Updating the Geothermal Database and the Heat Flow Density Map of Hungary

László Lenkey, János Mihályka and Petra Paróczi

Department of Geophysics and Space Science, Eötvös Loránd University, Budapest 1117, Pázmány s. 1/c, Hungary

lenkey@caesar.elte.hu

Keywords: Heat flow density, database, temperature, thermal conductivity

ABSTRACT

The heat flow density map of Hungary was presented in the Atlas of Geothermal Resources in Europe in 2002 and was last updated in 2005. Since that time several geothermal projects, e.g. TransEnergy (2010-13), assessment of the geothermal potential of the Drava basin (2013) Paks-II, NPP (2016) and continuous drilling activity in the country have been in progress. Large amount of temperature data became available, which allowed the update of the Geothermal Database of Hungary.

The Geothermal Database of Hungary presently contains more than 14000 single temperature data and numerous temperature logs from about 5000 boreholes and wells. The temperature data derive from different types of measurements: BHT, DST, temperature of water entering into the well at the screening, outflowing water temperature at the well head and well logs. The measured temperatures are corrected for the disturbing effects, e.g. cooling due to drilling (BHT) or cooling of the water due to upwelling in the well. The corrected temperature data are ranked into nine classes depending on the quality of the data and the applied corrections.

The database also contains the lithology of the boreholes and wells in order to estimate the thermal conductivity of rocks. The thermal conductivity of the rocks is known from laboratory measurements made on core samples. In case of Neogene and Quaternary clastic sediments, which constitute the subsurface rock types in 70 % of the country, the thermal conductivity versus depth functions established for sands and shales are used.

The heat flow density is calculated using the Bullard-plot technique in which the temperature data are weighted according to their quality. The heat flow density data are not corrected for the topography and the paleoclimatic variations. The heat flow density map is constructed using 2000 heat flow density data. The mean heat flow density in Hungary is 90 mW/m^2, varying between 30 mW/m^2 and 120 mW/m^2. The high values are found over buried basement highs in the eastern and southern part of the country, while the low values are located in the recharge areas of karstic flow systems. In the sedimentary basins, where the thickness of the Neogene and Quaternary sediments reaches 5-7 km, the heat flow is slightly below the mean value (80-90 mW/m^2) due to the transient effect of sedimentation. These basins contain the main thermal water aquifer in Hungary utilized for district heating and green house heating. The buried basement highs are characterized by high heat flow (100-120 mW/m^2), and these areas are the potential sites for EGS utilization.

The heat flow map of the country and the temperature data are the most important input data or control data in 3D numerical modelling aimed to identify or characterize geothermal reservoirs or predict deep temperatures in EGS exploration.

1. INTRODUCTION

The utilization of geothermal energy in Hungary has a long tradition, because several geothermal reservoirs exist in the Neogene sediments and buried karstified and fractured carbonates. The temperature of the produced water is below 100 °C, and it is mainly used for heating and bathing.

Temperature data and heat flow density determinations are the most important tools in geothermal exploration. The Geothermal Database of Hungary has been developed 25 years ago (Dövényi, 1994). It contains temperature data measured deeper than 200 m, or data with temperature higher than 30 °C. It was last updated properly in 2005 (Rezessy et al., 2005). Since that time several geothermal projects have been carried out though: e.g. TransEnergy (Lenkey et al., 2017), Drava-basin geothermal project (Horváth et al., 2014), Paks-2 Nuclear Power Plant (2016), where either new temperature measurements were made or existing data from the project area were collected. Additionally, some dozens of deep hydrocarbon exploration boreholes were drilled, and a few of them are deeper than 6000 m. Large amount of temperature data became available, which allowed the update of the Geothermal Database of Hungary. The database contains 14462 temperature data measured in 5023 boreholes and wells. The data are quality controlled depending on the type and circumstances of the measurement. The database also contains the lithology of the borehole, which enables thermal conductivity estimations.

In this paper we present the most important characteristics of the database and the updated heat flow density map of Hungary and temperatures maps in different depths.

