Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Hydrogeological Model of Cenomanian Aquifers for Geothermal Water Prospective Area, Miechowska Trough, Poland

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Keywords: sulphurous water, geothermal water, regional model, filtration modelling

ABSTRACT

The Miechowska Trough is a part of the Mid-Polish Troughs system in the Permian and Mesozoic formations. The Cenomanian aquifer (upper Cretaceousis) is a specific structure which consists of sands and sandstones. In this aquifer, there are good hydrogeological parameters. For example, the Cenomanian aquifer is a widely spreading structure with huge groundwater resources. Moreover, there is an area where the groundwater in Cenomanian aquifer have specific properties because of hydrogen sulphide. This groundwater is generally recognized as therapeutic groundwater. The groundwater temperature in the Cenomanian aquifer reaches to about 20°C to 30°C in some places within the Miechowska Trough. According to polish laws, that kind of groundwater is considered as geothermal water.

The main goals of this study in the Miechowska Trough are the comprehensive analysis of the Cenomanian structure and the creation of a model of water circulation conditions and groundwater recharge. Although the Cenomanian groundwater is not a fresh water spring, there is well mineralization in the water. Moreover, there is a reason why the model of groundwater filtration should be personalized to these conditions. The application of a regional model for the Cenomanian aquifer is necessary because the Miechowska Trough is a large structure (about 5000 km^2).

Based on studies and the creation of a numerical model, the prospective area of geothermal groundwater can will be determined. This will be the first step to creating a mass transport and heat transport model for the prospective exploration of this geothermal area.

1. INTRODUCTION

There are a three regional tectonic units in Poland where the geothermal water exists. These are the West European Paleozoic Platform, Sudetes, and the Carpathian massifs together with their foredeeps. Some of this area was broadly recognized and there are groundwater exploitation currently ongoing. Results of investigations from using geothermal energy in Poland were reported by Kepinska (2010, 2013), Hajto and Gorecki (2010), and Gorecki et al. (2013). Studies performed by Tomaszewska and Pajak (2010) and Bujakowski et al. (2010) discussed the search and utilization methods for geothermal water in the central part of Poland.

According to data from the Polish Geological Institute, a national research institute, there are 39 evidenced geothermal water deposits that qualify as mineral in Poland. A number of these sites, a total of 25 deposits, are located in Paleozoic Platform units. The other deposits belong to the Sudetes and Carpathians provinces and the Precambrian Platform. More than half of these deposits are in the troughs of the Paleozoic Platform. These troughs form a wide structure, which is the Szczecin-Miechow Synclinorium. Deposits of geothermal water in this Synclinorium are situated in the Jurassic and Cretaceous aquifers. The mineralization of this water ranges from 0.5 g/L (Lodz, central Poland) to more than 120 g/L (Stargard Szczecinski, NW Poland).

In the Podhalanska Trough (southern part of Poland), good geothermal groundwater deposits conditions can be found because of the outflow volume from geothermal wells and the low water mineralization (0.1 g/L to 3.0 g/L). The Podhalanska Trough groundwater reservoir is a part of the larger hydrogeothermal system, which spreads up to Slovakia. Low mineralized geothermal water with flowing well temperatures about 86°C are being used for the regional heating system. Other applications of this water are for balneotherapy and recreation.

For many years, the Miechow Trough was a subject of research and analysis and there were a lot of studies conducted by various hydrogeologists (Barbacki, 2004, 2007; Chowaniec, 2010; Szczepanski 2007, 2010; Zuber, 2010). The Miechow Trough is a very interesting area because of its location, complicated geological structure, different hydrogeological conditions in various parts of Trough, and the exploitation of the sulphuric treatment water in Busko-Zdroj area. Busko-Zdroj is a special area not only on account of extraordinary groundwater. This region has a complicated tectonic character because of many faults, which are pushing across the Busko-Zdroj town and the countryside. Sulphuric water deposits in this area are characterized by different deposition regions.

A comprehensive investigation is needed to assess the possibility of geothermal energy utilization in the Miechow Trough area. Particularly, there is a requirement of doing a geologically accurate hydrogeological model. This paper presents a background of the conceptual model, which includes the geological units.

