WP2 – Deliverable 2.13

Report on storage potential of Upper Silesia

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1. Document History

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2. Executive Summary

Based on the initial screening of multiple storage sites completed in STRATEGY CCUS from an initial portfolio of eight European regions in seven countries, three regions were selected for full characterization of the storage complex, and two (including Upper Silesia region in Poland) for enhancement of knowledge on the existing CO_2 storage capacity.

Building on those results, PilotSTRATEGY aims at increasing the maturity and readiness assessment of storage resources in the Upper Silesia region. The main objective of the PilotSTRATEGY project for Poland is to increase the maturity and confidence level of storage resources to start planning as contingent resources, based on new available data, reprocessing of old data and new dynamic simulation studies.

This report summarises the work conducted as part of work package 2, task 2.8 (Storage potential of Upper Silesia region) of the PilotSTRATEGY project that contributed to this Deliverable 2.13, Report of storage potential of Upper Silesia.

Within the framework of assessment of the Upper Silesia region actions in the WP2 included an exhaustive analyses and re-interpretation of available data of the Miocene Dębowiec layers which are molasse deposits (Skoczów Deep Saline Aquifer; DSA) overlying the Upper Silesia Coal Basin of Carboniferous age; and the Jurassic Ładzice Fm (Ładzice DSA). An exhaustive review of existing data allowed the development of a conceptual geological model and the construction of a static model.

Previous research regarding the CO_2 storage potential in the Miocene Dębowiec Beds found an estimated static CO_2 storage capacity about 46.2 Mt. Here an additional area of approximately 115 km^2 named “Kęty”, was identified. The additional potential static CO_2 storage capacity was estimated at 14.3 Mt CO_2. Finally, the total static capacity of the Skoczów DSA is estimated at about 60.5 Mt CO_2 using a storage efficiency factor of 2%.

For the Jurassic Ładzice DSA of the Czestochowa District, a static calculation was not made as dynamic simulations were performed as part of PilotStrategy WP3. Based on these simulations, the maximum value of flow rate for injection is 1.25 Mt/year in optimal scenario which gives a maximum potential CO_2 storage capacity about 31.3 Mt within 25 years and a range of 29 – 33.5 Mt.

The possibilities of developing CCS in Upper Silesia were analyzed through proposed locations for pilot projects covering the two analyzed potential CO_2 reservoirs and selected CO_2 emitters. The first potential CO_2 storage site – Ładzice Deep Saline Aquifer – is located approximately 27 km from the Rudniki cement plant and about 60 km from the main emitters, including the iron and steel plant. The proposed location of the second selected pilot project in the Miocene Dębowiec Beds, including the injection well and planned 3D seismic survey area, is approximately 800 m from the location of the Kostkowice agricultural biogas plant.

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3. Introduction

This document aims to complete the deliverable 2.13, task 2.8 of work package 2 (WP2, Geocharacterization) of the PilotSTRATEGY project. Detailed description of the regional geological framework, including sedimentological, structural, stratigraphical characterization and characterization of the storage complex is presented in section 5 – Regional Geological Characterization. Storage potential within the Upper Silesia region in two analysed potential CO_2 storage reservoirs is presented in section 6. Section 7 includes a description of proposed CCUS development scenarios in the Upper Silesia region.

The objectives of PilotSTRATEGY Task 2.8 (Storage potential of Upper Silesia region), of which this report is deliverable D2.13, are:

1) To synthesise existing knowledge to create the background needed for new work;

2) To collate existing (legacy) data from Upper Silesia region, mostly well data;

3) To collect new data where required to enhance the confidence and accuracy of interpretation;

4) To synthesise existing and new data into the most detailed and accurate interpretations possible of the sedimentology, geometry, reservoir and seal characteristics of the target horizons;

5) To update information about the area and the environment of the Skoczów reservoir, supplementing existing geo-data for the reservoir with new data from newly drilled boreholes, which were made in order to better define coal deposits for the newly planned and partly already established coal mine "Bzie", and boreholes projected for geothermal purposes. The proposed work will be expanded in the future to include seismic surveys which will allow a pilot scheme to be implemented;

6) To pass the data to PilotSTRATEGY WP3 for the construction of static and dynamic reservoir models of the Dębowiec layers (Skoczów DSA) and Ładzice Fm (Ładzice DSA) (D3.2: Urych et al. 2024a; D3.3: Urych et al. 2024b);

7) To prepare geochemical data for the purposes of task 3.3 – data required for geochemical calculations and reservoir modelling of the fate of CO_2 in the long term in the Ładzice Deep Saline Aquifer (D3.4: Urych et al. 2025);

8) To analyse the range and distribution of petrophysical parameters of the reservoir in the area of the maximum range of Miocene deposits in Dębowiec layers. To identify an area with the highest potential for CO_2 storage and to calculate an additional static CO_2 storage capacity;

9) To analyse the possibilities of developing CCS in the Upper Silesia region through pilot projects covering the two analysed potential CO_2 reservoirs and selected CO_2 emitters.

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4. Location and methodology

Poland was the second largest CO_2-equivalent emitter of verified ETS emissions in 2023 in the EU with a total of 152.5 Mt of CO_2-eq (EEA GHG data viewer 2024). In 2023, approximatively, 117 Mt CO_2-equivalent was emitted from the combustion of fuels. In 2023, Poland generated nearly three-quarters (73%) of its electricity from fossil fuels, mainly from coal. Total annual CO_2 emissions in the Upper Silesia region exceeded 33 Mt (2023) with over 100 carbon dioxide emitters covered by the EU ETS and large industrial emitters (coal-fired power plants, heating plants, steelworks, coking plant). Over 90% of emissions come from approximately 15 large hard coal power plants and from the coke and metallurgical complex. Air pollution is associated with the industrial sector and household heating. Electricity and heat are produced mainly from hard coal and natural gas, although the share of renewable energy sources is increasing. The energy source in Poland is mainly from coal, however as the country has important agricultural activity, biogas could play a significant role in the energy transition.

A CCUS scenario for Upper Silesia, which encompasses emitters, capture plants, transport routes, as well as utilisation and storage sites until 2050, was developed in 2022 (Śliwińska et al., 2022). The baseline scenario assumes capture of carbon dioxide in seven installations, use of the CO_2 in two methanol plants and transport and injection into two deep saline aquifers (DSA). The proportion of captured CO_2 from flue gas was assumed at the level of 25 – 90 %, depending mainly on the limited capacity of storage (Śliwińska et al. 2022; Table 4.1). To recognise the views of society on development of the CCUS technologies in Upper Silesia, thirteen interviews with different types of stakeholders (industry, research and education, policy makers) were conducted. The respondents evaluated CCU as much better than CCS.

The techno-economic assessment of CCUS carried out on a scenario basis showed that the economic outcome of the scenario with CCUS is EUR 3807.19 million more favourable compared to the scenario without CO_2 capture and storage.

Table 4.1: *The long-term baseline scenario assumptions - up to 2050 (Śliwińska et al. 2022)*

Emitter	CO_2 Captured to 2050 (Mt)	% of CO_2 Captured	Period	CO_2 Transport	Captured CO_2 (Mt/y)	Destiny
Combined heat and power plant Tychy	4.77	90%	2025–2050	rail	0.18	Methanol-chemical plant
Zakład Wytwarzania Nowa	17.53	25%	2027–2047	pipeline	0.84	Storage (Jurassic Ładzice DSA of the Czestochowa District)
New Jaworzno	24.68	25%	2027–2047	pipeline	1.18	

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Emitter	CO_2 Captured to 2050 (Mt)	% of CO_2 Captured	Period	CO_2 Transport	Captured CO_2 (Mt/y)	Destiny
New Rybnik	24.00	50%	2027–2050	pipeline	1.00	Storage (Miocene Dębowiec Beds)
IGCC Łaziska	15.75	75%	2030–2050	pipeline	0.75	
Power Plant of Coke Plant 'Przyjaźń'	5.50	90%	2025–2050	pipeline	0.32	Utilization (Methanol JSW plant)
Combined heat and power plant of Coke Plant 'Przyjaźń'	2.95	90%	2025–2050			

Based on the initial screening of multiple storage sites completed in the STRATEGY CCUS project, two regions in Upper Silesia were selected for full characterization of the storage complex in the PilotSTRATEGY project (Figure 4.1). The best conditions in this region are present in DSA in the Miocene deposits of the Dębowiec Beds (StorageUnit-03 in Figure 4.1). Storage capacity has also been identified in Ładzice DSA in deposits of the Jurassic Czestochowa District (SU-04 in Figure 4.1). Estimated storage capacity for two unmineable coal beds (UCB) areas located in the Pawłowice-Mizerów (SU-02) and Studzienice-Międzyrzecze (SU-01) is relatively small, however, it can be exploited by the local industry along with methane extraction (ECBM).

Within the framework of assessment of the Upper Silesia region, actions in WP2 included an exhaustive analysis and re-interpretation of available data of the Dębowiec layers (Skoczów DSA) and Ładzice Fm (Ładzice DSA) – Figure 4.1. A review of existing data fed the conceptual geological model and was used to start building the static model.

Two possible storage areas have been identified in the region in deep saline aquifers with potential CO_2 storage capacity of 0.1 Gt:

- Skoczów DSA - Upper Silesian Coal Basin, Miocene
- Ładzice DSA - Jurassic Czestochowa District.

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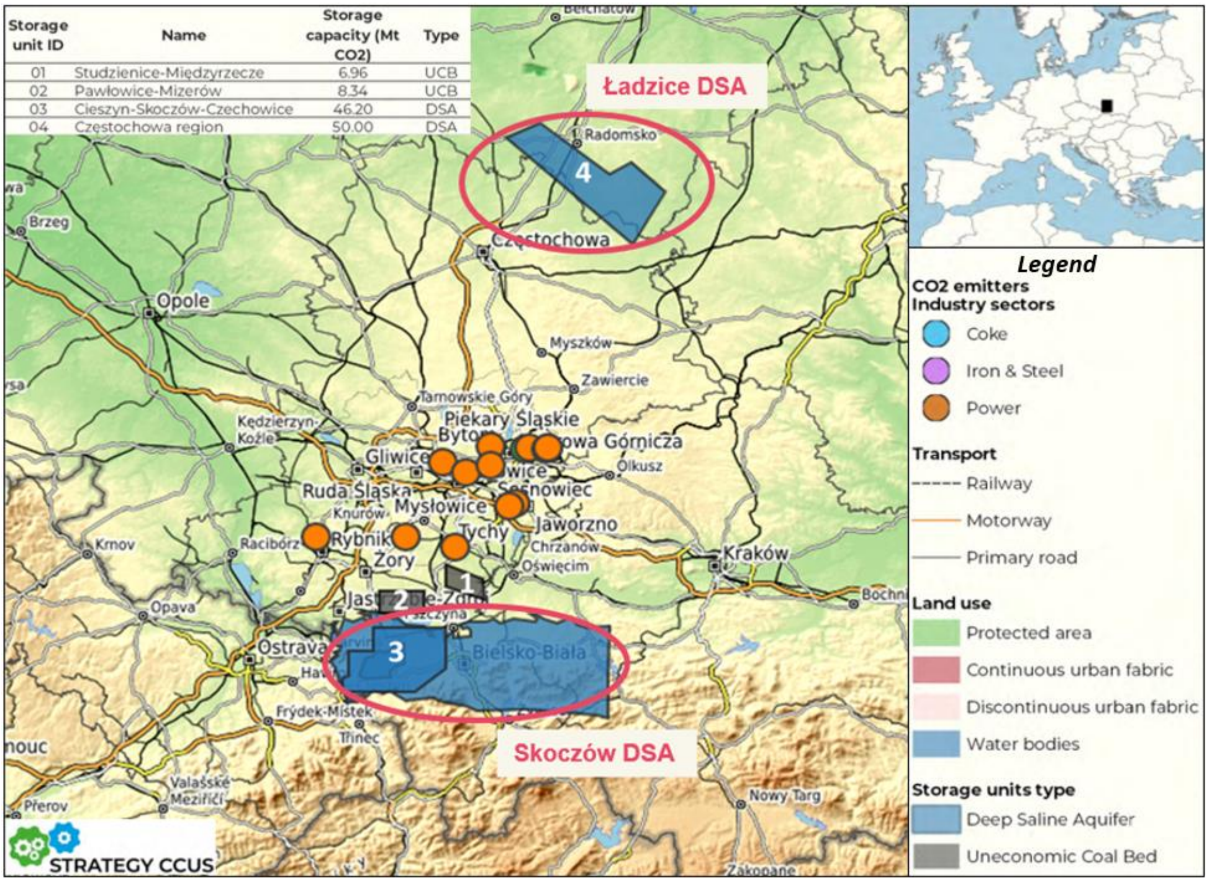

Figure 4.1: Location of the main potential storage units in Upper Silesia (STRATEGY CCUS, 2020)

The objective of PilotSTRATEGY project for Poland is to increase the maturity and confidence level of storage resources to start planning as contingent resources, based on newly available data, reprocessing of old data (WP2) and new dynamic simulation studies (WP3). The research in relation to the analysis of the potential to CCUS development in the Upper Silesia region were focused on enhancing the maturity and confidence level of CO_2 storage resources by studying new data, reprocessing current data within the framework of WP2 (Geo-characterization, Task 2.1 Compilation of existing data and choice of pilot locations, and Task 2.8 Storage potential of Upper Silesia).

Within the framework of task 2.1. for the Upper Silesia region, data has been acquired and re-interpreted in order to advance the understanding of the prospects for CO_2. Progress was made in the study of two deep saline aquifers and work included:

1. Upper Silesian Coal Basin (Skoczów DSA) progress:
    - compilation of additional well data;
    - lithologies in the boreholes;
    - hydrogeological parameters (porosity, permeability);
    - digital Well Log data (Log ASCII Standard - LAS).
    - works included preparing data regarding parameters of reservoir fluids such as properties of reservoir water, mineralization and other in order to provide inputs for reservoir modeling.

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2. Jurassic Częstochowa District (Ładzice DSA) progress:
- compilation of additional well data:
- compilation of lithologies in 10 boreholes
- part of wells with petrophysical data
- part of wells with porosity (effective), permeability,
- mineralization data, properties of reservoir water.

Within the framework of the first part of task 2.8 (Storage potential of Upper Silesia), structural surfaces in the area of the Jurassic Częstochowa District/Ładzice DSA reservoir have been developed including the analysis of the depth, thickness and structural framework of reservoir deposits.

Two candidate areas were identified for the Jurassic Ładzice formation. Based on data availability and parameter values of reservoir layers, the area named "Pągów-Milianów" with an area of approximately 190 km^2 was selected for further work. A detailed characterization of reservoir formations and sealing layers in the selected area was prepared. Additional well data were analyzed and prepared for the needs of 3D static modelling (Task 3.1). The range and distribution of petrophysical parameters of the reservoir were analyzed in the area of the maximum range of Miocene deposits in Dębowiec layers. An additional area named "Kęty" with the highest potential for CO_2 storage was identified. The selected area of approximately 115 km^2 is being analyzed in detail for storage of carbon dioxide within the framework of tasks 2.8 and 3.1.

Regarding the methodology used in geo-characterization of Upper Silesia region, firstly works were focused on understanding of regional geology of sedimentary basins (Figure 4.2). The next step was well data analysis which included mainly:

a. Compilation of existing data,
b. Well petrophysics,
c. Well log data analysis.

The final step of work was preparation of elements of geological conceptual models based on the results of previous works. All collected data will be used for creating static reservoir models and dynamic simulations in WP3. The same steps of analysis were used for both selected DSA's.