## 2. DATA AND DATA PROCESSING

2.1 Temperature data

There are only a few wells in Hungary in which the temperature is in steady state. Those wells are regarded to be in steady state, where two years have passed since the termination of the last operation in the well. DST temperatures or temperature of fluid, mainly water, flowing into the well are regarded to be the „true" temperature of the formation if the depth of measurement is in the

screened section of the well or slightly below the screening, and additionally the production layer is a few tens of meters, the layer is horizontal and secondary effects e.g. expansion of gas are negligible. Such conditions often exist in wells in Hungary or it is possible to check if they prevail. Other types of data are not equilibrium temperatures and they need corrections. These are the bottom hole temperatures (BHT) or temperature logs measured a few hours after the termination of drilling mud circulation. The formation temperature can be calculated following the methods of Horner (1951), Dowdle and Cobb (1975). Temperature of water measured above the screened section of the well, e.g. in the surface at the well head was corrected using the empirical formula of Gálfi and Liebe (1977).

The database contains the names of the wells and boreholes, their short names, coordinates, elevation above the sea level, depth of the temperature measurement, method of the measurement, types listed above, the observed value and the lithology of the well. The correction of the observed values is made automatically using the methods mentioned above. The reliability of the temperature data varies according to the type of the data and the circumstances of the observation. The temperature data are ranked into 9 classes according to their reliability: first class is the best, ninth class is the worst. Steady state temperatures are ranked to the first class, they are followed by the data observed by DST, capacity measurements and inflowing fluid temperatures. Usually BHT values are ranked into higher class (lower quality) depending on the correction and the worst classes are the temperatures observed on the well head. Those data where some essential information is missing, e.g. depth of the measurement, or the length of the screened sections are ranked into class 0. These data are not used to determine heat flow density or interpolate temperature. They present in the database to indicate approximate temperature in those areas where reliable data are missing.
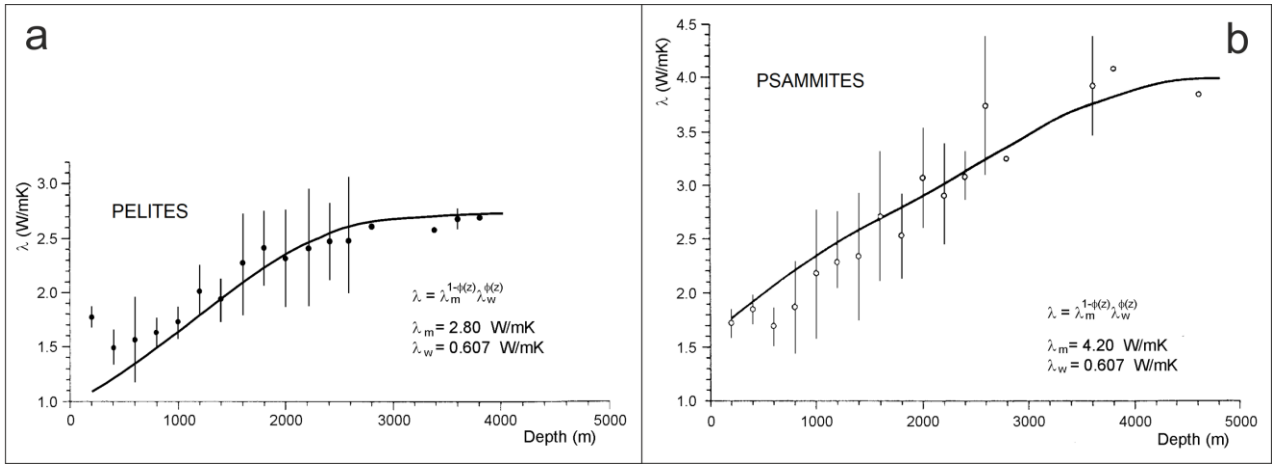
2.2 Thermal conductivity of rocks