2. MIECHOW TROUGH - GEOTHERMAL PERSPECTIVE AREA

According to the newest regionalization of polish tectonic areas (Zelazniewicz (ed.), 2011), Miechow Trough is part of a larger unit named Szczecin-Miechow Synclinorium. This structure spreads from NW to SE. Figure 1 shows the scheme of tectonic units in Poland, along with the position of Miechow Trough. Figure 2 shows a map of the geothermal units in Poland, it also includes the area of investigation. In addition, Miechow Trough has a widely spreading brachy-synclinal form that includes Cretaceous sediments. The NW border of the Miechow Trough is a structure called the Radomsko Fault (Zelazniewicz (ed.), 2011). The SW and NE borders are a range of Cretaceous sediments and there is a neighborhood that includes the tectonic area of Krakow-Silesian Homocline (SW) and Holy Cross Mountains Fold Belt (NE). Moreover, the Miechow Trough was created in a Carpathian Foredeep base in the south and buried deep within the Miocen rocks (Barbacki, 2004).

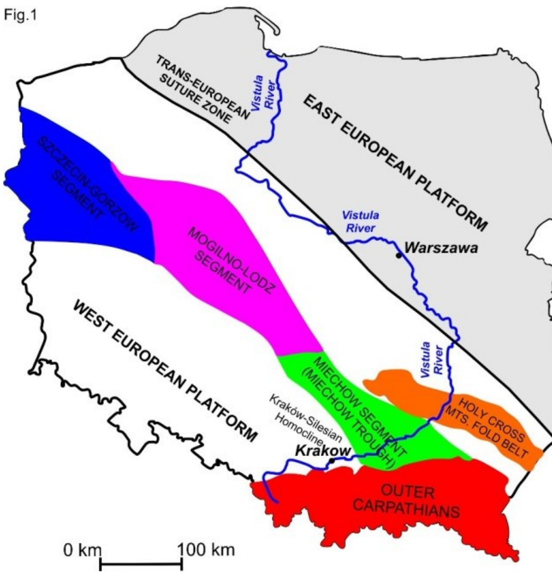

Figure 1: Map of subdivision of Poland into tectonic units with surface before Cenozoic (after Zelazniewicz (2011), modified).

Figure 2: Map of subdivision of Poland into geothermal provinces (after Kepinska (2010), modified)

The average geothermal gradient ranges from 1.72 to 2.96°C/100 m in the Miechow Trough area (Barbacki, 2004). On average, the terrestrial heat flow density is from 65 to 70 mW/m^2 in the investigated region. In the NW part of Miechow Trough, there is an increase of this parameter range to 80 to 95 mW/m^2 (Szewczyk and Gientka, 2009). Moreover, the geothermal water in the research area occurs in the Cretaceous, Jurassic, Triassic, Carbonous and Devonian multiaquifer formations. However, there are huge differences of hydrogeothermal parameters between particular reservoirs (Barbacki, 2007). The most attractive prospect for geothermal utilization is the Cenomanian aquifer (Upper Cretaceous).

3. HYDROGEOLOGICAL CONDITIONS OF CENOMANIAN AQUIFER

The major goal for the assessment of a perspective area for geothermal utilization is the identification of hydrogeological conditions such as the following: microhydraulic properties of rocks (permeability and effective porosity), quantity of groundwater resources, temperature values, reservoir pressure, and mineralization. In addition, the spread of groundwater in the reservoir is also important.

The hydrogeological profile of the Alpine structure of the Miechow Trough consists of the following formations: Quaternary, Neogenic, Cretaceous, Jurassic, and Triassic multiaquifer (Rozkowski and Rozkowski, 2010). The Jurassic multiaquifer form fractured limestones and dolomitic limestones (Upper and Middle Jurassic). Moreover, this aquifer is source of local groundwater. Cretaceous marls and limestones and Jurassic limestones are characterized by a low coefficient for fracturing. The high permeability sediments only exist in fractured and/or karsted zones. Thus, the flow of mineral water is sporadic and of limited magnitude. Because of good permeability and large effective porosity, the Cenomanian sandstones and sands are the major aquifer sources of chloride- sulphate- sulphurous mineral water (Zuber et al., 2010).

