

Geothermal Energy Potential of Czech Republic

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ABSTRACT

In the last four years a group of specialists reevaluated basic data for geothermal potential. The territory of Czech Republic presents two different geothermal parts: the Bohemian Massif and the Moravian part of the Carpathian structure. There were identified eight localities with possibilities for exploration of geothermal heat for heating and two localities for exploitation of electrical energy.

1. INTRODUCTION

Geothermal energy in the territory of Czech Republic was studied, in detail, over the last ten years. Project team was headed by Dr. Vlastimil Myslil of GEOMEDIA Ltd. and in a contract with Czech Geological Survey, has elaborated a first study of geothermal potential. The geothermal energy is included in energy policy as a renewable source of energy for the future period up to 2020 in the documents of Ministry Industry and Business. Recently a new project for geothermal energy exploration is in preparation.

Initial data compilation, processing and preliminary analysis of geothermal energy potential was performed and presented for the evaluation by Czech Republic government and World Bank.

2. GEOLOGY BACKGROUND

The territory of the Czech Republic consists of three basic units of geological structures of Europe (see figure 1):

- The Bohemian Massif, which is the easternmost part of the European Hercinides,
- The Brno unit –Brunovistulicum, which is a part of Paleo-Europe,
- The West Carpathians, which belong to the Alpine-Carpathian orogenic belt.

The main structures have different conditions for the geothermal heat flow. The Bohemian Massif represents an old consolidated basement which is formed by Proterozoic and Paleozoic crystalline rocks. These basement rocks are overlain by several sedimentary basins of Paleozoic, Cretaceous and Neogene age. The West Carpathian unit is in general younger and is represented by the nappe structure of alpine type.

The basement of Bohemian Massif is tectonically affected by Variscian, Hercynian and Alpinian orogenic activities, which caused the block faulting as well as folded chains by various types of movements. Numbers of sedimentary basins have developed on the hard-rock basement, such as:

- *Barrandian* (Precambrian clastics and shells upto Silurian shells and Devonian carbonates), tectonically affected to the total depth of about 1000m.

- Permocarbiniferous platform terrestrial sediments (*Plzeň - Rakovník Basin, Kladno Basin, Žaclěř Basin* and *Upper Silesian Basin*), which include clastics on the bottom and then alternate fine sandstones, shells with coal beds. The total thickness of sedimentary formations varies from 300m to 400m in the first two basins up to 1500 – 2000 m in *Žaclěř* and *Upper Silesian basins*.

- Czech Cretaceous basin in the north of Bohemian Massif is represented by cenomanian fine sandstones and clay, turonian marls and sandstones and senonian fine sandstones and clay. The total thickness of sediments reaches a maximum of 600 m. Two small depressions in the southern part of Bohemian Massif at the *České Budějovice* and *Třeboň basins* are tectonically limited. The total thickness is 400 m near *České Budějovice*. The *Třeboň basin* is shallow with a maximum of only 150 m.

- Of the many Tertiary basins the more promising ones are: *Sokolov - Karlovy Vary Tertiary basin, Chomutov - Most - Teplice Tertiary basin* and Foredeep on the contact of the Bohemian Massif and West Carpathians which is followed by Vienna basin. Sokolov - Karlovy Vary as well as Chomutov - Most - Teplice basins reach a maximum depth of 250 m. They are formed by clastics on the base and then by clay, tuffitic clay which include tertiary coal beds. The upper part is represented by clayey shales. Locally there exist Permian and Cretaceous sediments preserved in tectonically sunken blocks. The basement is formed mostly by metamorphic rocks and partly by granite.

- The *Carpathian Foredeep* is divided into three parts with various thicknesses of sedimentary formations from a few hundred meters up to more than 6000 m. The depth increases to the southwest to the Vienna Basin. The bottom of the tertiary sedimentary formation is by Devonian carbonates and granitic rocks.

