The most prospective areas for geothermal energy utilization for heating and power generation in Poland

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ABSTRACT

Resources of geothermal waters and energy in Poland are hosted in groundwaters of various stratigraphic units located at various depths in different geological region: the Polish Lowlands, the Sudety Mts., the Carpathian Foredeep and in the Carpathians. For decades the AGH University of Science and Technology has conducted scientific research related to the occurrence of geothermal waters in sedimentary basins of Poland. Analysis of reservoir, hydrogeological and thermal parameters in the geological profile allowed for determination of prospective areas in terms of geothermal water development for heating and power generation in Poland.

Particularly favourable conditions for the utilization of geothermal energy are in the region of the Polish Trough (part of the Polish Lowlands) and Podhale area (Inner Carpathians), where geothermal energy is currently used for a different purposes. In many areas of the Polish Lowlands geothermal energy is not yet used despite of significant geothermal potential. Prospective areas for geothermal energy utilization have been identified also in other parts of Poland. However geothermal potential related to utilization of geothermal waters of the Carpathian Foredeep and Outer Carpathians is limited.

Article shows in particular results of geothermal projects carried out by AGH team since EGC2013 (Bujakowski and Tomaszewska (eds.) 2014; Wójcicki et al (eds.) 2013).

1. INTRODUCTION

From many years the Department of Fossil Fuels from University of Science and Technology takes part in researches and implementation works which aim is to predict the optimum areas useful for geothermal water and energy utilization for practical purposes. At the Department, geological conditions of the occurrence of geothermal waters are analyzed, together with the energy resources and technology required for development of the geothermal resources within geological units of the Polish Lowlands, Carpathians and Carpathian Foredeep. Recapitulation of the studies of the occurrence and utilization of geothermal waters and energy has been reflected in geothermal atlases of different regions of Poland (Górecki (ed.) et al. 1990; 1995; 2006a; 2006b; 2011; 2013; Bujakowski and Tomaszewska (eds.) 2014) as well as monographs connected with geothermal energy utilization (Wójcicki et al (eds.) 2013); Sowiżdżał 2009, 2012 etc.).

2. GEOLOGICAL SETTING

Poland is situated at the interface between three main European geostructural units: the Precambrian East European Platform, the Paleozoic units of Central and Western Europe (Caledonian and Variscan) and the Carpathian range (part of the Alpine system) (Fig. 1). Each of these structures is characterized by distinct geothermal conditions, both in Europe and Poland. Sedimentary rocks covers almost throughout the territory of Poland, exception is the area located in SW of Poland (Sudets Mts.) where mostly crystalline rocks occurs.

Based on seismic investigations, the total thickness of the sedimentary cover in the deepest area of the Palaeozoic part of the basin can reach as much as 20 km (Guterch et. al. 1997). The area of the East European Craton (EEC) is characterized by a thin, about 1–2 km thick sedimentary cover. In the region of Mazury–Suwałki elevation (NE Poland), the depth to basement is only 0.3–1 km but increases south-westwards to 7–8 km along the margin of the EEC. In the area of Poland the Teisseyre–Tornquist Zone (TESZ) the sedimentary layer attains thicknesses of up to 9–12 km. Its upper parts consist of Permian and Mesozoic sequences that reach maximum thicknesses of 7–8 km, whereas Devonian and Carboniferous epicontinental deposits form its lower part. Variscan consolidated crust with a 1–2 km thick sedimentary cover. The Variscan crust (Palaezoic platform) has a much simpler structure than the crust of the EEC and TESZ, due to the absence of a high velocity lower crust (Guterch and Grad 2006). The basement of the Permian-Mesozoic sedimentary basin within the Palaeozoic Platform consists of Carboniferous, Devonian and older formations, folded during the Variscian Orogenesis. The large Mesozoic sedimentary basin was deformed during the Laramide tectonic phase between the Cretaceous and Tertiary periods. During this phase the plastic salt layer was pressed up to the surface, piercing almost 6 km thick overlying Triassic, Jurassic and Cretaceous deposits. Increasing tectonic movements split the basin into two subbasins: the Szczecin-Lodz synclinorium and the Grudziadz-Warsaw synclinorium. Between them the Central-Polish anticlinorium was formed. Mesozoic structures were eroded after this deformation, and later covered by flat-lying Tertiary and Quaternary horizontally lying sediments (Hajto and Górecki 2010). In the Carpathians, sediments reaching to depths of some 20 km (Guterch and Grad 2006).

