PROCEEDINGS. 42nd Workshop on Geothermal Reservoir Engineering
Stanford University. Stanford. California. February 13-15. 2017
SGP-TR-212

Creating a Geothermal Atlas of Hungary

Aniko N. Toth

University of Miskolc

Miskolc-Egyetemváros. 3515 Hungary

toth.aniko@uni-miskolc.hu

Keywords: Geothermal database. thermal well. abandoned hydrocarbon well. national geothermal atlas

ABSTRACT

Hungary's excellent geothermal potential is well-known. Traditionally, most of the country's thermal water has been used for spas. Most of the country's geothermal energy production is used as a direct heat supply to heat housing projects and businesses. As yet there is no operational geothermal power-plant in Hungary. Neither is the market for ground-source heat-pumps very strong, no doubt because of a depressed economy that has still not recovered from the global recession. Despite the weak economy, a few large-scale projects are being prepared. Until now, these have been hindered by the absence of a strong reliable and official government authority which can absolutely and unequivocally vouch for Hungary's geothermal data. For this reason, the Hungarian Energy and Public Utility Regulatory Authority requested in 2016 that a study be made to analyze and summarize the geothermal potential of every one of the country's 19 counties.

The resulting study used information from the Hungarian Geological and Geophysical Institute, and consulted the geothermal databases of the Hungarian Office for Mining and Geology. These two sources yielded data for 1622 thermal wells. In addition, more than 70 abandoned hydrocarbon wells were also analyzed, as the Hungarian Mine Utilization Authority judged those wells to be suitable for geothermal use. In the course of assembling the necessary data into a national geothermal atlas, numerous smaller-scale charts and graphs and maps were also created

1. HUNGARY'S ENERGY SITUATION

Hungary has never been energy independent and has always imported the energy it needed. With fewer energy-intensive industries surviving to compete in the post-communist world, however, Hungary's overall energy consumption has dropped to levels not seen since the 1970s. Hungary's primary energy consumption was 1058.8 PJ in 2010, for example but only 962.5 PJ in 2014.

Hungary currently imports 52% of its energy, mostly from Russia. Natural gas makes up most of the imported energy, although Hungary's natural gas consumption has decreased since 2008. 80% of this natural gas is imported from Russia through Ukraine and Austria. Nuclear energy plays a significant role in Hungary's energy mix, with 45% of the country's electricity production provided by the Paks nuclear plant. About 20% of our electricity is imported directly, again mostly from Russia. Coal plays an insignificant role both in terms of energy use (10%) and electricity production (18%).

Renewables are an even less significant energy source, though steadily increasing (now at 8% of total energy production, in line with EU requirements). Geothermal energy utilization is stuck at 938.6 MWt (A. Tóth, 2015), despite Hungary's favorable natural conditions. Hungary also uses biogas and biomass, the latter mostly as wood burned at electric power plants, but their use is not growing very rapidly. Hydropower, popular in some neighboring countries, is still an underused resource in Hungary. More positively, Hungary's total wind-turbine capacity has reached 328 MW, and solar energy production has been steadily increasing: Hungary's largest photovoltaic power plant has 72 thousand solar panels, providing 16MW of energy (data provided by Hungary's UK embassy, 2015).

Total energy consumption in Hungary's apartments and public buildings is 435 PJ per year, or 45% of the country's primary energy consumption. Heating and air conditioning alone make up more than 330 PJ. Unfortunately, 4.3 million Hungarian homes -- more than 65% -- fail to meet EU standards for good thermal insulation. The Hungarian government would like to improve this figure, so as to reduce the heating/cooling demand in buildings. The government has also tried to encourage greater use of renewable energy sources, and of geothermal energy use in particular. The importance of renewable and clean energy sources was obvious to many Hungarians this winter, when coal- and trash-burning created air pollution so severe that many cities warned their residents not to go outside.

Energy	Consumption [PJ] 2010	Percent of total	Consumption [PJ] 2014	Percent of total
Natural gas	424.7	40.11	380.6	39.54
Petroleum	399.7	37.75	397.6	41.31
Nuclear	172.4	16.28	170.7	17.73
Coal	125.8	11.88	117.5	12.21
Biomass	77.7	7.34	82.4	8.56
Geothermal	7.6	0.72	9.5	0.99
Wind	1.9	0.18	2.4	0.25
Hydropower	0.7	0.06	1.1	0.11
Other	4.4	0.41	5.0	0.52
Export	-156.1		-204.3	
Consumption	1058.8		962.5	

Table 1: Primary energy consumption in Hungary in 2010 and 2014 (KSH. 2014)

2. HUNGARY'S GEOTHERMAL POTENTIAL

Hungary lies in the Pannonian basin, notable in Europe as a positive geothermal anomaly. The Pannonian Basin has a heat-flow density ranging from 50 to 130 mW/m^2, with a mean value of 90-100 mW/m^2 and a geothermal gradient of about 45 °C/km (Dövényi et al. 1983, 2002). There are two major types of geothermal reservoirs in Hungary. *Type 1* is a multi-layered porous sediment (Upper Miocene-Pliocene "Pannonian" basin fill sequence), has low heat conductivity and is composed of successively clayey and sandy deposits. Within this thick basin-fill sequence the main thermal-water bearing aquifers are those 100-300 m thick sand-prone units (former delta-front facies deposits), found at depths of ca. 700-1800 m in the middle of the basin. There, the temperature ranges from 60 to 90 °C. This reservoir type has an almost uniform hydrostatic pressure and is widely used for direct heat purposes. *Type 2* is associated with the uppermost karstified zones of the deeply buried Palaeozoic-Mesozoic basement carbonates, as well as the fractured-weathered zones of crystalline rocks, characterized by high secondary porosity. At this depth (on average 2000 m or more) temperatures can exceed 100-120 °C, and may provide favourable conditions for developing medium-enthalpy geothermal systems (e.g. CHP plants).

