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Resources and Possible Directions of Use of Geothermal Waters in the Polish Part of the Eastern Carpathians

Marek Hajto

AGH University of Science and Technology, Al. Mickiewicza 30, 30-059 Krakow, Poland

mhajto@agh.edu.pl

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ABSTRACT

The article presents the results of estimation of geothermal energy resources in flysch formations, and the Miocene, Mesozoic and Paleozoik basement of the flysch in the area of the Polish Eastern Carpathians from the meridian of Gorlice to the Bieszczady Mts. This area covers approximately 9830 km^2, which is ca. 3.2% of the Polish territory. The paper also shows the location of the prospective zones, possibilities and directions of optimal use of geothermal waters for heating purposes and/or balneotherapy in this area. The calculations were carried out according to the McKelvey's geothermal energy resources classification. The estimates of energy accumulated in individual geothermal aquifers and the results of calculations are referred to the size of geothermal energy resources accumulated in other geothermal provinces of Poland. The relatively low geothermal potential was found as well in the flysch cover as in the geothermal aquifers of the Mesozoic-Paleozoic basement.

The analyzes show that the Miocene aquifers covered with flysch sediments are locally characterized by favourable reservoir properties. The most interesting aquifers, from the point of view of possibility of using geothermal water for heating purposes, are present in the area of Błędowa Zgłobieńska, about 15 km west of Rzeszów. According to the estimates, it is possible to set up a small power plant which will use thermal water with intakes at approximately 30 m^3/h, with a temperature of about 72°C and TDS of ca. 54 g/dm^3.

1. INTRODUCTION

The study area is situated in southeastern Poland and covers the southern part of the Podkarpacie Province and the easternmost part of the Małopolska Province, from the meridian of Gorlice. Estimation of geothermal energy resources was carried out in the area bounded in the west by the 2nd order watershed along the Biała river (west of Gorlice), in the east and south by the state border, and in the north by the boundary of the Flysch Carpathians overthrust. The study area measures approximately 9830 km^2, which represents ca. 3.2% of the area of Poland. The location of the study area and the geological-structural map of the eastern part of the Polish Carpathians are shown in Figures 1 and 2, respectively.

Figure 1. Location of the study area

The Carpathian region has been considered the birthplace of the petroleum industry. The first Polish oil mine was launched in 1854 in Bóbrka near Krosno, on the initiative of Ignacy Łukasiewicz. The first Polish distillation plant was set up in 1856 in Ulaszowice near Jasło, the second in 1858 in Klęczany, and the third in 1861 in Polanka. One of the world's oldest oil refineries was opened in 1884 in Gorlice. Analysis of archival materials and databases, including those from the Polish Oil and Gas Company (PGNiG S.A.), has indicated that more than 7500 boreholes were drilled in the eastern part of the Polish Carpathians, including deep regional, exploratory and production boreholes. In the years 1990-2012, in that part of the Carpathians, 245 exploratory boreholes were drilled, of which 10 boreholes after 2010. From the beginning of exploration in the discussed part of the Carpathians, 47 oil fields or oil and gas fields were discovered. In 1988 the Kuźmina-1 borehole was drilled down to 7541 m and it is still the deepest borehole in Poland. In it, the formation temperature of 178.5°C was recorded, being the highest temperature in that part of the Carpathians. The highest temperature of geothermal water in the eastern part of the Polish Carpathians was noted in the Brzegi Dolne IG-1 borehole (in the Ustrzyki Dolne commune). In that borehole, from the Inoceramian Beds of the Skole Unit at the depth of ca. 4300 m, inflow of water with temperature of 105°C was obtained (Chowaniec et al., 2001). In that area, the most recent boreholes are Niebieszczany-1 (total depth of 4219 m) and Dukla-1 (TD of 5500 m), both drilled in 2012.

In spite of the numerous boreholes drilled, from the geothermal point of view the so-far recognition of that part of the Carpathians is relatively poor. Basically, no deep, typical geothermal boreholes were drilled there and the recognition was based on the geological information found in the petroleum industry reports. In the Polish Eastern Carpathians, four concessions have been hitherto granted for prospecting, exploration and exploitation of medicinal and thermal waters and brines in the following localities: Wapienne, Wysowa, Rymanów, Iwonicz and Polańczyk. The water containing carbon dioxide, which was developed by previous oil wells Lubiatówka-12 (depth of 1151.5 m) and Lubiatówka-14 (820 m) in the region of Iwonicz, is the only thermal water utilized in the analysed area.

2. OUTLINE OF THE GEOLOGICAL STRUCTURE

The Polish Carpathians to the east of the meridian of Gorlice border on the Slovak Carpathians in the south and on the Ukrainian Carpathians in the east. The Polish Eastern Carpathians comprise the Outer Carpathians (externides) where stratigraphically continuous sandstone/shale sequences with small proportion of carbonate and tuffogenic rocks crop out. Those series are called the Carpathian flysch (Bieda et al., 1963). The allochthonous, deep-marine, folded flysch deposits are overthrust onto younger, Miocene sedimentary series that fill up the Carpathian Foredeep.

