GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2023 Volume 39 Issue 1 Pages 193–216

DOI: 10.24425/gsm.2023.144636

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Verification of the geothermal conditions in the Polish Lowlands based on data from new drilling performed in the years 2000–2022

Introduction

By 2022, over 9,300 deep boreholes (with depths of more than 1000 m) have been drilled in the area of Poland, of which 2,477 were in the Polish Lowlands, which is one of the most promising structures for geothermal use. In the Polish Lowlands, thirty-one of these were made for geothermal exploration (as of December 21, 2022) (CBDG 2022).

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The use of geothermal energy for heating purposes has been performed in Poland since the nineteen-eighties (Ney and Sokołowski 1987; Sokołowski et al. 1992; Kępińska 2003; Bujakowski and Barbacki 2004; Górecki et al. 2010; Górecki et al. 2015; Sowiżdżał et al. 2020a). The experimental stage of the first geothermal plant was opened in the Podhale region in 1992. Since then, seven district heating plants have been commissioned, six of which are located in the Polish Lowlands (Ney and Sokołowski 1987; Bujakowski and Barbacki 2004; Sokołowski et al. 1992; Kępińska 2003a, b; Górecki et al. 2015; Ziółkowski et al. 2021). For many years, activities have been conducted in exploring and using geothermal resources for district heating, during which many wells were drilled.

The entire area of the Polish Lowlands was covered with a comprehensive analysis of the recognition of Poland's geothermal resources. As a result of the research conducted under the supervision of Prof. W. Górecki, the Geothermal Atlases were published: *Atlas of geothermal resources in the Polish Lowlands. Mesozoic formations* and *Atlas of geothermal resources in the Polish Lowlands. Paleozoic formations* (Górecki ed. 2006a, b; Górecki et al. 2015).

The area of the Polish Lowlands covers over 80% of the territory of Poland (ca. 270,000 km^2) and is the largest geothermal region in the country. However, geothermal waters occur in several aquifers, mainly within Cretaceous, Jurassic, and Triassic reservoir rocks. The degree of recognition of these areas varies. In this region, geothermal waters occur in the Mesozoic and Paleozoic sedimentary rocks, creating extensive, trough-type structures of a reservoir nature (Górecki ed. 1990, 2006a, b; Hajto 2008). The Lower Cretaceous and Lower Jurassic reservoirs of the Polish Lowlands have been extensively studied (Dowgiałło 1976; Sokołowski ed. 1995; Kępińska 2003; Sowiżdżał et al. 2021).

Based on the balance of mineral resources deposit in Poland, prepared and published annually by the Polish Geological Institute – National Research Institute, it was indicated that at the end of 2021, there were thirty-five geothermal water deposits, of which twenty-one were located in the Polish Lowlands, and their exploitation resources have been documented with over thirty deep geothermal boreholes (BMRD in Poland 2022). In turn, the number of deposits of medicinal waters and brines in Poland was 113, including twenty-six in the Polish Lowlands. The total exploitation resources of all intakes of geothermal water

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amounted to 5,245.3 m^3/h, intakes of medicinal waters totaled 1,960.22 m^3/h, and brines totaled 3.70 m^3/h (Sokołowski 2021; Sokołowski and Skrzypczyk 2022). Sokołowski (2021) indicates that when using new hydrogeological data, it is advisable to present a regional synthesis of hydrogeological conditions prevailing in deep aquifers, consisting of the introduction of the required updates in the works presented so far (Górecki ed. 2006a, b; Sokołowski 2021).

Previous studies have shown that in the Polish Lowlands, there are geothermal waters with temperatures from below 20°C to 125°C, relatively evenly distributed (Hajto and Górecki 2010a; Bujakowski and Tomaszewska ed. 2014; Sowiżdżał et al. 2019; Sowiżdżał et al. 2020b). Currently, the highest temperature of geothermal waters, with an intake of about 150 m^3/h, was recorded in Konin, in the area of the Mogilno-Łódź Trough. The temperature of the geothermal water in the deposit (in Lower Jurassic reservoir) at the final depth of 2,660 meters was 97.5°C with mineralization of 150 g/L and high intake efficiency. In this intake in the Lower Cretaceous reservoir, the water temperature was 62°C, with mineralization of 35 g/L and an intake capacity of 300–500 m^3/h (Sowiżdżał et al. 2017; CBDG 2022).

The aim of this work is to show the potential of using geothermal energy in the Polish Lowlands for heating purposes. To recognize this potential, the state of geothermal exploration at the end of 2022 was analyzed to update the hydrogeothermal conditions in selected regions. Data from the CBDG (Central Geological Database) and published works of, among others, Górecki ed. (2006a, b), Sokołowski (2021), and Felter et al. (2021) were collected. The state of exploration of geothermal resources for 2010–2020 has already been presented by Sokołowski (2021). However, the novelty of this work is an attempt to identify changes that have occurred in forecasting the values of hydrogeothermal parameters in various places as a result of performing new drilling operations, obtaining the actual values in these wells (Górecki ed. 2006a; Sokołowski 2021; CBDG 2022).

1. State of knowledge based on published works

Synthetic information on the basic hydrogeological and geothermal parameters of the Lower Cretaceous and Lower Jurassic geothermal water reservoirs against the background of the regional geological structure and lithological geological profiles in the Polish Lowlands were originally determined within the Geothermal Atlases (Górecki ed. 2006a, b; Górecki et al. 2010). It was emphasized that the Geothermal Atlases contain important information for investors, researchers, and local authorities. Within the Polish Lowlands, areas with favorable conditions for the construction of geothermal installations have been indicated from Szczecin Through in the north-western part of Poland to Miechów Through in the south-eastern part of Poland (Hajto and Górecki 2010b; Nawrocki and Socha 2021). Sowiżdżał (2018b) emphasized that geothermal energy still has a marginal share in the Polish energy mix. The Mogilno-Łódź Through (Sowiżdżał et al. 2017, 2018a) and the previously mentioned Szczecin Through (Sowiżdżał 2009, 2010) within the Polish Lowlands have been studied by many researchers due to their favorable geothermal parameters. The southern part of the Mogilno-Łódź Through (Polish Lowlands) was indicated as having potential for the sustainable use of ATES (Hałaj et al. 2022). Research conducted in the area of Malanów (Polish Lowlands) aimed at the recognition of the Lower Cretaceous reservoir parameters confirmed that seismic methods can be successfully used in the exploration and assessment of geothermal waters deposits, to determine reservoir parameters, such as the depth to the top surface of the reservoir, its thickness, and porosity. Seismic data can support the selection of areas that are optimal for future investments in geothermal installations (Sowiżdżał et al. 2019). In the area of Polish Lowlands, the potential of geothermal energy was also investigated in terms of the production of electricity (Bujakowski and Tomaszewska ed. 2014; Sowiżdżał 2016) and utilization for heating and power generation (Bujakowski and Tomaszewska ed. 2014; Sowiżdżał et al. 2016).

The potential of Polish geothermal resources is still not fully used. Based on the balance of mineral resources deposit, in 2021 only about 54% of the total number of mineral and thermal water deposits were exploited (BMRD in Poland 2022). Geothermal waters in the Polish Lowlands are used for heating purposes from deposits: municipal heating – Mszczonów, Uniejów I, Pyrzyce, Stargard Szczeciński I, Poddębice, Toruń; local heating – Kleszczów GT-1, as well as for recreational purposes (several swimming pool complexes located in, among other places, Uniejów, Mszczonów, Poddębice, Poznań, Tarnów Podgórne, Lidzbark Warmiński), thermophilic fish farming (Trzęsacz), in the food industry (Uniejów) for the production of vegetable preserves and municipal purposes (Mszczonów, Uniejów). Over 50% of the exploitation resources of deposits are located within Polish Lowlands (Sokołowski and Skrzypczyk 2022).

By the end of 2022, six geothermal plants were operating in the Polish Lowlands using geothermal waters for heating purposes, i.e. central space heating systems and warm-water supply. These were: Pyrzyce, Mszczonów, Uniejów, Poddębice, Toruń and Stargard (Kępińska et al. 2023). Since 2000, twenty-three new geothermal wells have been drilled in the Polish Lowlands (Kępińska 2003; Bujakowski et al. 2020; Felter et al. 2021; Sokołowski 2021; CBDG 2022).