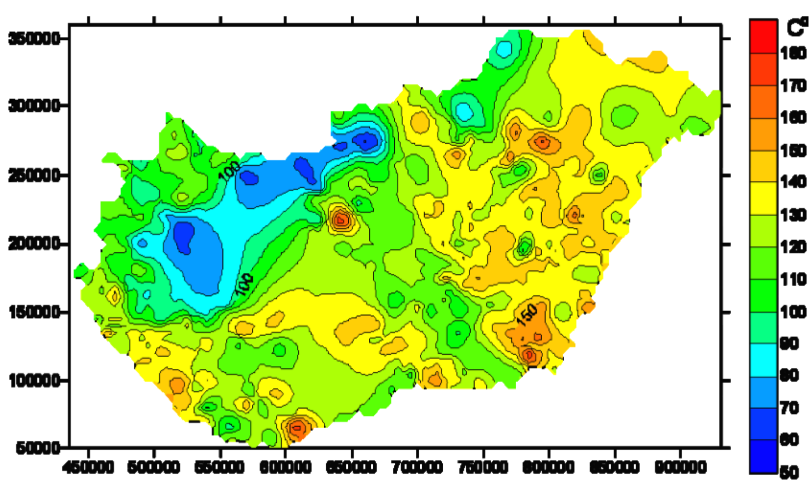

Figure 1: Heat-flow density at a depth of 2500m

There are also some high-enthalpy reservoirs in Hungary, related to deep-lying (3500-4000 m) and over pressured fractured rocks (dolomites). Their existence was most dramatically proven by a steam-blow-out in Fábiánsebestyén, at a pressure of 360 bars and a temperature of 189 °C. This event went on for 47 days. Hungary also has deeply-buried granitic rocks with high in-situ rock temperatures (≥ 200 °C) and favourable seismic-tectonic settings (extensional regime w/ low level of natural seismicity). These provide promising settings for future EGS project developments.

3. GEOTHERMAL ENERGY PRODUCTION

Most of Hungary's thermal water, about 70%, is drawn from the Upper Miocene-Pliocene "Pannonian" basin (type 1 reservoirs). The remaining 30% comes from the karstified, deeply buried Palaeozoic-Mesozoic reservoirs (type 2). Thermal water production varies in intensity, but has been growing continuously over the last 50 years.

The only Hungarian wells which can be registered officially as geothermal wells are those which produce at least 30 ^{o}C water at the wellhead. There are 1622 such registered geothermal wells in Hungary. According to the Hungarian Office for Mining and Geology. Hungary produced about 25 million m^3 thermal water (2,509,519 GJ) in 2015. Table 2. shows the relationship between wellhead temperature and usage as it applies to thermal water producing wells in Hungary. The first column shows the temperature in 10 ^{o}C intervals. The next columns give the numbers of wells within a given temperature range, according to how the thermal water is used. (B – balneology (spas). A – agriculture. C – communal. I – industrial. M – multipurpose). Table 3. shows the direct heat uses in Hungary (A. Tóth. 2016)

T_{wh}[^{o}C]	B	A	C	I	MP	Σ
30-40	250	278	2	102	67	699
40-50	213	29	32	24	58	356
50-60	98	51	4	22	26	201
60-70	66	39	17	12	41	175
70-80	14	25	8	9	25	81
80-90	6	37	3	6	9	61
90-100	5	33	5	1	1	45
100<		1	2		1	4
Σ	**652**	**493**	**73**	**176**	**228**	**1622**

Table 2: Wellhead temperature and usage

Heating residences	33.02 MWt
District heating	186.56 MWt
Green house heating	271.0 MWt
Fish farms	6.0 MWt
Livestock	4.0 MWt
Agricultural drying	25.0 MWt
Industrial application	19.0 MWt
Balneology (spas)	352 MWt
Ground source heat pumps	42.0 MWt
Total:	**938.58 MWt**

Table 3: Direct heat using in Hungary in 2015

4. GEO-ISTHERMAL MAPS OF HUNGARY

Until now, there was no precise geothermal map for all of Hungary, only generalized maps showing different areas where the geothermal gradient and heat flow was more or less the same. These temperature gradients yielded maps which were based on a not always systematically calculated average of several measurements. Where there was more drilling, such as in Bekes and Csongrad counties in SE Hungary, there is very good and extensive geothermal data. In counties such as Komarom and Fejer, by contrast, no exact geothermal measurements had been previously documented – yet those counties were still included in national geothermal-gradient maps.

The value of this new geo-isothermal atlas is that it yields a much more accurate and comprehensive map of Hungary's geothermal resources. It is based on direct measurement *throughout* the country, for every one of Hungary's 19 counties. To make it easier for the average user, we created five different isothermal maps of Hungary, showing the different depths at which a particular temperature was attained. Those temperatures were 90 ^{o}C, 70 ^{o}C, 60 ^{o}C, 50 ^{o}C and 90 ^{o}C. Our isothermal choices were dictated by practical considerations: 30 ^{o}C (Fig. 2) is the minimum temperature required by the Hungarian government for a well to be considered a thermal well, and only 3% of Hungarian wells can boast of values greater than 90 ^{o}C. Ease of use was a major consideration, since the atlas was meant to be used and popularized by county officials, who have an interest in showing their constituents how to make practical use of available geothermal resources. With this knowledge, Hungarian and foreign investors can more easily benefit from the European Union's clean-energy investment subsidies.