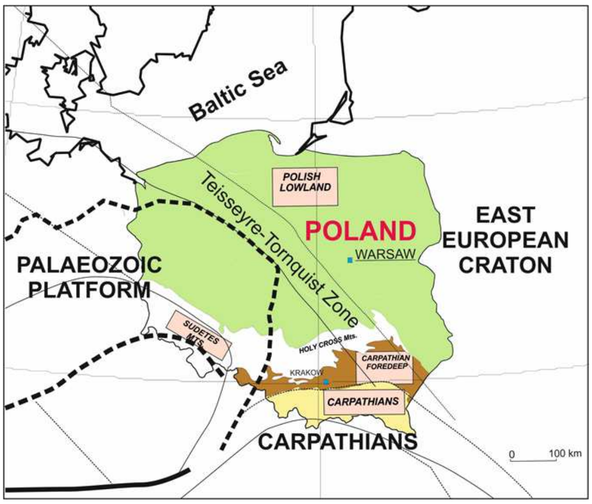

Figure 1: Geological setting of Poland.

3. PROSPECTIVE LOCATION FOR HEATING

In case of the heating sector, six geothermal district heating plants were operational in 2013 (the oldest one in the Podhale region since 1994; the most recent one in Poddebice since 2013). The remaining installations are located in: Pyrzyce (since 1996), in Mszczonow (since 1999), in Uniejow (since 2001), in Stargard (since 2012, reopened after closure in 2008). In addition, individual heating systems were in some recreation centers. In 2013 their total installed geothermal capacity was ca. 87.2 MWt and heat sales ca. 633 TJ (including peak boilers it was ca. 147.1 MWt and 745.56 TJ, respectively). Most geothermal heat was produced by the Podhale plant: 300.27 TJ/2013, one of the largest geothermal district heating plants in continental Europe (Kępińska 2015).

Regional studies conducted for years at the Department of Fossil Fuels of the UST-AGH shows that the most prospective areas of geothermal energy utilization for heating purposes including GEODH in Poland are connected with the Polish Lowlands and Podhale area (The Western Carpathians). Water in these areas are characterized by favourable temperatures (even above 90°C) and relevant value of discharges of wells (to several hundreds m^3/h). Low discharges of wells is the fundamental problem in the rest of analyzed regions (The Carpathian and Carpathian Foredeep areas).

The main resources of geothermal waters in the Polish Lowlands are related with the Mesozoic formations, where particulary the most promising are Lower Jurassic and Lower Cretaceous formations. Significant resources of geothermal energy are accumulated also in the Upper Jurassic, Middle Jurassic, Upper Triassic and Lower Triassic formations, but their characterize by significantly less geothermal potential when heating purposes are considered.

Within the Lower Jurassic aquifers permeable rocks constitute 40-80% of the total thickness of the Liassic sequence. The temperature of geothermal waters divers from those typical of subsurface waters to 120°C at the depths, below 3000 m. – (axial part of the Łódź Trough). The TDS of Lower Jurassic groundwaters is closely related to the depth of occurrence and change from few to over 200 g/dm^3, however, in the whole aquifer dominating are values from 10 to 100 g/dm^3. In most part of Lower Jurassic aquifer discharges over 100 m^3/h can be expected.

