The latest results of geothermal projects in Poland

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ABSTRACT

The paper presents the latest results of geothermal projects carried out by the interdisciplinary research team at the AGH University of Science and Technology, in cooperation with numerous scientific institutions in Poland and abroad. For many years the Department of Fossil Fuels at the Faculty of Geology, Geophysics and Environment Protection, AGH University of Science and Technology, has conducted the fundamental research and implementation work, including selection of optimum areas for utilization of geothermal waters and energy for practical purposes. At the Department, geological conditions of the occurrence of geothermal waters are analysed, 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 six Atlases which represent unique works. In recent years the results of research into the utilization of geothermal water in the polish part of the Carpathians and the Carpathian Foredeep was published.

In 2011 an extensive publication was issued, namely the "Atlas of geothermal waters and energy resources in the Western Carpathians" (Gorecki (eds.) et al., 2011). The contents of the Atlas provided full information covering the whole of interdisciplinary problems of geothermal resources, which can be useful for those who are involved in this field of knowledge. In 2012 "Geothermal Atlas of the Carpathian Foredeep" (Gorecki (eds.) et al., 2012) was published. Atlas constitutes a comprehensive and exhausting source of information on the occurrence and production potential of geothermal waters in the polish part of the Carpathian Foredeep. In 2013 "Geothermal Atlas of the Eastern Carpathians" (Gorecki (eds.) et al., 2013) will be issued.

Results of this studies made it possible to select optimum areas for utilization of geothermal waters and energy in polish part of Carpathian and Carpathian Foredeep.

Since 2010, the project "Evaluation of potential, thermal balance and prospective geological structures for needs of Enhanced Geothermal System in Poland" is carried out. The project is implemented by a consortium which includes leading scientific institutions in Poland. The main aim of the project is to identify areas and geological structures for the location of Enhanced Geothermal System.

1. INTRODUCTION

For decades the St Staszic AGH University of Science and Technology (formerly: University of Mining and Metallurgy) has conducted scientific research and has issued a lot of publications related to the occurrence of geothermal waters in sedimentary basins of Poland. Hot groundwater represent carriers of environmentally clean energy which can be important for numerous regions in Poland. This internal energy of the Earth can be used for heat engineering, technological processes, agriculture, gardening, fish farming, balneotherapy, and recreation. Utilization of the geothermal energy enters into the European Union policy which aims at decentralization of energy management and introduction of renewable energy sources wherever it is possible from the point of view of the environment protection and enterprise costs. On the country scale, distributed sources of energy are also essential factors improving the energy security of Poland.

Utilization of geothermal waters and energy is particularly justified in areas characterized by unique value of nature and tourist amenities, and in towns exposed to the influence of gas and particulate pollutants as a result of burning of traditional energy carriers in local boiler plants and domestic furnaces.

For many years the Department of Fossil Fuels at the Faculty of Geology, Geophysics and Environment Protection, AGH University of Science and Technology, has conducted the fundamental research and implementation work, including selection of optimum areas for utilization of geothermal water and energy for practical purposes.

The latest geothermal projects in Poland are relate to:

-recognition of geothermal conditions of polish part of the Carpathians (results were published in "Atlas of geothermal waters and energy resources in the Western Carpathians"; "Geothermal Atlas of the Eastern Carpathians" will be issued soon),

-recognition of geothermal conditions of Carpathian Foredeep (results were published in "Geothermal Atlas of the Carpathian Foredeep"),

- recognition of the possibility of using reservoirs in sedimentary rocks for building the closed geothermal systems (hot dry rocks project in Poland).

Location of analyzed areas in this projects is shown in figure 1.

Figure 1: Location of analayzed areas in latest geothermal projects in Poland.

2. ATLAS OF GEOTHERMAL WATERS AND ENERGY RESOURCES IN THE WESTERN CARPATHIANS

As a continuation of work carried out over the years 1980 - 2010 on the evaluation of geothermal resources in Poland, in 2011 the "Atlas of Geothermal waters and energy resources of the Western Carpathians" (Gorecki (eds.), 2011) was published.