Two third of Hungary's surface is covered by Neogene and Quaternary clastic sediments. The average sediment thickness is 1-3 km, but in the deepest troughs it reaches 5-8 km (Fig. 1). The thermal conductivity of more than 300 sediment core samples was measured in laboratory and trends of the conductivity-depth functions were established for shales and sandstones (Fig. 2). The database contains the lithological description of the boreholes and wells. Based on the shale to sand ratio the thermal conductivity of the sediments is estimated automatically in the database. In cases where the ratio is missing the shale to sand ratio is assumed to be 0.5. A present research is going on to determine the thermal conductivity of sediments more reliably and with high resolution using well logs (Mihályka et al., this volume). The thermal conductivity of other rocks is taken from the literature, because only 46 thermal conductivity determination was carried out on other rock samples, e.g. limestones, dolomites, andesites from Hungary (Dövényi et al., 1983).
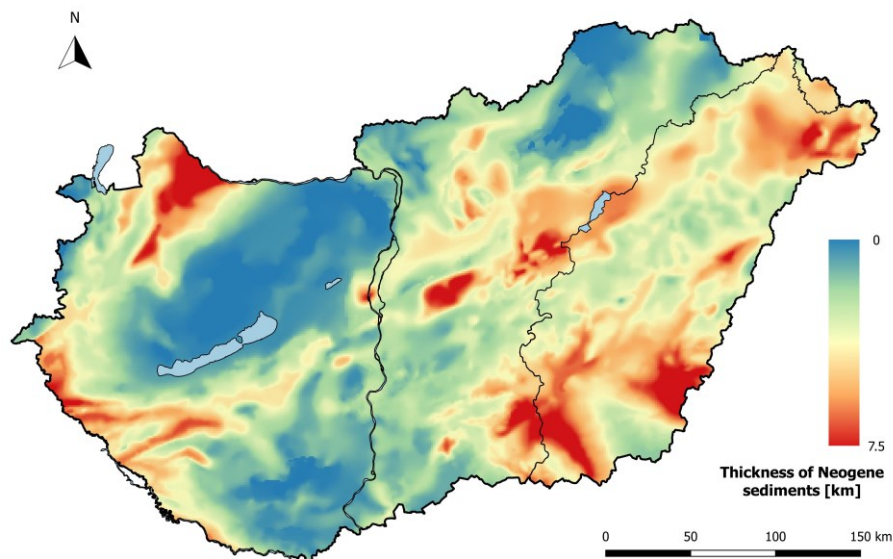
**Figure 1: Thickness of the Neogene and Quaternary sediments in Hungary**

3. HEAT FLOW DENSITY AND SUBSURFACE TEMPERATURE IN HUNGARY AND THEIR INTERPRETATION

Heat flow density was calculated applying the Bullard-plot technique. During the calculation the reliability of the data was taken into account by weighting the temperatures with the inverse value of their class. The accuracy of the heat flow density determination in the boreholes and wells is estimated to be ±15 % due to errors in temperature observations and thermal conductivity assessment. Temperatures observed deeper than 1 km were used in the heat flow density calculation, therefore paleoclimatic correction was not applied. The heat flow density map shown in Fig. 3 is based on data from 2001 boreholes and wells.

Figure 2: Thermal conductivity-depth functions of Neogene and Quaternary pelites (a) and psammites (b) based on laboratory measurements (Dövényi and Horváth, 1988)