The second of regional scale relevance with a significant extent aquifer in the Polish lowlands is the Lower Cretaceous aquifer Total thickness of Lower Cretaceous formation varies from several to over 400 m with dominating values between 20 and 200 m. Geothermal water temperatures varies from 20 to over 90°C. Highest temperatures were observed in the north-east of Konin. Regional analysis of hydrogeological data sets indicates that potential discharges of wells varies from beneath 25 m^3/h, to over 100 m^3/h (Górecki (ed.) and Hajto et al. 2006a).

Geothermal water resources accumulated within Paleozoic formations in the Polish Lowlands represents minor importance when heat purposes are considered. According to the research geothermal waters were found only locally in the Devonian and Carboniferous formations accordingly in the the Lublin Trough and Pomerania Synclinorium region (Górecki (ed.) and Hajto et al. 2006b).

In the Polish part of the Carpathians the best reservoir and exploitation properties for heating occur in the inner Carpathian - Podhale, represented by: favourable reservoir parameters and lithology, usually high discharge and low TDS. The most favourable and prospective geothermal aquifer (being exploited for heating purposes since the 1990-s) occurs within the Middle Triassic limestone-dolomites and in overlying Middle Eocene Nummulitic limestones and carbonate conglomerates. These formations are found over the entire Podhale system, prolonging to the Slovakian territory. Usually their total thickness is considerable ranging from 100 to 700 m, while the effective thickness is equal to 100 m (Kępińska 2004). The water circulation and high flowrates are primarily conditioned by the secondary fractured porosity and permeability. The temperature at the depth of 2-3 km amounts to 80-100°C being higher than that resulted from the geothermal gradient (Hajto 2011). The artesian flow rates from individual wells vary from several to 550 m^3/h. The highest flow rates (up to 270-550 m^3/h) were obtained after acidizing treatment of carbonate reservoir rocks.

In the remaining part of the Carpathians reservoir parameters are much worse. Relatively low geothermal potential was found both in the flysch cover and in the geothermal aquifers of the Mesozoic-Paleozoic basement as well. Distribution of the basic petrophysical parameters of rocks in the outer Carpathians shows that improvement of hydrogeological conditions of potential aquifers can be found particularly along the surfaces of overlaps of different flysch tectonic nappes and units. Geothermal waters of flysch aquifers found in existing boreholes are diagenetic origin. Layers characterized by relatively high porosity and permeability, have a rather limited range and small thickness, what have important implications for size and stability of geothermal water intakes.

Within the Miocene and Palaeozoic-Mesozoic basement of the Carpathians prospective areas for location of potential geothermal water intakes were found within Cenomanian (Western Carpathians) and Middle Jurassic aquifers, especially in the marginal zone of Carpathian overthrust. Favourable conditions are confirmed also in some areas of carbonate Devonian-Carboniferous aquifer (e.g. in Ustroń area – Fig. 2). Predicted geothermal water intakes of flysch and Miocene, Mezozoic and Palaeozoic aquifers in the outer Carpathians were calculated in the range of 1 m^3/h, to 60 m^3/h - in the western part of the Polish Carpthians Predicted water temperatures are in the range of 30-72ºC, and TDS may vary from about 20 g/dm^3 to over 120 g/dm^3 (Górecki (ed.) and Hajto et al. 2011).

In Carpathian Foredeep the aquifers of the Cenomanian, Upper Jurassic, Devonian-Carboniferous and Miocene are most prospective (Górecki (ed.) and Sowiżdżał et al. 2012). However, in these aquifers, the most favourable parameters for location of geothermal intakes occur in small areas and depth intervals. The Cenomanian aquifer is an exception, as high discharges (to 250 m^3/h) can be expected over the whole area of its occurrence (central part of Carpathian Foredeep). Zones with increased potential discharges of wells are encountered in the Upper Jurassic (tens m^3/h) aquifer and in the Miocene aquifer (above 100 m^3/h). The best hydrogeological and geothermal parameters that indicate the possibility of using the Miocene geothermal water for heating purposes occur in the depth interval 500-1500 m bsl. The remaining depth intervals seem to reveal low prospective because of low temperatures or weak hydrogeological parameters that determine low discharges of geothermal water intakes. With reference to some areas distinguished principally in the Miocene formations it should be emphasis that geothermal waters occur often in the form of sandstone lenses or pinch-outs, what may affect on stable intakes production parameters. Waters accumulated in the Carboniferous clastic deposits and in the Carboniferous and Devonian carbonate rocks can locally be characterized with potential discharge of wells to max. 50 m^3/h and temperature above 200°C.

