Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Geological Analysis and Assessment of Geothermal Energy Resources in Selected Devonian, Carboniferous and Permian Reservoirs in the Polish Lowlands.

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Keywords: Poland, Geothermal energy, Geothermal resources, Palaeozoic, Geology.

ABSTRACT

From the early 1980-ties several tens of research projects, publications and scientific reports have been undertaken in order to assess geothermal potential of the Mesozoic sedimentary cover in Poland.

This paper presents the results of the studies and analyses carried out recently at the Department of Fossil Fuels of the University of Science and Technology, evaluating the geothermal resources of the Palaeozoic aquifers and possibility of its utilization. The Research project covers majority of the area of Poland and focuses mainly on the regional-scale assessment. Geological recognition of sedimentary formations in the Polish Lowlands from the point of view of their geothermal potential has evidenced possible utilization of geothermal resources in water-bearing sediments of the Palaeozoic cover of the Devonian through Permian age.

Identification of geothermal conditions in the Palaeozoic rocks represents important complement of the knowledge of domestic geothermal energy resources in the Polish Lowlands.

1. INTRODUCTION

As with members of the European Union and the majority of other countries in the world, Poland aims at achieving sustainable development in which the economy, environment and mineral resources protection are integrated into a coherent system. For Poland, important is the standpoint of the European Union where current preferences aim at the reduction of greenhouse-gas emissions and other pollutant releases by an extension of the role of renewables. Among the various renewable energy-sources available in Poland, geothermal energy may play an important role in both the local and regional energy balances.

The following paper aims to present the results of the researches carried out at the Department of Fossil Fuels. The present study were focused on assessment of geothermal energy resources of Palaeozoic water-bearing formations in respective categories in order to indicate areas which are characterized, in a regional scale, by favourable geothermal conditions that would evidence their industrial usability.

2. GEOLOGICAL BACKGROUND OF THE POLISH SEDIMENTARY BASIN

From the geological point of view, the Polish Lowlands occupy the area between the Baltic Shield in the northeast, the Sudetes Mountains massif in the southwest and the Lower San River Anticlinorium in the southeast. The Lowlands form an intercratonic deep, filled with Palaeozoic and Mesozoic sediments overlain by a thin Cainozoic cover.

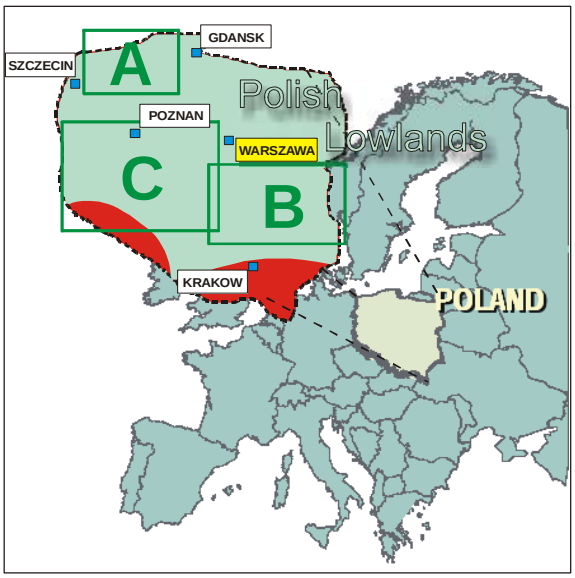

Figure 1: Location of geothermal prospects (A, B, C) within Palaeozoic formations in the Polish Lowlands.

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., 1999. The sediments are, however, much thinner within the Precambrian craton. The thickness varies from 200 to 500 m in NE Poland, where the Cainozoic-Mesozoic sediments directly overlie the crystalline Precambrian basement, up to 8 km southwest of the craton. Two structural complexes are present: a lower unit of Cambrian to Silurian age and an upper unit of Permian to Cainozoic age. 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 base of the Permian sediments reaches 5-7 km depths in central Poland and at the northwest margin of the Palaeozoic platform, decreasing to the southwest, south, east and northeast. Upper Permian strata consists mostly of evaporate sediments which were formed during the Laramide tectonic phase. 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 sub-basins: 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.