Area of geological investigation and assessment of the geothermal resources in the western part of the Polish Carpathians measured approximately 10,275 km^2 that represents less than 3.3 percent of the territory of Poland.

From the geological point of view the Polish Carpathians are a part of the great arc of mountains, which stretches for more than 1300 km from the Vienna Forest to the Iron Gate on the Danube. In the west the Carpathians are linked with the Eastern Alps, while in the east they pass into the Balkan chain. The Carpathians have been subdivided into two distinct ranges. The Inner Carpathians are the older range and the Outer Carpathians the younger one (Figure 2).

In the western part of the Polish Carpathians, the Inner Carpathians are divided into two geological units: The Tatra Mts. and Podhale basin. The Tatra Mountains - composed of crystalline massif and its sedimentary cover, is surrounded from the north by the post-tectonic Podhale basin filled with the Paleogene Flysch deposits which are up to 3 km thick and underlain by numulitict limestones and conglomerates. This basin belongs to the biggest geothermal basins in Poland.

The Polish Outer Carpathians are composed of the Late Jurassic-Early Miocene Flysch deposits – deep-water siliciclastic turbidities, deposited by submarine gravity flows, mainly turbidity currents. Exception is the Late Cretaceous-Eocene Sub-Silesian succession represented by variegated marls deposited in pelagic environments. The Carpathian Flysch is composed of an alternation of conglomerates, sandstones, mudstones, claystones and less frequently by marls and cherts. In the Cretaceous-Paleogene Flysch formations these components are mixed in different proportion. The Polish Outer Carpathians are built up of stacked nappes and thrust-sheets, which reveal different lithostratigraphy and structure.

The porosity and permeability of Flysch sandstones are low, with exception of the Ciezkowice Sandstones and partly the Upper Istebna Sandstones. In general the hydrogeological properties of the Carpathian Flysch strongly decrease with the depth (Oszczypko et al., 1981; Szczepanski et al., 2011). It means that on the big depths, where geothermal waters are distributed, improved hydrogeological properties may be associated only with the strongly tectonicaly fractured rock zones.

In the basement of Outer Carpathians, beneath the Carpathian overthrust surface, the inner Carpathian Foredeep is buried (Oszczypko et al., 2006a; Oszczypko, 2006b). The inner Foredeep is filled by Middle and Early Miocene deposits underlain by the platform basement. In basement of Outer Carpathians important role for the deep water circulation is played not only by sandy/sandstone aquifer with good filtration properties (Cambrian, Lower Devonian, Middle Jurassic, Cenomanian and Miocene - Debowiec and Stachorowka conglomerates) but also by fissured horizons of the carbonate rocks connected with buried erosive surface.

Hydrogeochemistry of groundwater in the Western Carpathians and their margin has been characterised on the basis of the chemical composition of groundwater rendered accessible with deep boreholes. The recognition of this hydrogeochemical area is generally limited to its north-eastern and north-western parts, and the analyses of groundwater composition refer to specified depth intervals.

The results of chemical analyses of groundwater from the Flysch sediments and the distinguished stratigraphic units of the Flysch basement (Miocene, Upper Cretaceous excluding Cenomanian,

Cenomanian, Upper Jurassic, Middle Jurassic, clastic Carboniferous, and carbonate Carboniferous-Devonian) were tested with statistical methods.

The values of total dissolved solids (TDS) of the groundwater from the Flysch strata change in a very wide range from 2.1 do 176 g/dm^3. Thus, the samples analysed represent brackish waters, saline waters and brines, and their dominant chemical type is Cl-Na, according to the classification of Altowski and Szwiec. The mean TDS values in the specified sections of the holes (at every 500 m asl) are not correlated with the depth of the sections.