On the basis of data from boreholes which have been drilled in the Miechow Trough, it is possible to conclude that the Cenomanian aquifer can be a reservoir for geothermal water. Furthermore, the temperature distribution indicates wide differences within the particular area of investigation. The temperature range is from 11.2°C (B-13 borehole, Busko-Zdroj) to 70°C (Lakta 25 borehole) and it depends on structural position of the well location. In the central part of the Cenomanian aquifer (Jedrzejow-Bochnia), the temperature range is from 30°C to 35°C. In contrast, in the Busko-Zdroj area, there are only about a dozen points that reach 23°C. Figure 3 presents the temperature distribution in the Cenomanian aquifer in the Miechow Trough.

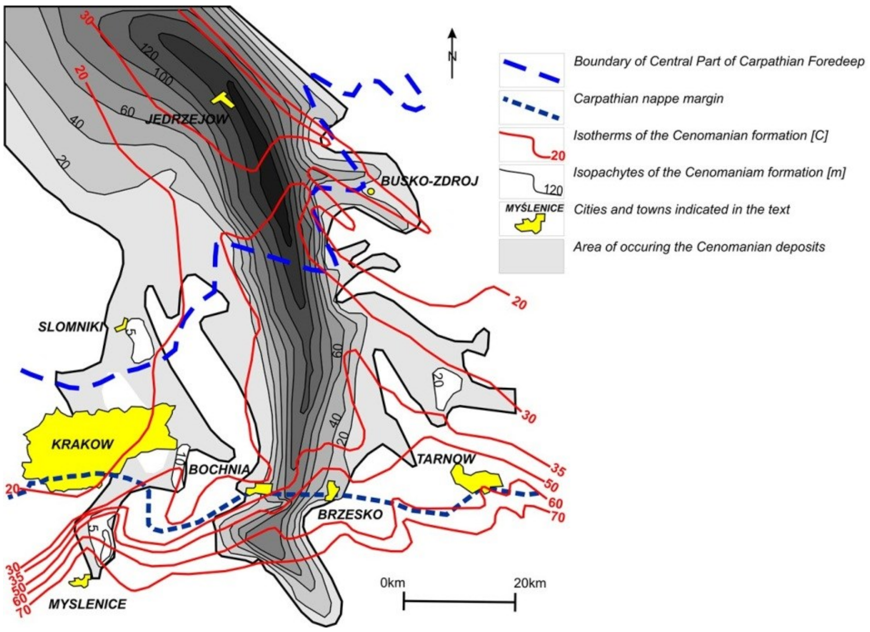

Figure 3: Isopach map of the Cenomanian formation and temperature map of Cenomanian aquifer waters (after Barbacki (2004), modified)

The Cenomanian sands and sandstones occurring in the central part of the investigation structure created an important regional reservoir of minerals, fresh groundwater, and treatment of sulphurous water in Busko-Zdroj area. The base of sand sediments is the erosion surface in Upper Jurassic limestones. Additionally, there are aquiclude marl and marly limestones (Turon-Senonian) above the Cenomanian aquifer roof. Furthermore, the base of the Miechow Trough created the Paleozoic sediments (Oszczypko and Oszczypko-Clowes, 2010).

There are a lot of dislocations and faults in the Cretaceous sediments. The Cenomanian aquifer is a fault-block build structure, its major axis is NW-SE directed. It is possible to split the Cenomanian aquifer into a few zones which were generated by sedimentation conditions and later tectonic occurrences. Figure 4 presents an example of the geological position of the Cenomanian aquifer in the Busko-Zdroj area.

