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Geothermal Potential for Geothermal District Heating Development in the Czech Republic

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ABSTRACT

A long-term perspective of increasing uptake of geothermal district heating in Europe is subject of on-going GeoDH project (2012-2014) lead by European Geothermal Energy Council (EGEC). Although the GeoDH project primarily aims at removing administrative and financial barriers and adopting right regulatory framework, the promotion and development of geothermal district heating systems requires detailed investigation of geothermal potential. Previous geothermal studies in the Czech Republic confirmed large geothermal potential of the country for energy purposes from shallow resources. Lower-temperature resources of several types are being tapped for space heating and industrial processing. This paper describes unique geothermal system for district heating in the Czech Republic, in the town of Decin. The paper provides summary of findings from the past R&D geothermal study which is considered within further geothermal development.

1. POTENTIAL FOR GEOTHERMAL DISTRICT HEATING IN THE CZECH REPUBLIC

Territory of the Czech Republic is formed by granite bed rock of Bohemian Massif. Considering that 4 km thick massif is cooled by 1ºC down, the theoretical potential equals 500 000 PJ while the annual consumption of primary energy resources in the Czech Republic is 1 800 PJ (Motlik, 2007). More than 60 sites potentially favourable for geothermal energy exploitation might be identified within the Czech territory (in total estimated 250 MW for geothermal electricity and 2 000 MW for heating) (Myslil et al., 2006). With the exception of the Bohemian Massif, the exploitable geothermal resources are rather of low potential. Despite this, large-scale geothermal project focusing on geothermal cogeneration is currently under development (Jirakova et al., 2013; Myslil and Frydrych, 2007; GEOMEDIA Ltd., 2007).

Additionally, as the Czech Republic is famous for its rich mining history, great quantities of water stored in old Czech mines could represent a considerable source of geothermal energy (Novak and Kasikova, 2010, Stibitz et al., 2012). This energy source has been used only exceptionally and its further development will be governed by technical solutions.

Although several sites would be favourable for development of geothermal district heating systems in the Czech Republic, only the area on the northwestern part of the Czech Republic in the municipality of **Decin** (Fig. 1) is a typical example of such type of geothermal resource exploitation in the country

Figure 1: Location of geothermal district heating system in Decin.

Central heating within the right river side of the municipality of Decin represents unique project in the Czech Republic. Experimental borehole was drilled in 1998 and was put in operation in 2002 (TERMO Decin Co.). The project is partially financed by State Environmental Fund of the Czech Republic. The geothermal borehole reaches 550 m below surface. As the temperature of spontaneous water outflow is rather low (30ºC), heat pumps cool water down to 10ºC and is consequently used for drinking purposes. Acquired heat is treated in municipality Heating Plant with other heat sources – cogeneration gas engines and gas kettles. Installed capacity of individual facilities is given in Table 1.

Table 1: Installed capacity of Heat Plant in Decin.

Heat pumps	2x 3,28 MWt
Cogeneration gas engine	0,8 MWe/1,01 MWt
Cogeneration gas engine	1,94 MWe/2,09 MWt
Gas kettles	2x 16,5 MWt

So far, Decin project is the only District Heating Plant project in the Czech Republic.

2. RESEARCH PROJECT – POTENTIAL FOR GEOTHERMAL USE FOR ENERGY PURPOSES IN THE CZECH REPUBLIC

2.1 Project background

The research project „Potential for geothermal use for energy purposes in the Czech Republic“ (ZO/630/3/99) financed by the Ministry of Environment was led by GEOMEDIA Ltd. during four years between 1999-2002. The project team included other institutes such as Institute of Geophysics of Academy of Science of the Czech Republic, Czech Geological Survey, Geofond, City Plan Ltd., Department of Environmental Engineering of Czech Technical University.

The project focused on potential use of geothermal energy as one of renewable energy resources.

Like in surrounding European countries, favorable conditions for geothermal energy use have been identified also in the Czech Republic. Most commonly used low temperature sources are being exploited by geothermal heat pumps (Jirakova et al., 2013). However, particular system of geothermal exploitation has to be evaluated and projected for specific site conditions and expected application.

Although the overall research project included several topics which are all described in the final report of the research project (Myslil et al., 2002), this paper is focusing on methodological approach during treatment of drilling documentation, elaboration of geothermal maps and heat flux measurements.