Folding of the Outer Carpathians, including the Beskids, took place during the final stage of the Alpine orogenic movements in the Savian phase, at the turn of Paleogene and Neogene. At the end of Burdigalian, as a result of the collision between the European Plate and the Alcapa and Tisza-Dacia terranes, the Outer Carpathians were folded and uplifted. At the same time the process of thrusting of the Carpathians toward the north started, combined with formation of the Carpathian Foredeep. The folded rock masses were detached from their basement, pushed to the north and overthrust in the form of nappes onto sediments of the foredeep that was formed before the front of the Carpathians. In the eastern part of the Polish Outer Carpathians, three groups of structural/facies units can be distinguished: the Magura Group, the Middle Group and the Marginal Group. Within the groups, individual nappes or structural/facies units, characterized by different lithostratigraphic and tectonic development, can be separated. On the geological-structural map, the following nappes can be distinguished from the south to the north: Magura, Dukla, Silesian, Sub-Silesian, and Skole (so-called Middle Group), and Boryslav-Pokuttya, Stebnik and Zgłobice (Fig. 2).

Deposits of the Magura Series are developed mainly in the western part of the Polish Carpathians. The depth to the base of the flysch rocks, estimated from drilling and seismic survey results, is great and locally exceeds 6500 m below sea level (bsl).

Thickness of the flysch cover increases to the south, toward the so-called Central Carpathian Depression. In the eastern part of the Polish Carpathians, the basement of the Carpathian tectogene in the foreland area was recognized in numerous boreholes, but beneath the Carpathian overthrust the recognition is limited to the frontal zone of the Carpathians, with maximum width of approximately 20-23 km. It is built up of Proterozoic, Paleozoic, Mesozoic and Cainozoic rocks which go into the composition of the Małopolska Block. The oldest recognized rocks are diagenetically altered and weakly metamorphosed phyllites of the Late Neoproterozoic (Ediacaran) through Early Cambrian age (Samsonowicz, 1955; Głowacki and Karnkowski, 1963; Moryc and Łydka, 2000). In the study area, Permian deposits have not been found. On the Carboniferous or older sequences, Triassic deposits rest (Moryc, 1971a,b,c; 1992; 1996). In the lower part, they are principally developed as classic rocks: conglomerates, variegated sandstones and claystones, representing the Lower and Middle Buntsandstein. Higher are carbonate rocks included to Roethian: limestones, dolomites and marls with intercalations and patches of anhydrite. The Muschelkalk (Middle Triassic) is developed mainly as crystalline limestones. The highest part of Triassic is represented by Keuper deposits. In the study area, their presence was noted only in the Zagorzyce-6 borehole (Maksyn et al., 1998). Early Jurassic formations occur only locally in consequence of erosion.

The Jurassic succession is represented by Middle Jurassic (Doggerian) rocks – mainly sandstones, silty sandstones, siltstones and shales, as well as by Late Jurassic (Malmian) rocks – Oxfordian carbonates with possible reef-like forms and Kimmeridgian limestones and dolomites. Total thickness of the Upper Jurassic strata reaches ca. 1300 m. In the study area, Lower Cretaceous (Neocomian) strata occur only fragmentarily in the Dębica and Ropczyce-Zagorzyce areas (Kijakowa and Moryc, 1991; Moryc, 1997; Urbaniec et al., 2010). Those are organogenic carbonates and dark mudstones and claystones.