The thickness of the crust in the Bohemian Massif as well as in the both other units varies between 32 up to 40 km generally. But the deep and shallow tectonic divide territory into different zone with better or worse geothermal conditions. Very important geothermal structures are in the Krušné hory rift structure, under the Czech Cretaceous Basin, in some Permocarbiniferous relict structures, in the Carpathian Foredeep, in Vienna Basin and generally in the nearest position to the SN or WE faults with deep reach in the crust.

3 ANALYSIS OF GEOTHERMAL CHARACTERISTICS

3.1 Temperatures

Data related to geothermal potential are primarily the temperature measurements in various depths in boreholes. These data were collected from 1490 measured boreholes on the whole territory of the Czech Republic.

The subsurface temperature data measured in the boreholes for Czech Republic have been obtained by Geofond Praha. The temperature data for the depth of 100m for the whole

Czech Republic were elaborated by Čermák and Šafanda (1992). Present review data for the depth of 500 m were worked out by V. Myslil and J. Burda from the Czech Geological Survey.

The southern part of the Bohemian Massif is cold with respect to the heat flow. Most of Bohemian Massif shows the heat of low-enthalpy. More promising areas are only: Foreland fault of Krušné hory, the axial and western part of the Bohemian Cretaceous Basin, Permocarboniferous basin and West Carpathian Foredeep from the Vienna Basin up to the Ostrava region in North Moravia.

Local anomalies of warm and hot waters in the Czech Republic have been used as spas for a long time. The warmest spring with the temperature 72°C in Karlovy Vary has been used for many hundreds of years. The other springs have a lower temperature: Teplice Spa 42°C, Jáchymov 32°C, Jánské Lázně 32°C, Velké Losiny Spa 34°C, Darkov Spa 28°C, Teplice nad Bečvou 23°C.

3.2 Heat Flow

The heat flow (figure 2) on the territory of Czech Republic was measured on more than 800 points. These values were in some cases confronted with the geological position and the form of heat flow isolines was modified following the borderlines of geological structures.

The heat flow map indicates mostly lower value on the south part of the Bohemian Massif (below 50 mW.m⁻²) in Moldanubicum, where the thickness of Earth's crust reaches to more than 42 km. North part of Bohemian Massif from the line W - E approximately following Cheb - Praha - Ostrava shows the thickness of the crust of only 32 km.

The most promising areas of the Bohemian Cretaceous Basin are in its axial part where the average heat flow exceeds 80 mW.m⁻², tertiary basins in the foreland of Krušné Hory shows heat flow of more than 100 mW.m⁻², Permocarboniferous basins show also 90 to 100 mW.m⁻² and the Foredeep on the border of the Bohemian Massif and West Carpathians reaches the value of heat flow upto 90 mW.m⁻². There are some anomalous localities outside these regions, which show also higher value of heat flow. These places are located on the junctions of regional fault systems that enable an easier and faster ascent of geothermal heat. The most promising zones are on the junctions of NS and WE faults. The NS faults show also the highest seismic activity in South-West part of the Krušné hory region.

4. GEOTHERMAL POTENTIAL OF THE CZECH REPUBLIC

4.1. Potential geothermal reservoirs

4.1.1. North Bohemian Tertiary Basin

The Basin spreads between the Krušné Hory and České Středohoří Mts., trending roughly SW-NE. It is the largest tertiary basin on the territory of the Bohemian Massif situated at the foot of the Krušné Hory and covers an area of about 800 km². The Basin is structurally divided into three parts (Chomutov, Most and Teplice) with various geological and geothermal conditions.

This zone was active in the geological history since the late Proterozoic, when it served for the spillitic volcanism and it was also used by the intrusion of late Variscian plutons. On the metamorphic and granitic rocks of Basement the tertiary sedimentary basins are developed. The basin has a character

of a rift structure related to the main fault zone under the Krušné hory Mts. which was used by young volcanism in two centers - in the Doupov volcanic area and in the České Středohoří Mts. On the periphery of Doupov volcanic area the hot spring Karlovy Vary appears.