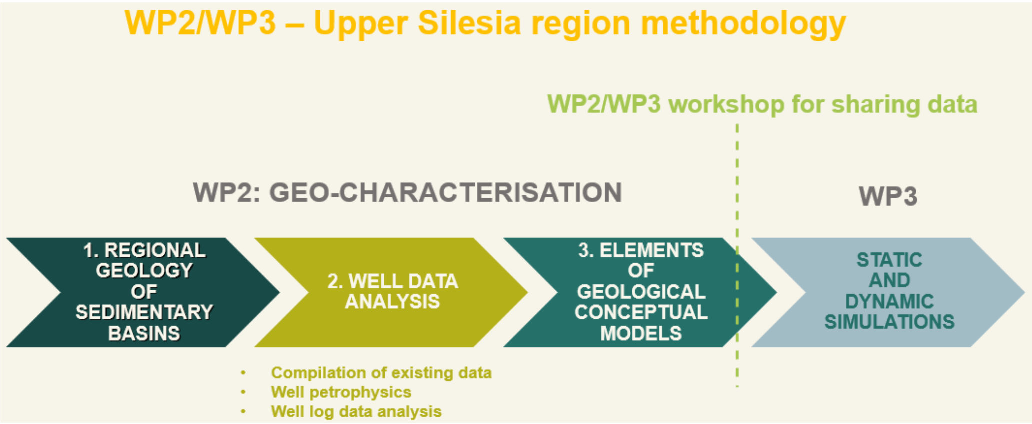

Figure 4.2: WP2/WP3 Upper Silesia region methodology

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5. Regional Geological Characterisation

5.1 Skoczów DSA - the area of Dębowiec layers

Based on stratigraphic and hydrogeological analysis, the most prospective conditions for potential storage of CO_2 are present in deep saline aquifers in the Miocene deposits of the Dębowiec Beds which is located in the southern part of Upper Silesia region (Figure 5.1).

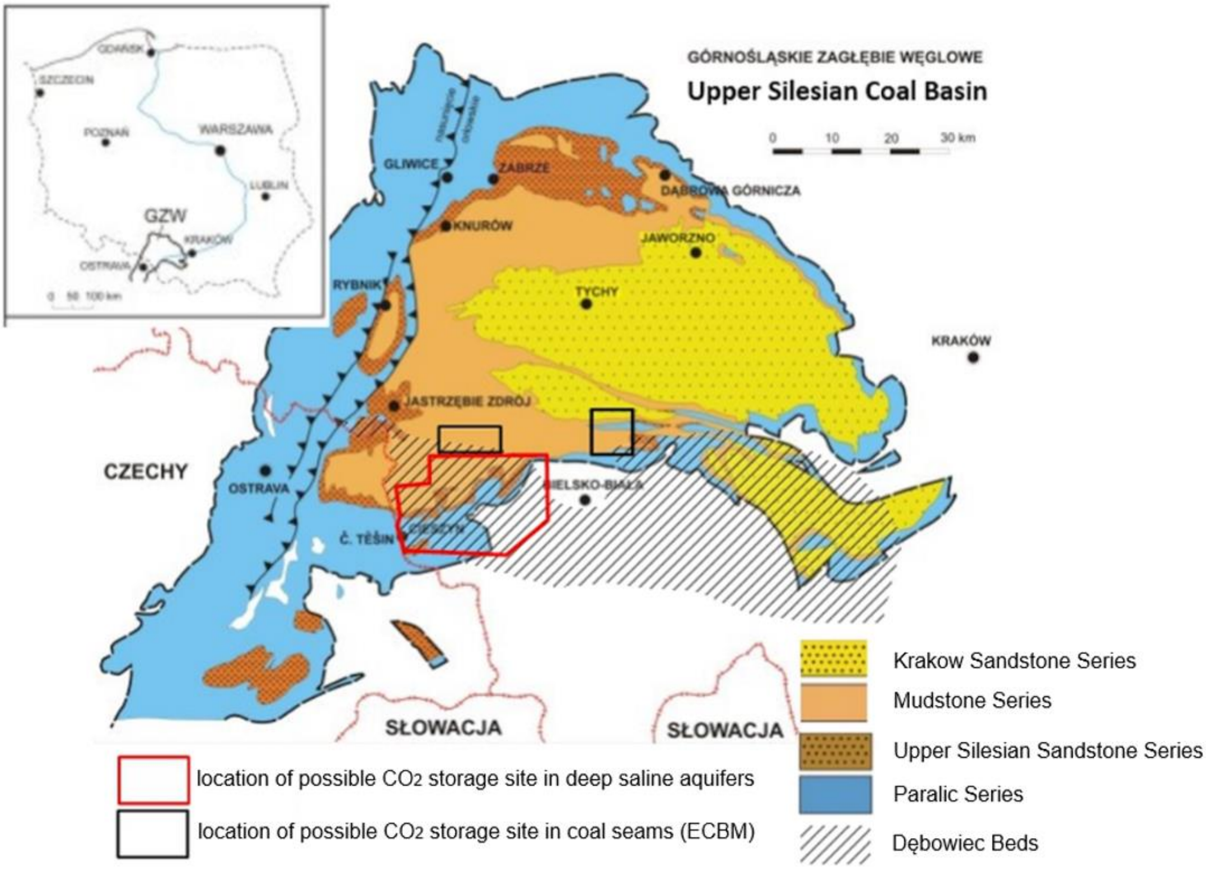

Figure 5.1: The Miocene deposits of the Dębowiec Beds located in the southern part of Upper Silesia Coal Basin

The Dębowiec formation is a Miocene macroclastic molasse composed of two lithofacies: conglomerates and sandstones (Figure 5.2). The Zamarskie beds occur locally at the base of the Dębowiec formation and are composed mainly of olistostromes. Potential geological targets for carbon dioxide storage in the USCB region also include the top part of the lower Carboniferous carbonate strata and the terrigenous strata of the Lower Devonian and Cambrian; however, these series are located at great depths (usually significantly exceeding 2000 m) and are very poorly characterised.

In the area of the Upper Silesian Coal Basin (USCB) the Dębowiec beds (lower Miocene sandstones) were chosen as prospective formation for the purposes of CO_2 storage in deep saline aquifers. The coverage of the study area with wells penetrating Miocene and its basement is relatively dense, but cores were preserved for only a few wells. Well logging data are available in virtually all the deep boreholes, but the interpretation of lithology and petrophysical parameters was conducted only for

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a few, because the area was explored for hard coal resources in the Upper Carboniferous than, for example, to determine the properties of the overlying Miocene strata.

In the vertical profile of the Dębowiec layers gradation is observed, from the thickest in the bottom part (coarse-grained conglomerates) to fine in the top (fine-grained sandstones). The thickness of the Dębowiec Beds is variable and is usually in the range from 50 to 250 m (Figure 5.3). In the case of the sandstone and conglomerate formations of Dębowiec beds the average effective porosity is only slightly higher than 10% (the minimum for geological storage) and average permeability of about 40 mD. Similar properties are characteristic for Zamarskie beds (of a small thickness) occurring locally underneath (Figure 5.2).

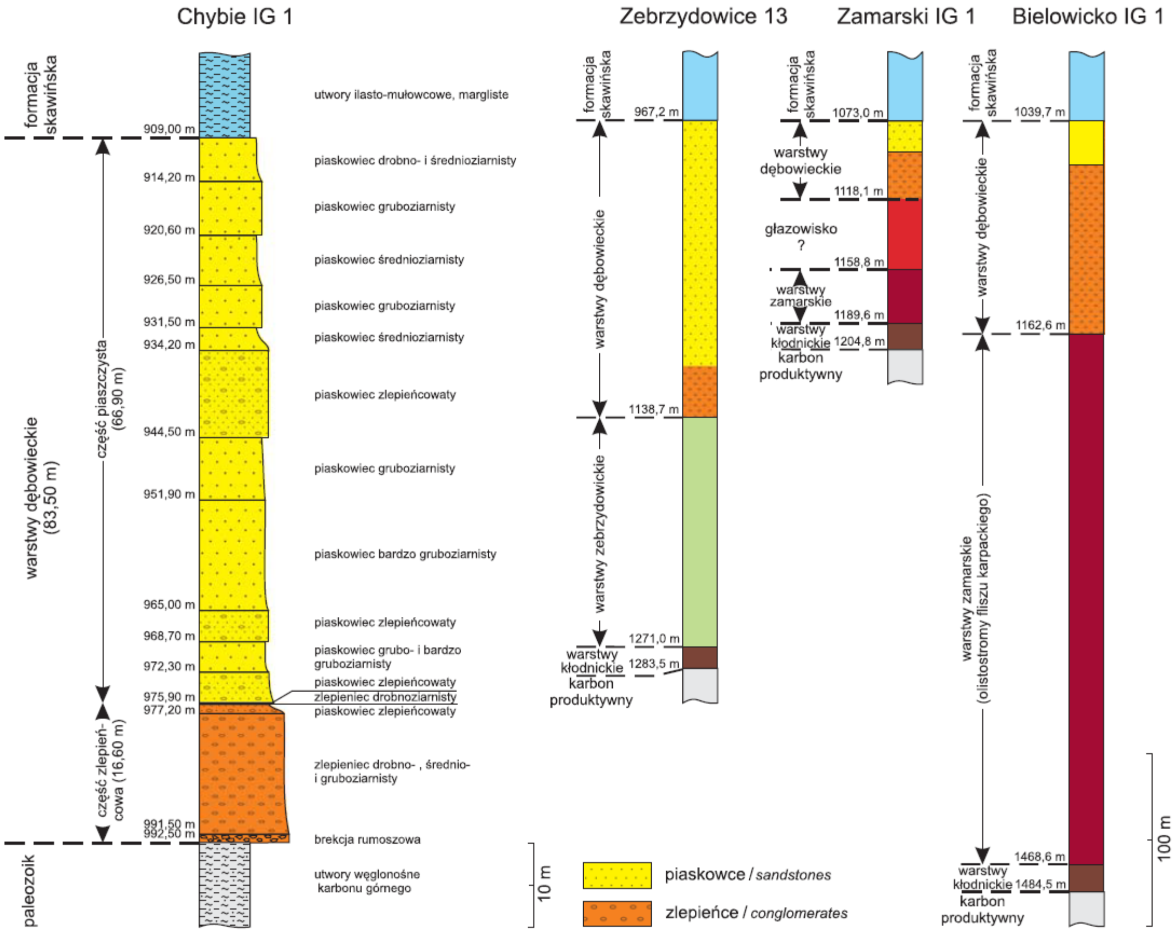

Figure 5.2: Profiles of Dębowiec Beds and Miocene strata basement (Jureczka et al., 2012)

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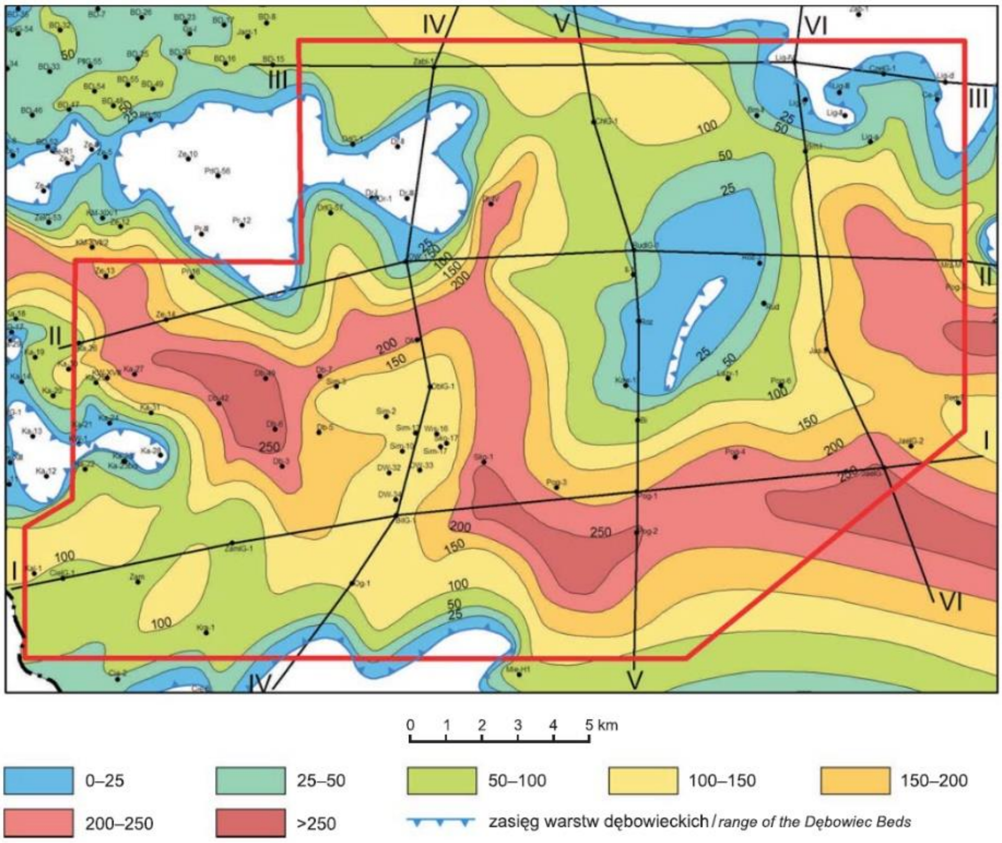

Figure 5.3: Thickness of Dębowiec Beds in the Cieszyn-Skoczów-Czechowice area (Jureczka et al., 2012)

5.1.1 Extension of the analysed Miocene aquifer area

Important work has been done to extend the area of the analyzed aquifer to the maximum range of Miocene deposits in the area of Dębowiec layers (Figure 5.4) in order to identify the maximum storage capacity. This is based on the compilation of existing data with data location using maps and analysis of data uncertainty and of different degrees of geological exploration (Figure 5.5).

Figure 5.4: The maximum range area of the Dębowiec layers

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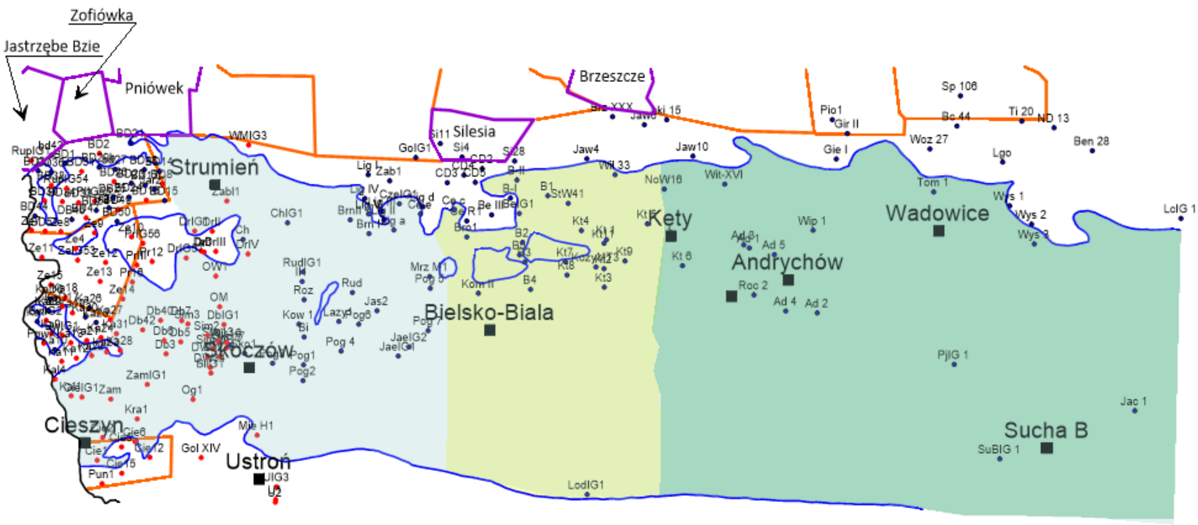

Figure 5.5: Different degree of geological exploration in the maximum range area of the Dębowiec layers

Work has included analysis of the structural model of the storage formations based on data from 14 additional wells and updating of the structural model in the area of the maximum range of the Dębowiec layers (updating the main zones in the east part of the model; Figure 5.6).

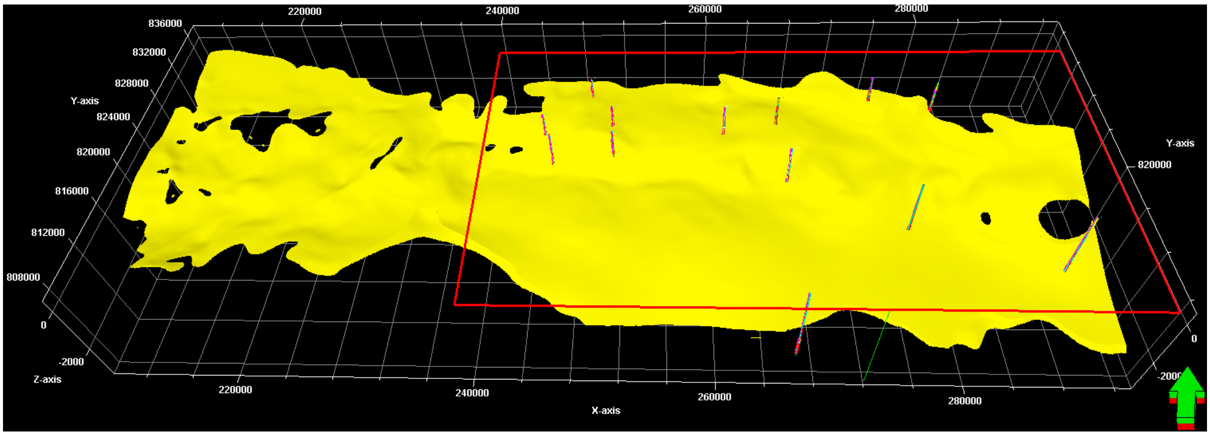

Figure 5.6: The eastern part of the model with additional wells

Static 3D models were carried out using the Schlumberger Petrel software (Schlumberger Information Solutions, 2010) with Geoscience Core and Reservoir Engineering Core. Available well data were loaded into the model and discretized (well log upscaling) in order to assign properties to the cells which are penetrated by wells. 14 additional LAS format log files with porosity and shale content (Vshale) data were loaded into the model in order to perform upscaling and petrophysical modelling (Figure 5.7).