Financial support for the Polish geothermal energy sector is mainly provided by the National Fund for Environmental Protection and Water Management (NEEP&WM) under priority programs (Sowiżdżał et al. 2018b).

2. Geothermal investments carried out in the years 2000–2022

The analysis used a map of the management of groundwater classified as minerals in Poland, which presents information on the occurrence of curative, geothermal, and brine waters, and in particular, an explanatory text for this map (Felter et al. 2019, 2021).

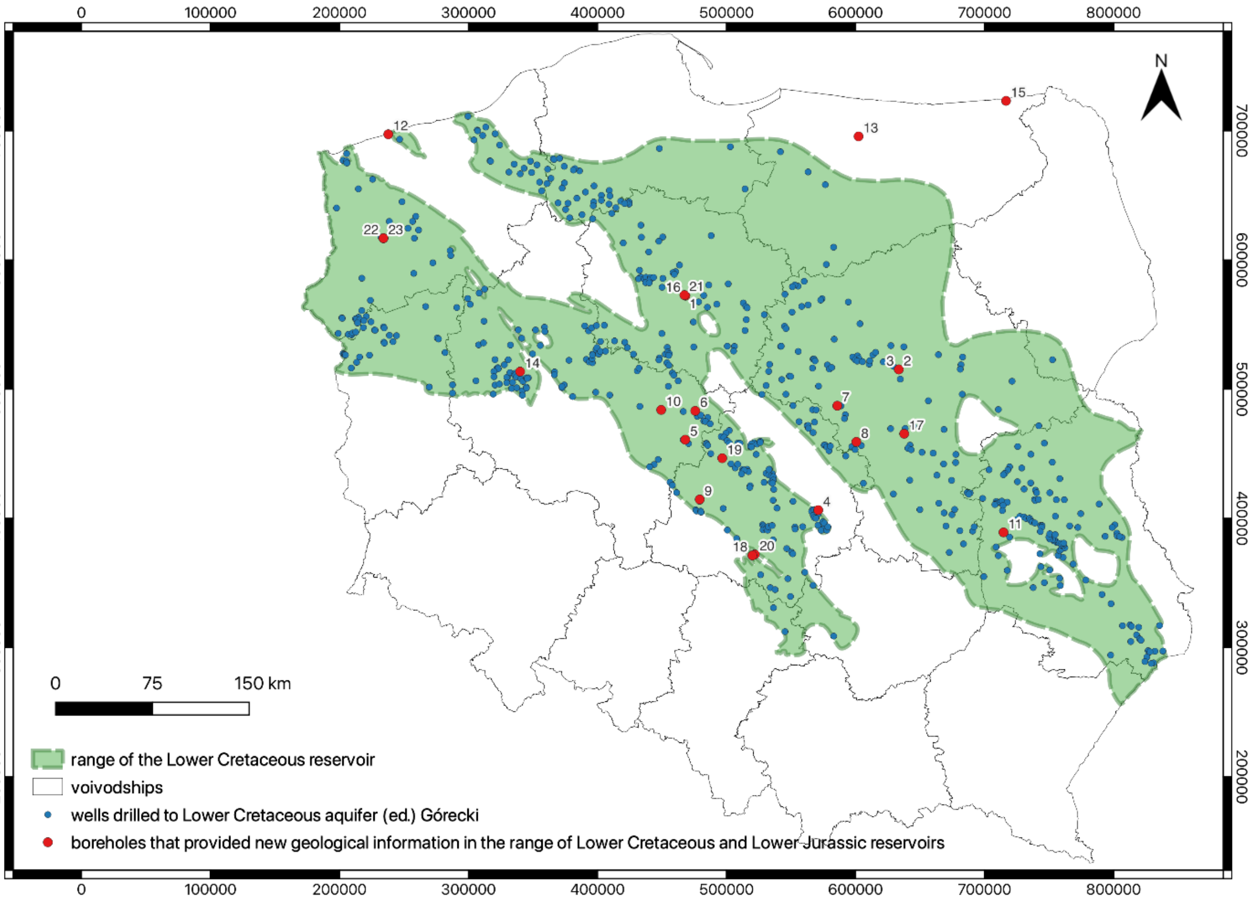

Fig. 1. Boreholes that provided new geological information in the range of the Lower Cretaceous reservoir

Rys. 1. Otwory wiertnicze, które dostarczyły nowych informacji geologicznych w zasięgu zbiornika dolnej kredy

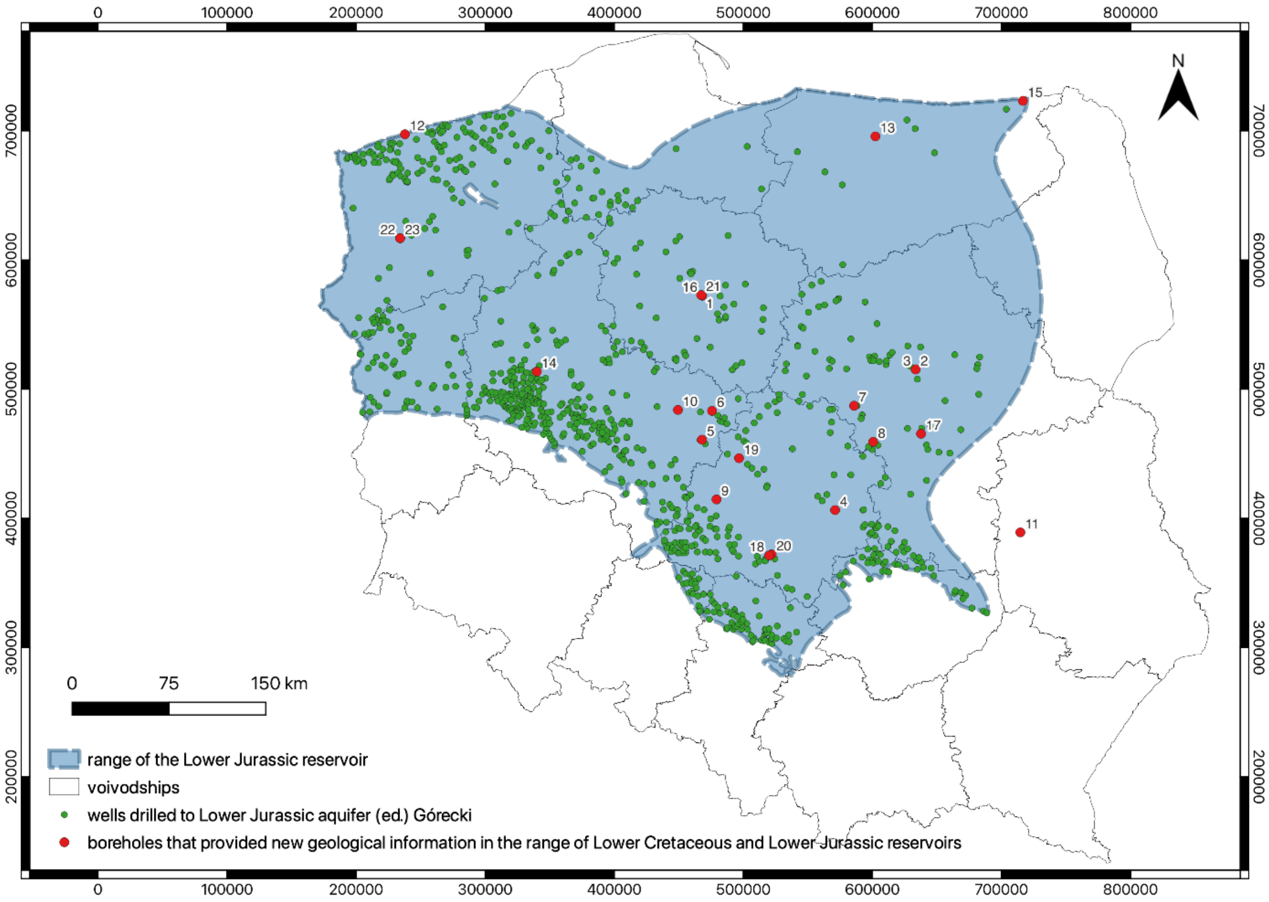

Fig. 2. Boreholes that provided new geological information in the range of the Lower Jurassic reservoir

Rys. 2. Otwory wiertnicze, które dostarczyły nowych informacji geologicznych w zasięgu zbiornika dolnej jury

Since 2000, twenty-three geothermal boreholes have been drilled throughout Polish Lowlands. Figures 1 and 2 show geothermal wells that provided new geological information within the Lower Cretaceous reservoir (Figure 1) and within the Lower Jurassic reservoir (Figure 2) against the background of the wells contained in Geothermal Atlas (Górecki ed. 2006a). Table 1 provides more details on geothermal data (Felter et al. 2021; CBDG 2022).