The Eastern Carpathians represents the lowest geothermal potential among all of studied geothermal provinces of Poland. Geological, hydrogeological, parameters of the flysch rocks, Miocene deposits and the Mesozoic-Paleozoic basement of the Eastern Carpathians indicate very limited potential for utilization especially when heating purposes are considered. The results of analysis carried out under the research project aiming the possibilities of geothermal waters utilization in this area (Górecki (ed.) and Hajto et al. 2013) shows that possible discharges of intakes and predicted water temperatures, are sufficient to build a small heating installations with thermal power output ranging from several hundred kilowatts to 5 MWt. Nowadays geothermal plants with thermal power below 2 MWt operate in Poland in a number of installations that utilize geothermal waters for recreational purposes. Several other geothermal plant have installed capacity which slightly exceed of 2 MWt (eg. Mszczonów - 2.7 MWt, Uniejów - 3.2 MWt). They are usually working with peak load sources staff, eg. absorption heat pump (Mszczonów) or biomass-fired boilers (Uniejów).

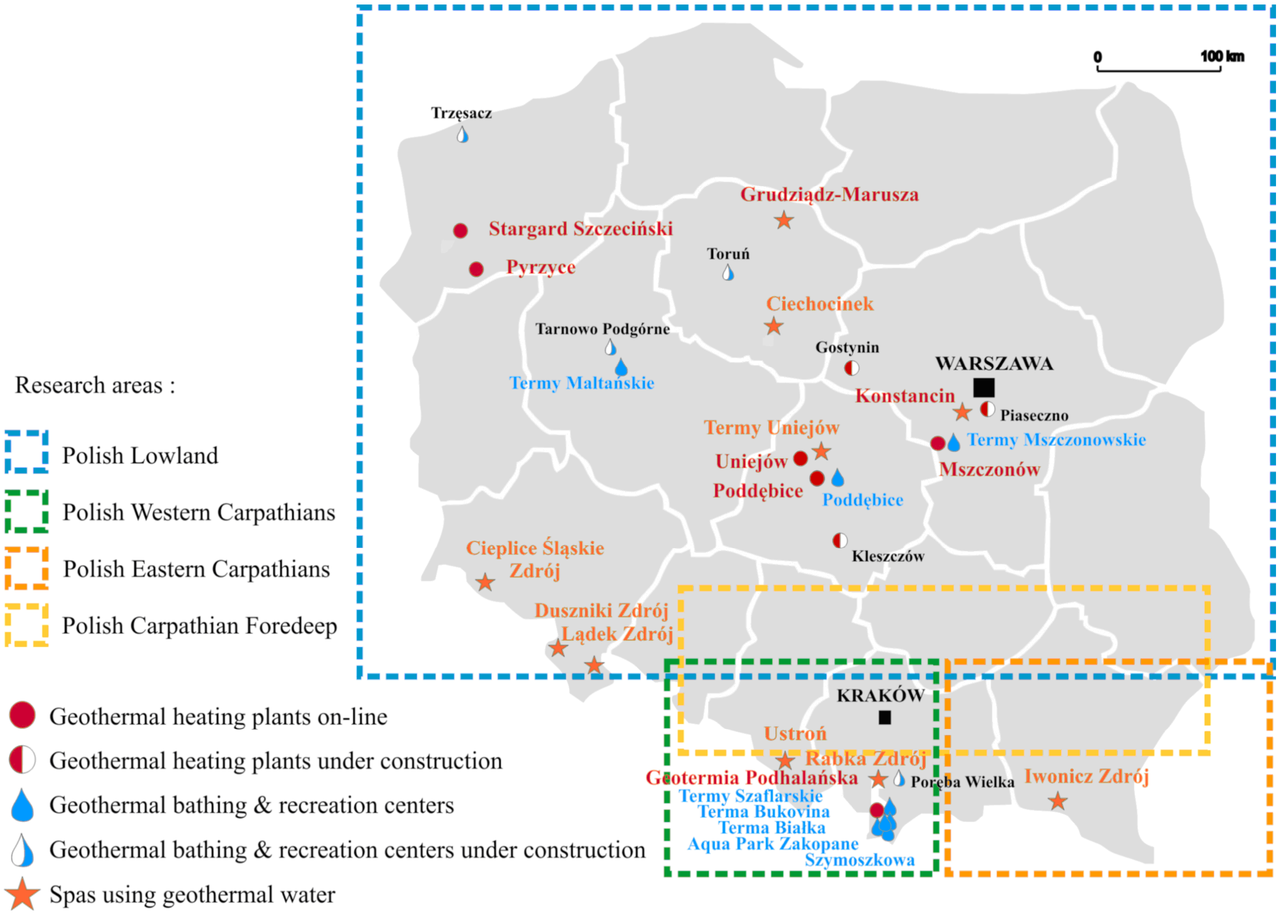

Figure 2: Regional study areas and location of geothermal heat plants in Poland.

3. PROSPECTIVE LOCATION FOR EGS

In the years 2010-2013, analysis of rocks that build the sedimentary covers in Poland was carried out from the point of view of energy utilization accumulated in hot dry rocks – used in Enhanced Geothermal Systems (EGS) (Wójcicki et al (eds.), 2014). During the realization of the project, based on international experiences (Brown et al. 2012; Tester et al. 2006; Tenzer 2001; Antkowiak et al. 2010), requirements for EGS in sedimentary rocks have been specified. Critical requirements for the EGS location comprise: thermal parameters of the rocks (temperatures >150°C), thickness of the reservoir (minimum 300 m), porosity and permeability of the reservoir rocks (as the lowest) and the depth of the reservoir (3-6 km).