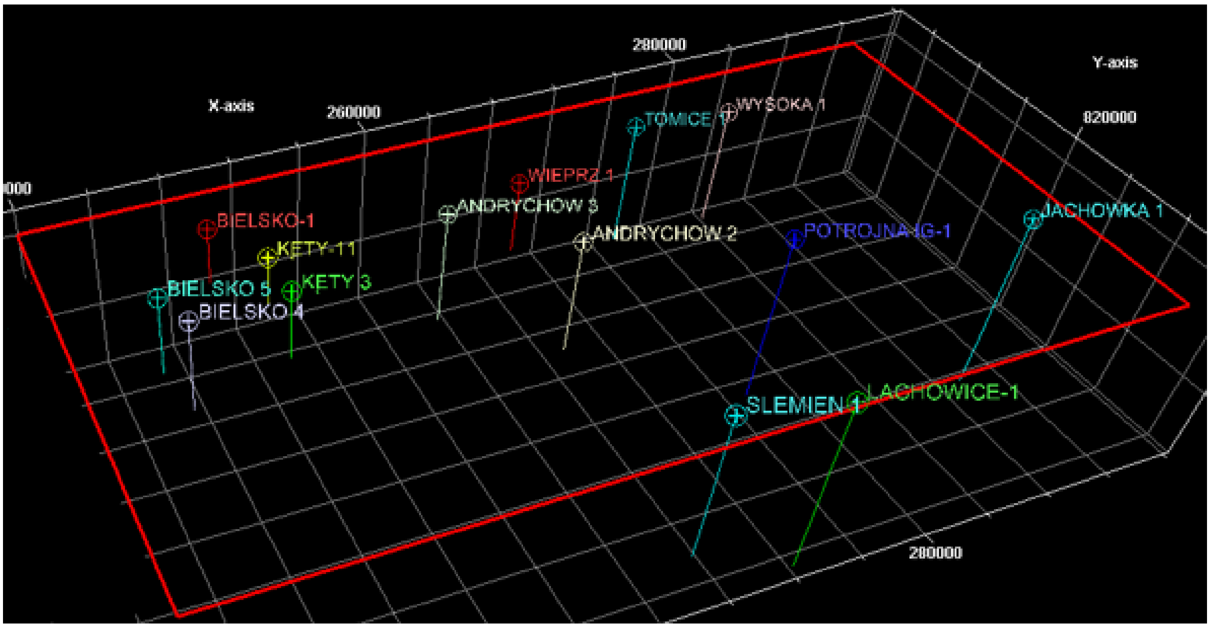

Figure 5.7: Additional wells in the area of eastern part of the model

5.1.2 Well data analysis

For the Dębowiec formation, in the Skoczów reservoir site, data from new boreholes have been acquired and all data have been re-interpreted in order to advance the understanding of the prospects for CO_2 storage. Location of new boreholes and example of the borehole profiles with lithological, petrophysical (porosity, permeability) and hydrogeological data are presented in Figure 5.7 and Figure 5.8. Moreover, compilation of petrophysical parameters from eastern part of Dębowiec layers analysed earlier also has been prepared.

Works included preparing data regarding parameters of reservoir fluids such as properties of reservoir water, mineralization and other in order to provide inputs for reservoir modeling within the framework of WP3.

Sources of data:

- Database of Polish Geological Institute – National Research Institute;
- Other available data from literature, reports, scientific papers, websites and other reputable sources.

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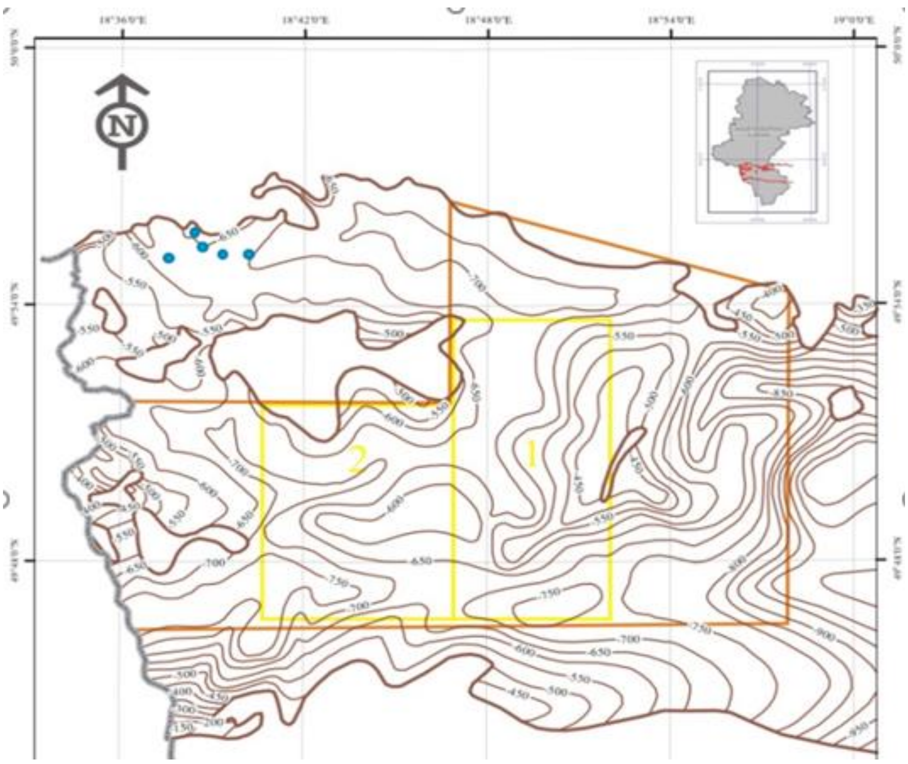

Figure 5.7: Location of new boreholes

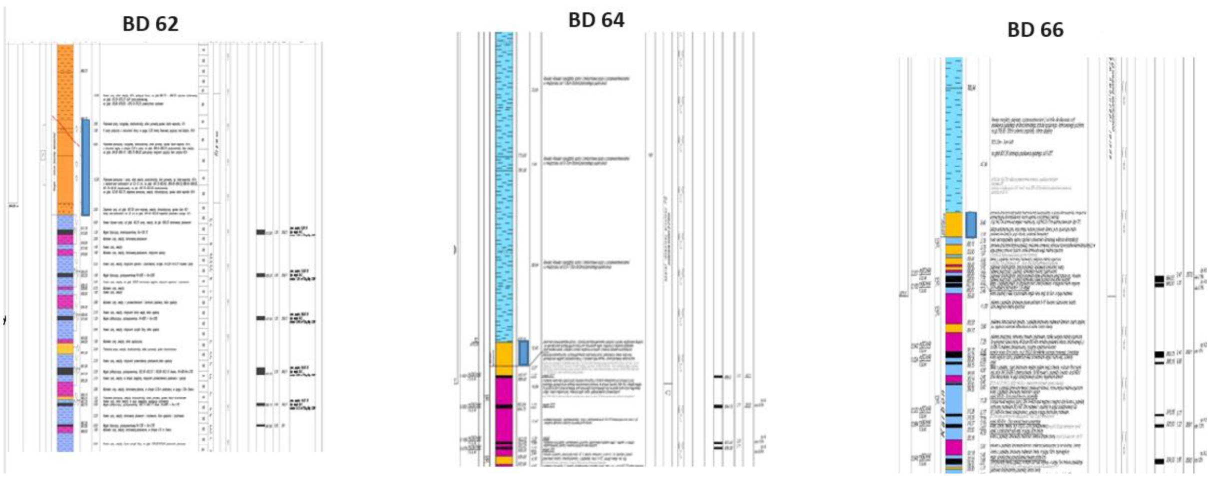

Figure 5.8: Example of well profiles with lithological data

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5.1.3 Available data shared in LAS files

The examples of available digital well log data (Log ASCII Standard - LAS) are presented in Figure 5.9 and Figure 5.10. Stratigraphic inter-well correlations developed in previous works were also prepared (Figure 5.11 and Figure 5.12).

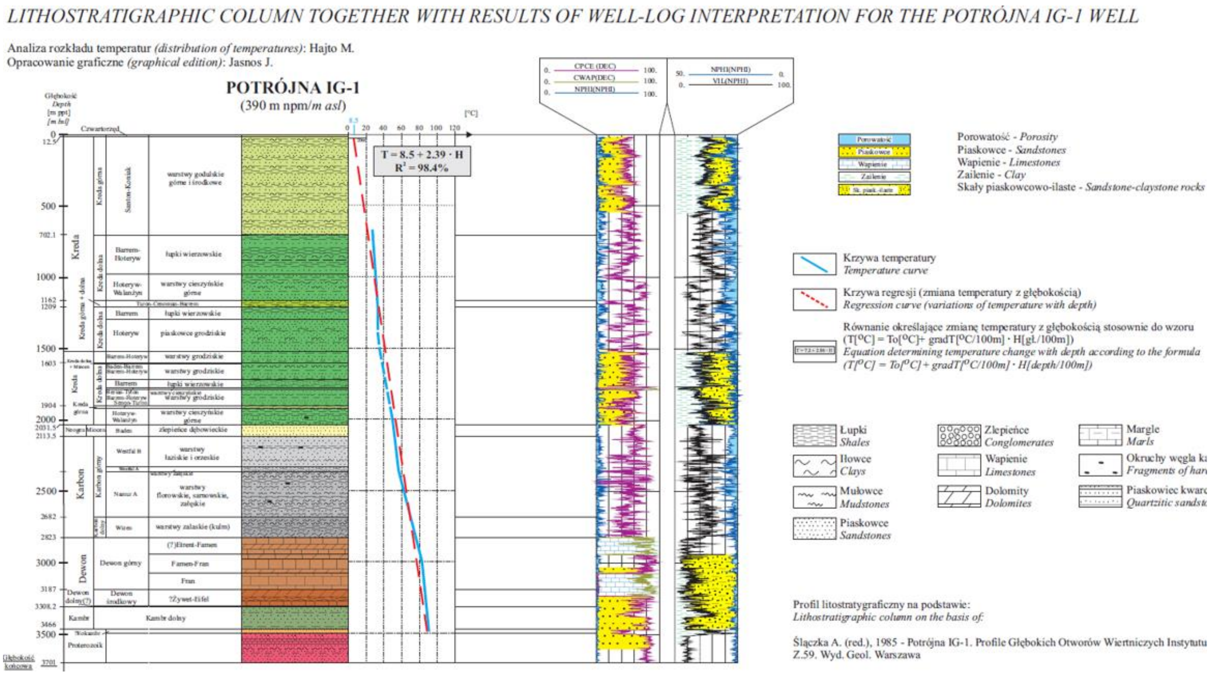

Figure 5.9: Lithostratigraphic column with results of well-log interpretation for the Potrójna IG-1 well (Ślączka, 1985)

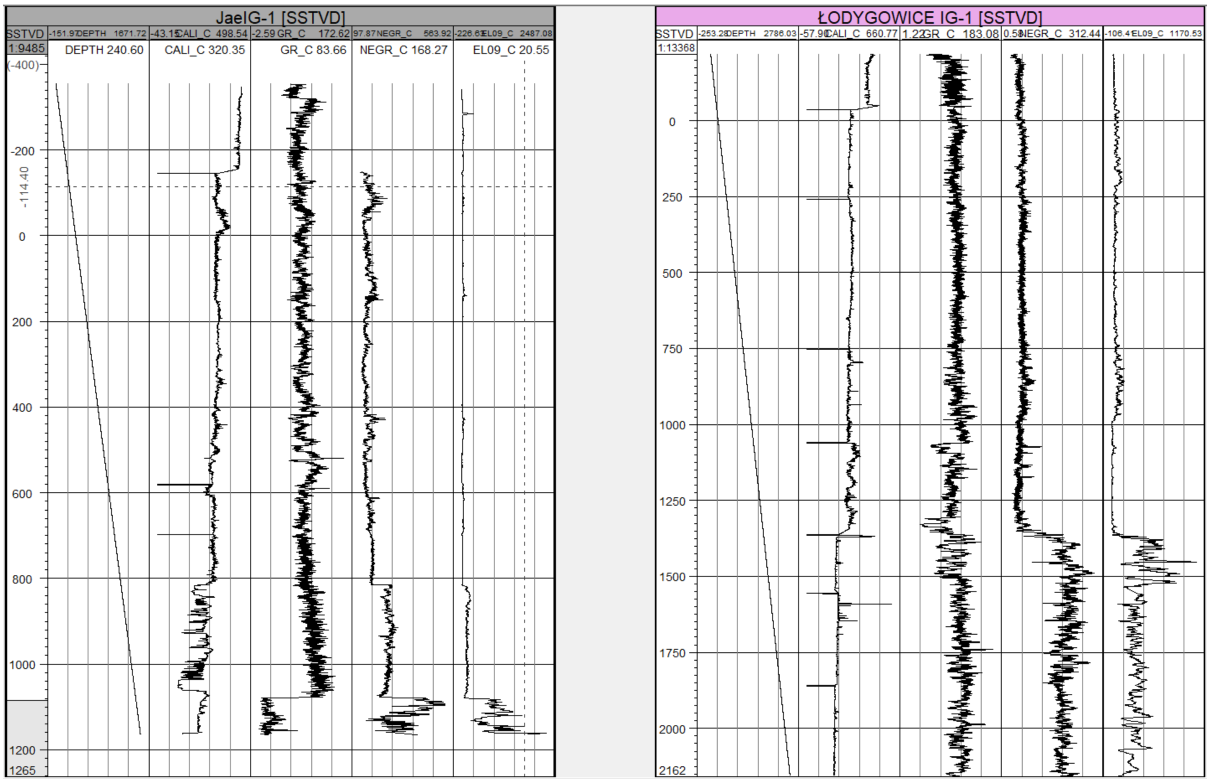

Figure 5.10: Example of well-log LAS data (Log ASCII)