The heat flow density in Hungary varies between 30 mW/m^2 and 120 mW/m^2 with lowest values in the Transdanubian Range and highest values in the southern part of the country. The average value is 90 mW/m^2, which is higher than the mean continental heat flow density of 65 mW/m^2 (Pollack et al., 1993, Jaupart et al., 2007). Hungary lies in the central part of the Pannonian Basin, and the high heat flow density is due to Middle Miocene (17.5-12.5 Ma) lithospheric extension in the Pannonian Basin (Royden et al., 1983, Lenkey, 1999, Horváth et al., 2015) resulting in thin lithosphere and elevated asthenosphere. The low heat flow density values are due to meteoric origin groundwater flow in fractured and karstified carbonatic rocks in the Transdanubian Range, Bükk Mts. and Aggtelek-Gömör karst area. The recharge areas, and therefore the cooled areas are much larger than the heated discharge areas, which are concentrated along faults at the feet of the mountains (e.g. Hévíz, Budapest, Eger, for location see Fig. 4). The downward groundwater flow cools the recharge area at least until 2 km depth (see also Figs. 4, 5, 6). The upward groundwater flow mainly heats the upper 500 m – 1 km of the subsurface. Since the heat flow density map was constructed from temperatures observed below 1 km, the high heat flow density of the discharge areas is not visible on the map. On the other hand, the discharge areas characterized by elevated temperature are clearly present on the temperature shown in 500 m depth (Fig. 4).
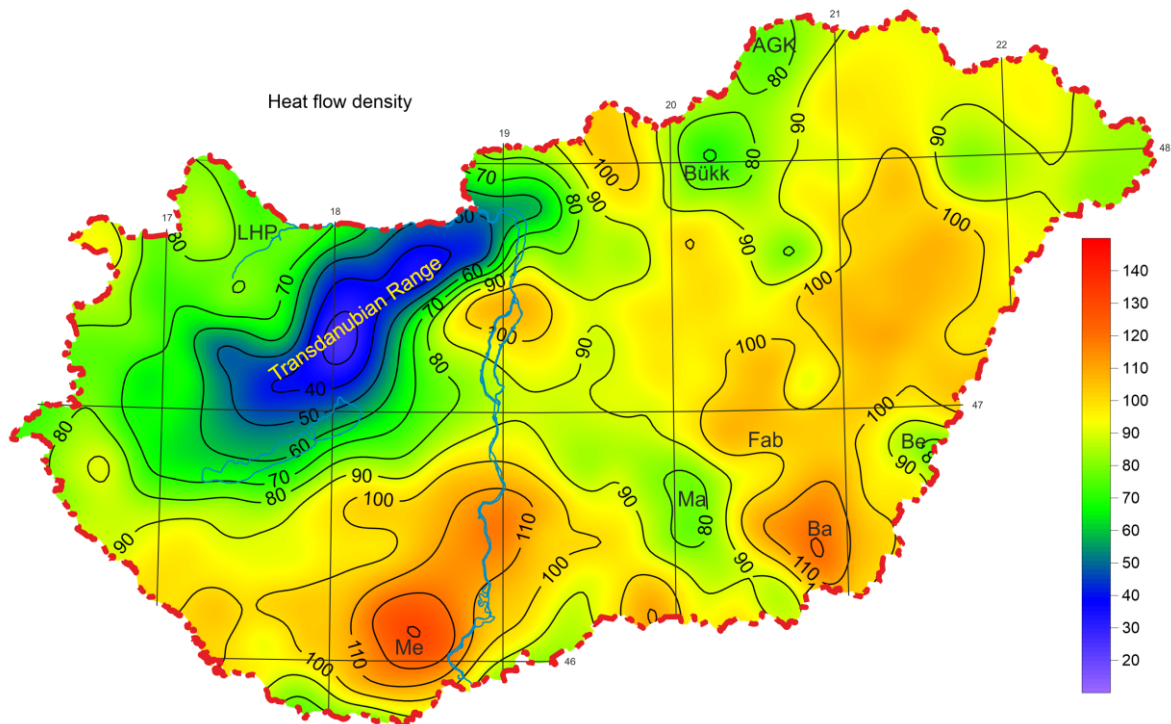
Figure 3: Heat flow density in Hungary. The contour interval is 10 mW/m^2. LHP: Little Hungarian Plain, Me: Mecsek Mts., Ma: Makó trough, Be: Békés depression, Ba: Battonya basement high, AGK: Aggtelek-Gömör Karst, Fab: Fábiánsebestyén geothermal reservoir. See also Fig. 1 for the location of the subbasins and outcrops.