Many of the first holes drilled in Hungary date from the 1920s and 1930s, when companies first began prospecting for oil. This drilling revealed the existence of many large and porous underground reservoirs of thermal water. Based on the resulting data, T. Boldizsár (1958, 1967) recognized a high terrestrial heat flux and geothermal gradient in Hungary's Pannonian Basin. In the 50s and 60s hundreds more geothermal wells were drilled, mainly for agricultural purposes. In the 70s and 80s MOL Ltd. (the Hungarian Petroleum Company) drilled several hundred additional holes in search of oil and natural gas. Another thousand or so wells were also drilled for other purposes, reaching and passing through the Miocene layer.

As shown below in Fig.2, the rock temperature of 30 ^{o}C occurs at a depth of 250-450 m everywhere in Hungary except in the Bakony and Bükk plateaus. At 30 ^{o}C, thermal water is primarily used for spas in Hungary. That temperature is more than adequate for heat-pump applications, however, and some are already being used for various industrial services throughout the country.

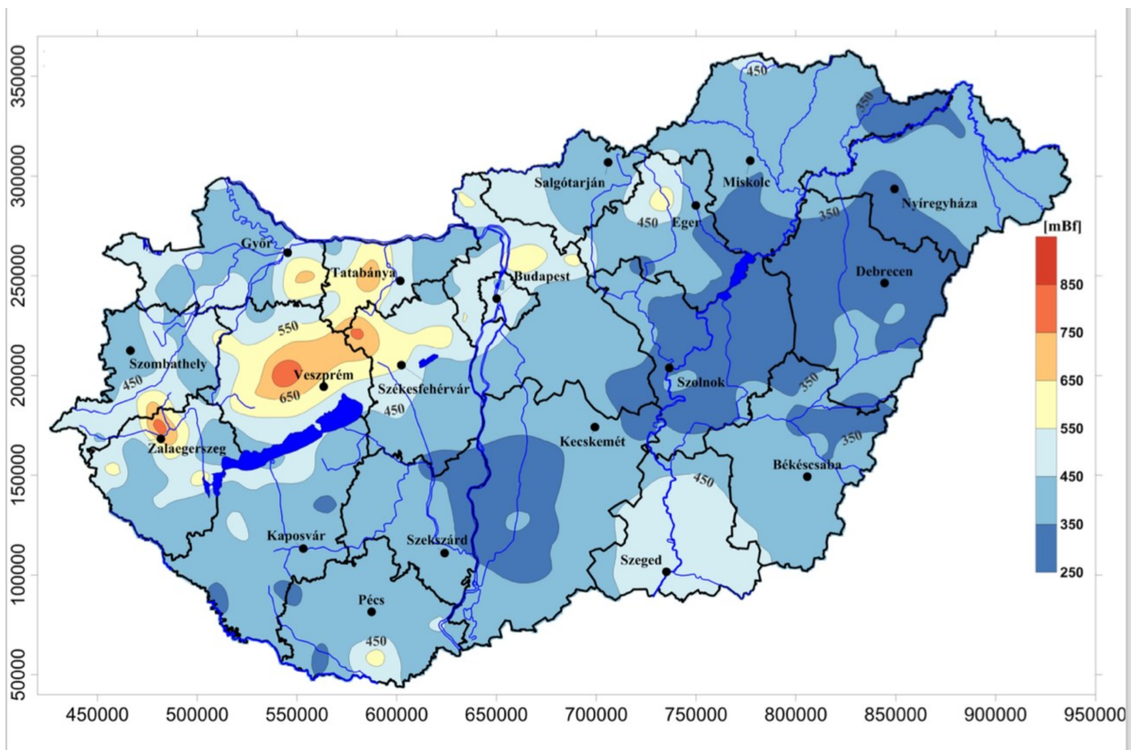

Figure 2: Geo-isothermal depth distribution map at 30 ^{o}C rock temperature

Fig. 3 shows that a 50 ^{o}C rock temperature is reached almost everywhere at the 700-900 m depth. This temperature is high enough for use in heating houses with panel radiators -- one of the most common forms of heating in Hungary. In combination with a heat pump, a temperature of 50 ^{o}C is sufficient for large-scale district heating systems. 50 ^{o}C thermal water is also quite suitable for such agriculture purposes as heating greenhouses or maintaining livestock. Fig. 4 makes evident the outstanding geothermal gradient in the hills of Zemplén and Tolna counties, where a rock temperature is attained at the relatively shallow depths of 500-700m. Fig 5 shows the geo-isothermal map for 70 ^{o}C and Fig. 6 shows 90 ^{o}C, at which temperature the thermal water is hot enough to meet almost any industrial and communal heat demand. In the Alfold plain, in SE Hungary, 90 ^{o}C rock temperature is attained at 1600-1700 m. A noteworthy anomaly occurs in Cserehat, where the rock temperature reaches 90 ^{o}C at 1400 m.