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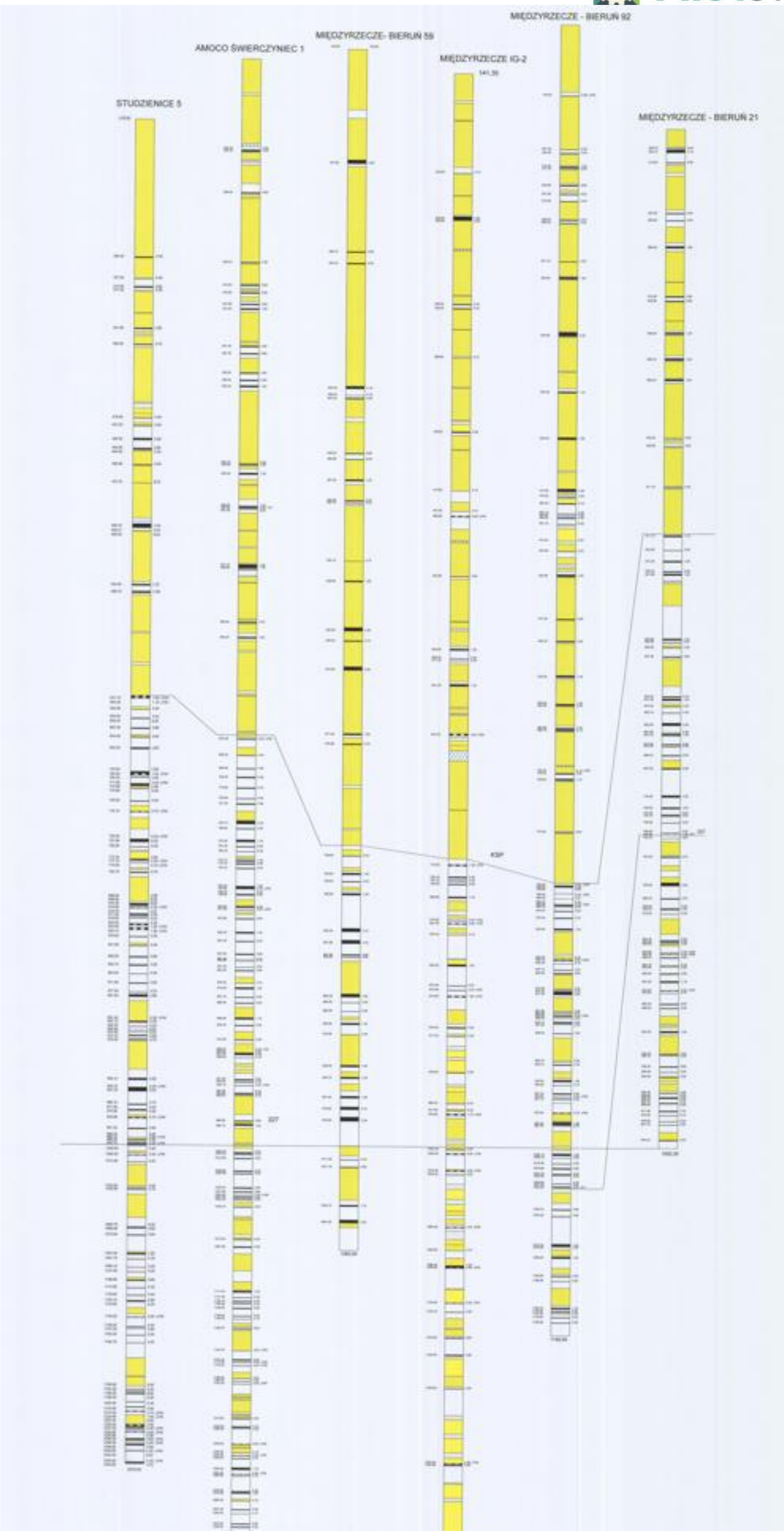

Figure 5.11: Example of stratigraphic inter-well correlations

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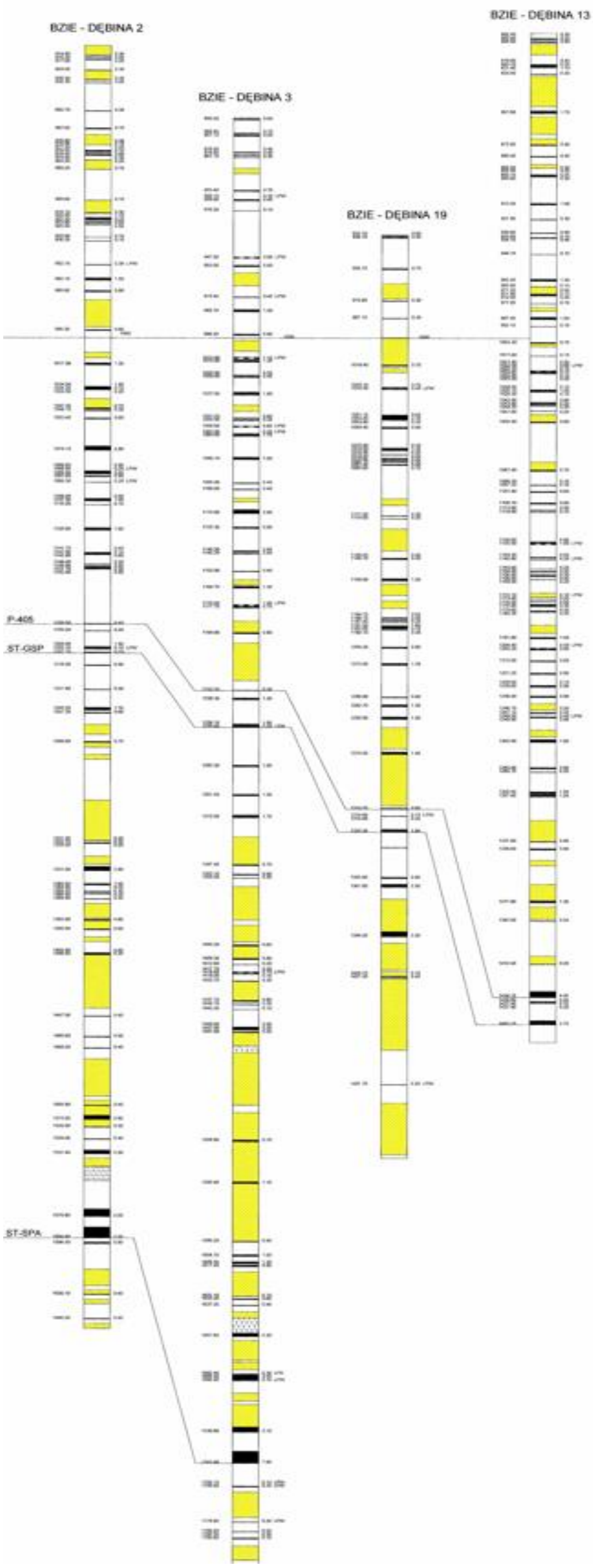

Figure 5.12: Example of stratigraphic inter-well correlations

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5.1.4 Geo-characterization of the storage complex zone

Characterizing the geological aspects of the storage complex (reservoir, caprock and structural elements; Figure 5.13) data analysis and re-interpretation of the maximum range area of the Dębowiec layers has produced the following maps:

- map of the thickness in the area of the maximum range of the Dębowiec layers (Figure 5.14),
- structural map of the top of the Dębowiec layers (Figure 5.15),
- structural map of the top of the Palaeozoic formations (Figure 5.16, Figure 5.17).

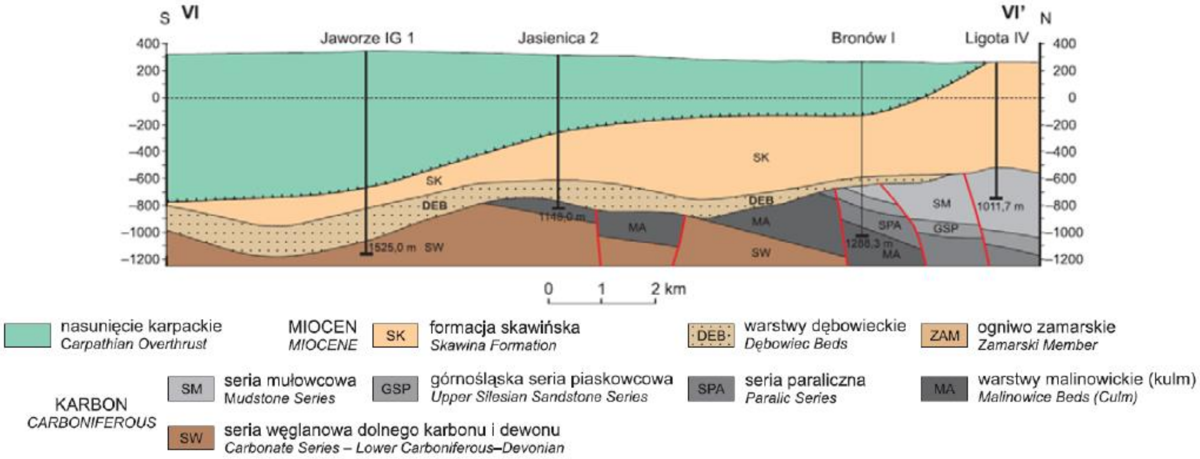

Figure 5.13: Geological cross-sections in the area of the maximum range of the Dębowiec layers (Jureczka et al., 2012)

The average thickness of the Dębowiec layers is 100-150 m (max: 265 m).

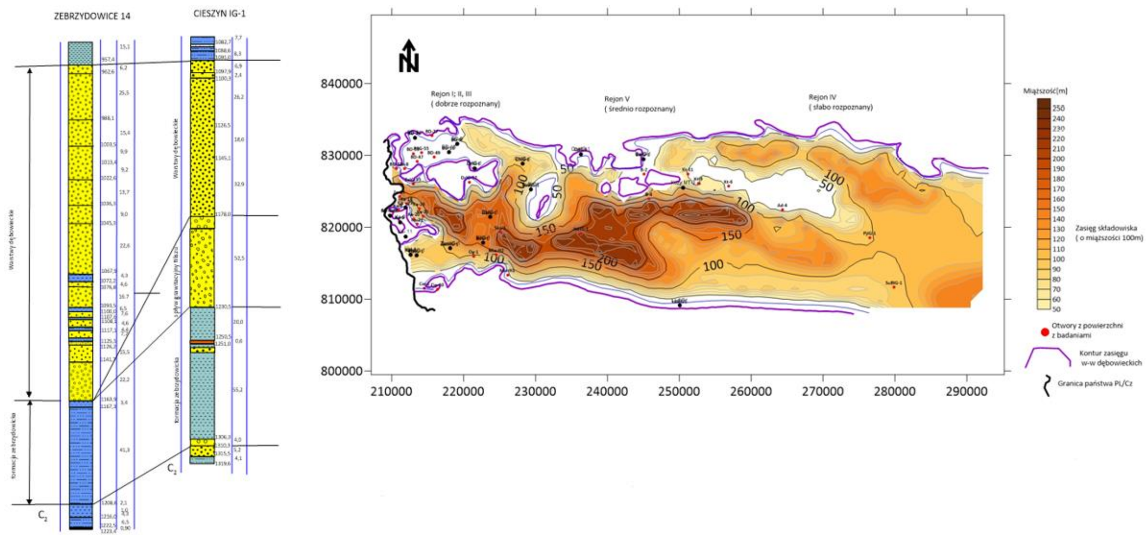

Figure 5.14: Map of the thickness in the area of the maximum range of the Dębowiec layers

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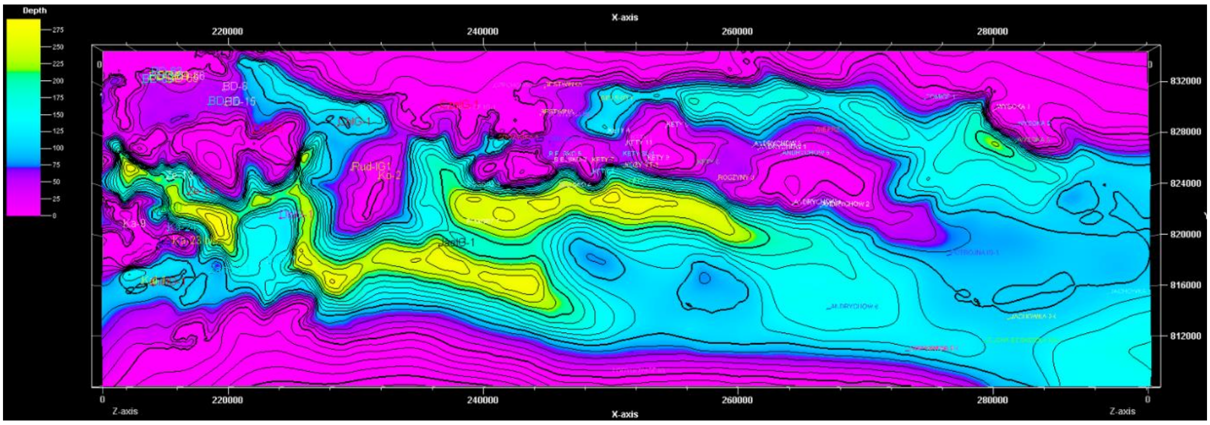

Figure 5.15: Structural map of the top of the Dębowiec layers in model

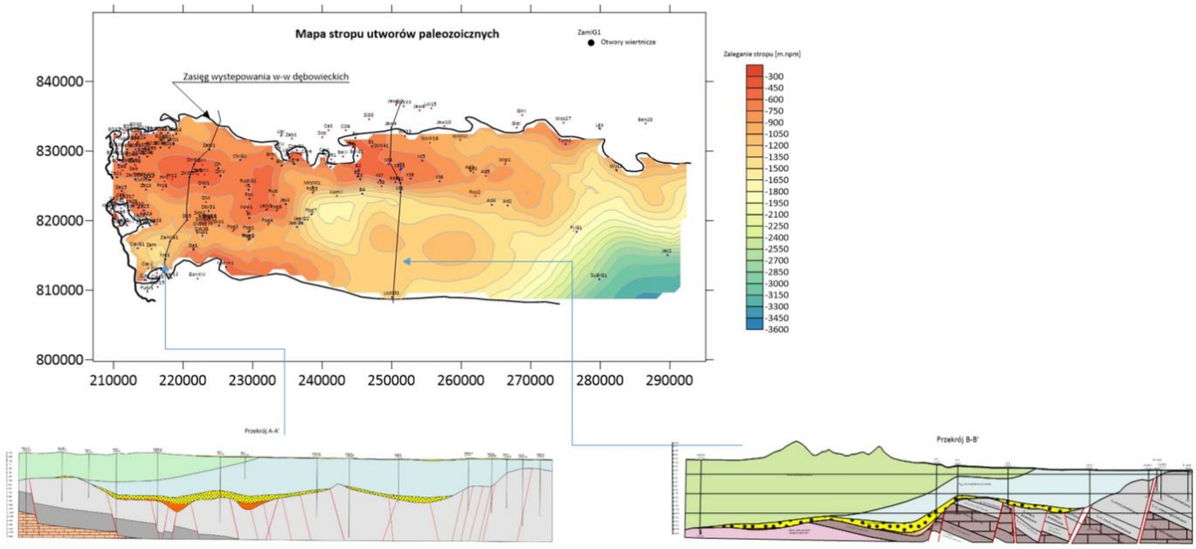

Figure 5.16: Structural map of the top of the Palaeozoic formations with cross-sections

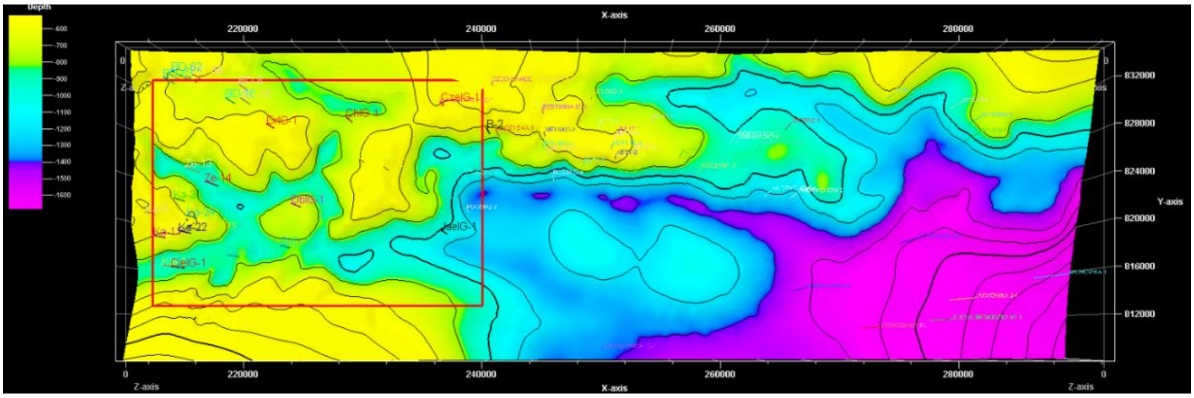

Figure 5.17: Structural map of the top of the Palaeozoic formations with cross-sections in model

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Based on stratigraphic and hydrogeological analysis, the most prospective conditions for potential storage of CO_2 are present in deep saline aquifers in the Miocene deposits of the Dębowiec Beds which is located in the southern part of Upper Silesia region.

Faults occur only in deep layers underlying the potential reservoir - faults do not continue in the layers of reservoir nor above the reservoir (Figure 5.18, Figure 5.19).