Groundwater flow also occurs in the sediments (Fig. 1), but its vertical flux is considerably less than in the karstic rocks, because of the lower vertical permeability, and thus the associated heat flow density anomalies are in the error range of the heat flow density determination except a few places (e.g. Tiszakécske for location see Fig. 4). Areas with the highest heat flow density in the southern part of Hungary are located in the Mecsek Mts. and over the Battonya basement high (covered with 800 – 1000 m thick sediments), because heat flow is refracted towards the basement comprising of good conductivity crystalline and metamorphic rocks. On the contrary, the basin areas filled with thick sedimentary pile (5-8 km, Fig. 1) are characterized by lower heat flow density of 80 mW/m^2 e.g. in the Little Hungarian Plain, Makó trough and Békés depression. It is partly due to heat refraction, and partly because the sediments have not reached equilibrium temperature yet due to high sedimentation rate during the Neogene and Quaternary (Lenkey, 1999).
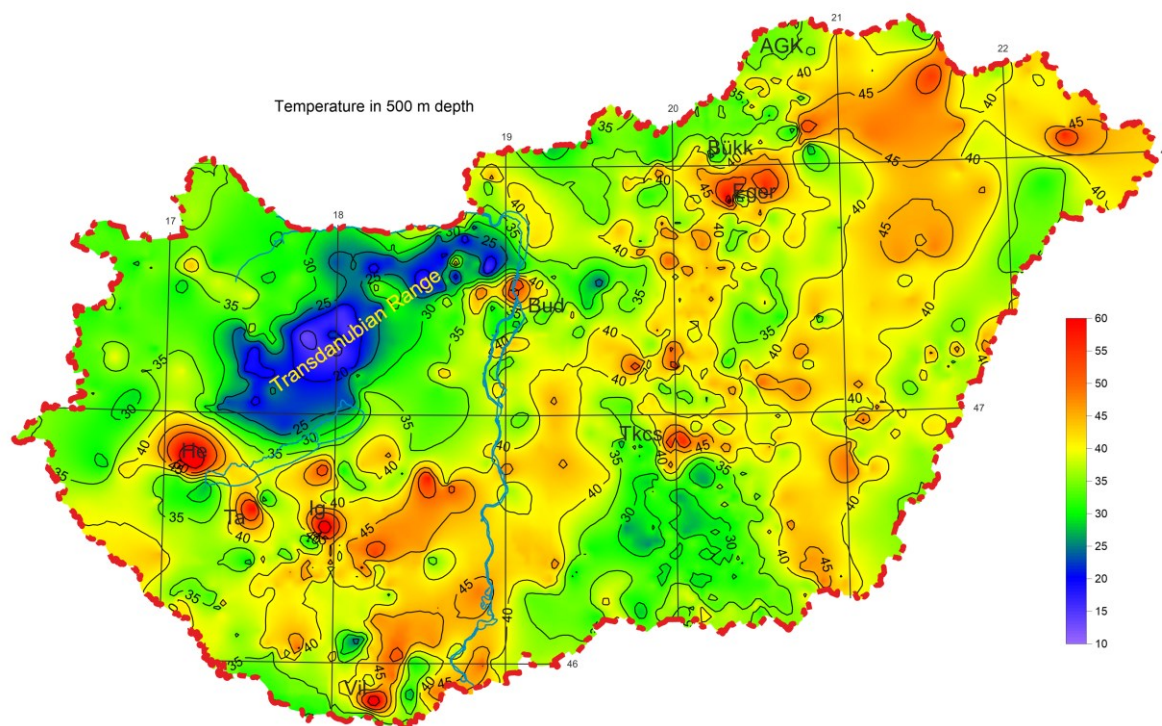
Figure 4: Temperature at 500 m depth below surface. The contour interval is 5 °C. He: Hévíz, Ta: Táska, Ig: Igal, Vil: Villány Mts., Bud: Budapest, Tkcs: Tiszakécske, AGK: Aggtelek-Gömör Karst.

