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Evaluation of Possibilities for the Utilization of Thermal Waters for Space Heating, Recreation and Balneology in the Busko-Zdrój Vicinity**

1. Introduction

The forecasts on the energy-market development in the EU predict an increase in the utilization of renewable energy sources from 6% currently (in Poland approximately 3–4%) to 12% in 2010. In *The Strategy of Renewable Power Industry Development* adopted by the Polish government in September 2000, a rise has been assumed of the renewable energy utilization in the fuel-energy balance to 7.5% in 2010 and to 14% in 2020 with regard to the structure of the primary-energy resources utilization. The most recent EU directives (2007) have assumed a 20% exploitation of the renewable energy sources in the EU.

Among the various types of renewable energy available and adaptable in Poland, geothermal energy may play an important role. The currently available results of the analyses and studies by many national scientific institutions reveal that utilization of the geothermal energy resources can be economically justified in a considerably large area of Poland (i.a. [1–3, 6, 8, 9]). The research and the implementation works conducted in Poland since the mid 1980s have resulted in a start-up of six geothermal power plants of the total power of ~170 MW (including 90 MW from geothermy) namely in the Podhale region, Pyrzyce, Mszczonów, Uniejów, Stargard and Słomniki [7]. The value, compared to the thermal power of about 15 GW installed before 2000 in seventy countries worldwide (green houses, recreation, heating, industrial processes) is not especially high.

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In the global scale, it corresponds to the total stream of thermal liquids of approximately 53 t/s and to the annual savings in petrol utilization at the level of 13 M t/a [5]. Results of geological and hydrogeological studies on occurrence conditions and exploitation possibilities of the geothermal energy show possibilities in Poland to make use also of the low-temperature waters through application of the heat pump technology. Irrespective of that, the thermal waters can play a significant role in recreation and balneology.

Underground thermal waters, as an ecologically-pure carrier of energy, may serve an important function in many regions of Poland. Particularly legitimate can be the use of geothermal energy in the regions of unique nature values, in national parks and landscape parks, and in smaller towns and city districts (as heating source). Viewed in this perspective, utilization of thermal waters of the Busko region (location on Fig. 2) can also be justified, not only in the heating context but also (or mainly) for recreation and balneology.

2. Reservoirs of Thermal Waters

The geological position of the town is the borderline between two regional geological units of Poland, namely, the Miechów Trough and the Carpathian Foredeep. Structural variability of the units is rather low. The Miechów Trough structure is constituted by the Mesozoic stage formations, continuing in the Carpathian Foredeep but then covered by the marine Miocene formations. Therefore, in the area of both the Miechów Trough and the Carpathian Foredeep the same Mesozoic formations occur, continuing up to the Pieniny Klippen Belt. However, southward of the Brzesko region, the Mesozoic formations of the Miechów Trough are covered not only by the Miocene formations but also by the Carpathian flysch forming the Carpathians [4].

Lithologic similarity of the Mesozoic formations of the Miechów Trough, the Carpathian Foredeep, and the basement of the Carpathians does not indicate the hydrogeological similarities. Aquifer parameters of the Mesozoic formations are much more favourable in the Miechów Trough area and in the Carpathian Foredeep than in the Carpathians basement.

The shallowest water-bearing strata are: Quaternary, Miocene and Upper Cretaceous and they comprise the underground water reservoirs utilized as a source of fresh-water. The waters of the bottom formations of the Upper Cretaceous (Cenomanian) containing much iodine and bromine are exploited also for curative purposes (not only in the Busko region) and are typical of a higher or lower content of hydrogen sulphide (depending on the depth of the water intake and location of the water drawing well).

Figure 1 presents seismic profiles showing the spatial configuration of the underground aquifers in the examined area (localisation in figure 3). Shown in the figure is the characteristic dislocation crossing the Busko region in the form of a reverse fault where the Cenomanian formations on the upthrow side are set at about 100 m below the ground level (approx. + 150 m above the sea level – Fig. 1C) whereas on the downthrow side – deeper than 600 m below the ground level (approx. – 350 m above the sea level, the zone of the borehole Busko 2, Fig. 1C and 3). The run of the dislocation crossing the town's vicinity in the NW-SE direction is shown in figure 4.

