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THE MOST PROSPECTIVE AREAS OF USE OF THERMAL WATERS FOR HEATING PURPOSES IN THE POLISH LOWLANDS

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Abstract. The paper presents results of assessment of geothermal energy resources accumulated within nine Paleozoic and Mesozoic aquifers in the Polish Lowlands, carried out within the framework of the project entitled "Geothermal atlases of the Mesozoic and Paleozoic formations – geological analysis and thermal water and energy resources in the Polish Lowlands". The project commissioned by the Polish Ministry of Environment was carried out in the years 2004–2006 by a research team of specialists from several institutions, with AGH – University of Science and Technology in Kraków as a leader.

The paper presents also the results of studies and proposals for geothermal investment projects in selected towns of central and northwestern Poland. Potential locations of the new geothermal projects are determined. Towns with the most favourable geological and hydrogeological conditions and appropriate market of heat consumers for a geothermal plant construction are indicated.

The calculation area amounts approximately to 270 thousand km^2 that represents more than 87% of the territory of Poland. As regards the amount of accumulated energy, the most interesting and promising areas of the Polish Lowlands occur in the Warsaw, Mogilno–Łódź (in the central part of Poland) and Szczecin (in the northwestern part of Poland) troughs.

Key words: geothermal energy, atlas of resources, Polish Lowlands.

INTRODUCTION

Poland is characterized by significant low-enthalpy geothermal resources, connected mostly with the Mesozoic sediments. Space heating represents the main type of direct uses. Five geothermal heating plants are in operation. The biggest one (Bańska–Biały Dunajec) is located in the Podhale Trough (Carpathians Mts.), while the remaining operate in the Polish Lowlands: Mszczonów, Pyrzyce, Uniejów and Stargard Szczeciński (Fig. 1). Total installed geothermal power is estimated at about 68 MWt with annual production of energy ranging about 393 TJ/a (Kępińska, 2010).

IDENTIFICATION OF POTENTIAL AQUIFERS WITHIN THE GEOLOGICAL PROFILE OF THE POLISH LOWLANDS

Within the geological profiles of the Polish Lowlands, from the Early Paleozoic through Early Cretaceous age, a number of series reavealing good geothermal parameters are present (Górecki, ed., 2006a, b). Analysis of hydrogeological and thermal parameters of aquifers in the Polish Lowlands indicate the possibility of complex utilization of thermal waters, both for energy production and balneotherapy/recreation purposes.

Geological analysis and calculation of geothermal resources concern nine major aquifers in the Polish Lowlands: Lower Cretaceous, Upper Jurassic, Middle Jurassic, Lower Jurassic, Upper Triassic and Lower Triassic aquifers of the Mesozoic formation, and Lower Permian, Carboniferous and Devonian aquifers of the Paleozoic formation.

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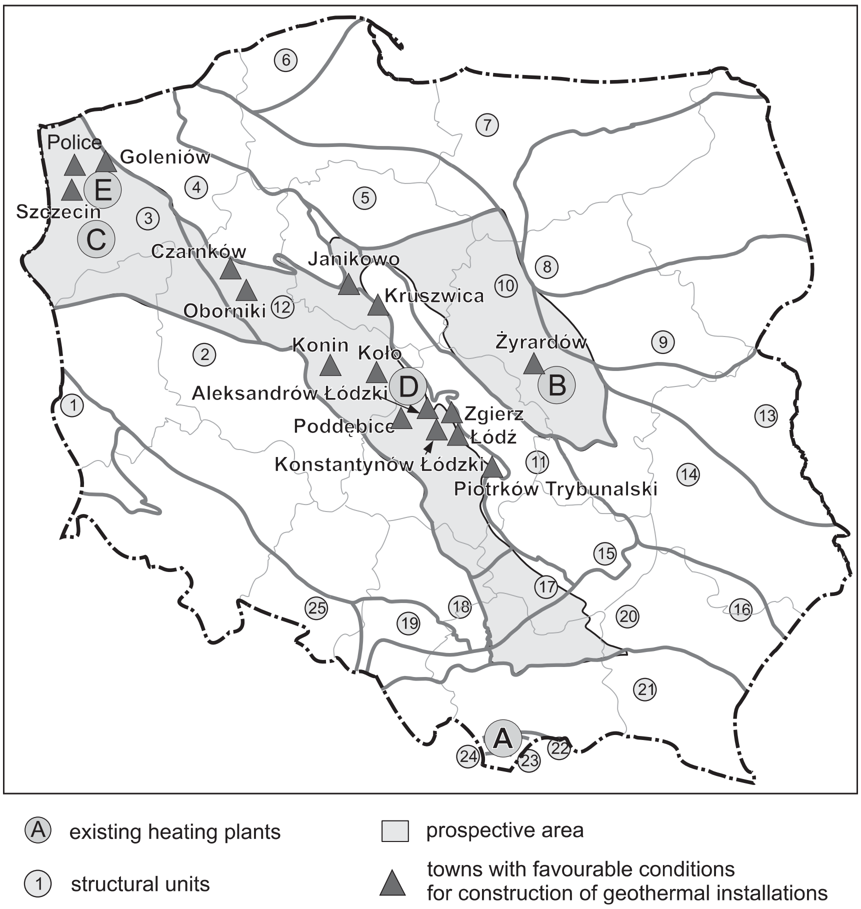