The central deepest part between Teplice and Most has a thickness of tertiary formation between 200 – 250 m. The tertiary sedimentation begins by basal sands followed by coal and impermeable clay with layers of fine sand in varying thickness. Some of these sandy layers form a confined aquifer. The maximum thickness of the aquifer is 50 m, water is slightly mineralized (max 2 g.l⁻¹) and specific flow rates vary from 1 to 10 m³/h/m. Thermal water in Teplice Spa circulates in the fractures system of porphyrite.

4.1.2. Bohemian Cretaceous Basin

The Bohemian Cretaceous Basin was gradually sinking and was being filled with Permocarboniferous and later with Cretaceous sediments. The Cenomanian base sediments are fine sandstones with small lenses of clay and coal. These base sediments are followed by lower turonian marlites, middle turonian sandstones and senonian fine clayey sandstones. The mean thickness of cenomanian and turonian aquifer is 100 m. The reservoir is a confined aquifer. The main deep structure is in the axis of Cretaceous Basin and namely in its western part which carries on to Germany. The eastern part of this basin is less favorable.

Two zones with higher heat flow have been registered there:

- *Ústí nad Labem - Děčín* which is located on the axis of the basin on the junction of regional NS and SW-NE fault system and it corresponds with the maximum thickness of Cretaceous sediments on the Bohemian Massif,
- *Mělník - Slaný* located on the junction of three regional fault system - cretaceous basin axis, NS Jizera Fault and WE limit of lower thickness of the crust of Bohemian Massif.
- *Semily - Nová Paka* located on the contact Permocarboniferous basin with sediment structure of Czech Cretaceous basin in vicinity of lužický fault.

The water of this confined aquifer has a low mineralization (maximum 2 g.kg⁻¹) and the temperature varies from 32 to 42°C. The dynamic groundwater reserve in the deepest part of this structure by Ústí nad Labem and Děčín was evaluated to 200 l.s⁻¹. The second zone *Mělník - Slaný* and *Semily - Nová Paka* is not as favorable due to its hydraulic conditions - lower permeability of aquifer.

4.1.3. West Carpathian Foredeep

The West Carpathians nappe structure represents the Alpine orogenic system which borders upon the south-eastern edge of the Bohemian Massif. On the border of these two structures developed a relatively narrow foredeep. The foredeep is connected in the southern direction to the Vienna Basin.

The highest value of heat flow in the foredeep has been measured in the vicinity of Ostrava in the carboniferous Upper Silesian coal mining district. This can be explained by the combined effect of the contact of the Bohemian Massif and West Carpathians which is at the same time accompanied by the zone of smaller thickness of the Earth's crust of the Bohemian Massif.

The main confined aquifer has usually developed on the base of tertiary sediments of various ages and also in larger depth in Devonian limestones and conglomerates. The total depth is several thousand metres. The knowledge of hydrogeological parameters is very limited, because the main interest was given to the exploration of oil and gas in this region.

The porosity of tertiary aquifers is usually less than 15 %. Effective total thickness of the aquifers is about 100 m. The dynamic water level is several tens of metres under the surface. This basal aquifer has a positive artesian pressure with the outflow of some ten litres per second at certain sites. The mineralization is typical for the oil and gas structures, more than 30 g/l.

4.2 General geothermal potential of the Czech Republic

Geothermal energy potential can be calculated in four categories:

- Energy of hydrothermal resources high temperature (>130°C) for exploration of electrical energy:
energy potential estimation.....10 MW
- Energy hot dry rock („HDR“) temperature >130°C for exploration of electrical energy:
theoretical estimation of potential..2 385 900 MW
For the borehole deep up to 5km for 847 localities 4MW capacity:
energy potential estimation.....3 388 MW
- Energy of hydrothermal resources high temperature (<130°C) for heat production:
heat potential estimation.....25 MW
- Geothermal energy for low thermal systems (thermal pump):
potential estimation (dry rock).....8 750 MW
(groundwater).....2 390 MW

A newly developed heat-flow map of the Czech Republic served to delineate areas, whose heat flow (T_1) exceeds 85 - 115 kW/km². Each area was given a specific number, and its spatial extent was determined quantitatively. The quantified area was divided by 5 km², because each borehole couplet of the HDR system requires a minimum of 5 km² (1.5 km borehole spacing, and an area with no “dry” heat consumption around). According to literature, such a borehole couplet can produce approximately 8 MW assuming c. 20 l/s of water pumped into a depth of 3.5 to 4 km. The actual production, however, depends on the local heat flow.