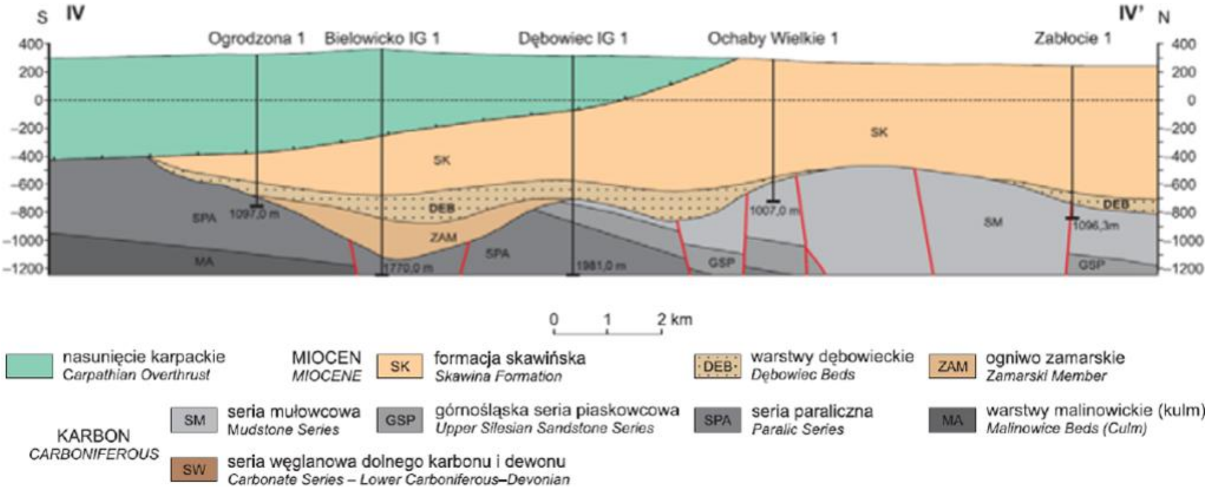

Figure 5.18: Geological cross-sections in the area of the maximum range of the Dębowiec layers (Jureczka et al., 2012)

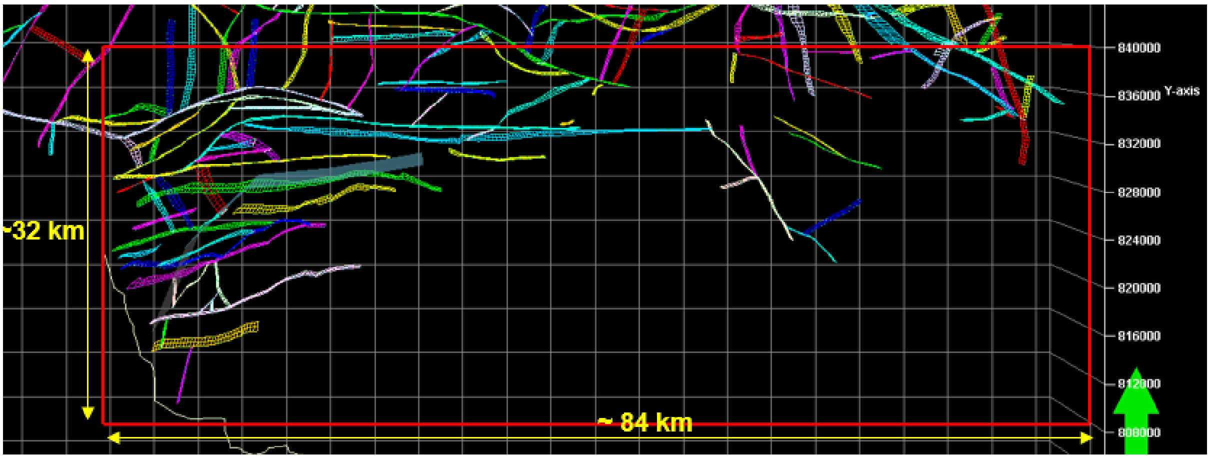

Figure 5.19: Fault and fracture framework (fault model)

The geological models of the storage complex zone consist of reservoir, caprock and structural elements. The structural model consists of the main geological horizons for this area including:

- structural maps of the top and the bottom of the Dębowiec layers (Figure 5.20),
- other horizons in the overburden of the reservoir (units in the zone of the Carpathian overthrust) - Figure 5.21, Figure 5.22.

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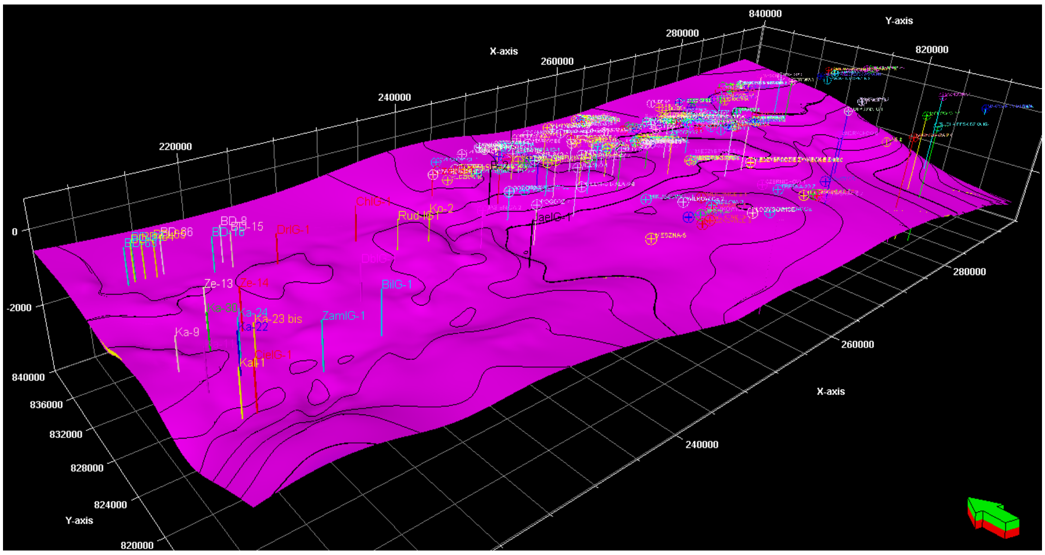

Figure 5.20: Structural maps of the top of the Dębowiec layers

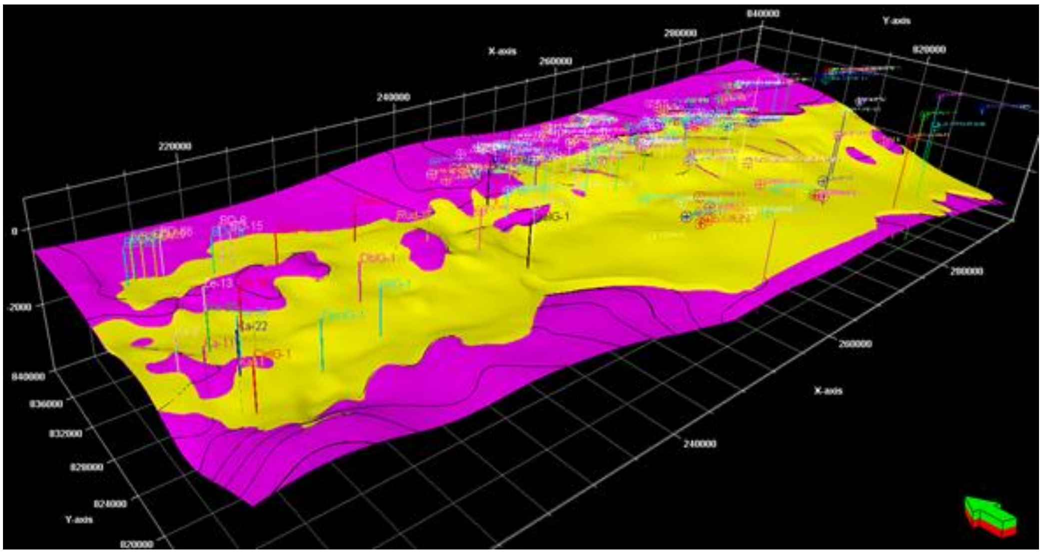

Figure 5.21: Geological grid of the Dębowiec layers

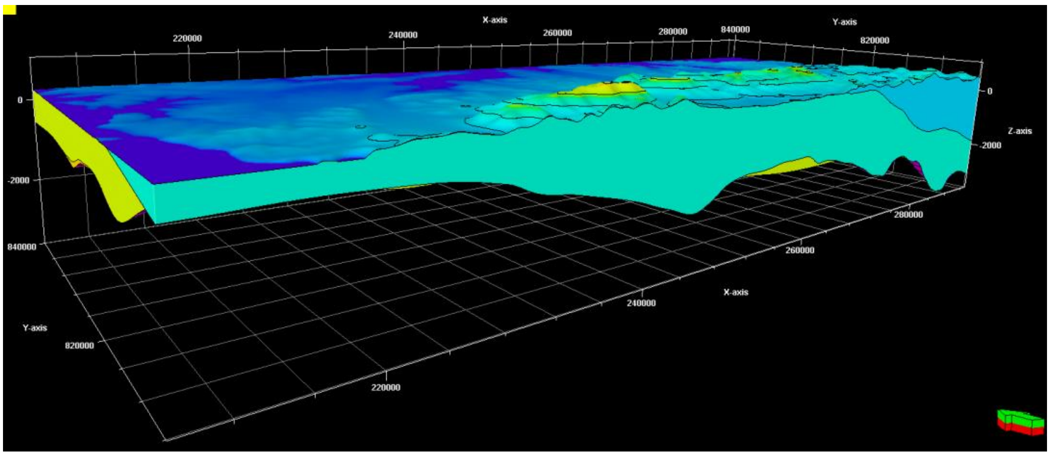

Figure 5.22: Model of the overburden of the reservoir layer

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5.2 Jurassic Czestochowa District (Ładzice DSA)

5.2.1 Regional geology of sedimentary basins

Potential CO_2 storage capacity has also been identified in DSAs in marine deposits of the Jurassic Radomsko District (Ładzice DSA). This potential CO_2 storage reservoir, about 100 km away from the main emitters is here treated as the second possible option for CO_2 storage in the Upper Silesia region (see Figure 5.23).

Reservoir formations of Ładzice (DSA) are associated with water-saturated sediments of the Lower Jurassic and the lower stages of the Middle Jurassic (Figure 4.10). The aquifer is made up of sandstones with a fine- to coarse-grained structure as well as poorly-sorted sandstones. The top of the sediments is located at a depth of 1000 to 1500 m. The overburden is formed by a continuous layer of poorly permeable Middle and Upper Jurassic formations (marls, clays, claystones and mudstones) are 350 - 620 m thick. The area of the potential reservoir is relatively poorly explored in terms of hydrogeology. Test results indicated porosity from 7.69 to 22.1% and permeability from 16 to 1478 mD.

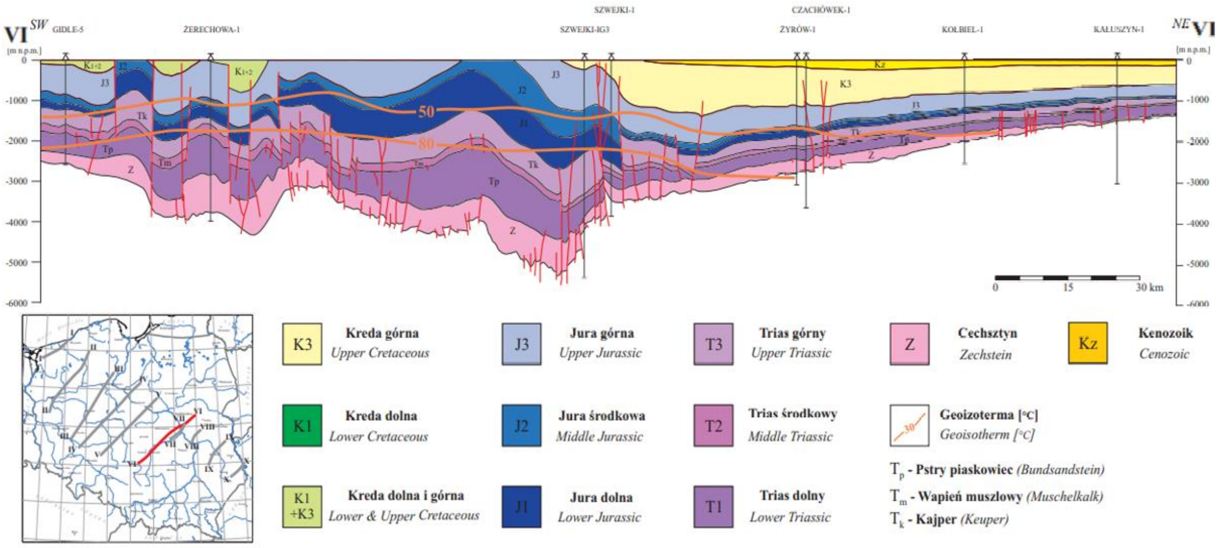

Figure 5.23: Geological cross-sections in the area of the Jurassic sediments

5.2.2 Well data analysis

Location of boreholes and example of the borehole profiles with facies data are presented in Figure 5.24 and Figure 5.26.

Location of boreholes with petrophysical (porosity, permeability) data are presented in Figure 5.25. Work for this project included preparing data regarding parameters of reservoir fluids such as solute content (Figure 5.27) to provide inputs for reservoir modeling.

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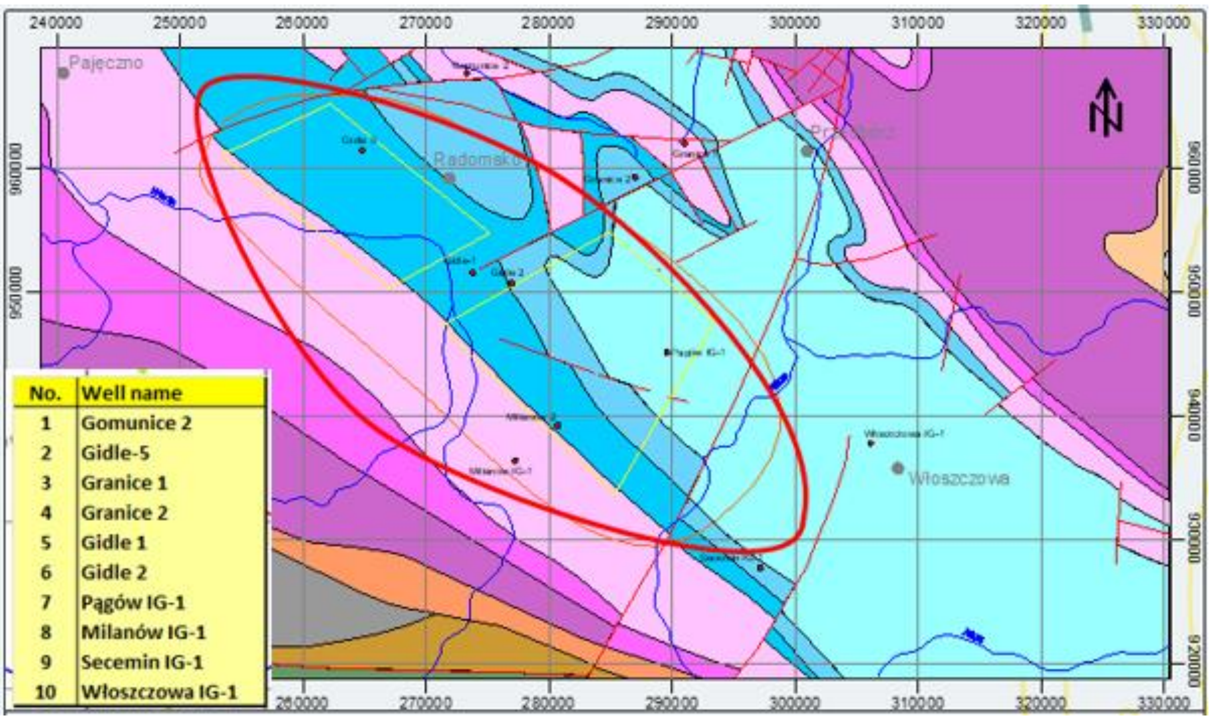