Fig. 1. Location of towns with favorable conditions for construction of geothermal installations in the Polish Lowlands and existing geothermal heating plants in Poland

Structural units: 1 – Intra-Sudetic Depression, 2 – Fore-Sudetic Region, 3 – Szczecin Trough, 4 – Pomeranian Swell, 5 – Pomeranian Trough, 6 – Łeba Elevation, 7 – Peribaltic Syneclise, 8 – Mazury–Suwałki Elevation, 9 – Podlasie Depression, 10 – Warsaw Trough, 11 – Kujawy Swell, 12 – Mogilno–Łódź Trough, 13 – Łuków–Hrubieszów Elevation, 14 – Lublin Trough, 15 – Holy Cross Mts. Massif, 16 – Lower San Elevation, 17 – Miechów Trough, 18 – Cracow-Silesian Monocline, 19 – Upper Silesian Depression, 20 – Carpathian Foredeep, 21 – Outer Flysch Carpathians, 22 – Pieniny Klippen Belt, 23 – Podhale Trough, 24 – Tatra Mts., 25 – Sudety Mts. **Existing heating plants:** A – Bańska–Biały Dunajec, B – Mszczonów, C – Pyrzyce, D – Uniejów, E – Stargard Szczeciński

METHODOLOGY OF DATA INTERPRETATION

Due to the broad spectrum of considered problems, various interpretation methods and techniques were applied, supported by database tools and basic statistical data processing procedures. The basic materials originated from interpretation of lithostratigraphic profiles and interpretation of well-log data due to identification of groundwater and sealing horizons in Paleozoic and Mesozoic formations. Full stratigraphic columns were analyzed, excluding Ceinozoic strata. All available data were taken into consideration: petrophysical properties of rocks, lithological and petrographic descriptions of drill cores and cuttings, and geophysical data (including Average Velocities Logs). Moreover, results of hydrogeological testing in analyzed wells were incorporated. Basic element of interpretation was the construction of lithological profile based upon the well-log data. Analyses were run for single wells. Parameters used in the interpretation were calibrated with the results of laboratory measurements. Basic source data for porosity interpretation originated from Gamma and Neutron Logs supported by well diameter logs. These are the only well-logs which enable true porosity calculations for wells drilled in the Polish Lowlands. The obtained true porosity was then recalculated into effective porosity using statistical parameters determined for given lithotypes. Analysis of criteria applied for identification of groundwater horizons and seals indicate the complex influence of various parameters on final result. Basic petrophysical parameters: effective porosity and permeability, which were the crucial parameters, reveal high variability within the particular lithotypes. Additional complications were caused by fracturing of rocks, which might increase reservoir properties. Fracturing may become a dominating factor influencing the reservoir properties of the Middle Triassic, Cambrian, Devonian and Carboniferous aquifers. Numerous analyses enabled identification of potential groundwater horizons with the complicated criterion based upon both the lithology and the porosity. Out of 84 defined in an interpretation system lithotypes, four lithotypes were selected as potentially most effective groundwater horizons in the Polish Lowlands: sandstones, limestones, dolomites and gaizes. Additionally, all these lithotypes must show at least 5% true porosity. Both the analyzed porosity types reveal strong linear correlation. Thus, the linear correction formula for true porosity was accepted for interpretation procedures. Relative error of porosity determination increases with the decreasing true porosity. Similar relationships were found for limestone, dolomite and gaize lithotypes.