3. TECHNIQUES AND METHODS OF CALCULATION

Quantitative interpretation of hydrogeothermal parameters of deep buried aquifers as that Palaeozoic age in Poland should be connected with detailed analysis of the geophysical well log data. Usefulness of existing, russian-styled, old well logs and possibilities of their integrated interpretation in the context of geothermal investigation were the objectives of the co-project carried out on Iceland in 2002, Hajto, 2002, in cooperation with the specialists from National Energy Authority (Orkustofnun). The results of that project show that well-permeable, potential geothermal horizons exist within the Carboniferous strata in the Pomerania Region (zone A on Figure 1). That was confirmed during the latest, detailed analysis and is reflected on the map of disposable reserves of Carboniferous strata in the Polish Lowlands (not attached).

3.1 Data Management and Computing

Calculation of the respective types of reserves requires the collection of the hydrogeothermal dataset, its relevant interpretation and construction of a geological model of individual geothermal horizons. Achievement of this object required the following processes:

- Detailed recognition of occurrence conditions of Devonian, Carboniferous, and Permian geothermal waters in the Polish Lowlands;
- Estimation of geothermal water and energy resources in prospective water-bearing horizons in Devonian, Carboniferous, and Permian reservoirs;
- Indication of areas where possibility exists for industrial utilization of geothermal energy.

The study was prepared with use of the *GeoGraphix* and *Z-MAP Plus* integrated system of geological data interpretation (from Landmark Graphics Corporation), basing upon data collected in the geothermal data bank.

In the course of the study preparation, the following work was accomplished:

1) Geothermal data bank was completed for the Devonian, Carboniferous, and Permian reservoirs;
2) Geological and geophysical analyses were made and interpretation of hydrogeothermal parameters was carried out for individual reservoirs;
3) Estimation of geothermal water and energy resources was made for the Devonian, Carboniferous, and Lower Permian reservoirs;
4) Prospective areas for location of geothermal water intakes were indicated for respective geothermal reservoirs.

Results were presented as the text and tables, as well as in the graphical form as maps.

3.2 Categorization of Geothermal-Energy Reserves

In order to assess the geothermal energy resources in selected reservoirs of Palaeozoic age formations within the Polish Lowlands the methods and standards of the European Union were applied: Enel, Hurter, (2002), Fridleifsson, Fresson, 1994, Gosk, 1982, Górecki et.al., 1995.

The categorizations of geothermal reserves are usually based upon the temperature of heat-carrying media and aim to separate the reserves suitable for electric-power generation and direct use (above and below 150^{o}C respectively). In Poland for the specific conditions of geothermal, low enthalpy resources, with the dominance of waters at temperatures below 90^{o}C, the following categories of geothermal waters and energy are being distinguished:

- Static geothermal waters and energy resources - the volume of free (gravitational) water filling the pores, fractures or cavities in the particular unit (e.g. specific rock horizon), expressed in cubic metres (m^3) or recalculated as energy in joules (J). Static reserves could be calculated if continuous water horizons or layers can be distinguished in the study area and for such a layer the parametres like: thickness, porosity and permeability can be determined.
- Static recoverable geothermal waters and energy resources – a part of static reserves reduced by the recovery index Ro which depends mainly on the exploitation technology, expressed in cubic metres (m^3) or joules (J).
- Disposable geothermal waters and energy reserves – the volume of free (gravitational) geothermal water contained in a particular unit (e.g. horizon) which can be utilized under the given conditions without the specification of detailed localization of an intake and its technical and economical characterization, expressed in cubic metres per annum (m^3/year) or recalculated as energy in joules per annum (J/year).
- Admissible geothermal waters and energy reserves - the volume of free (gravitational) water which can be extracted under the given geological and environmental conditions from an intake of optimum technical and economic parameters, calculated in cubic metres per annum (m^3/year), at the relevant drawdown.