Boreholes in Stargard were drilled at the beginning of the twenty-first century – Stargard GT-1 in 2001 and Stargard GT-2 in 2003 – and they are located within the range of both reservoirs (Figures 1 and 2). GT-1 was originally used as a production well, whereas now it operates as an injection well. They both work in the Stargard district heating system (Geotermia Stargard). Water is exploited from the Lower Jurassic reservoir (Felter et al. 2021; CBDG 2022).

In 2011, the resources were documented in four new geothermal wells, of which two were drilled in 2009 (Toruń TG-2 and Kleszczów GT-1), one in 2010 (Poddębice GT-2) and one in 2011 (Kleszczów GT-2) (Table 1). The Poddębice GT-2 production well located in the range of both reservoirs (Figures 1 and 2) operates today in the district heating system (Geotermia Poddębice) and supplies geothermal water from the Lower Cretaceous reservoir, which is used for district heating purposes and in the recreation center. It provides only hydrogeological data from Lower Cretaceous formations (Felter et al. 2021; CBDG 2022). In Kleszczów, apart from the Kleszczów GT-1 production borehole, in 2011 injection well Kleszczów GT-2 was also drilled. Production well exploits Jurassic sources of geothermal water. Both wells are located within the Lower Cretaceous and Lower Jurassic reservoirs (Figures 1 and 2) (Sokołowski 2021). Similarly to Kleszczów, in Toruń in 2009 two geothermal boreholes were drilled. It was assumed that Toruń TG-1 would operate as a production well, while Toruń TG-2 as an injection well. Wells are located within the range of both reservoirs and provide geothermal water from the Lower Jurassic reservoir (Table 1; Figure 1 and 2). It was assumed that both boreholes would play an important role in the city's district heating system (Geotermia Toruń; Sokołowski 2021).

In 2010 in the northern part of Poland, within the range of the Lower Jurassic reservoir (Figures 1 and 2), the Gołdap GZ-1 borehole was drilled. It exploited water from the Lower and Middle Jurassic aquifers (Felter et al. 2021). In the following year, a decision was made in the Tarnowo Podgórne to drill the Tarnowo Podgórne GT-1 borehole. This well, located within the range of both reservoirs, exploits water from the Lower Jurassic aquifer, which is used for recreational purposes (Table 1; Figures 1 and 2) (Felter et al. 2021; CBDG 2022). In 2011, the Lidzbark Warmiński GT-1 borehole was drilled within the Lower Jurassic reservoir, the resources of which were documented in 2012 (Table 1; Figures 1 and 2) (Sokołowski 2021). In 2012 the Trzęsacz GT-1 borehole was drilled in Trzęsacz by the Baltic sea (resources were also documented in 2012), supplying water from the Lower Jurassic age (Table 1; Figures 1 and 2). Here, geothermal water is used for fish farming, which makes this project unique in Poland (Felter et al. 2021; CBDG 2022).

Then, in 2015, two geothermal wells were drilled: Konin GT-1 (resources documented in 2016), where the highest temperature available in Poland in the Lower Jurassic formations

Table 1. Geothermal boreholes in the Lower Jurassic and Lower Cretaceous range delivered new geological information

Tabela 1. Odwierty geotermalne w zasięgu jury dolnej i kredy dolnej, które dostarczyły nowych informacji geologicznych

No.	Borehole name	Borehole drilling date	Year of documenting resources	Total borehole depth (m)	Final object depth (m)	Stratigraphic top surface depth (m)	Ordinate of the stratigraphic top surface (m.a.s.l.)	Total thickness (m)	Aquifer stratigraphy	Water temp. (°C)	Discharge of wells (m^3/h)	Borehole purpose
1	Toruń TG-2A	2021	2022	2,420	nd	134 K1 1,794 J1	–97 K1 –1,757 J1	476 K1 623 J1	J1	nd	nd	nd
2	Jachranka GT-1	2019	2020	1,780.5	1,780.5	931 K1 1,524 J1	–831.1 K1 –1,424.1 J1	54 K1 230 J1	J1	43.2	188.5	injection
3	Jachranka GT-2K	2019	2020	1,775.4 (2,150 m MD)	1,775.4	932.7 K1 1,508.4 J1	–832.8 K1 –1,408.5 J1	55.2 K1 249 J1	J1	42.5	201	production
4	Tomaszów Mazowiecki GT-1	2019	2020	1,672	1,577	1,437 J1	–1,275.62 J1	128 J1	J1	41.7	80	production
5	Turek GT-1	2019	2019	2,169	2,151	1,228 K1 2,100 J1	–1,116.51 K1 –1,988.51 J1	85 K1 48 J1	J1	77.9	54	production
6	Koło GT-1	2018	2019	3,905	2,815	2,533 K1 3,814 J1	–2,423.18 K1 –3,704.18 J1	402 K1 62 J1	K1	84.3	257	production
7	Sochaczew GT-1	2018	2019	1,540	1,540	1,347.0 K1	–1,265.89 K1	>193 K1	K1	44.3	180	production
8	Wręcza GT-1	2018	2019	1,688	1,688	1,521 K1	–1,357.5 K1	146 K1	K1	40.15	150	production
9	Sieradz GT-1	2018	2018	1,505	1,505	413 K1 1,279 J1	–2,74.87 K1 –1,140.87 J1	56 K1 220 J1	J1	51.8	249	production
10	Konin GT-1	2015	2016	2,660	2,660	1,612 K1 2,578 J1	–1,529.3 K1 –2,495.3 J1	138 K1 63 J1	J1	92	114	production
11	Celejów GT-2	2015	2015	1,229	1,229	912 K1 914 J3 1,171 J2	–742.3 K1 –744.3 J3 –10,001.3 J2	2 K1 257 J3 > 58 J2	J2, J3	29.2	28	production

No.	Borehole name	Borehole drilling date	Year of documenting resources	Total borehole depth (m)	Final object depth (m)	Stratigraphic top surface depth (m)	Ordinate of the stratigraphic top surface (m.a.s.l.)	Total thickness (m)	Aquifer stratigraphy	Water temp. (°C)	Discharge of wells (m^3/h)	Borehole purpose
12	Trzęsacz GT-1	2012	2012	1,224.5	1,215.5	66 K1 527 J1	–60.9 K1 –521.9 J1	28 K1 681 J1	J1	25.4	180	production
13	Lidzbark Warmiński GT-1	2011	2012	1,035	1,035	839 J1	–752.4 J1	155.5 J1	J1	21	120	production
14	Tarnowo Podgórne GT-1	2011	2012	1,200	1,200	391 K1 804 J1	–295.5 K1 –708.5 J1	19 K1 366 J1	J1	43.46	225	production
15	Gołdap GZ-1	2010	2012	851	646.5	560 J2 628 J1	–404.66 J2 –472.66 J1	68 J2 13 J1	J1, J2	22	12	production
16	Toruń TG-1	2009	2012	2,925	2,925	196 K1 1,776 J1 2,755 T2	–154.46 K1 –1,734.46 J1 –2,713.46 T2	345 K1 559 J1 129 T2	J1	60.5	320	production
17	Piaseczno GT-1	2012	2012	1,911	nd	nd	nd	nd	nd	nd	nd	nd
18	Kleszczów GT-2 (Chłonny)	2011	2011	1,725	1,725	258 K1 1,112 J2 1,606 J1	–54.4 K1 –908.4 J2 –1,402.4 J1	36 K1 494 J2 > 119 J1	J1, J2	45.9	240.6	injection
19	Poddębice GT-2	2010	2011	2,101	2,101	10 K1	109.5 K1	2,053 K1	K1	68.4(72.2)	252	production
20	Kleszczów GT-1	2009	2011	1,620	1,620	1,484 J1	–1,269.9 J1	106 J1	J1	52.2	200.6	production
21	Toruń TG-2 (Chłonny)	2009	2011	2,362	2,362	142 K1 1,793 J1	–107 K1 –1,758 J1	411 K1 556 J1	J1	–	–	injection
22	Stargard GT-2	2003	2006	3,080	3,080	2,255 K1 2,444 J1	–2,223.3 K1 –2,412.3 J1	10 K1 612 J1	J1	68.9	200	production
23	Stargard GT-1 (Chłonny)	2001	2006	2,670	nd	nd	nd	nd	T	nd	nd	injection

