



**Państwowy Instytut Geologiczny**  
**Państwowy Instytut Badawczy**

państwowa służba geologiczna  
państwowa służba hydrogeologiczna

# HYDROCARBON PROSPECTIVE OF POLAND

**NFEP&WM agreement No. 307/2021/Wn-07/FG-sm-dn/D of 21-04-2021**  
**PGI–NRI project No. 22.5004.2101.00.1**

**KOŁO**

**TENDER AREA**

*GEOLOGICAL PACKAGE ENGLISH ABSTRACT*

**VI LICENSING ROUND**

**FOR CONCESSIONS FOR PROSPECTION AND EXPLORATION  
OF HYDROCARBON FIELDS AND PRODUCTION OF HYDROCARBONS FROM FIELDS  
IN POLAND**

**Team leaders:**

**Sara WRÓBLEWSKA**  
**Adam WÓJCICKI**



**NATIONAL FUND  
FOR ENVIRONMENTAL PROTECTION  
AND WATER MANAGEMENT**

Project manager:

**Krystian WÓJCIK**

**Dariusz BRZEZIŃSKI, Martyna CZAPIGO-CZAPLA, Grzegorz CZAPOWSKI,  
Joanna FABIAŃCZYK, Anna FELDMAN-OLSZEWSKA,  
Anna GABRYŚ-GODLEWSKA, Marek JASIONOWSKI,  
Dominika KAFARA, Hubert KIERSNOWSKI, Sylwia KIJEWSKA,  
Aleksandra KŁOS, Paulina KOSTRZ-SIKORA, Przemysław KOWALSKI,  
Aleksandra KOZŁOWSKA, Olimpia KOZŁOWSKA, Marta KUBERSKA,  
Krzysztof LESZCZYŃSKI, Marcin ŁOJEK, Elżbieta PRZYTUŁA,  
Olga ROSOWIECKA, Leszek SKOWROŃSKI, Marcin TYMIŃSKI,  
Paweł URBAŃSKI, Krzysztof WAŚKIEWICZ, Piotr WESOŁOWSKI,  
Dorota WĘGLARZ, Michał WOROSZKIEWICZ, Jarosław ZACHARSKI**

**Warsaw, 2023**

---

1. GENERAL INFORMATION .....	3
1.1. LOCATION .....	3
1.2. ENVIRONMENTAL CONDITIONS.....	8
2. GEOLOGY .....	13
2.1. GENERAL GEOLOGY AND TECTONICS .....	13
2.2. STRATIGRAPHY .....	23
2.2.1. CARBONIFEROUS .....	23
2.2.2. PERMIAN – ROTLIEGEND .....	25
2.2.3. PERMIAN – ZECHSTEIN .....	28
2.2.4. TRIASSIC .....	32
2.2.5. JURASSIC .....	33
2.2.6. CRETACEOUS .....	37
2.2.7. CENOZOIC .....	40
2.3. HYDROGEOLOGY .....	41
3. PETROLEUM PLAY .....	44
3.1. GENERAL CHARACTERISTICS.....	44
3.2. SOURCE ROCKS.....	45
3.3. RESERVOIR ROCKS .....	49
3.4. SEAL ROCKS .....	53
3.5. UNCONVENTIONAL PETROLEUM PLAY .....	53
3.6. GENERATION, MIGRATION, ACCUMULATION AND TRAPS .....	55
4. HYDROCARBON FIELDS .....	60
5. WELLS .....	60
6. SEISMIC SURVEYS.....	64
7. GRAVIMETRY, MAGNETOMETRY AND MAGNETOTELLURICS .....	67
7.1. GRAVIMETRY .....	67
7.2. MAGNETOMETRY .....	67
7.3. MAGNETOTELLURICS .....	67
8. SUMMARY CHART .....	74
9. REFERENCES.....	76

## 1. GENERAL INFORMATION

### 1.1. LOCATION

The Koło tender area of 1035.32 km<sup>2</sup> is located onshore in western Poland (concession blocks 189, 190, 209, 210 and 230; Fig. 1.1). The precise location is defined by geographic coordinates listed below.

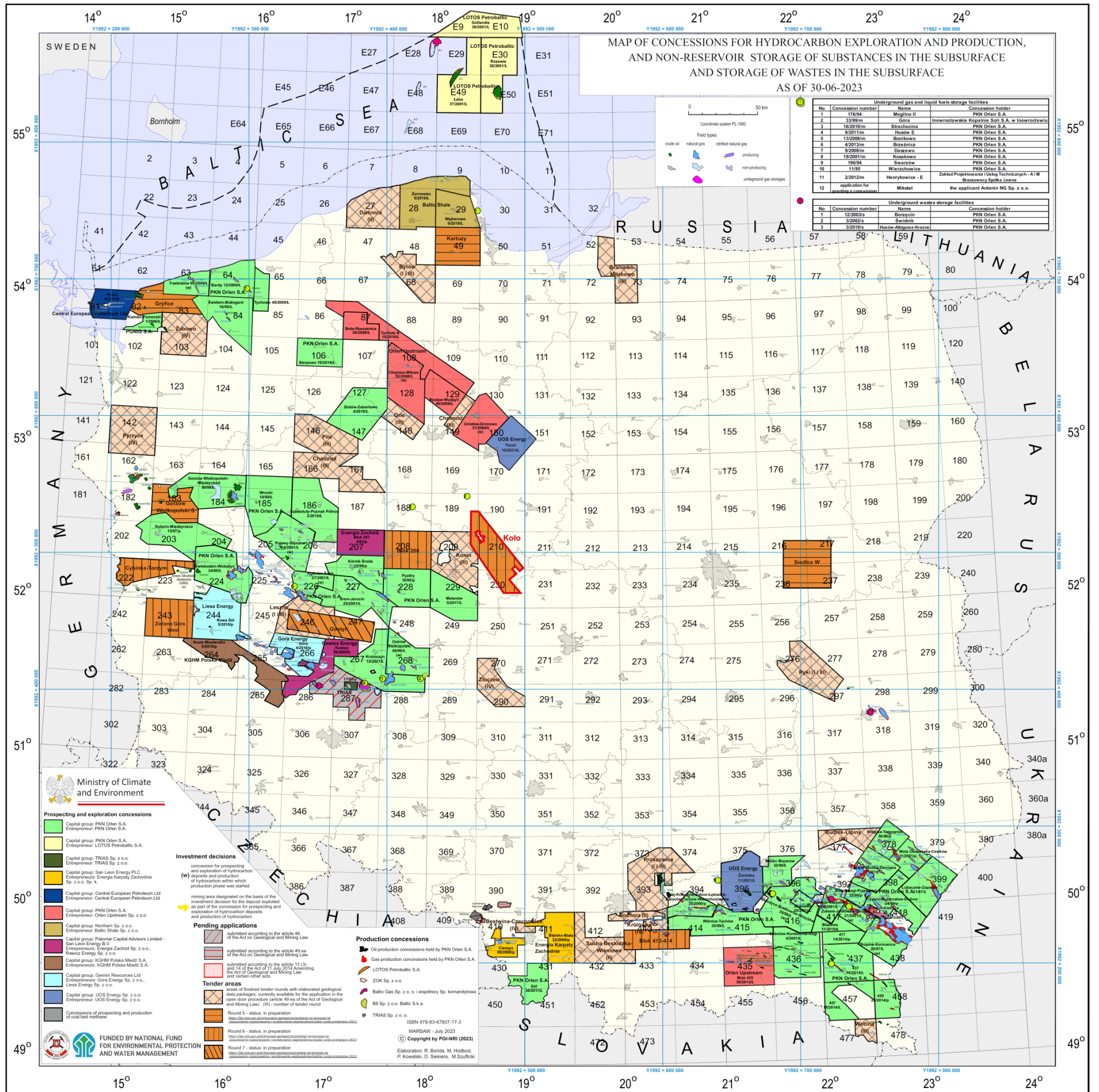
Border points	1992 coordinate system	
	X	Y
1	529967.77	466172.40
2	488641.34	498789.16
3	486438.55	496164.37
4	489957.06	493014.61
5	487890.95	490706.30
6	484446.05	493790.15
7	480134.00	488652.00
8	470399.21	496820.43
9	470399.21	484545.58
10	505767.09	460565.18
11	530004.01	460948.02
excluding the area defined by points 12–37		
12	511761.56	470471.74
13	510890.57	470321.23
14	510548.30	470289.27
15	510275.58	469386.68
16	508585.79	470240.02
17	507227.64	467937.05
18	508438.78	468164.41
19	508686.68	468071.55
20	508552.29	467753.83
21	509029.12	467425.48
22	509000.98	466860.16
23	509786.65	466458.84
24	510712.28	466533.66
25	510863.68	466135.08
26	511413.87	466119.07
27	512301.03	464657.54
28	512945.40	465015.52
29	514274.41	464099.56
30	514887.48	464919.13
31	515164.02	464836.89
32	515654.00	465231.28
33	515464.92	465948.84
34	515240.12	467390.59
35	513488.00	467015.12
36	511733.89	468344.28
37	511927.13	469427.80

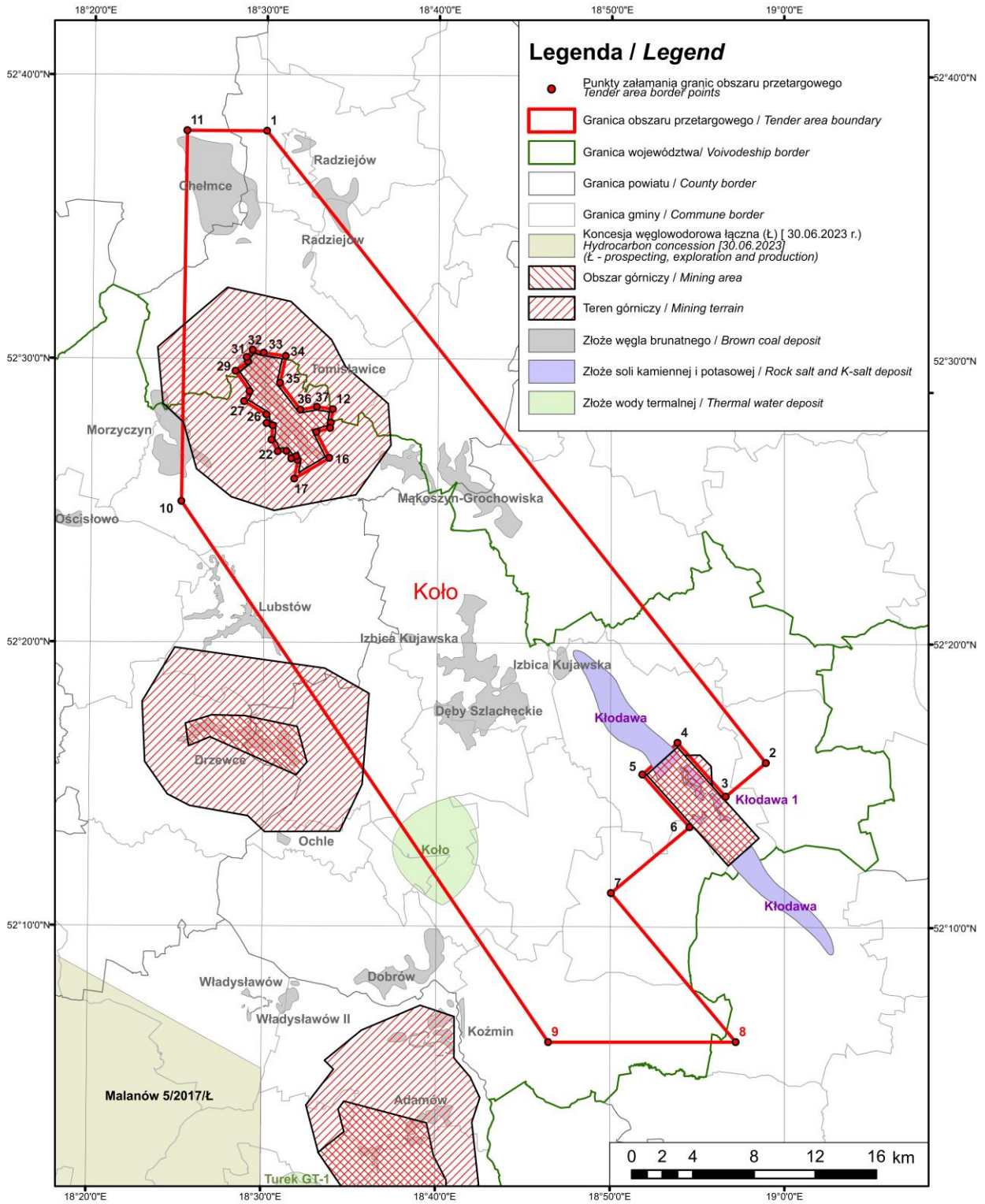
**Tab. 1.1.** Border points' coordinates of the Koło tender area (Fig. 1.2).

The Koło tender area was previously subjected to hydrocarbon prospecting and exploration concessions No. 53/2011/p Koło, 3/2016/p Koło, and 1/2017/p Koło Zachód (Strzelecki Energia). Currently, there are no active concessions in the neighborhood of the area (Figs 1.1–1.2). Only to the west, the Koło tender area is adjacent to the Konin area, dedicated previously to the 3<sup>rd</sup> licensing round for hydrocarbon concessions in Poland.

The Koło area is prospective for exploration of conventional and unconventional oil and gas fields in the Mesozoic of the Polish Lowlands. Especially, in the latter case, the Middle and Upper Jurassic shales are the exploration target.

→**Fig. 1.1.** Location of the Koło tender area in the map of concessions for hydrocarbon exploration and production, and non-reservoir storage of substances in the subsurface, and storage of wastes in the subsurface, as of 30-06-2023.





**Fig. 1.2.** Border points of the Koło tender area and location of the hydrocarbon concessions and fields of mineral resources in the neighborhood, as of 30-06-2023.

## 1.2. ENVIRONMENTAL CONDITIONS

THE ENVIRONMENTAL CONDITIONS DATASHEET FOR TENDER AREA KOŁO				
1.	LOCATION OF THE TENDER AREA ON THE MAP	1 : 50 000 geological map sheet	Sompolno 478, Kłodawa 515, Koło 514, Radziejów 440, Dąbie 551, Jeziora Wielkie 439, Ślesin 477, Izbica Kujawska 479, Turek 550	
2.	ADMINISTRATIVE LOCATION	Voivodeship	<b>Kujawsko-Pomorskie</b>	
		County	<b>Inowrocław</b>	
		The commune and % of the area within the tendering area	Kruszwica (2.58%)	
		County	<b>Radziejów</b>	
		Commune	Bytoń (2.70%), Piotrków Kujawski (11.22%), Radziejów City (0.14%), Radziejów (1.69%), Topólka (4.66%)	
		County	<b>Włocławek</b>	
		Commune	Izbica Kujawska (7.18%), Lubraniec (0.04%)	
		Voivodeship	<b>Łódzkie</b>	
		County	<b>Łęczyca</b>	
		Commune	Grabów (0.06%)	
		Voivodeship	<b>Wielkopolskie</b>	
		County	<b>Koło</b>	
		Commune	Babiak (12.91%), Chodów (0.48%), Dąbie (5.69%), Grzegorzew (7.07%), Kłodawa (9.09%), Koło City (0.09%), Koło (6.84%), Olszówka (4.46%), Osiek Mały (4.13%), Przedecz (1.15%)	
		County	<b>Konin</b>	
Commune	Sompolno (8.39%), Wierzbiniek (9.43%)			
3.	PHYSIOGRAPHIC REGIONALIZATION (after KONDRACKI, 2013 and SOLON et al., 2018)	Macroregion	Pojezierze Wielkopolskie (315.5)	
		Mesoregion	Równina Inowrocławska (313.25), Pojezierze Kujawskie (315.57)	
		Macroregion	Nizina Południowowielkopolska (318.1-2)	
		Mesoregion	Wysoczyzna Kłodawska (318.15), Kotlina Kolska (318.14)	
4.	COORDINATES OF THE TENDER AREA BORDER POINTS	PL-1992 [X; Y]	529967.77	466172,40
			488641.34	498789,16
			486438.55	496164,37
			489957.06	493014,61
			487890.95	490706,30
			484446.05	493790,15
			480134.00	488652,00
			470399.21	496820,43
			470399.21	484545,58
			505767.09	460565,18
			530004.01	460948,02
			excluding the area defined by points:	
			511761.56	470471,74
			510890.57	470321,23
			510548.30	470289,27
			510275.58	469386,68
			508585.79	470240,02
			507227.64	467937,05
			508438.78	468164,41
			508686.68	468071,55
			508552.29	467753,83
			509029.12	467425,48
			509000.98	466860,16
509786.65	466458,84			
510712.28	466533,66			

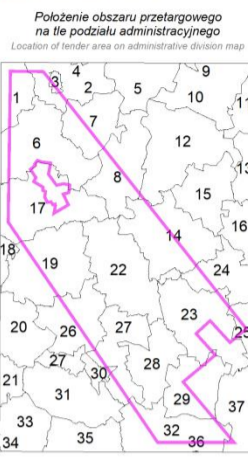
THE ENVIRONMENTAL CONDITIONS DATASHEET FOR TENDER AREA KOŁO				
			510863.68	466135,08
			511413.87	466119,07
			512301.03	464657,54
			512945.40	465015,52
			514274.41	464099,56
			514887.48	464919,13
			515164.02	464836,89
			515654.00	465231,28
			515464.92	465948,84
			515240.12	467390,59
			513488.00	467015,12
			511733.89	468344,28
			511927.13	469427,80
5.	SURFACE OF THE TENDER AREA	[km <sup>2</sup> ]	1035.32	
6.	CONCESSION TYPE		prospecting, exploration and production of hydrocarbons	
7.	AGE OF HYDROCARBON FORMATION		Jurassic, Mesozoic	
8.	PROTECTED NATURAL AREAS	[yes/ no] if "yes": the name of the tender area and its % within the total area	no	
	National Parks		Kawęczynskie Brzęki (<1 %)	
	Natural Reserves		no	
	Landscape Parks		Goplańsko-Kujawski (27.01 %), Jezioro Głuszyńskie (4.08 %), Jezioro Modzerowskie (3.11 %)	
	Protected landscape areas		PLH100006 Pradolina Bzury-Neru (<1%)	
	Natura 2000, (Special Area of Conservation, SAC)		PLB100001 Pradolina Warszawsko-Berlińska (<1%), PLB300002 Dolina Środkowej Warty (<1%)	
	Natura 2000, (Special Bird Protection, SPA)		no	
	Nature and landscape complexes		2	
	Ecological area		47 (including 119 objects)	
	Nature monuments		[yes (quantity) / no]	
9.	PROTECTED SOIL	[yes / no]	yes	
10.	FOREST COMPLEXES	[yes / no]	yes	
11.	PROTECTIVE FORESTS	[yes (% of the total area / no)]	26.4 km <sup>2</sup> (2.55%)	
12.	CULTURAL HERITAGE FACILITIES Archaeological monuments	[yes (quantity) / no]		
		Hillfort	4	
		Hamlet	no	
		Cemetery	2	
		others	1	
13.	MAJOR GROUNDWATER RESERVOIRS	[yes (number, name and age of the aquifer) / no]nie]	yes 226 Zbiornik Krośniewice-Kutno, J3 151 Zbiornik Turek-Konin-Koło, Cr 144 Dolina Kopalna Wielkopolska, Q	
14.	PROTECTIVE ZONES OF WATER INTAKE	[yes / no]	yes	
15.	SPA PROTECTION ZONES	[yes / no]	no	
16.	FLOOD HAZARD AREA	[yes / no]	yes	
17.	POROVEN MINERAL DEPOSITS	[yes (type of mineral deposit)/ no]	yes (natural aggregates, sands, brown coal, salts)	
18.	PROGNOSTIC AND PERSPECTIVE AREAS OF OCCURRENCE OF MINERAL RESOURCES (excluding hydrocarbons)	[yes (type of mineral deposit)/ no]	yes (sand, sand and gravels, gravels, peat, crude oil, natural gas, salt, brown coal)	
19.	NATURAL GAS PIPELINES	[yes / no]	yes	
20.	UNDERGROUND GAS STORAGE	[yes / no]	no	

THE ENVIRONMENTAL CONDITIONS DATASHEET FOR TENDER AREA KOŁO		
21.	DATE OF THE DATASHEET COMPLETION	18.11.2021
22.	<i>DATA COLLECTION AND ELABORATION</i>	Aleksandra Kłos, Dominika Kafara

**Tab. 1.3.** The environmental conditions datasheet for the Koło tender area.

→**Fig. 1.3.** Environmental Map of the Koło area.

**Mapa środowiskowa obszaru KOŁO**  
Environmental Map of the KOŁO area



- woj. KUJAWSKO-POMORSKIE  
powiat inowrocławski  
1 - gm. Kruszwica  
2 - gm. Radziejów  
3 - m. Radziejów  
4 - gm. Dobrze  
5 - gm. Osiecin  
6 - gm. Piotrków Kujawski  
7 - gm. Bytów  
8 - gm. Topolka  
powiat aleksandrowski  
9 - gm. Bądkowo  
powiat włocławski  
10 - gm. Brześć Kujawski  
11 - gm. Włocławek  
12 - gm. Lubraniec  
13 - gm. Chocień  
14 - gm. Izbica Kujawska  
15 - gm. Boniewo  
16 - gm. Chodzież
- woj. WIELKOPOLSKIE  
powiat koniński  
17 - gm. Wierzbinek  
18 - gm. Slesin  
19 - gm. Sompolno  
20 - gm. Kramsk  
21 - gm. Krzymów  
powiat kolski  
22 - gm. Babiak  
23 - gm. Kłodawa  
24 - gm. Przedecz  
25 - gm. Chodów  
26 - gm. Osiek Mały  
27 - gm. Koło  
28 - gm. Grzegorzew  
29 - gm. Olszówka  
30 - m. Koło  
31 - gm. Kościelec  
32 - gm. Dąbie  
powiat turecki  
33 - gm. Władysławów  
34 - gm. Tuliszków  
35 - gm. Brudzew  
woj. ŁÓDZKIE  
powiat łęczycki  
36 - gm. Swinice Warckie  
37 - gm. Grabów

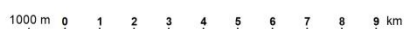
Polozenie obszaru przetargowego na arkuszach 1:50 000  
Location of tender area on maps with a scale of 1:50 000

439 Piotrków Kujawski (Jeziora Wielkie)	440 Radziejów	441 Brześć Kujawski	442 Włocławek
477 Slesin	478 Sompolno	479 Izbica Kujawska	480 Lubień Kujawski
513 Konin	514 Koło	515 Kłodawa	516 Krosnice
549 Tuliszków	550 Turek	551 Dąbie	552 Łęczyca

Copyright by PIG-PIB, Warszawa

18°45'

Współrzędne prostokątne w układzie PL-1992, podkład topograficzny na podstawie VMap L2 19°00'



Zestawienie danych oraz redakcja komputerowa mapy: **Aleksandra Kłos**  
Data compilation and map editor:  
Weryfikacja: **Olimpia Kozłowska**  
Verification:

Objaśnienia do Mapy Środowiskowej obszaru  
KOŁO

Legend of the Environmental Map of the KOŁO area

(opracowano na podstawie bazy MGŚP z zasobów PIG-PIB\*)

(based on MGŚP database\*)

ZŁOŻA KOPALIN ORAZ  
PERSPEKTYWY I PROGNOZY ICH WYSTĘPOWANIA

MINERAL DEPOSIT AND  
PERSPECTIVE AREA'S, PROGNOSTIC AREA'S FOR DOCUMENTING DEPOSITS



172 identyfikator z bazy MIDAS złoża małoekologicznego  
ID from the MIDAS database of the small environmental conflict

1352 identyfikator z bazy MIDAS złoża ekologicznego  
ID from the MIDAS database of the environmental conflict

414 CHELMCE identyfikator z bazy Midas oraz nazwa złoża bardzo ekologicznego  
ID from the MIDAS database of the very environmental conflict



GÓRNICTWO I PRZETWÓRSTWO KOPALIN

MINING AND MINERAL PROCESSING



Symbol kopaliny:  
Mineral symbol:

Wb - węgiel brunatny  
coal

G - gaz ziemny  
natural gas

R - ropa naftowa  
crude oil

Na - sól kamienna  
rock salt

kj - kreda jeziorna  
lacustrine chalk and gyttja

z - żwiry  
gravels

pż - piaski i żwiry  
sands and gravels

p - piaski  
sands

pk - piaski kwarcowe  
quartz sands

t - torfy  
peat

Symbol jednostki stratygraficznej:  
Symbol of the stratigraphic unit:

Q - Czwartorzęd  
Quaternary

Ng - Neogen  
Neogene

Pg - Paleogen  
Paleogene

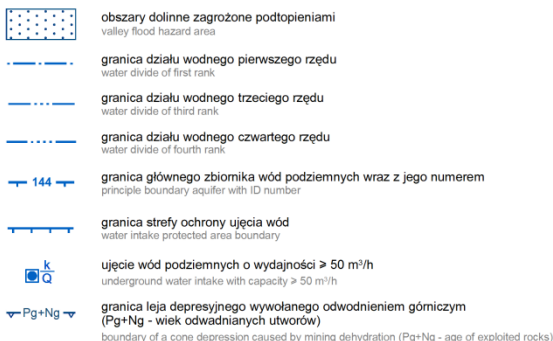
Cr - Kreda  
Cretaceous

J - Jura  
Jurassic

P - Perm  
Permian

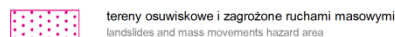
WODY POWIERZCHNIOWE I PODZIEMNE

SURFACE AND UNDERGROUND WATERS



WARUNKI PODŁOŻA BUDOWLANEGO

BUILDING SUBSTRATE CONDITIONS



OCHRONA PRZYRODY, KRAJOBRAZU  
I DZIEDZICTWA KULTUROWEGO

PROTECTION OF NATURE, LANDSCAPE AND CULTURAL HERITAGE



INFORMACJE DODATKOWE

ADDITIONAL INFORMATIONS



\* Wykorzystano informacje udostępniane przez: RZGW, GDOŚ, GDLP, IMGW-PIB, NID, PSE, GAZ-SYSTEM, urzędy morskie oraz z baz danych PSG i PSH w PIG-PIB

\* Data source: RZGW, GDOŚ, GDLP, IMGW-PIB, NID, PSE, GAZ-SYSTEM, maritime offices and from database of PSG and PSH

## 2. GEOLOGY

### 2.1. GENERAL GEOLOGY AND TECTONICS

The Koło tender area is located on the Western European (Paleozoic) Platform (Żelaźniewicz et al., 2011; Figs 2.1–2.2). Within the area and its vicinity, 3 main structural units can be distinguished based on available well and seismic data: Cenozoic, Permian-Mesozoic, and Devonian-Carboniferous. Below, it is assumed that the Lower Paleozoic and Precambrian rocks exist but they have not been drilled, so far. Moreover, the thick succession of Zechstein evaporates makes it difficult to access seismically.