From the viewpoint of geothermal energy utilization temperature is one of the key parameters. We constructed temperature maps in 500 m, 1 km and 2 km depths (Figs. 4., 5., 6, respectively), because 90 % of the produced thermal water in Hungary comes from shallower depth than 2 km (Szanyi and Kovács, 2010). Assuming constant heat flow density, we extrapolated 3241 temperature data observed between 300 m and 1 km into 500 m depth, 2478 data between 500 m and 2 km into 1 km depth, and 1536 data between 1 km and 3 km into 2 km depth. The mean temperature at 500 m depth is about 40 °C. Temperatures significantly different from this value indicate groundwater flow: the Transdanubian Range is characterized by low temperature less than 25 °C due to downward groundwater flow, and there are several small areas (Hévíz, Táska, Igal, Villány, Budapest, Eger, Tiszakécske), where the temperature is higher than 50 °C. In these areas upward groundwater flow takes place. In some places the water discharges to the surface in warm springs (e.g. Hévíz, Budapest, Eger), in other places the warm water heats up the overlying sediments (e.g. Táska, Igal). Most of the shallow warm thermal anomalies tend to dissipate with depth, and in 2 km depth most of them disappear except the Táska and Igal anomalies. They belong to elongated lines of thermal anomalies running to ENE-WSW direction (Fig. 6) and are associated with the elevated carbonatic basement, in which probably thermal convection occur. In 1 km and 2 km depths the pattern of the temperature distribution is similar: the lowest temperatures are observed in the areas of the carbonatic outcrops and they are attributed to downward groundwater flow, the highest temperatures are observed above structural basement highs and they can be attributed to thermal convection in the carbonatic basement and/or to heat refraction where the basement is crystalline and metamorphic. In 2 km depth in the central and eastern part of the country there are several areas, where the temperature is above 120 °C. Unfortunately, in these areas no permeable rocks are present at this depth, because the 120 °C isotherm is located in the crystalline, metamorphic basement, or in impermeable marls. Permeable sediments are found until 2 km depth in the Little Hungarian Plain and the Makó trough, where the temperature is between 90 °C and 100 °C, or slightly above 100 °C. This is the highest temperature thermal water, which can be produced from the Neogene sandstones. Higher temperature water can be found only in larger depth in the fractured and karstic carbonates located in the basement of the sediments.
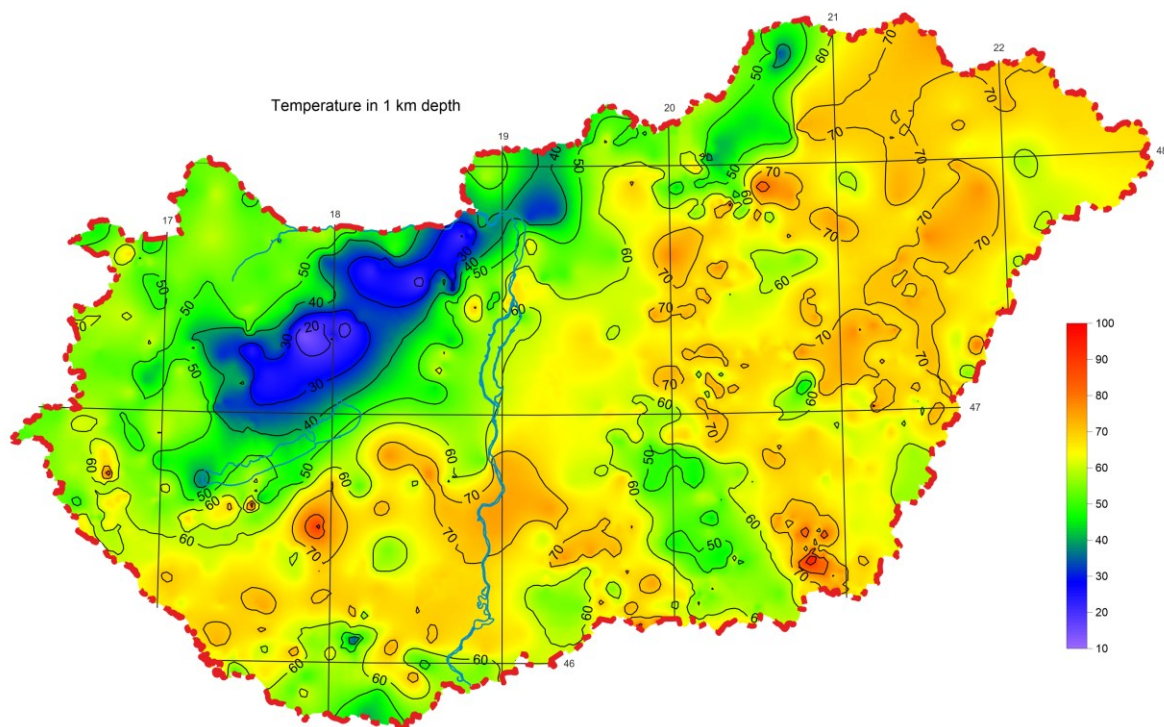
Temperature in 1 km depth