2.2 Statistics and treatment of drilling documentation

The construction of the geothermal maps of the Czech teritorry is based on vast database of wells in Geofond where 3 826 wells from 5 447 wells in total were appropriate for further analysis. Moreover, 743 wells comprise well logging record. Obtained drilling documentations involves following depth configurations:

- 174 wells deeper than 2 000 m
- 474 wells with drilling depth of 1 000 – 2 000 m
- 414 wells with drilling depth of 1 000 – 500 m
- 1 219 wells with drilling depth of 500 – 100 m
- 781 wells with drilling depth of 100 – 50 m
- 108 well shallower than 50 m (subject of applicability consideration)

Modified databases from Vienna Basin, Carpathian Fore-deep and mountains Beskydy and specific database obtained from Institute of Geology of Academy of Science of the Czech Republic were involved into the final database to be processed. Obtained databases were uniformly interpreted in terms of temperature conditions. Temperature data were taken from documents of the Czech Hydrometeorological Institute and temperature value for altitude 0 m.a.s.l. was using the following formula:

$$T_0 = (z\text{-}h)/h/(T_m - T_A) + T_m, \qquad [1]$$

where T_0 is calculated temperature at 0 a s.l. [°C], z is altitude [m.a.s.l.], h is well depth with temperature record [m], T_A is air temperature [°C] and T_m is recorded water temperature in the well [°C].

2.3 Methodological approach for well temperature data use

For all wells, the uniform procedure was applied, as following:

1. Geographic coordinates φ (latitude) and λ (longitude) were calculated using X and Y coordinates for all wells under investigation and altitude z was took over.

2. Using geographic coordinates, the air temperature T_A was calculated according the following formula:

$$T_A (\varphi, \lambda, z) = 26{,}175 - 0{,}076\cdot\lambda - 0{,}302\cdot\varphi - 0{,}00588\cdot z, \qquad [2]$$

where T_A is air temperature [°C], φ is latitude, λ is longitude and z is altitude [m a.s.l.].

3. The calculated value T_A was applied to calculate the geothermal gradient G according to the formula:

$$G = (H / (T_{well} - T_A))\cdot 1000, \qquad [3]$$

where G is geothermal gradient, H is well depth [m], T_{well} is well temperature [°C] and T_A is air temperature [°C].

4. Heat flux q was calculated from geothermal gradient as following:

$$q = G / 1000\cdot\Lambda, \qquad [4]$$

where q is heat flux [mW/m^2], G is geothermal gradient [°C/km] and Λ is thermal conductivity [W/mK].

5. Maps of temperature were calculated according to the following formula in various depths:

$$T_H = G \cdot H/1000 + T_A, \qquad [5]$$

where T_H is temperature in the respective depth [°C], G is geothermal gradient, H is well depth [m] and T_A is air temperature [°C].

Such calculated geothermal values were used for map compilation subsequently displayed on the map with geological background. Geothermal gradient was consequently used for calculation of temperatures values in levels 200 m and 0 m a.s.l. that were used for contour lines displayed on geological background.

Geothermal gradient values lower than 10 mW/m^2 were automatically excluded from the data set and values exceeding 100 mW/m^2 were automatically considered as 100 mW/m^2 as they were often subject of great errors.

2.4 Geothermal maps elaboration

Acquired data set was used for elaboration of individual geothermal maps with geological background. A whole range of constructed maps is included in the project final report (Myslil et al. 2002). Elaborated maps include following examples:

- Map of spatial distribution of wells
- Map of thermal gradient
- Map of heat flux
- Map of temperatures for levels 0 m a.s.l., 200 m a.s.l. and 3 000 m a.s.l.

These maps were constructed as a tool for projects in the field of geothermal energy, primarily for use of 'dry' heat from rock environment using heat pumps.

Furthermore, these maps were taken into account during evaluation of most favourable geothermal conditions on particular sites considered for potential use of Earth's heat directly for energy use and electricity generation.

Construction of maps for both levels 0 m.a.s.l. (Fig. 1) and 200 m below the surface (Fig. 2) have practical application on the Czech territory as the level of 0 m.a.s.l. approximately corresponds to the level -200 m (at the lowest base level of the river Elbe in Decin and below the valley of the river Morava in southern Moravia) in the Czech Republic.

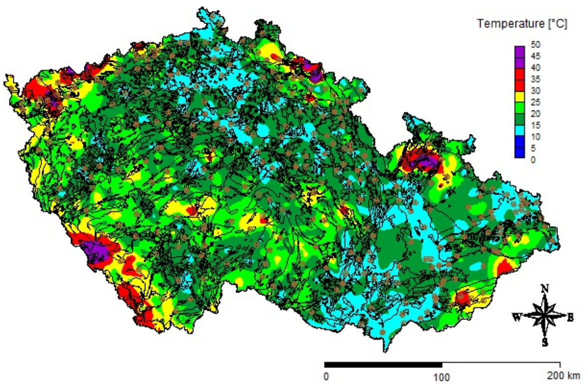

Figure 1: Temperature map in 0 m a.s.l. as calculated from all available well data (Myslil et al., 2002).