In the sub-Cenozoic structural plan, the Koło tender area is located between the Mogilno-Łódź segment of the Szczecin-Łódź-Miechów Synclinorium and the Kuyavian segment of the Mid-Polish Anticlinorium (Żelaźniewicz et al., 2011; Nawrocki and Becker, 2017; Figs 2.1–2.2). About 2/3 of the area (SW part) has a trough-like structure (Łódź Synclinorium), whereas the remaining part constitutes the western edge of the Mid-Polish Anticlinorium (Kuyavian segment).

Under the thick Permian-Mesozoic succession, the Devonian-Carboniferous succession probably occurs, representing the Variscan orogeny and/or Variscan foredeep basin. The above mentioned horizons have not yet been drilled, so far. The nearest wells, in which rocks of the Carboniferous age were recognized, are located to the SW (Malanów-1) and NE (Byczyna 1) from the Koło tender area. The quality of seismic survey, due to the significant thickness of Zechstein salts, is highly unreliable within the pre-Zechstein sediments. Therefore, the exact boundary between the extent of the Variscan deformation zone and the Variscan foredeep basin has not been clearly defined, so far. According to Żelaźniewicz et al. (2011), the Koło tender area is located within the Variscan foredeep, outside the deformation zone. However, according to Nawrocki and Becker (2017), it is located within the Variscan orogeny deformation zone (Fig. 2.2).

The Variscan structural unit is bounded from the top by the subaerial erosional surface, which is located at depth of about 6900 m b.g.l. in the SW part of the area and generally decreases to 7400 m b.g.l. in the SE (Kudrewicz, 2007; Figs 2.3). The surface rises

sharply from 7300 m b.g.l. to less than 6000 m b.g.l. in the northern part of the tender area. This is most likely caused by the existence of a local normal fault with a throw of about 700 m. The sub-Permian surface exposes sedimentary rocks of the Variscan foreland basin, which, as mentioned earlier, have been – at least in some part – affected by Variscan deformations.

Based on the regional studies and analysis of the nearest wells, it is hypothesized that the Carboniferous formations are directly unconformably overlain by the Rotliegend sedimentary rocks, formed during synsedimentary block tectonic movements in extensional and strike-slip regimes (Karnkowski, 1991, 1999). These rocks begin the Permian-Mesozoic sedimentary succession.

In the Koło area, the base of Zechstein is important structural surface for hydrocarbon exploration. Below this thick, evaporite succession, accumulations of natural gas occur at the top of the Rotliegend, recognized in a number of fields located to the west and south-west from the Koło tender area. Within the analyzed region, the sub-Zechstein surface is located at the depth of 6500 m b.g.l. with local rises and depressions up to 7000 m b.g.l. (Fig. 2.4).

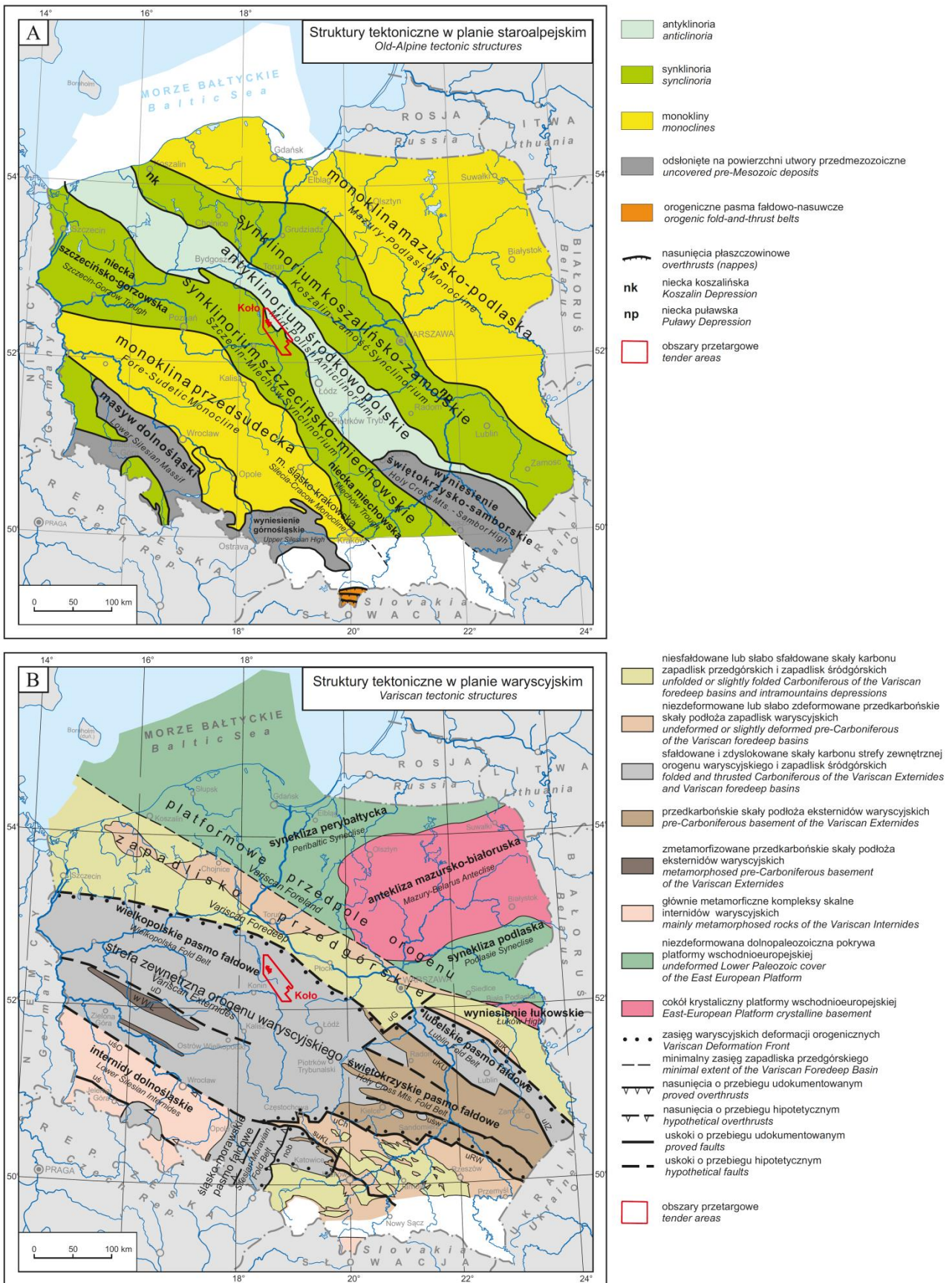
The Polish Basin was formed as one of numerous Mesozoic epicontinental basins of the Central Europe (Ziegler, 1990; Scheck-Wenderoth et al., 2008; Pharaoh et al., 2010). Permian-Mesozoic sediments were deposited in the axial part of the basin, called the Mid-Polish Trough, parallel to the NW-SE oriented T-T Zone (Teisseyre-Tornquist Zone; Kutek and Głazek, 1972; Pożaryski and Brochwicz-Lewiński, 1978; Dadlez, 1997; Kutek, 2000; Guterch et al., 2010), which is the border between the Eastern and Western European platforms. This area underwent strong subsidence from the Permian to the Late Cretaceous, resulting in development of several kilometers thick Permian-Mesozoic succession. Subsequently, in the Late Cretaceous and Paleogene, there was an inversion phase associated with Laramide orogenic movements, which affected almost all basins of the Alpine-Carpathian area (Pożaryski,

Brochwicz-Lewiński, 1978; Dadlez, 1997; Ziegler, 1990; Krzywiec, 2002, 2004a, b, 2012; Mazur et al, 2005; Resak et al., 2008). Simultaneous uplift and erosion of the basin led to the formation of the Mid-Polish Anticlinorium. Its recent boundaries are defined by the extent of the Lower Cretaceous and older rocks on the sub-Cenozoic surface (Pożaryski and Brochwicz-Lewiński, 1978; Ziegler, 1990; Dadlez et al., 1995). In the Koło tender area there is a distinct difference in the geological structure of the SW and NE part of the Kłodawa salt diapir (Figs 2.5–2.6). The difference in geological structure is most probably caused by a stronger uplift of the NE limb of the Kłodawa fault. The hanging limb was more strongly eroded in comparison to the SW part, which resulted in the removal of the whole Cretaceous and a large part of Jurassic sedimentary cover.

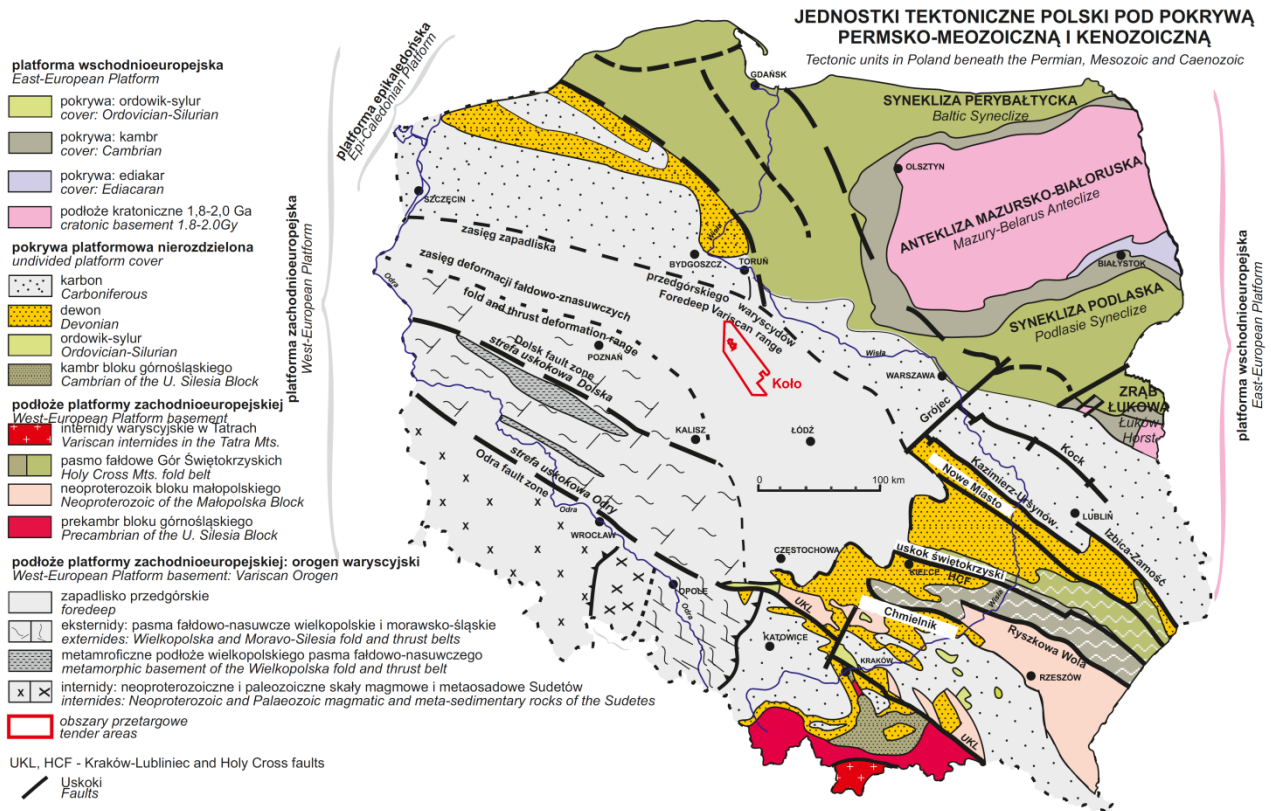
Halotectonics, initiated in the Early Triassic and lasting locally even into the Cenozoic, played an important role in structural evolution of the Permian-Mesozoic succession. The formation of salt diapirs, including the Kłodawa diapir, dates to the Late Triassic, when faulting and subsidence of the basement and accompanying lateral recession of salt intensified. The fault zones were exploited by ductile Zechstein salts that moved upwards in the form of diapirs. They were then covered by the uppermost Triassic and Jurassic sediments (Krzywiec, 2004a). Salt structures are particularly characteristic for the central and north-western parts of the Mid-Polish Anticlinorium. They are mainly salt pillows and diapirs

parallel to the boundaries of the Mid-Polish Anticlinorium. There are also allochthonous structures in the form of salt tongues occurring as interbeds several kilometers long within Mesozoic rocks. A form of this type was recognized at the Kłodawa diapir (Krzywiec, 2004b, 2012; Burliga et al., 2012a). The main halotectonic structures in the discussed area are the Kłodawa, Ponętów-Wartkowice and the Gopło diapirs (Fig. 2.7). The zone of the Kłodawa diapir runs along the NE border of the Koło tender area. In its central part, the diapir pierces Mesozoic sediments. On the SW side of the area the north-western part of the Ponętów-Wartkowice diapir zone is marked and on the NW side – the southern end of the Gopło diapir. These structures partly pierced Mesozoic sediments. It was the reason for stratigraphic gaps in the Mesozoic and Cenozoic sedimentary cover above them.

The following section presents the characteristics of individual stratigraphic units. The lithostratigraphic description is based on data from wells situated within the tender area: Augustynowo 1, Banachów IG-1, Bierzwienina K-31, Bolesław-1, Długie K-68, Gopło GEO10, Gopło GEO9, Izbica 2, Izbica Kujawska K-37, Izbica Kujawska K-67, Izbica Kujawska K70, Kocewia-A, Kłodawa 66, Kłodawa 71, Koło GT-1, Koło IG-3, Marcjanowo K-33, Pagórki IG-1, Podtymień K-69, Ponętów 1, Ponętów 2, Przybyłów 1, Wrząca IGH-1. Their location can be found in Fig. 2.8.



**Fig. 2.1.** A. Location of the Koło tender area in relation to the Old-Alpine tectonic structures (Nawrocki and Becker, 2017; modified). B. Location of the Koło tender area in relation to the Variscan tectonic structures (Nawrocki and Becker, 2017; modified).



**Fig. 2.2.** Location of the Koło tender area in relation to the main tectonic units in Poland beneath the Permian, Mesozoic and Cenozoic (Żelaźniewicz et al., 2011; modified).

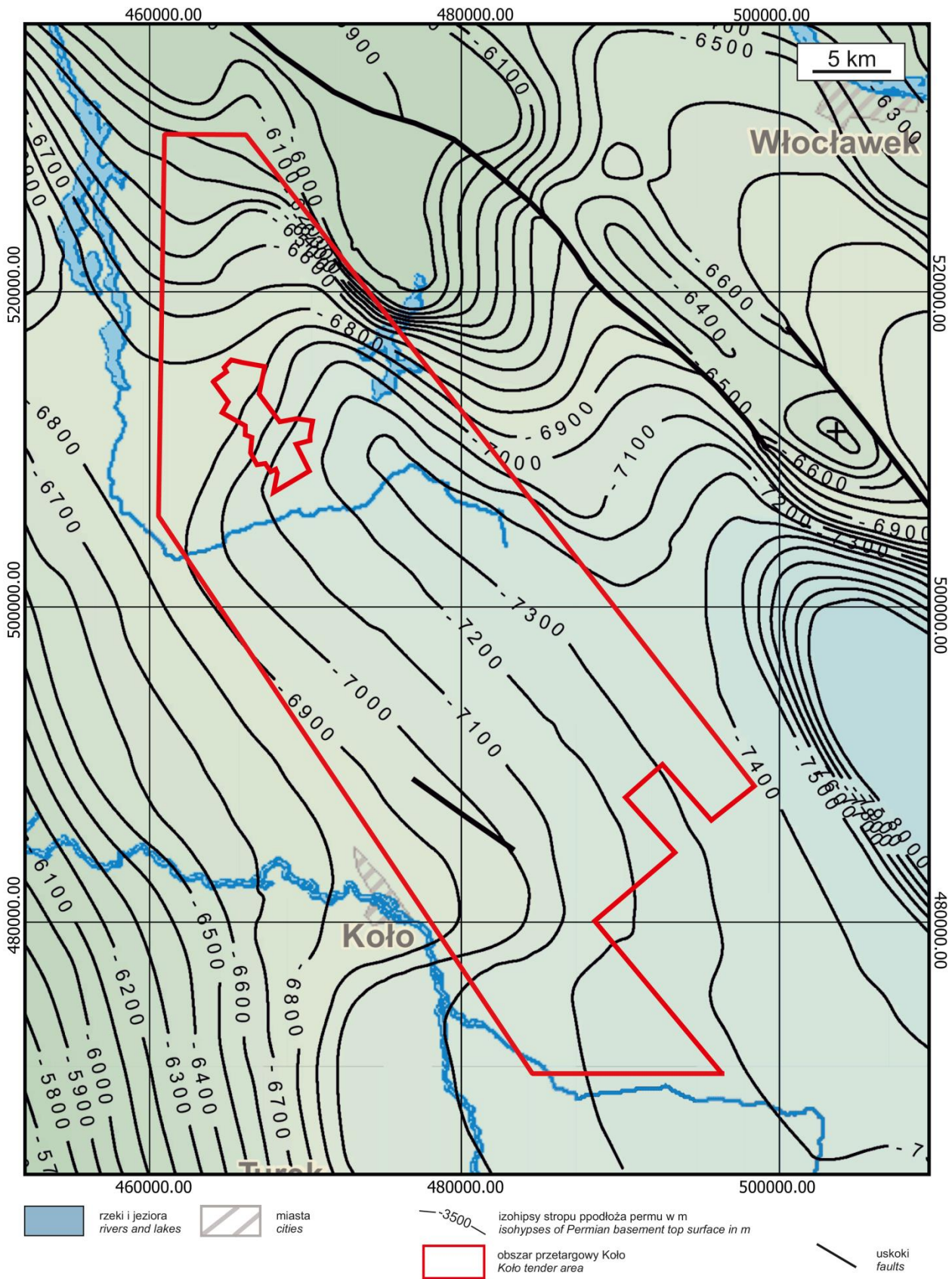


Fig. 2.3. Location of the Koło tender area on the map of the Permian basement top surface (Kudrewicz, 2007).

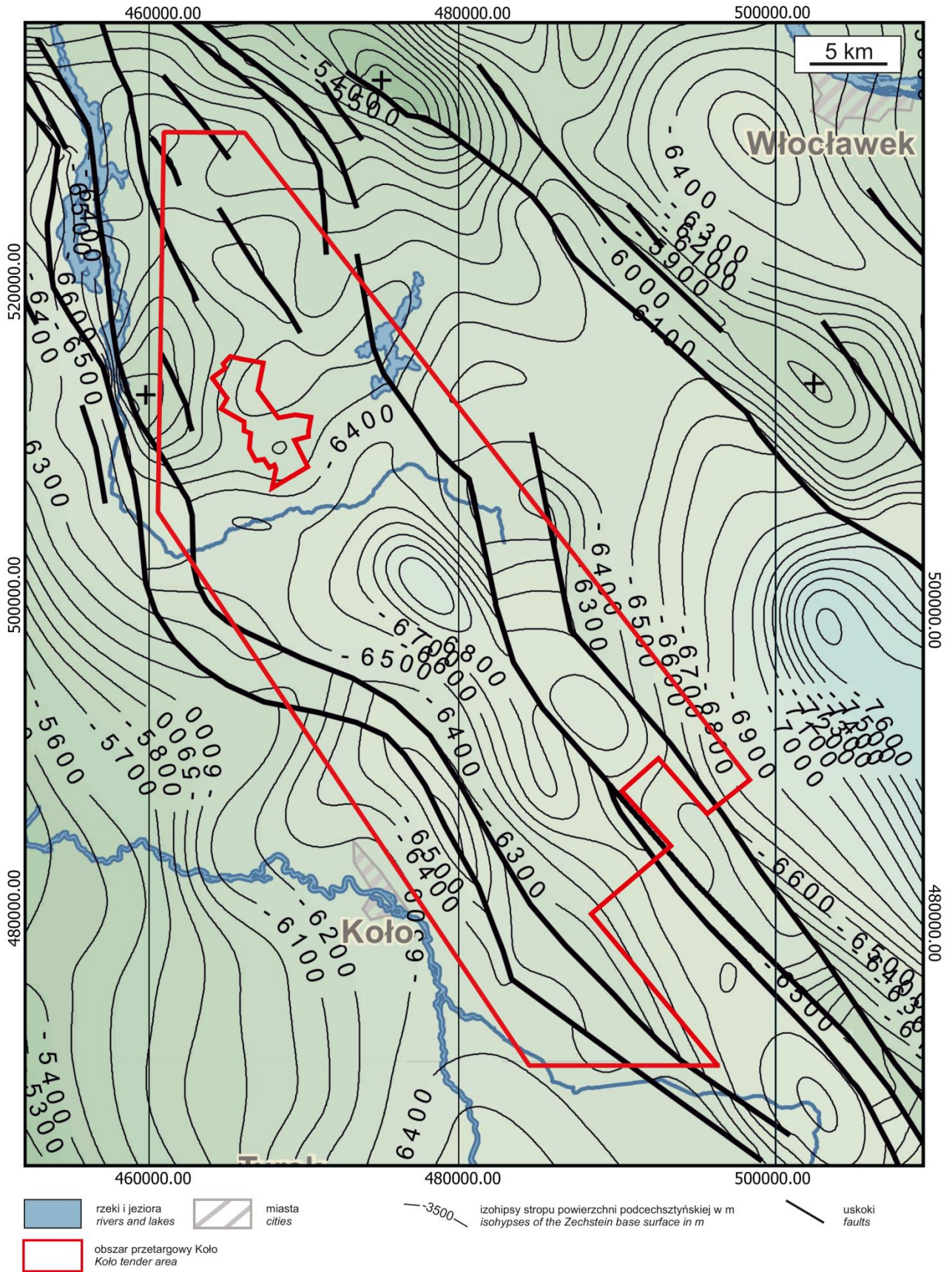
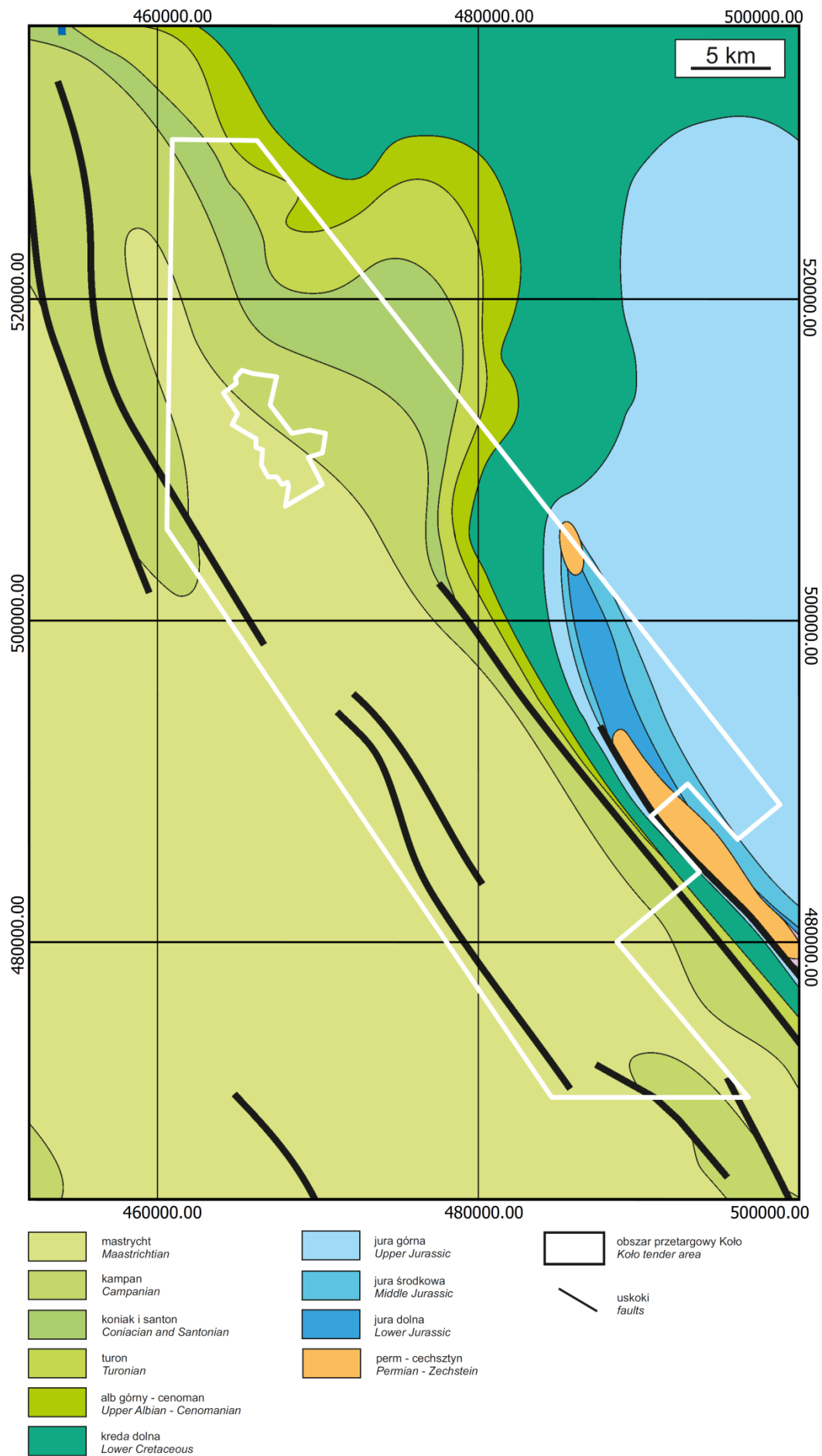


Fig. 2.4. Location of the Koło tender area on the map of the Zechstein base surface (Kudrewicz, 2007).



**Fig. 2.5.** Location of the Koło tender area on the Geological map of Poland without Cenozoic deposits (Dadlez et al., 2000).