Figure 5: Temperature at 1 km depth below surface. The contour interval is 10 °C.
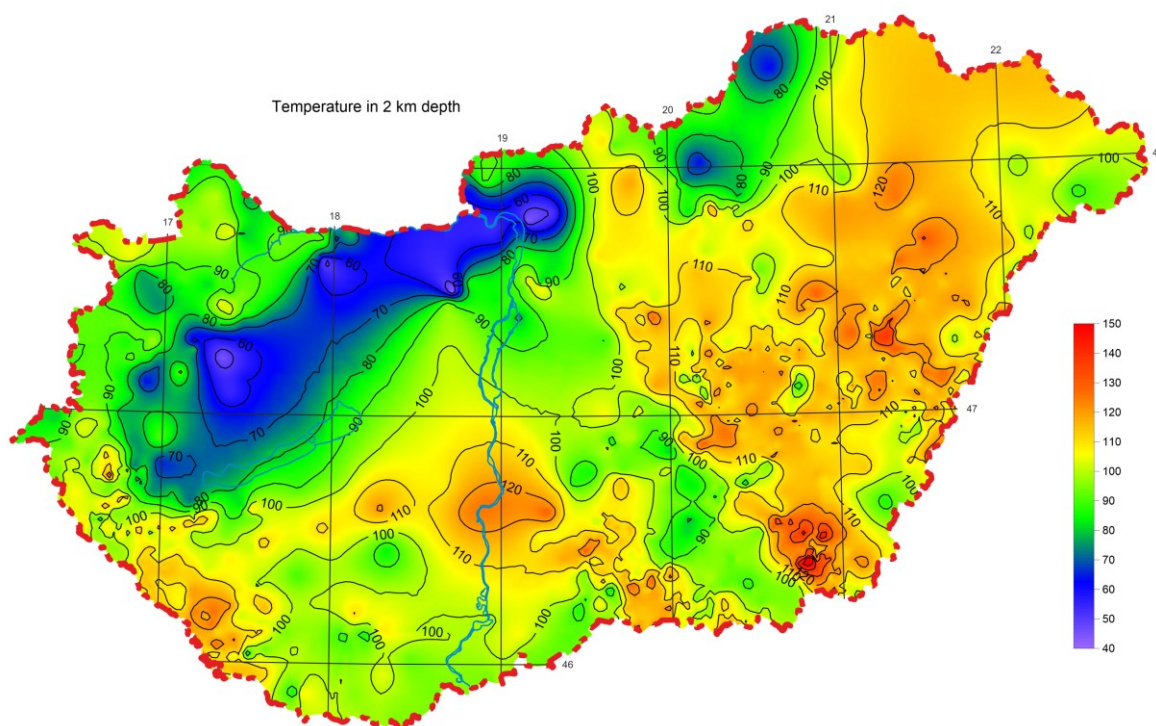
Temperature in 2 km depth

Figure 6: Temperature at 2 km depth below surface. The contour interval is 10 °C.

4. DISCUSSION AND CONCLUSIONS

There are two regional groundwater reservoirs in Hungary, which are exploited: the traditionally called Upper Pannonian sandstone reservoir located in the basin areas (Fig. 1), and the Triassic carbonatic rocks (Horváth et al., 2015). The carbonates outcrop in the Transdanubian Range, Bükk Mts., Aggtelek-Gömör Karst and Villány Mts., and continue in the basement of the Tertiary sediments around the outcrops. These reservoirs recharge in the outcrops and discharge along faults at the feet of the mountains. The groundwater flow has a very strong signal in the temperature field, and based on the thermal anomalies the flow system can tracked. Some part of the covered carbonatic reservoir may or may not be connected to the recharge area, but there is a strong thermal anomaly over it (e.g. Táska, Igal). It is because probably thermal convection occurs in the reservoir. Some other buried carbonatic reservoirs in the basement are definitely isolated as indicated by the high overpressure (e.g. Fábiánsebestyén, Stegena et al., 1994). The Fábiánsebestyén reservoir is found in 4 km and it has a temperature over 170 °C. Apparently, it does not have a thermal signal in the sedimentary cover.

The heat flow density map of Hungary and the temperature maps in different depths highlight several thermal anomalies connected to groundwater flow, and thus geothermal reservoirs can be identified. Regional or local 3D groundwater flow and coupled heat transport models can be constructed and temperature data from the Geothermal Database of Hungary can be used to verify these models. Based on the results of the modelling "hidden" reservoirs in the basement can be predicted. Thus, 3D thermal modelling together with qualified temperature data of the database may reduce the risk of exploration of deep reservoirs, e.g exploration of EGS.