The performed analyses allowed to determine several prospective locations. Considering the resources accumulated in sedimentary, volcanic and crystalline rocks, it should be noted that the most abundant resources occur in three locations: in the central part of the Polish Lowlands (sedimentary rocks). Gorzow block (volcanic rocks) and Karkonosze pluton (crystalline rocks).

The goal of the research conducted by AGH-UST team was to indicate the best location for EGS in sedimentary rocks. In the Polish Lowlands, two areas become apparent. The first area encompasses partly the region of the Szczecin Trough and the north-western part of the Fore-Sudetic region, whereas the second area is situated in the region of the Mogilno-Łódź Trough and fragmentarily in the Kujawy Swell region. When analysing the regions of the Carpathians and Carpathian Foredeep, the central part of the Upper Silesian Block may be considered to be prospective (Fig. 4).

As a result of a number of analytical studies, the area situated in the central part of Poland was selected as one of prospective areas for location of EGS in sedimentary rocks. This area encompasses a major part of the Mogilno-Łódź Trough, a part of the Kujawy Swell and a small fragment of the Fore-Sudetic Monocline (Fig. 3). In the selected area, prospects for building closed geothermal systems have been indicated in the Middle Triassic, Lower Triassic, Lower Permian and Carboniferous rocks. There are several potential places for location of closed geothermal systems. Buntsandstein strata, which seem to be a complex meeting the EGS requirements in the investigated area very well, is given as an example. The most favourable conditions for development of EGS occur in deposits of the Lower Triassic in the Krośniewice-Kutno vicinity where they are buried to depths greater than 5000 m b.s.l., have thicknesses exceeding 1500 m and are characterized by porosity about 3% and permeability about 0.02-0.1 mD. In the selected area, thermal characterization of the formation was carried out for location of the EGS in sedimentary rocks. The temperature at the top of Lower Triassic reservoir is modelled in the range 165-175°C (Sowiżdżał et al. 2013; Sowiżdżał and Kaczmarczyk, 2016).