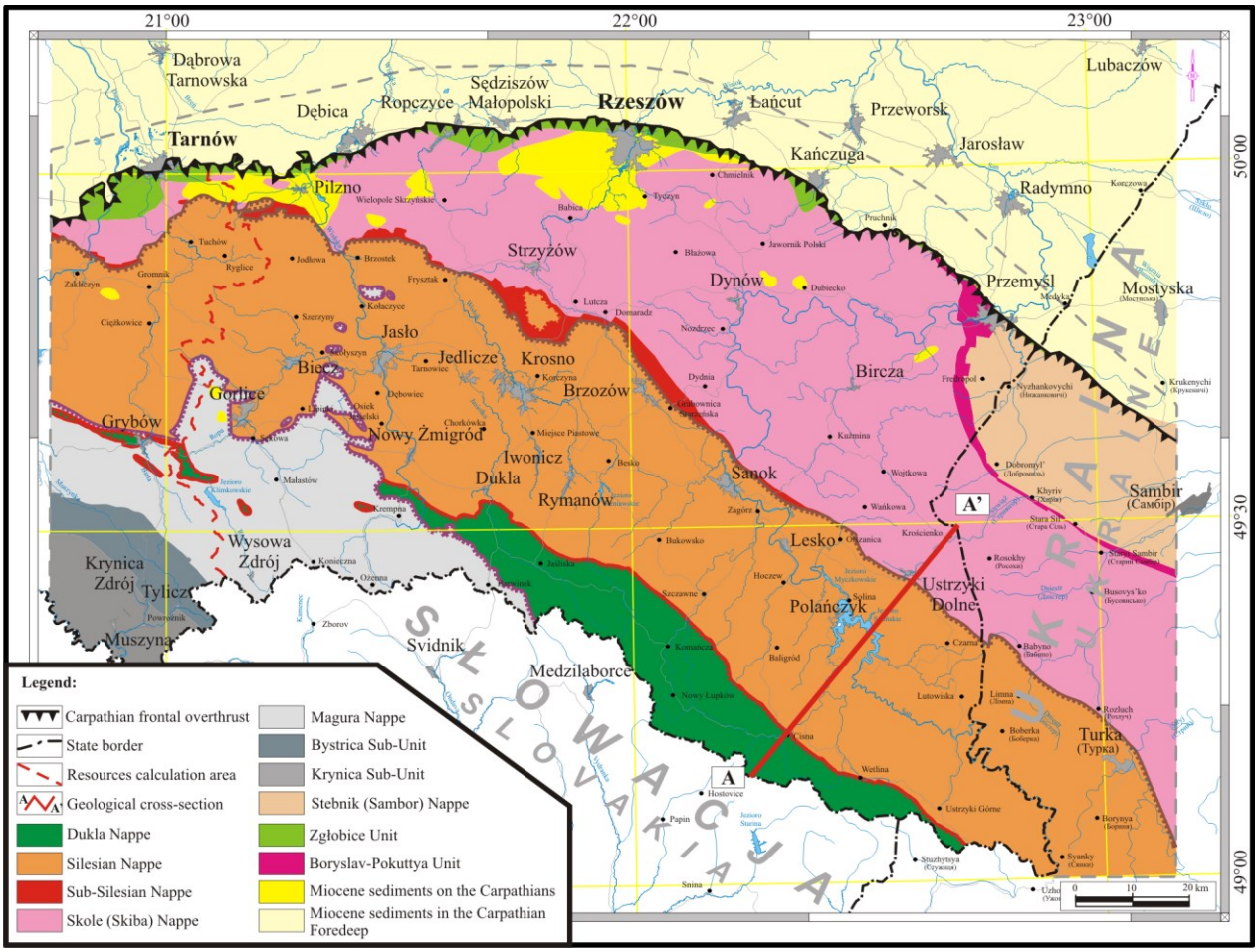

Figure. 2. Geological-structural map of the Polish Eastern Carpathians (based on: Żytko et al. (1989); Jankowski et al. (2004))

In the Małoplska Block area, Upper Cretaceous is represented by clastic deposits of Cenomanian – principally sandstones and conglomerates. In the Polish Eastern Carpathians they have small thickness and extent. Higher up and only locally occur strongly eroded carbonate rocks of Turonian, Santonian, Campanian, and Maastrichtian. In the area between Sędziszów and Rzeszów, in erosional paleochannels, terrestrial deposits occur: conglomerates, siltstones and claystones, to which the Paleogene age is attributed.

The youngest sediments occurring in the basement of the flysch sequences are represented by Miocene molasse deposits of so-called internal depression. In the light of the current recognition, the oldest autochthonous Miocene strata are dated at Karpatian (Ślączka, 1977; Oszczypko, 1996; 2001; 2006; Oszczypko et al., 2006). In the basement of the Polish Eastern Carpathians, principally Middle-Miocene marine deposits have been hitherto recognized, belonging to the Skawina (Baranów) Formation, Evaporites and the Machów Formation. Farthest to the south, the autochthonous Miocene formations were encountered in the Kuźmina-1 borehole. The Miocene succession is represented mainly by conglomerates, claystones, siltstones and shaly sandstones, and evaporites (anhydrite, gypsum). The subsurface structure along the Cisna-Krościenko cross-section, located in the southern part of the study area, is presented in Figure 3.