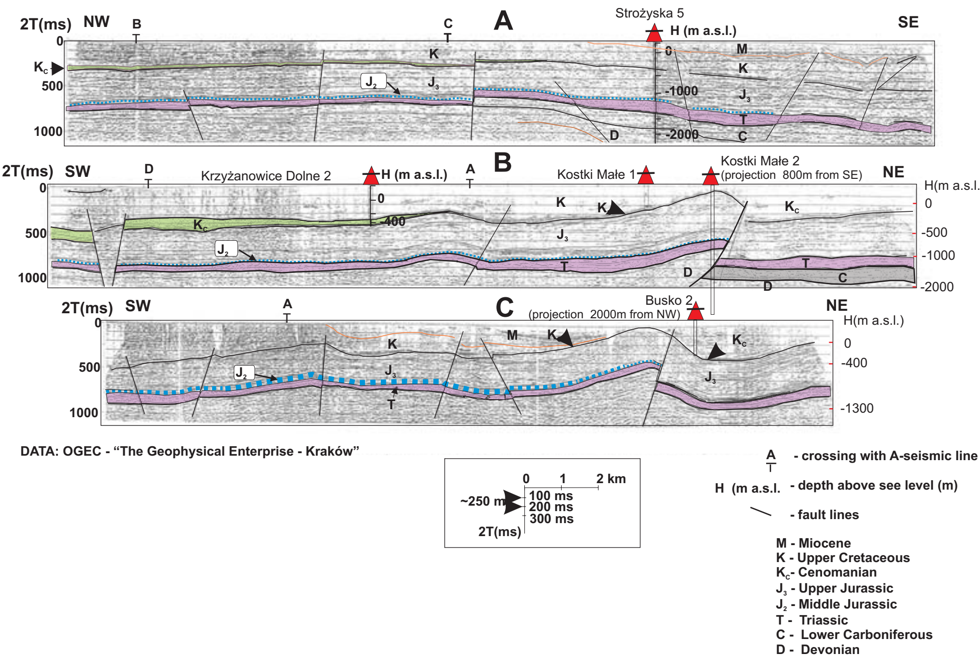

Fig. 1. Seismic profiles of the Busko region (localization in figures 3 and 4)

The height difference between the formations of the Cenomanian aquifer in this zone on both sides of the dislocation is therefore about 500 m, which implies variability in both water temperatures and mineralization.

Beside the Cenomanian, the same regularity concerns all the low-sitting aquifers in this region, i.e., the Jurassic, the Triassic, the Carboniferous and the Devonian, where the thermal waters flows were detected. Erosion of the Carboniferous on the upthrow side results in a larger height difference in the Devonian aquifer on both sides of the dislocation and is even more obvious, reaching the value of about 700 m. Irrespective of the resultant high variability in waters mineralization of the Devonian aquifer on both sides of the dislocation, the difference in the water temperature can be as high as 15–17°C.

In the Busko region, thermal waters were detected in all above-listed underground aquifers [1]. However, water in these aquifers differs by the hydrogeothermal parameters, such like water yield, temperature, mineralization and reservoir pressure. Temperature and yield measurements were carried out only in a few boreholes. In the borehole Żerniki 1 (approx. 15 km east of Busko – Fig. 2) the iodine-bromine brines were drilled from the Upper Triassic formations (Keuper) at a depth of about 500 m. No data are, yet, available regarding the water yield but the measured temperature reaches 25°C (non-stationary state measurement) and the mineralization is rather high, i.e. 108 g/l.

The borehole Zagość 2 (Fig. 4) was drilled as exploratory-oil; in the limestone formations of the Lower Carboniferous, the brine flow was detected at a depth of about 1,550 m, yielding 4 m^3/h. The estimated water temperature is about 50°C.

In the Devonian aquifer flows of the thermal waters were detected, among others, in the boreholes Żółcza 1 and Radzanów 2. In the first (Fig. 4), at a depth of 2,265 m brine was drilled in the Upper Devonian formations; the temperature is 90°C but the water yield data are limited to information about the flow being more than 1 m^3/h. As for the borehole Radzanów 2 (Fig. 4), the data are more interesting as they concern the determined free outflow of highly mineralised formation water (169 g/l) from the Devonian formations. The water-bearing stratum here was determined at a depth of 2,430 m, which means that the temperature of the aquifer waters may reach 80°C.