The mean TDS of the groundwater occurring in the basement of the Flysch Carpathians in the study area is 72 g/dm^3 and changes in the range 2.3 – 270 g/dm^3.

The Miocene strata, covered by Flysch sediments, represent the most variable hydrogeochemical environment as their groundwater range from brackish types (TDS below 5 g/dm^3) to highly mineralised brines (above 100 g/dm^3). The concentration of chloride and sodium ions is the major factor determining the high TDS values of Miocene groundwater.

Complicated geological structure of the Outer Carpathians results in high, horizontal and vertical variability of petrophysical, volumetric and hydrogeological parameters in selected depth intervals. The effective porosity and permeability of Flysch sediments vary in wide ranges: from 0.01 to 27.8% and from 0.002 to 875.8 mD, respectively, which points out to the presence of both the favourable and the extremely poor reservoir properties.

The results of calculation of geothermal energy resources accumulated within the Flysch formation and within Miocene/Mesozoic/Palaeozoic geothermal aquifers located in the basement of the Polish Western Carpathians is presented at the Atlas (Hajto, 2011). The calculations were made with regard to the accepted classification of geothermal resources, in accordance with the McKelvey's diagram. Estimates of energy accumulated in particular aquifers was given, and results of the calculations were compared to geothermal energy resources accumulated in the Polish Lowlands.

The locally encountered, better hydrogeological conditions for the occurrence of geothermal waters (and other groundwaters) should be related to tectonic and diagenetic controls. Higher values of filtration parameters of Flysch sediments may occur in the zones of overthrusts of various tectonic units. Geothermal waters were found under similar tectonic conditions in the overthrust zones of the Magura and the Dukla-Grybow units, in the vicinity of Skomielna Biala, Rabka and Poreba Wielka.

Geothermal waters encountered in completed wells drilled through the Flysch sediments are mostly of diagenetic provenance. The potential reservoir clastics (mostly sandstones) reveal relatively high porosities and permeabilities but their extents are relatively limited and their horizons are not recharged recently. This may by vitally important for the volumes and stability of yields of geothermal water intakes.

The basis for eventual designs of future geothermal installations must be the results of relevant hydrogeological observations made in wells and determination of the character of particular geothermal aquifers including the opinion if the resources will be rechargeable - the feature which would enable the long-lasting, sustainable exploitation under proper parameters. Moreover, the character of deposits should determine the future utilization of geothermal waters (heat generation/balneotherapy).

Applying the unified evaluation criteria for petrophyscial, volumetric, hydrogeological and thermal parameters, the following areas perspective for geothermal waters prospection were identified: Myslenice – in the frontal zone of the Magura Unit: (depth interval 1500 – 2000 and 2000 – 2500 m bsl); Ciezkowice – in the frontal zone of the Silesial Unit: (depth interval 2000 – 2500 m bsl) and Zywiec – single interval on depth 1000 – 1500 m bsl (Figure 2).

Within both the Miocene sediments and the Palaeozoic-Mesozoic basement of the Western Carpathians the perspective areas for localization of geothermal water intakes were found within the Cenomanian and the Middle Jurassic aquifers (figure 2). Both areas occur in the frontal zone of the Carpathian Overthrust, south from Bochnia and Brzesko.

The best hydrogeological and geothermal conditions in the Polish Western Carpathians occur in the Podhale basin (Kepińska&Wieczorek, 2011). Podhale is a region where geothermal waters are utilized recently and will be utilized in the future, preferably for heat generation but also for recreation and balenotherapy. Currently, six installations are in operation, the geothermal heat distribution network of the PEC Geotermia Podhalanska SA is still under development and in 2011 the third exploitation well will be spud. Moreover, in 2010 the next four recreation centers were at various stages of construction. However, the need for rational, long-range development strategy of the Podhale geothermal deposit must be underlined.