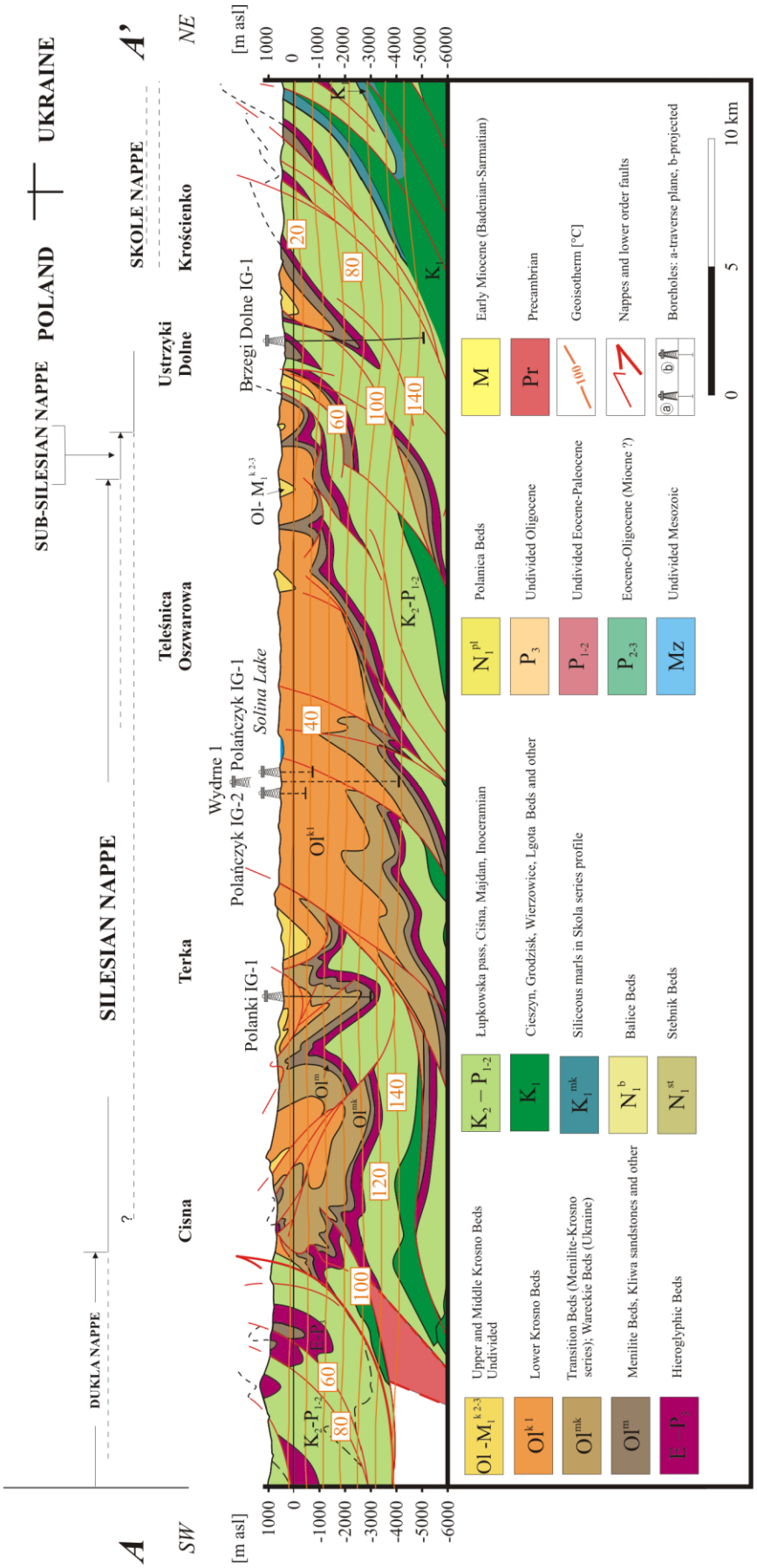

Figure 3. Geological cross-section Cisna-Krościenko (A-A') in the area of the Polish Eastern Carpathians (modified from Kuśmierek, Baran and Golonka, 2013)

3. IDENTIFICATION AND CHARACTERIZATION OF POTENTIAL GEOTHERMAL AQUIFERS IN THE POLISH EASTERN CARPATHIANS

In the Polish Eastern Carpathians, geothermal aquifers are connected mainly with clastic rocks – sandstones occurring in the geological section of the flysch cover. In the basement of the tectogene, geothermal aquifers related to clastic rocks occur, as well as fractured aquifers in carbonate rocks: limestones and/or dolomites.

Beneath the overthrust surface of the Flysch Carpathians, geothermal waters may occur in aquifers related to clastic deposits of Miocene, Cenomanian and Lower Cretaceous, Middle Jurassic, Lower Triassic (Tp1+Tp2), clastic deposits of Carboniferous and clastic deposits of Lower Devonian. Locally, beneath the flysch overthrust, the following carbonate rocks can reveal favourable reservoir properties: limestones of Upper Cretaceous (without Cenomanian), Upper Jurassic and Middle Triassic (T2+Tp3), as well as limestones and dolomites of Upper Devonian and Lower Carboniferous which form a homogeneous aquifer. Good reservoir properties in Devonian-Carboniferous carbonates were locally confirmed in the western part of the Polish Outer Carpathians, in the Ustroń and Bielsko-Biała areas (Górecki [ed.] et al., 2011).

Sandstones representing almost all stratigraphic horizons from Lower Cretaceous to Oligocene inclusive (Kuśmierek et al., 2001a) are the basic lithotype of reservoir rocks of the flysch cover in the Polish Eastern Carpathians. The sandstones of the flysch are characterized by high lithological differentiation, which can be observed even within particular lithostratigraphic horizons of a given tectonic unit. Potential reservoir horizons can be related, among others, to the Lower Cretaceous strata encountered in numerous boreholes penetrating the Silesian, Sub-Silesian and Skole nappes. In the Skole Nappe, potential reservoir strata for geothermal waters are represented by sandstones occurring within the series of dark Spas Shales where fracturing makes significant contribution to their favourable reservoir properties.