nd – no data; K1– Lower Cretaceous; J1– Lower Jurassic; J2 – Middle Jurassic; J3 – Upper Jurassic, T – Triassic.
Based on: Felter et al. 2021; Sokołowski 2021; CBDG 2022; CBDH 2022.

was confirmed (92°C), and Celejów GT-2 (resources documented in 2015), which exploits the Middle and Upper Jurassic reservoir (Table 1). The Konin GT-1 well is located within the range of both the Lower Cretaceous and Lower Jurassic reservoirs, while Celejów GT-2 is located outside the range of the Lower Jurassic reservoir (Figure 1 and 2) (Felter et al. 2019; Sokołowski 2021).

Three years later, in 2018, four geothermal wells were drilled in the area of the Lower Cretaceous and Lower Jurassic reservoirs: Koło GT-1 (resources documented in 2019), Sochaczew GT-1 (resources documented in 2019), Wręcza GT-1 (resources documented in 2019), and Sieradz GT-1 (resources documented in 2018) (Table 1; Figure 1 and 2) (CBDG 2022). The area of the city of Konin is well-explored, and geothermal resources are a prospect for district heating utilities. Wręcza GT-1, Sochaczew GT-1, and Koło GT-1 provide water from the Lower Cretaceous aquifer, while Sieradz GT-1 provides water from the Lower Jurassic (Felter et al. 2021; Sokołowski 2021; CBDG 2022).

The last geothermal wells with documented resources were drilled in 2019 and 2021 within the range of both Lower Cretaceous and Lower Jurassic reservoirs: Jachranka GT-1 and Jachranka GT-2K (in both resources were documented in 2020), Tomaszów Mazowiecki GT-1 (resource documented in 2020), Turek GT-1 (resources documented in 2019) and Toruń TG-2A (resources documented in 2022) (Table 1; Figure 1 and 2). All five geothermal wells provide water from the Lower Jurassic reservoir. In the future, the Turek GT-1 well will be used in district heating (Sokołowski 2021; CBDG 2022). The aforementioned boreholes, presented in Table 1, provided new hydrogeological information about the Lower Cretaceous and Lower Jurassic reservoirs in the area of Polish Lowlands. Five of them (Stargard GT-1, Stargard GT-2, Toruń TG-1, Toruń TG-2A, Poddębice GT-2) are yet to be used in geothermal district heating in Poland. Currently, they are extremely important in the production of heat.

3. Research methodology

Maps of geothermal parameters of Lower Jurassic (J1) and Lower Cretaceous (K1) reservoirs, i.e. maps of the top surface of formations, total thickness, and maps of potential discharge of wells, included in the work of Górecki, ed. (Górecki ed. 2006a) *Atlas of geothermal resources of the Mesozoic formation in the Polish Lowlands*, were used to try to identify changes that occurred in the course of forecasting the values of hydrogeothermal parameters in various places as a result of performing new drilling operations, due to obtaining the actual values in these wells (Table 1). The geological conditions have been slightly updated using the QGIS Desktop 3.24.1 software. The analysis was based on the results of drilling works, which provided new geological information (Table 1) (CBDG 2022; CBDH 2022). The criterion was adopted that these boreholes should cover geological conditions at least within the Lower Cretaceous formations. Access to geological information from twenty-three newly drilled geothermal wells (after 2000) in the range of the Lower Jurassic and

Lower Cretaceous reservoirs was obtained (Figures 1 and 2). The indicated maps from the *Atlas of geothermal resources of the Mesozoic formation in the Polish Lowlands* (Górecki ed. 2006a) in the form of jpeg maps were imported into the QGIS Desktop 3.24.1 software application for georeferencing. The shapefile isolines of the top surface of Lower Jurassic and Lower Cretaceous reservoir deposits, the total thickness of this formation, and maps of the potential discharge of wells from raster maps were then created. The isoline shapefiles created were slightly updated/corrected based on geological and hydrogeological information from the twenty-three new geothermal wells identified. The changes covered the course of isolines on all analyzed maps.

4. Results

4.1. The top surface of the Lower Cretaceous and the Lower Jurassic formations (Polish Lowlands)

The top surface of the Lower Jurassic formations in the Polish Lowlands occurs from –3500 m.a.s.l. up to 250 m.a.s.l., with a predominance of more than –750 m.a.s.l. (Figure 3), while Lower Cretaceous formations occur from –2500 m.a.s.l. up to 250 m.a.s.l., with the vast majority exceeding –500 m.a.s.l. (Figure 4) (Górecki ed. 2006a). Corrections of the course of isolines made in the QGIS Desktop 3.24.1 program, based on the work of Górecki, ed. (2006a), were introduced mainly in the central part of both the Lower Cretaceous and the Lower Jurassic (in the east and west wings, in the south-east to the north-west range) reservoirs (Figures 3, 4). They were made based on new data from twelve geothermal wells (Trzęsacz GT-1, Lidzbark Warmiński GT-1, Tarnowo Podgórne GT-1, Toruń TG-1, Koło GT-1, Sieradz GT-1, Turek GT-1, Konin GT-1, Tomaszów Mazowiecki GT-1, Kleszczów GT-1, Jachranka GT-1, and Jachranka GT-2K) for Lower Jurassic reservoir, and eight wells (Toruń TG-1, Toruń TG-2, Sochaczew GT-1, Wręcza GT-1, Sieradz GT-1, Kleszczów GT-2, Koło GT-1, and Stargard GT-2) for the Lower Cretaceous reservoir.

In their analysis, Górecki ed. (Górecki ed. 2006a) used boreholes drilled up to 2006 (Figures 1 and 2), which were input data for a multi-variant analysis using numerical processing techniques and special numerical software. Structural maps of the hydrogeothermal top surface of formations were constructed based on the available analog data, including maps of seismic surfaces in the Polish Lowlands and the interpretation of borehole data (Szczepański et al. 2006). In the case of the presented study, the actual documented depths of the top surface of the Lower Cretaceous and the Lower Jurassic formations in wells were used to update.