4. CASE STUDY

4.1 Geothermal Energy Resources of Palaeozoic Formations in the Polish Lowlands.

Results of the resource calculation for individual stratigraphic stages are given on Table 1.

4.1.1 Devonian aquifers geothermal resources

Total static geothermal energy resources for the Devonian reservoir amount to 6.09x10^{20} J (Table 1). Area occupied by the resources is equal to 47,281.50 km^2. The highest values of static resources appertain to the temperature-class range 40-60^{o}C. Resources from the temperature range above 80^{o}C represent only about 7% of the total static resources. Water temperature does not exceed 110^{o}C.

Table 1: Geothermal energy resources in the most likely geothermal Palaeozoic aquifers of the Polish Lowlands.

Formation	Temperature	Area	RESOURCES				
			Static resources	Static recoverable resources	Disposable reserves		
					Area	Energy	Energy
	[°C]	[km^2]	[J*10^{20}]	[J*10^{19}]	[km^2]	[J/year* 10^{17}]	[TOE/year]
I. DEWONIAN	below 40	10790.00	0.86	0.96	0.00	0.00	0.00E+00
	40 - 60	16008.50	2.56	4.91	4538.00	1.05	2.38E+06
	60 - 80	12394.00	1.80	4.18	6980.00	3.45	7.85E+06
	80 - 100	7869.00	0.83	2.10	2444.00	4.65	1.06E+07
	above 100	220.00	0.05	0.13	220.00	4.79	1.09E+07
	TOTAL	**47281.50**	**6.09**	**12.28**	**14182.00**	**13.94**	**3.17E+07**
II. CARBONIFEROUS	below 40	17263.00	0.77	0.52	0.00	0.00	0.00E+00
	40 - 60	5620.00	0.68	1.29	827.00	0.20	4.66E+05
	60 - 80	4914.00	0.71	1.65	2427.00	0.86	1.94E+06
	80 - 100	2515.00	0.55	1.42	1377.00	0.73	1.66E+06
	above 100	2652.00	1.10	3.12	2568.00	2.16	4.90E+06
	TOTAL	**32964.00**	**3.81**	**8.00**	**7199.00**	**3.95**	**8.97E+06**
III. PERMIAN	below 40	28335.50	0.44	0.37	0.00	0.00	0.00E+00
	40 - 60	18256.00	1.09	2.19	285.00	0.07	1.68E+05
	60 - 80	17544.00	1.39	3.31	3045.00	1.19	2.70E+06
	80 - 100	17620.00	1.50	3.92	4853.00	2.62	5.96E+06
	100 -120	16839.00	2.14	5.90	5568.00	3.90	8.86E+06
	120 -140	15810.00	3.29	9.33	9567.00	8.14	1.85E+07
	140 -160	13338.00	3.29	9.52	8307.00	8.29	1.88E+07
	above 160	17162.00	5.53	16.54	4658.00	5.91	1.34E+07
	TOTAL	**144904.50**	**18.67**	**51.08**	**36283.00**	**30.13**	**6.85E+07**

The disposable geothermal energy reserves for the Devonian aquifers amount to about 13.94x10^{17} J/year, which is equivalent of to 3.17x10^7 TOE/year. With total calculation area being equal to 14,182 km^2, this figure represents approximately 30% of the total area occupied by the Devonian resources. The Devonian disposable reserves refer to geothermal waters with temperatures higher than 40°C. The greatest disposable reserves occur within the temperature class above 100°C, unfortunately they occupy only 0.5% of the total Devonian prospecting area.