The Upper Jurassic aquifer was drilled, among others, in the borehole Solec 3 (Fig. 3). From the Raurak-Kimmeridgian level – depth interval 310–680 m, free outflows were obtained of 0.3 m^3/h brine and 40 g/l mineralization. Estimated temperature of the water is about 25°C.

Directly in the Busko region, in the borehole Busko 2 (Fig. 1 and 3), the thermal waters were detected in the Cenomanian aquifer at a depth of 620 m in the downthrow side zone of the discussed dislocation. Estimated temperature of the water is about 23°C.

2.1. Cenomanian Aquifer

Seen from the perspective of geothermal utilization, the most suitable seems the Cenomanian aquifer (Fig. 2). Relatively low water temperatures (from approx. 23°C on the downthrow side and between ten and twenty on the upthrow side) are compensated by high water yields, considerable surface area of the reservoir and favourable reservoir parameters in the entire area.

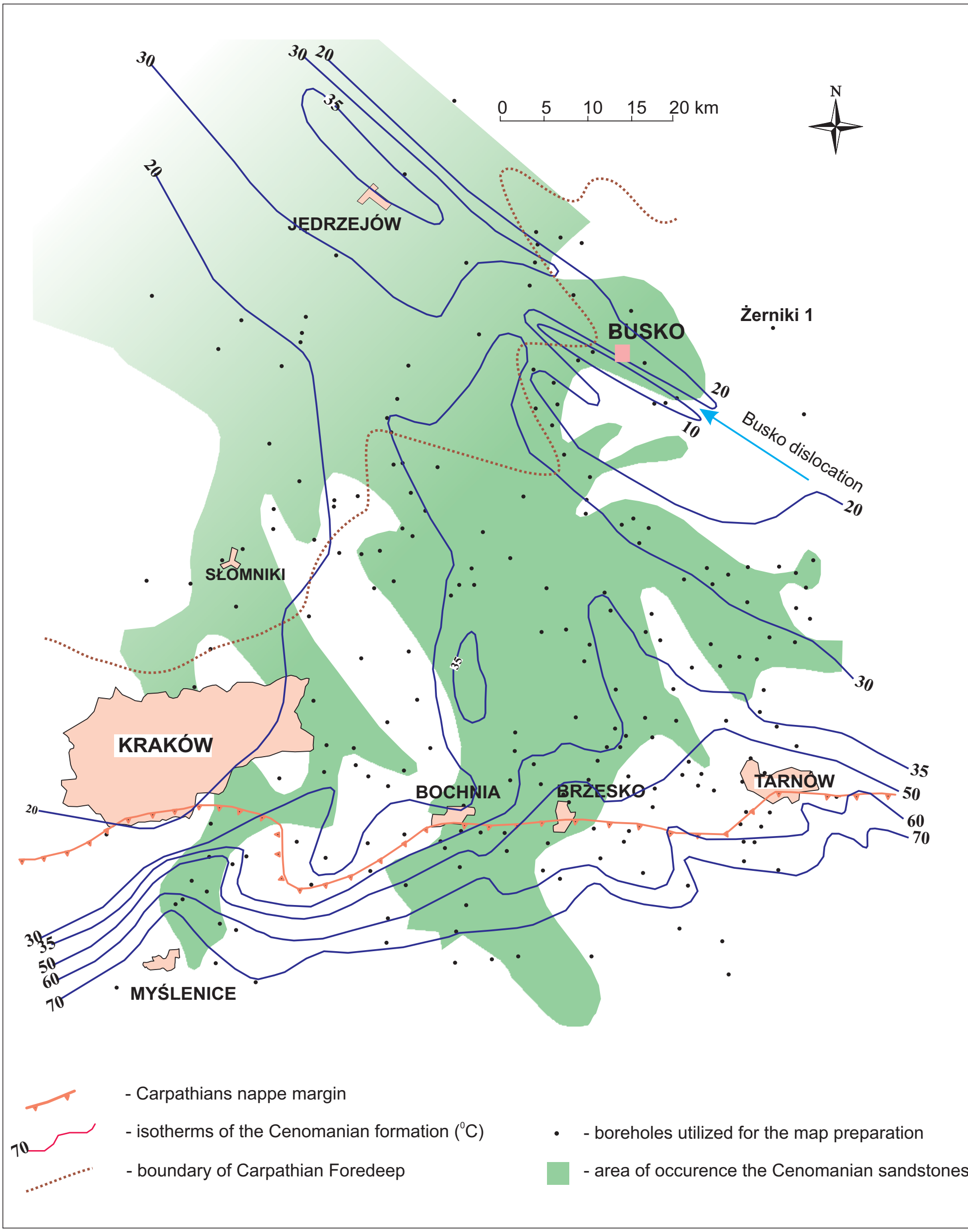

Fig. 2. Temperature chart of the Cenomanian aquifer waters

The Busko region is situated in the peripheral zone of the aquifer thus in the distance as short as 10 km E of the town the formations pinch out completely. In the borehole Krzyżanowice Dolne 2 (Fig. 1) the thickness of the aquifer is 104 m, in the borehole Busko 2–25 m, and in the borehole Żerniki 1 the formations are absent. The higher the Cenomanian aquifer's thickness, the better the hydrogeothermal parameters. They achieve the most favourable values in the central zone of the aquifer, about 25 km W of Busko (Fig. 2). Temperatures of these waters reach 30–35°C. Regular free outflows are observed of up to 40 m^3/h (the zone ~10 km S of Jędrzejów).

Presumably, in the Busko region the free outflows will not occur however, the water yields can develop at the level of a few tens m^3/h.

2.2. Jurassic Aquifer