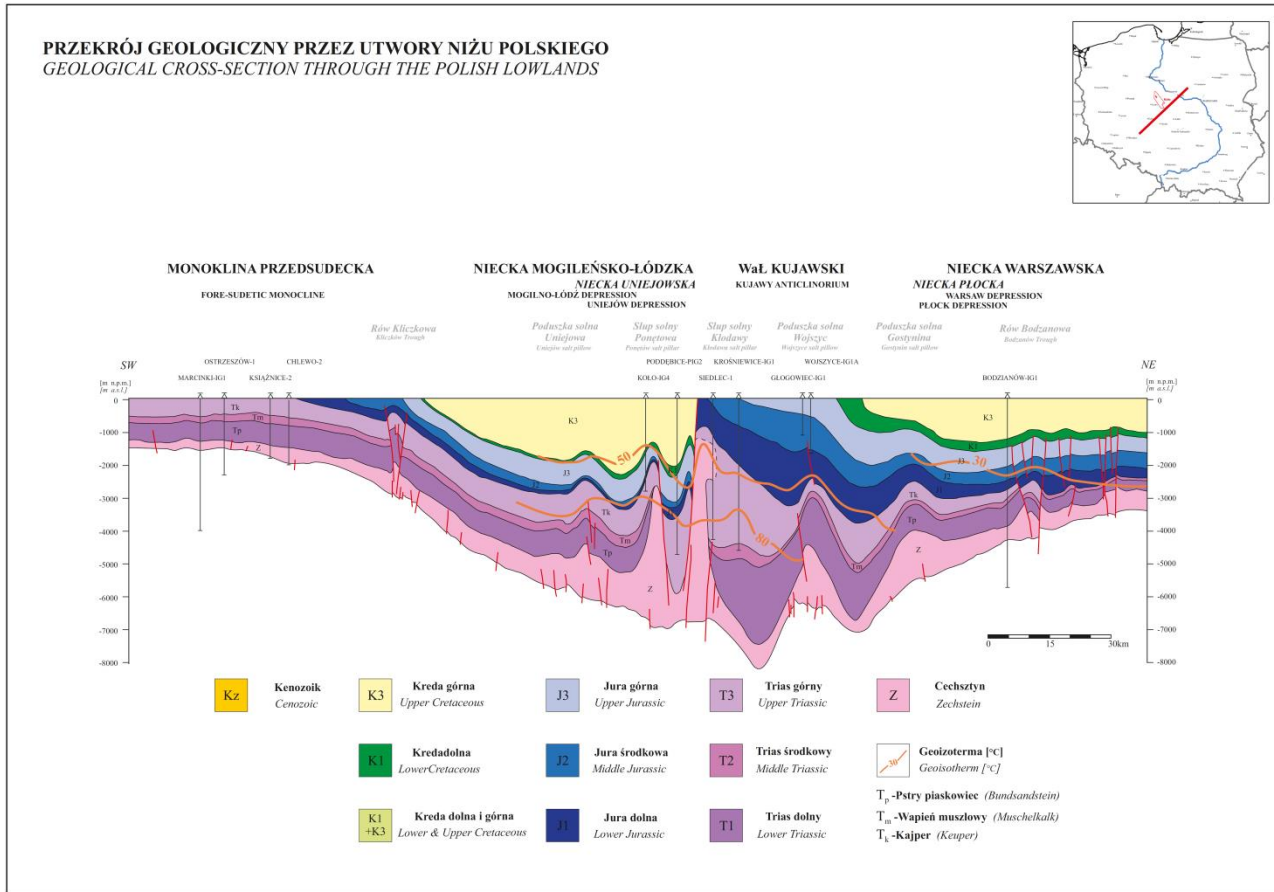
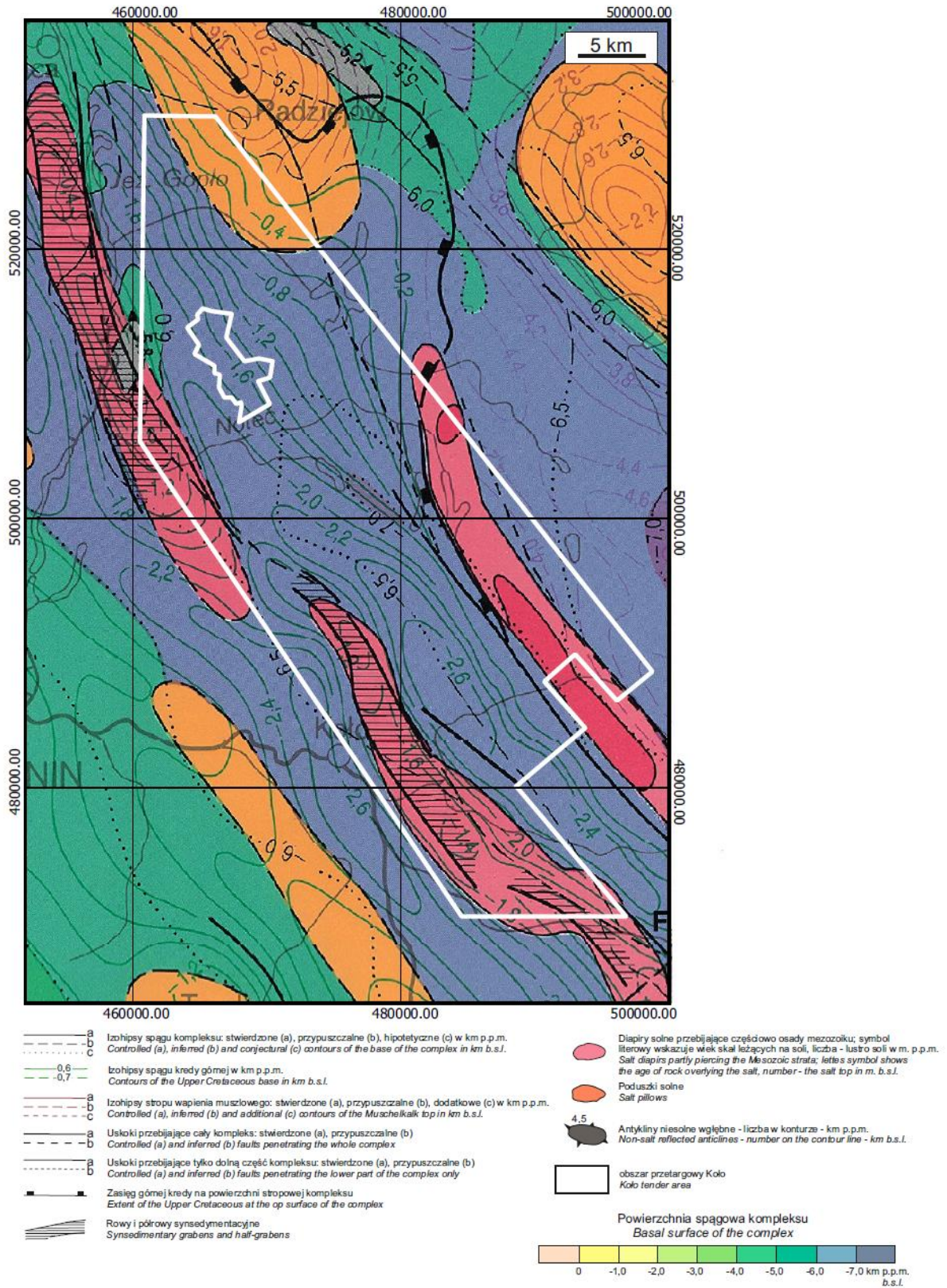
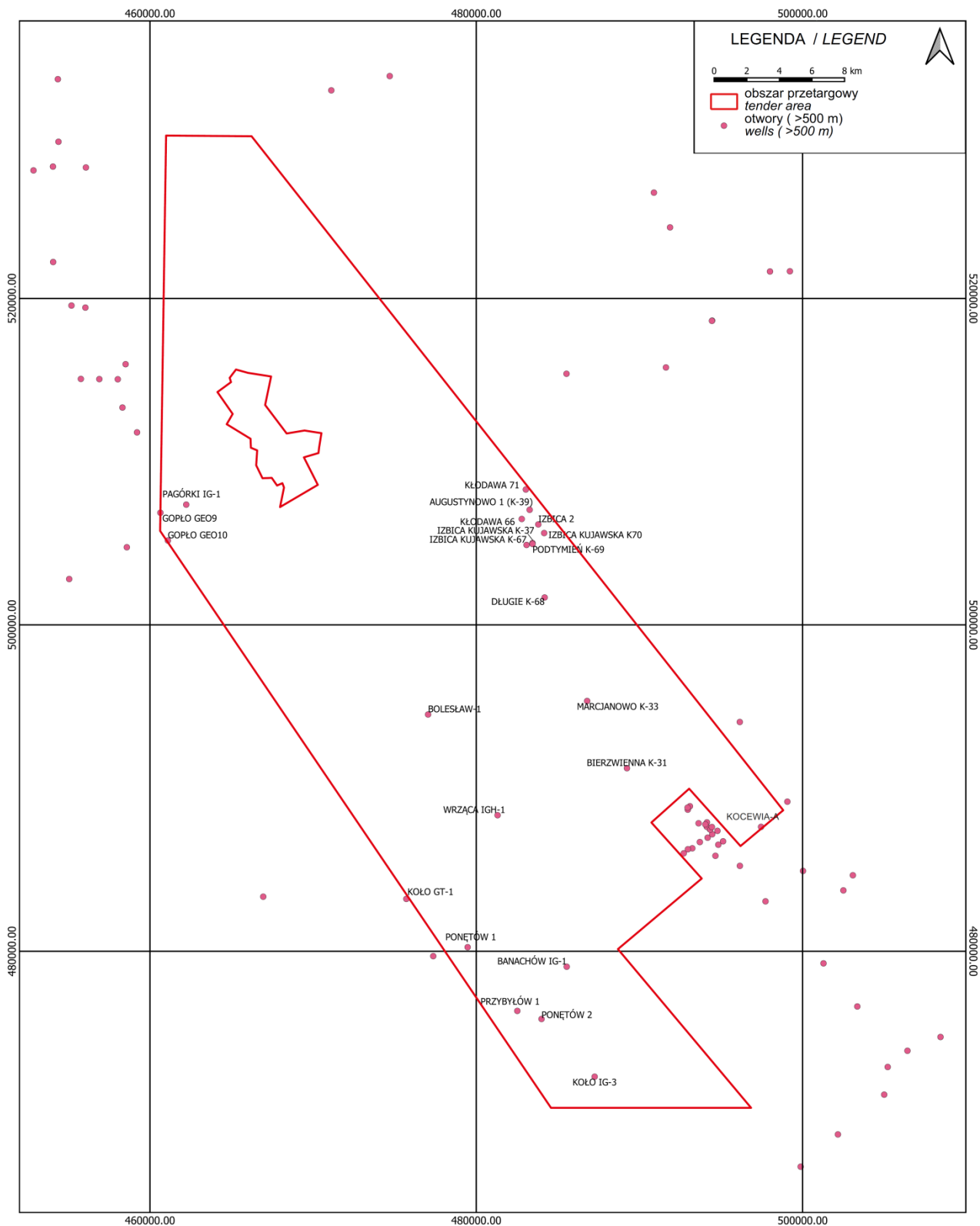


Fig. 2.6. Geological cross-section through the Polish Lowlands (Górecki and Hajto, 2006, modified).



**Fig. 2.7.** Location of the Koło tender area on the Tectonic map of the Zechstein and Mesozoic complexes on the Polish Lowlands (Dadlez et al., 1998).



**Fig. 2.8.** Location of deep wells within the Koło tender area as crucial for geological characteristics.

## 2.2. STRATIGRAPHY

### 2.2.1. CARBONIFEROUS

#### *Distribution and thickness*

No rocks of Carboniferous age were drilled within the Koło tender area. Information on lithology was completed based on the Byczyna 1 and Malanów 1 wells, situated respectively to the NE and SW of the area. Based on available data, it is not possible to determine the thickness of the Carboniferous within the Koło area and in its vicinity.

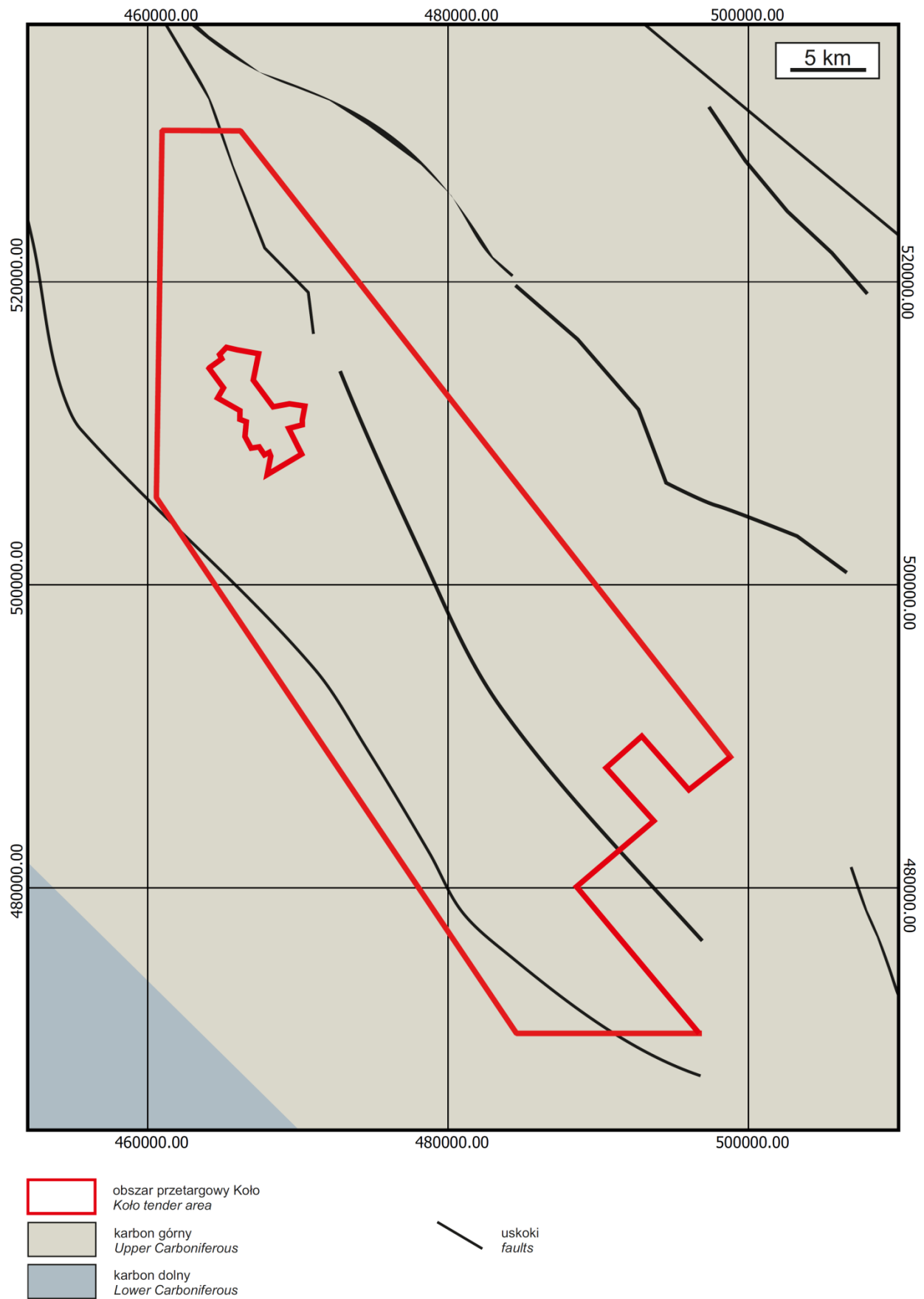
#### *Lithology and stratigraphy*

Carboniferous rocks in the Byczyna 1 well are represented mainly by fine-grained rocks, predominantly dark-gray siltstones with a high content of micas, interlayered with claystones and gray sandstones. The sandstones are generally poorly-sorted. The mineral composition is dominated by quartz (sub-lithic sandstones) with subordinate grains of metamorphic, siliceous, and volcanic rocks. Sometimes exotic content exceeds 25% (lithic arenites). The matrix in sandstones is clayey, often calcareous with dispersed ferruginous substances. Locally there is carbonate cementation and authigenic quartz in the form of syntaxial overgrowths around detrital grains. The increased proportion of siliceous cementation means that macroscopically the sand-

stone can be defined as quartzitic sandstone. To the SW of the Kolo tender area, the Carboniferous rocks are characterized by a higher proportion of sandy rocks than in the NE part, with a variable degree of sorting. They are characterized by a high content of feldspars, lithic grains, and muscovite. Mineral grains and recrystallized feldspars, as a result of compaction, often form a pseudo matrix between the more resistant components of the grain framework.

#### *Petroleum prospects*

Carboniferous rocks are one of the basic source rocks in the area of the European South Permian Basin including the Polish Basin (e.g., Kotarba et al., 1992, 1999, 2005, Kotarba and Lewan, 2004, 2013; Karnkowski, 1999). The Upper Carboniferous rocks are considered to be particularly important, where the role of source rocks is played mainly by coal seams. It is assumed that rocks of this age occur in the basement of the Koło tender area (Fig. 2.9), which creates high hopes for possible generation and migration of hydrocarbons into Mesozoic reservoirs during movement of salt masses.



**Fig. 2.9.** Location of the Kolo tender area on the Geological map of Poland without Permian and younger strata (Waksmundzka and Buła, 2017).

## 2.2.2. PERMIAN – ROTLIEGEND

### *Distribution and thickness*

The Rotliegend deposits in the Koło tender area are almost unrecognized. None of the wells located within the area drilled this horizon. The nearest wells in which Rotliegend has been recorded are:

- Byczyna 1: 5054.0–5535.0 m,
- Kutno-2: 6198.0–6577.2 m,
- Malanów 1.

The Rotliegend in the Koło tender area is deeply buried. The succession and its basement are divided into tectonic blocks (Fig. 2.4; Kudrewicz, 2007). Individual blocks are separated by faults with a general NW-SE trend. The deepest Rotliegend deposits occur in the central part of the tender area (Fig. 2.4). The top of the Rotliegend runs there over 7000.0 m b.g.l. The remaining part is characterized by a slightly shallower depth ranging from about 6000.0 to 6400.0 m b.g.l. (Fig. 2.4). It is believed the thickness of the Rotliegend in the Koło tender area is significant. It is probably the thinnest in the northern part (below 600.0 m), while towards the SW the thickness increases reaching up to 800.0 m (Fig. 2.10; Wagner et al., 2008; Gast et al., 2010).

### *Lithology and stratigraphy*

Due to the lack of wells reaching the Rotliegend rocks in the Koło tender area, the general lithological characteristics of the succession can be adopted only from the Byczyna 1 well (Bloch et al., 1984) located about 10 km to the NE of the area. Some general view brings also the palaeogeographic map of the Upper Rotliegend (Fig. 2.11; Kiersnowski et al., 2020).

The Rotliegend succession is probably limited only to the sedimentary series defined as the Upper Rotliegend (equivalent to the traditional Saxonian unit; Pokorski, 1981, 1988, 1997). It is composed of dark brown and red mudstones, siltstones, and fine-grained sandstones. Abundant anhydrite nodules were also observed. Deposition of these sediments took place in the marginal, south-eastern part of the playa-lake area (Fig. 2.11; Kiersnowski et al., 2020). Generally, in terms of facies and petrophysical properties (Byczyna 1 well: porosity 0.06–4.08 %; permeability ~0.01 mD), the Upper Rotliegend in this region could not have prospective reservoir properties.

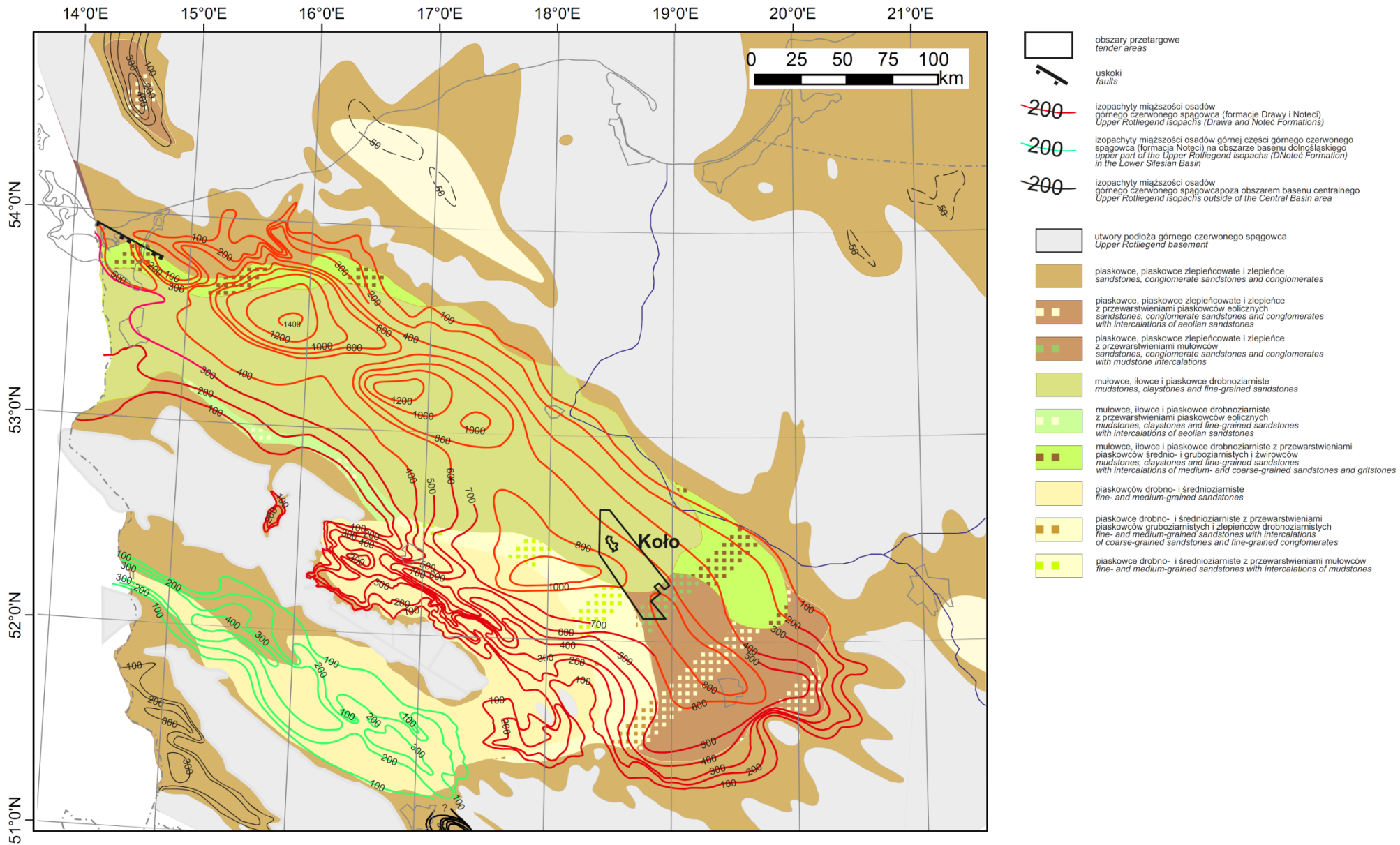
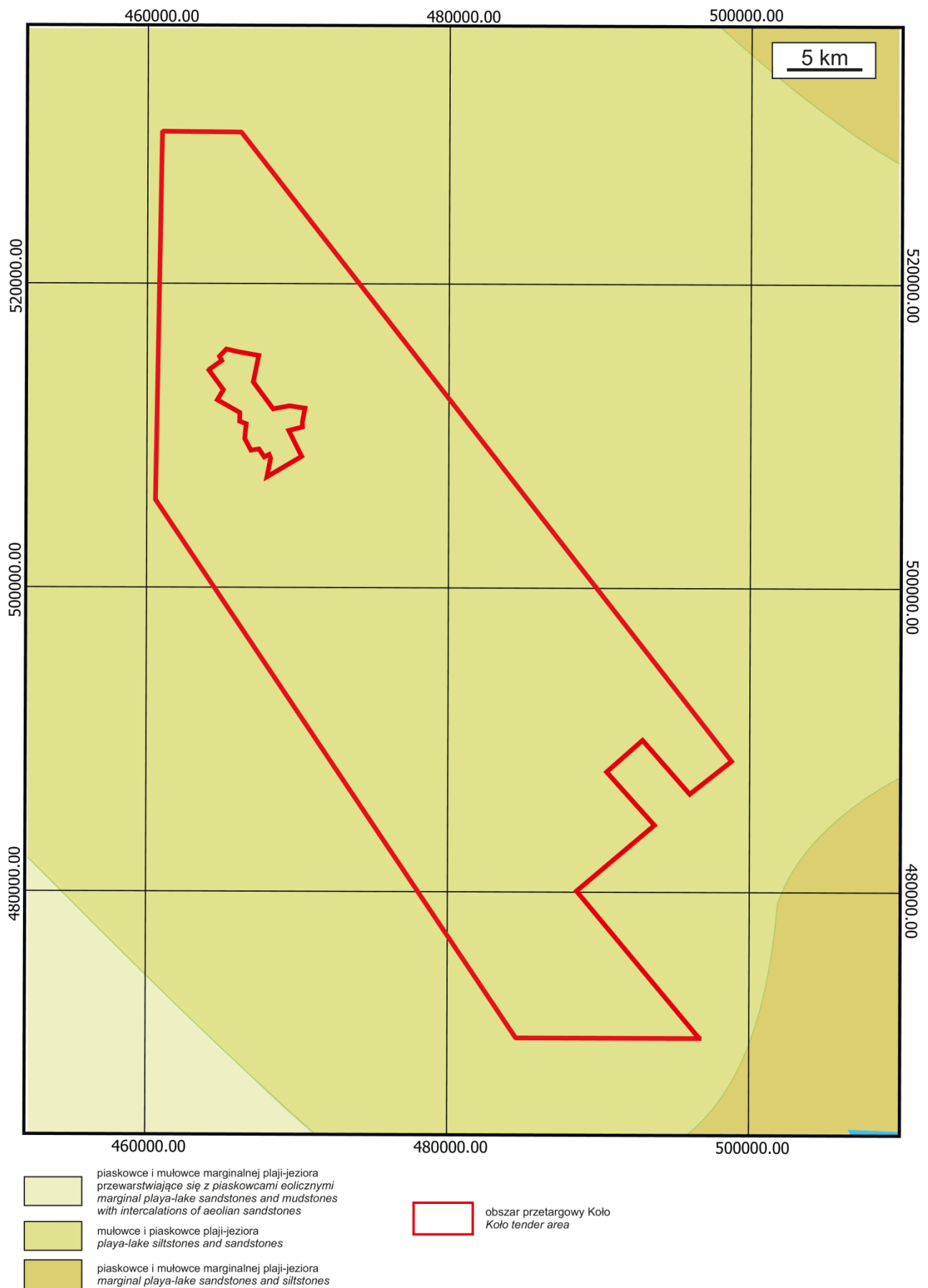


Fig. 2.10. Map of Upper Rotliegend distribution and thickness in Poland with location of the Koło tender area (Wagner et al., 2008).



**Fig. 2.11.** Lithofacies and palaeogeographic map of the topmost part of the Upper Rotliegend in the Koło tender area just before the transgression of the Zechstein sea (Kiersnowski et al., 2020).

## 2.2.3. PERMIAN – ZECHSTEIN

*Distribution and thickness*

The Upper Permian (Zechstein) formations were recognized in 10 wells within the Koło tender area:

- Augustynowo 1: 300.0–630.0 m,
- Bierzwienna K-31: 227.6–1024.4 m,
- Izbica 2: 219.6–1200.0 m,
- Izbica Kujawska K-37: 354.5–1212.3 m,
- Izbica Kujawska K-67: 310.0–521.0 m,
- Izbica Kujawska K70: 215.3–590.5 m,
- Kłodawa 71: 118.0–510.0 m,
- Marcjanowo K-33: 334.7–1002.7 m,
- Podtymień K-69: 412.0–600.1 m,
- Przybyłów 1: 3855.0–3857.0 m.