5. ACKNOWLEDGEMENT

REFERENCES

Dowdle, W. L. and Cobb, W. M.: Static formation temperature from well logs - an empirical method, *Journal of Petroleum Technology*, **27** (1975), 1326-1330.

Dövényi, P., Horváth, F., Liebe, P., Gálfi, J. és Erki, I.: Geothermal conditions of Hungary, *Geophys. Transactions*, **29/1** (1983), 3-114.

Dövényi, P. and Horváth, F.: A review of temperature, thermal conductivity, and heat flow data from the Pannonian Basin. In: L.H. Royden and F. Horváth (Editors), The Pannonian Basin, a Study in Basin Evolution. *Amer. Assoc. Petr. Geol. Mem.*, **45**, (1988), 195-233.

Dövényi, P.: A Pannon-medence litoszférájának vizsgálata geofizikai módszerekkel. Kandidátusi értekezés, Eötvös Loránd Tudományegyetem, Geophysical characteristics of the Pannonian lithosphere, *PhD thesis*, Budapest, (1994), pp. 127.

Gálfi J. és Liebe P.: Magyarország geotermikus hőmérséklettérképei a vízfeltáró fúrások alapján. Kutatási Jelentés, VITUKI adattár, Budapest, (1977).

Horner, D.R.: Pressure bulid-up in wells. *Proceedings*, Third World Petroleum Congress. The Hague (1951).

Horváth, F., Pap, N., Reményi, P., Tóth, T., (Eds.): Geothermal Resource Assessment of the Drava Basin. ID Research Kft., (2014), 1-221.

Horváth, F., Musitz, B., Balázs, A., Végh, A., Uhrin, A., Nádor, A., Koroknai, B., Pap, N., Tóth, T., Wórum, G.: Evolution of the Pannonian basin and its geothermal resources. *Geothermics*, **53**, (2015), 328-353.

Jaupart, C., Labrosse, S. and Mareschal, J.-C.: Temperatures, heat and energy in the mantle of the Earth, in: *Treatise on Geophysics*, Vol. **7**, Mantle Convection, edited by: Bercovici, D., Elsevier, (2007), 253–303.

Lenkey, L.: Geothermics of the Pannonian basin and its bearing on the tectonics of basin evolution. *PhD thesis*, Vrije Universiteit, Amsterdam, (1999), 215 pp.

Lenkey, L., Raáb, D., Goetzl, G., Lapanje, A., Nádor, A., Rajver, D., Svasta, J., Zekiri, F.: Lithospheric scale 3D thermal model of the Alpine-Pannonian transition zone, *Acta Geodaetica Geophysica*, **50/1**, (2017), 1-22.

Mihályka, J., Paróczi, P., Lenkey, L., Drahos, D. and Balázs, L.: Preliminary Results of Elaborating a Methodology for Determining the Thermal Conductivity of Clastic Sediments Using Well Logs in Hungary. *Proceedings* World Geothermal Congress 2020. Reykjavik, Iceland, April 26 – May 2.

Paks-2 NPP.: Site investigation of the Paks-2 Nuclear Power Plant, *Report*, (2016).

Pollack, H.N., Hurter, S.J. and Johnson, J.R.: Heat-Flow from the Earths Interior – Analysis of the Global Data Set, Reviews in Geophysics, **31**, (1993), 267–280.

Rezessy, G., Szanyi, J. and Hámor, T.: A geotermikus energiavagyon állami nyilvántartásának előkészítéséről. I. fázis. Magyar Geológiai Szolgálat. Budapest, p. 85. Report on the registration of geothermal resources in Hungary. First phase. *Report*, Hungarian Geological Survey, Budapest, (2005), p. 85.

Royden, L.H., Horváth F., Nagymarosy A. and Stegena L.: Evolution of the Pannonian basin system: 2. Subsidence and thermal history. *Tectonics*, **2**, (1983), 91-137.

Stegena, L., Horváth, F., Landy, K., Nagy, Z. and Rumpler, J.: High-temperature geothermal reservoir possibilities in Hungary. *Terra Nova*, **6**, (1994), 282-288.

Szanyi, J., Kovács, B.: Utilization of geothermal systems in South-East Hungary. *Geothermics*, **39**, (2010), 357-364.