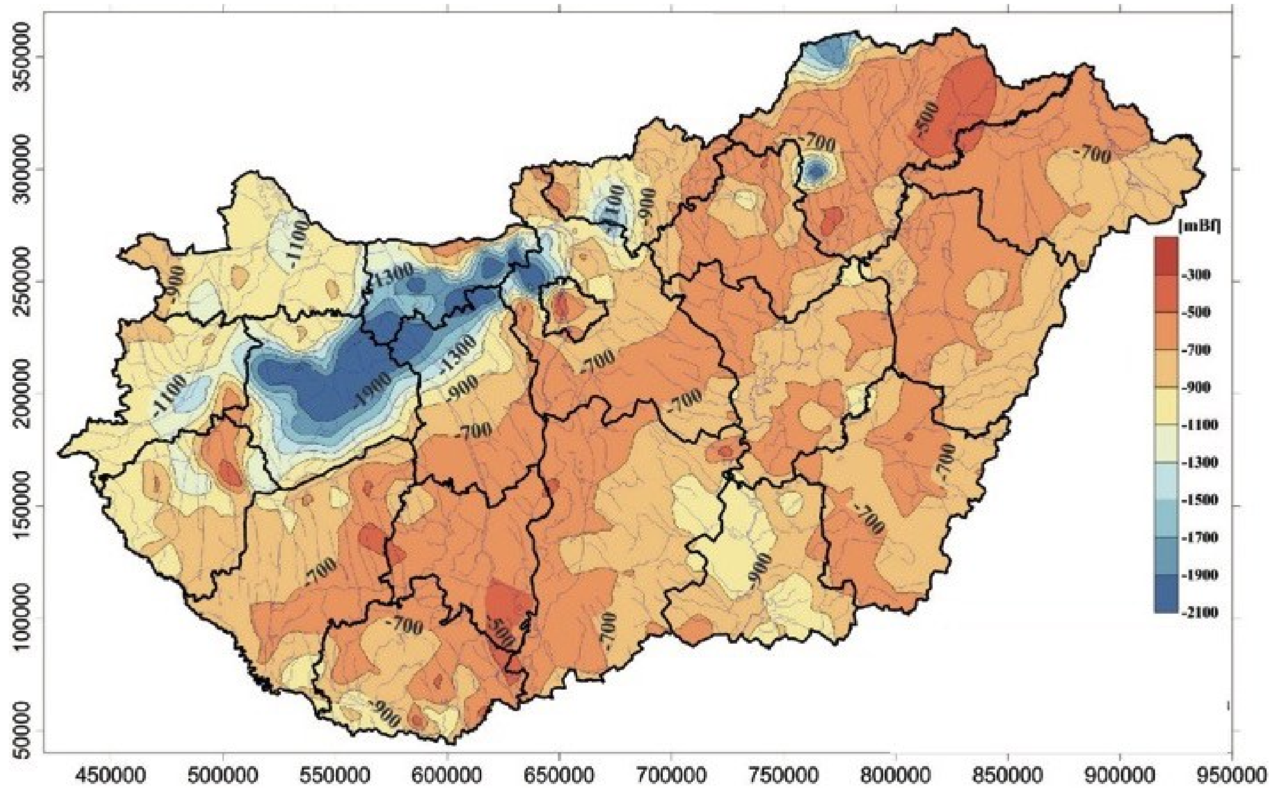

Figure 3: Geo-isothermal depth distribution map at 50 ^oC rock temperature

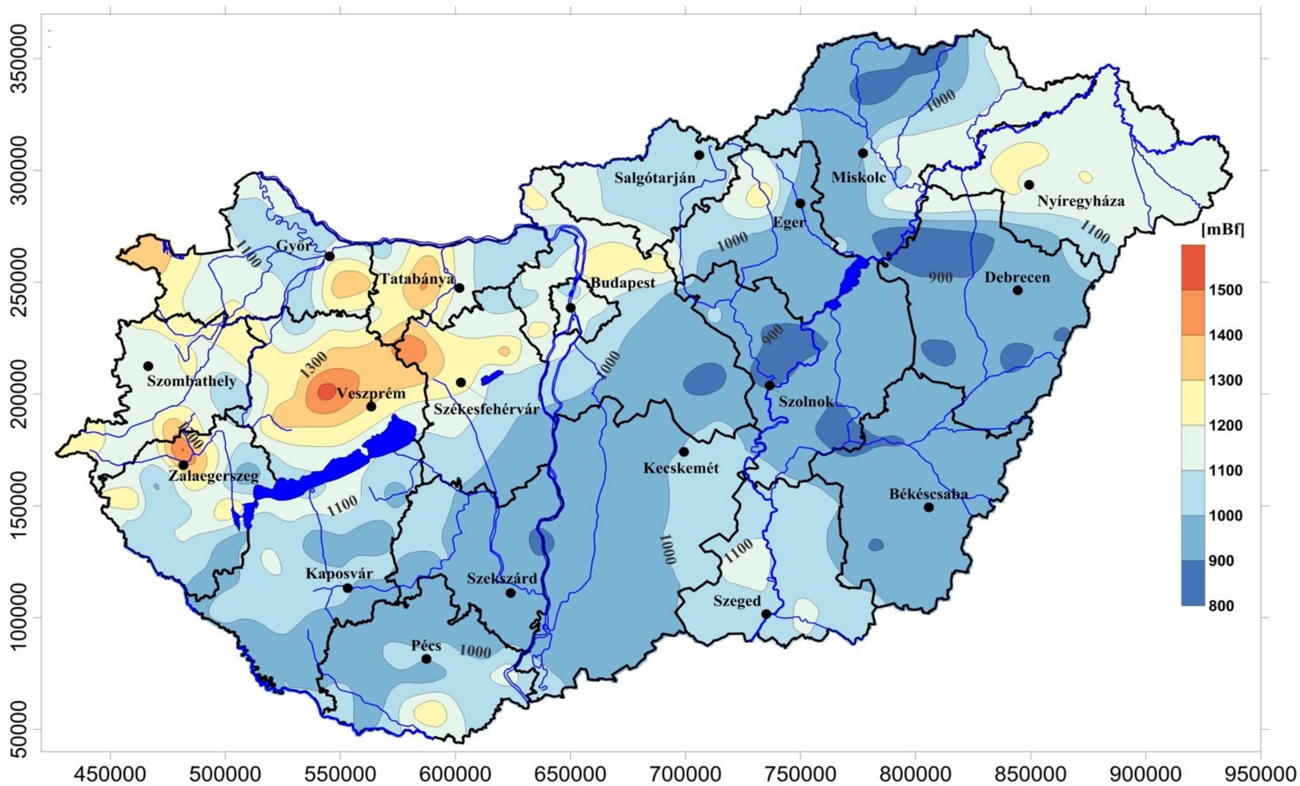

Figure 4: Geo-isothermal depth distribution map at 60 ^oC rock temperature

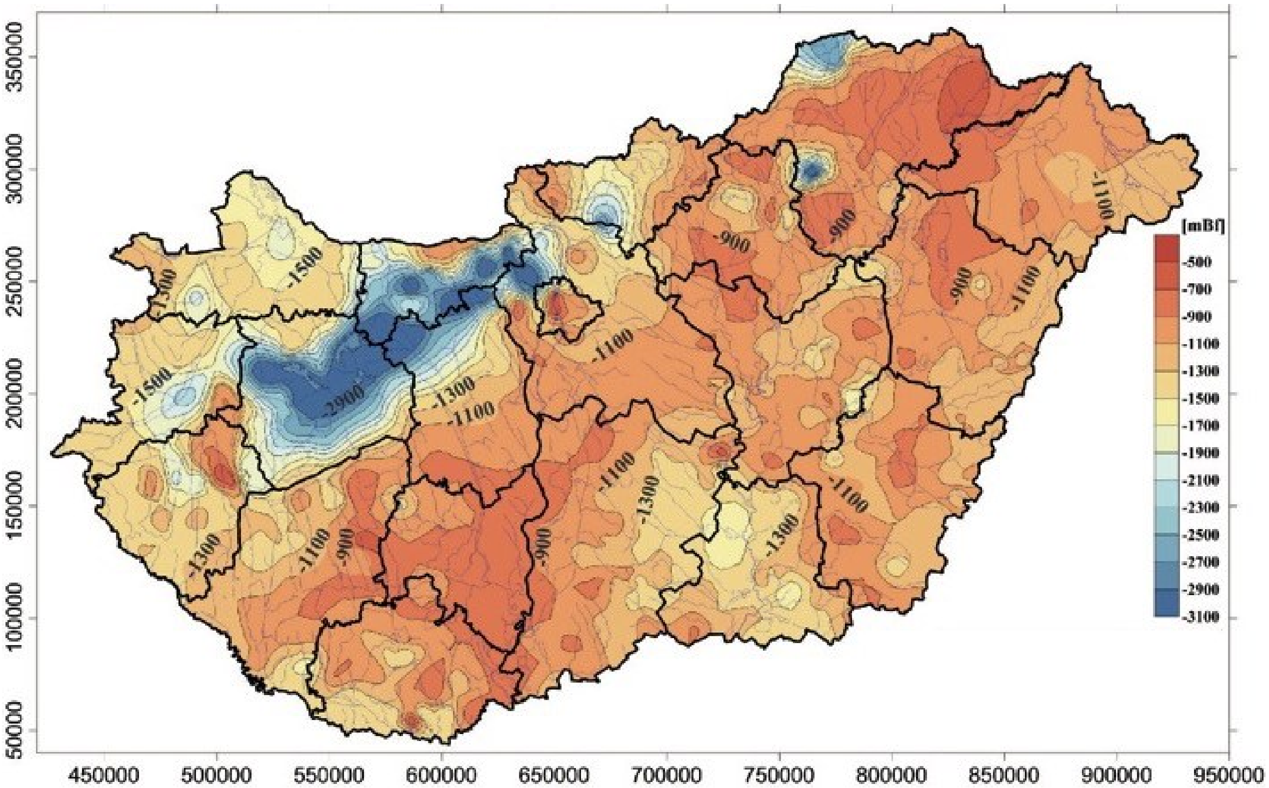

Figure 5: Geo-isothermal depth distribution map at 70 °C rock temperature

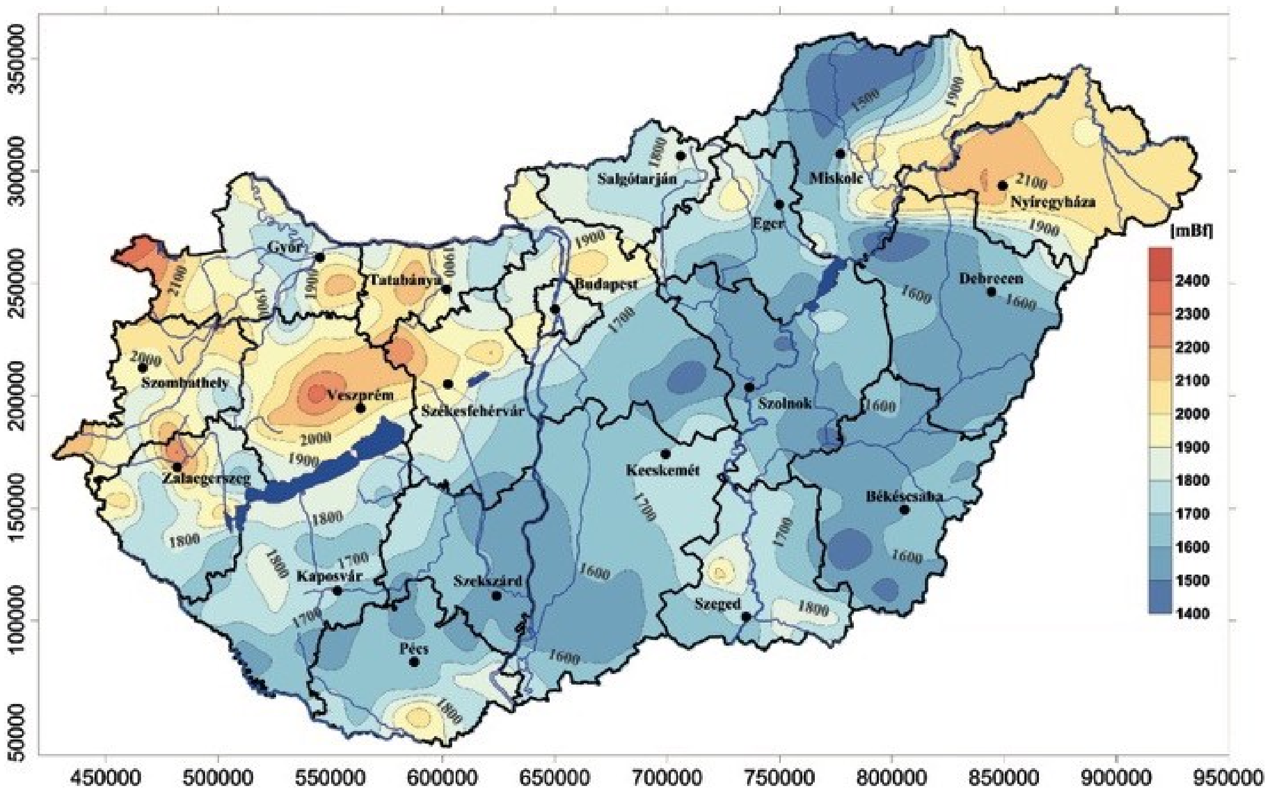

Figure 6: Geo-isothermal depth distribution map at 90 °C rock temperature

5. HOW THIS GEOTHERMAL DATABASE DESCRIBES THE DIFFERENT COUNTIES OF HUNGARY

Hungary has 19 counties, each with its own geothermal wells. The number and temperature of their wells varies greatly, as does the economic health of these 19 counties. Previously, Hungary's counties lacked a unified, integrated database, and thus lacked a practical means of evaluating their various geothermal opportunities. Following a request from the Hungarian