The Koło tender area is located in the central part of the large Zechstein basin in Poland (e.g. Wagner, 1995). The almost complete Upper Permian (Zechstein) succession can be investigated in the Kłodawa salt diapir, which is the subject of salts exploitation in the KŁODAWA S.A. salt mine for over 70 years. The Zechstein lithostratigraphic units are well-recognized in the mine. Only the lowermost part of the PZ1 succession (Kupferschiefer T1, Zechstein Limestone Ca1, and Lower Anhydrite A1d) was insufficiently

documented (Burliga et al. 1995; Mazurek et al. 2016; Misiek, 1997; Werner et al. 1960), so far. Although the PZ1 rocks have been observed as carbonate and sulfate clasts within the folded PZ2 complexes (e.g., Sadowski et al., 2007), their presence seems to be unquestionable if to compare the regional palaeogeography of the Zechstein Basin in Poland (Oszczepalski and Rydzewski, 1987; 1991; Peryt and Antonowicz, 1990; Peryt and Peryt, 2012; Peryt and Wagner, 1998; Wagner, 1995). Perhaps deeper exploration of the diapir will provide more reliable data on the PZ1 lithostratigraphic units.

The stratigraphic position and estimated thicknesses of the Zechstein lithostratigraphic units occurring in the Koło area are shown in Table 2.1 (see also Fig. 2.12). The thicknesses given therein are based on observations from the Kłodawa salt diapir (these data usually represent apparent rather than real thicknesses of individual units. The diapir underwent intensive tectonics which resulted in duplications, reductions, or even lack of particular units in various analyzed profiles) and regional data (e.g. Czapowski, 1994; Czapowski et al., 1991, 1994; Wagner, 1995).

*Lithology and stratigraphy*

<b>PZ4</b>
<p><b>Top Terrigenous Series (PZt)</b> – the Zechstein succession in the Kłodawa salt diapir have not yet recorded the presence of the Top Terrigenous Series. A clear lithological similarities to the top part of the Upper Youngest Clay Halite make it impossible to distinguish between the two units. It is also possible that the Top Terrigenous Series was included to the Lower Triassic due to lack of the core samples in wells.  <b>Thickness:</b> (60–120 m)</p>
<p><b>Upper Youngest Clay Halite (Na4t)</b> = the Upper Youngest Clay Halite (Na4t) completes a succession of Zechstein deposits that can be traced in the Kłodawa salt mine. They are composed of laminated, gray to beige rock salts, layered and massive, sometimes with claystone fragments, and brown layered and massive clay halite, often with claystone fragments of various size. These rocks are separated by layers of brown claystones and claystone breccia that are from several to several tens of meters thick. In the lowermost part of the succession, there are marly clays with thin overgrowths and concretions of carbonates and anhydrite.  <b>Thickness:</b> 90–160 m (up to 217 m)</p>
<p><b>Youngest Halite (Na4a) = Lower Youngest Halite (Na4a1) + Upper Youngest Halite (Na4a2)</b> – pink and orange, coarse- and medium-crystalline salt interlayered with clayey rock salt laminated with anhydrite.  <b>Thickness:</b> 20–140 m (several–80 m)</p>
<p><b>Lower Pegmatite Anhydrite (A4a1)</b> – a layer of dark gray anhydrite laminated with clays, with clasts of brown and white-gray halite. Regionally, in the lower part these rocks are developed as shallow-water massive anhydrite with layers of selenite crystals (gypsum pseudomorphoses).  <b>Thickness:</b> 0.6–1 m (0.5–1.5 m)</p>
<p><b>Underlying Halite (Na4a0)</b> – grayish, medium- to coarse-crystalline rock salt, with anhydrite smudges and crumbs of claystones (probably Lower Red Pelite) and Zuber beds.  <b>Thickness:</b> 2–3 m (0.5–3 m)</p>

**Lower Red Pelite (T4a)** – a thin layer of grayish to reddish clay with larger halite crystals, locally tectonically reduced to several cm, occurring between the Zuber beds and the Underlying Halite (Na4a0). The regional basin analysis of the PZ4 Zechstein cyclothemedescribes this unit as red mudstones and claystones with intercalations of sandstones in the lower and upper part of the succession.

**Thickness:** ~0.4 m (2–40 m)

### PZ3

**Younger Clay Halite (Na3t)** – gray halite laminated with clays with an admixture of anhydrite. Subordinately thin layers of gray-beige non-textured rock salt and interbeds of tens of cm to 4 m thick massive, brown clay halite and up to 2 m thick brown clays occur. The upper part of the succession is formed of Zuber beds with intercalations of claystones up to several meters thick. Locally, a several meter thick layer of claystone breccia also appears. Wagner (1995) assigned this succession the Tuczno Member.

**Thickness:** 100–110 m (30–70 m)

**Upper Younger Halite (Na3b)** – pink and orange halite, medium- to coarse-crystalline, massive in the lower part of the succession, regularly layered with anhydrite and clays above. In addition, in the upper part of the lower rock salt succession, single desiccation cracks have been described. The principal minerals are halite, anhydrite, clay minerals, sylvinitic and carnallite, with occasionally automorphic quartz.

**Thickness:** 4–16 m

**Transitional deposits: Younger Halite + Younger Potash (Na3+K3)** – fine-crystalline rock salt, gray, laminated rhythmically with layers of kieseritic carnallite. In contrast, the Younger Potash (K3) is composed of alternating medium- to fine-crystalline rock salt, layered with clays and anhydrite, with laminae of kieserite carnallite, and layers of kieserite carnallite with coarse-crystalline and crystalline halite. The carnallite bearing series of about 15–45 m thick is distinguished as the so-called industrial deposit, which occur in the central part of the succession.

**Thickness:** 20–120 m (up to 20 m)

**Lower Younger Halite (Na3a)** – white, grey, and variegated, medium- to coarse-crystalline rock salt, regularly layered with anhydrite in of 5–25 cm intervals. In addition, within the upper part of the succession, there are locally thick lenses and veins (3–8 meters thick) of epigenetic kieseritic carnallite and sylvinitic and zones with blue halite.

**Thickness:** 120–180 m (over 300 m, including Na3a, Na3+K3, K3, and Na3b)

**Main Anhydrite (A3)** – gray, massive, highly fractured anhydrite with clay smudges and veins of epigenetic halite, polyhalite, and sylvinitic. Regional analysis of this unit indicates a similar thickness of sulfate deposits in the central part of the evaporite basin, developed as shallow-water massive anhydrite in the lower part with a transition to more deep-water laminated in the upper part of the succession.

**Thickness:** 30–40 m (30–40 m)

**Platy Dolomite (Ca3)** – brown-gray dolomites and clays. The regional analysis indicates the presence of sediments composed of dolomitic mudstones with interbedding of magnesite. They sometimes contain bivalve fauna, microfau- na, and peloids.

**Thickness:** <1 m (2–4 m)

**Grey Pelite (T3)** – gray shaly claystones with an admixture of anhydrite and calcite, as well as w magnesite in the upper part. The presence of quartz grains, as well as mollusk and brachiopod fauna has been recorded in the lower part of the succession. The regional analysis indicates grey and dark grey mudstones and claystones with sandy intercalations in the middle and upper part of the succession.

**Thickness:** ~ 6 m (0.5–3 m)

### PZ2

**Screening Anhydrite (A2r)** – gray anhydrite laminated with clays.

**Thickness:** ~1 m (1–4 m)

**Screening Older Halite (Na2r)** – white, whitish and orange rock salt, coarse and medium crystalline, streaked and laminated with anhydrite with an admixture of clays, sometimes massive with dispersed anhydrite and secondary polyhalite. Major minerals include halite, anhydrite, clay minerals, sylvinitic, and secondary kieserite, and polyhalite.

**Thickness:** 1–3 m (2–10 m)

**Transitional deposits Na2+K2 and Older Potash (K2)** – Potassium-bearing deposits of the PZ2 in the Kłodawa salt diapir include the Older Potash (K2) and adjacent transitional deposits of the Na2+K2 with K-Mg concentrations of chloride salts. The thickness of these units is estimated at 11–7 m, including transitional deposits of about 5 m thick. The Na2+K2 transition beds, which smoothly passes into the Older Halite (Na2), consist of whitish-gray coarse crystalline rock salt with admixtures of clays, laminated with anhydrite. In the topmost part they contain concentrations and more or less regular overgrowths of K-Mg salts, dominated by kieserite, polyhalite, carnallite, and sylvinitic. In contrast, the Older Potash (K2) unit is composed of anhydrite-sylvinitic-polyhalite potassium salt, which in the lower part contains admixtures of carnallite and kieserite as well as langbeinite, bischofite, and kainite. Regional analysis indicates an accumulation of 600–800 m thick chloride sediments in the central part of the basin.

**Thickness:** transitional deposits Na2+K2 ~5 m, Older Potash ~6–12 m (several–120 m)

**Older Halite (Na2)** – white and whitish coarse- and medium-crystalline (locally fine-crystalline) rock salt with lenses of secondary crystal salt. This salt is streaked and laminated with anhydrite and clays, with laminae up to several millimeters thick in 5–40 cm intervals, forming salt-anhydrite rhythms. Medium-crystalline salt dominates in the lower part of the succession, while the upper part is dominated by fairly pure coarse- to medium-crystalline, white,

<p>and whitish to bluish salt. The observed lamination in the marginal zone of the diapir is plastically deformed, forming systems of folds of different size. In the lower part of the succession, the salt is more strongly tectonically involved and differentiated: coarse-crystalline, centimeter-thick anhydrite-salt overgrowths with a black-gray clays appear here. Numerous systems of salt fractures are scarred by epigenetic polyhalite, while at the top of the succession, in tectonically disturbed parts, the clusters of blue halite appear, sometimes accompanied by sylvinite. The thickness of the salt succession was estimated at 300 m. The main minerals are halite, anhydrite, and clay minerals.</p> <p><b>Thickness:</b> ~300 m (600–800 m including Na<sub>2</sub>, Na<sub>2</sub>+K<sub>2</sub> and K<sub>2</sub>)</p>
<p><b>Basal Anhydrite (A2)</b> – gray anhydrite laminated with clays, which is often a collector for gases and liquids and most often occurs in the form of tectonic xenoliths in rock salt complexes. Regional analysis indicates the presence of deep-water layered and laminated anhydrites originated in the central parts of evaporite basin.</p> <p><b>Thickness:</b> up to 20 m (2–4 m)</p>
<p><b>Main Dolomite (Ca2)</b> – mainly bituminous marly claystones occurring as xenoliths within the rock salt complexes. Occasionally, beige-gray, weakly streaked dolomites can be observed. The regional analyses indicate the presence of stromatolite boundstones and bioclastic packstones in the lower part, and wackstones with intercalations of shales in the upper part of succession.</p> <p><b>Thickness:</b> 0.3–several m (~5 m)</p>
<p><b>Shale (T2)</b> – densely laminated gray dolomitic shale, rich in gaseous and liquid bitumen, usually occurring as xenoliths in rock salt complexes.</p> <p><b>Thickness:</b> 1–3.7 m</p>
<b>PZ1</b>
<p><b>Upper Anhydrite (A1g)</b> – anhydrite laminated with clays, locally visible horizontal to smudge and nodular lamination.</p> <p><b>Thickness:</b> 1.3–20 m (~50 m)</p>
<p><b>Oldest Halite (Na1)</b> – brownish-gray and honey-yellow fine crystalline rock salt (base), white and cream medium to coarse crystalline at the top.</p> <p><b>Thickness:</b> 300-315 m (over a dozen to 50 m)</p>
<p><b>Lower Anhydrite (A1d)</b> – gray spartite and micrite anhydrite. Regional analyses indicate relatively thin lower part made up of shallow-water anhydrites with pearly and mosaic structures, whereas the upper part – of deep-water sediments – is irregularly layered and regularly laminated.</p> <p><b>Thickness:</b> Approx. 30 m (30–70 m)</p>
<p><b>Zechstein Limestone (Ca1)</b> – brownish-gray carbonate rocks. Regional analyses indicate micrite-sparite limestone in the lower part of the succession and oncolite-stromatolite limestone in the upper part (basin-plain facies).</p> <p><b>Thickness:</b> 1–3 m (5–10 m)</p>
<p><b>Kuperschiefer (T1)</b> – dark gray siltstone, claystone, and marls, highly fractured and locally with Fe-sulphides. Regional analyses indicate grayish, calcareous shale, with copper, lead, and zinc sulfides.</p> <p><b>Thickness:</b> ≥ 1 m (0.3–0.6 m)</p>

**Tab. 2.1.** Stratigraphy, lithology and thickness of Zechstein lithostratigraphic units in the Kłodawa salt diapir and vicinity of the Koło tender area (based on: Wagner, 1995; Tomassi-Morawiec i in., 2008, 2009, 2019; Misiek, 1997; Oszczepalski and Rydzewski, 1987, 1991; Peryt and Antonowicz, 1990; Burliga et al., 1995; Czapowski and Tomassi-Morawiec, 2018; Hanczke, 1969; Charysz, 1973; Werner, 1972; Dębski et al. 1989). Thickness is given based on observations from the Kłodawa salt diapir and from regional study (in brackets) .

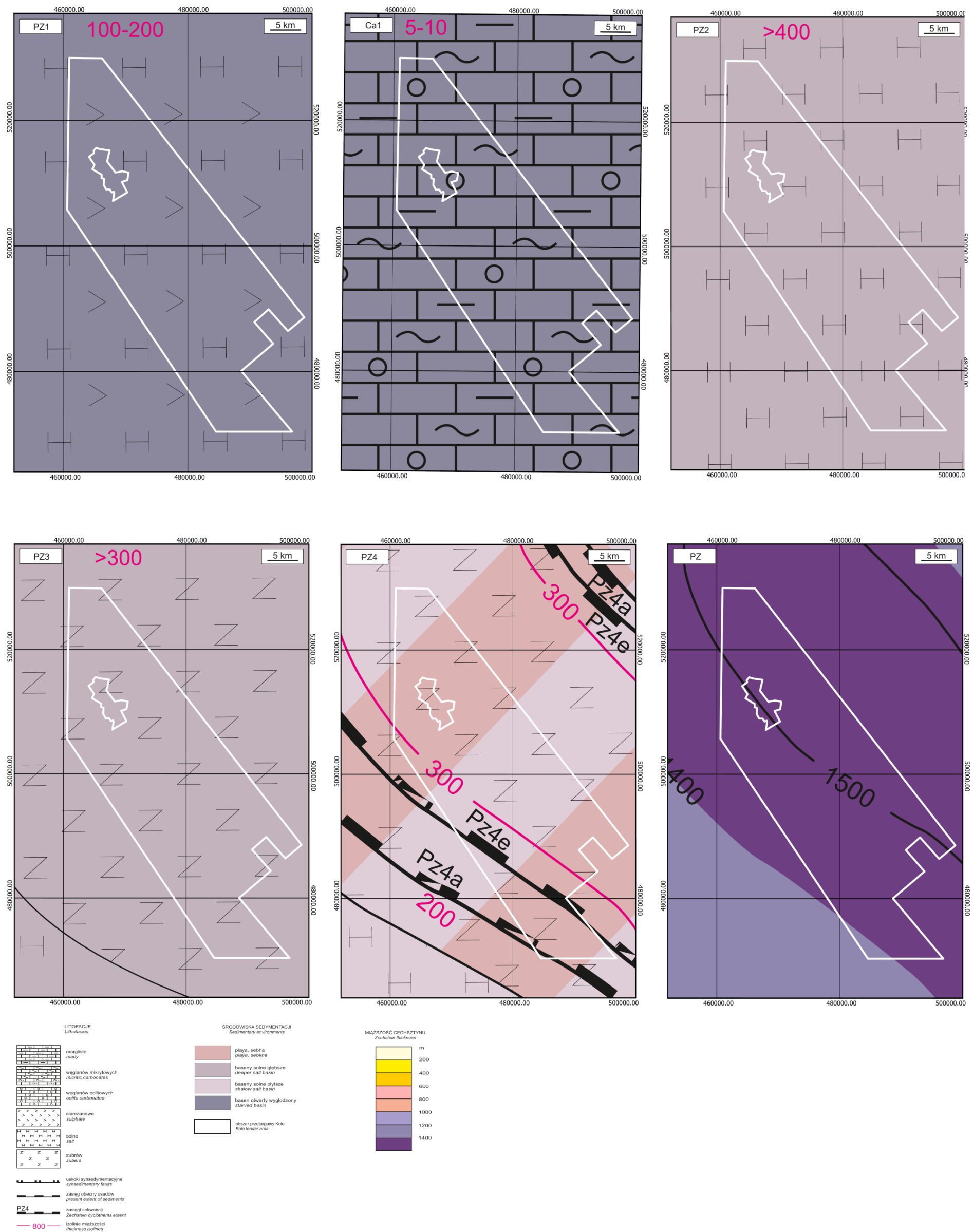


Fig. 2.12. Palaeogeography, lithofacies and thickness of the Zechstein PZ1–PZ4 cyclothem, Zechstein Limestone Ca1, and Zechstein total thickness in the Koło tender area (Wagner, 1998).

## 2.2.4. TRIASSIC

### *Distribution and thickness*

The Triassic deposits in the Koło tender area were recognized in three wells:

- Augustynowo 1: 203.5–300.00 m,
- Koło GT-1: 3876.5–3905.0 m,
- Przybyłów 1: 2766.5–3855.0 m.

The variable thicknesses of Triassic sediments in the tender area are closely related to halotectonics. The greatest thickness was recorded on the eastern side of the Kłodawa diapir zone, where they can exceed 1500 m. Increased thickness of Triassic rocks exceeding 1000 m is also present in the Ponętów-Wartkowice zone. On the other hand, in close vicinity and above the Kłodawa diapir, the Triassic thickness varies from 0 to over 200 m.

### *Lithology and stratigraphy*

The most complete succession of the Triassic sediments in the Koło tender area was recognized in the Przybyłów 1 wells, situated close to the SW margin of the area. The following lithostratigraphic units are present: Bunter Sandstone (with a thickness of 137.0 m), Muschelkalk (416.0 m), and Keuper (535.5 m).

#### Bunter Sandstone

The Bunter Sandstone sediments were deposited in a shallow marine epicontinental basin that was periodically transformed into an extensive, episodic salt lake. During the periods of calm water stagnation, sedimentation of evaporite complexes and gypsum-anhydrite deposits occurred. During transgressions, on the other hand, clastic and carbonate rocks were developed. The Triassic succession in the southern part of the area begins with brown-red, grey, or grey-green siltstones and claystones with possible intercalations of calcareous/shaly sandstones of the Lower and Middle Bunter Sandstone. The upper part is dominated by red mudstones with possible intercalations of fine-grained sandstones and calcareous/dolomitic sandstones belonging to the Upper Bunter Sandstone (Röt). The uppermost part of this interval is dominated by dolomitic mudstones with anhydrite and dark gray marls intercalations. In the southeastern

part of the area, the Upper Röt is characterized by a predominance of the carbonate rocks (marly and nodular limestones) with subordinate clay and calcareous rock intercalations, making the smooth transition with the overlying Muschelkalk deposits.

#### Muschelkalk

The deposition of the Muschelkalk took place in the extensive shallow-marine epicontinental basin, mainly in the sublittoral zone (Sikorska-Jaworowska and Jaworowski, 1997). The Muschelkalk deposits in the study area are dominated by fine crystalline, dolomitic, marly, and nodular limestones intercalated with dark, marly, grey/brown claystones. Less common are calcareous sandstones (SW) or sandstones with concentrations of anhydrite (SE).

#### Keuper

The Keuper sediments were deposited in an extensive shallow (lagoon-like) continental basin, as a residual Muschelkalk basin. Sedimentation of the Lower Gypsum Beds was followed by intensive development of river channels system and deltas of the Reed Sandstone. The subsequent change of climate to hot and dry caused a decrease in sedimentation rate. The Upper Gypsum Beds were dominated by floodplain sediments with a system of small rivers and periodic lakes. The uppermost Triassic was characterized by freshwater and brackish sedimentation with a slight influence of marine environments in a humid climate.

The Lower Keuper Formation in the Przybyłów 1 well is characterized by dark grey micaceous siltstones with plant detritus and thin intercalations of sandy and carbonate rocks. The lower Keuper is overlaid by the Lower Gypsum Beds of dark grey and brownish-grey siltstones and mudstones interlayered with anhydrite and gypsum beds. Above the Reed Sandstone appears, dominated by fine-grained sandstones of greenish color or its clayey equivalents. The uppermost part of the succession is developed as greenish fine-grained rocks (mudstones and claystones) with gypsum and anhydrite of the Upper Gyp-

sum Beds. Above, brownish-red mudstones and claystones with minor intercalations of medium-grained sandstones and conglomerates occur.

#### *Petroleum prospects*

A potential for hydrocarbon occurrences in the Triassic deposits in the Koło tender area is related to the Reed Sandstone unit, in which gas shows were observed. This unit is composed of sandstones with high quartz content (quartz arenites, sublithic and subarcosic). The Reed Sandstone deposits originated in the sandy river channels and lake environments in the area of an extensive floodplain. It is difficult to determine where sandstones dominate over the fine-grained rocks without advanced 3D seismic methods. The thickness of the Reed Sandstone rocks in the Koło tender area can exceed 100 m. They often show favourable reservoir properties as a result of secondary porosity produced by diagenetic dissolution of rock components, mainly feldspars, lithic grains, and quartz (Maliszewska, 1999).

In addition, increased porosities may also occur sporadically in the sandy rocks of the Bunter Sandstone.

The source rocks for hydrocarbons trapped in the Triassic deposits in Western Europe are generally sub-Permian formations: hydrocarbons migrated through fault zones or with Permian salts during its halotectonic activity. In the diapir surroundings, the migration of hydrocarbons may also have passed from younger, Jurassic organic-rich sediments to uplifted Triassic sandstones. Such an example is the Thonse deposit in Germany. Other examples of oil and gas fields in Triassic formations in Western Europe include the Caister deposit in Great Britain, the De Wijk and F15-A deposits in the Netherlands, and the Rehden field in Germany (Doornenbal and Stevenson, 2010; Kilhams et al., 2018). Potential accumulations may be sealed by clays and evaporites occurring within the Triassic succession. The presence of fault zones and active salt tectonics could also lead to the formation of combined traps.

### 2.2.5. JURASSIC

#### *Distribution and thickness*

Jurassic formations were recognized in 13 wells within the Koło tender area:

- Banachów IG-1: 2492.0–3403.0 m,
- Długie K-68: 120.8–627.0 m,
- Izbica Kujawska K-67: 151.2–310.1 m,
- Kłodawa 66: 120.0–500.7 m,
- Kłodawa 71: 99.0–118.0 m,
- Koło GT-1: 2935.0–3876.5 m,
- Koło IG-3: 2008.0–3156.2 m,
- Marcjanowo K-33: 292.0–334.7 m,
- Pagórki IG-1: 1295.0–1562.1 m,
- Podtymień K-69: 173.7–412.0 m,
- Ponętów 1: 2013.5–3007.0 m,
- Ponętów 2,
- Przybyłów 1: 1962.0–2766.5 m.

The Koło tender area is located on the border between the Łódź Trough and Kuyavian Swell. These areas had a different geological history in the Jurassic period. The Łódź Basin was located within the so-called Wielkopolska Hump (Dadlez and Franczyk, 1976), which is

characterized by the absence of older Lower Jurassic sediments (Hettangian, Sinemurian), and a strongly reduced profile of the younger Lower Jurassic (Pliensbachian and Toarcian, which is locally absent), as well as by the absence of the oldest Middle Jurassic. Only the Upper Jurassic in this area shows a complete stratigraphic succession with significant thickness. The NE border of the Wielkopolska Hump runs to the SW from Koło IG-3, Ponętów 2, Ponętów 1, and Racice 2 wells. The area of the Kuyavian Swell, on the other hand, was strongly subsiding in the Lower and Middle Jurassic, which caused that the succession is complete and its thickness is significant.

The current Jurassic thickness is strongly differentiated in the Koło tender area. In the close vicinity of the Kłodawa diapir, the Jurassic sediments are absent (Izbica Kujawska K70, Izbica Kujawska K-37, Izbica 2 and Augustynowo 1) or only small thickness from 19 to 238.3 m is observed (Podtymień K-69,

Marcjanowo K-33, Kłodawa 71 and Izbica Kujawska K-67). This reduction is related to erosion of Cretaceous and Jurassic strata during Kłodawa salt diapir formation and later inversion of the Mid-Polish Through.

The highest Jurassic thickness was recorded in Koło IG-3, Ponętów 1, Przybyłów 1, and Banachów IG-1 wells (Leszczyński, 2000). In this zone the Lower and Middle Jurassic sediments have different thickness as a result of the activity of synsedimentary faults and salt uplift movements within salt pillows (Feldman-Olszewska 2012a, b).

In addition, significant Jurassic thicknesses occur to the northeast of the Kłodawa diapir zone and increase toward the axial part of the Kuyavian Swell.

### *Lithology and stratigraphy*

#### **Lower Jurassic**

The Lower Jurassic is mainly represented by the Pliensbachian, with the Toarcian in some places. The thickness of the Lower Jurassic ranges from several tens of meters in the area of the Wielkopolska Hump (Przybyłów 1) to 900 m on the NE side of the Kłodawa diapir, with an increasing trend towards the NE, towards the axis of the Kuyavian Swell.

According to Pieńkowski (2004) the Lower Jurassic was divided into the following formations belonging to the Kamienna Group: Zagaje, Skłoby, Ostrowiec, Gielniów, Drzewica, Ciechocinek, and Borucice. The total thickness of the Kamienna Group is up to 1400.0 m in the central part of the Mid-Polish Anticlinorium (Deczkowski and Franczyk, 1988; Feldman-Olszewska, 1998). Its lower boundary is determined by the erosional surface preceding the deposition of Jurassic rocks. The upper boundary of the Lower Jurassic succession in the area of the Kuyavian Swell is transitional to the Middle Jurassic rocks, whereas in the area of the Wielkopolska Hump it is determined by another erosional surface.

#### **Hettangian-Sinemurian**

The Zagaje Formation is characterized by the occurrence of rocks of fluvial genesis. This includes sandstones with excellent reservoir properties and mudstones with coal intercalations of fluvial plain and lacustrine genesis.

The thickness of the Zagaje Formation in the Koło tender area and its neighbourhood is several tens of meters and even sometimes exceeds 100 m.

In the middle and upper Hettangian, the rocks of the fluvial genesis of the Zagaje Formation are replaced by transgressive sediments of the Skłoby Formation, which is dominated by well-sorted sandstones (quartz arenites) with common horizontal and cross-bedding including hummocky cross-stratification. In addition, heteroliths with numerous trace fossils also occur in the Skłoby Formation. Genetically, these deposits represent coastal, deltaic, and/or lagoon environments. The lower boundary of the formation is defined by a transgressive surface, while the upper one is washed out by sediments of fluvial genesis. In the Sinemurian, the Skłoby Formation is replaced by the Ostrowiec Formation, consisting of gray and light gray sandstones (quartz arenites) with numerous intercalations of mudstones and dark gray claystones with plant detritus. The Ostrowiec Formation is characterized by the occurrence of numerous cross-beddings and trace fossils typical for a coastal marine depositional environment. Three packages of sediments of deltaic or fluvial origin can be observed within the formation (Pieńkowski, 2004; Feldman-Olszewska, 2008a).