The data on the borehole Kostki Małe 2 allowed determining the porosity range of the Upper Jurassic limestone for 1–16% with the average porosity of 5% (J_3 – Figs 1 and 3). This indicates a high variability and discontinuity of the aquifer's parameters along its profile. The reason is the strong variability in the sedimentation conditions of the individual units of the complex and large thickness of the aquifer, regularly exceeding 1,000 m. The high thickness of the Upper Jurassic aquifer is also the reason for considerable temperature difference between the top and the bottom formations.

In the Busko region, temperature of the top formations and of the water of the Upper Jurassic on both sides of the dislocation develops in analogous way to the Cenomanian aquifer, i.e., 11–12°C – downthrow side, 22–23°C – upthrow side. On the other hand, temperature of the Upper Jurassic water and formations in the bottom of the complex can be estimated from the bottom depth; according to the borehole data 33°C – the upthrow side (Jurassic bottom depth approx. 1,100 m), about 40°C – the downthrow side (bottom depth approx. 1,500 m, Figs 1 and 3).

The Jurassic bottom formations turned out interesting mainly because of the high water yield of ~7.5 m^3/h obtained in the upthrow side zone at a depth of 1,100 m with water temperatures of 40°C (borehole Kostki Małe 2, Figs 1 and 3).

Because of the 1,000-m thickness of the Upper Jurassic aquifer, the occurrence of shallower water-bearing strata should not be excluded.

The formations sitting underneath – i.e. the Middle Jurassic are characterized by a low degree of sanding up, marl nature and low thickness, therefore, they constitute no source for geothermal utilization (J_2 – Fig. 1).

The Jurassic aquifer, due to large variability in depth level of the individual water-bearing stratas collects water varying considerably in mineralization: from 20 to about 100 g/l.