In the Upper Cretaceous (Senonian)-Paleocene succession, within the Silesian Nappe, a complex of reservoir Istebna Sandstones occurs, which attains the greatest thicknesses (unfolded) in the Jasło-Krosno area (up to 2000 m) (Kuśmierek et al., 1991-1994). In general, reservoir properties of the Istebna Sandstones are good. Their porosities reach 10-15%. Within the Magura, Dukla and Skole nappes, Upper Cretaceous deposits of the Inoceramian Facies, which are usually characterized by low porosity, may form geothermal aquifers in zones of fracturing in marginal thrust areas. In the Inoceramian Beds of the Skole Nappe, porosities range from 3 to 18% (Słonne, Babica, Brzegi Dolne), and in the Magura Nappe – approximately 11% (Sękowa, Siary). In the Dukla Nappe, good reservoir properties were noted in the Cisna Beds. Besides the Istebna Beds, the second potential reservoir formation for geothermal waters with a regional extent is represented by the Eocene Ciężkowice Sandstones which constitute the best reservoir rocks in the Carpathian flysch. In a regional scale, within the Ciężkowice Formation, a tendency is marked to reduce thickness of individual horizons southeasterly. The greatest total thicknesses of the sandstones were recorded in the Gorlice-Krosno area (Bromowicz et al., 2001; Żytko et al., 1973). From the point of view of prospecting for geothermal waters, the most favourable situation within the Ciężkowice reservoir can be observed in the Gorlice, Krosno and Bóbrka-Iwonicz areas where the Ciężkowice Sandstones crop out at the surface and the outcrops can represent areas of the reservoir recharge with meteoric waters. Those sandstones are characterized by favourable reservoir properties, i.e. porosity on the order of 15-20% and permeability from ca. 50 to 600 mD (Lenk, 1980); Kuśmierek et al., 2001a; Kuśmierek and Semyrka, 2003). Within the Skole Nappe, Eocene reservoir rocks are represented principally by the Hieroglyphic Beds occurring among the Variegated Shales. However, the sandstones occur in the form of lenses with reduced extent, they are thin-bedded and intercalated with shales, and that is why their geothermal potential should be considered poor. Within the Dukla Nappe, in the Hieroglyphic stage, the Przybyszów Sandstones occur. Their reservoir properties are similar to those of the Ciężkowice Sandstones but their occurrence is local in nature (e.g. the Ropianka area), which essentially limits classification of this reservoir horizon as regionally prospective for the purpose of geothermal water exploitation.

In all structural/facies units of the Middle Group, the stratigraphic horizon of the Globigerina Marls is overlain by the youngest flysch strata, distinguished as the Menilite-Krosno Series (Jucha and Kotlarczyk, 1958; Koszarski and Żytko, 1961). On the whole, the sandstones are characterized by poor reservoir properties, although in the Polańczyk area at depth of 1000-1154 m bsl an aquifer was encountered in those sandstones. Chloride water is exploited by the Polańczyk IG-1 and Polańczyk IG-2 boreholes and utilized for balneotherapy, including crenotherapy (drinking therapy). The intakes have relatively low discharges and exploitable resources for the Polańczyk IG-1 and Polańczyk IG-2 boreholes were determined at 0.5 and 0.3 m^3/h, respectively. In the Gorlice area, thick-bedded Magdalena Sandstones occur (Świdziński, 1947), which may have favourable reservoir properties. However, the so-far research has not confirmed any geothermal potential of those aquifer.

Analysis of hydrogeological properties of the flysch sequences indicates high diversification of petrophysical/volumetric parameters within the same depth intervals. Decrease in the number of determinations of petrophysical and hydrogeothermal parameters in deeper parts of the flysch limits the ability of interpretation, including objective assessment and determination of regularities connected with the occurrence, origin and renewability of geothermal water resources. Results of laboratory tests show that values of the parameters for the flysch rocks are as follows: effective porosity values range from 0.02 to 47.8% (average 9%), permeability values range from 0.001 to 2998 mD (average 1.4 mD); for the distinguished intervals of the subsea elevations the respective average values range from 1.7 to 11.5% and from 0.002 to 9.94 mD. Variation in permeability values is as high as several orders of magnitude in similar depth intervals. According to the division applied by Pazdro and Kozerski (1990), the flysch rocks can be ranked among semi-permeable, and locally – poorly permeable or moderately permeable (maximum 2553-2998 mD). The variability range of basic reservoir parameters of the flysch rocks, presented as average values of those parameters in 500-m depth intervals related to the sea level, is depicted in Figure 4.