Assuming 8 MW capacity HDR plant, the calculation presented in the appended tables suggests the potential for:

- 17 geothermal power plants with the bulk capacity of 140 MW, or up to
- 23 geothermal power plants with the bulk capacity of 190 MW.

There are 59 favorable areas in the Czech Republic, but some of them are spatially restricted according to the current evaluation. A new, detailed evaluation using supplementary techniques or drilling would be suitable considering the geological and geothermal conditions. In many areas it appears worthy to evaluate applicability of the geothermal heat for house heating, pool-water heating, or heating of thermal spas.

The following requirements were taken into account in further considerations:

- sufficient source of water,
- location outside of the existing spa protection zones, and
- presence of a suitable consumer of the electric energy and heat

4.3 Prospective geothermal areas

One of the hottest areas of the Czech Republic covers the Cheb and Sokolov basins. These areas reach the required temperature 130 – 150 °C at relatively shallow depths of 2.5 to 3 km. Utilization of these two areas is, however, limited by their inclusion in protection zones of the Františkovy Lázně and Karlovy Vary spas. That is because the mineral and thermal waters of these spas are fuelled with carbon dioxide. Release of the carbon-dioxide pressure might affect ascent of the mineral waters. Areas outside of the protection zones provide sufficient space for 2 geothermal power plants. However, a confirmative survey of the relationship of these areas to the existing spas would be needed.

Chomutov and Most basins of the Krušné Hory Piedmont basin northeast of the Doupov Hills are relatively well understood in their structure to the depth of c. 1 km. Interpretation of deeper structural elements requires a supplementary geophysical survey and drilling. Heat flow values suggest that the required temperatures might be reached at depths of 3 to 3.5 km. Up to 3 geothermal power plants can be placed to this area.

Continuation of the Krušné Hory Piedmont basin beneath deposits of the Bohemian Cretaceous Basin near Ústí nad Labem and Děčín is confirmed to the depth of 1 km (deeper in places). Two geothermal power plants can be proposed in this area. Teplice thermal springs can be included in this area, although they are structurally separated from it.

Area between the towns of Lovosice and Litoměřice, which represents the southern flank of the Středohoří volcanic complex, appears to be quite a promising one. It has been drilled extensively to the depth of 1.5 km, and can accommodate 1 or 2 geothermal power plants.

Mělník area can be readily interpreted in terms of its geology. The area is spatially restricted, because no boreholes of sufficient depth are found in its vicinity. However, the structural conditions appear suitable for at least one geothermal power plant.

The area between the towns of Pardubice and Chrudim might be structurally suitable, but geological documentation is restricted to the uppermost few hundreds of meters only. This area would require a new, detailed geologic and structural assessment. Based on the current knowledge, the area is considered a very promising site for one geothermal power plant.

The most areally extensive area is that to the northwest of Krnov. Evaluation of this site is, however, based mostly on shallow (<200 m) boreholes. The available data suggest structural conditions that are likely to provide favorable geothermal conditions at deeper levels. The area extends to Poland. A cooperative solution could provide space for 2 geothermal power plants.

Similar conditions requiring cooperation with Polish authorities are found in the vicinity of Opava.

Another favorable area is located between Prostějov and Kroměříž. It has been penetrated by a number of petroleum-exploration boreholes, but favorable temperatures are found at deeper levels (up to 4.5 km). At least one geothermal power plant could be placed to the area after a detailed evaluation.