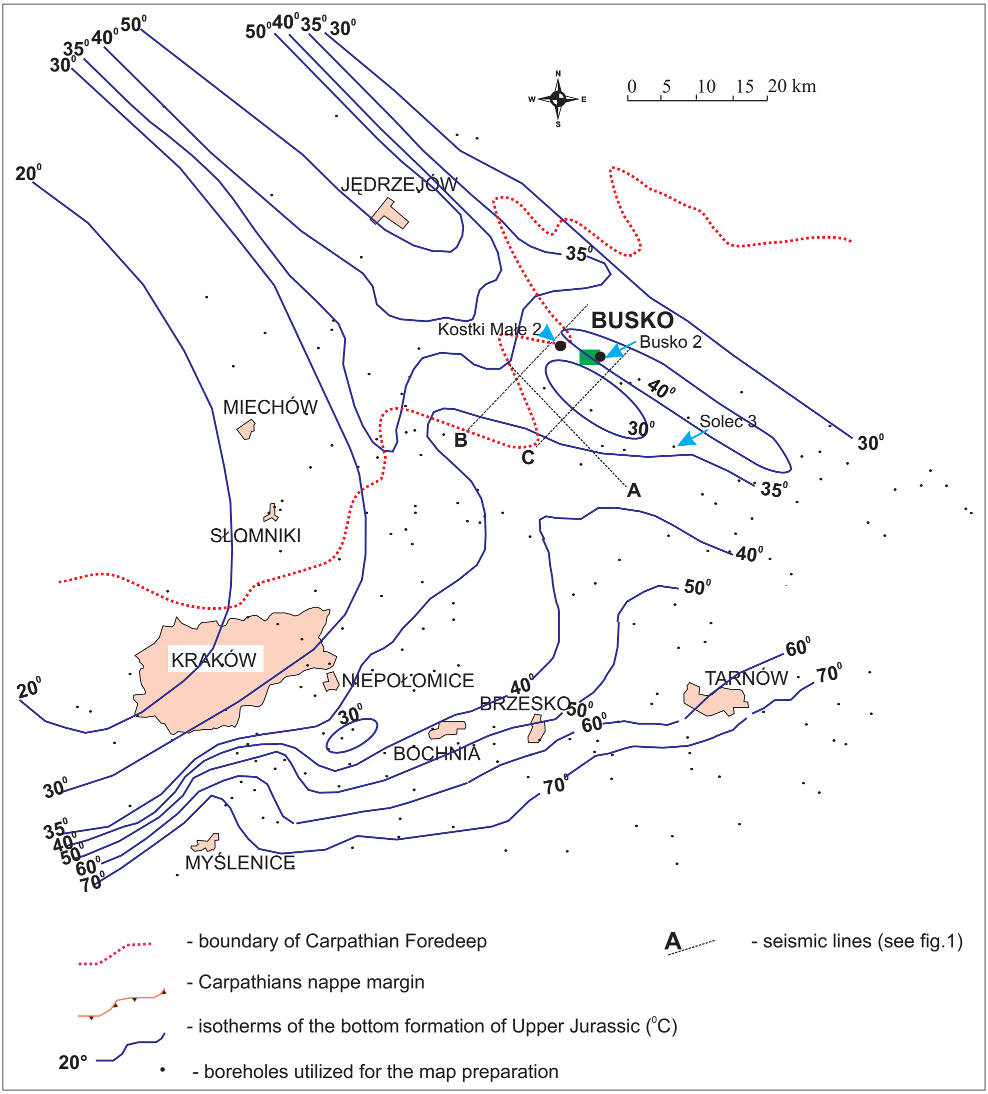

Fig. 3. Temperature chart of the bottom formations of the Upper Jurassic [1]

2.3. Triassic Aquifer

Even though the data on the borehole Kostki Małe 2 indicate considerable porosity of the Triassic formations, reaching 10% in the case of the sandstone of the Lower Triassic and 18% of the Middle Triassic dolomite, the water flows detected within the Middle Triassic were rather low (1.6 m^3 in the period of less than 20 hours). Presumably, effective porosities are much lower or the formations have minimal permeability. Concluding, the Triassic aquifer should be regarded as a low-utility source from the viewpoint of the geothermal waters utilization.

An important water-bearing level is however the top at the interface with the Jurassic bottom formations, the extent and the character of which has not been recognized yet.

2.4. Carboniferous Aquifer

The Lower Carboniferous limestone has a porosity of up to 6% observed sporadically, thus the improvement of aquifer parameters relays mainly on fissure and fracturing connecting to the dislocation zones. These zones are difficult to localize and usually distributed irregularly. Flows of 4 m^3/h obtained from these formations should rather be considered exceptional, such as the case of the borehole Zagość 2.