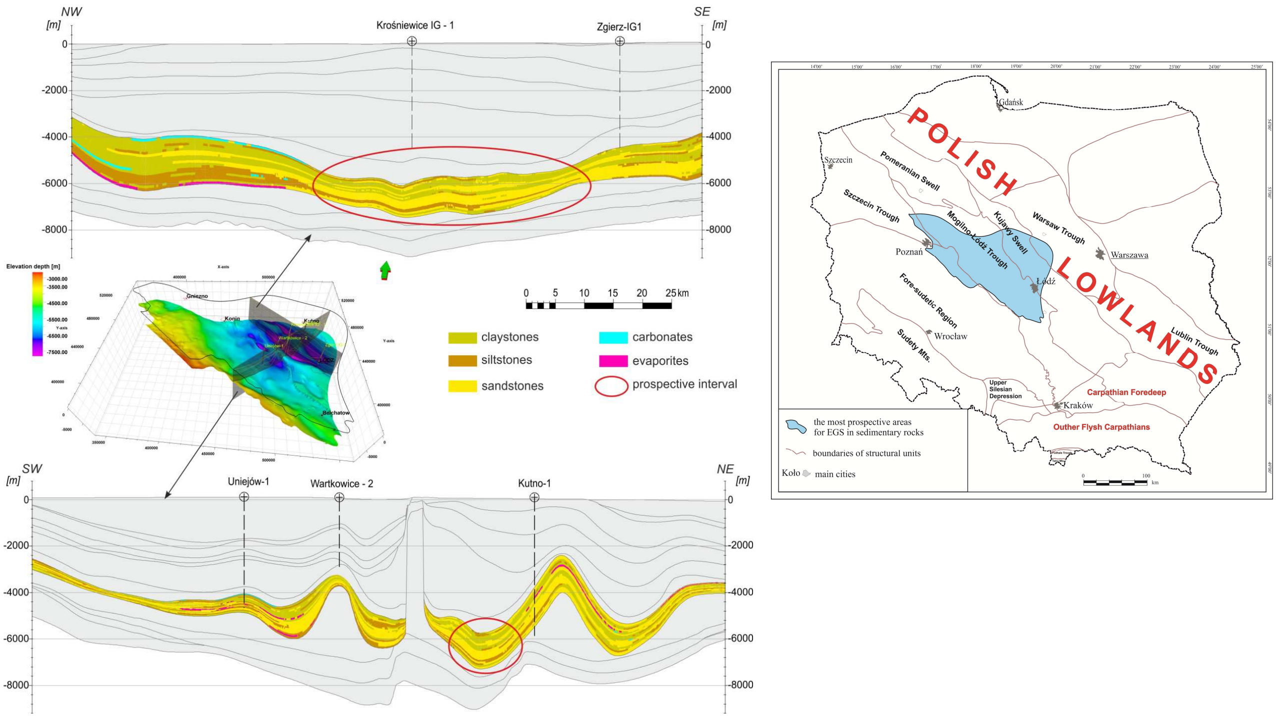

Figure 3: Location of the prospective depth interval of the Lower Triassic in the Krośniewice-Kutno area, location of cross-sections shown in the background of the structural map of the top of the Rotliegend.

4. PROSPECTIVE LOCATION FOR BINARY INSTALLATION

In 2014 *Atlas of the possible use of geothermal waters for combined production of electricity and heat using binary systems in Poland* (Bujakowski and Tomaszewska (eds.), 2014) was issued. The work has been carried out by a scientific consortium of the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences in Krakow, AGH University of Science and Technology in Krakow and the Carpathian Division of the Polish Geological Institute – National Research Institute in Krakow. The main goal of the study was to indicate the suitability of the hydrogeothermal conditions existing in Poland for generating electricity from geothermal waters, as well as to select the most effective method for implementing binary technologies taking account of the existing geothermal potential and local infrastructural conditions.