A similar setting is found to the south of Brno, where Carpathian nappes cover the easternmost flank of the Bohemian Massif. The structural conditions are known from petroleum-exploration boreholes. The area could accommodate 1 to 2 geothermal power plants after a detailed evaluation.

A potentially favorable structure with respect to geothermal exploitation lies by the Austrian borders, near the upper stretch of the Dyje river. This structure is, however, known from shallow boreholes only. Moreover, it is probably centered in Austria.

The area between the towns of Frenštát and Příbor is considered suitable for at least one geothermal power plant. Relatively deep drilling – over 4 km – is, however, needed in this area to reach the required temperatures. The existing petroleum-exploration documentation is quite extensive, and should be studied prior to the decision. The ongoing petroleum production and exploration in the area must be taken into account.

5. GEOTHERMAL UTILIZATION

Actually there are any Electric power installations and generation using geothermal energy on the Territory Czech Republic.

Direct-use of thermal water in spas and swimming pools is known same hundred years back. The main localities are shown in Table 1.

Table 1: Overview of major spas and thermal springs in the Czech Republic

SITE	Y [Krovak]	X [Krovak]	Wellhead Temperature [°C]
Soos	-885256	-1020040	17.5
Karlovy Vary	-853441	-1012890	72.0
Jachymov	-843573	-998431	32.0
Ostrov n. Ohří	-842382	-1003030	16.5
Teplice Spa	-776043,	-976286	42 to 45.8
Jehličná	-861437	-1011280	21.0
Jánské Lázně	-629712	-999878	28 to 32
Bohdaneč	-653531	-1056110	21.0
Velké Losiny	-557234	-1071160	33.0
Bludov	-566422	-1080180	24.0
Teplice nad Bečvou	-511978	-1131820	22.5

Thermal natural springs and boreholes and wells are indicated on the Geothermal thematic map (figure 3.).

5.1 Spas and Natural Thermal Springs

The warmest and most important geothermal natural spring with the hundreds years' tradition is Karlovy Vary in the Krušné hory foreland "rift" zone. Its temperature is 72 °C, the total yield of 12 springs is 40 l.s⁻¹ with the total dissolved solids (TDS) 6 g/l. This mineral water is Na-HCO₃-SO₄-Cl type. These springs rise on the crossing of a three fault system: transversal fault, north-south headed fault and W-E fault confining the Krušné hory foreland "rift".

In the same "rift" structure the Teplice Spa with its thermal springs is situated. Thermal water circulates in the fractures system of Carboniferous quartz porphyry. There are many small springs with differing temperatures. Actually the thermal water is captured in a deep well (900 m), its yield is about 25 l.s⁻¹ with a temperature of 42.0 to 45.8 °C. The spring Pravčické has a mineralization of about 1 g/l with the type Na-HCO₃. Some of the small mineral springs are radioactive.

In the same tectonic structure there are radioactive thermal springs in Jáchymov but its temperature is only 32 °C. These thermal mineral waters are captured in the 600 m deep old silver uranium mine.

On the S-W-E limit of Krkonoše granite massif is the spa Jánské Lázně with thermal springs of 28 to 32 °C.

There are also several springs in Moravia as: Teplice nad Bečvou (22.5 °C, 16 l.s⁻¹ yield), Velké Losiny (33 °C, 15 l.s⁻¹ yield) and Bludov Lázně (24 °C, 7 l.s⁻¹ yield).

5.2 Geothermal Installations

Geothermal heat pump use is in progress. Actually there are more than 10000 installations with main capacity 20kW. so a total of 200 MW of heat energy. The primary resource of geothermal heat there are: shallow borehole collectors (depth 100 m) (60%), ground water (30%) and ground flach collectors (10%)

- The small scale private installations are typically used for heating of family houses (output less than 20 kW), hotels, accommodation facilities, swimming pools and small businesses (20 to 100 kW) as well as 3 water treatment plants using heat pumps with output more than 100 kW each.