Overall, the Lower Carboniferous formations despite the large area of occurrence (Fig. 4), constitute a hydraulic-isolation complex between the Palaeozoic and the Mesozoic aquifers.

2.5. Devonian Aquifer

The hydrogeothermal conditions of the Devonian aquifer are also strongly connected with the tectonic conditions. Porosity of a few per cent and permeability in the order between ten and twenty milidarcy result in strong water flows, related to fissure occurring in the tectonic dislocation zones.

The unfavourable attribute of this region is that the fractured Devonian formations become obstructive due to scars (visible on the drilling cores) in the fracture and fissure zones made by numerous calcite precipitates. Presumably, water table of the Devonian aquifer stabilizes at a few tens meters under the ground level. Despite the considerable extent of the aquifer (Fig. 4) and its large thickness exceeding 800 m in this area, the aquifer has been hardly recognized. Free outflows observed in the boreholes Radzanów 2 and Żółcza 1 (Fig. 4) in the downthrow side zone of the dislocation indicate hydraulic continuity of the Devonian aquifer with the uplifted areas of the direct and indirect charging zones in the Holy Cross Mountains region. This would imply that the more favourable hydrogeothermal conditions of the Devonian aquifer are related to the downthrow side of the dislocation. The waters of the Devonian aquifer are bromine--iodine brines, considerably mineralized – above 100 g/l. In the Busko region, in the upthrow side zone (borehole Kostki Małe 2) temperature of the formations and of the Devonian waters range from 40°C (top) to 60°C (bottom) whereas in the downthrow side zone (borehole Busko 2) from 60°C to 80°C, respectively (Fig. 5).

