-dimensional sections along a line or lines. A water saturated uniform rock formation has in general lower resistivity, and if the temperature of the fluid is higher the resistivty is reduced further.

The formation most likely to give enough fluid for geothermal utilization is below the Pannonian formations. Because of the high and rather uniform temperature gradient observed for Hungary, the thicker the Pannonian layer is, the higher is generally the temperature in the underlying water bearing layer in the basement. For the proposed study it has been assumed that the optimal temperature for electrical productions is between 120° and 170°C corresponding to a depth of between 2000 m and 3000 m.

In other words the required temperature is most likely present in the layers that will be drilled into, but the permeability is, however, not known. It is assumed that the permeability, or the ability of the formation to pass flowing water through it, is rather low. It is therefore essential to look for some tectonic features that could provide greater permeability. In case there are some water carrying fissures present, it is very likely that the hot water will rise up through the fissure and may be detected by MT-surveying. It is also assumed that permeability means higher water/rock ratio thus giving greater resistivity contrast for the MT/gravity survey to detect.

Gravity surveying methods are useful in detecting fault systems below the surface. The fault system information can be used to analysis and understand groundwater channels and water flow directions. At the same time, gravity data may be used to analysis volcanic rock distribution and help find out the heat source. The gravity data are normally displayed on a contour map, and can identify large and deep fault and shallow fault systems. They do, however, have a lower vertical (depth) resolution unless constrained by seismic data, log data or other information.

Gravity based geophysical methods are usually, applied in order to provide additional support for the definition of the geological structures at a regional scale. With deep penetration the resolution is lower. In this situation the gravitational survey offers significant benefits in the interpretation of the MT measurements at a low additional cost, costing only about 10% of the MT survey.

The intrinsic ambiguity of the gravity data is reduced by the high level of redundancy of the acquired data set and integration with other data. This detailed density information can be successively utilized in conjunction with conventional MT data performing integrated inversion procedures.

These models will be automatically and reciprocally consistent because they represent the simultaneous solution of a joint minimization process honouring observed MT and gravity data at the same time.

In this project densely spaced gravity data along several 2-D MT lines with selective 3D will is acquired. This is done in order to perform cooperative (no direct link of model parameters) and joint (overlapping model parameters) inversions of MT and Bouguer anomalies and an as needed basis.

MT and gravity survey

All available data were used to outline the most prospective areas for geothermal electrical production and space heating in Hungary. Before locating wells to be drilled for geothermal utilization more data was needed. It was decided to use integrated MT and gravity survey in additional to the existing data in an attempt to further strengthen the possibility of drilling successful wells. Survey lines were proposed on the geosciences data and optimized for the clients concerns. The spacing for the 2-D MT lines was 1000 m, but 250 m for the gravity points. When the surveying was finished for a given line the geological cross section is derived and used for constraints on the MT and gravity interpretation.

Results

Three survey lines were finished before the end of of 2007 and the geological cross sections were made available soon after. Figures 1 and 2 show 2 of these cross sections with the interpretation. In all three sections are pockets where the density is low (high porosity) and the resistivity is low (higher temperature, more fluid). We believe that these pockets indicate the geothermal reservoirs and potential drilling targets. Next further 3D and/or controlled source measurements are planning to defined specific targets.