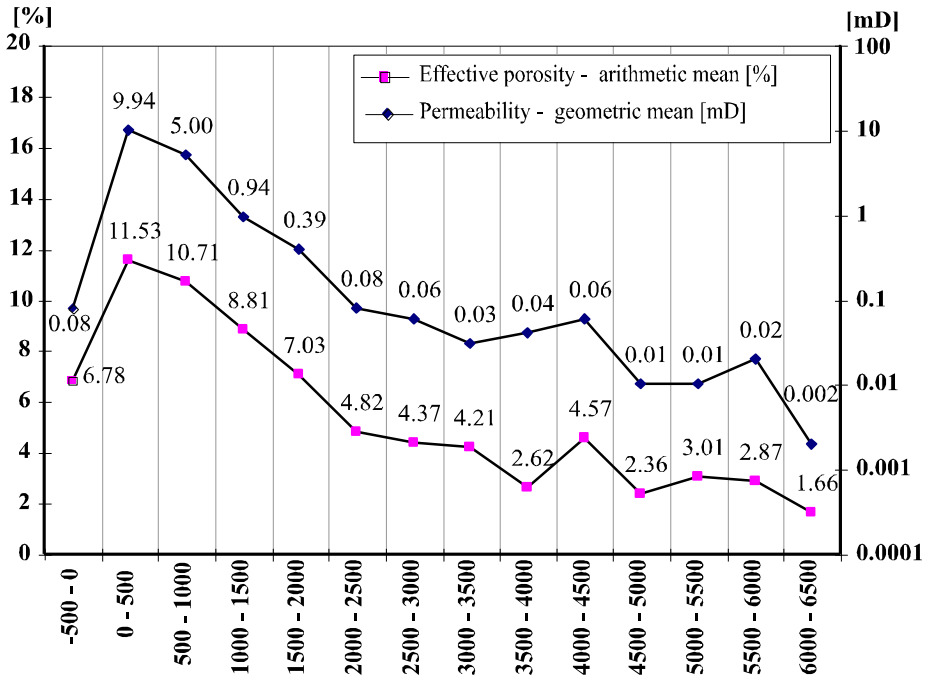

Figure 4. Distribution of the average values of porosity and permeability of flysch cover sediments in the area of the Polish Eastern Carpathians in 500-m depth intervals related to the sea level

The poor hydrogeological properties implicate low values of predicted discharges of water intakes. Assuming an optimal intake of water-bearing strata, from most of the distinguished intervals and aquifers discharges higher than 10 m^3 of geothermal water per hour cannot be expected. The waters may be characterized by diversified temperatures, from 20 to over 150°C.

At the front of the Carpathian overthrust and in the basement of the flysch formations in the Polish Eastern Carpathians, Miocene, Mesozoic and Paleozoic successions occur. Their lithologic development indicates the possibility of occurrence of geothermal water-bearing strata. Beneath the Flysch Carpathians overthrust, the internal depression is present, in which principally Middle Miocene marine deposits have been hitherto recognized. They were dominated by argillaceous sediments and characterized by unfavourable reservoir properties. For the most part, the reservoir strata of the Miocene aquifer are characterized by low porosity (to 5%) and permeability (to 1 mD). At the Carpathian margin, in places where thicker sandy series occur, porosity increases up to 10-12% and permeability up to over 10 mD. According to the Pazdro and Kozerski classification (1990), those rocks can be considered semi-permeable. Average values of principal reservoir parameters, determined on the basis of collected archival results of laboratory tests on cores, amount to 11.7% for porosity and ca. 1.2 mD for permeability (Fig. 5). In consideration of the not very favourable reservoir properties of the Miocene deposits in the zone of the Carpathian overthrust, it should be expected that recharges of intakes will be low and in majority will not exceed 5 m^3/h. In single areas connected mainly with gas and oil fields, improvement of reservoir properties can be observed. It regards the Brzezówka, Ropczyce, Husów, Jodłówka and Przemyśl areas where potential discharges of geothermal intakes were estimated at 5-10 m^3/h. Exceptionally higher discharges, up to 20-30 m^3/h, can be expected to the southwest of Rzeszów where the Nosówka and Kielanówka fields are located, and in the Błędowa Zgłobieńska area where discharges of approximately 30 m^3/h can be expected. Analyses show that from among the above described sequences, the Miocene strata are locally characterized by favourable reservoir properties, with average effective porosity of 11.7% and permeability of 1.2 mD (Fig. 5). Unfortunately due to an extremely small amount of petrophysical parameters measurements of the Middle Triassic rocks determination of the mean values of porosity and permeability was not possible.

In case of the remaining stratigraphic units, average effective porosity in general amounts to a few percent and permeability does not exceed 1 mD. According to the Pazdro and Kozerski classification (1990), they can be ranked among impermeable or poorly permeable deposits.

Deposits ranked among moderately permeable occur within the Miocene succession where maximum values of permeability reach 3102 mD. Rocks with higher permeability occur sporadically in Lower Cretaceous (max. 605 mD), Upper Jurassic (max. 474 mD) and Lower Triassic (max. 901 mD). Waters of the Late Paleozoic sequences belong to strongly mineralized sodium-chloride-calcium brines. Their total mineralization is high, from ca. 120-150 g/dm^3 in the Gromnik and Zakliczyn areas to 210-240 g/dm^3 between Tarnów and Pilzno and in the Rzeszów area.