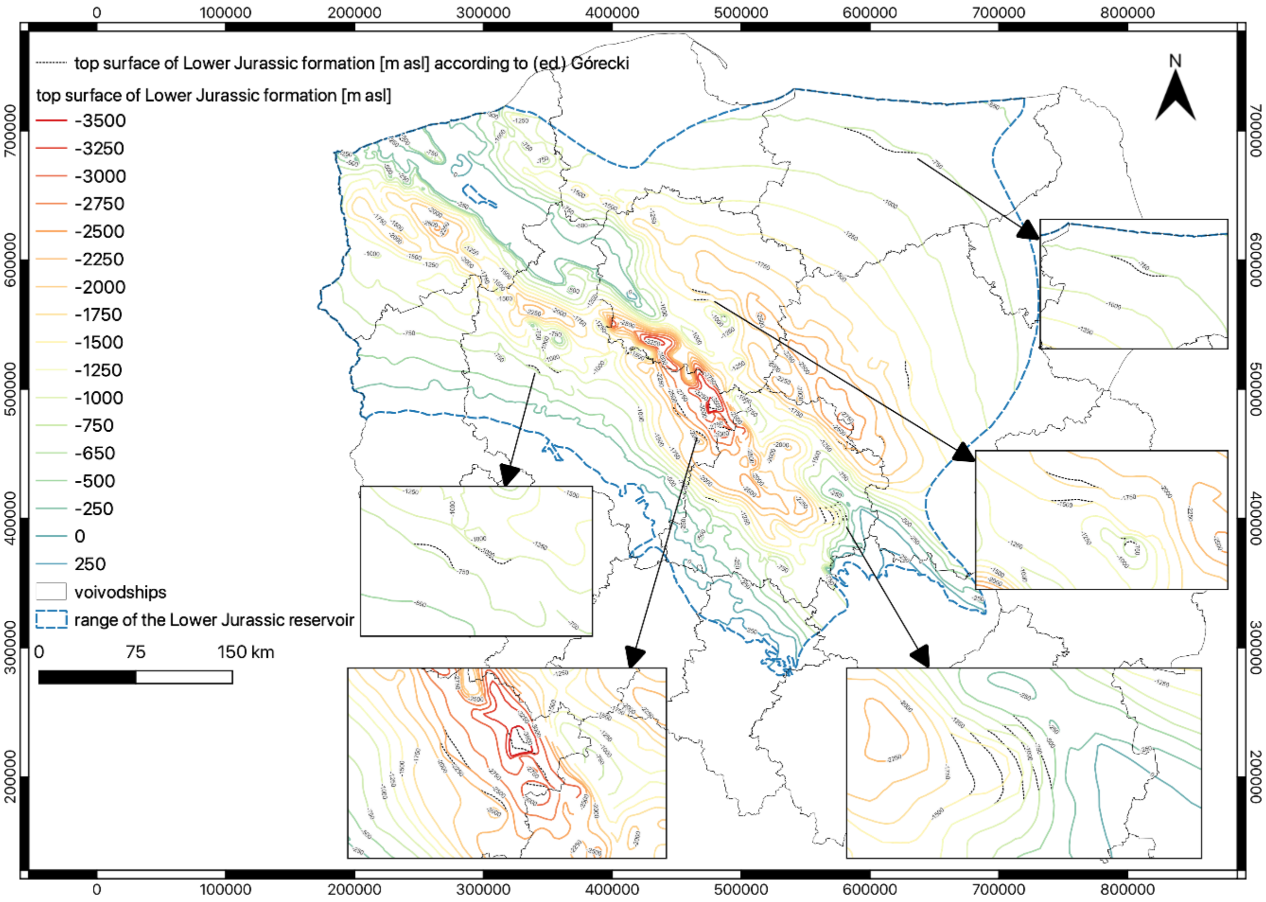

Fig. 3. Structural map of the top surface of the Lower Jurassic reservoir deposits in the Polish Lowlands (based on Górecki ed. 2006a), with introduced changes

Rys. 3. Mapa strukturalna stropu utworów jury dolnej na Niżu Polskim

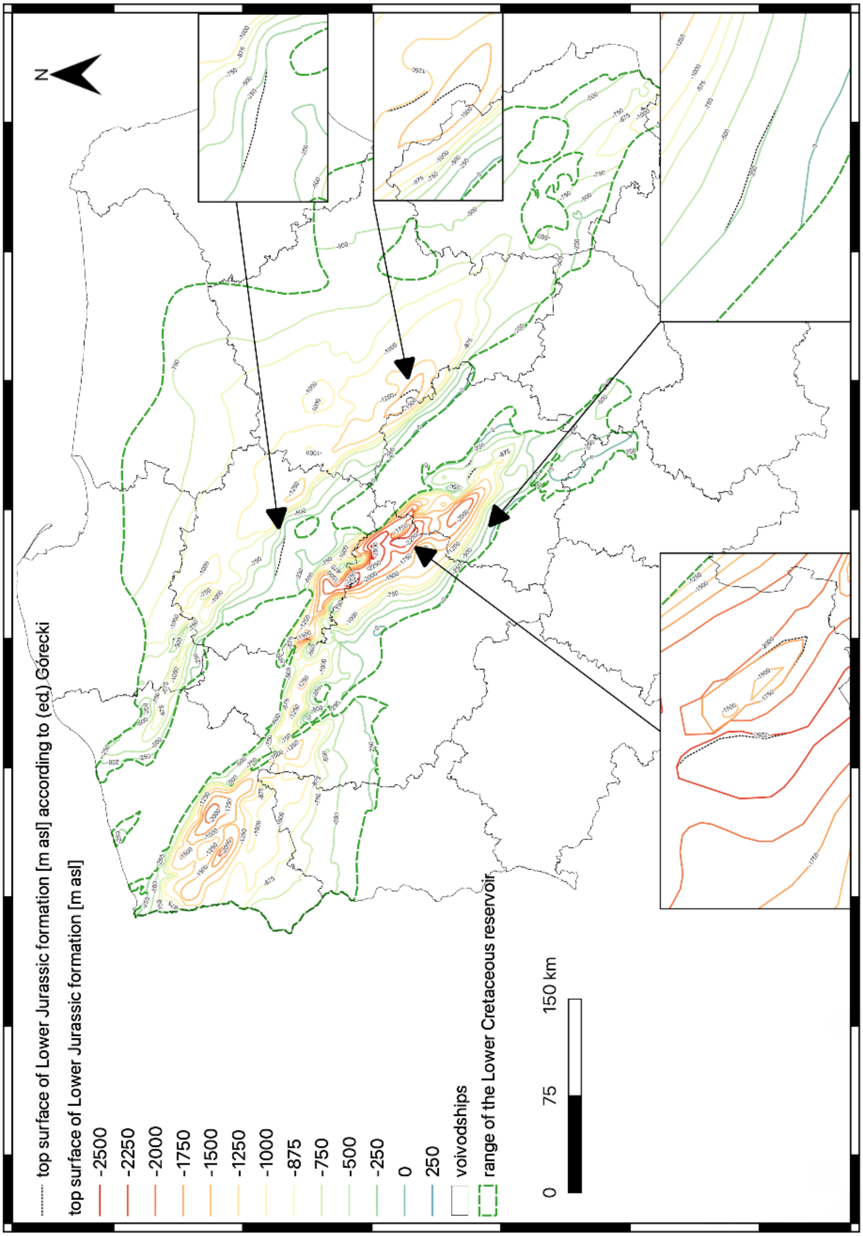

Fig. 4. Structural map of the top surface of the Lower Cretaceous reservoir deposits in the Polish Lowlands (based on Górecki ed. 2006a) with introduced changes

Rys. 4. Mapa strukturalna stropu utworów kredy dolnej na Niżu Polskim

4.2. The total thickness of the Lower Cretaceous and the Lower Jurassic formations (Polish Lowlands)

The total thickness of the Lower Jurassic formations in the Polish Lowlands ranges from 20 to 1250 m, with most of them exceeding 200 m (Figure 5), while Lower Cretaceous formations range from 25 to 500 m (this value is up to 25 m in the boundary parts of the reservoir) (Figure 6) (Górecki ed. 2006a). The changes in the course of the isolines are slight in the central and northeastern parts of the Lower Jurassic reservoir. For the Lower Cretaceous, they concern only the central part of the reservoir. Data from six newly drilled geothermal wells (Koło GT-1, Trzęsacz GT-1, Tomaszów Mazowiecki GT-1, Kleszczów GT-1, Kleszczów GT-2, and Stargard GT-2) for the Lower Jurassic reservoir, and seven wells (Koło GT-1, Sieradz GT-1, Jachranka GT-1/Jachranka GT-2K, Toruń TG-1, Toruń TG-2, and Koło GT-1) for the Lower Cretaceous were used for cosmetic changes in the course of the isolines.

Maps of the total thickness of individual stratigraphic formations contained in the Geothermal Atlas (Górecki ed. 2006a) were made based on the interpretation of borehole data and the superposition of structural maps (Szczepański et al. 2006).