Figure 5.24: Geological map with location of boreholes

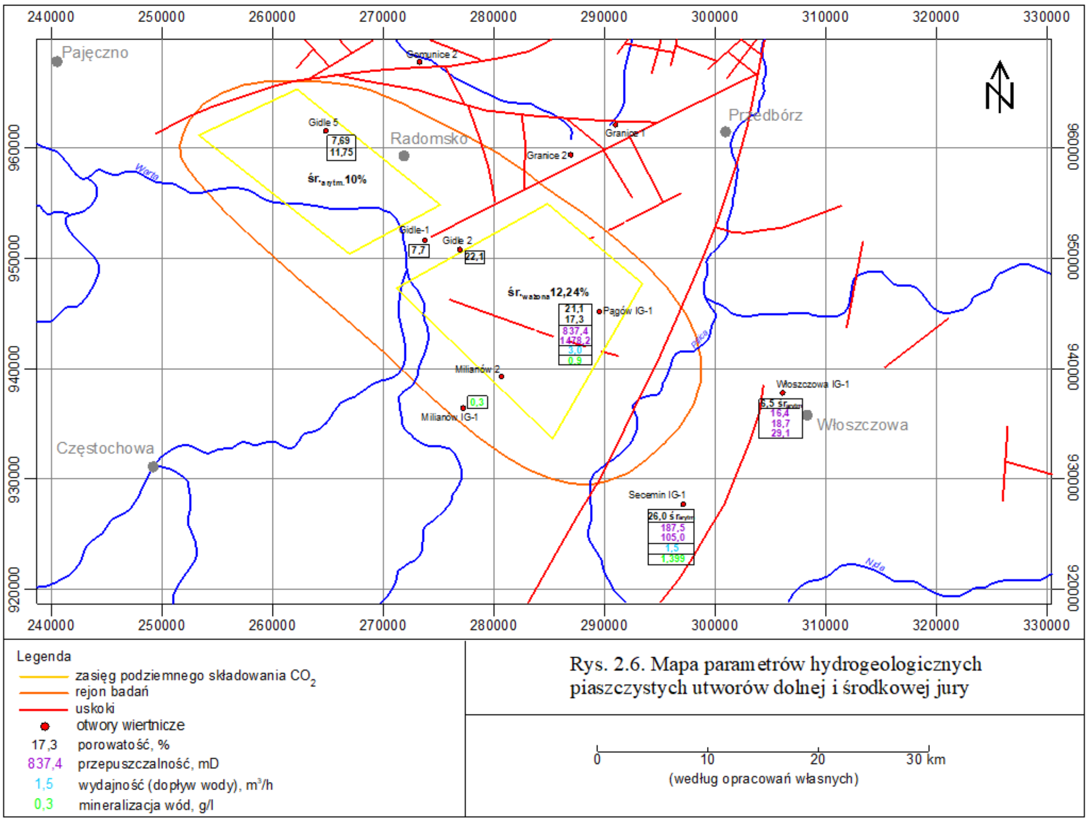

Figure 5.25: Map of hydrogeological properties of sandstones of Lower and Middle Jurassic - only part of wells with available petrophysical data (Wachowicz et al., 2010)

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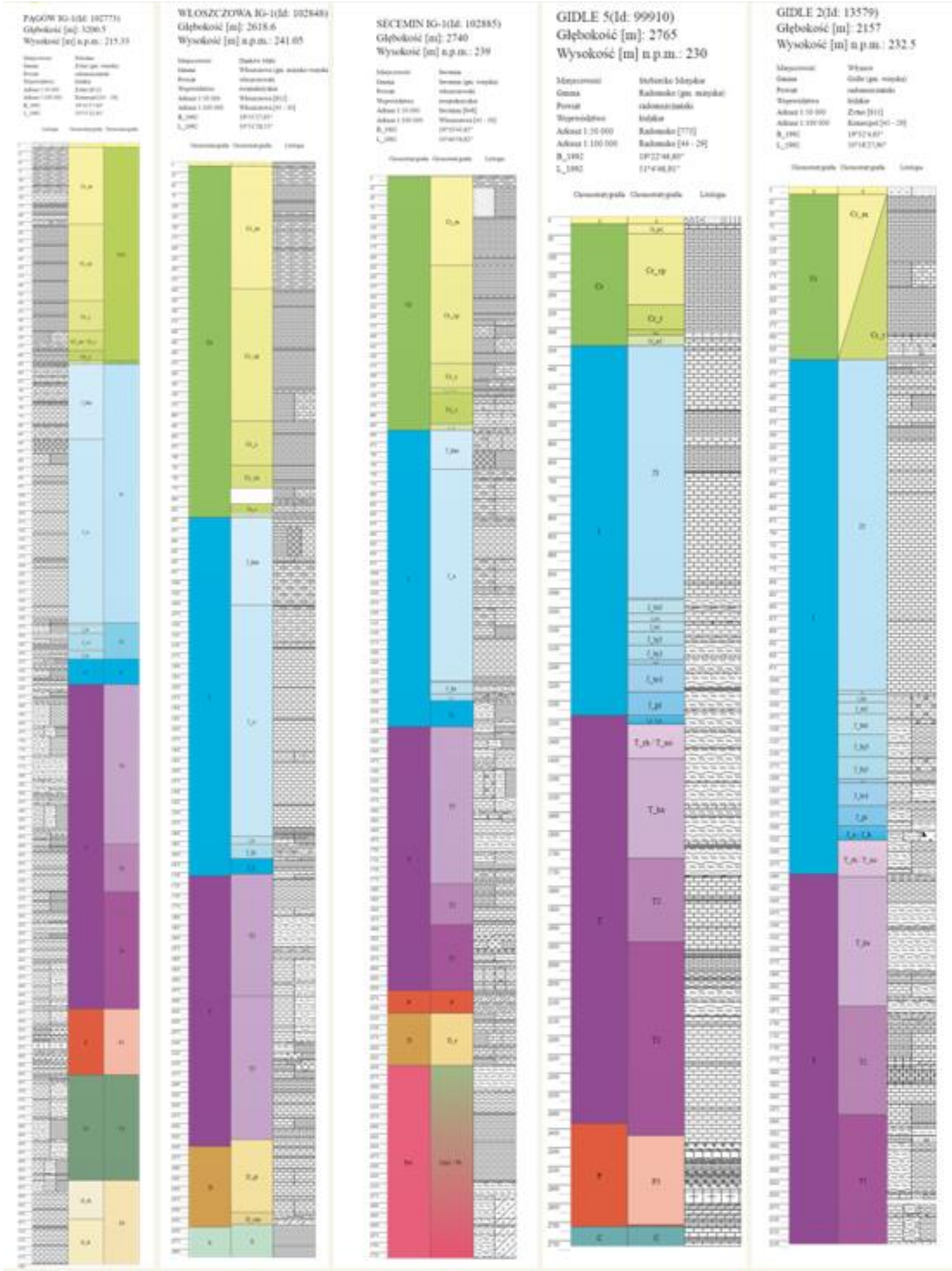

Figure 5.26: Compilation of lithologies in 10 boreholes

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$$M^{1,399}\frac{Cl^{50,93}\ HCO_3^{39,82}\ SO_4^{5,59}}{Na^{96,91}\ Ca^{2,25}\ K^{1,15}\ Mg^{0,29}}$$

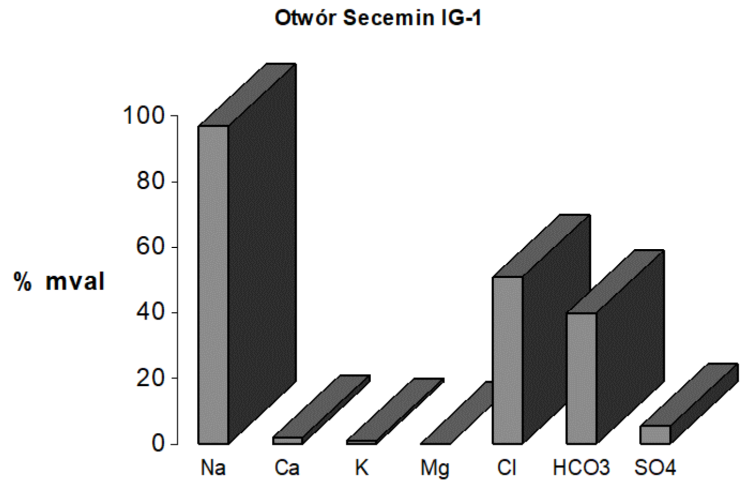

Figure 5.27: Chemical composition of Lower Jurassic waters (Wachowicz et al., 2010)

5.2.3 Elements of geological conceptual models

Based on chronostratigraphy and lithostratigraphy borehole data, well data correlation and analysis of geological cross-sections (Figure 5.28), 21 structural surfaces were developed in the area of the Jurassic structure.

Structural surfaces were developed in the area of the Jurassic Częstochowa District/Ładzice DSA reservoir, taking into account the depth, thickness and structural framework of the selected area of reservoir deposits - maps of top and base of reservoir layers (Figure 5.29).

Structural geology analysis and fault models were conducted to develop a structural framework model (Figure 5.30, Figure 5.31).

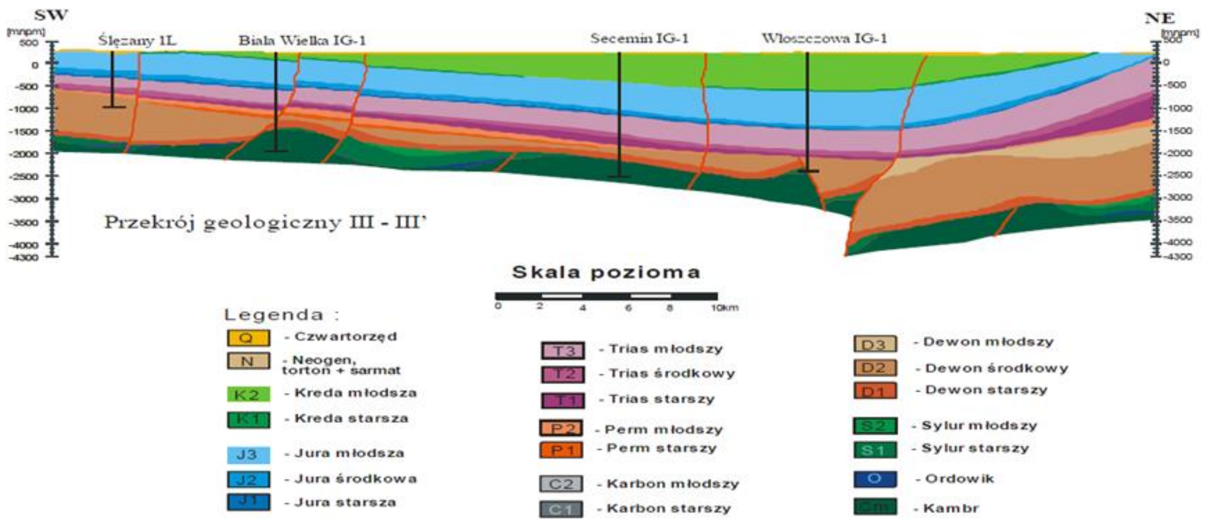

Figure 5.28: Analysis of geological cross-sections (Złonkiewicz, 2001, Górecki et al., 2002)

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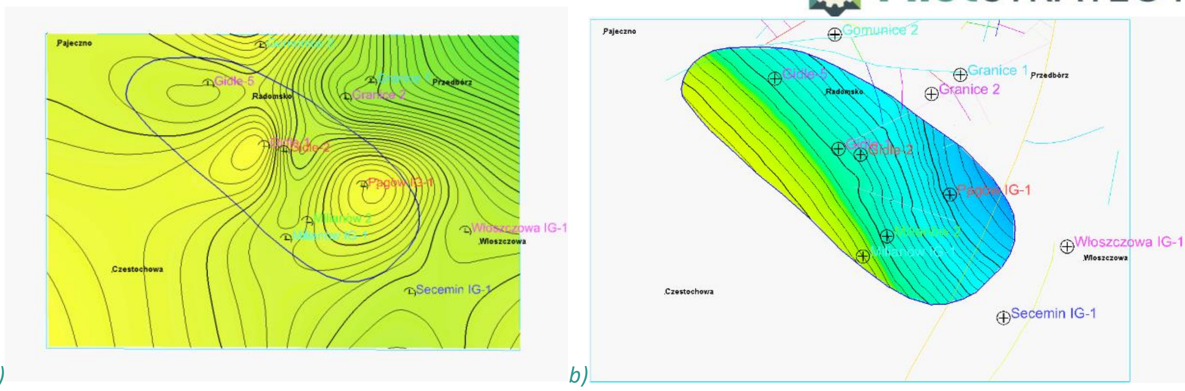

a) b)

Figure 5.29: Structural surfaces of the top (a) and the base (b) of reservoir layers in the area of the Jurassic structure

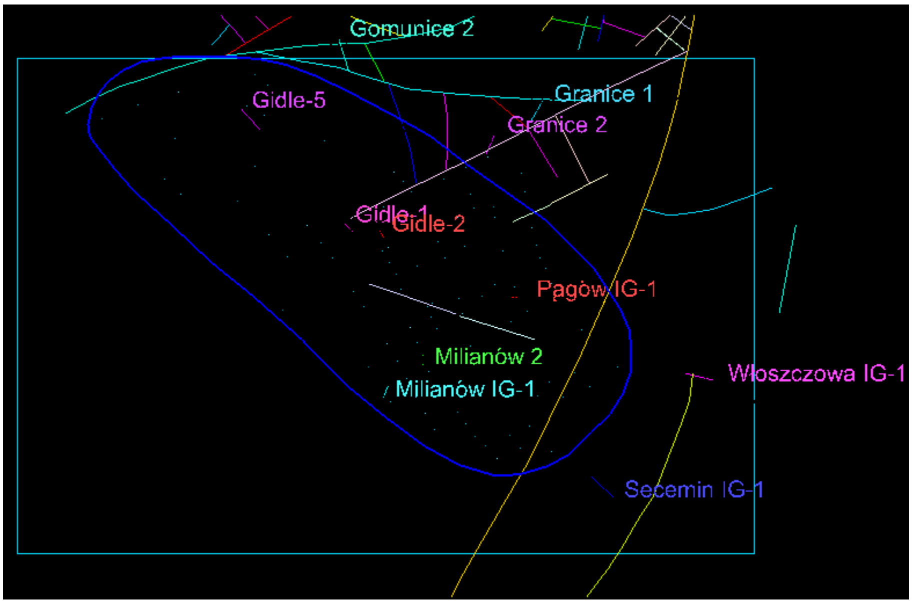

Figure 5.30: Fault lines in structural framework model in the area of the Jurassic structure

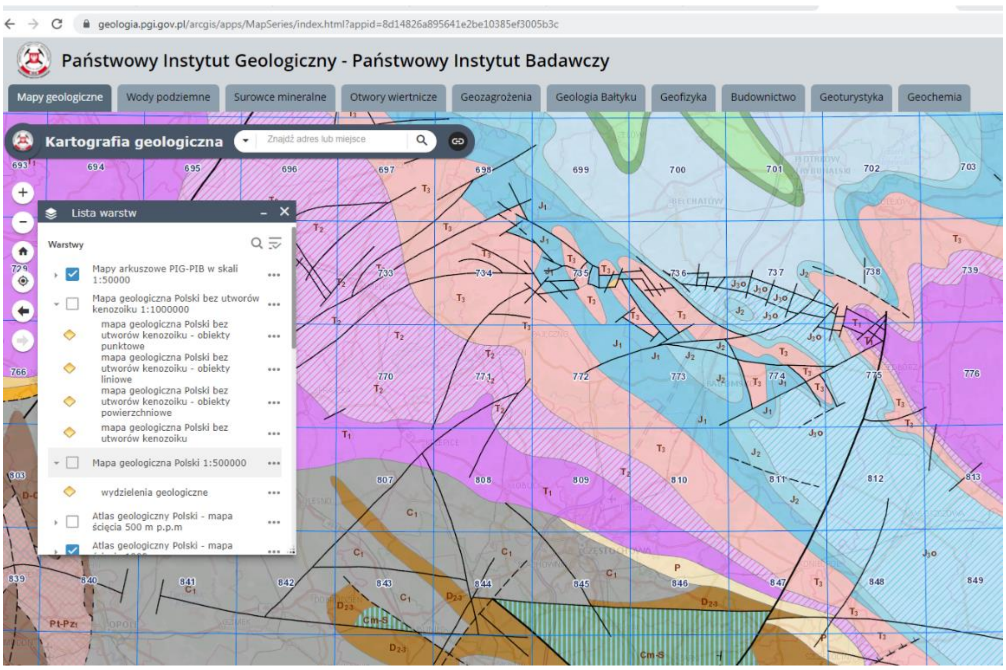

Figure 5.31: Geological map of the area of the Jurassic structure (Polish Geological Institute)

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A fault model was built based on the geological maps, cross-sections and other data. Locations of some of the faults are confirmed but some part of faults are only hypothetical but we implemented it for the purposes of uncertainty and risk analysis (Figure 5.32). The length of the model is about 62 km and its width is about 24 km (Figure 5.33).