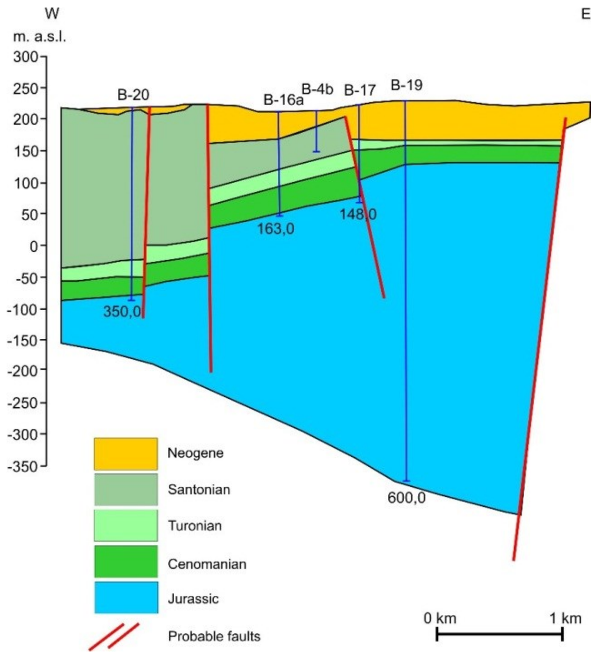

Figure 4: Geological cross-section, Busko-Zdroj area (after Smiech (2005), modified)

Some area near the SE and NE boundary of the Miechow Trough lies directly under the Quaternary sediments. There is a marginal zone of Cenomanian aquifer that consists of coarse-grain conglomerates with quartz boulders and cherts of carbonate-clayey cement and Upper Jurassic marl boulders. On the other hand, the central zone created sandstones and fine-grained sands. There are glauconitic rocks with mudstone addition that are poorly compact and are without lime. Rocks in the upper part of the central zone are characterized by the compactness and presence of lime cement. On the top of profile, sandy limestones can be found. From the marginal to central zones, there are changes in the sediments' lithology from medium- and fine-grained conglomerates to coarse- and medium-grained sandstones (Barbacki, 2004). A zone without Cenomanian sediments is located on the east of Krakow (Puszcza and Wyciaze-Luczyce elevations) because there were no sedimentation processes in this area. The upper surface of the Cenomanian aquifer is divided between the western and eastern part of the Miechow Trough. Elevation values for this surface ranges from -852 m.a.s.l. to 159 m.a.s.l and there are alternate elevations that are narrower by one to two km and depressions with a width of 10 km (Oszczypko, 2010).

4. CHARACTERISTIC OF HYDROGEOLOGICAL PARAMETERS OF CENOMANIAN RESERVOIR

For geothermal utilization, the Cenomanian aquifer exhibited good temperature conditions and hydrogeological parameters. This parameters distribution is relevant to the reservoir structure, especially to the zonality of the facies. The axial part of the investigated reservoir is filled by Cl-SO4-Na and Cl-Na groundwater with 10 to 20 g/L mineralization. In the marginal part of the reservoir, the groundwater mineralization value can be more than 30 g/L with the highest values ranging from 80 to 100 g/L (Oszczypko, 2010). In the Slomniki area (E of the Krakow), the mineralization is less than 1 g/L (Barbacki, 2004). On the other hand, in the Busko-Zdroj area, there are Cl-Na-S types of groundwater with mineralization values below 1 g/L (Szczepanski, 2007).

The axial part of the Cenomanian reservoir (Jedrzejow-Bochnia) is characterized by artesian pressure and outflow values greater than 50 m^3/h from the wells. Artesian flow is often observed with a maximum value of 40 m^3/h in the outflow. In addition, the artesian flow appear in marginal zone as well (maximum of 10 m^3/h). In subsurface zone, under quaternary sediments, there is an unconfined groundwater region. The biggest well outflow from the Cenomanian aquifer is in the Slomniki area. The flow rates here are greater than 100 m^3/h in depth range of 132,0 to 134,0 and 231,0 to 234,5 m.b.g.l. and the temperature is approximated to be at 18°C (Barbacki, 2004). In the Busko-Zdroj area, the well outflow range is from 0.13 to 1.0 m^3/h (Lisik, 2010).