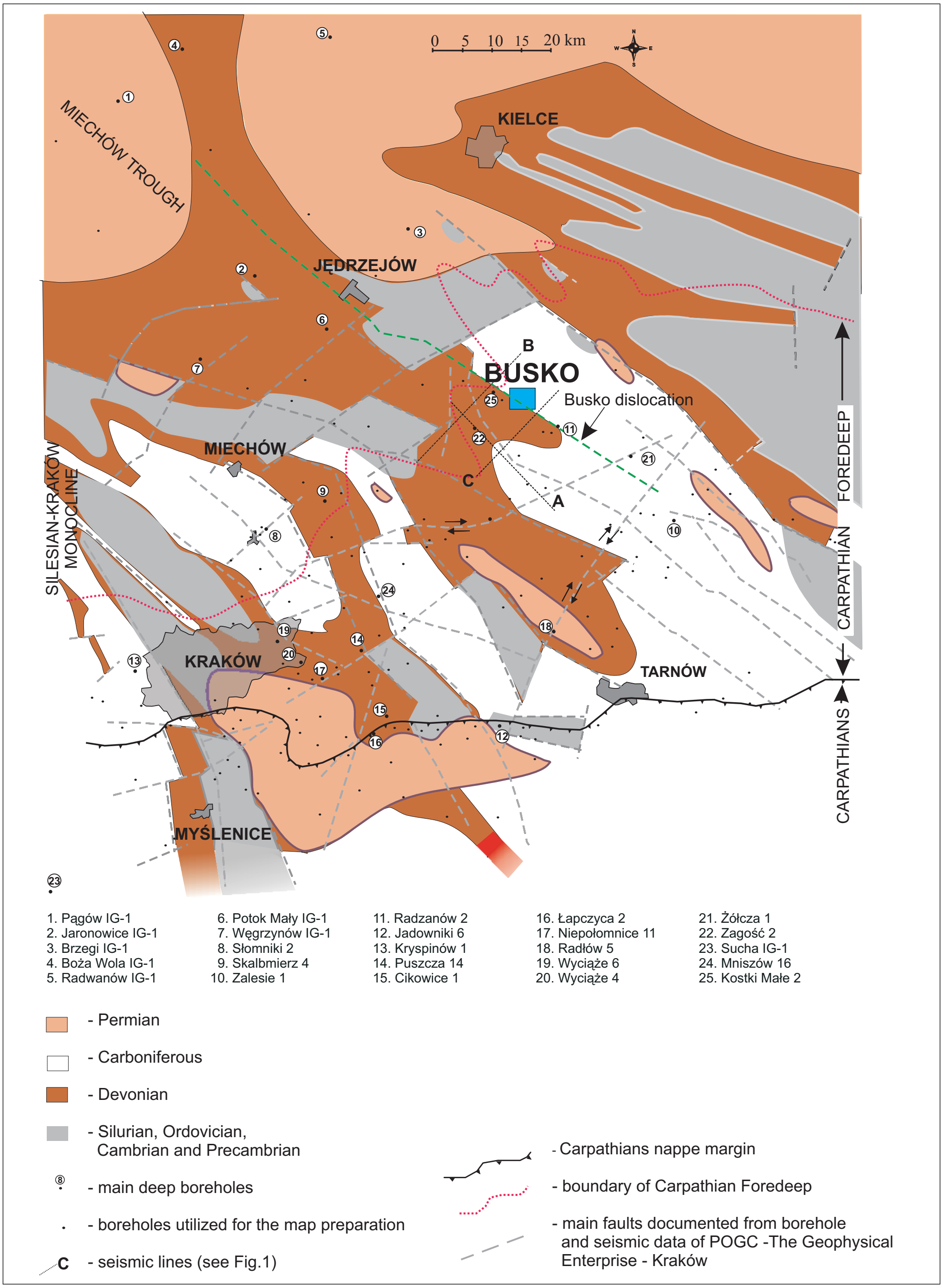

Fig. 4. Geologic map of the surface of Palaeozoic and Precambrian formations ([10, 11, 12] and data from POGC-The Geophysical Enterprise – Kraków)