- A heat pump with 1 MW output has been installed at the Prokop Mine of the Příbram ore mining district in the framework of these research activities. The warm water is pumped from the Prokop shaft (28 °C), the heat pump works with the heat gradient of 10 K and water flux of 10 l.s⁻¹. The heat pump increases the water temperature up to 65 °C which was then suitable for the mine facilities as well as of the adjacent administrative buildings.

Future project of development and installation possibilities for use of geothermal energy have been investigated:

- Prefeasibility study has shown a potential of heat pump installations of 15 MW in the town of Břeclav for district heating.

- In the region of Ústí nad Labem the thermal water from the Cretaceous aquifer is used for the industry (soap

factories) and for the heating of Zoo Park and for open swimming pool in Střekov.

- Two sites (Mušov and Písek by Jablunkov) were preliminarily studied and prepared for the project of utilization for thermal spas, heating, swimming pool and glass-houses.

- Preliminary study for one locality for electrical power installation will be in preparation

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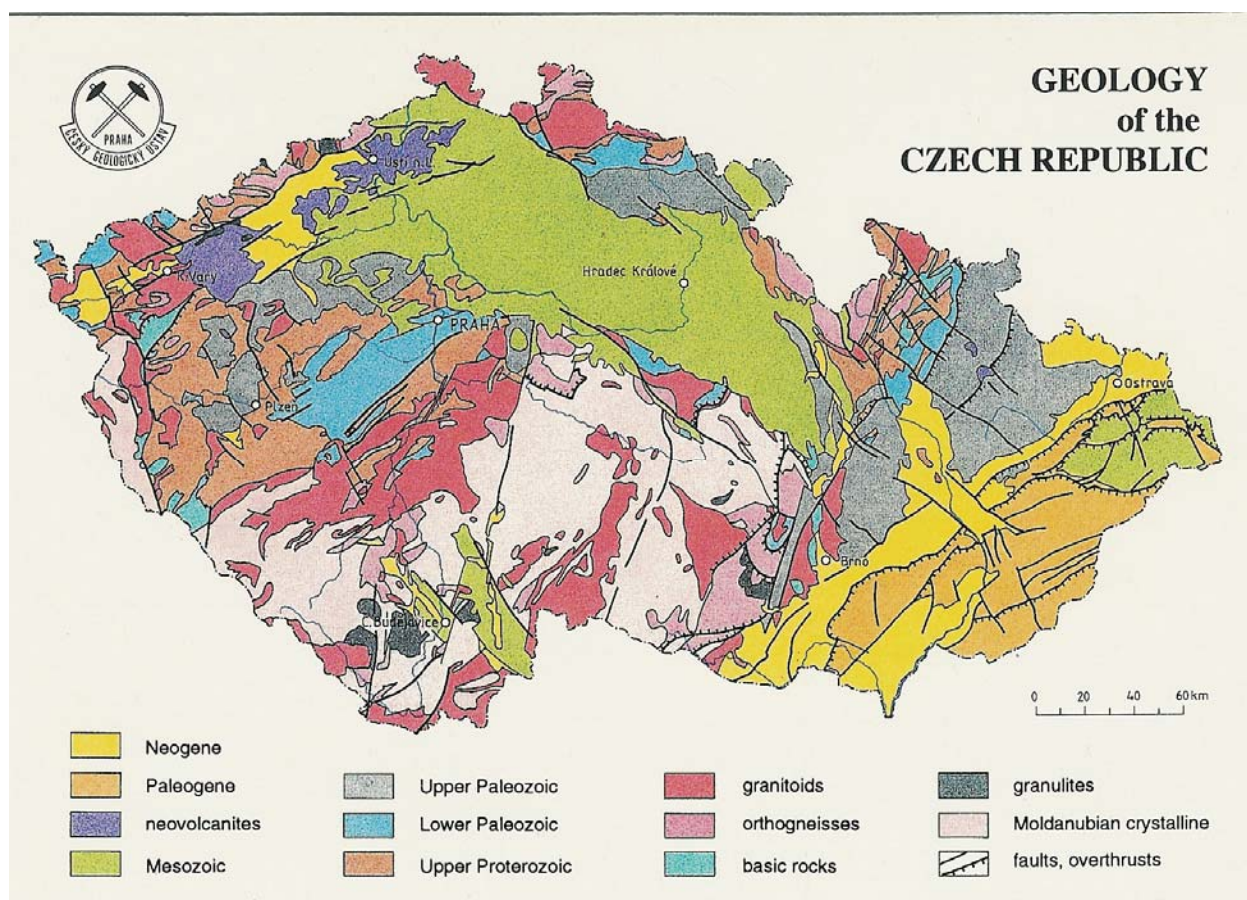