The temperature map for altitude 0 m.a.s.l. eliminates effect of topography for most of the area of the Czech Republic and gives relevant information about rock massif thermal conditions as it eliminates the effect of sedimentary layers. Moreover, it also eliminates palaeoclimatic effects and changes in temperatures of groundwater during its circulation.

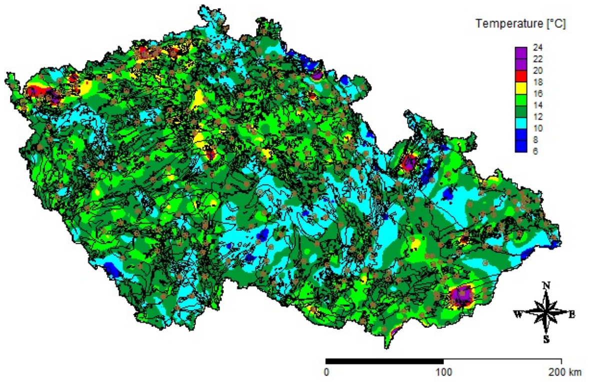

Figure 2: Temperature map in -200m as calculated from all available well data (Myslil et al., 2002).

Some of the wells had to be excluded from the data set due to high inaccuracy for shallow wells (less than 30 m deep and 50 m primarily with regard to morphological characteristics in the well surrounding).

Other ambiguity for geothermal gradient and consequently heat flux determination results from different well depths. The geothermal gradient is generally considered as an average value at particular site and as evident, its value depends on heat conductivity of rocks. Deeper the well is and therefore comprising various rock types, higher inaccuracy is.

The research activities related to temperature measurements considered sufficient time to reach thermal equilibrium. Equilibration time depends on borehole geometry, rock properties and groundwater flow regime. Measurements taken under non thermal equilibrium conditions in the borehole will always provide unrepresentative temperature values (Jirakova et al., 2011).

The analysis of well logging confirms the effect of climatic and microclimatic conditions at depths up to several tens of metres. There is no doubt for relation of geothermal conditions with climatic and palaeoclimatic conditions (Safanda, 1994), notably in the mountainous areas where the differences in temperature are considerable as well as the changes in the geothermal gradient values.

Spatial distribution of boreholes is displayed in Fig. 3. and shows that the Czech Republic is divided into several sections of different level of knowledge.

As evident form Fig. 3, boreholes shallower than 50 m are generally concentrated in southern and southwestern part of the country as well as boreholes between 50 – 100 m deep. Although the spatial heterogeneity of borehole distribution suggests misrepresenting geothermal pattern, the overall characteristics are acceptable and allow the analysis.

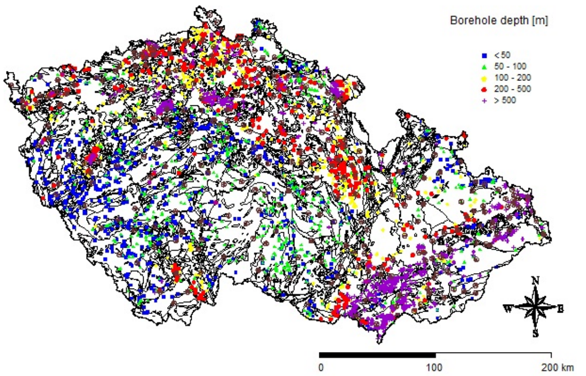

Figure 3: Spatial distribution of borehole data set according the depths (Myslil et al., 2002).

Processing of maps allow to eliminate inaccuracies in the geothermal gradient determination for different depth levels. Based on this, it is possible to localize several areas in the Czech Massif and Carpathian units with significantly better geothermal conditions (Fig. 4):

- SW part of the Podkrusnohorsky Rift
- Contact with the Karlovy Vary granite massif and the crystalline part of the Krusne Mountains
- Central part of the Podkrusnohorsky Rift
- NE part of the Podkrusnohorsky Rift
- Crossing of significant deep structures (Usti nad Labem – Decin)
- Krkonose region near the boundary structure of Cretaceous Basin
- Melnik region – basement of Carboniferous coal basin
- Losiny – Krnov (Eastern part of the country)
- Ostrava region (Eastern part of the country)
- Vsetin – Jablunka (Eastern part of the country)