The results of the study presented prospective areas for joint production of heat and electricity through binary system. In Poland low-temperature geothermal resources exist which could be used in binary power plants operating according to organic Clausis-Rankine (ORC) or Kalina cycles.

In the areas characterized by the best hydrogeothermal conditions main structures prospects for use of binary technologies were indicated. The most prospective region for hydrogeothermal energy utilization (including electricity production) is Podhale Basin. In the Polish Lowlands the best prospects for the utilization of geothermal water in binary systems occur in the central part of Polish Lowlands, especially in the Konin area where the temperature of the water accumulated in Lower Jurassic reservoir exceed 90°C, as well as the Szczecin Through area. Due to existence of geothermal anomalies Sudetic Region appears to be appropriate for the location of binary system. In Cieplice water with temperature 86,7ºC was obtained from the depth of 2002,5 m.

5. CONCLUSIONS

Currently in Poland hydrogeothermal energy (connected with geothermal water) is utilized. Although petrogeothermal energy that constitutes heat resources of rocks has not yet been utilized, the research work tending to assess the possibility of utilization of this type of energy is carried out.

At present geothermal applications involve space heating, balneotherapy, bathing and recreation, nevertheless, research on the possibilities of using geothermal energy for electricity production are carried out. Recognition of geological structures for direct or indirect use of geothermal energy is an important direction of carried geological research. The most prospective regions for geothermal energy development in Poland are connected with Polish Lowlands and Podhale area (Western Carpathians).

The principal resources of geothermal waters in the Polish Lowlands are accumulated in the Mesozoic groundwater horizons. Geothermal waters are accumulated first of all in the Lower Jurassic and Lower Cretaceous formations but significant resources of geothermal energy are accumulated also in the Upper Jurassic, Middle Jurassic, Upper Triassic and Lower Triassic formations.

The brines from practically all the aquifers of the Polish Lowlands basin contain specific elements of iodine, bromine and iron. The waters from Devonian, Carboniferous, Lower & Upper Triassic, Lower & Middle Jurassic reservoirs may be utilized both for recreation, bathing and balneotherapy. Those brines characterize of high content of bromine, sometimes also potassium and magnesium. The carried out analyses indicate that the geothermal potential related to utilization of geothermal waters of the Carpathian Foredeep as well as Eastern Carpathians for recreation and/or balneotherapy is much higher than that related to utilization for heating purposes. It results as well from the lower energy demand of geothermal water intakes as from favourable physicochemical parameters of these waters, confirmed by numerous wells drilled especially over vast areas of the Carpathian Foredeep. In some regions, it is possible to develop the groundwater also for heating purposes (space heating, agriculture, agribusiness), usually in association with other sources, including heat pumps.

The most perspective area for geothermal energy utilization is shown at Fig. 4.

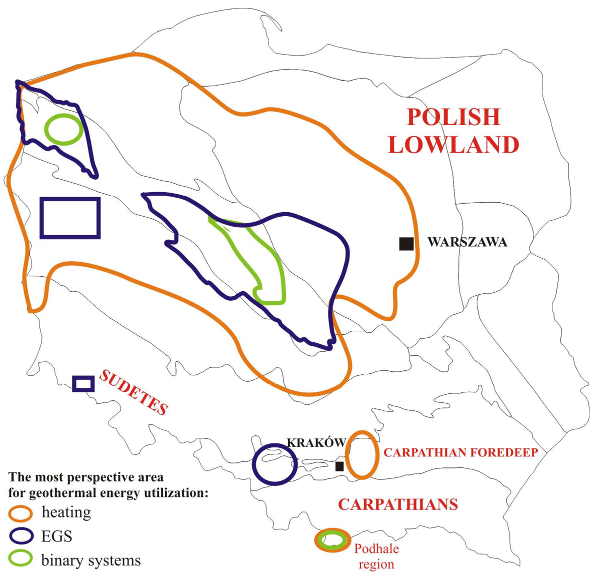

Figure 4: The most perspective area for geothermal energy utilization in Poland.

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