Figure 1: Geological map of Czech Republic

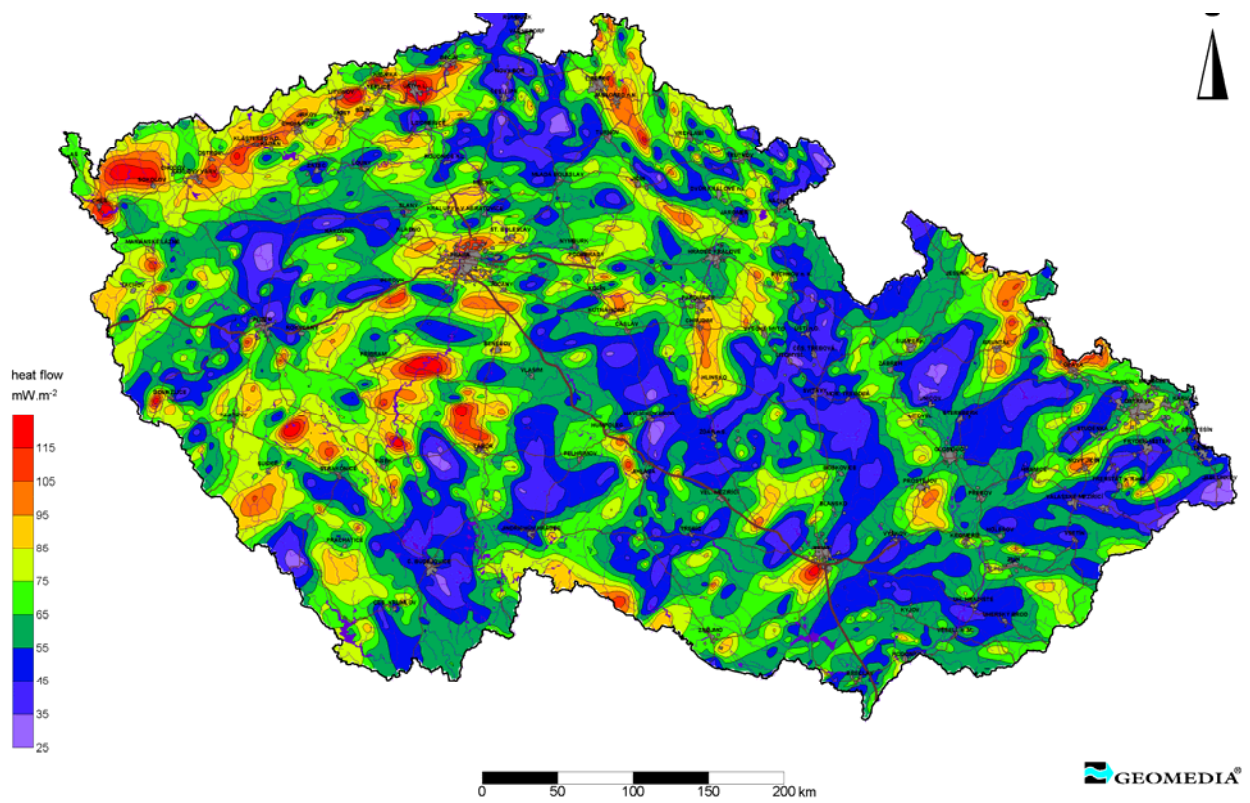


Figure 2: Heat flow map of Czech Republic