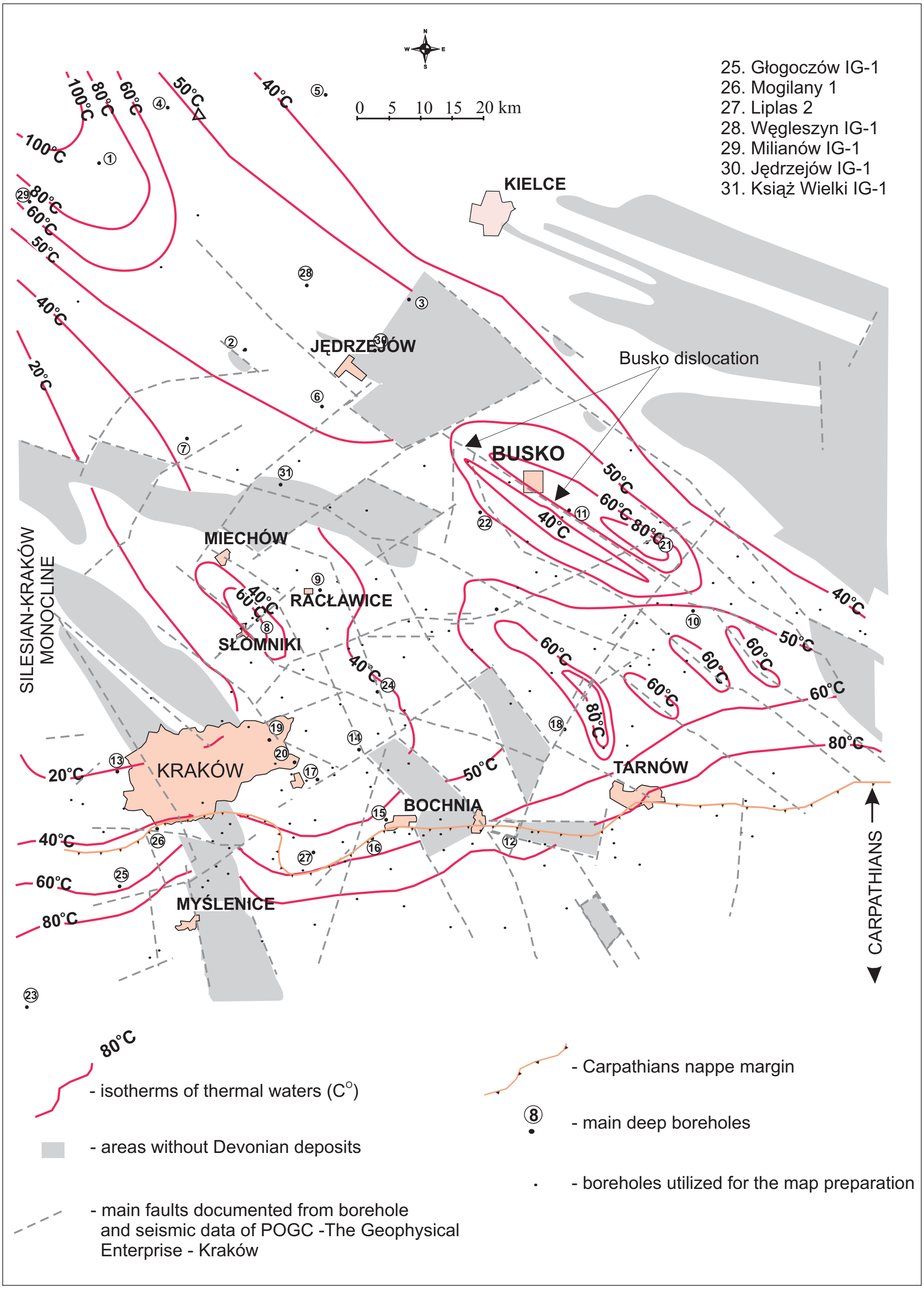

Fig. 5. Temperature chart of the waters in the top of the Devonian aquifer

3. Conclusions

The geothermal aquifers in the Busko region, bearing the potential to use their geothermal capacities, are connected mainly with the Cenomanian, the Upper Jurassic and the Devonian formations.

Favourable aquifer parameters of the Cenomanian and the Upper Jurassic formations occur on both sides of the "Busko dislocation" whereas of the Devonian presumably on the downthrow side.

The dislocation zone and the upthrow side zone alone do not guarantee considerable water yields of the Devonian formations. Nonetheless, it may be interesting from the viewpoint of the Jurassic-Triassic contact zone utilization. Water temperatures in the Busko region do not exceed the value of about 35°C and only in the Krzyżanowice Dolne region (upthrow side, Fig. 1) and in the downthrow side zone (Busko 2) they may reach ca. 40°C.

Larger depths of the underground water reservoirs (higher temperatures) and seemingly the better hydraulic connection with the charging zones (renewable resources) indicate more favourable conditions for underground waters utilization in the zone located NE of the dislocation line (downthrow side).

The main problem in the assessment of the potential to utilize the thermal waters in this region is the hard to estimate water yield. An exception makes the Cenomanian aquifer (on both sides of the dislocation). In its case, the yield of a few tens m^3/h seems realistic, especially in the upthrow side zone (problematic may be the ongoing exploitation of these waters by the operating spas).

With regard to temperatures and water yield, the Cenomanian aquifer is especially designated for balneology and recreation. The downthrow side zone should guarantee temperatures of about 20–25°C, still, the large yield and application of the heat pump technology may render its use economically feasible. The curative valor of this aquifer is of crucial importance.

The hydrogeothermal conditions of this region, at the current stage of recognition, do not allow confirmation of its usability for the heating purposes. Improvement of the current state of the conditions detection would have occurred provided the holes in this zone were reconstructed.

Utilization of the old boreholes for the recognition of the hydrogeothermal conditions and simultaneously for the future exploitation, considerably reduces the costs of geothermal projects. In this context, the borehole Kostki Małe 2, after reconstruction, may have served not only as a source of information on geothermal conditions in the region but also, for instance, as the production borehole for the bottom Jurassic water-layer.

As for the use of the Cenomanian aquifer in the downthrow side zone, the reconstruction of the hole Busko 2 is required.

The cost of a borehole reconstruction is usually three times lower than that of drilling a new one, yet the feasibility conditions are numerous, such like: technical condition of the casing column, borehole cementation condition, size of the formation damage near the drilling zone (so-called „skin effect"), presence of steel elements in the hole and the mode of the hole liquidation after finished drilling. Each time, making the decision about reconstruction requires the assessment of the above-mentioned aspects.

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