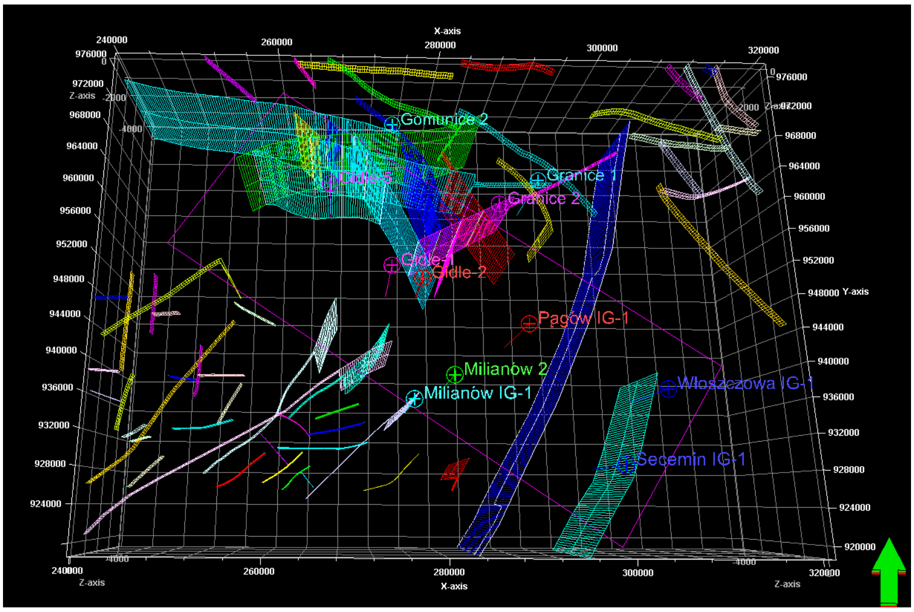

Figure 5.32: Fault and fracture model

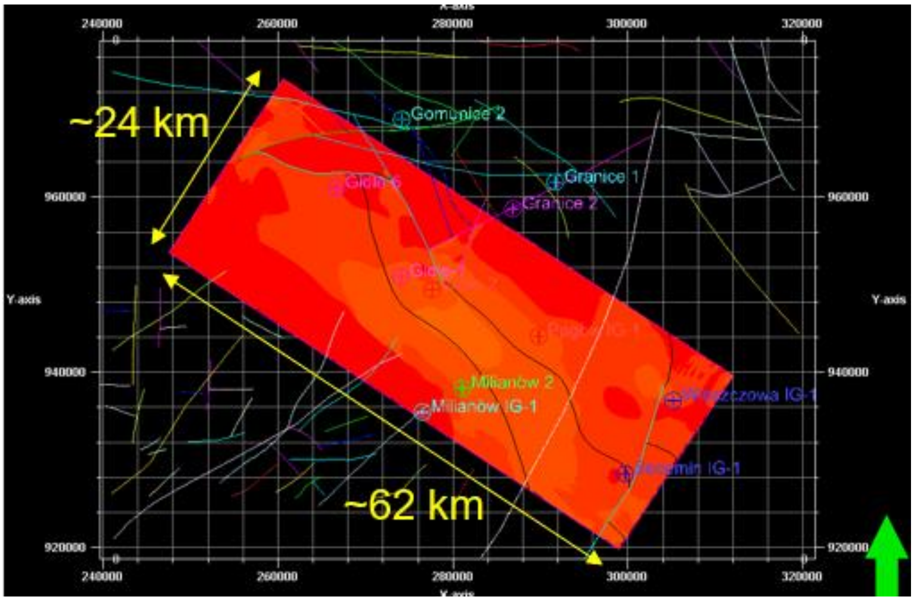

Figure 5.33: Location, range and grid orientation of the model

Geological models of the storage complex zone consist of reservoir, caprock and structural elements. Horizon interpretations have been made based on chronostratigraphy and litostratigraphy borehole data, well data correlation and analysis of geological cross-sections (Figure 5.34). Based on the data obtained, the analysis of the depth and thickness of reservoir deposits was carried out, and then the necessary modifications and corrections were introduced in the structural model.

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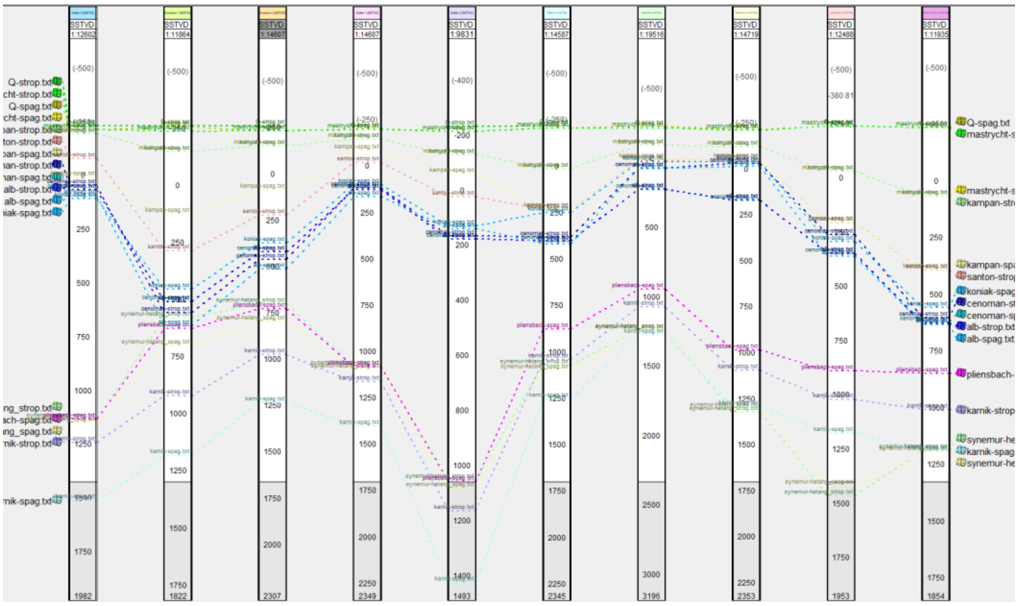

Figure 5.34: Well data correlation and development of structural surfaces in the area of the Jurassic structure

Analysis of data availability was performed and potential storage areas have been indicated (Figure 5.35):

- Area No. 1 - wells: Pągów IG-1, Milianów 2, Milianów IG-1 - all wells with data for porosity and permeability (lack of VSHALE data);
- Area No. 2 - wells: Gidle-1, Gidle-2, Gidle-5 – all wells with data only for porosity (lack of V_{SHALE} and permeability data).

Due to better availability of well data (both porosity and permeability data), only area no. 1 with dimensions of 10 km by 19 km (Figure 5.35) was selected for further analysis.

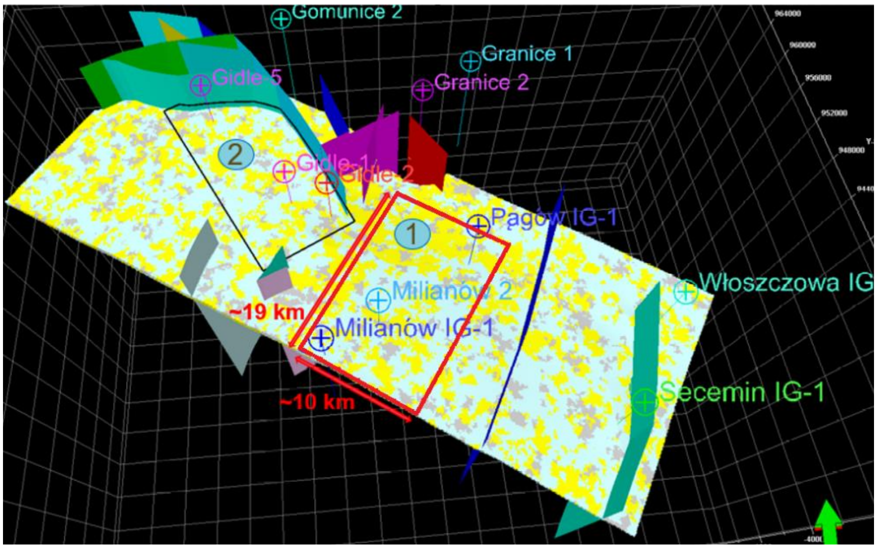

Figure 5.35: Two potential storage areas indicated based on analysis of data availability and part of the model selected for further analysis (in red)

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6. Storage potential of Upper Silesia region

6.1. Skoczów DSA - the area of Dębowiec layers

Based on previous research regarding the CO_2 storage potential in the Dębowiec Beds (Śliwińska et al., 2022; Koteras et al., 2020; Urych and Smoliński, 2019; Jureczka et al., 2012), the most suitable conditions exist in deep saline aquifers in the Miocene sediments of the Dębowiec Beds, located west of Bielsko-Biała (the area marked in Figure 6.1 as 'Expected area' – Figure 6.1) with the estimated CO_2 storage capacity about 46.2 Mt (Table 6.1).

Table 6.1: General geological properties of selected CO_2 storage site

Storage Site ID, Storage Type/Unit	Strat. Formation/Lithology	Unit Area (km^2), Depth/Thickness (m)	Seal Lithology/Thickness (m)	Estimated Capacity (Mt CO_2)
SU#01 Cieszyn-Skoczów-Czechowice, DSA/USCB	Dębowiec Beds/Miocene macroclastic molasse composed of four lithofacies: olistostromes, boulders, conglomerates and sandstones	371, 750–1300/150	mudstones and claystones with intercalations of sandstones/50–950 (mainly 300–850)	46.2

Figure 6.1: The maximum range area of the Dębowiec layers

Moreover, the PilotSTRATEGY project devoted significant effort to extend the area of the analysed aquifer to the maximum range of Miocene deposits in the area of Dębowiec layers and to determine the possibility of increasing the CO_2 storage potential of Skoczów DSA through a detailed geological analysis of the area located east of Bielsko-Biała. The range and distribution of petrophysical parameters of the reservoir were analysed in the area of the maximum range of Miocene deposits in Dębowiec layers. An area of approximately 115 km^2 with the highest potential for CO_2 storage in the east part of Dębowiec layers, named "Kęty", was identified. The additional potential static CO_2 storage capacity in saline aquifer of selected area was estimated at 14.3 Mt CO_2 using the volumetric equation of CSLF/US DOE.

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In order to additional analysis of distribution of porosity in the model, the deterministic kriging method was used. As a result of porosity modelling, an area with porosity above 10% and dimensions of 9 km by 13 km was identified in the area of wells: KĘTY-11 and BIELSKO-1 (Figure 6.2a). As a result of permeability modelling, an area with permeability from ~10 mD to ~80 mD was identified in the area of wells: KĘTY-11 and BIELSKO-1 (Figure 6.2b).

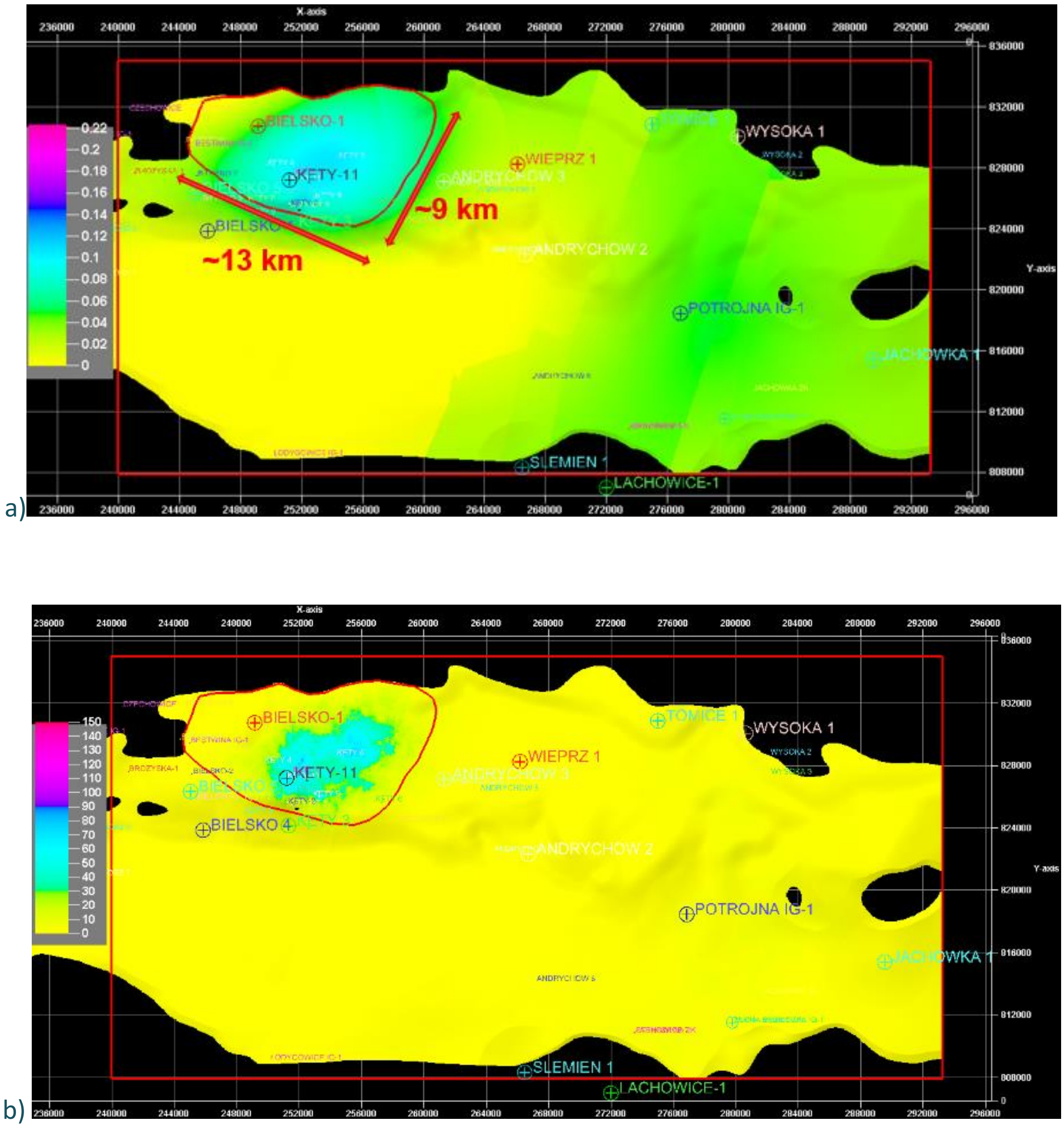

Figure 6.2: Selected part of the model with the highest values of porosity (a) and permeability (b)

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The static CO_2 storage capacity in saline aquifers of selected area applying the volumetric equation - Equation 6.1 (US DOE/CSLF) was estimated at 14.3 Mt CO_2.

$$G_{CO2} = A \text{ x } h_g \text{ x } f_{tot} \text{ x } \rho_{res} \text{ x } E_{saline} \quad \text{[Equation 6.1]}$$

Dimensions: Mass, function of L^2 x L x L^3/L^3 x M/L^3 x [%]

G_{CO2}	CO_2 storage potential of a prospect field as a mass (Mt, 1E+9 kg: M)
A	Total area of prospect reservoir (km^2, 1E+6 m^2: L^2)
h_n	Gross reservoir thickness (m: L)
f_{tot}	Average total porosity (%: L^3/L^3)
ρ_{res}	CO_2 density at reservoir storage conditions (kg/m3: M/L^3)
E_{saline}	Storage efficiency factor, fraction of volume occupied (% - dimensionless)

Finally, the total estimated capacity of Skoczów DSA is estimated at about 60.5 Mt CO_2 for storage efficiency factor of 2%. For regional aquifers it is suggested to use a storage efficiency factor of 2% based on work by the US DOE. Monte Carlo simulations result in a P50 between 1.8 and 2.2% for the storage efficiency factor of the bulk volume of a regional aquifer (Frailey, 2007). Based on these assumptions, the total CO_2 storage capacity is in the range of 54.5 to 66.6 Mt CO_2 (storage efficiency factor from 1.8 to 2.2%).

6.2. Ładzice DSA – Jurassic Czestochowa District

The numerical simulations, performed within the framework of task 3.2 (Deliverable 3.3; Urych et al. 2024b), focused on evaluation of CO_2 storage capacity based on well location and flow rate optimization. The dynamic simulations of CO_2 injection were carried out using the Petrel Reservoir Engineering software (Schlumberger Information Solutions, 2010) cooperating with the ECLIPSE reservoir simulator (Schlumberger Information Solutions, 2011).