At present, mineral and therapeutic waters of the Western Carpathians are utilized in balneotherapy in eight statutory health resorts, and in two of them these waters represent the geothermal variety. Geothermal waters of the Podhale basin are utilized for recreational purposes in Zakopane, Bukowina Tatrzanska, Bialka Tatrzanska and Szaflary.

All the geothermal waters recorded in the Western Carpathians may be primarily used in medicine, recreation or in both of them together, mainly in

bathing pools. Specific components, besides the parameter of temperature, include CO_2, H_2S, H_2SiO_3, F^-, Fe^{2+} and I^-. Geothermal waters of the Podhale basin represent a valuable balneological asset.

The waters of the Western Outer Carpathians recorded as geothermal ones are mainly of the chloride type. They may be use in balneotherapy and recreation because of great demand, particularly for bathing and swimming facilities, e.g. Sol, Jaworze, Poreba Wielka, Skomielna Biala and Sucha Beskidzka. The specific components include iodide and temperature. Considering their high mineralization and temperature, these waters can meet the criteria of balneotherapy and recreation but only after diluting them to the parameters required by the norm.

4. GEOTHERMAL ATLAS OF THE CARPATHIAN FOREDEEP

In 2012 Geothermal Atlas of Carpathian Foredeep (Gorecki (eds.), 2012) was published, which constitute a comprehensive and exhaustive source of information on the occurrence and utilization of geothermal waters and energy in Carpathian Foredeep.

The Carpathian Foredeep, genetically connected with the Flysch Carpathians, the youngest geological unit of Poland, is an asymmetric structure filled with Miocene molasse deposits developed as the sequence of shales, mudstones and sandstones, from several hundred to about 3000 metres thick. This complex is determined as so-called Autochthonous Miocene and its sediments originated from erosion of folded Carpathian flysch deposits. The distinct southern boundary of the Carpathian Foredeep is delineated by the margin of the thrust Carpathians, although the Miocene deposits with variable thickness occur also under the Carpathian overthrust. For this reason, the southern boundary of the area analysed in this study occurs about 15 km to the south of the border of the Carpathian overthrust.

Within the Polish state borders, the Carpathian Foredeep stretches latitudinally over more than 300 km, whereas its maximum width does not exceed 100 km. The asymmetry of the Foredeep structure is marked out as well in its transversal (meridional) cross-section where maximum thicknesses of the Miocene deposits are found in the south at the front of the Carpathian overthrust and decrease northwards, as in the longitudinal cross-section where the elevation of its Precambrian-Paleozoic basement, so-called "Cracow Bolt", divides it into unequal parts: the larger Eastern Foredeep and the smaller Western Foredeep. In the eastern part, the basement of the Carpathian Foredeep is formed of erosionally truncated deposits of the West European Platform of different ages: Precambrian and Paleozoic (in the Miechów-Rzeszów area) through Mesozoic (in the Miechów Trough). In the western part, the basement is represented by Mesozoic rock complexes and (principally) Paleozoic (Carboniferous) complexes of the Upper Silesian Trough, which rest over Precambrian metamorphic rocks of the Upper Silesian Block. The area analysed in the Atlas covers about 24 400 km^2, which represents approximately 7.8% of the area of Poland (Harasimiuk et al., 2012, and references therein).

Detailed interpretation was carried out for the following eleven hydrogeothermal aquifers occurring in the Carpathian Foredeep: Miocene; Upper Cretaceous (without Cenomanian); Cenomanian; Lower Cretaceous; Upper Jurassic; Middle Jurassic; Upper Triassic; Middle Triassic (T2+Tp3); Lower Triassic (Tp1+Tp2); clastic Carboniferous; and carbonate Devonian and Carboniferous (Sowiżdżał et al., 2011). In consideration of the large Miocene thickness exceeding locally 3000 m and wide variations in the development of particular stratigraphic units in its profile, for determination of hydrogeothermal parameters in the Miocene aquifer, depth intervals were distinguished, for which the analytical work was done (500-1000 m bsl; 1000-1500 m bsl; 1500-2000 m bsl; 2000-2500 m bsl; and 2500-3500 m bsl).