4.3. Potential discharge of wells – the Lower Jurassic and the Lower Cretaceous reservoirs (Polish Lowlands)

The potential efficiencies of geothermal intakes (potential discharge of wells) range from 50 to 450 m^3/h within the Lower Jurassic reservoir (Figure 7), while within the Lower Cretaceous reservoir, the range is from 25 to 300 m^3/h (in the boundary parts of the reservoir this value does not exceed 25 m^3/h) (Figure 8) (Górecki ed. 2006a). Minor changes in the course of the isolines were made in the strip from the south-east to the north-west and in the central part of the Lower Jurassic reservoir; for the Lower Cretaceous reservoir, they were made in the strip from the south-east to the north-west and in the central part. Changes were made based on data from ten geothermal wells (Tarnowo Podgórne GT-1, Sieradz GT-1, Turek GT-1, Tomaszów Mazowiecki GT-1 Toruń TG-1, Jachranka GT-2K, Toruń TG-1, Stargard GT-2, Konin GT-1, and Tomaszów Mazowiecki GT-1) for the Lower Jurassic reservoir and two geothermal wells (Wręcza GT-1 and Poddębice GT-2) for the Lower Cretaceous reservoir.

The maps of the potential efficiency of the hydrogeological wells included in the Geothermal Atlas (Górecki ed. 2006a) were made on the basis of calculations of the efficiency of the hypothetical exploitation well within individual reservoirs. Due to the significant diversification of hydrogeological parameters between individual reservoirs, the calculation parameters within individual reservoirs were varied. The theoretical assumption was made that for both the Lower Jurassic and the Lower Cretaceous reservoirs, the operational filter diameter will be 12 inches (0.305 m), and the operational depression will be 100 m.

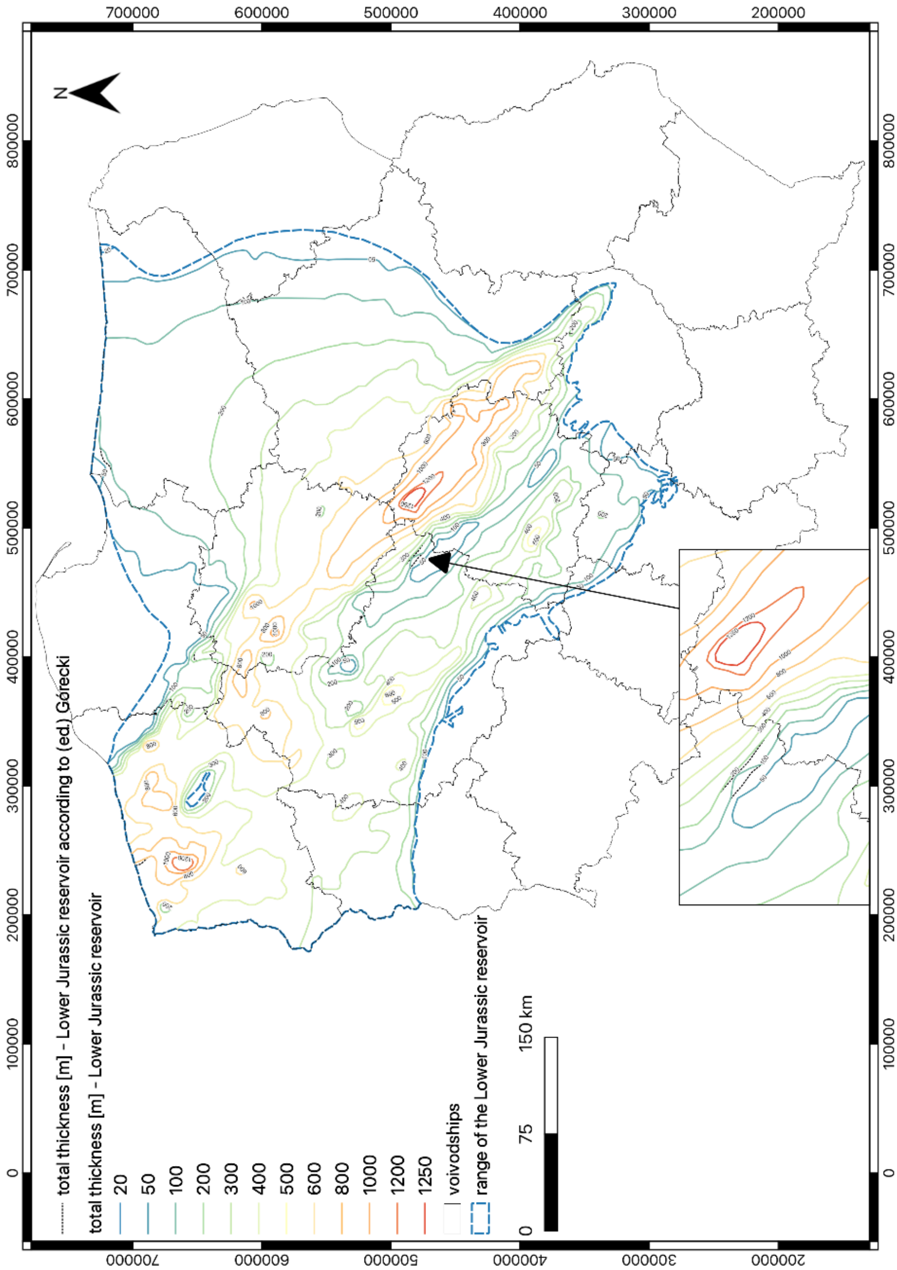

Fig. 5. Map of the total thickness of the Lower Jurassic formations in the Polish Lowlands (based on Górecki ed. 2006a) with corrections of the course of isolines