Optimization was performed to maximize the potential capacity while taking into account uncertainty in the reservoir model properties. The primary objective was to determine the location of the pilot-scale injection well. A screening method of potential locations was used to define the well location area investigation for the optimization. The manual screening was based on flow properties, pressure perturbation and properties and operational constraints: visual and statistical analysis of key characteristics regarding storage capacity and integrity.

Based on the fluid flow simulations, the output value of the CO_2 amount possible to be injected was estimated. The maximum value of flow rate for injection well IN-1A in the optimal scenario amounts to 1.25 Mt/year which gives the maximum potential CO_2 storage capacity about 31.27 Mt within 25 years in optimal scenario of the geological model. In the case of the IN5 and IN-6 wells, much lower values of injection rates and, consequently, low values of maximum potential storage capacity were observed. The results of uncertainty analysis prepared for different scenarios of simulation model with IN-1A well, including estimated maximum values and ranges of values of potential capacity, tornado charts showing the effects of individual uncertainty parameters on CO_2 volume, are shown in Table 6.2.

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Table 6.2: The results of uncertainty analysis for different scenarios of simulation model with IN-1A well

Scenario	Max. flow rate, Mt/yr	Max. potential capacity, Mt	Range of potential capacity, Mt
pessimistic	1.16	29.02	28.84 - 29.27
optimal	1.25	31.27	31.18 - 31.49
optimistic	1.34	33.52	33.30 - 34.09

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7. CCUS development scenarios in Upper Silesia region

As part of this task, the possibilities of developing CCS were analysed through pilot projects covering the two analysed potential CO_2 reservoirs and selected CO_2 emitters (Figure 7.1).

The potential CO_2 storage site in the Ładzice Deep Saline Aquifer is located approximately 27 km from a cement plant (Figure 7.2) and about 60 km from the main emitters, including iron and steel plant (Figure 7.3)

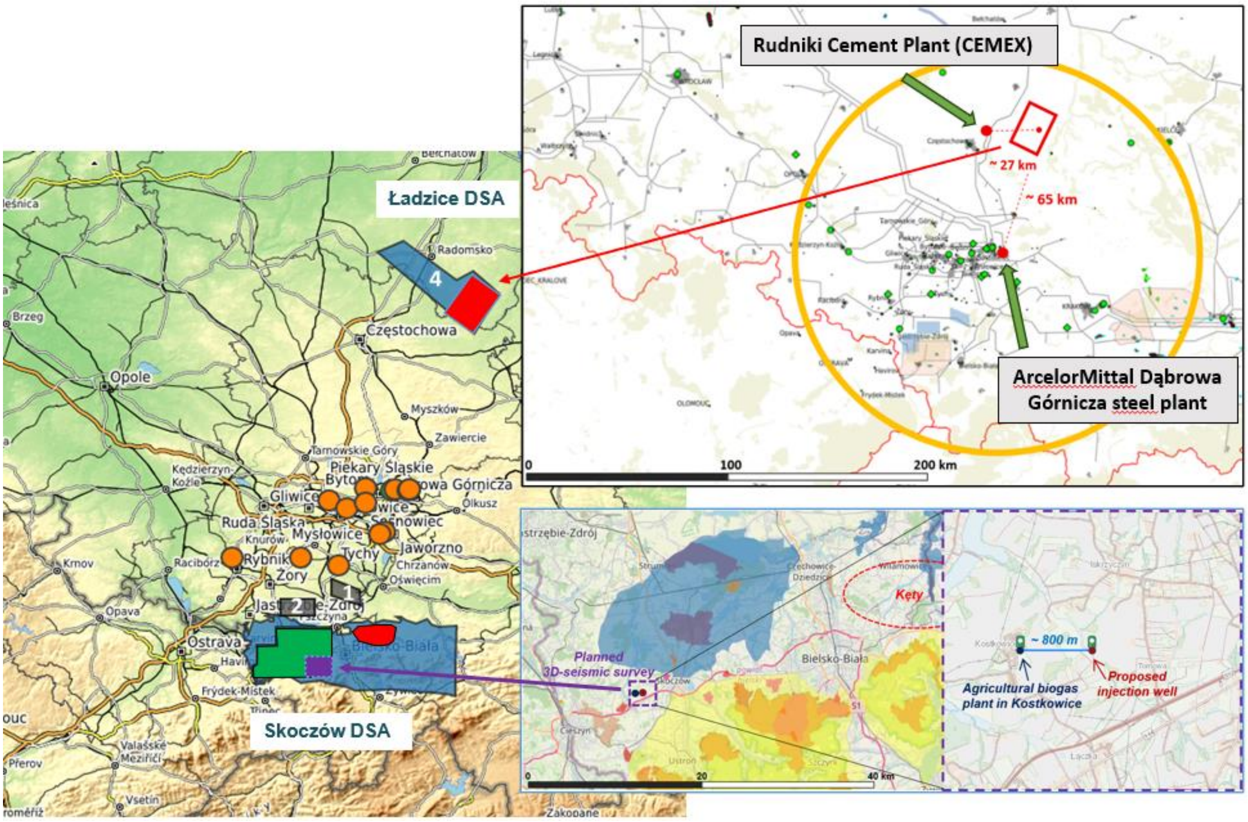

Figure 7.1: The analysed potential CO_2 reservoirs and selected CO_2 emitters in the Upper Silesia region

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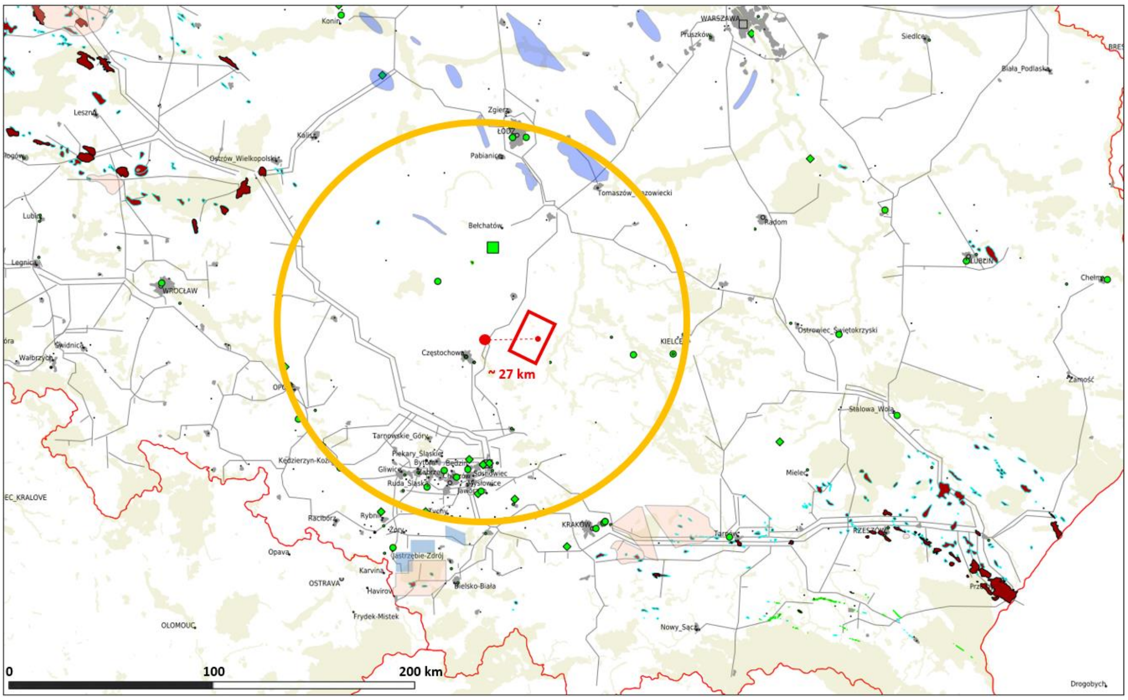

Figure 7.2: Location of potential CO_2 storage sites within a radius of 100 km from the Rudniki Cement Plant (CEMEX) including indication of Natura 2000 nature protection areas and distance to injection well in the Ładzice reservoir (source: https://skladowanie.pgi.gov.pl/co24/map/gis)

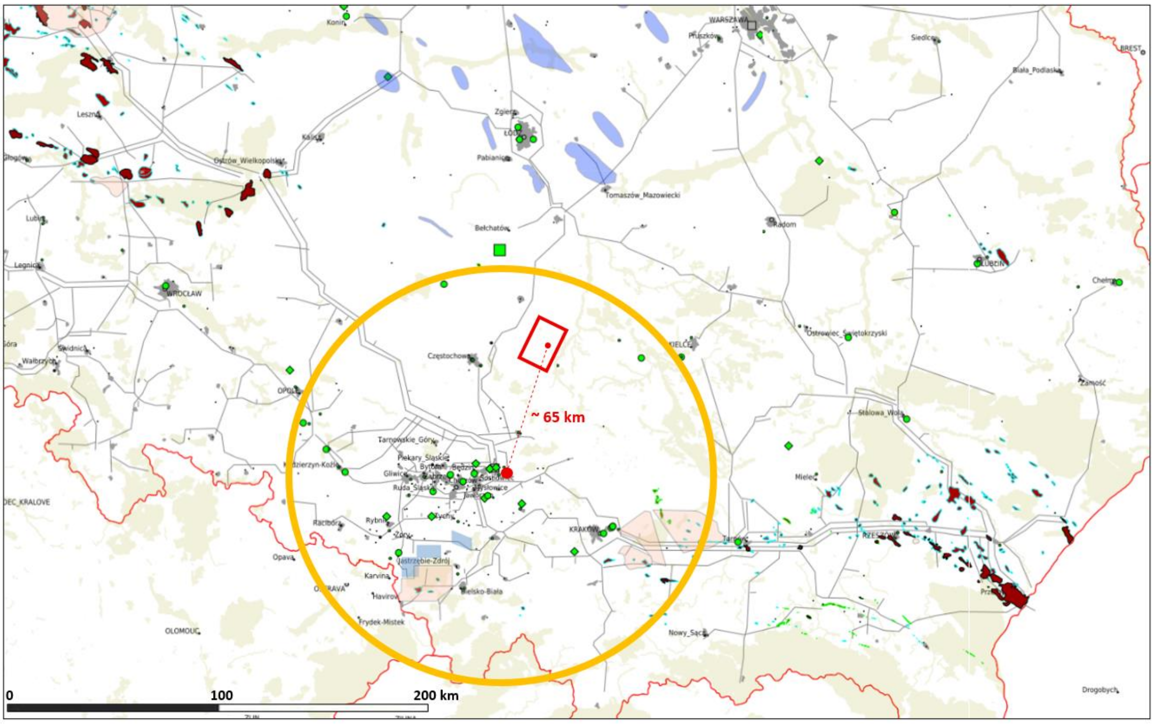

Figure 7.3: Location of potential CO2 storage sites within a radius of 100 km from the ArcelorMittal Dąbrowa Górnicza steel plant including indication of Natura 2000 nature protection areas and distance to injection well in the Ładzice reservoir (source: https://skladowanie.pgi.gov.pl/co24/map/gis)

Based on all the research carried out so far, the most promising area is located to the west of Bielsko-Biała (Skoczów DSA) between Cieszyn and Czechowice-Dziedzice (Figure 7.4). However, a considerable part of the studied area is covered by protected areas of the Nature 2000 Network and landscape parks, imposing specific limitations on surface activities associated with the theoretical CO_2 storage plans. Therefore, the area of planned research work here (3D seismic survey, proposed location of injection well, static and dynamic modelling), unlike the work carried out in previous research projects, is selected outside the protected areas of the Nature 2000 Network and landscape parks. The location of the proposed injection well, the planned 3D seismic survey area and the location of Kostkowice agricultural biogas plant are shown also in Figure 7.4.

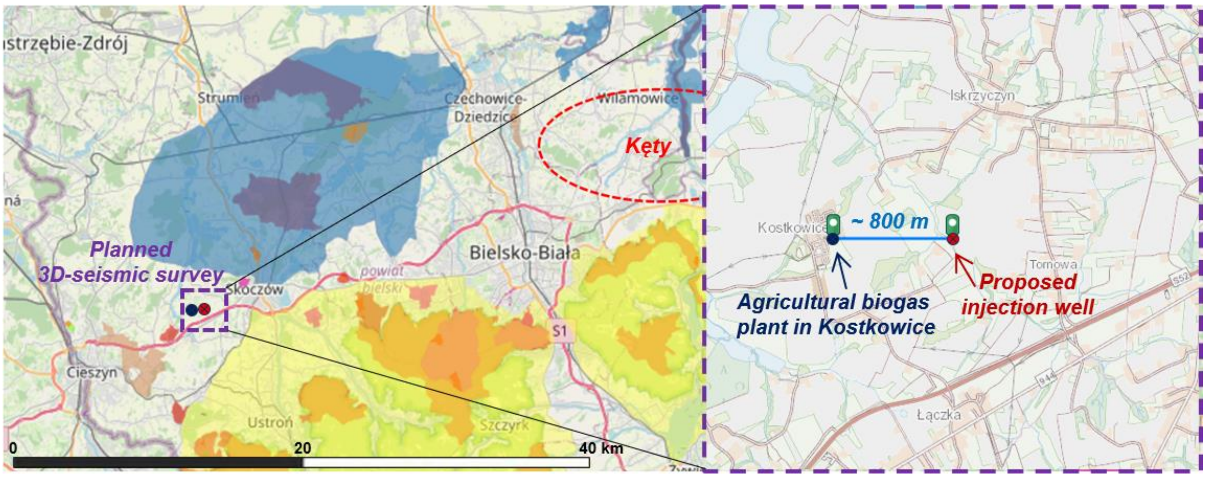

Figure 7.4: The protected areas of the Nature 2000 Network sites (red and blue) and landscape parks (yellow). Distance from biogas plant to proposed injection well is about 800 m (source: https://geoserwis.gdos.gov.pl/mapy).

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8. Conclusions and recommendations

Within the framework of assessment of the Upper Silesia region actions in the WP2 included an exhaustive analyses and re-interpretation of available data of the Miocene Dębowiec layers which are molasse deposits (Skoczów Deep Saline Aquifer; DSA) overlying the Upper Silesia Coal Basin of Carboniferous age; and the Jurassic Ładzice Fm (Ładzice DSA). An exhaustive review of existing data allowed the development of a conceptual geological model and the construction of a static model.

Previous research regarding the CO_2 storage potential in the Miocene Dębowiec Beds found an estimated static CO_2 storage capacity about 46.2 Mt. Here an additional area of approximately 115 km^2 named "Kęty", was identified. The additional potential static CO_2 storage capacity was estimated at 14.3 Mt CO_2. Finally, the total static capacity of the Skoczów DSA is estimated at about 60.5 Mt CO_2 using a storage efficiency factor of 2%.

For the Jurassic Ładzice DSA of the Czestochowa District, a static calculation was not made as dynamic simulations were performed as part of PilotStrategy WP3. Based on these simulations, the maximum value of flow rate for injection is 1.25 Mt/year in optimal scenario which gives a maximum potential CO_2 storage capacity about 31.3 Mt within 25 years and a range of 29 – 33.5 Mt.

It is worth mentioning that the precision of the spatial mapping of the variability of reservoir formations and sealing layers developed for both analyzed geological models would certainly be improved by the availability of more data, including an additional well data, as well as the results of seismic data processing and interpretation.

The possibilities of developing CCS in Upper Silesia were analyzed through proposed locations for pilot projects covering the two analyzed potential CO_2 reservoirs and selected CO_2 emitters. The first potential CO_2 storage site – Ładzice Deep Saline Aquifer – is located approximately 27 km from the Rudniki cement plant and about 60 km from the main emitters, including the iron and steel plant. The proposed location of the second selected pilot project in the Miocene Dębowiec Beds, including the injection well and planned 3D seismic survey area, is approximately 800 m from the location of the Kostkowice agricultural biogas plant.

A concept for a CO_2 storage project in the Ładzice Deep Saline Aquifer has been developed in the framework of PilotSTRATEGY WP4 – Pilot development and Implementation plans, considering a pilot scale injection of CO_2 at the rate of 30 kt/y through 3 years and then upscaling to a commercial plant with an injection 300 kt/y through 25 years (D4.5: Lachen et al. 2025, D4.3: Canteli at al. 2025a, D4.9: Canteli at al. 2025b).

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