Energy and Public Utility Regulatory Authority, and based on the various existing Hungarian geothermal databases, 1620 geothermal wells data were analyzed and summarized. In addition, the geothermal potential of every one of the country's 19 counties was evaluated. The study also investigated 168 abandoned hydrocarbon wells, which were considered promising from the standpoint of geothermal use.

The current geothermal atlas is based on the integrated evaluation of four different datasets. The first is that of the Hungarian Office for Mining and Geology, derived from the self-declaration of users who pay mining royalties, i.e., data from energy users only. The second major source of information was the registry of thermal water production (i.e., water with outflow temperature > 30°C), maintained by the National Institute for Environment and containing data from all operating thermal wells. The third source was the geothermal well register, which is obligate to check the accuracy of every well's EOVX, EOVY, EOVZ coordinates, as well as its depth, its age, and its ownership. The fourth source of data was the abandoned hydrocarbon wells register.

There were of course many discrepancies between these four databases. These discrepancies could sometimes be resolved when comparison revealed a logical impossibility. In other cases, professional judgement was required. For the drilled holes in question, the holes' ages, ownership, diameters, geographical position, rock or water temperatures at prescribed depths, and maximum hole-depths were accurate – the more questionable value was always the amount of water and energy officially produced.

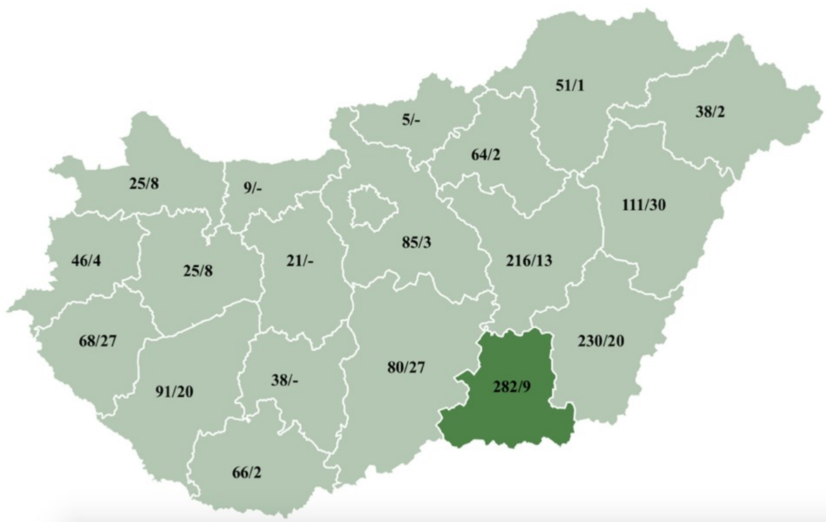

Figure 7: Hungarian counties with the number of existed geothermal wells and the prosperous hydrocarbon wells