Rys. 5. Mapa całkowitej miąższości utworów jury dolnej na Niżu Polskim

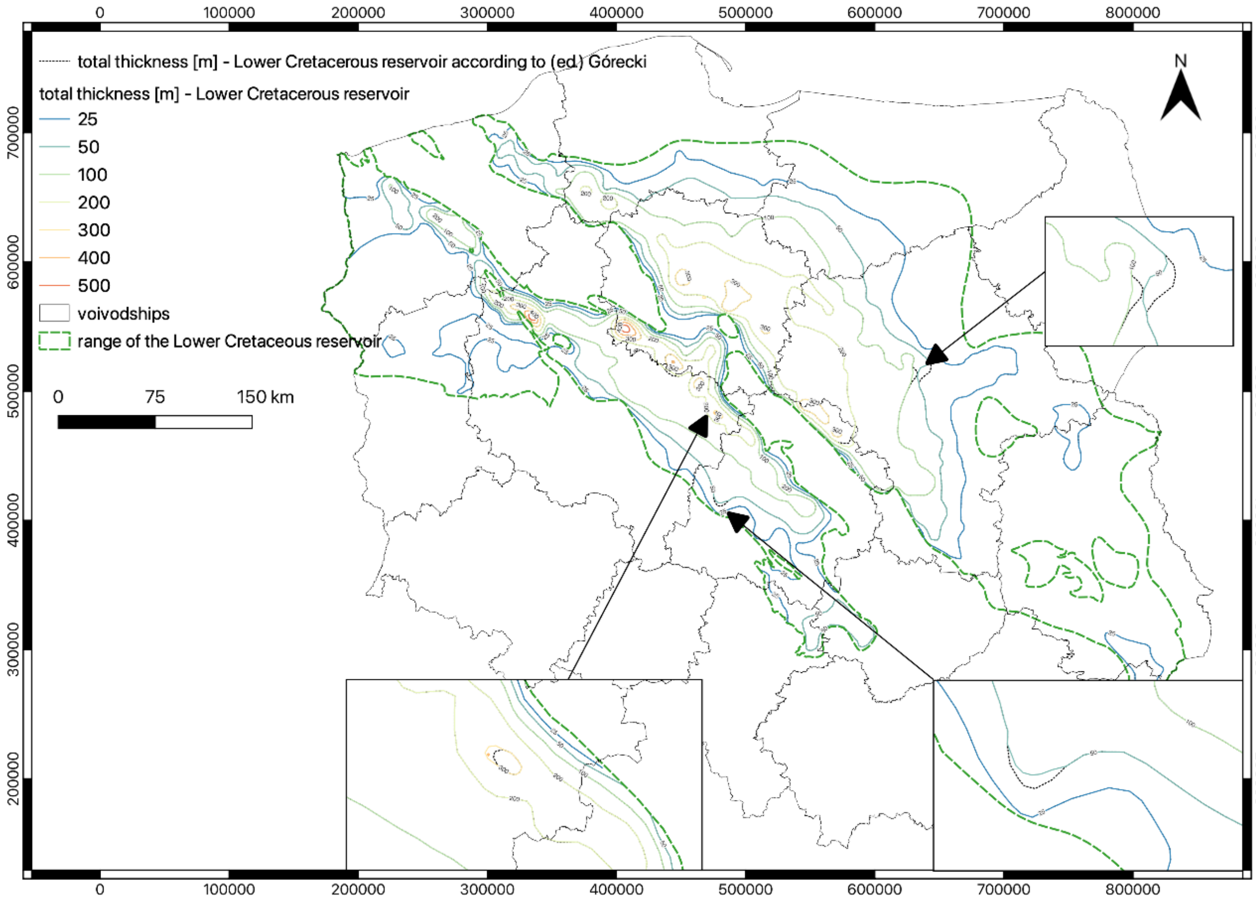

Fig. 6. Map of the total thickness of the Lower Cretaceous deposits in the Polish Lowlands (based on Górecki ed. 2006a) with introduced changes

Rys. 6. Mapa całkowitej miąższości utworów kredy dolnej na Niżu Polskim

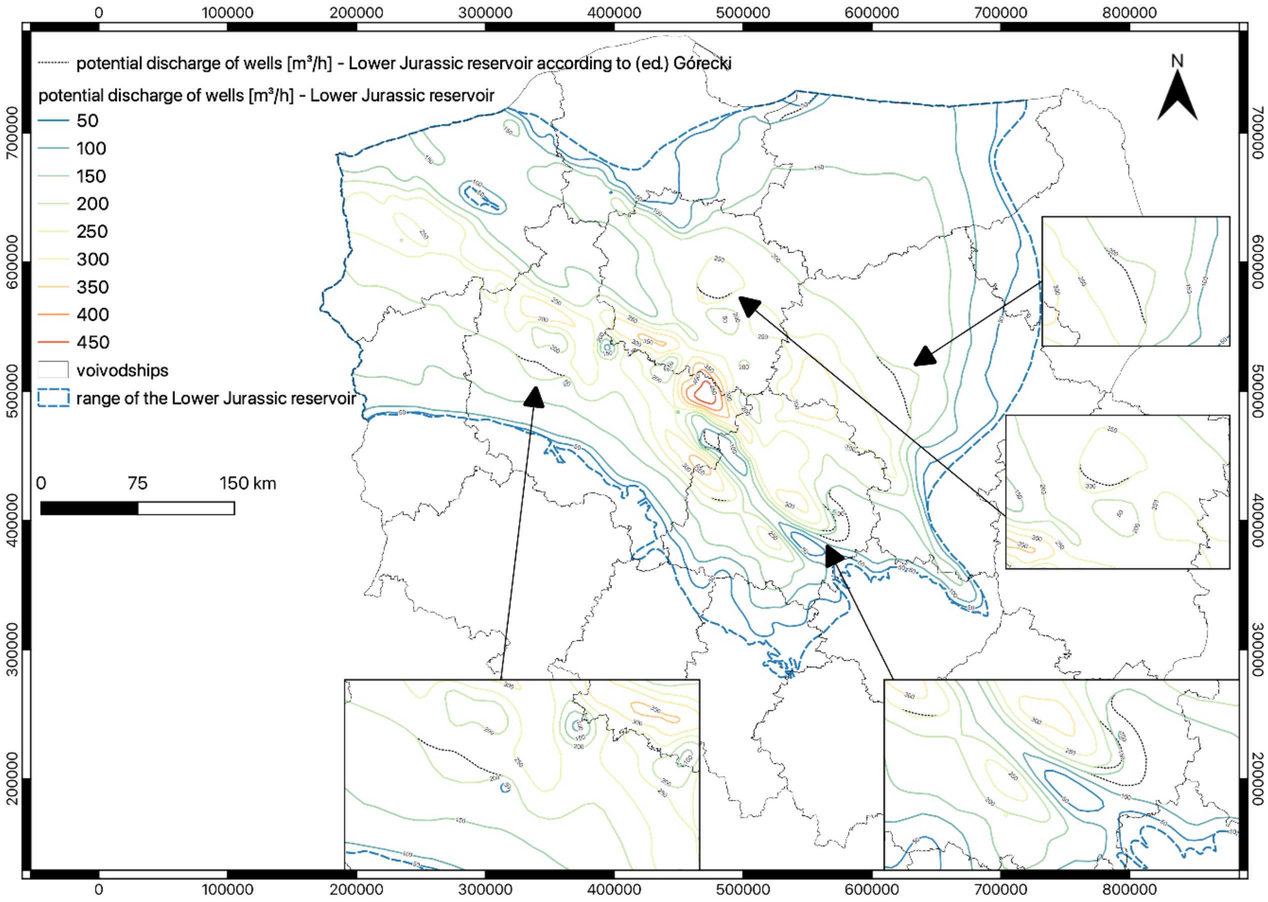

Fig. 7. Map of potential discharge of wells within the Lower Jurassic reservoir in the Polish Lowlands (based on Górecki ed. 2006a) with introduced changes

Rys. 7. Mapa potencjalnych wydajności studni w obrębie zbiornika jury dolnej na Niżu Polskim