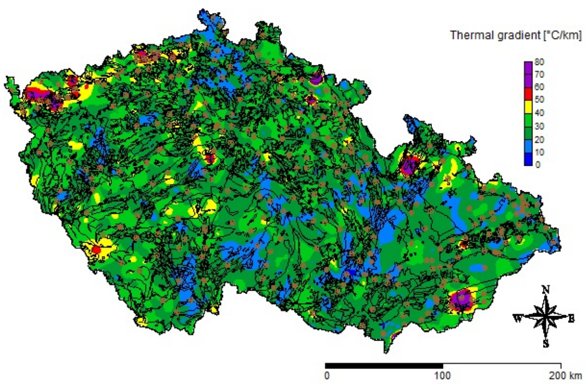

Figure 4: Map of thermal gradient as calculated from all available well data (Myslil et al., 2002).

Analysis of geothermal data and subsequent construction of heat flux maps (e.g. Fig. 5) on the territory of the Czech Republic enables to ass the overall geothermal potential. The territory of the Czech Republic was divided into sub-regions presented in Table 2 according to the heat flux value for which the thermal potential was established. As observed from the Table 2, in 85% of the Czech territory heat flux values range between 30 – 70 mW/m^2. The total heat potential is estimated at about 3 900 – 4 700 MW.

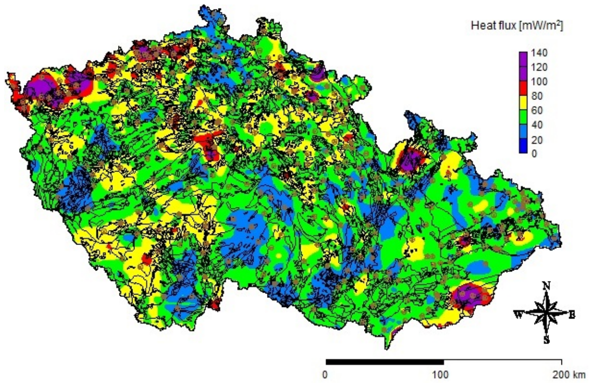

Figure 5: Map of heat flux as calculated from boreholes with depth > 50 m (Myslil et al., 2002).

Table 2: Overall thermal potential of the Czech Republic (Myslil et al., 2002).

Heat flux	Concerned area [km^2]	Heat potential of the Czech Republic according heat flux [MW]
< 10 mW/m^2	0.00	0 – 0
10 – 20 mW/m^2	4,12	0,0412 – 0,0825
20 – 30 mW/m^2	1 896,35	37,9269 – 56,8904
30 – 40 mW/m^2	11 853,35	355,5970 – 474,1294
40 – 50 mW/m^2	21 382,09	853,1237 – 1 066,4046
50 – 60 mW/m^2	19 426,23	971,3113 – 1 165,5736
60 – 70 mW/m^2	13 740,66	824,4398 – 961,8465
70 – 80 mW/m^2	6 009,11	420,6379 – 480,7290
80 – 90 mW/m^2	1 980,34	158,4270 – 178,2304
90 – 100 mW/m^2	865,18	77,8661 – 86,5178
> 100 mW/m^2	1 760,68	176,0683 – 246,4956
Total amount	**78 864,00**	**3 875,4393 – 4 716,8998**

2.5 Heat flux measurements

A well logging device was constructed at the Institute of Geophysics of Academy of Sciences of the Czech Republic in order to measure the heat in the newly drilled wells for exploiting dry heat from rocks. As in some geological structures, e.g. in granitic massifs, were no wells measured for dry heat exploitation purposes, a borehole 150 m deep in granites was drilled in the scope of the research project. The well was located in the Central Bohemian Pluton at the municipality of Svojsice and was used for measurements of heat and thermal rock parameters as well as monitoring of temperature changes caused by annual climatic fluctuations. Similarly, other boreholes were monitored, such as in Frantiskovy Lazne, Velky Luh, Lomnice u Karlovych Varu, Bludov (depth 95 m), Potucky (depth about 300 m) and second well in the Svojsice (depth 70 m) and other monitoring well had been monitored also in the area of the Institute of Geophysics of Academy of Sciences of the Czech Republic in Prague which is drilled into clayey shale. The monitoring of temperature at the air-soil interface was also initiated at the Svojsice site as the well is situated at the higher altitude.

2.6 The evaluation of geothermal data

The company GEOMEDIA Ltd. analyzed the possibility of geothermal energy exploitation for Krkonose National Park and Sumava National Park in 1997 and 1998. The heat potential was analyzed in numerous sites in the Czech Republic, such as in Chomutov, Most, Melnik, Usti nad Labem, Karlovy Vary, Potucky, Plzen, Jihlava, Decin and Moravia-Silesia region in 1999-2002.