The work tending towards the assessment of the geothermal potential comprised: characterization of the geological setting of the Carpathian Foredeep (Peryt, 2012) together with construction of a structural-parametric model (Papiernik et al., 2012); interpretation of hydrogeological parameters (Haładus et al., 2012); hydrochemical characterization of groundwaters (Sowiżdżał&Jasnos, 2012); and thermal analysis (Hajto&Szewczyk, 2012). The construction of the parametric model was based on results of quantitative interpretation of geophysical well logs (Czopek et al., 2012). The work resulted in assessment of geothermal resources in distinguished resource groups (Hajto&Kotyza, 2012).

The carried out analyses indicate that the geothermal potential related to utilization of geothermal waters of the Carpathian Foredeep 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 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 aquifers of the Cenomanian, Upper Jurassic, Devonian-Carboniferous and Miocene are most prospective. However, in these aquifers, the most favourable parameters for location of geothermal intakes occur in small areas and depth intervals. For example, the best hydrogeological and geothermal parameters that indicate the possibility of using the Miocene geothermal water occur in the depth interval 500-1500 m bsl The remaining depth intervals seem to reveal low prospectivity because of low temperatures or weak hydrogeological parameters that determine low discharges of geothermal water intakes. Location

of prospective areas in the Carpathian Foredeep is presented in Figure 2.

5. GEOTHERMAL ATLAS OF THE EASTERN CARPATHIANS

The Eastern Carpathians, part of the Outer Carpathians, stretch mainly over the territories of Ukraine and Romania, with only their small fragment being situated in Poland and Slovakia. This minor part of the Polish Eastern Carpathians varies both in its geology and environment from the Western Carpathians situated west of the San river valley.

Geographical division of the Carpathians differs from that used in this Atlas hydrogeological division. According to this division the western border of the research area situated west of the Biala river valley. Southern and eastern boundaries of the research area state border sets, while the northern border sets Carpathian overlap.

The eastern part of the Polish Carpathians includes only the Externides, i.e., the Outer Carpathians (called also the Flysch Carpathians or the Beskid Mountains. They contain exposed series of pelitic to psammitic sediments of generally continuous stratigraphy, dominated by various associations of deposits of turbiditic and psammitic-aleuritic flows with a minor contribution of carbonate and tuffogenic rocks. The nappes and tectonostratigraphic units of the Externides form a typical fold-and-thrust structural belt with its vergence polarized against the platform border, although the folds and thrusts within the margins of structural depressions can also reveal reversed dips. The extent of thrusting and the degree of folding of allochtonous covers justify the opinions on their being detached from a primeval basement, at least in the outer and central zones.

In the Polish Outer Carpathians three structural-facies units can be distinguished: the Magura (innermost one), the Middle and the Marginal groups. Within each of them individualized nappes are distinguished, i.e., the structural-facies units (or zones) characterized by their specific lithostratigraphic profiles and/or different tectonic styles. The Magura Group is developed in the western part of the Polish Carpathians. The Middle Group is developed best in the eastern part of the Polish Carpathians, being the widest within the drainage basins of the San and Ondava rivers (Slovakia). The presence of the youngest flysch sediments (Oligocene – Early Miocene), distinguished as the Menilite-Krosno series with the thickness reaching 3000 m in the upper San river basin, is a characteristic feature in the profiles of the nappes and units of this group.

The area of the Carpathians is considered to be the birthplace of the world petroleum industry. The first Polish oil mine was started in 1854 on the initiative of Ignacy Łukasiewicz in Bóbrka near Krosno. The first Polish crude-oil distillation plant was built in 1856 in Ulaszowice close to Jasło, the second in 1858 in Klęczany, and the third in 1861 in Polanka. One of the oldest oil refineries in the world was opened in 1884 in Gorlice. In the Gorlice region, the beginning of using crude oil dates back to the 17th century. Crude oil was firstly drawn with wooden buckets from wells, 15-60 m deep, dug by hand. During the initial stage, recognition of the study area and development of views on its geologic setting was based on interpretation of cartographic data from the field work and on shallow wells located mainly on anticlinal structures.