#### **Pliensbachian**

The Lower Pliensbachian in the Polish Lowlands is included into the Gielniów and Łobez Formations. The Gielniów Formation contains heteroliths, mudstones, and layered sandstones with plant fragments. Various trace fossils and bivalve shells are found. Shallow marine and deltaic areas are considered to be the depositional environments of the formation. Above, in western Poland, the Łobez Formation occurs, which is represented by dark gray mudstones with scattered pyrite and heteroliths with a high proportion of mud. In addition, numerous trace fossils and marine fauna including ammonites occur within the formation (Pieńkowski, 2004).

The Upper Pliensbachian is represented by the Drzewica Formation. Its thickness ranges from 33.0 m in the Banachów IG-1 well to as much as 189.5 m in the Brześć Kujawski IG-

2, located NE of the tender area boundary. The thickness of the Drzewica Formation increases to the east of the Kłodawa salt diapir. The dominant lithofacies are sandstones with cross-bedding, intercalated with heteroliths and mudstones. Numerous trace fossils, plant fragments, and roots occur within the rocks (Pieńkowski, 2004; Feldman-Olszewska, 2008a).

#### Toarcian

The Middle Toarcian in the Koło tender area is represented by the Ciechocinek Formation, while the Middle and Upper Toarcian – by the Borucice Formation. The Ciechocinek Formation is composed of gray-green heteroliths, mudstones, and claystones with subordinate intercalations of fine-grained sandstones and siltstones. A high chlorite content brings characteristic green color of rocks (Pieńkowski, 2004). Trace fossils and charred plant detritus can be found within the formation, which are deposited in a shallow brackish bay environment. The Borucice Formation, on the other hand, is characterized by the occurrence of medium- to coarse-grained sandstones with common remains of charred plants and root structures. Genetically, the sandstones are classified as rocks of fluvial (meandering and/or braided) or deltaic origin.

#### Middle Jurassic

The Middle Jurassic thickness ranges from 105.0 m to 311.0 m in the southwestern part of the tender area. Between the Kłodawa Diapir and the Ponętów-Wartkowice Anticline, an incomplete succession of the Upper Bajocian–Callovia is present (Feldman-Olszewska 2012b). In the Ponętów-Wartkowice Anticline, the Middle Jurassic is complete. The variation in thickness and presence of stratigraphic gaps are caused by strong synsedimentary tectonics in this area, superimposed by salt movements (Dadlez and Franczyk, 1976; Dadlez, 1997; Marek, 1997). To the NE of the Kłodawa Salt Diapir, the Middle Jurassic succession is complete and its thicknesses increase towards the Kutno depression (Feldman-Olszewska, 1997a, b).

Sedimentation of the Middle Jurassic took place in the epicontinental basin, where several transgressive-regressive cycles were ob-

served (Feldman-Olszewska, 1997a, b). During transgressions, sedimentation of deep shelf mudstones occurred. On the other hand, shallowing of the basin was marked by deposition of sandy rocks and heteroliths. Their age is precisely determined by ammonites and foraminifers. There are no lithostratigraphic subdivisions for the Middle Jurassic in central Poland.

#### Aalenian and Bajocian

Deposition of the Middle Jurassic in central Poland took place in the area of an extensive epicontinental sea (Dayczak-Calikowska and Moryc, 1988; Feldman-Olszewska, 1997a, b). The Lower Aalenian is dominated by fine-grained sandstones with coals formed in the shallow zone of the siliciclastic shelf or within the estuary (Feldman-Olszewska, 1997a, b, 2008b, 2012b). They are mostly quartz arenites with low textural maturity (Maliszewska, 1999), characterized by poor sorting. Among diagenetic processes, the effects of slight quartz cementation and kaolinite are visible. Ankerite dominates among the carbonate minerals.

The upper Aalenian is developed as dark mudstones and heterolithic rocks formed in a shallow marine basin (Dayczak-Calikowska, 1990), which was a deeper, anoxic zone of the siliciclastic shelf (Feldman-Olszewska, 1997a, b). Rocks of this age are generally poor in carbonates.

In the central zone of the Kuyavian Swell, the lower Bajocian is represented by heteroliths and fine-grained sandstones deposited in the nearshore zone of the shallow epicontinental basin (Dayczak-Calikowska 1990, Feldman-Olszewska, 2012b). The Upper Bajocian forms a thick complex composed of mudstones, claystones, and mudstone-sandstone heteroliths, with siderite concretions and abundant bivalve and ammonite fauna. These formations were deposited in the anoxic shelf zone. Siderite mudstones and clayey siderites with fauna are also recorded in some places (Maliszewska, 1999). In the uppermost Upper Bajocian, mudstone and sandstone formations deposited in the offshore environment of the marine epicontinental basin are present.

### Bathonian and Callovian

The Lower Bathonian is represented by mudstones and claystones, with concretions and siderite horizons, as in the Upper Bajocian deposited in the deeper marine basin zone (offshore). The Middle and Upper Bajocian is dominated by rocks that are more sandy compared to the lower Middle Jurassic sediments. Sometimes conglomerate intercalations appear.

In the lower Callovian, on the other hand, sandstones and calcareous sandstones with bivalves and belemnites were deposited. The Middle and Upper Callovian is developed in the form of the so-called nodular layer, which is a stratigraphic condensation level several tens of centimeters thick (Dayczak-Calikowska and Moryc, 1988).

### Upper Jurassic

In the Kolo tender area, the Upper Jurassic was recognized in 7 wells. Its thickness is several hundreds of meters. The succession is often complete. Only in the vicinity of the Kłodawa Salt Diapir it is reduced or not clearly recognized. The Upper Jurassic succession begins with the Oxfordian. Carbonate rocks of this age were formed in a shallow epicontinental basin of varied subsidence. In the Kuyavian Swell, Dembowska (1979) and Niemczycka (1997) distinguished several formations typical for this region.

### Oxfordian

The lowest Oxfordian in the Kolo tender area is represented by marly and calcareous-marly rocks with clay/sandy intercalations of spongy-limestone (I) and limestone-marly (II) formation (Dembowska, 1990; Gaździcka, 2012). The spongy-limestone is represented by spongy and spongy-bryozoan bundstones, rudstones, and floatstones with sponges, and spongy mudstones and packstones (Maliszewska, 1999). In the lower part of the succession, a dolomitized layers occur, whose thickness varies from 5 to 100 m. In places, cherts and flints are present within the series, resulting from the silicification of carbonate sediments. The source of silica was most likely secondary – dissolved, siliceous sponge spicules. The variation in diagenetic processes indicates a multi-stage process, which Radlicz

(1972) described as dolomitization interrupted by silicification. Locally, clusters of anhydrite, fluorite, halite, and sulfides were found (Maliszewska, 1999). This facies gradually pass into the Middle Oxfordian limestone-marly formation. It is mainly composed of nodular and oncoid floatstones and rudstones in the marly matrix and marly shales (mudstones, packstones and wackstones; Radlicz, 1997, 2008). The Upper Oxfordian in the Kolo tender area, on the other hand, is developed mainly as oolitic formation. This formation, according to Niemczycka (1997), overlaps with the coral formation. Both formations are characterized by a high content of calcium carbonate and a great diversity of lithofacies. They include coral-spongy, oncoid, conchoidal, intraclastic and nodular rudstones and floatstones. Bioclastic grainstones and packstones with algal mats and coral-sponge bundstones are also found in places. Several oncoid-bioclastic horizons are also present within the series. For the hydrocarbon exploration, the most prospective is the microfacies of ooid and peloid grainstones and packstones, which exhibit porosity of 10–20% resulting from the dissolution of granular components and/or fracturing (Maliszewska, 1999).

### Kimmeridgian and Tithonian

The Kimmeridgian and Tithonian in the Kolo tender area are represented by rocks of the calcareous-marly-conchoidal formation and the Pałuki and Kcynia Formations, within which the boundary between the Tithonian and the Lower Berriasian runs. The calcareous-marly-conchoidal formation in the Kuyavian Swell is represented by mudstones and wackstones with intercalations of conchoidal and intraclastic floatstones and rudstones, the origin of which is correlated with halotectonic impulses occurring within the area (Dravis and Yurewicz, 1985; Pierson, 1981). The fine clastic inserts are primarily bioclastic-siltstone packstones with glauconite. Porosity ranges from 1 to 4%. Towards the top, this series pass into the Pałuki Formation, developed as mudstones, marly mudstones, and marls (Dembowska, 1979), which in places show higher organic matter contents (up to 9.2% TOC; Wierzbowski and Wierzbowski,

2019). The youngest Kcynia Formation was separated into 3 members. The oldest member, the corbuloid limestone, is built of carbonate rocks composed of mudstones, wackstones, and peloidal and bioclastic packstones. The Wieniec Member is a dolomitic-anhydrite series with interbeds of mudstones, wackstones and packstones with ostracods. In contrast, the Skotniki Member is represented by clay-marly rocks composed of mudstones and wackstones with intercalations of packstones, floatstones, and rudstones with ostracods and bivalves (Maliszewska, 1999).

#### *Petroleum prospectives*

The greatest reservoir potential in the Koło tender area is represented by Lower Jurassic sandstones (Zagaje, Skłoby, Ostrowiec, Drzewica, and Borucice Formations) and Middle Jurassic sandstones (Lower Aalenian, Lower Bajocian). Their textural maturity decreases to the top of the succession (Krystkiewicz, 1996). The Lower and Middle Jurassic, despite being deeply buried, are characterized by high porosity and permeability, which has been preserved by authigenic quartz mineralization formed during eodiagenesis (Maliszewska, 1999). Syntaxial quartz overgrowths stiffened the grain framework and prevented more intense compaction during later mesodiagenesis. Only fine-grained sandstones may have been fully cemented, which may result in significant or complete porosity reduction. Destruction of reservoir properties of the Jurassic sandstones

may have been influenced by fibrous illite formed during meso- and telodiagenesis during the intrusion of meteoric waters. Kaolinite, on the other hand, formed from the dissolution of feldspars may have caused secondary microporosity. In addition, favorable reservoir properties are also exhibited by the Upper Jurassic limestones, in which processes such as cementation, corrosion, dissolution, dolomitization, dedolomitization, stylolithization, and fracturing may have led to the formation of secondary porosity within the carbonate rocks.

The Jurassic fine-grained rocks, as well as the Middle and Upper Jurassic carbonates have also hydrocarbon generation potential. Results of  $R_o$  thermal maturity (vitrinite reflectance) analyses indicate that Middle and Upper Jurassic formations are characterized by  $R_o$  parameter values corresponding to the oil window ( $0.6 < R_o \leq 1.1\%$ ). On the other hand, new TOC results (Wierzbowski and Wierzbowski, 2019) indicate the Pałuki Formation as source rocks, in which TOC values reach an average of 2.5% for the lower and middle parts of the formation. The Jurassic rocks show various degree of thermal maturity from low in the Upper Jurassic (Kosakowski et al., 2015; Wierzbowski and Wierzbowski, 2019) to medium in the Middle Jurassic shales (Kosakowski et al., 2015), which means that they may have been a source of hydrocarbons, especially in the most buried parts of the basin.

## 2.2.6. CRETACEOUS

#### *Distribution and thickness*

In the Koło tender area Cretaceous rocks were recognized in 12 boreholes:

- Augustynowo 1: 123.0–203.0 m,
- Banachów IG-1: 22.0–2492.0 m,
- Bolesław-1: 82.0–1550.0 m,
- Gopło GEO9: 85.0–751.5 m,
- Gopło GEO10: 78.0–507.1 m,
- Koło GT-1: 30.0–2935.0 m,
- Koło IG-3: 45.0–2085.0 m,
- Pagórki IG-1: 86.4–1295.0 m,

- Ponętów-1: 47.0–2013.5 m,
- Ponętów-2,
- Przybyłów-1: 33.5–1887.0 m,
- Wrząca IGH-1: 65.0–2934.8 m.

The thickness of Cretaceous rocks is generally high in synclines and ranges from 1208.6 m (Pagórki IG-1) to 2905.0 m (Koło GT-1). In the eastern part, in the Mid-Polish Anticlinorium, the Cretaceous wedges out. No Cretaceous rocks occur in the Izbica-Kłodawa salt structure, as well. The thickness of the Cretaceous in the Koło tender area is huge in relation to the

other part of the Polish Lowlands (Jaskowiak-Schoeneichowa, 1977; Leszczyński, 2002, 2012), exceeding probably up to 3000 m in synclines. The Lower Cretaceous thickness varies from 187.0 m (Przybyłów-1) to 402.0 m (Koło GT-1), while the Upper series is from 826.6 m (Pagórki IG-1) to 2503.0 m (Koło GT-1).

### *Lithology and stratigraphy*

#### **Lower Cretaceous**

All Lower Cretaceous stages from the Berriasian to the Albian have been distinguished in the Koło tender area. The Lower Berriasian is represented by the Kcynia Formation. It is composed of the Purbeck facies and divided into the Wieniec Member, built of organodetritic limestones with gypsum and anhydrite intercalations, and the Skotniki Member of marly mudstones with lumachelles (Dembowska, 1979; Marek and Raczyńska, 1979). In the Upper Berriasian the Kajetanów Member of the Kcynia Formation, and the lower part of the Rogoźno Formation (Zakrzew Member and lower part of the Opoczki Member) have been distinguished. The Kajetanów Formation is composed of dark gray laminated mudstones and marly mudstones with shell-rich intercalations passing into sandstones with intercalations of mudstones, and organodetritic sandy and dolomitic limestones. Mudstone layers predominate in the upper part of the succession. Above them, there is a sandstone-mudstone complex that can be identified as the Zakrzew Member. In the Gopło area (northern part of the tender area), laminated calcareous-dolomitic sandstones and mudstones occur, often with bioturbation and chamosite-siderite and microsparite ooids. Above, a complex of dark, almost black claystones and mudstones (Opoczki Member) appears. A characteristic feature of this member is the occurrence of siderite concretions and shale intercalations.

Within the Lower Valanginian two distinct lithofacies occur: the lower one – dark grey and black claystones and mudstones of the Opoczki Member of the Rogoźno Formation, and the upper one – sandy lithofacies – of the Bodzanów Formation.

The Upper Valanginian (Włocławek Formation, Wierzchosławice Member) is com-

posed of dark grey (often sandy) claystones and siltstones.

The Lower Hauterivian (Włocławek Formation, Gniewków Member) is formed by a complex of mudstones and claystones with concentrations of Fe-ooids and intercalations of very fine-grained sandstones.

The Upper Hauterivian (Włocławek Formation, Żychlin Member) includes two lithological complexes: the lower one – sandy complex and the upper one – mudstone and claystone complex. The lower complex is composed of fine- to coarse-grained, grey quartz sandstones. Iron hydroxide impregnations are common. In the Banachów IG-1 and Koło IG-3 wells, gray-green glauconitic-chamosite sandstones were found. The upper complex is dominated by gray to black claystone-mudstone sediments, sometimes with shales and sphaeroidites. In the Pagórki IG-1 well there are also levels of oolitic ores (Osika, 1959; Raczyńska, 1961).

Above the claystone and mudstone sediments attributed to the Upper Hauterivian, a complex of Barremian–Middle Albian sandy sediments occurs. This is the Mogilno Formation, which is divided into 3 members: Pagórki (Barremian), Gopło (Aptian), and Kruszwica (Lower and Middle Albian). The Pagórki Member is composed of whitish and gray very fine-grained sandstones with intercalations of sandy and muddy heteroliths and numerous fragments of charred and sometimes pyritized flora/wood remains. The Gopło Member has mudstone-sandstone sediments. The Kruszwice Member is rather monotonous series of light gray and grayish-green calcareous to non-calcareous sandstones with horizons of gravels, sometimes conglomerates. A significant proportion of coarse clastic sediments is a characteristic feature of this member. Glauconite and charred detritus are generally abundant. The thickness of the Kruszwice Member is significant and generally exceed 100 m.

The lower part of the Upper Albian is represented by (up to 1 m) grey-green quartz-glauconite sandstones with clay or marly/phosphate matrix and phosphate concretions. Above, there is a marly-clayey series, followed by the marly series with limestone interbeds. The Upper Albian/Ceno-

manian boundary coincides with the sharp marl/limestone lithological boundary.

The stratigraphy of the Lower Cretaceous in Central Poland is shown in the table below (Tab 2.2).

Chronostratigraphy		Litostratigraphy (Marek and Raczyńska, 1979; Wagner et al., 2008)		
Albian	Upper	Mogilno FM	Kruszwica Member	
	Lower-Middle			
Aptian			Gopło Member	
Barremian			Pagórki Member	
Hauterivian	Upper	Włocławek FM	Żychlin Member	
	Lower		Gniewków Member	
Valanginian	Upper			Wierzchosławice Member
	Lower	Bodzanów FM		
		Rogoźno FM	Opozki Member	
Berriasian	Upper	Kcynia FM	Zakrzew Member	
	Middle		Kajetanów Member	
	Lower			Skotniki Member
				Wieniec Member

**Tab. 2.2.** Lower Cretaceous stratigraphy in Central Poland.

### Upper Cretaceous

No lithostratigraphic units were distinguished in the Upper Cretaceous. According to the chronostratigraphic subdivision (Jaskowiak-Schoeneichowa, 1977), the Upper Cretaceous is represented by all the stages from the Cenomanian to the Maastrichtian.

Limestone and marly limestones predominate in the Cenomanian. The Turonian and Lower Coniacian is an interval of great lithological diversity and significant thickness. Two main lithological complexes can be distinguished:

- lower complex – marly-limestone with characteristic layer of almost black marly claystones at the bottom;
- upper complex – marly-opokas.

The Upper Coniacian is formed by a homogeneous carbonate-siliceous complex. The Santonian is also dominated by carbonate-siliceous facies with marls and marly limestone intercalations. In the eastern part, near the Kłodawa Salt Diapir, in the Upper Santonian sandstones (found in the Koło IG-3 well) have significant thickness (Leszczyński, 1990, 1997, 2000). They are represented by

very fine- to coarse-grained quartz wackes. Graded bedding is common. Bimodal grain size distribution is sometimes observed, especially in coarse-grained facies. Sandstones are interlayered with siliceous carbonates, sandy siliceous carbonates, sometimes mudstones or marly claystones and marls.

In the Campanian and Maastrichtian, siliceous carbonates predominate. In the Campanian the transition into marls and marly limestones is visible. Locally, intercalations of porous calcareous gaizes appear. The Campanian has the greatest thickness among all the Upper Cretaceous stages.

The Maastrichtian rocks are similar. They are locally interlayered with porous calcareous gaizes and sandy gaizes (e.g. Koło IG-3). They occur in the lower and upper part of the Maastrichtian succession. The middle part is dominated by siliceous carbonates. Due to the post-Cretaceous erosion, the Maastrichtian is usually reduced.

### Depositional environments

The following Cretaceous depositional systems and environments have been distinguished in the Koło tender area (Leszczyński, 2002):

- marine environment: siliciclastic shelf system (Lower Cretaceous) with two sub-systems – shallower siliciclastic shelf and deeper siliciclastic shelf; carbonate-clastic shelf system (deeper part of the shelf, lower Upper Albian); open basin carbonate system (deeper carbonate shelf, mainly in the Cenomanian and Turonian); open basin carbonate-siliciclastic system (siliceous carbonates and gaizes lithofacies); open basin siliciclastic system (dark claystones in the base of the Turonian); submarine turbidite system of basin floor fans (Santonian);
- transitional environment: deltaic system (Bodzanów Formation, part of Żychlin and Gniewków Members, possibly part of Pagórki Member);
- terrestrial environment: alluvial plain system (part of Pagórki Member).

*Petroleum prospects*

The Lower Cretaceous clastic rocks have the greatest hydrocarbon potential within the Cretaceous succession in the Koło tender area. They are mainly represented by mostly fine-grained sandstones with a high quartz content (arenites and quartz waxes). In general, the Cretaceous clastic rocks show favourable petrophysical properties. They are related to both the kaolinitization process and dissolution of some components of the grain framework, leading to the formation of secondary

porosity and microporosity. Secondary quartz and carbonate cementation slightly affected reservoir properties of sandy rocks, but minimized an impact of mechanical compaction (Połńska, 1999, in: Maliszewska, 1999). The reservoir potential of the Lower Cretaceous in the tender area is confirmed by gas shows observed in wells. The seal is formed by the horizons of clayey and evaporite mudstones. The Upper Cretaceous carbonate-siliceous rocks can also play a role of a potential seal (Wójcicki et al., 2013).

## 2.2.7. CENOZOIC

*Distribution and thickness*

The Paleogene (Paleocene, Eocene, Oligocene) and Neogene (Miocene) occur in the Koło tender area. The Paleogene is represented by a weathered cover of Mesozoic succession, which was probably formed in the Paleocene. The Neogene, which constitute the main coal-bearing complex, is common in the area. It includes the Miocene and (possibly) the lowermost Pliocene. The Neogene fill paleovalleys incised into the Cretaceous basement. Some of these trenches have tectonic assumptions. The Palaeogene and Neogene succession is most complete near the Izbica Kujawska Salt Diapir, where significant accumulations of brown coal were developed. In the area of the Koło tender area, the Tomisławice brown coal deposit is a subject of exploitation.

*Lithology and stratigraphy*

## Paleocene

In the Przedecz-Kłodawa and Dęby Szlacheckie-Izbica Kujawska areas the weathered sub-Cenozoic basement occurs. Decalcified marls and siliceous-carbonates, weathered debris with flints and residual clays of thickness up to several meters can be found. The age of these deposits is not precisely defined, although it is most often referred to as Paleocene.

## Eocene

The oldest paleontologically dated Paleogene sediments in the Koło tender belong to the Jerzmanowice Formation of the Late Eocene age. This formation is known from the vicinity of Sompolno and Izbica Kujawska and is represented by sandy and clayey mudstones with sandstone intercalations. The thickness of the Jerzmanowice Formation does not exceed several meters.

## Oligocene

The Lower Oligocene is composed of green glauconitic sands and sandy siltstones with glauconite. They appear in the area of Izbica Kujawska. Above, the Lower Oligocene Czempin Formation occurs, with the bottom part containing brown coal beds, whose thickness ranges from 0.2 m to 7 m in the vicinity of Kłodawa. They are overlain by a thin complex of gray fine-grained quartz-muscovite sands with mudstone intercalations. This complex, which reaches the thickness of 0.5–3.1 m, occurs only in the northern part of the region. In its upper part, there is a compact series of gray-brown silty clays, horizontally laminated by sand with a significant admixture of muscovite. The thickness of this series varies between 0.6 and 7.0 m. Above it, there is a complex of very fine and fine-grained quartz sands, gray-green in colour, with glauconite and muscovite admixtures. The thickness of these sediments is up to 40.0 m in the northern part of the area. They belong to the Upper Oligocene. The total thick-

ness of the Paleogene is 6.0–43.4 m (20 m average).

### Miocene

The Lower Miocene occurs as the overburden of salt diapirs in the region of Dęby Szlacheckie-Izbica Kujawska. These deposits, included into the Ścinawa Formation, are developed as the fine-grained and muddy brown quartz-muscovite sands. In the topmost part of the Ścinawa Formation, there are sporadic thin lenses of brown coal. The Middle Miocene occurs in the whole Koło area (excluding a narrow zone of erosion), reaching the average thickness of 30–50 m. The succession in the lower part is built of the Adamów Formation, formed of grey and brown fine-grained sands, often with an admixture of coal dust, with thin intercalations of coarse-

grained sands, silts, and brown coals. The thickness of this part reaches 39.0 m in the vicinity of Piotrków Kujawski. The upper part of the Middle Miocene, and possibly also the lowermost part of the Pliocene, is represented by the Poznań Formation. At the bottom, there is a lignite seam 8–12 m thick of economic significance. This deposit locally occurs in the form of two banks separated by a sandy layer, locally there are intercalations of fine-grained quartz sands and dark-brown clays (less frequently muds). Above the coal bed, a mud and clay series (Poznań Clays) built of gray and green mud and clay with intercalations of very fine-grained quartz sands occurs. The thickness of the Poznań Clays varies from 1.5 m in the Sompolno region to 16 m in the Piotrków Kujawski area.

## 2.3. HYDROGEOLOGY

According to the regional classification of fresh groundwater, the Koło tender area is situated on the border of two large hydrogeological units – the Kutno Region and the Mogilno-Łódź-Miechów Region, as well as belonging to GWB 43, 47, 62 and 72. The area is crossed by the main surface water divide between the Odra and Vistula drainage basins, which is also the groundwater watershed (Figs 2.13–2.14).