Favourable reservoir parameters and outflow are proportional to the thickness of sandy sediments. Based on this, the central part of Cenomanian aquifer (about 25 km W of the Busko-Zdroj) has the optimum value for these parameters. The Busko-Zdroj area is located on the marginal zone and the Cenomanian sediments disappear at about 10 km E of the town. The thickness of sediments is about three m in the marginal zone of the investigated reservoir and it rises towards the central zone to greater than 100 m (Barbacki, 2004). The distribution of the Cenomanian sediments thickness is shown in Figure 3.

In addition, the distribution of porosity parameters are likewise linked to the facial structure of the Cenomanian reservoir. In the marginal zone, the effective porosity is on the several percent level and the permeability values are about a number of mD. Towards the central zone, the porosity value rises to 25% to 30% and the permeability can be on a few D level (Barbacki, 2004).

5. GROUNDWATER CIRCULATION CONDITIONS IN MIECHOW TROUGH

Regional groundwater drainage in Miechow Trough is directed from N and NE to S and SE, toward the Nida River (Malina, 2010). The aspects of Cenomanian aquifer recharge and groundwater renewal are discussed. According to Rozkowski and Rozkowski (2010), the Krakow-Czestochowa Upland area and Holy Cross Mts. Fold Belt area can be a major recharge zone for the Cenomanian reservoir because of their geological structure and hypsometric localization. Another way to recharge the Upper Cretaceous sediments in Miechow Upland is by the slow percolation of atmospheric water through the carbonate rocks with reduced thickness. Other ideas generated in this study are related to the possibility of recharging trough tectonic dislocation and fault zones, especially in terms of regional spreading.

Opposing ideas are presented in Zuber et al. (2010), Szczepanski (2007 and 2010) and Lisik (2010). According to Zuber et al. (2010), the block structure of the Miechow Trough caused that faults planes to rub for lateral flow. That may contribute to the isolation of some regions and the lack of groundwater renewal in the deposits.

The recharge region for the Busko-Zdroj area is located probably on NW of this town. The Wojcza-Pinczow elevation is built from the fractured Upper Jurassic and Miocene sediments. Other mechanisms for recharge in the Busko-Zdroj area can be the ascension of the Upper Jurassic sediments or the movement of infiltration water from the recharge zone for thousands of years (estimated inflow time is about 30000 to 60000 years) (Szczepanski, 2007). The quantity of sulphurous groundwater in Busko-Zdroj area is limited because there is no possibility for the renewable resources of deposits. The weak renewal of the deposits is caused by the low permeability and gravity drainage capacity coefficients, lack of direct precipitation infiltration, and the substantial distance from recharge area.

Tectonic structures can be another reason for the lack of recharge and renewal of deposits in the Busko-Zdroj area. Particular faults and whole fault zones can isolate individual deposits of sulphurous groundwater (Szczepanski, 2007). There were studies done in the Busko-Zdroj resorts. The subject of analysis was the interactions between boreholes during the groundwater exploitation and water table changes. In addition, there was an analysis of mineral components of groundwater taking off from different catchments. Results of the investigation suggests that there are no connections between deposits in Busko-Zdroj area (Lisik, 2010). The intensive exchange of groundwater zone is located only in the central part of the Cenomanian reservoir. This groundwater can be used for consumption.

6. CONCLUSION

The distribution of geothermal water in Poland is related to tectonic structures. Geothermal water deposits are located in the units of West European Paleozoic Platform and Sudetes and Carpathians massifs with their Foredeeps. At present there are exploration activities in the geothermal prospect area in the Szczecin-Gorzow Trough and Miechow-Lodz Trough within the Paleozoic Platform. The Miechow Trough can be a potential area with geothermal water deposits based on the preliminary recognition of hydrogeological conditions.

Lack of compelling results from research activities that are relevant to flow direction, recharge area, and renewable of deposits of Cenomanian aquifer are currently the biggest problems. Solving these problems is necessary for proper water management in the region. The explanation of hydrogeological conditions in the regional picture is essential for determining prospective areas that have geothermal water deposits and desirable conditions for exploration.

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