At present, in the Eastern Carpathians, exploration for oil and gas accumulations is conducted as well in conventional traps as in unconventional ones (“shale gas”). According to data from the Ministry of the Environment (www.mos.gov.pl), in the Eastern Carpathian region, concessions for prospecting, exploration and exploitation of crude oil, natural gas and methane is held by three entities: PGNiG SA, RWE Dea AG and Aurelian Oil & Gas Poland Sp. z o.o.

According to the long term of petroleum activity in the Eastern Carpathians over 7500 were drilled. They constitute an abundant source of information on geological conditions including the possibility of occurrence of geothermal waters.

The previous recognition of the Eastern Carpathians from the geothermal point of view has been relatively poor. In substance, no deep geothermal wells were drilled in this region of the Carpathians. In accordance with the current regulations of the Geological and Mining Law (Official Journal of 2011, No 163, Item 981), prospecting, exploration and exploitation of low-temperature groundwater resources for the energy production are not amenable to concession procedures. In the Eastern Carpathians, concessions were also granted for prospecting, exploration and exploitation of medicinal and thermal waters and brines. As of 1st January 2013, according to available data, five concessions have been granted in the Eastern Carpathians in: Wapienne – Health Resort Wapienne (Institution for Medicinal and Rest-Cure Services)’ Wysowa – Health Resort Wysowa S.A., Rymanów – Health Resort Rymanów S.A., Iwonicz – Health Resort Iwonicz S.A., Polańczyk – Communal Institution in Polańczyk (figure 2).

The work carried out so far shows that hydrogeothermal conditions of occurrence of geothermal waters in the Easter Carpathians are similar or even worse than these in the western part of the Polish Carpathians.

High, horizontal and vertical variability of petrophysical and hydrogeological parameters in selected depth intervals affects that the flysch sediments are not much perspective geothermal aquifer in regional scale.

The project is in progress and the results will be known later this year.

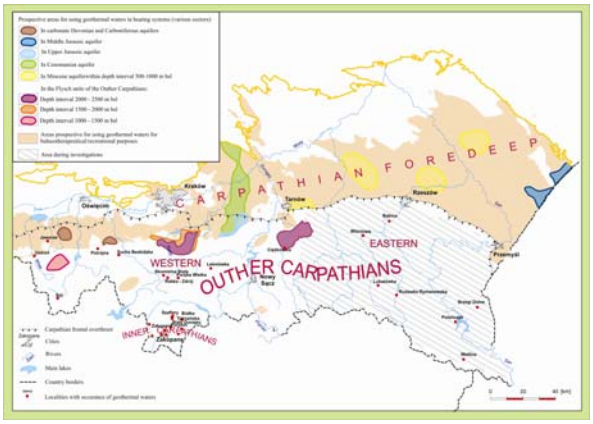

Figure 2: Location of perspective areas for use of geothermal waters in the polish part of Carpathians and Carpathian Foredeep.

6. HOT DRY ROCKS PROJECT IN POLAND

Currently in Poland hydrogeothermal energy is utilized, for which warm groundwater produced from boreholes represents the energy carrier. On the other hand, petrogeothermal energy that constitutes heat resources of rocks, has not yet been utilized. For this, energy (heat) carriers are represented by media (usually water) pumped through boreholes into heated rock formations, so named hot dry rocks (HDR).