In the Koło area fresh groundwater is found within the hydrogeological system of Quaternary, Neogene-Paleogene, Upper Cretaceous and Upper Jurassic multi-aquifer complexes (Fig. 2.13). None of these complexes occurs continuously throughout the area meeting the parameters appropriate for the main usable aquifers according to criteria determined by the Hydrogeological Map of Poland (MhP). The most widespread is the Upper Cretaceous hydrogeological complex developed in fractured limestones and marls. However, essentials for water supply is the Quaternary groundwater complex associated with sandy-gravel sediments of intermoraines and buried glacial valleys. Within, there are tree water-bearing horizons such as shallow unconfined groundwater horizon, and upper

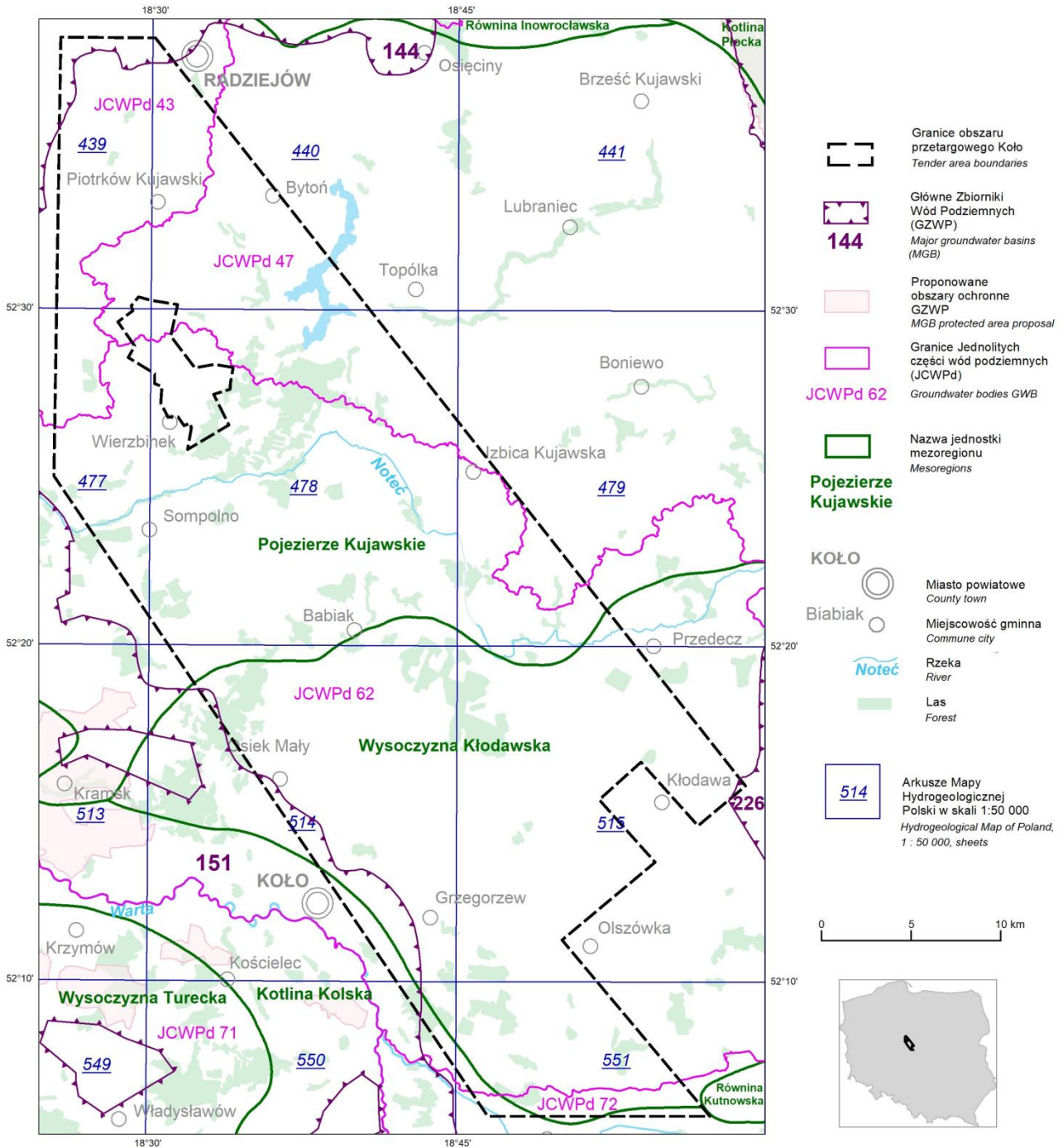
and deeper intermoraine horizon. The Neogene-Paleogene complex represented by sandy Miocene aquifer, is fairly well recognized in the eastern and south-eastern parts of the area, but it is relatively rarely exploited. Jurassic water-bearing sediments, consisting of limestone and marls, have been recognised in the south-eastern tiny part of the area. These multi-aquifer complexes are in hydraulic contact with each other. The Koło tender area is a groundwater recharge area. Under natural conditions, the drainage of ground water took place in the valleys of rivers and lakes at least. The natural hydrodynamic conditions have been disturbed as a result of intensive drainage of the lignite open pit mines located nearby the area. Because of shutting down some of the pits, the groundwater table is gradually recovering. Currently, mine drainage is carried out in the Tomisławice and Drzewce.

Recognition of deeper aquifers is regional in nature. They contain salty (mineralized) water, the mineralization of which increases with depth. Mineralized waters may also co-occur with fresh water in Upper Cretaceous and Jurassic sediments as well as in Quaternary aquifers in the vicinity of salt diapir nearby Kłodawa.

The fresh groundwater's quality is generally good or average due to increase content of iron, manganese and nitrogen compounds. The thickness of the aquitard layers which

cover the exploited aquifers cause medium, low or very low risk for groundwater quality.

There are about 350 hydrogeological wells in the Koło tender area, often out of order due to collective water supply systems.



**Fig. 2.13.** Location of the Koło tender area in relation to physico-geographic units, Major Groundwater Basins (MGB) and Groundwater Bodies (GBW).

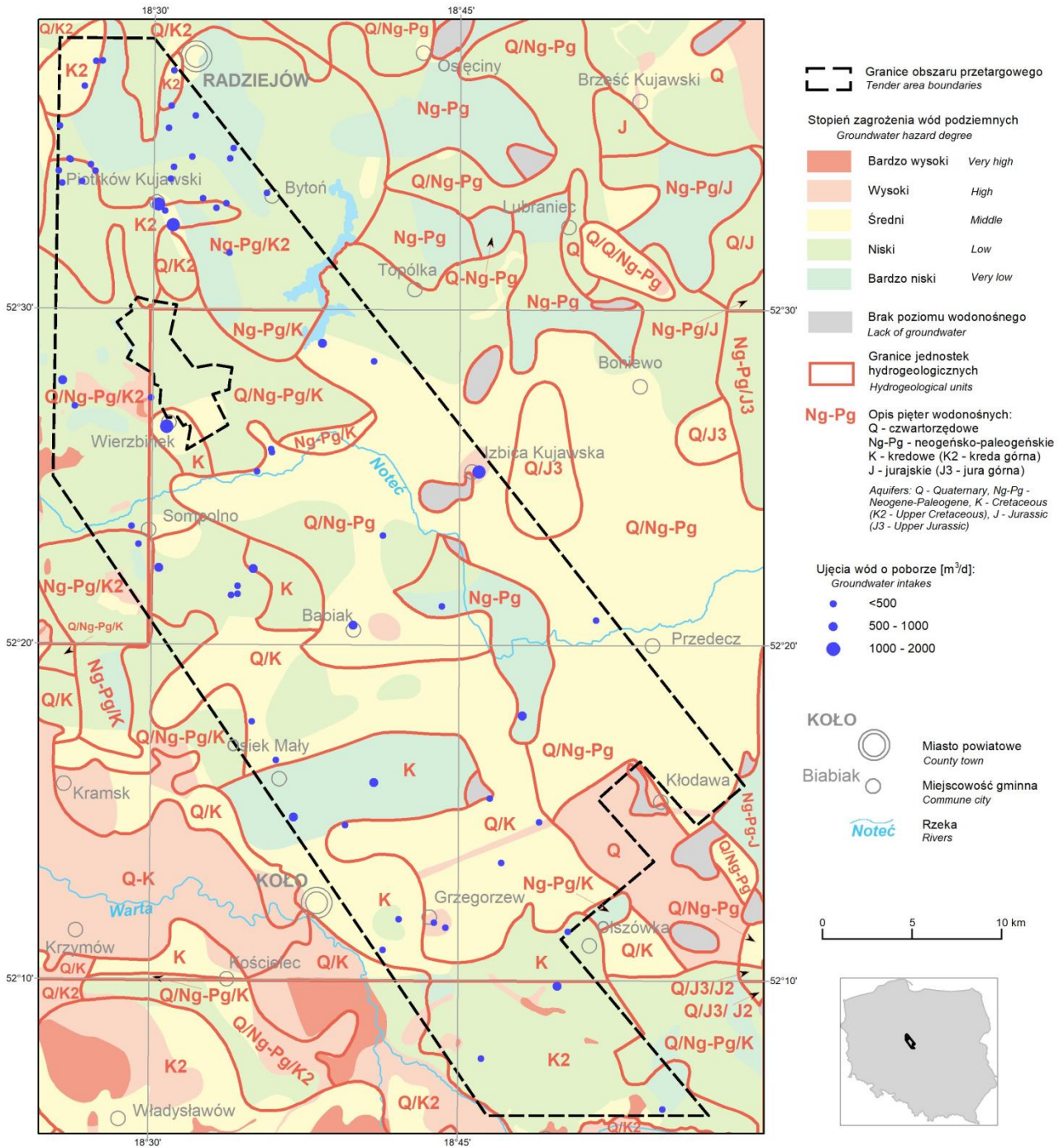


Fig. 2.14. Location of the Koło tender area in relation to hydrogeological units.

### 3. PETROLEUM PLAY

#### 3.1. GENERAL CHARACTERISTICS

The petroleum play is defined as the set of geological and petroleum processes leading to the formation of a hydrocarbon field. The petroleum play includes source rocks, reservoir rocks, and seal rocks. In addition, an essential element of the petroleum play in conventional accumulations is a trap, which, due to its structural, stratigraphic, lithological and tectonic features, creates a place of accumulation of hydrocarbons. The existence of a petroleum play and the formation of a hydrocarbon reservoir require a set of processes located in space, as well as in geological time, consisting of generation, expulsion, migration and accumulation of hydrocarbons and formation of a reservoir trap. The temporal interrelationships between the mentioned elements and processes of the petroleum play allow the formation of oil and gas fields.

The geology and tectonic of the Koło tender area, as well as geochemical parameters, and results of petrophysical studies in individual lithostratigraphic units, allow to distinguish:

- Mesozoic conventional petroleum play (Triassic, Jurassic, Cretaceous);
- Jurassic unconventional (shell-type) petroleum play.

In addition, the existence of the Devonian/Carboniferous/Permian petroleum play below the Mesozoic succession should be assumed. However, deep burial of these rocks (>5000 m) may be associated with poor petrophysical properties of potential reservoir rocks. However, a different scenario is also possible, in which hydrocarbons migrated from Permian and sub-Permian strata to Mesozoic reservoirs along discontinuities associated with the salt diapirs or faults.

In regional scale, in the area of the Łódź Trough and Kuyavian Anticlinorium, the Mesozoic strata have been buried deeper in comparison to the neighboring areas, and had generation potential. The Middle to Upper Jurassic shales are regarded as potential source rocks. Subordinately, small accumulations of organic matter are also found in the Triassic – Muschelkalk and Keuper. In addition, older source rocks within the Permian and sub-Permian horizons may have been another important source of hydrocarbons. As reservoir rocks, the Triassic, Jurassic, and Cretaceous sandstones and limestones should be assumed.

The unconventional petroleum system is associated with Jurassic fine-grained clastic rocks. The Middle (and partly Upper) Jurassic shales have the greatest potential and can be considered simultaneously as source rock, reservoir rock, and seal rock (Zhao et al., 2016).

In this study, all source rocks are described together in subsection 3.2, whereas reservoir and seal rocks are described in subsections 3.3 and 3.4, respectively. Subsection 3.5, however, is dedicated to unconventional Jurassic petroleum system. Subsection 3.6 deals with the generation, migration, and expulsion of hydrocarbons and examples of possible analogues of hydrocarbon accumulations in Western Europe.

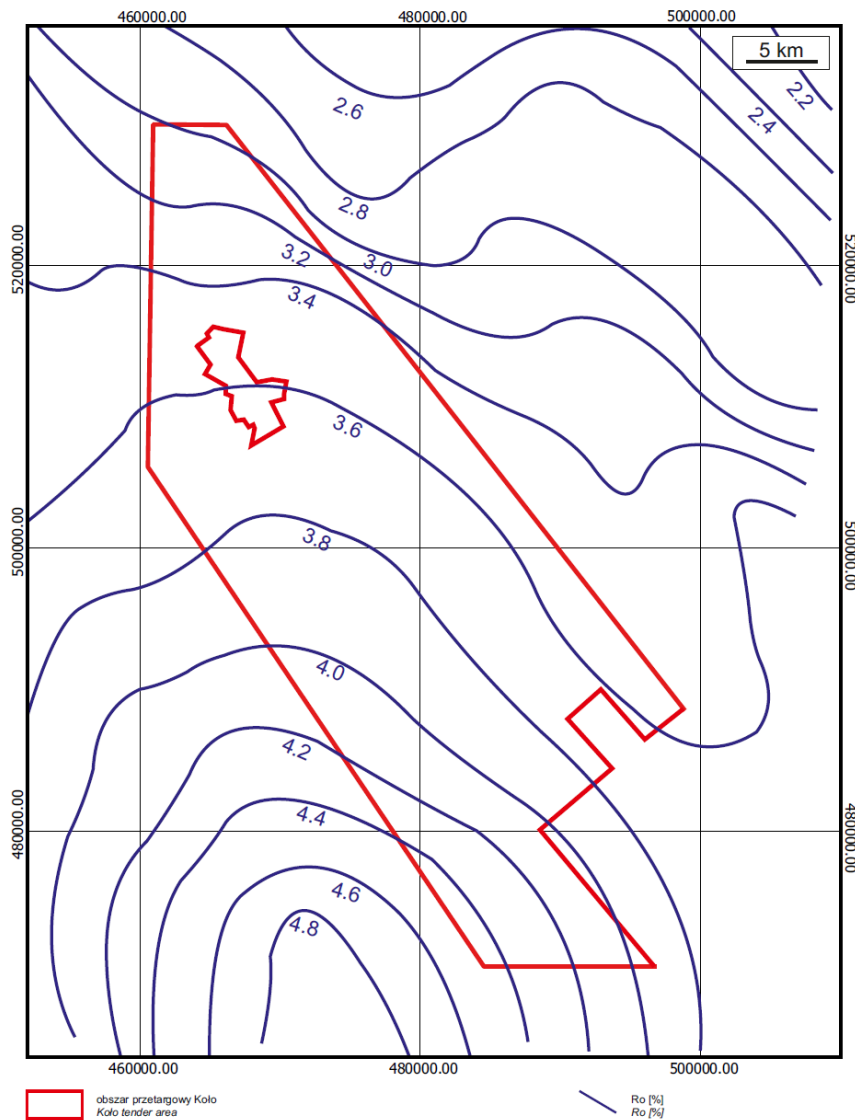
### 3.2. SOURCE ROCKS

The Middle and Upper Jurassic fine-grained clastic rocks are the most prospective source rocks within Mesozoic succession. In addition, sub-Zechstein horizons are considered as potential source rocks, as well.

*Carboniferous  
fine-grained clastic rocks /  
hard coals (hypothetically)*

It is generally accepted that the gas accumulated in the Rotliegend horizon was generated from the Carboniferous source rocks (e.g., Kotarba et al., 1992, 1999, 2005; Kotarba and Lewan, 2004, 2013; Karnkowski, 1999). Analysis of the chemical and isotopic composition of the natural gas accumulated in the Rotliegend of the Western Pomerania and Fore-Sudetic Monocline has revealed genetic similarity with accumulations occurring in Carboniferous source rocks (Kotarba et al., 1992, 1999, 2005; Kotarba and Lewan, 2004, 2013; Lokhorst, 1997). However, the Carboniferous rocks in Poland are not fully comparable to those that are the source for numerous deposits in Western Europe, due to the lack of Westphalian coal seams in the Upper Carboniferous. Due to the very deep burial of Carboniferous rocks in the area of the Łódź Synclinorium and Mid-Polish Anticlinorium, it was not possible to recognize the facies of the Upper Carboniferous in this area. The existence of coal seams cannot be confirmed. Nevertheless, the content of organic matter in the Lower and Upper Carboniferous is sufficient to supply numerous hydrocarbon deposits in the Polish Basin.

Based on studies of organic matter in the Kujawy and Mazovia regions, it was determined that high values of vitrinite reflectance in the Carboniferous ( $R_o \geq 3\%$ ) are expected in the Koło tender area, as well (Fig. 3.1; Botor et al., 2013). To the east, near Warsaw, the potential of Carboniferous rocks (S1+S2) varies from very low to excellent. The TOC content ranges from 0.3 to 15%, but in some samples containing charred plant remains reaches 80% (Matyasik, 1998; Botor et al., 2002; Pletsch et al., 2010; Botor et al., 2013). The rocks are dominated by type II and III kerogen, and especially type III humic kerogen in the Westphalian samples. The hydrogen index (HI) in the Carboniferous rocks shows values between 11 and 620, with a mean value of 160. Tmax, on the other hand, oscillates around 420–455°C. In the area of Kujawy and Mazovia, two generation episodes of hydrocarbons from Carboniferous rocks are distinguished (Botor et al., 2013). The first one is marked in the Triassic and/or Jurassic, while the next one occurred in the Late Cretaceous. The transformation of the kerogen varied. In the axial zone of the Mid-Polish Through (Krośniewice-Kutno-Łódź), gas generation started already in the Early Triassic and gradually increased until the Late Jurassic. In less buried zones gas generation started in the Late Triassic and reached its maximum in the Early Jurassic, similarly to the area of the Fore-Sudetic Monocline. At the end of the Cretaceous, the generation of hydrocarbons from the deepest buried Carboniferous rocks was already completed.



**Fig. 3.1.** Vitrinite reflectance in the Carboniferous rocks in the Koło tender area (based on well data and Botor et al., 2013).

*Middle and Upper Jurassic  
Lithology: calcareous and marly shales,  
mudstones and claystones*

No hydrocarbon fields have been found in the region of the Łódź Anticlinorium, so far. It is poorly recognized in terms of sub-Permian, Permian, and Mesozoic source rocks potential.

Within the Middle and Upper Jurassic, the black shales of Aalenian/Bajocian and Bathonian (Middle Jurassic), as well as Kimmeridgian and Tithonian marly shales (Upper Jurassic) are considered as the main source rocks horizons. The organic matter investigation results are variable, which is most likely caused by the variable burial history of rocks

in different parts of the basin, as well as insufficient data. Analyses of the amount, composition, and maturity of organic matter and bitumen from Jurassic shales are the basis for determining their generation potential (Figs 3.2–3.3). Of particular importance are the values of TOC, Ro, and CPI. The Jurassic sediments reached a major phase of catagenesis at the end of the Cretaceous corresponding to  $Ro > 0.65\%$  (beginning of the oil window) in the most deeply buried zones of the basin, i.e., below 2500 m (Karnkowski, 1993). Such depths of burial of potential Middle (Upper Aalenian–Upper Bathonian) and Upper Jurassic (Kimmeridgian–Lower Tithonian) source rocks are to be expected throughout the Koło area, where the Middle Jurassic rocks are bur-

ied even at 3000–4000 m in the central part (Kotański, 1997 ). In the Poddębice PIG-2 well, located on the border of the Łódź Synclinorium and Kuyavian Swell, the  $R_o=0.5–0.89\%$  for the Middle Jurassic rocks indicates that they entered to the phase of oil window (Grotek, 2012; Klimuszko, 2012). The Rock-Eval analysis of the Middle Jurassic source rocks was performed by Zakrzewski et al. (2022) in the Koło IG-3 well and in neighboring wells. The results of this study showed that the major source for hydrocarbons within the Middle Jurassic are the Upper Aalenian and Lower Bajocian clay rocks, genetically related to deposition in anoxic shelf. These rocks have a very high content of organic matter of kerogen type III and subordinately of type II. The TOC of the Aalenian rocks ranges from 0.17 to 9.76% (average 4.5%). This result allows to classify the Aalenian shales as excellent source rocks, but the average S1 and S2 results of 0.42 mg HC/g rock and 3.24 mg HC/g rock, respectively, classify them as rocks with medium or poor generation potential. The results of the study conducted by Kosakowski et al. (2015) in the Mogilno-Łódź Synclinorium, which took into account data from (among the others) Koło

IG-3, Banachów IG-1, and Przybyłów 1 wells, classify the Middle Jurassic strata as good source rocks with an average TOC of 5.5%, in which the hydrocarbon content is 4.5 mg HC/g rock and the hydrocarbon potential is 282 mg HC/TOC. On the other hand, Obarowski et al. (2015) presented different results (Tab.3.1), which suggest that the Middle Jurassic strata (Bajocian and Bathonian) are within the oil window, and they are good source rocks in terms of average TOC values 2%, but their generation potential is not so high. The presence of type II and III (or II/III) kerogen was indicated. In addition, analyses of organic matter from the Middle Jurassic rocks of the Mid-Polish Anticlinorium were carried out on rock samples from several wells in earlier studies (Gondek, 1980; Wilczek, 1986). A predominance of marine organic matter was found only in single samples from the Lower Bathonian (Koło IG-3) and Upper Bajocian (Koło IG-3). The results showed that bitumen occurring in the Middle Jurassic source rocks in the Koło IG3 and Ponętów 1 wells contain mature hydrocarbons ( $CPI = 1.0–1.1$ ).

Middle Jurassic source rock parameters	Banachów IG-1	Koło IG-3	Przybyłów 1
$R_o$ [%]	0.93	0.74	0.77
TOC [% wt.]	2.68	1.85	2.195
$T_{max}$ [°C]	453	447	439
S1 [mg HC/gRock]	0.215	0.179	0.105
S2 [mg HC/gRock]	2.010	1.63	1.41
HI [mg HC/gTOC]	74.5	90.00	63.5
PI	0.095	0.096	0.065
Typ kerogenu*	II	II(II/III)	III

**Tab. 3.1.** Characteristics of Middle Jurassic source rocks in the Banachów IG-1, Koło IG-3 and Przybyłów 1 wells (Obarowski et al., 2015).

$R_o$  – thermal maturity of organic matter on vitrinite reflectance scale; TOC – organic carbon content;  $T_{max}$  – maximum temperature of S2 peak; S2 – residual petroleum potential; S1 – oil and gas yield; PI – productivity index; HI – hydrogen index. \*according to Espitalie et al. (1985).

Stratigraphy Index	Szczecin–Miechów Synclinorium		Mid-Polish Anticlinorium	
	Lower	Upper	Lower	Upper
TOC [wt. %]	$\frac{0.13 \text{ to } 2.1}{0.39}$ (84) (15)	$\frac{0.19 \text{ to } 4.7}{1.78}$ (45) (10)	$\frac{0.18 \text{ to } 6.8}{0.94}$ (13) (6)	$\frac{0.25 \text{ to } 6.6}{2.6}$ (59) (9)
$T_{max}$ [°C]	$\frac{421 \text{ to } 439}{429}$ (82) (15)	$\frac{420 \text{ to } 449}{433}$ (41) (10)	$\frac{418 \text{ to } 432}{421}$ (11) (6)	$\frac{419 \text{ to } 435}{428}$ (59) (9)
$S_2$ [mg HC/g rock]	$\frac{0.07 \text{ to } 5.2}{0.51}$ (84) (15)	$\frac{0.14 \text{ to } 18.9}{4.1}$ (45) (10)	$\frac{0.05 \text{ to } 24.8}{0.94}$ (13) (6)	$\frac{0.26 \text{ to } 25.6}{4.1}$ (59) (9)
$S_1 + S_2$ [mg HC/g rock]	$\frac{0.12 \text{ to } 5.3}{0.63}$ (84) (15)	$\frac{0.19 \text{ to } 19.8}{4.4}$ (45) (10)	$\frac{0.09 \text{ to } 25.4}{1.05}$ (13) (6)	$\frac{0.34 \text{ to } 26.1}{4.2}$ (59) (9)
PI	$\frac{0.06 \text{ to } 0.42}{0.17}$ (84) (15)	$\frac{0.02 \text{ to } 0.26}{0.06}$ (45) (10)	$\frac{0.02 \text{ to } 0.44}{0.10}$ (13) (6)	$\frac{0.01 \text{ to } 0.24}{0.04}$ (59) (9)
HI [mg HC/g TOC]	$\frac{54 \text{ to } 408}{139}$ (84) (15)	$\frac{32 \text{ to } 458}{189}$ (45) (10)	$\frac{25 \text{ to } 363}{94}$ (13) (6)	$\frac{58 \text{ to } 441}{141}$ (59) (9)
Kerogen type	III (III/II)	II/III (III, II)	III (III/II)	II/III (III, II)
Maturity	immature/ low-mature	immature/mature	immature/ low-mature	immature/ low-mature
Hydrocarbon potential	poor	fair/good	fair	good

**Tab. 3.2.** Comparison of maturity of organic matter in Lower and Upper Kimmeridgian rocks for the Mid-Polish Anticlinorium and Szczecin–Miechów Synclinorium (Więclaw, 2016).

TOC – organic carbon content; Tmax – maximum temperature of S2 peak; S2 – residual oil potential; S1 – oil and gas yield; PI – productivity index; HI – hydrogen index; the range of geochemical parameters is given in the numerator and the mean value in the denominator, in brackets: number of samples (numerator) and number of sampled wells (denominator); kerogen type in brackets – subordinate occurrence.

In the case of the Upper Jurassic rocks, the Oxfordian and Kimmeridgian calcareous shales contain syngenetic bitumen whose maturity parameters allow to consider these as the source rocks. Sapropel-type kerogen was found in the Upper Kimmeridgian and Tithonian. Other horizons are dominated by humic organic matter (Karnkowski, 1993). Data from the Poddebice PIG-2 well obtained for the Upper Kimmeridgian and Lower Tithonian ( $R_o=0.59-0.63\%$ ) indicate that these rocks entered the initial phase of the oil window (Grotek, 2012; Klimuszko, 2012). Recent studies of the hydrocarbon potential of the Kimmeridgian in the Łódź Trough were conducted by Więclaw (2016), among the others, based on analyses of core samples from e.g. Koło IG-3 and Przybyłów 1 wells. They show that the TOC content in Lower Kimmeridgian rocks varies from 0.13 to 2.1%, while in the Upper Kimmeridgian is from 0.19 to 4.7%. Residual hydrocarbon content ( $S_2$ ) and TOC values are generally quite low in Lower Kimmeridgian rocks. The highest median

TOC value was recorded in the Koło-Przybyłów zone (Table 3.3). The correlation between HI and Tmax indicates that the Lower Kimmeridgian rocks are dominated by the type III kerogen, whereas the Upper Kimmeridgian rocks are dominated by the type II kerogen. Moreover, Obarowski et al. (2015) presented the results of Rock-Eval analyses of the Upper Jurassic source rocks (Tab. 3.3), which suggests that the Kimmeridgian and Tithonian rocks occur in the range of the oil window, and they are rather good source rocks as far as averaged TOC values are 2–3%, and their generation potential is clearly higher than in the case of the Middle Jurassic source rocks. The occurrence of the type II and III (or II-III) kerogen was investigated. Earlier analyses of the Kimmeridgian organic matter from the Mid-Polish Anticlinorium were carried out in the Koło IG-3 and Ponętów 1 wells (Gondek, 1980; Wilczek, 1986). Bitumens contain there mature hydrocarbons ( $CPI = 1.0-1.1$ ).

Upper Jurassic source rock parameters	Banachów IG-1	Koło IG-3	Ponętów 2	Przybyłów 1
Ro [%]	0,91	0,82	0,79	0,79
TOC [% wt.]	1,96	2,53	3,198	2,44
T <sub>max</sub> [°C]	436	433	432	433
S1 [mg HC/gRock]	0,238	0,412	0,768	0,198
S2 [mg HC/gRock]	3,55	8,146	13,27	5,815
HI [mg HC/gTOC]	154,8	290,9	297,9	237,3
PI	0,075	0,047	0,065	0,033
Typ kerogenu*	III	II	III	II-III

**Tab. 3.3.** Characteristics of the Upper Jurassic source rocks in the Banachów IG-1, Koło IG-3, Ponętów 2 and Przybyłów 1 wells (Obarowski et al., 2015).

Ro – thermal maturity of organic matter on vitrinite reflectivity scale, TOC – organic carbon content, Tmax – maximum temperature of S2 peak, S2 – residual petroleum potential, S1 – oil and gas yield, PI – productivity index HI - hydrogen index. \*according to Espitalie et al. (1985).