From a geothermal point of view, the most promising county is Csongrád. This southeastern county has 282 geothermal wells (Fig. 8), and 7 abandoned hydrocarbon wells which are being evaluated for geothermal uses (Fig.9). The geothermal gradient is 37- 45 ^{o}C/km, with a county-wide heat flow of 90-106 mW/m^2 (Dövényi 1983). For purposes of easy classification, Csongrad's geothermal reservoirs can be divided into three parts. The first and highest layer has very good permeability, a rather low TDS value, and a temperature of about 30-35 ^{o}C. It is used not for energy production, but only for drinking water. The second or Levante layer is less permeable, but has a similar TDS value and a higher temperature. The third and most valuable layer is the Upper-Pannonian, which has diverse properties, and produces the most fluid. Drawing from the Upper Pannonian, Csongrad's oldest thermal well was drilled in 1927. After the interruption of WWII, geological exploration in Csongrad county started again in 1944 and continued at an increased intensity, spurred on by the prospect of oil and natural gas. Because of its significant history of secondary petroleum production, there is also a fund of injection-technology experience available in the county, with some barren hydrocarbon wells re-designated as geothermal wells. Csongrad produces 25–30 million m^3 of thermal water annually, or 1/6 of all Hungarian geothermal water production. Every town in the county has a geothermal heating system. The largest is in Hódmezővásárhely, with 8 producing and 2 injection wells. The Hódmezővásárhely reservoir is located in South-Eastern Hungary, near the Tisza river. Its basement rock contains a deep, extensive geological trench. In 1967, the first thermal well was drilled there as an individual system, to help heat the local hospital. In 1993, the local government began developing an integrated geothermal heating system. Starting in 1998, the cooled water was injected into the sandy, sandstone geothermal reservoir. At that time, more than 3,000 residences received geothermal heating.

In Fig. 10 and Fig. 11 show Heves county's geothermal opportunities. This northern county has 64 thermal wells, of which 6 wells have wellhead temperatures exceeding 60 ^{o}C. These thermal water wells are used mainly as spas in Bükkszék, Egerszalók, Eger, Demjén, Hatvan and Mátraderecske, although a few localities are just starting to use heat exchangers for heating purposes. It is interesting that there is a lack of sufficient drinking water in the county uplands, but their medium temperature thermal water is cooled and used for drinking, notably in the cities of Eger, Lőrinci, Hort and Heves.