4.1.2 Carboniferous aquifers geothermal resources

Total static geothermal resources in the Carboniferous reservoir amount to 3.81 x10^{20} J (Table 1). Area occupied by the resources is equal to 32,964 km^2. More than 50% of this area relates to water temperature classes under 40°C and 32% represents resources for water temperature classes up to 80°C, the remaining 18% representing water-class with temperatures up to 110°C

Total disposable reserves of geothermal energy in the Carboniferous aquifers were calculated as 3.95x10^{17} J/year, with equivalent of 8.97x10^6 TOE/year. The calculation area is equal to 7,199 km^2 that represents approximately 22% of the total area occupied by the Carboniferous resources. No disposable reserves were recorded down to 40°C.

4.1.3 Permian aquifers geothermal resources

Permian resources of geothermal energy are related to the Lower Permian aquifers. Total static resources of geothermal energy in the Lower Permian reservoir amount to 18.67×10^{20} J (Table 1), with the area occupied by the resources being equal to 144,904.50 km^2.

The map of unit static geothermal resources within the Lower Permian aquifers is shown on Figure 2.

This is the most widespread geothermal reservoir. The distribution of unit static resources of geothermal energy per a unit area of the Lower Permian aquifer in the Polish Lowlands is diversified. The highest values of unit recoverable resources appear in the central parts of the Mogilno-Lodz Synclinorium and amount to 90 GJ/m^2. These extremely high values are correlated with occurrence of geothermal waters at great depths (below 3500 m), with temperature ranges above 160^{o}C. These waters are strongly mineralised, which reduces their value as potential geothermal energy sources.

The map of disposable geothermal reserves in the Lower Permian aquifers (Figure 3) displays the amounts and simultaneously the most likely areas for exploitation of geothermal energy.

Total disposable reserves of geothermal energy in the Lower Permian aquifers amount to 30.13×10^{17} J/year, which corresponds to 6.85×10^7 TOE/year (Table 1).

The calculation area is equal to 36,283 km^2 and represents approximately 25% of the total area occupied by the Lower Permian resources, which means that only for 25% of the total area of the aquifer the power factor is higher than 1 and disposable reserves where calculated there. It is assumed that in the remaining area, the disposable reserves amount to zero (0).

When considering the different temperature classes of disposable reserves, it may be seen that the greatest area of 9567km^2 (26% of total disposable) is related to the water temperature class ranging from 120 to 140^{o}C.