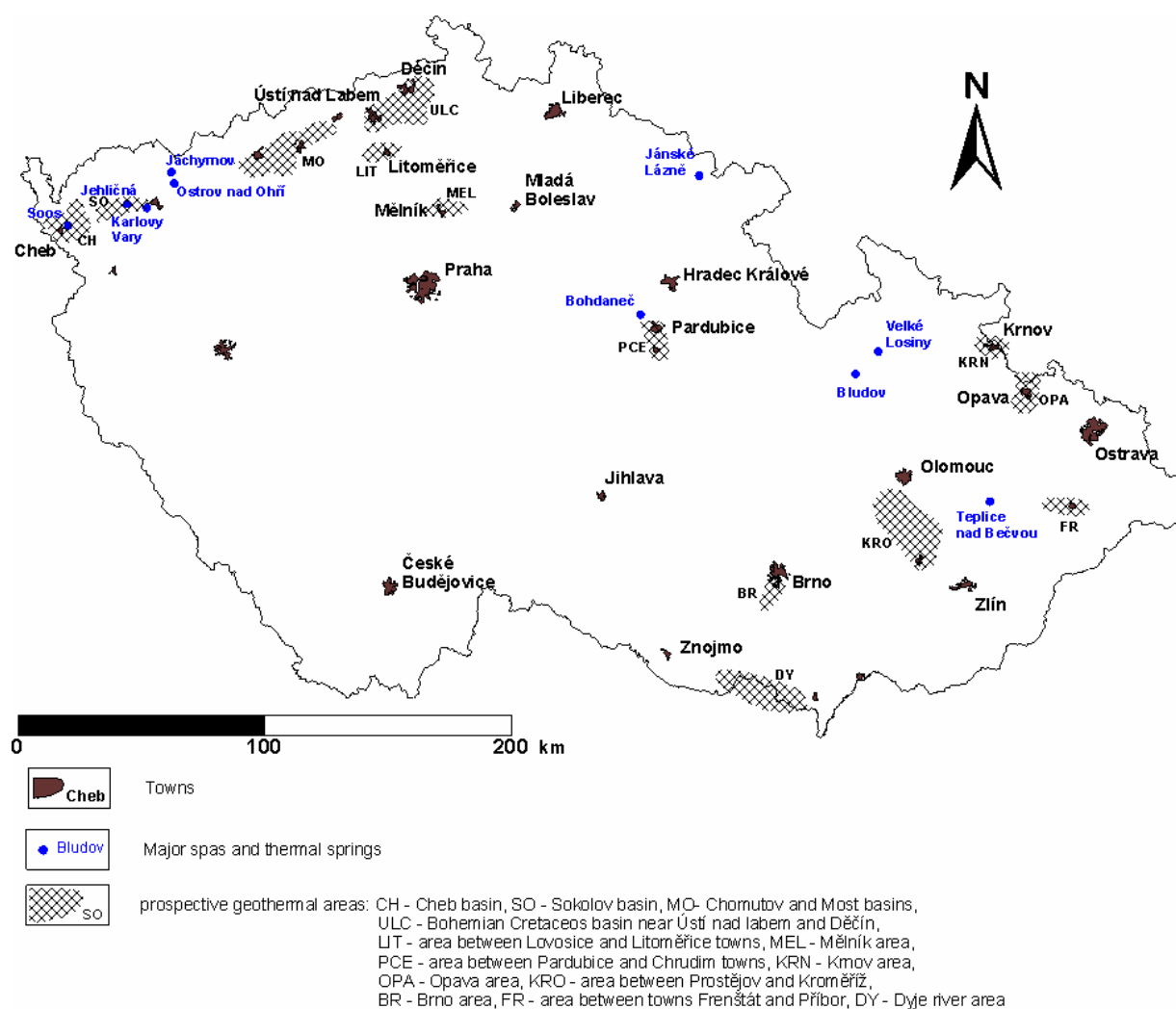


Figure 3: Map of major spas and thermal springs, prospective geothermal areas of Czech Republic