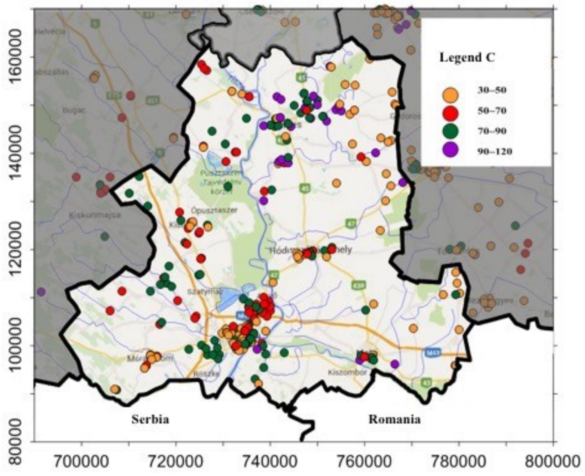

Figure 8: Geothermal wells in Csongrad county

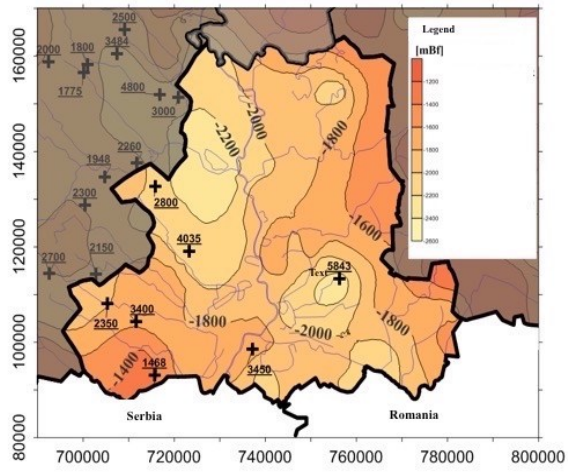

Figure 9: Abandoned hydrocarbon wells with good geothermal potential

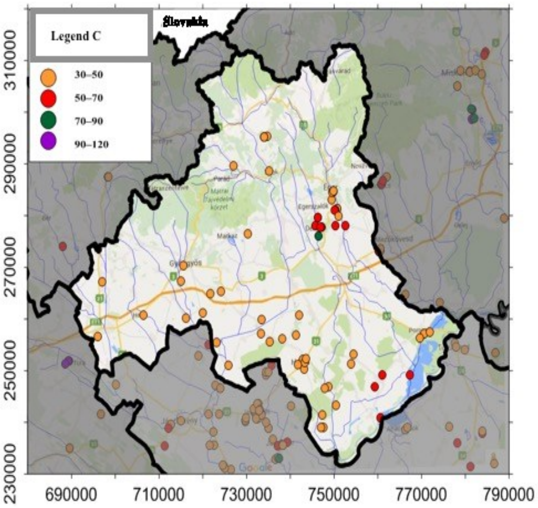

Figure 10: Geothermal wells in Heves county

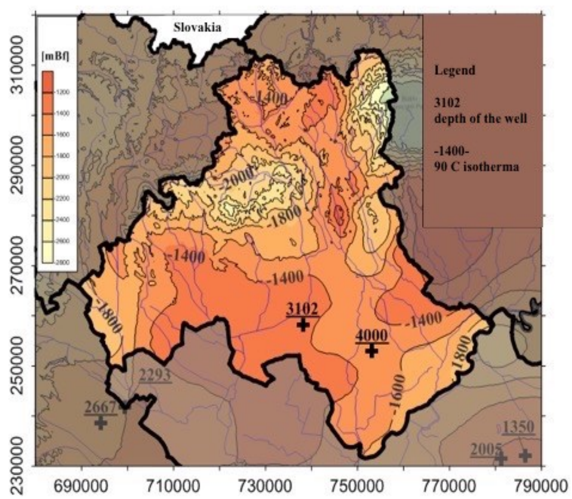

Figure 11: Abandoned hydrocarbon wells with good geothermal potential

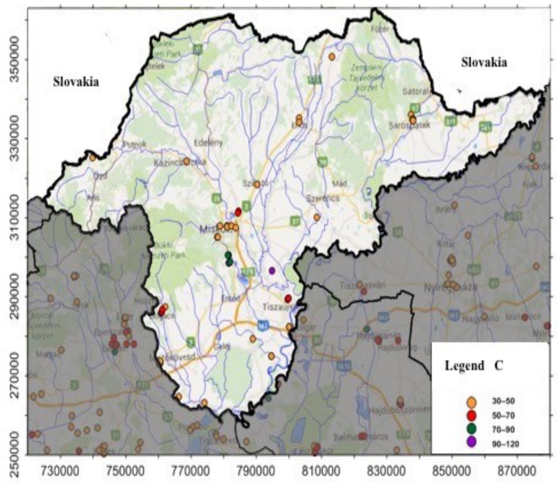

Figure 12: Geothermal wells in Borsod county

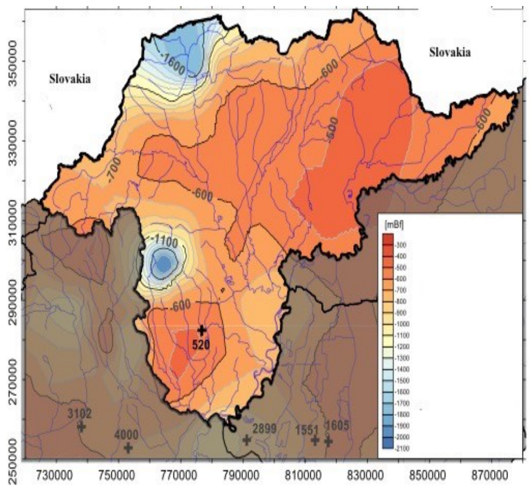

Figure 13: Abandoned hydrocarbon wells with good geothermal potential

The most promising geothermal counties are in SE Hungary, in Csongrád and Békés, where the wells are drilled to the porous reservoirs. Yet one should not overlook the Bükk Mountains in NE Hungary, which has a considerable amount of hot- and cold-karst reservoir capacity. Although cold-karst water production is declining, production from the hot karst has been gradually rising since 2001. Thermal water produced from from the hot karst has a temperature of 40-95 °C, and warms up with increasing depth. The county has 51 geothermal wells (Fig. 12) and 1 abandoned shallow hydrocarbon well. There are twenty towns in the county where thermal water production is underway. These wells were drilled mostly for hydrocarbon purposes in Mezőkövesd-Zsóry (1939), Bogács (1955), and Tiszaújváros (1976). Despite the relatively high water temperature (68-73 ° C), these wells are used for spas.

Hungary's largest geothermal based district heating system is the Miskolc-Mályi Project in Borsod-Abaúj-Zemplén County, which began its first operational phase in 2013. Miskolc-Mályi is the first "large-scale" project in Hungary, and its geothermal-based district-heating system supplies several hundred apartments in the Avas housing estate, in the county capital of Miskolc. A total of 5 wells were drilled. Two production wells went to a depth of 2,305 m and 1,514 m, yielding 6,600-9,000 l/min fluids with a temperature between 90 and 105°C, from a karstified- fractured Triassic limestone reservoir. Three injection wells were also established, as well as a 22 km pipeline.

6. SUMMARY

Although Hungary has favorable natural conditions for geothermal energy production, there a couple of reasons why production and utilization has lagged behind expectations: 1/ the country's weak economy, which has not yet recovered from the world economic crisis of 2008; 2/ the previous lack of any accurate, reliable and comprehensive geothermal map for the entire country. Instead of the latter, there was only an assortment of generalized maps, showing different areas where the geothermal gradient and heat flow was more or less the same. These temperature gradients yielded maps which were based on a not always systematically calculated average of several measurements.

The value of this new geo-isothermal atlas is that it yields a much more accurate, comprehensive and useful map of Hungary's geothermal resources. In addition to creating a solid informational basis where none had existed before, the study was valuable as a means of showing all 19 Hungarian county governments how they might profit from their geothermal potential. Where the national government is unable to provide rural counties what they need, it is all the more important that those county governments be empowered to assure their own energy-independent future and pollution-free environment.

REFERENCES

Boldizsár, T.: The Distribution of Temperature in Flowing Wells. *American Journal of Science* **Vol. 256**, pp.294-298. (1958).

Boldizsár, T.: Terrestrial heat and geothermal resources in Hungary. Bull. Volcanologique XXX. 221-227. (1967)

Dövényi, P. et al.: Geothermal Conditios of Hungary, Geophys Transact., 29:3-114, (1983)

Dövényi, P. et al.: Atlas of Geothermal Resources in Europe, Official Publication of European Communities, (2002)

Nathenson, M et al.: Preliminary map of temperature gradients in the United States GRC,4,53-71. (1980)

Tóth A.: Geothermal Resources of Hungary at a Glance, Proceedings 24th New Zealand Geothermal Workshop, Auckland, New Zealand (2002)

Tóth, A.: Hungarian Country Update 2010-2014, Proceedings World Geothermal Congress 2015, Melbourne, (2015)

Tóth, A.: Magyarország geotermikus atlasza, Study for the Hungarian Energy and Public Utility Regulatory Authority, (2016)