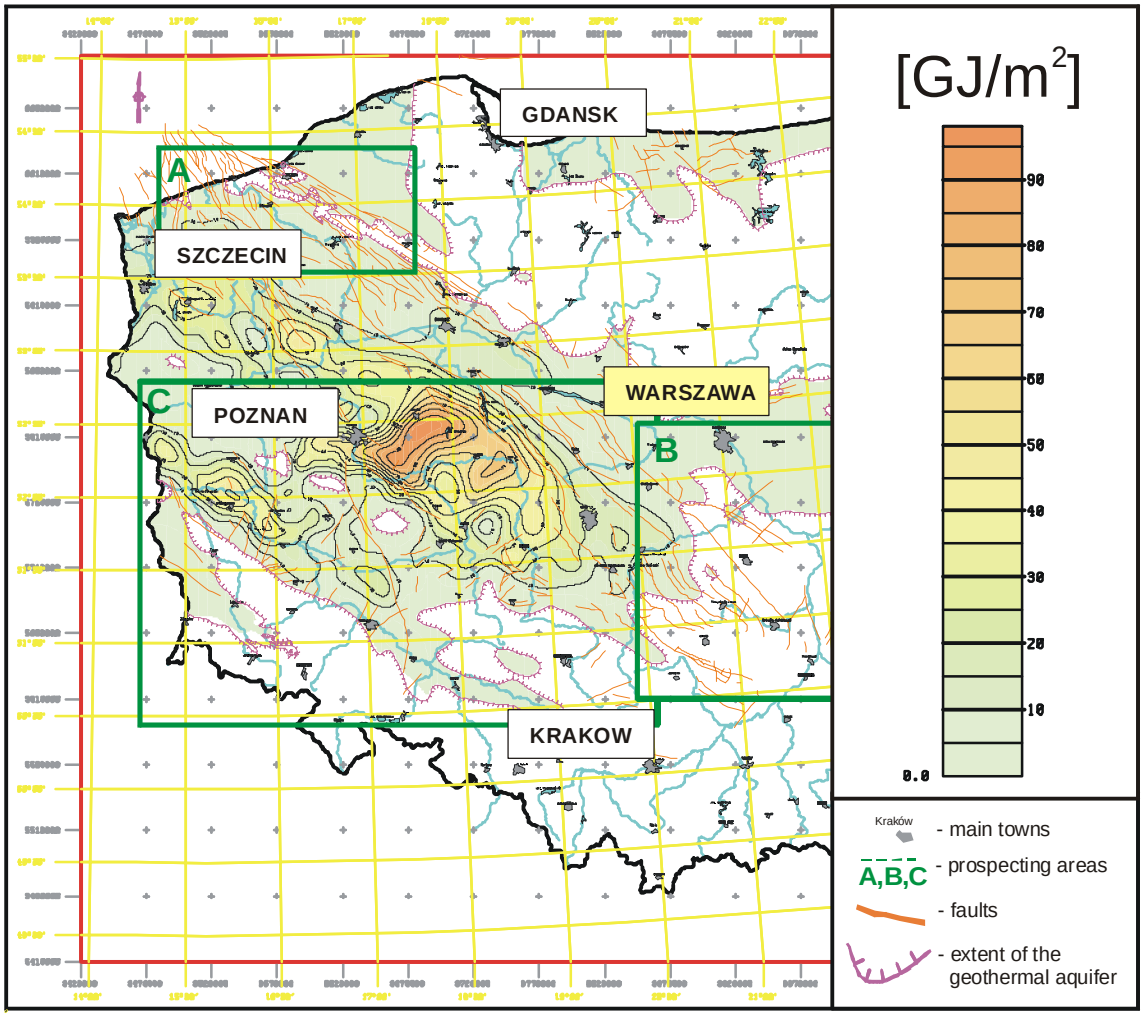

Figure 2: Map of unit static geothermal resources in the Lower Permian aquifer.