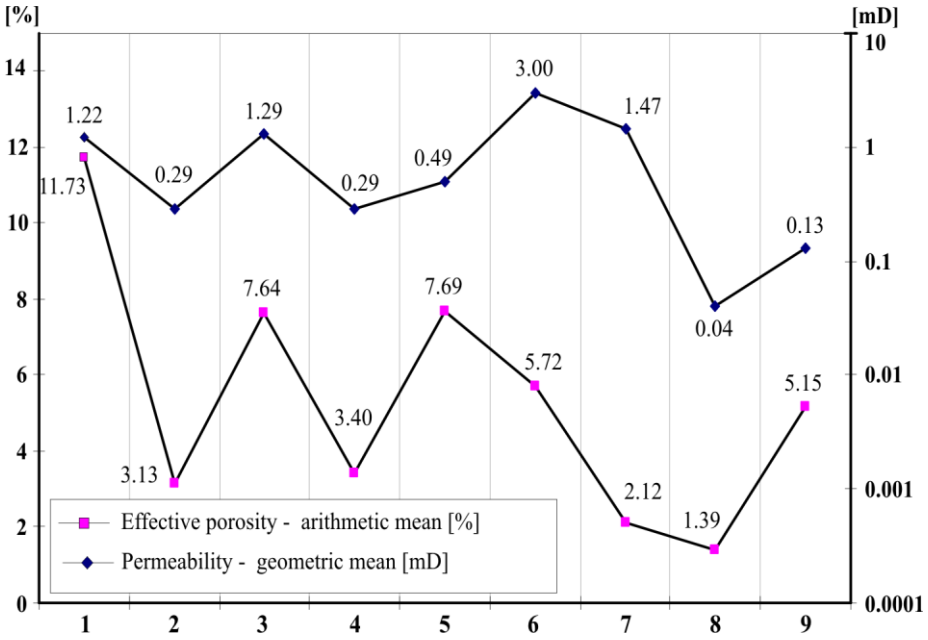

Figure 5. Distribution of the average values of porosity and permeability of Miocene sediments and Mesozoic-Paleozoic basement in the area of the Polish Eastern Carpathians (1- Miocene, 2- Upper Cretaceous without Cenomanian, 3- Cenomanian-Lower Cretaceous, 4- Upper Jurassic, 5- Middle Jurassic, 6- Lower Triassic, 7- Carboniferous (clastic), 8- Carboniferous and Devonian (carbonate), 9- Lower Devonian)

4. GEOTHERMAL ENERGY RESOURCES IN THE POLISH EASTERN CARPATHIANS

The so-far recognition of geothermal conditions and resources of geothermal energy accumulated in groundwaters of the Polish Eastern Carpathians have been obtained in points only and the information has usually regarded possibility of geothermal water utilization in a given location. The magnitude of geothermal energy resources was estimated according to the McKelvey's classification that distinguishes accessible, static, static-recoverable resources, disposable and exploitable reserves. The assessment of geothermal energy resources was carried out for twelve potential aquifers located in the Polish Eastern Carpathians: the flysch (Skole, Silesian, Dukla) aquifer; the Miocene aquifer; the Upper Cretaceous aquifer (without Cenomanian); the Cenomanian-Lower Cretaceous aquifer; the Upper Jurassic aquifer; the Middle Jurassic aquifer; the Middle Triassic (Roethian-Muschelkalk) aquifer; the Lower Triassic (Lower and Middle Buntsandstein) aquifer; the Carboniferous clastic aquifer; and the Devonian-Carboniferous carbonate aquifer. The estimates of the geothermal resources indicate low geothermal potential in the Polish Eastern Carpathians. The accessible resources of geothermal energy were estimated at 2.95 10^{21}J (ab. 3.8% of the Polish Lowlands accessible geothermal resources), static resources at 6.37 10^{20}J (ab. 4.4% of the Polish Lowlands static geothermal resources), and static-recoverable resources at 1.52 10^{20}J (ab. 5.2% of the Polish Lowlands static-recoverable geothermal resources) (Hajto, 2013). Figure 6 shows static-recoverable resources of energy accumulated in rocks and waters of the distinguished geothermal aquifers. Regional analysis of hydrogeological parameters, supplemented by the economic indicator analysis, indicates absence of disposable resources and, consequently, very limited potential for economic utilization of the geothermal waters for heating purposes in the study area. Discharges of intakes and predicted water temperatures indicate the possibility of building small heating installations with thermal powers ranging from several hundred kilowatts to 5 MWt at the outmost.

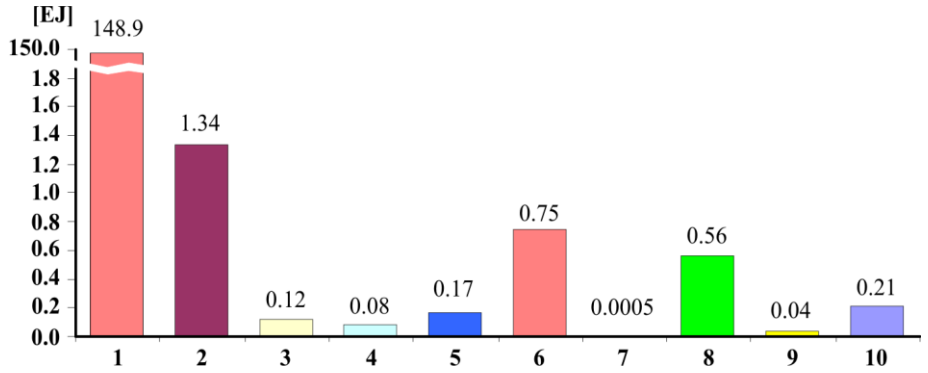

Figure 6. Static-recoverable resources of energy accumulated in selected geothermal reservoirs in the polish Eastern Carpathians (1- Flysch (together), 2- Miocene, 3- Upper Cretaceous without Cenomanian, 4- Cenomanian-Lower Cretaceous, 5- Upper Jurassic, 6- Middle Jurassic, 7- MiddleTriassic, 8- Lower Triassic, 9- Carboniferous (clastic), 10- Carboniferous and Devonian (carbonate))