### 3.3. RESERVOIR ROCKS

In the Koło tender area two main reservoir horizons should be distinguished: Reed Sandstone (Upper Triassic) and Lower and Middle Jurassic sandstones (Tables 3.4–3.6). The Reed Sandstone, due to its fluvial genesis, has variable reservoir properties. The Lower Jurassic reservoir horizon contains alternating sandstones and fine-grained clastic rocks. The Middle Jurassic (Aalenian, Bajocian), on the other hand, shows the best reservoir properties in the Koło tender area, in which sandy lithofacies predominate. In some places, the reservoir potential have also the Upper Jurassic limestones and Cretaceous sandstones. In all the above-mentioned horizons, hydrocarbon shows were observed (Tables 3.5–3.6).

#### *Reed Sandstone (Upper Triassic)*

*Lithology: quartz sandstones, fine- and medium-grained sandstones intercalated with mudstones*

The thickness of the Reed Sandstone may oscillate in the range of tens or even exceed 100 m with a tendency to increase to the E and NW direction (Górecki and Hajto, 2006).

The top surface of this unit runs at depths from 2000 to 3500 m.b.g.l.

The Reed Sandstone is poorly recognized interval. However, because of favorable reservoir parameters and good seal of the Lower and Upper Gypsum Beds, it should be regarded as a prospective horizon for hydrocarbon occurrences in the Łódź Synclinorium and Kuyavian Swell. Analyses of petrophysical parameters show that sandstone lithofacies have porosities of several to even 20%. Very poor porosity (0–2%) and low permeability can also occur in fine-grained clastic rocks, however.

The traps within the Reed Sandstone are probably stratigraphic type of wedging sandy bodies within the claystone-mudstone flood plain deposits. In addition, combined traps may have formed as a result of salt tectonics.

*Lower and Middle Jurassic**Lithology: fine- and medium-grained quartz sandstones*

The Lower and Middle Jurassic sandstones have the greatest reservoir potential in the Koło tender area. They are of fluvial (Zagaje, Drzewica, and Borucice Formations) and nearshore genesis (Skłoby and Ostrowiec Formations). The total thickness of the Lower Jurassic is varied and increases from 10 to even 800 m to the NE (Górecki and Hajto, 2006). The thickness of the reservoir rocks also increase to the NE direction, with the lowest values observed in the SW part of the tender area (~50 m) and the highest (~500 m) in the N and SE parts. On average, the thickness of the Lower Jurassic rocks with good reservoir parameters ranges from 200 to 350 m. The sandy rocks show high effective porosities exceeding 24% in some places (Tab. 3.6), with average values for the Lower Jurassic rocks oscillating around several percent. Horizontal permeabilities are higher than the vertical and range from several hundred to 1300 mD. However, strong siliceous and carbonate cementation (siderite, ankerite, dolomite) destroyed the parameters. In addition, the rocks contain kaolinite and fibrous illite, which are responsible for lowering of the permeability.

The Middle Jurassic thickness, similarly to the Lower Jurassic example, increases to the NE direction and oscillates from 100 to even 400 m (Górecki and Hajto, 2006). The thickness of the reservoir rocks (Aalenian and Bajocian sandstones) is from several tens of meters to ~150 m. The effective porosity often significantly exceeds 20% and in some places even 30%. This resulted from primary intergranular porosity, but secondary porosity, formed as

an effect of dissolution and transformation of rock components, is also observed. The permeability of sandstones oscillates between 0.0 and 1500 mD.

*Upper Jurassic**Lithology: sponge limestones, ooid limestones, marls, dolomitic limestones and dolomites*

In the Upper Jurassic, reservoir potential is exhibited by Oxfordian carbonate rocks, in which fracturing and stylolithization processes may have led to the formation of secondary porosity. In addition, the limestones developed in detrital and organogenic facies undergone dissolution, corrosion and dolomitization processes. However, these rocks are characterized by low permeability despite their commonly high total porosity. According to Górecki and Hajto (2006), the thickness of the Upper Jurassic reservoir rocks in the Koło tender area ranges from 300 to 900 m.

*Lower Cretaceous**Lithology: quartz sandstones*

The Lower Cretaceous clastic rocks have often favorable reservoir properties. High porosities reaching values of several percent and permeabilities exceeding 1500 mD (Tab. 3.5) are associated with both the dissolution of some grains and kaolinitization. As an effect, a secondary microporosity was formed. The mechanical compaction process is prevented by quartz cementation causing stiffening of the grain framework of the rocks. The reservoir potential of the Lower Cretaceous in the Koło tender area is confirmed by gas shows recorded in wells within the area (Tab. 3.6).

Wells	Stratigraphy	Top surface depth (m. b.g.l.)	Thickness (m)
Brześć Kujawski IG-2	Upper Jurassic – Oxfordian	101.00	359.0
	Middle Jurassic – Callovian	460.0 (710.0 – Bajocian)	746.0 (496.0 – Aalenian + Bajocian)
	Lower Jurassic	1206.0	>644.0 (Sinemurian – Upper Toarcian)
Wartkowice 1	Upper Jurassic – Tithonian	1461.0	698.0 (Oxfordian, Kimmeridgian, Tithonian)
	Middle Jurassic	2159.0 (2172.0 – Upper Bajocian)	72.0 (59.0 – Upper Bajocian)
	Lower Jurassic	–	–
	Triassic	2231.0 (Rhaetian)	>295.6 (Carnian, Norian, Rhaetian)
Wartkowice 2	Upper Jurassic – Tithonian	1319.5	630.5 (Oxfordian, Lower Kimmeridgian, Tithonian)
	Middle Jurassic	1950.0 (2070.0 - Bajocian)	325.0 (205.0 – Aalenian + Bajocian)
	Lower Jurassic	2275.0	269.0 (Pliensbachian, Lower Toarcian)
	Triassic	2544.0 (Rhaetian)	456.0 (Carnian, Norian, Rhaetian)
Wojszyce IG-1A	Upper Jurassic – Oxfordian	103.5	571,5
	Middle Jurassic	675.0 (877.0 – Upper Bajocian)	943.0 (741.0 – Aalenian + Bajocian)
	Lower Jurassic – Upper Toarcian	1618.0	>146.0 (Upper Toarcian)
Aleksandrów Łódzki-1	Upper Jurassic	452.0	883.0 (Oxfordian, Lower Kimmeridgian, Tithonian)
	Middle Jurassic	1335.0 (1505.5 – Upper Bajocian)	527.0 (356.5 – Aalenian + Bajocian)
	Lower Jurassic	1862.0 (Upper Toarcian)	>456.4 (Pliensbachian, Toarcian)
Banachów IG-1	Upper Jurassic	2492.0	650.0 (Oxfordian, Kimmeridgian, Tithonian)
	Middle Jurassic	3142.0	105.0 (Bathonian, Callovian)
	Lower Jurassic	3247.0 (Upper Toarcian)	>156.0 (Pliensbachian, Toarcian)
Przybyłów 1	Upper Jurassic – Tithonian	1962.0	578.0 (Oxfordian, Kimmeridgian)
	Middle Jurassic	2540.0 (2660.0 – Upper Bajocian)	160.0 (40.0 – Upper Bajocian)
	Lower Jurassic	2700.0 (Pliensbachian)	66.5 (Pliensbachian)
	Trias	2766.5 (Rhaetian)	1088.5 (Middle and Upper Triassic)
Ponętów 1	Upper Jurassic	2013.5	661.5 (Oxfordian, Kimmeridgian, Tithonian)
	Middle Jurassic	2675.0 (2800.0 – Upper Bajocian)	275.0 (150.0 – Aalenian + Bajocian)
	Lower Jurassic	2950.0 (Upper Toarcian)	>57.0 (Upper Toarcian)
Pagórki IG-1	Upper Jurassic	1295.0	>267,1
Koło IG-3	Upper Jurassic	2008.0	692.0 (Oxfordian, Kimmeridgian, Tithonian)
	Middle Jurassic	2700.0 (2822.5 – Upper Bajocian)	285.5 (163.0 – Aalenian + Bajocian)
	Lower Jurassic	2988.5	>167.7 (Toarcian)

**Tab. 3.4.** Thickness and top surface depth of main reservoir horizons and in the Koło tender area and in its vicinity (according to final well documentations).

Wells	Samples	Stratigraphy	Depth [m b.g.l]	Total porosity [%] Min.–Max. (average)	Effective porosity [%] Min.–Max. (average)	Permeability [mD] Min.–Max. (average)
Brześć Kujawski IG-2	5	Upper Jurassic	200.1–354.2	6.9–19.0 (11.12)	6.8–18.83 (10.8)	0,1–0,56 (0,2) x 0,1–0,85 (0,34) y
	113/57	Middle Jurassic	489.1–1200.4	0.35–26.5 (8.4)	0.3–24.08 (7.9)	0,1–600 (18,6) x 0,1–470 (13,7) y
	39/37	Lower Jurassic	1206.2–1846.2	2.31–28.2 (15.6)	1.83–24.6 (13.9)	0,1–1300 (285,5) x 0,1–1300 (259,4) y
Aleksandrów Łódzki-1	6	Upper Jurassic	720.0–112.5	0.3–5.7 (3.7)	n/a	n/a
	11/8	Middle Jurassic	1341.7–1816.2	2.58–21.11 (13.25)	n/a	0,0–1537,0 (363,4) x
	7/2	Lower Jurassic	1926.8–2277.7	2.72–17.15 (13.1)	n/a	142,8–174,5 x
Wartkowice 2	22/13	Upper Jurassic	1538.5–1940.2	0.16–25.27 (9.0)	n/a	0,0–10,0 (2,0)
	25/15	Middle Jurassic	1981.0–2268.5	0.16–14.84 (9.6)	n/a	0,0–55,2 (8,3)
	5/2	Lower Jurassic	2302.7–2454.8	0.17–14.97 (9.0)	n/a	0,0–7,0
Wojszyce IG-1A	27/22/26	Upper Jurassic	504.1–671.3	1.08–11.68 (4.4)	0.15–9.42 (2.77)	0,2–150 (9,4) x 0,2–26,5 (1,29) y
	132/75/7 8	Middle Jurassic	694.2–1673.9	1.11–30.22 (13.5)	0.37–28.2 (8.4)	0,2–546,0 (92,4) x 0,2–510 (86,8) y
	12	Lower Jurassic	1706.0–1763.7	10.3–20.3 (15.8)	8.07–18.19 (13.5)	0,62 – 880 (226,9) x 0,49 – 540 (147,4) y
Banachów IG-1	7	Lower Cretaceous	2181.5–2435.0	7.48–15.75 (13.07)		112–1010 (462)
	11	Lower Jurassic	3247.0–3403.0	3.09–4.42 (3.66)		0.1–69 (11.8)
Przybyłów 1	11	Cretaceous	1668.0–1856.0	0.95–19.29 (15.44)		3020–0 (932.565)
	28	Jurassic	1892.0–2588.0	0.42–9.22 (1.657)		0 (0)
	3	Triassic	3405.0–3718.05	0.93–5 (2.32)		0 (0)
Ponętów 1	9	Lower Cretaceous	1723.0–1720.0	4.81–16.02		406.7–1583.8
	12	Upper Jurassic	1970.7–2668.6	0.41–4.17		0
	4	Middle Jurassic	2701.3–851.5	4.53–9.47		0–3.2
	11	Lower Jurassic	2914.3–3005.4	1.63–5.45		0

**Tab. 3.5.** Porosity and permeability of Mesozoic reservoir horizons (according to final well documentations).

Wells	Stratigraphy	HC shows
Przybyłów 1	Upper Jurassic	trace oil seeps from fractures in limestone, distinct bituminous smell
Ponętów 1	Lower Cretaceous	mud gasification
Koło IG-3	Upper Jurassic (Oxfordian)	bituminous smell
Banachów IG-1	Upper Jurassic (Tithonian)	mud gasification

**Tab. 3.6.** Hydrocarbon shows in core samples and mud (according to final well documentations).

### 3.4. SEAL ROCKS

Several seal rock horizons can be distinguished within the Koło tender area. The potential reservoir horizons located within or below the Zechstein are sealed by evaporates of different cyclothems. The Mesozoic horizons can be sealed by both Triassic fine-grained and evaporite rocks (Lower and Upper Gypsum series) and Lower and Middle Jurassic shales. The basic seal is represented by the Ciechocinek claystone Formation together with the uppermost part of the Drzewica Formation (thickness: 50–140 m). The Zagaje Formation of thickness about 30–80 m can be treated as a supporting seal, similarly to the locally occurring Gielniów Formation. In the case of the Middle Jurassic sandstones,

the main seal is formed by the Upper Aalenian and Lower Bajocian black shales with a thickness of 30–100 m (permeability <0,01 mD). The relatively weak sealing complex includes the Lower Bathonian shales with a thickness of ~60 m (permeability approx. 1 mD). On the other hand the Upper Bajocian (permeability 0.1–0.2 mD), Bathonian and Lowermost Callovian shales can be another primary/equivalent or supporting seal (Wójcicki et al., 2013). Within the Cretaceous, the Lower Cretaceous mudstone-evaporite rocks have sealing properties. In addition, a complex of the Upper Cretaceous strata comprises intervals impermeable to the migration of fluids (Wójcicki et al., 2013).

### 3.5. UNCONVENTIONAL PETROLEUM PLAY

The unconventional petroleum play in the Koło tender area is formed by the Middle and Upper Jurassic shales. They are characterized in the source rock chapter (3.2).

*Middle and Upper Jurassic shales*  
*Lithology: black shales*  
*and marly shales*

It can be assumed, that in the Koło tender area the unconventional oil and gas accumulations occur in the Middle Jurassic (Aalenian/Bajocian and Bathonian black shales) and in the Upper Jurassic (Kimmeridgian and Tithonian rocks). This conclusion is based on the results of several studies (Gondek, 1980; Wilczek, 1986; Karnkowski, 1993; Grotek, 2012; Klimuszko, 2012; Obarowski et al., 2015; Więclaw, 2016; Zakrzewski et al., 2022). These studies show that Middle and Upper Jurassic rocks are in oil window ( $0.6 < R_o \leq 1.1\%$ ). Lower maturity ( $0.6 > R_o$ ) is seldom. However, the recent Rock-Eval analyses, especially TOC contents  $>2\%$  wt. indicate the southern part of the Koło tender area as prospective for the occurrence of unconventional accumulations in the Upper Bajocian, Bathonian, Kimmeridgian, and Tithonian (Banachów IG-1, Koło IG-3, Ponętów 2, Przybyłów 1). In general, the Upper Jurassic

source rocks are characterized by a slightly higher content of organic matter than the Middle Jurassic ones. This trend is even more visible for parameters such as residual hydrocarbon content (S2) and total hydrocarbon content (S1+S2), i.e. generation potential. For the northern part of the Koło tender area, there is an insufficient amount of data for detailed analyses. Available archival data from wells situated in the NW vicinity (Młyny 1: Surmiak, 1971; Strzelno IG-1: Raczyńska, 1973), are not fully comparable with the new data characterized above. In the case of the Strzelno IG-1 well, the vitrinite reflectance values are available for Lower Cretaceous samples, which is not considered in our case. These values are too low for oil window. The occurrence of unconventional oil accumulations in the Middle Jurassic in the northern part of the Koło tender area should be investigated yet.

In the case of the Upper Jurassic (Upper Kimmeridgian, Tithonian), the occurrence of sapropelic, type II (marine organic matter) kerogen is characteristic, except for the Lower Kimmeridgian where the type III (II/III, II-III?) kerogen prevails (Więclaw, 2016). In contrast, the Middle Jurassic shales are domi-

nated by humic kerogen, probably type III (II/III, II-III?), of marine-land origin.

*Possible analogs –  
examples from other European countries*

The EUOGA (EU Unconventional Oil and Gas Assessment) project, carried out in 2015-2016 by the European geological surveys and coordinated by GEUS (Danish Geological Survey), produced several reports dedicated to natural gas and oil occurrences in shale formations in Europe (Anthonsen et al., 2016; Schovsbo et al., 2017; Zijp et al., 2017). They investigated unconventional petroleum systems across 26 European countries, with shale formation ages ranging from Cambrian to Paleogene (Eocene, Oligocene) and even Neogene (Miocene).

From our point of view, it would be interesting to analyze unconventional petroleum plays especially in the Jurassic and Triassic. In the latter case, shales of the Middle (Ladinian) and Upper Triassic (Norian) in the Lombard Basin of Northern Italy (kerogen type II-III), carbonates of the Upper Triassic and Lower Jurassic in the Emma Basin of Italy (kerogen type I, II, sapropelic), and Koessen marls of the Upper Triassic (Norian/Rhaetian) in the Zala Basin of western Hungary (kerogen type II, sapropelic) were characterized. These prospects are predominantly for liquid hydrocarbons.

In the Lower Jurassic in NW Europe, prospects for gas were found in the Lower Jurassic Posidonia Shales (especially in Germany, Netherlands, and France) and for oil in the Middle and Upper Jurassic shales of the Weald oil basin in southern England, as well as in Romania, Bulgaria, Italy, France, Spain and Portugal. For the Middle and Upper Jurassic, the Oxford Clay (Callovian/Oxfordian), Corallian Clay (Upper Oxfordian) and Kimmeridge Clay (Kimmeridgian) formations within the Weald oil basin in southern England can be given here, as well as the Etropole (Upper Aalenian, Lower Ba-

jocian) in Bulgaria (and possibly its counterpart in the Romanian part of the Moesian Platform petroleum basin), the Lemeš (Kimmeridgian-Tithonian) in Croatia, the Mikulov Marl (Malmian) and Mikulov Formation (Oxfordian) in the borderland between the Czech Republic and Austria, as well as dark carbonates and mudstones in the Lombardy Basin in Italy.

The above-mentioned unconventional petroleum plays in the Jurassic, which may include both source rocks for conventional hydrocarbon fields and unconventional reservoir rocks, are characterized by the occurrence of almost all types of kerogen (I, I-II, II – mostly, II-III and II/III and III). They cannot be fully compared with the Middle and Upper Jurassic sediments considered for the Kołotender area, since formations of similar age from other European countries were not formed in an analogous sedimentary environments and are not characterized by the same type of kerogen and degree of maturity. For example, in the relatively well-recognized Weald Basin in southern England, which could provide a somewhat (but rather limited) hypothetical analogue for our area, the Oxfordian Clay (Callovian/ Oxfordian) are characterized by the type II kerogen in the lower part of the formation, and the type III in the upper part, the Corallian Clay (Upper Oxfordian) shales by type I, II and III, and the Kimmeridgian Clay (Kimmeridgian) shales by type II in the center part of the basin, plus III, II-III and I (Andrews, 2014). In the southwestern edge of the basin, there are oil (and oil-associated gas) fields in the Mesozoic that have been in production for decades (e.g., Wytch Farm Oil Field, Kimmeridge Oil Field). The unconventional oil system in the Jurassic rocks of the Weald Basin most probably comprises tight oil accumulations, i.e. accumulations of oil and associated gas in low permeability shales, carbonate rocks, and tight sandstones, so in principle, it should be referred to as a hybrid system.

### 3.6. GENERATION, MIGRATION, ACCUMULATION AND TRAPS

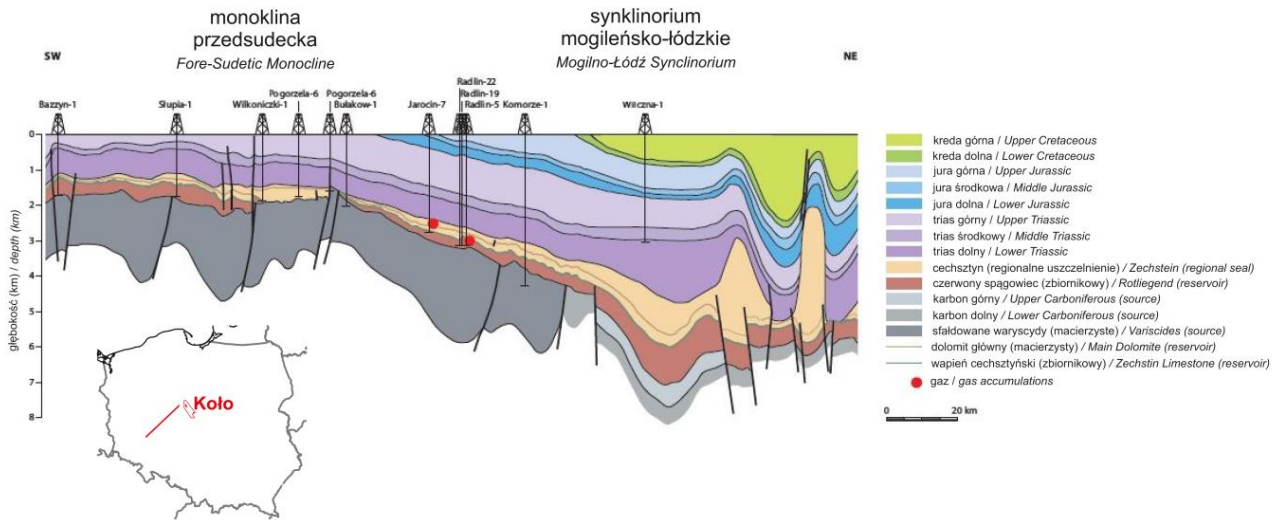
So far no conventional or unconventional hydrocarbon deposits have been discovered in the Koło tender area. However, the geology and tectonics of the Szczecin-Łódź-Miechów Synclinorium and Mid-Polish Anticlinorium (Fig. 3.2) creates possibilities for discovering new fields of different nature. Clay formations of the Middle and Upper Jurassic and probably organic-rich Zechstein and sub-Zechstein Palaeozoic rocks can act as potential source rocks for porous sandstones and limestones of Mesozoic age. Jurassic shales, on the other hand, act as both source rocks and reservoir rocks in the unconventional system.

**Age and mechanism of generation and expulsion of hydrocarbons:** Studies on Jurassic organic matter maturity and thermal history modeling carried out in the Łódź Synclinorium by Kosakowski et al. (2015) allow us to believe that the maturity increased in two phases. The first started during the Late Jurassic, while the second one occurred in the Late Cretaceous (Fig. 3.3). Both, Middle and Upper Jurassic rocks reached the oil window, with a maximum maturity of 0.95% and 0.70% Ro, respectively (according to Kosakowski et al., 2015) and 0.71 and 0.77% Ro (according to Karnkowski, 1993; Fig. 3.3). It was assumed that the Lower and Middle Jurassic rocks entered the early generation phase in the Cretaceous at a depth of 2500 m and a temperature of 80°C. However, they reached the peak of generation at the turn of the Late Cretaceous and Paleogene. The generation phase was terminated by a regional basin inversion.

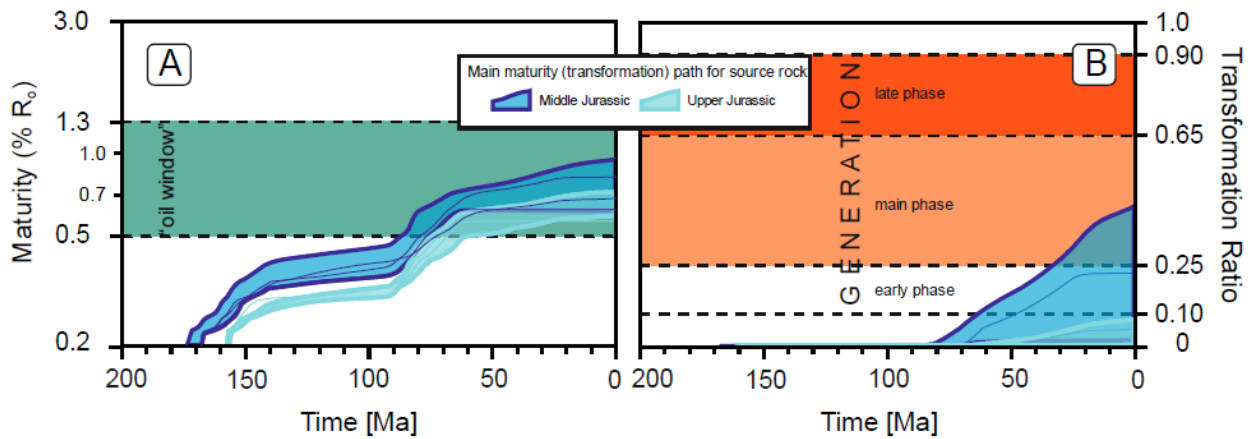
**Characteristics of Mesozoic traps:** The current state of knowledge does not allow for precise characterization of potential hydrocarbon traps. However, using an analogy with areas where hydrocarbon deposits were discovered in Mesozoic formations of Western Europe (Doornenbal and Stevenson, 2010; Kilhams et al., 2018) it should be stated, that probably these are traps of structural and mixed (structural-stratigraphic) type. There

are also possible stratigraphic traps in the form of bioherms within Oxfordian limestones and in the form of fluvial channels in the Reed Sandstone. Possible traps in the Koło area are closely related also to intensive salt tectonics and may range in form from anticlinal structures associated with the existence of salt pillows, through structures formed by inversion of the sub-Zechstein basement, to combined traps (Fig. 3.4).

**Possible analogues of the conventional system – examples from other European countries:** Examples of hydrocarbon reservoirs are found in the Northern German Basin (Doornenbal and Stevenson, 2010; Kilhams et al., 2018), both in its eastern part, which is an extension of the Polish Basin, and in its western part (Fig. 3.5). An example of a reservoir whose analogues we can expect to find within the Koło tender area, is the Rehden gas field discovered in north-western Germany. The current structure of the Rehden field, similarly to the Mid-Polish Anticlinorium, was formed during the Late Cretaceous inversion, which was the cause of deformations within the Permian-Mesozoic and older sediments, which included both faulting of rocks and plastic movements of Zechstein salts. There are three prospective horizons within the deposit: Upper Carboniferous sandstones, Zechstein (Ca2 Main Dolomite), and Lower Triassic sandstones (Bunter Sandstone). An example of a reservoir with the highest reservoir potential in the Mesozoic is the Wytech Farm field in Dorset, England. The primary reservoir horizons are Triassic sandstones of the Sherwood Sandstone and Lower Jurassic Bridport Sands. The primary source rocks are the Jurassic shales of the Oxfordian Clay and Kimmeridge Clay formations. The migration of hydrocarbons from younger to older formations occurred along faults associated with the compressional phase of the Alpine orogenesis. The Upper Jurassic shales are the primary source rocks for many European South Permian Basin deposits (Doornenbal and Stevenson, 2010; Kilhams et al., 2018; Figs 3.6–3.7).



**Fig. 3.2.** Cross section through the Fore-Sudetic Monocline, Szczecin-Łódź-Miechów Synclinorium and Mid-Polish Anticlinorium and location of the Koło tender area (Pletsch et al., 2010).



**Fig. 3.3.** Organic matter thermal maturity and kerogen transformation ratio in the Łódź Synclinorium (Kosakowski et al., 2015).