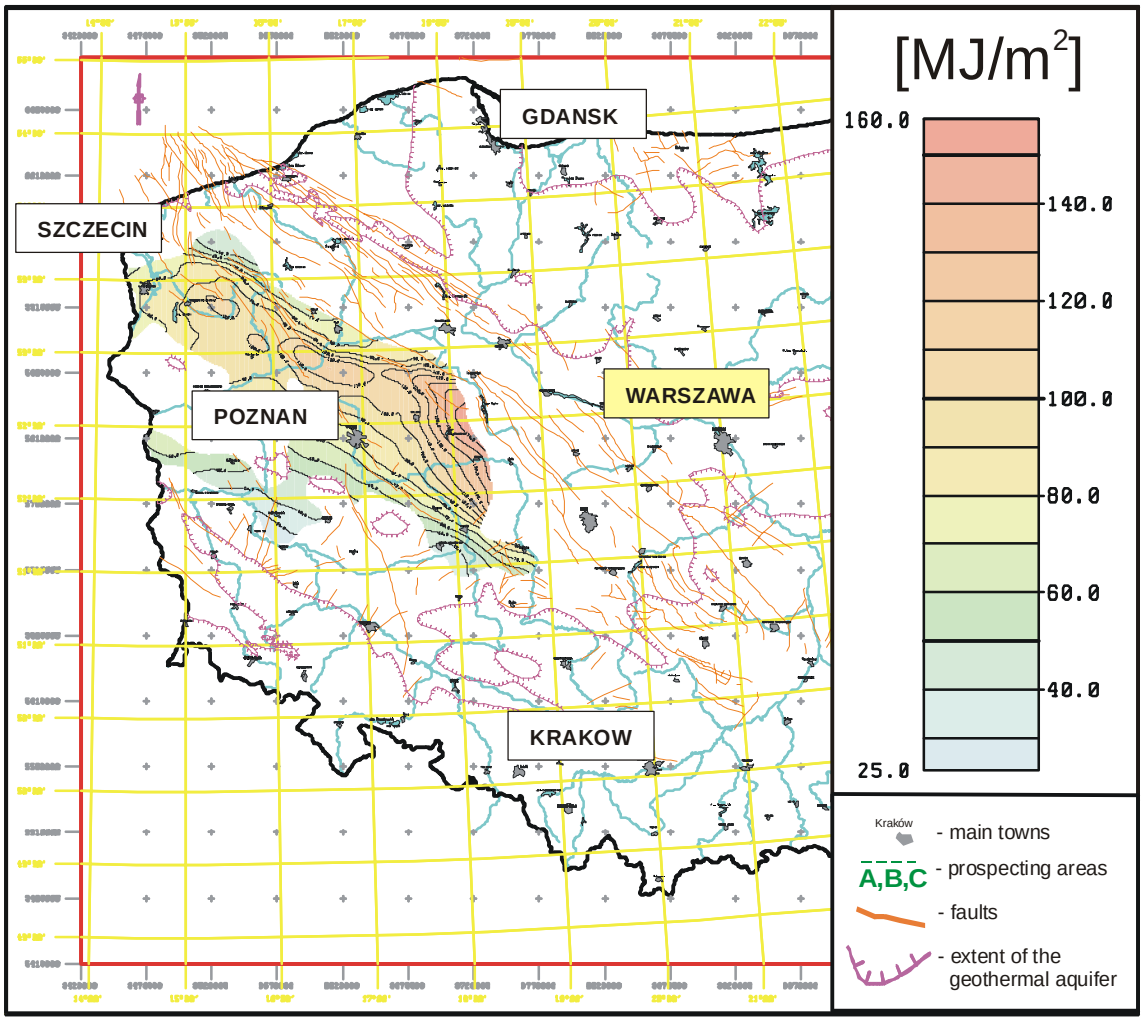

Figure 3: Map of unit disposable geothermal reserves in the Lower Permian aquifer.

5. CONCLUSIONS

Geological recognition of sedimentary formations in the Polish Lowlands from the point of view of their geothermal potential has evidenced possible utilization of geothermal resources in water-bearing sediments of the Palaeozoic cover of the Devonian through Permian age.

The obtained results offer new prospects for the extension of geothermal energy use and related uses (balneology, recreation etc.) in areas situated beyond the limits of occurrence of hot underground waters in Mesozoic formations. The most prospective areas for utilization of geothermal resources for the particular stratigraphic units are as follows:

Devonian - prospective areas of geothermal water occurrence in the Devonian reservoir exist in the Radom - Lublin zone (zone B on Figure 1) in the Pomeranian zone (zone A on Figure 1). As regards the amount of resources, the following areas seem to be the most interesting: the area of Mogielnica (Tomaszow Mazowiecki - Radom), the area of Radomsko (NW part of the Miechow Trough) and in Pomerania, the Szczecinek - Chojnice area and the area of Kolobrzeg.

Carboniferous - within the limits of the study, prospective areas of geothermal water occurrence in the Carboniferous reservoir are the area of Skierniewice in the Radom - Lublin zone (zone B on Figure 1) and areas to SW of Koszalin and to SW of Kolobrzeg (in the vicinity of Trzebiatow) (zone A on Figure 1).

Permian - the following zones are prospective areas of geothermal water occurrence in the Lower Permian reservoir: the Szczecin Trough, SE part of the Pomeranian Swell (zone A on Figure 1), NW part of the Mogilno - Lodz Trough, and the zone situated to SW of the Wolsztyn Ridge (Kostrzyn - Krosno Odrzanskie - Leszno) in the Fore-Sudetic Monocline zone (zone C on Figure 1).

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