5. PROSPECTIVE AREAS FOR GEOTHERMAL WATER UTILIZATION IN THE POLISH EASTERN CARPATHIANS

The analysis of hydrogeological conditions of the groundwater occurrence and characterization of basic reservoir parameters of the flysch rocks and potential aquifers in the Miocene strata and in the Mesozoic-Paleozoic basement of the Eastern Carpathians show relatively poor hydrogeological properties of deposits that form the geological section down to 4000 m bsl. It implicates low values of predicted discharges of water intakes. Assuming an optimal intake, recharges over 10 m^3/h should not be expected from the majority of the distinguished intervals and aquifers. The waters may be characterized by diversified temperatures, from 20 to over 150°C. Somewhat better hydrogeological parameters are connected with a few depth intervals within the flysch formations of the Skole and Silesian nappes and in the Miocene, Middle Jurassic and carbonate Carboniferous and Devonian formations. In areas of somewhat better hydrogeological parameters, the possibility of using the geothermal water for heating purposes can be considered, with support from other sources, e.g. a heat pump, biomass-fired boiler etc. The Lubiatówka area is a prospective, well recognized and documented area for utilization of thermal waters containing carbon dioxide in balneotherapy. Thermal waters are exploited by the Lubiatówka-12 and Lubiatówka-14 boreholes and are being used only partly. In the flysch formations, several areas can be distinguished where somewhat better reservoir parameters occur in different depth intervals, e.g.: the Rzeszów-Tyczyn-Chmielnik area (depth 500-1000 m bsl; 10-12 m^3/h, water temperature 30-31°C, TDS 40-60 g/dm^3); the Krościenko-Wojtkowa area (depth 500-1000 m bsl, ca. 12 m^3/h, water temperature 30-34°C, TDS 40-50 g/dm^3); the Brzozów area (depth 2000-2500 m bsl, 10-13 m^3/h, water temperature 80°C, TDS 40-60 g/dm^3); the Zagorzyce-Babica-Strzyżów-Domaradz area (depth 2500-3000 m bsl, 10-13 m^3/h, water temperature ca. 80-95°C, TDS ca. 30-60 g/dm^3); the Dubiecko area (depth 2500-3000 m bsl, 15 m^3/h, water temperature ca. 80°C, TDS ca. 40-60 g/dm^3); the Dynów area (depth 3000-3500 m bsl, 8 m^3/h and after enhancement 12 m^3/h, water temperature ca. 95-100°C, TDS ca. 43 g/dm^3); the area east of Błażowa (depth 3500-4000 m bsl, potential discharges of intakes ca. 10-12 m^3/h, water temperature ca. 110-115°C, TDS ca. 40-50 g/dm^3); the area east of Frysztak (depth 3500-4000 m bsl, discharges of intakes up to ca. 24 m^3, water temperature ca. 110-120°C, TDS ca. 40-50 g/dm^3); the Jedlicze area (depth 2500-3000 m bsl, potential discharges up to 20 m^3/h, water temperature ca. 90°C, TDS ca. 20-30 g/dm^3); the Gorlice area (depth 3500-4000 m bsl, ca. 10 m^3/h, water temperature ca. 120-130°C, TDS lower than 30 g/dm^3); and the Szczawne area (potential discharges up to ca. 30 m^3/h, water temperature ca. 130°C, TDS ca. 20 g/dm^3). In the Miocene strata, the Błędowa Zgłobieńska area to SW of Rzeszów is the best prospective area. There, potential discharges ca. 32 m^3/h, water temperature ca. 72°C and TDS ca. 54 g/dm^3 can be expected.

In the remaining aquifers, not high potential of geothermal waters is related to Middle Jurassic and Carboniferous-Devonian fractured aquifers. Analyses have shown that in the Tarnów and Sędziszów Małopolski areas, discharges of intakes on the order of 16-20 m^3/h can be expected. Predicted water temperatures are from 70 to 80°C. The waters will be characterized by high mineralization: TDS over 120 g/dm^3 and in case of the Carboniferous-Devonian aquifer even 200 g/dm^3.

For projects of thermal water intakes, discharges of the intakes present fundamental problems. As it has been indicated by the so-far analyses, the flysch aquifers are closed and do not get enough recharge from meteoric waters. The groundwaters represent a mixture of dehydration waters, diagenetically altered fossil marine waters and subordinately meteoric waters, i.e. infiltration waters of the recent hydrologic cycle and/or paleoinfiltration waters. In the Polish Eastern Carpathians, also valuable mineral and medicinal waters occur. They are waters containing carbon dioxide, acidulous waters, sulphide waters from numerous springs, and chloride waters (brines) which are thermal waters, documented by numerous exploratory boreholes but not used at present. Waters with higher temperatures, mainly of the Cl-Na+I type, suitable for potential utilization, occur commonly over the whole area of the Polish Eastern Carpathians. Iodine (I-) is a specific component commonly occurring in chloride waters of the study area. Waters containing carbon dioxide and acidulous waters occur in the health resorts of Wysowa, Iwonicz and Rymanów. Waters of these types occur also in Rabe near Baligród but are not used there. Sulphide waters are utilized for balneotherapeutic purposes only in the Wapienne health resort where possibility of development of the existing therapeutic base exists. Sulphide waters were documented in the following localities: Nieborów, Lesko, Czarna, Lubenia and Szklary.

The abundance of mineral and medicinal waters in the Polish Eastern Carpathians offers great possibilities of the Carpathian region development through investment in development of the therapeutic base and health resort sanatoria.

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