The research project, carried out in the years 2010-2013 by leading scientific centres (the Consortium composed of: the Polish Geological Institute – National Research Institute, the AGH University of Science and Technology, the Mineral and Energy Economy Institute of the Polish Academy of Sciences, and the PBG Geophysical Exploration Co. Ltd.), is the first enterprise of this type, which tends to recognize the potential of hot dry rocks (HDR) for heat and electricity production. The main objective of the project was to assess the possibility of using geological structures for building closed geothermal systems – Enhanced Geothermal Systems (EGS) in the territory of Poland through cartographic imaging of selected structures, prospective for this type of systems in Poland.

As one of the Consortium members, a research team from the AGH University of Science and Technology conducted the work connected with analysis of the possibility of using reservoirs in sedimentary rocks for building the closed geothermal systems.

The performed analyses of the map of surface heat flow density, map of subsurface temperatures, gravimetric map and magnetic map allowed to determine several prospective locations.

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 (Figure 3– area 1), whereas the second area is situated in the region of the Mogilno-Łódź Trough and fragmentarily in the Kujawy Swell region (Figure 3– area 2).

When analysing the regions of the Carpathians and Carpathian Foredeep, the central part of the Upper Silesian Block may be considered to be prospective (Figure 3– area 3).

For the selected areas a database was created, which formed the foundation for determination, in central Poland, of a prospective area for development of energy of hot dry sedimentary rocks, in consideration of predicted hydrogeothermal parameters and available geological information on deep reservoir horizons.

As a result of the analytical work, an area situated in the central part of Poland (Figure 3– area 2) was chosen as prospective for needs of closed geothermal systems in sedimentary rocks in Poland. Although prospects of occurrence of hot dry rocks appear also in the remaining indicated areas, the area 2 (Figure 3) was selected for modelling and further analyses due to sparse geological information on deep-lying strata in the other areas.

The distinguished area 2 covers the Mogilno-Łódź Trough region and a small part of the Kujawy Swell and Fore-Sudetic regions.

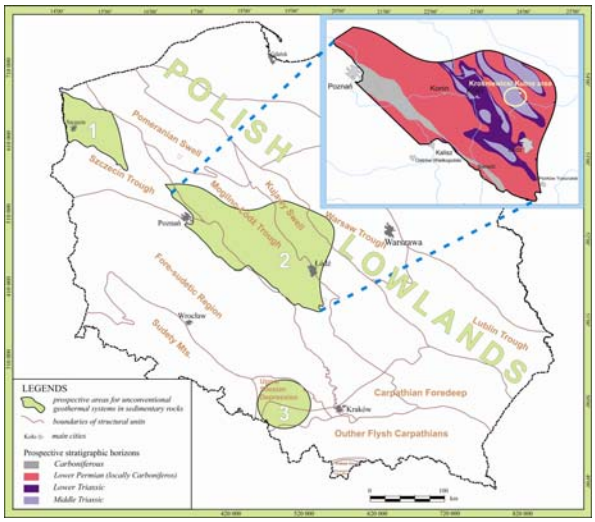

Figure 3: Location of prospective areas for unconventional geothermal systems in sedimentary rocks.

For the selected area (Figure 3– area 2), a number of analyses were carried out, among others: reprocessing of seismic data and their interpretation, petrological analysis of collected rock samples, analyses of petrophysical parameters, including thermal parameters. Hydrogeological analysis which allowed to improve the model of porosity and permeability in particular model strata. A three-dimensional structural model of geological complexes in the rank of series was constructed for the Carboniferous, Rotliegend, Zechstein, Lower Triassic, Middle Triassic, Upper Triassic, Lower Jurassic, Middle Jurassic, Upper

Jurassic, Lower Cretaceous and Upper Cretaceous. The framework built by this means was used for construction of a parametric model that included models of porosity, permeability, clay content, density and lithology. Three-dimensional modelling of density distribution for the selected structure was performed in order to supplement and correct the structural-parametric model.

Summary of the analysis was estimation of the energy balance for unconventional geothermal systems, and modelling of heat capacity and potential for heat and electricity production

In the selected area, prospects for building closed geothermal systems have been indicated in the Middle Triassic, Lower Triassic, Lower Permian and Carboniferous rocks (Figure 3). 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.