METHODOLOGY OF REGIONAL-SCALE EVALUATION OF PORE VOLUME SPACE AND CAPACITY FOR THERMAL WATER STORAGE IN THE MAIN AQUIFERS OF THE POLISH LOWLANDS

A separate interpretation problem was quantitative evaluation of well-log parameters: cumulative thickness of groundwater horizons and porosity of reservoir rocks in particular lithostratigraphic units of the Polish Lowlands. Results of well-log data interpretation for all wells are contained in the Access database. Densities of measurements in particular geothermal aquifers were different. Most wells document the reservoir parameters (effective porosity) of the Upper Jurassic aquifer (168 wells). In order to determine reservoir properties and to calculate geothermal resources accumulated in selected geothermal aquifers in the Polish Lowlands, effective porosity was estimated, according to the following formula:

$$\overline{p_e} = \frac{\sum (m_w \cdot p_e)}{\sum m_w} \ [-] \qquad [1]$$

where:

$\overline{p_e}$ – weighted mean effective porosity of reservoir rocks in the column [%];

p_e – effective porosity of single groundwater horizon [%];

m_w – thickness of particular groundwater horizon [m].

For calculations of weighted mean effective porosity all identified groundwater horizons were taken, i.e. those which effective porosity was above zero. Analysis of averaged effective porosities (Fig. 2) indicates that best reservoir properties occur in Lower Cretaceous (21.8%) and Lower Jurassic (18.9%) aquifers. The Paleozoic aquifers: Cambrian, Devonian and Carboniferous, reveal apparently lower averaged values of effective porosity. However, these formations may locally show favourable reservoir properties (high discharges) due to fracturing. Analysis of interpretation results of well-log geophysics provided essential information leading to quantitative evaluation of thicknesses of groundwater horizons (including the cumulative thickness) within the particular formations. For calculations of percentages of groundwater horizons only those datasets were considered which documented horizons in the full lithostratigraphic column (i.e. which penetrated the full thicknesses of given lithostratigraphic units).

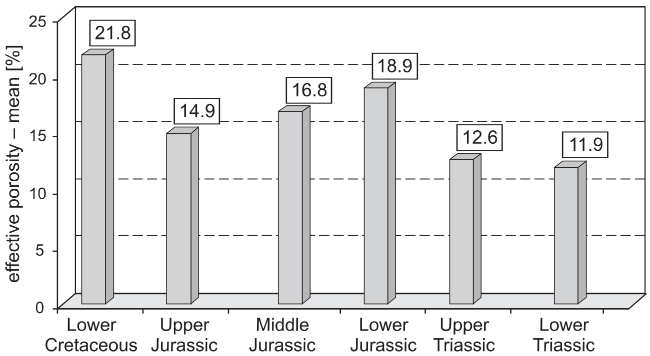

Fig. 2. Averaged values of effective porosity in reservoir layers in the Polish Lowlands

RESULTS OF GEOTHERMAL RESOURCES CALCULATION

The calculations made with regard to the classification of resources, in accordance with the McKelvey's diagram, assume that the total accessible geothermal resources accumulated in the rock formations down to 3 km depth or down to the top surface of the crystalline basement amount to $7.753 \cdot 10^{22}$ J, which is an equivalent of $1.85 \cdot 10^{12}$ TOE[2].

Considering the extent of the Mesozoic and Paleozoic geothermal aquifers in the Polish Lowlands, that expresses also the area of calculation (rounded up to 1 thousand km^2), they can be arranged in the following order: Lower Triassic (229 thousand km^2 – 73% of the territory of Poland), Middle Jurassic (205 thousand km^2 – 66%), Upper Jurassic (198 thousand km^2 – 63%), Upper Triassic (178 thousand km^2 – 57%), Lower Jurassic (160 thousand km^2 – 51%) and Lower Cretaceous (128 thousand km^2 – 41%). The largest calculation area among all the Paleozoic geothermal aquifers

[2] TOE – unit of energy representing that amount of energy released by burning one tonne of crude oil, approximately 41.87 GJ

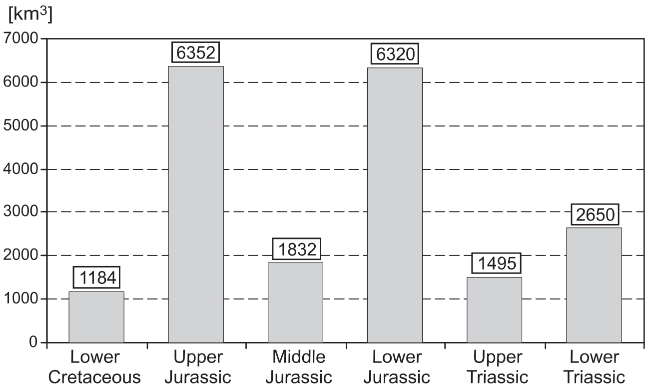

Fig. 3. Static resources of thermal water within particular geothermal aquifers of Mesozoic age in the Polish Lowlands

is occupied by the Lower Permian aquifer: about 102 thousand km^2, which constitutes 37% of total area of the Polish Lowlands and 33% of the whole territory of Poland.