The Tab.3 shows estimated values of the total heat potential according to the assessments executed by GEOMEDIA Ltd. in 1997 – 2002. Geofond, Czech Geological Survey, the Institute of Geophysics of Academy of Sciences of the Czech Republic (Dr. V. Cermak) and Geothermal resources in the Czech Republic (Myslil et al., 2002) data files were used for processing.

Table 3: Potential heat values in individual areas

Site	Potential from HDR [MW]	Potential from groundwater [MW]	Total
Karlovy Vary	94,8	38,0	132,8
Melnik	18,6	41,1	59,7
Most	28,8	7,7	36,5
Potucky	2,0	1,3	3,3
Usti nad Labem	7,0	11,6	18,6
Chomutov	71,9	21,1	93,0
Krkonose National Park	88,5	37,6	126,1
Sumava National Park	28,5	25,1	53,6
Jihlava			8
Liberec			11,8
Plzen district			451

The use of geothermal energy has much greater potential than it is its current use. Nowadays, new drilling technology and research techniques are developed and allow us to review the earlier approaches. However, GEOMEDIA Ltd. elaborated tentative geological profiles for four suitable areas of the Czech Republic. Calculations of temperatures at the depth of about 4 km is evident suggest that the temperature at 4 km depth reaches 130°C nearby the Podkrusnohorsky Rift.

From the geological and geothermal point of view, the most favorable structures are:

A. The area on the west of Doupovske mountains (Ostrov nad Ohri – Bozi Dar – Zlaty Kopec)
B. The area on the east of Doupovske mountains (Kadan-Chomutov-Most)
C. The Usti nad Labem – Decin – Dresden region
D. The area of Melnik – Mlada Boleslav

Ad A. The granite structure of Krusnohorsky granite is covered by metamorphic formations. Metamorphosed granite massif has significantly increased radioactivity in the youngest section of Czech Massif Jachymov – Bozi Dar – Potucky. The measured heat flux reaches 100 mW/m^2. This area has good thermal conditions due to higher levels of radioactivity.

Ad B. The granite structure is covered by Miocene and Cretaceous sediments. Additionally, Permian Carboniferous sediments can be encountered in the basement. The tectonic fault Jachmov and rift valley of Podkrusnohorsky Rift represent the contact of metamorphic rocks and Karlovy Vary granite massif.

Ad. C. Upper Cretaceous sediments and sediments of Cenomanian, Turonian and Santon represent main sedimentary units which are covered by Quarternary layer. Elevated geothermal potentail was observed in the areas with thick sedimentary layers and valleys of the river Bilina, Ohre, Elbe and Ploucnice. Mica and biotite paragneisses, gneisses, migmatites and granitoid rocks represent Krusnohorsky Crystalline basement.

As evident in Fig. 5, the average heat flux of the Czech Republic is around 60 mW/m^2 while some areas, such as the Usti nad Labem structure, reach significantly higher heat flux values more than 75mW/m^2. As a result of elevated heat flux values, existence of tectonic features and favourable geological conditions, regional basal aquifers represent hydrothermal fields. Temperature conditions of mentioned thermal system have been the subject of many recent studies (Hazdrova et al., 1980).

Ad. D Cretaceous sediments cover Carboniferous basin structure and basement is formed by granitic rocks. Values of heat flux reaches 90 mW/m^2.

4. CONCLUSION

The interest in geothermal energy use is in the Czech Republic increasing despite high investment costs.

Currently, heat pump installations belong to the most utilized technology. A unique geothermal district heating project was developed in the town of Decin where geothermal conditons reflect geologic-tectonical background of the northern part of the Eger rift.

The geothermal assessment of other Czech sites and regions was subject of numerous studies. R&D project supported by Ministry of Environment of the Czech Republic between years 1999-2002 „Potential for geothermal use for energy purposes in the Czech Republic“ (ZO/630/3/99), discussed in the presented paper, aimed at veryfying geothermal conditions in the Czech Republic. According to the study, average values about 60 mW/m^2 are locally exceeded up to 100 mW/m^2 owing to geological-tectonical and hydrogeological configuration. However, the heat flux calculation was often significantly complicated by groundwater circulation.

Based on the research results, a range of maps have been constructed expressing temperature contour lines as well as spatial distribution of heat flux and thermal gradient. Up to date, the degree of drilling reconnaissance is relatively high enabling further data treatment and interpretations.

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