Finally it was decided that the most prospective area for the location of Enhanced Geothermal System in sedimentary rocks in Poland is situated in the vicinity of Krośniewice/Kutno (Figure 3), where the top of the Lower Triassic reservoir of more than 1000 m thick, is behind at depths 5000-5500 m bsl and the temperature at the top is in the range 165-175°C. The porosity of reservoir rocks is approximately 2.5%, while the permeability is about 0,1 mD.

7. CONCLUSIONS

The Department of Fossil Fuels (leader in the geothermal research in Poland) at the Faculty of Geology, Geophysics and Environment Protection, AGH-UST, has carried out the research and implementation work including selection of optimum areas for construction of geothermal heating plants. Geothermal energy resources are analysed and technologies for development of geothermal water resources are examined by the Department in 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.

The Atlases are an example of developed at AGH-UST cooperation of specialists from various scientific domains, among others: geologists, hydrogeologists, chemists, geochemists, geothermisists, specialists in drilling engineering, production engineering, heat engineering and computer science, and economists and jurists.

The Atlases are intended for students of a new discipline, developed at the Faculty, named “Ecologic Energy Sources”, and for university teachers and students of specializations connected with the power engineering and environment protection. Representatives of the state administration and activists of local governments will find in Atlases essential information on geothermal waters and possibility of their utilization. The Atlases comprises important information for investors involved in recognition and production of warm brines for practical uses.

The Atlases represents a results of interdisciplinary, constructive cooperation of specialists from various fields of science. The selected geothermal aquifers were characterized from the point of view of geological setting, extent, depth and thickness of the aquifers, water temperature and mineralization, discharge of hydrogeological intakes and reservoir properties. Results of the research allowed to calculate geothermal resources and indicate the best locations for variety of utilization: balneoterapeuthic, recreation and heating.

The calculation of the geothermal resources for the needs of this Atlases was made using the unified criteria of the resource classification and the calculation methodology developed at the Department of Fossil Fuels, AGH University of Science and Technology. The results are comparable to the results of analogous calculations published in previous Atlases, i.e. the “Atlas of geothermal resources in the Polish Lowlands – Mesozoic and Paleozoic formations (Górecki (eds.), 2006).

In the studied polish part of the Carpathians and Carpathian Foredeep the best reservoir and exploitation properties for geothermal waters utilization occur in Podhale, represented by: favourable reservoir parameters and lithologies, usually high yields and regional extent of the aquifer (in both the Polish and Slovak parts) as well as recent recharge and low TDS.

Podhale is a region in the Western Carpathians where geothermal waters are utilized recently and will be utilized in the future, preferably for heat generation but also for recreation and balenotherapy.

Another geothermal research project, carried out in the years 2010-2013 with the participation of research team from AGH University of Science and Technology is named *Evaluation of potential, thermal balance and prospective geological structures for needs of unconventional geothermal systems (Hot Dry Rocks) in Poland*. As one of the Consortium members, a research team from the AGH University of Science and Technology conducted the work connected with analysis of the possibility of using reservoirs in sedimentary rocks for building the closed geothermal systems.

Complementary analyses of raw data and maps of surface heat flow density, subsurface temperatures, maps of gravimetric and magnetic anomalies allowed to determine several prospective locations. The most promising conditions occur in central part of Poland in an area covering the central part of Polish Lowlands (the Mogilno-Łódź Trough region and a small part of the Kujawy Swell and Fore-Sudetic regions). Preliminary analyses revealed prospects for building

closed geothermal systems in the Middle Triassic, Lower Triassic, Lower Permian and Carboniferous rocks. In order to select the best possible sites and rock complexes for locations of EGS systems thermal, structural and parametric modeling was performed. Buntsandstein strata, which seem to be a complex meeting the EGS requirements in the investigated area very well, is given as an example.

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