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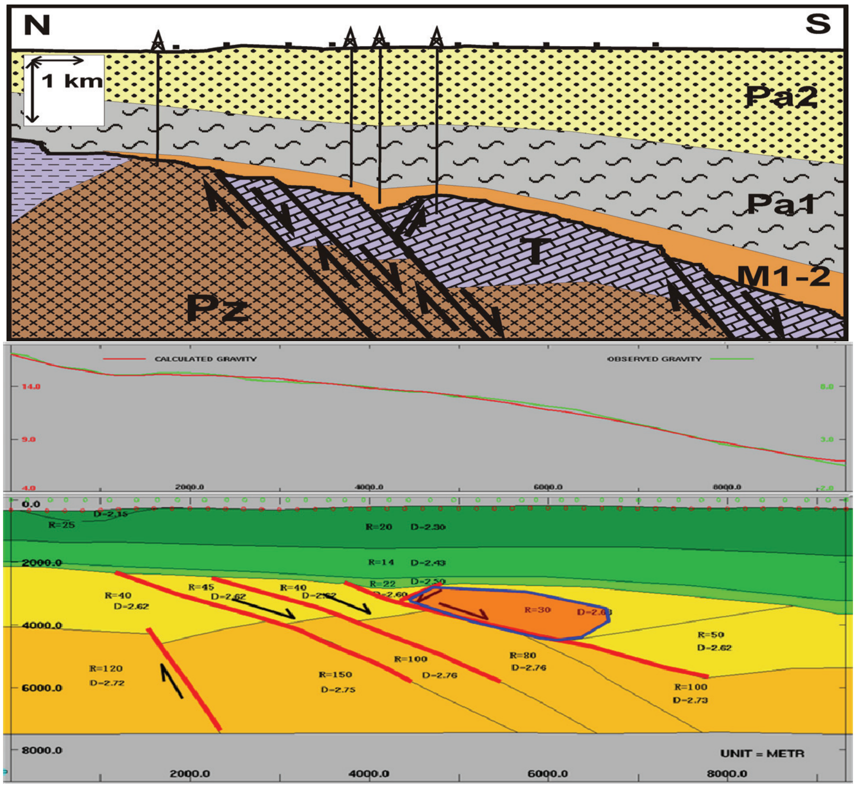

Figure 1: Top: Geological model; Bottom: Using integrated inversion result of MT & gravity, & local geology to obtain basement resistivity & density, and then interpreted basement fault system.

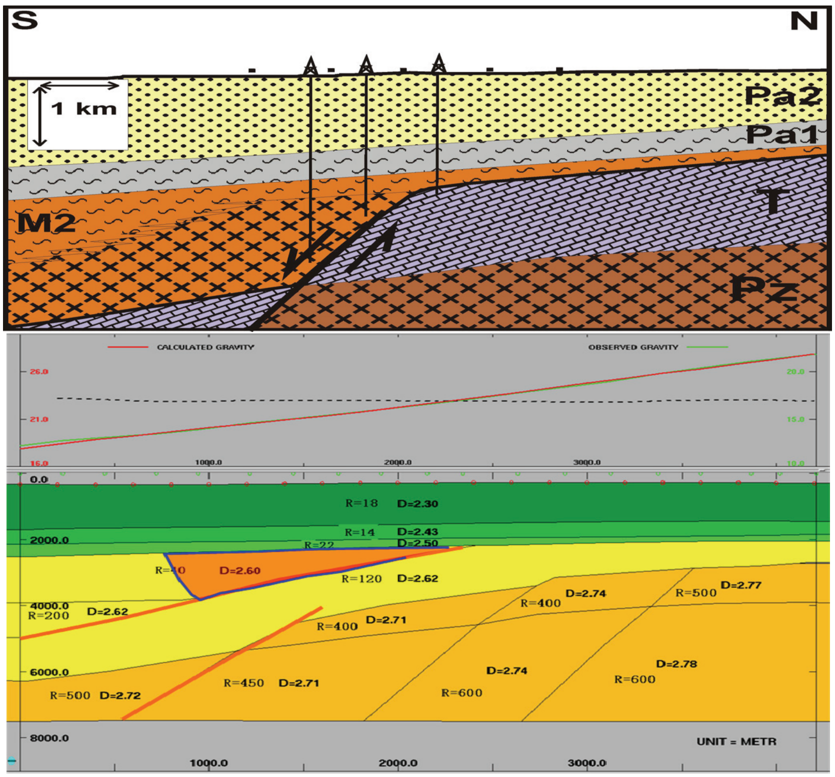

Figure 2: Top: Geological model; Bottom: Using integrated inversion result of MT & gravity, & local geology to obtain basement resistivity & density, and then interpreted basement fault system.

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