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

Total static geothermal resources which express the amounts of free (gravitational) thermal water hosted in pores, fractures or caverns expressed in cubic metres or kilometres of water, recalculated after taking the water temperature into the energy units – Joules, accumulated in thermal waters of the Polish Lowlands sedimentary formations are estimated at $1.45 \cdot 10^{22}$ J, which is an equivalent of $3.47 \cdot 10^{11}$ TOE. The largest static geothermal resources are accumulated in the Lower Jurassic aquifer and were estimated at about 6,320 km^3 of water with temperature ranging from 20 up to 120°C (Fig. 3).

Energy accumulated in waters of the Lower Jurassic aquifer was calculated to be $2.99 \cdot 10^{21}$ J ($7.14 \cdot 10^{10}$ TOE). Considering the distribution of static resources per unit area, the best parameters among the Mesozoic aquifers are revealed by the Lower Jurassic aquifer – $1.86 \cdot 10^{16}$ J of energy per 1 km^2. Mean unit static resources for the Mesozoic (from the Lower Triassic to the Lower Cretaceous, excluding the Middle Triassic) aquifer are equal to $9.41 \cdot 10^{15}$ J/km^2 (Hajto, 2006).

The amount of static-recoverable resources gives information on the fraction of geological (static) resources that can be theoretically recovered under specified technical parameters of exploitation and utilization of the geothermal medium, i.e at given cooling temperature and with given exploitation method (Gringarten, Sauty, 1975; Gringarten, 1979). The value of *Ro*[3] index depends on an exploitation method (single- or double-well system) and on relationships between the reservoir temperature, injection temperature (in double well system) and mean annual temperature at the Earth's surface. For the calculations it was assumed that waters are exploited by a double-well system and the injection temperature does not exceed 25°C. Averaged values of the recovery index calculated for all aquifers of the Polish Lowlands are ranging from 12.8% for the Upper Jurassic to 26.7% for the Lower Permian aquifer. Average *Ro* value calculated for all nine geothermal aquifers of the Polish Lowlands are estimated at 19.9% (Hajto, 2006).

These results demonstrate that under geological and temperature conditions dominating in the Polish Lowlands it will be possible to recover less than 20% of geological resources of accumulated geothermal energy. Total static-recoverable geothermal resources are equal to $2.9 \cdot 10^{21}$ J. The largest geothermal resources which are possible to be produced are accumulated in the Lower Triassic aquifer and are estimated at $6.13 \cdot 10^{20}$ J ($1.46 \cdot 10^{10}$ TOE) (*op. cit.*).

Additional estimation of energy accumulated in particular temperature classes of thermal waters enables a preliminary evaluation of the main directions of thermal water utilization. Using the methodology of factor evaluation of the heat recovery economic effectiveness (the power factor) made it possible to assess the geothermal energy utilization profitability at the regional scale and to indicate prospective areas within particular aquifers, but for this purpose the appropriate market of heat consumers for a geothermal plant construction should be specified.

PROSPECTIVE AREAS OF USE OF THERMAL WATERS FOR HEATING PURPOSES

The area of potential locations of new geothermal projects corresponds with the area revealing the most favourable geological and hydrogeological conditions within the main aquifers in the Polish Lowlands (Fig. 1). As regards the amount of accumulated energy, the most interesting and promising areas occur in the Warsaw, Mogilno–Łódź (in the central part of Poland) and Szczecin (in the northwestern part of the Polish Lowlands) troughs. Utilization of thermal waters for heating purposes in particular voivodships and towns of central Poland should, first of all, be based on the resources of the Lower Jurassic aquifer. Possibilities of geothermal energy utilization in remaining areas are rather low and related to limited areas.

[3] *Ro* – recovery index, which express the fraction of static resources that could be exploited with the given exploitation system

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