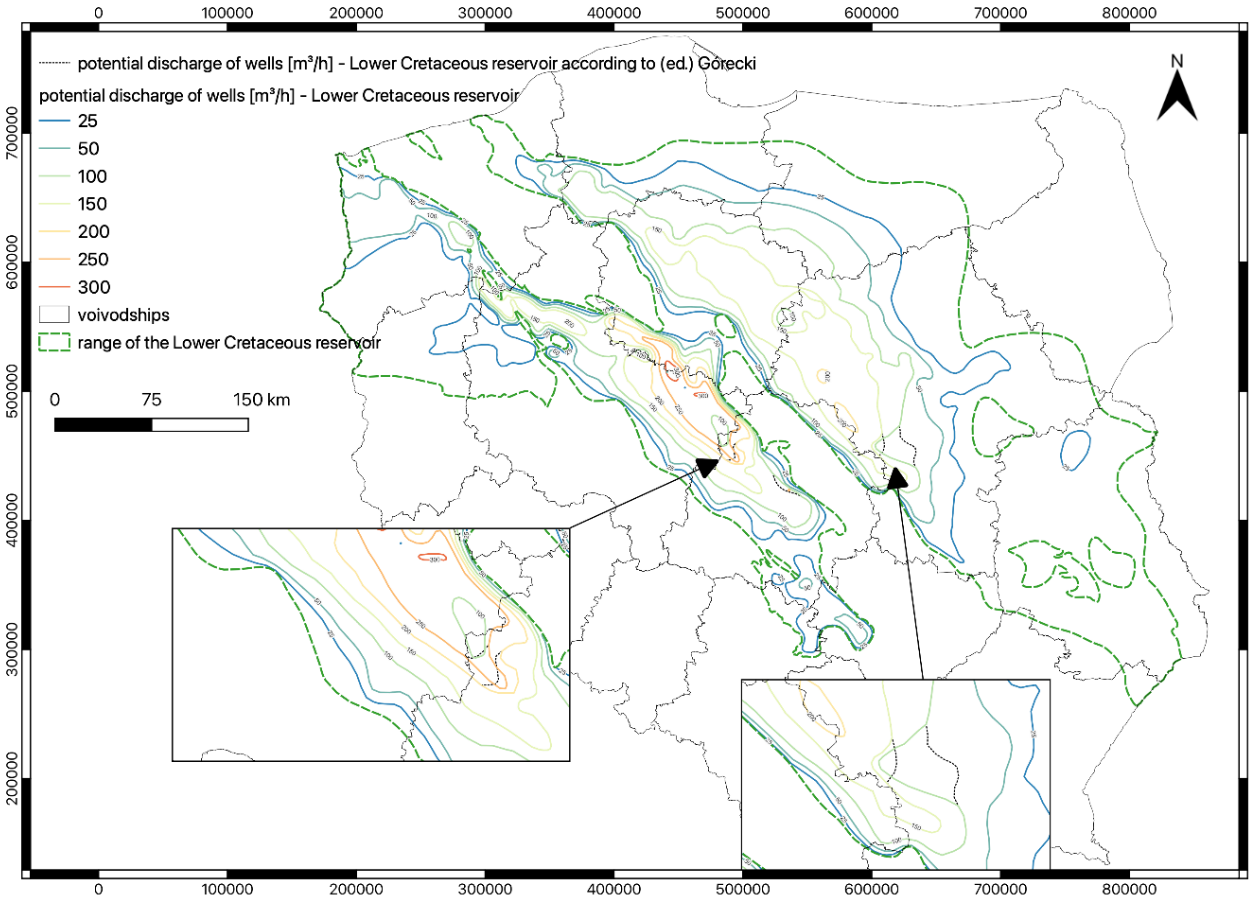

Fig. 8. Map of potential discharge of wells in the Lower Cretaceous reservoir in the Polish Lowlands (based on Górecki ed. 2006a) with introduced changes

Rys. 8. Mapa potencjalnych wydajności studni w obrębie zbiornika kredy dolnej na Niżu Polskim

The volume of the aquifer captured (100 m) was assumed to be equivalent to the length of the active working part of the filter. The Darcy-Dupuit equation was used to calculate the efficiency, while the theoretical efficiency of the production well was calculated by the superposition map method, which considers the permissible depression, the filtration coefficient, and the thickness of the aquifers (Szczepański et al. 2006). In the case of the presented study, the actual data from wells and documented exploitation resources were used to update the map of potential borehole performance.

Conclusions

As a part of this work, the authors attempted to identify changes that occurred in the course of the isolines with the predicted values of hydrogeothermal parameters in various places as a result of performing new drilling operations with the obtaining of actual values in these wells (Górecki ed. 2006a; Sokołowski 2021; CBDG 2022). The correction covered the course of isolines within all six analyzed maps, three for each reservoir: the Lower Jurassic (J1) and the Lower Cretaceous (K1).

In the case of the top surface, new information from twelve geothermal wells for the J1 reservoir and from eight wells for the K1 reservoir was used to make minor adjustments to the forecast of this parameter. In the Geothermal Atlas (Górecki ed. 2006a) analog and borehole data were the source of prediction data. Data from new boreholes enabled a local, spot correction of the forecast while maintaining regional trends, confirming the high value of the developed Geothermal Atlas (Górecki ed. 2006a). For K1, in the eastern wing, the values of the top surface, predicted and confirmed in boreholes, differ by about 100 m on average, while in the western wing, they differ by about several dozen meters. These differences for J1 range from several dozen meters for openings in the edge parts to over 200 m in the central part of the reservoir.

In the case of the total thickness for the J1 reservoir, the data from only six new geothermal wells were used for local changes in the course of the isolines of the parameter in question. For the K1 reservoir, in seven geothermal wells, the total thickness of the formations was documented in a slightly different value than predicted in the Geothermal Atlas. For K1, the values of the total thickness, the predicted and confirmed in boreholes, differ on average by about a couple of meters to about fifty meters in one case, while for J1, it is up to about 100 meters in places of high thickness.

In the Geothermal Atlas, the Darcy-Dupuit equation was used to calculate the efficiency and then the map superposition method to obtain a map of wells' potential efficiency. Within the K1 reservoir, only two geothermal borehole resources were documented with minor deviation from predictions. In the case of the J1 reservoir, there were more differences, they concerned the values documented in ten geothermal boreholes. For K1 and J1, the values of the potential discharge of wells, predicted and confirmed in boreholes, differ from less than 20 m^3/h to more than 50 m^3/h. In both cases, minor adjustments did not affect the overall trend of forecasts. Information obtained from newly drilled boreholes only enriched geothermal recognition within the Lower Jurassic and Lower Cretaceous reservoirs presented in Geothermal Atlases by Górecki ed. (2006a, b).

This study was financed by the National Fund for Environmental Protection and Water Management (Project No: 450/2021/Wn50/NE-OA-KU/D).

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VERIFICATION OF THE GEOTHERMAL CONDITIONS IN THE POLISH LOWLANDS BASED ON DATA FROM NEW DRILLING PERFORMED IN THE YEARS 2000–2022

Keywords

Polish Lowlands, geothermal conditions, the top surface of the Lower Cretaceous formations, the top surface of the Lower Jurassic formations, potential discharge of wells

Abstract

The aim of the presented work was an attempt to verify the geothermal conditions in the Polish Lowlands (Lower Jurassic and Lower Cretaceous reservoir) based on new geological information. The paper presents geothermal conditions in the Polish Lowlands according to the state of recognition at the end of 2022 in order to update the hydrogeothermal conditions in selected regions. Based on the scientific and research works published so far as well as numerous geothermal investments, and geological information from twenty-three new exploratory drilling events performed in the years 2000–2022 (nineteen of which were performed/documented after 2006), the authors undertook to update forecasts of the top surface of Lower Jurassic and Lower Cretaceous formations, the total thickness of these formations and the potential discharge of wells. The analysis was performed using the QGIS Desktop 3.24.1 software, a cross-platform and free open-source geoinformation software application (GIS) that enables the viewing, editing and analyzing of spatial data and the creation of maps. The correction covered the course of the isolines on all six analyzed maps. The presented analysis made it possible to make a spot correction of the forecasted course of the isoline in relation to the maps published earlier in the *Atlas of geothermal resources in the Polish Lowlands. Mesozoic formations* developed in 2006, edited by Wojciech Górecki. Information obtained from newly drilled geothermal boreholes enabled the local correction of the forecasted values of individual parameters while maintaining the general trend.

WERYFIKACJA UWARUNKOWAŃ GEOTERMALNYCH NA NIŻU POLSKIM NA PODSTAWIE DANYCH Z NOWYCH WIERCEŃ ZREALIZOWANYCH W LATACH 2000–2022

Słowa kluczowe

Niż Polski, uwarunkowania geotermalne, strop utworów kredy dolnej, strop utworów jury dolnej, wydajność ujęć geotermalnych

Streszczenie

Celem pracy była próba weryfikacji uwarunkowań geotermalnych na Niżu Polskim (zbiornik dolnej jury i dolnej kredy) na podstawie nowych informacji geologicznych. W pracy przedstawiono uwarunkowania geotermalne na Niżu Polskim według stanu rozpoznania na koniec 2022 r. w celu aktualizacji warunków hydrogeotermalnych w wybranych regionach. Na podstawie dotychczas

opublikowanych prac naukowo-badawczych, a także zrealizowanych licznych inwestycji geotermalnych, oraz informacji geologicznej z nowych 23 wierceń poszukiwawczych zrealizowanych w latach 2000–2022 (19 z nich wykonano/udokumentowano po roku 2006), autorzy podjęli się aktualizacji prognoz zalegania stropu utworów jury dolnej i kredy dolnej, miąższości całkowitej tych utworów oraz potencjalnej wydajności ujęć geotermalnych. Analizę wykonano z wykorzystaniem oprogramowania QGIS Desktop 3.24.1, wieloplatformowego, wolnego i otwartego oprogramowania geoinformacyjnego (GIS) umożliwiającego przeglądanie, edytowanie i analizowanie danych przestrzennych oraz tworzenie map. Korekta objęła przebieg izolinii na wszystkich sześciu analizowanych mapach. Zaprezentowane analizy pozwoliły na dokonanie punktowej korekty prognozowanego przebiegu izolinii w odniesieniu do publikowanych wcześniej map w *Atlasie zasobów geotermalnych na Niżu Polskim. Formacje mezozoiku* opracowanym w 2006 r., pod redakcją naukową Wojciecha Góreckiego. Informacje uzyskane z nowo wykonanych otworów geotermalnych pozwoliły na lokalną korektę prognozowanych wartości poszczególnych parametrów przy zachowaniu ogólnego trendu.