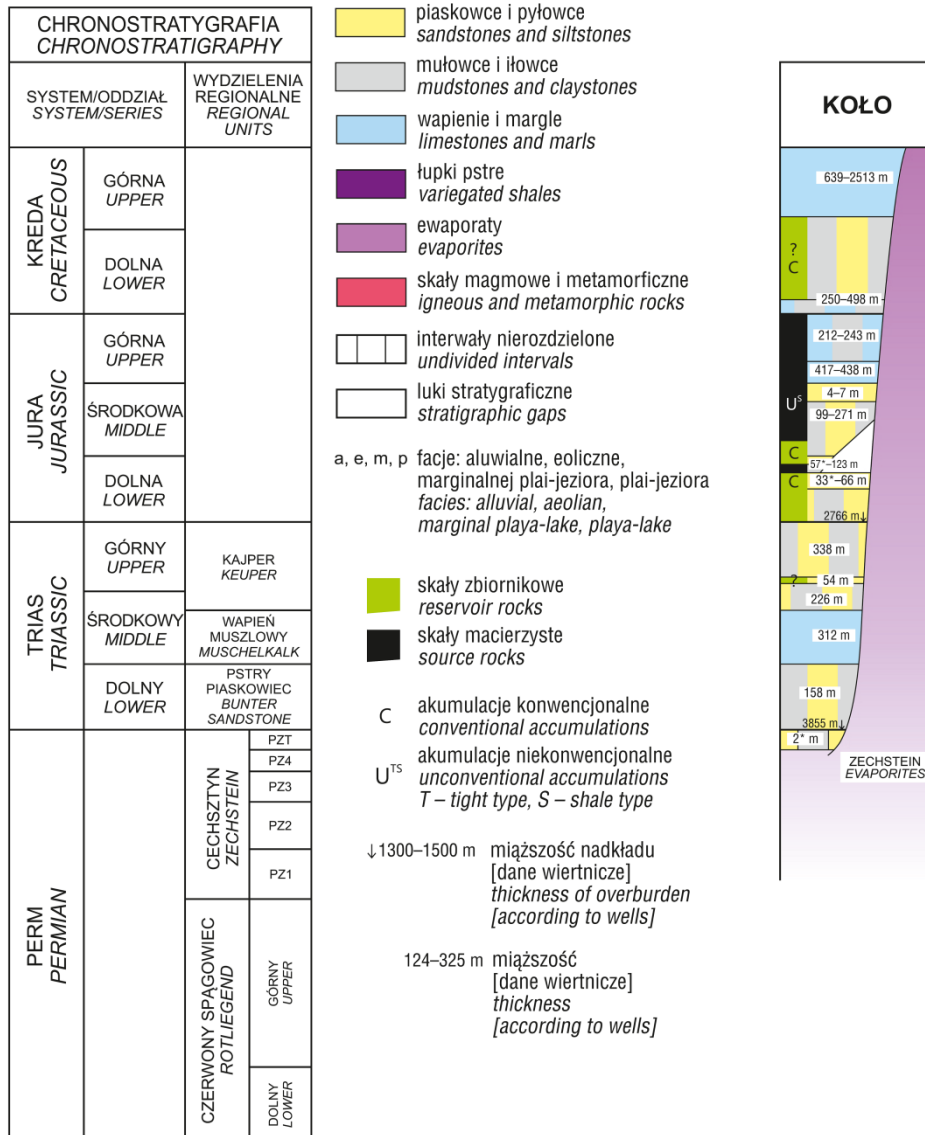


Fig. 3.4. Hydrocarbon generation, migration and accumulation scheme for the Koło tender area.

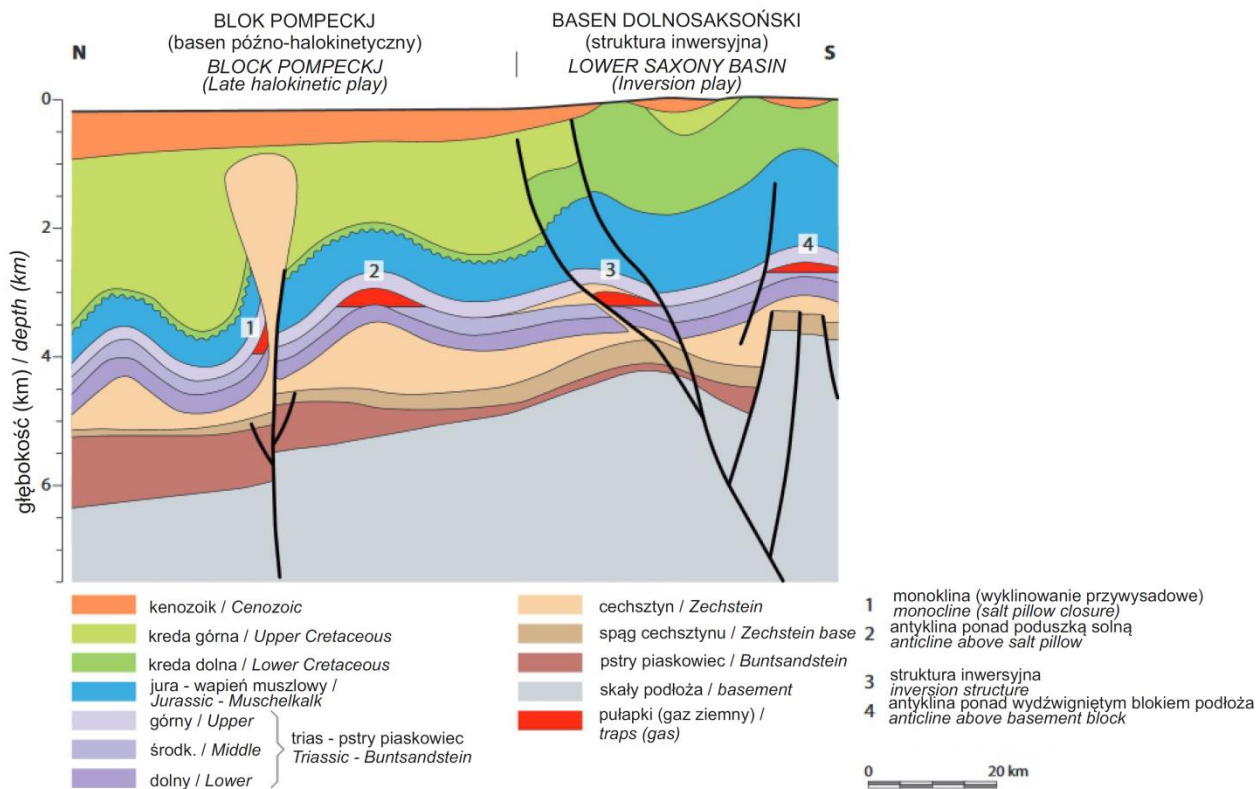


Fig. 3.5. Structural traps in Mesozoic of NW Germany (Karnin et al., 2006).

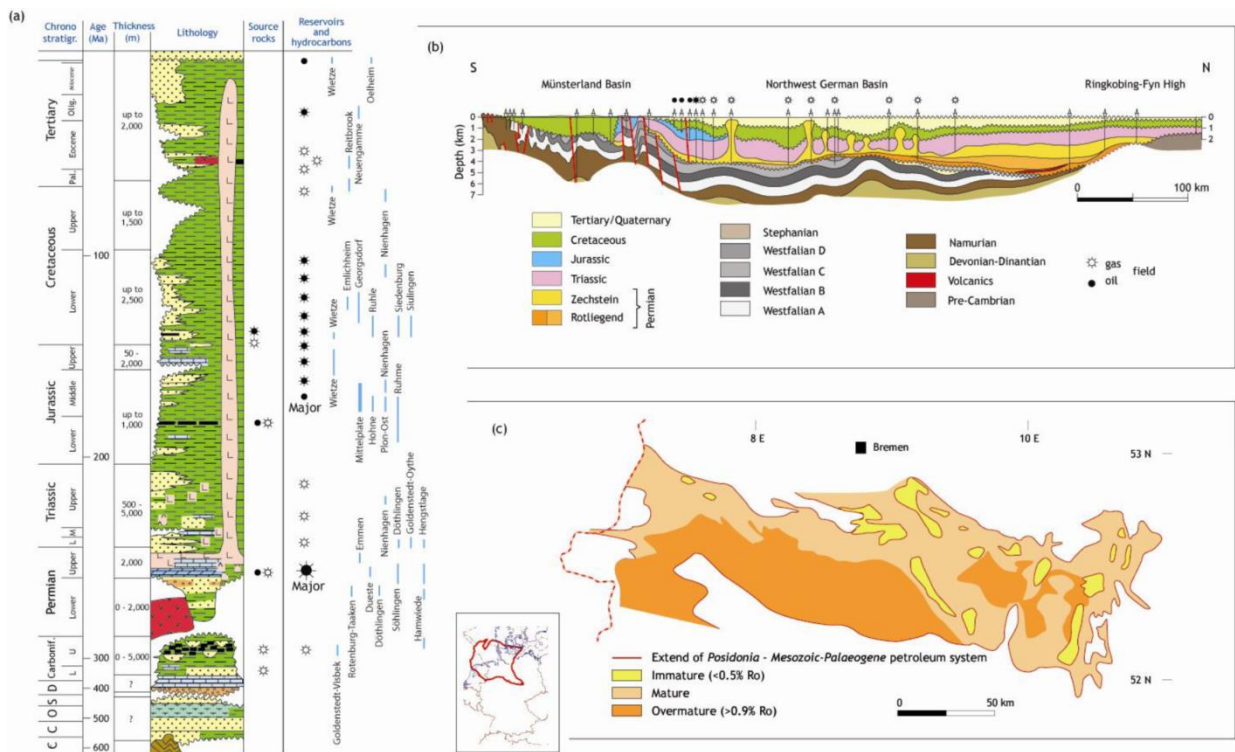
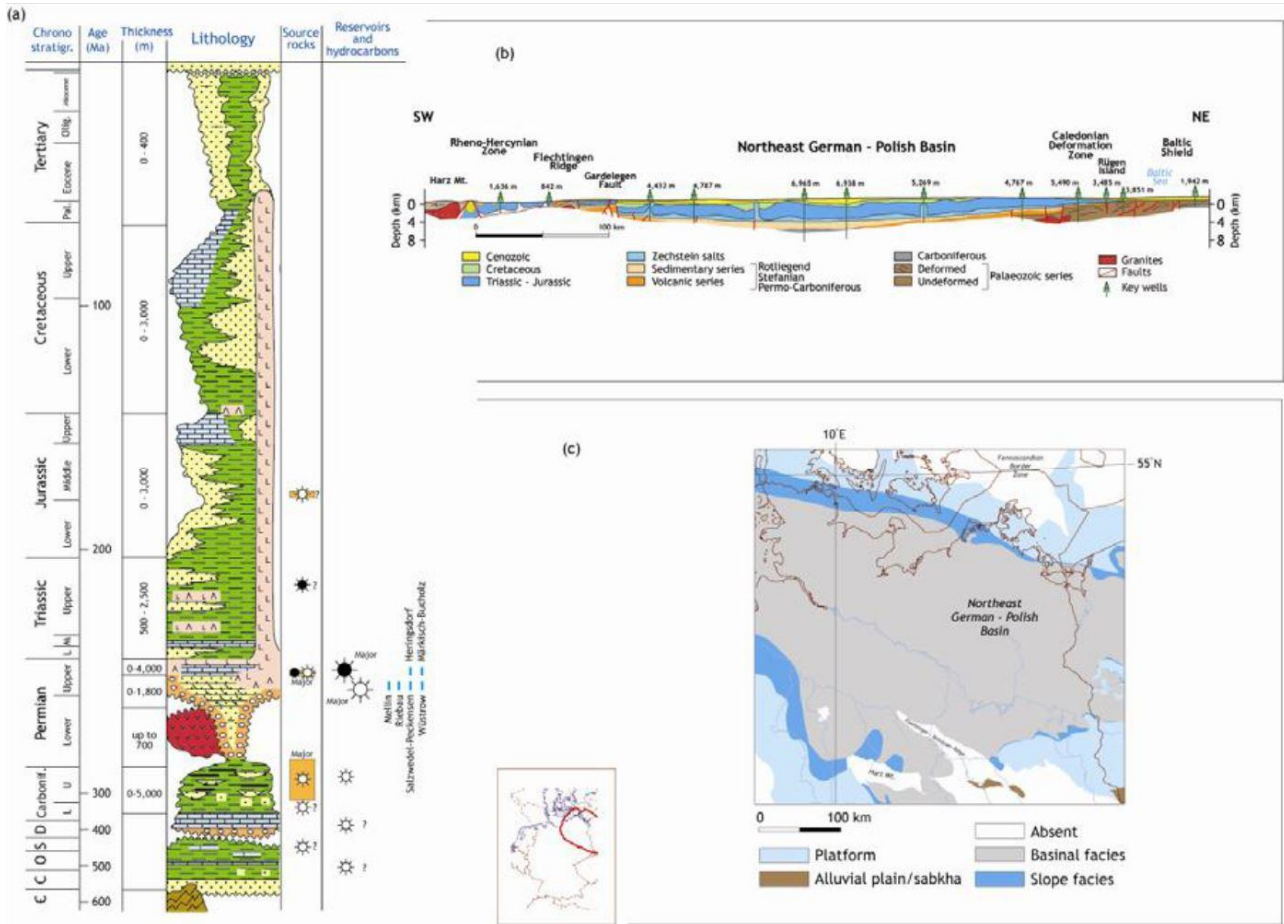


Fig. 3.6. Prospective formations and traps for hydrocarbon occurrences in Mesozoic in the Lower Saxony Basin (Gawenda, 2012). a – schematic lithostratigraphic chart showing main source and reservoir rocks in the NW German Basin; b – general, regional cross-section of the basin; c – extent of the Posidonia Shales – Mesozoic/Palaeogene petroleum system in the Lower Saxony.



**Fig. 3.7.** Prospective formations and traps for hydrocarbon occurrences in Mesozoic in the Northeast German-Polish Basin (Gawenda, 2012). a – schematic lithostratigraphic chart showing main source and reservoir rocks in the Northeast German-Polish Basin; b – general, regional cross-section through the Northeast German-Polish Basin; c – present day distribution of the Stassfurt facies.

#### 4. HYDROCARBON FIELDS

Neither conventional nor unconventional oil and gas fields have been documented within

the Koło tender area and in its vicinity.

#### 5. WELLS

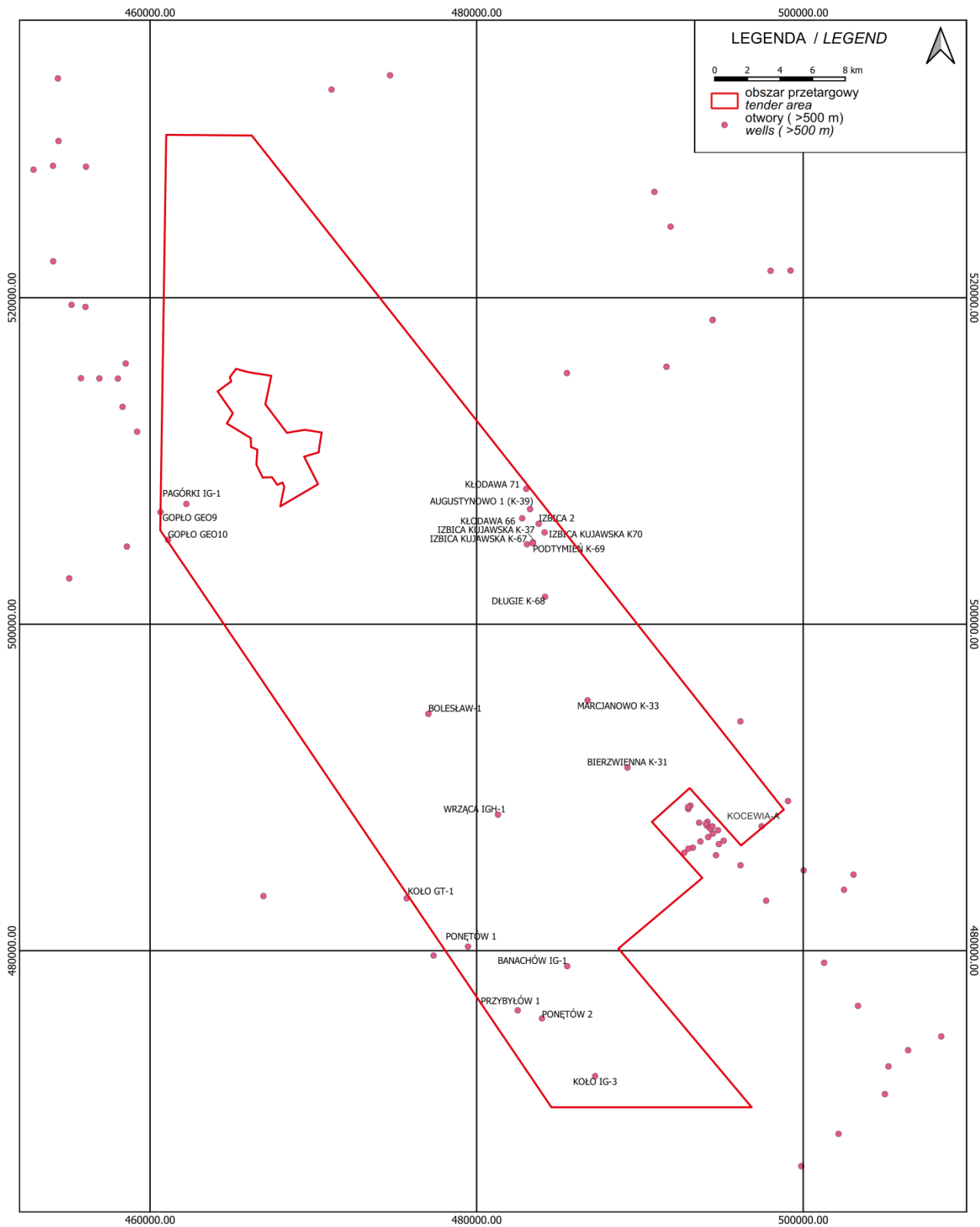
The following wells deeper than 500 m MD and reaching the prospective intervals were drilled in the Koło tender area:

Well name	Year	HC concessions (after 1994)	Owner	Depth [m]	Stratigraphy at the bottom
Augustynowo 1	1955		State Treasury	630.0	Permian
Banachów IG-1	1986		State Treasury	3403.0	Lower Jurassic
Bierzwienna K-31	1953		State Treasury	1020.4	Permian
Bolesław-1	2017	Koło 3/2016/p	State Treasury	1550.0	Cretaceous
Długie K-68	1958		State Treasury	627.0	Jurassic
Gopło GEO9	1957		State Treasury	751.5	Cretaceous
Gopło GEO10	1957		State Treasury	507.1	Cretaceous
Izbica 2	1955		State Treasury	1200.0	Permian
Izbica Kujawska K-37	1955		State Treasury	1212.3	Permian
Izbica Kujawska K-67	1959		State Treasury	521.0	Permian
Izbica Kujawska K-70	1958		State Treasury	590.5	Permian
Kłodawa 66	1959		State Treasury	500.7	Jurassic
Kłodawa 71	1958		State Treasury	510.0	Permian
Kocewia-A	1959		State Treasury	542.7	Jurassic
Koło GT-1	2018	*	State Treasury	3905.0	Upper Triassic
Koło IG-3	1968		State Treasury	3905.0	Lower Jurassic
Marcjanowo K-33	1953		State Treasury	1002.7	Permian
Pagórki IG-1	1957		State Treasury	1562.1	Upper Jurassic
Podtymień K-69	1958		State Treasury	600.1	Permian
Ponętów 1	1973		State Treasury	3007.0	Lower Jurassic
Ponętów 2	1992		ORLEN S.A.	2937.0	Lower Jurassic
Przybyłów 1	1988		State Treasury	3857.0	Permian
Wrząca IGH-1	1980		State Treasury	2934.8	Cretaceous

\*The drilling of the well was according to the decision of the Marshal of the Wielkopolska Voivodeship of November 10, 2016 approving the geological works project for drilling the Koło GT-1 prospecting and exploration well for exploitation of thermal waters in Chojny, Koło commune, Koło county, Wielkopolska Voivodeship; and according to the decision of the Marshal of the Wielkopolska Voivodeship of September 19, 2017 approving the Appendix No. 1 to the mentioned above geological project.

Location of the above-mentioned wells is presented in Fig. 5.1. Their general characteristics are shortly summarized in Tab. 5.1. The Banachów IG-1 well is illustrated in Fig 5.2 as an example.

The original data from the wells, which belong to the State Treasury, are collected in the DATA ROOM and will be available at the Polish Geological Institute – National Research Institute in Warsaw during the 6<sup>th</sup> tender round.



**Fig. 5.1.** Deep wells (>500 m MD) located within the Koło tender area and in its close neighborhood.

STRATIGRAPHY	Augustynowo 1		Banachów IG-1		Bierzwienna K-31		Bolesław-1		Długie K-68		Gopło GEO9		Gopło GEO10		Izbica 2		Izbica Kujawska K-37		Izbica Kujawska K-67		Izbica Kujawska K-70		Kłodawa 66		Kłodawa 71		Kocewia-A		Koło GT-1		Koło IG-3		Marcjanowo K-33		Pagórki IG-1		Podtymień K-69		Ponętów 1		Przybyłów 1		Wrząca IGH-1									
	top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]		top – bottom [m]									
QUATERNARY	0.0	55.4			0.0	20.4	0.0	82.0	0.0	40.0	0.0	85.0	0.0	49.0	0.0	219.6	0.0	201.6	0.0	20.5	0.0	54.0	0.0	38.8	0.0	99.0	0.0	35.6	0.0	30.0	0.0	45.0	0.0	292.0	0.0	65.0	0.0	173.7	0.0	47.0	0.0	33.5	0.0	65.0								
PALEOGENE-NEOGENE	55.4	123.0	0.0	22.0	20.4	227.6	82.0	1550.0	40.0	120.8							201.6	354.5	20.5	151.2	54.0	215.3	38.8	120.0			35.6	128.0			45.0	210.0			65.0	86.4			47.0	1712.0	33.5	1962.0	65.0	2934.8								
CRETACEOUS	123.0	203.5	22.0	2561.5			82.0	1550.0			85.0	851.5	78.0	507.1																																						
Maastrichtian			22.0	394.0			82.0	340.0																																												
Campanian			394.0	960.0			340.0	1095.0																																												
Santonian			960.0	1397.5			1095.0	1550.0																																												
Coniacian			1397.5	1677.0																																																
Turonian			1677.0	2053.5																																																
Cenomanian			2053.5	2152.0																																																
Upper Albian			2152.0	2181.5																																																
Middle and Lower Albian (Kruszwica Member)			2181.5	2300.0																																																
Aptian (Goplana Member)			2300.0	2316.5																																																
Barremian (Pagórki Mb)			2316.5	2324.0																																																
Hauterivian-Valanginian-Berriassian (Zychlin, Gniewków and Wierzchostawice members and Włocławek, Bodzanów and Rogoźno formations)			2324.0	2561.5																																																
JURASSIC			2561.5	3403.0					120.8	627.0																																										
Tithonian																																																				
Kimmeridgian			2561.5	2704.0																																																
Oxfordian			2704.0	3142.0																																																
Callovian			3142.0	3147.5																																																
Bathonian-Aalenian			3147.5	3247.0																																																
Upper Toarcian (Borucice Fm)			3247.0	3264.0																																																
L. Toarcian (Ciechocinek Fm)			3264.0	3370.0																																																
U. Pliensbachian (Drzewica Fm)			3370.0	3403.0																																																
TRIASSIC	203.5	300.0																																																		
Reatian-Norian																																																				
Carnian																																																				
Upper Gypsum Beds																																																				
Reed Sandstone																																																				
Lower Gypsum Beds																																																				
Sulechów Beds																																																				
Muschelkalk																																																				
Bunter Sandstone																																																				
UPPER PERMIAN	300.0	630.0			227.6	1020.4									219.6	1200.0	354.5	1212.3	310.1	521.0	215.3	590.5			118.0	510.0							334.7	1002.7			412.0	600.1														
Top Terigenous Series (PZt)																																																				

Tab. 5.1. Summary of stratigraphy and prospective horizons (green and blue) in the wells located within the Koło tender area (CGDB, 2023).

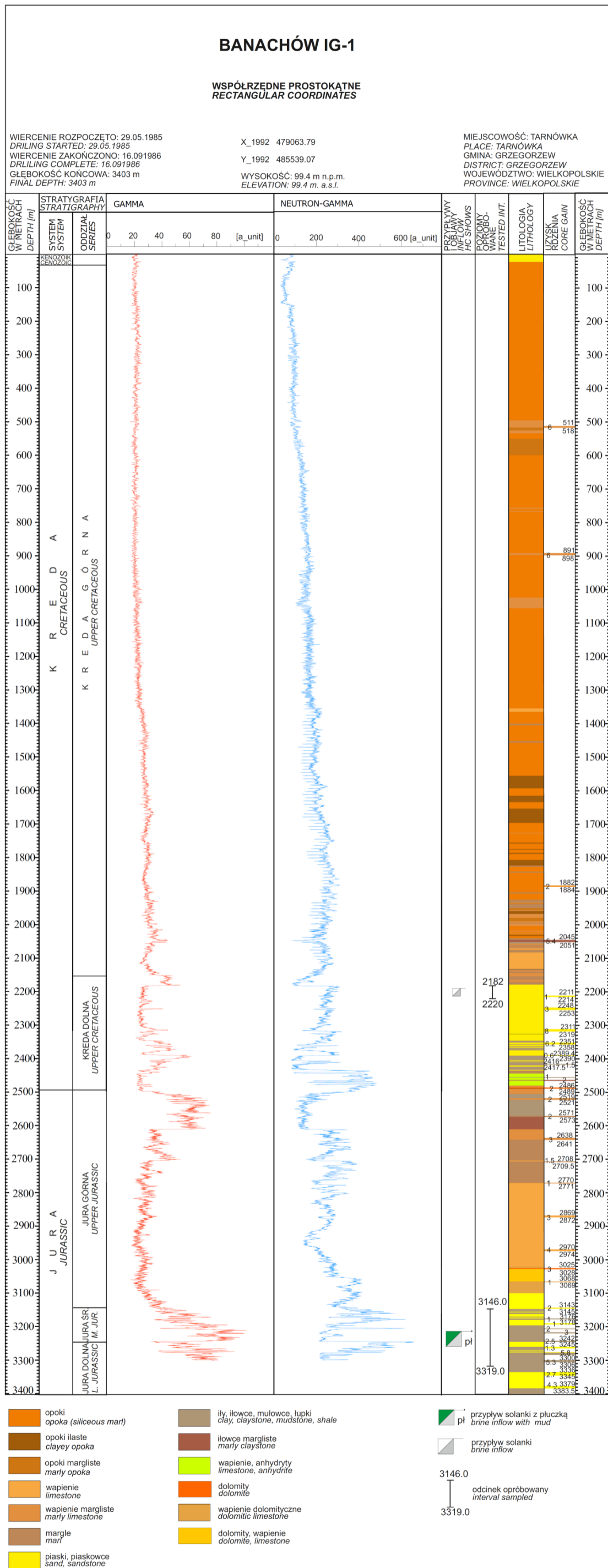


Fig. 5.2. Banachów IG-1 well lithology, stratigraphy and geophysics (Feldman and Marek, 1988).

6. SEISMIC SURVEYS

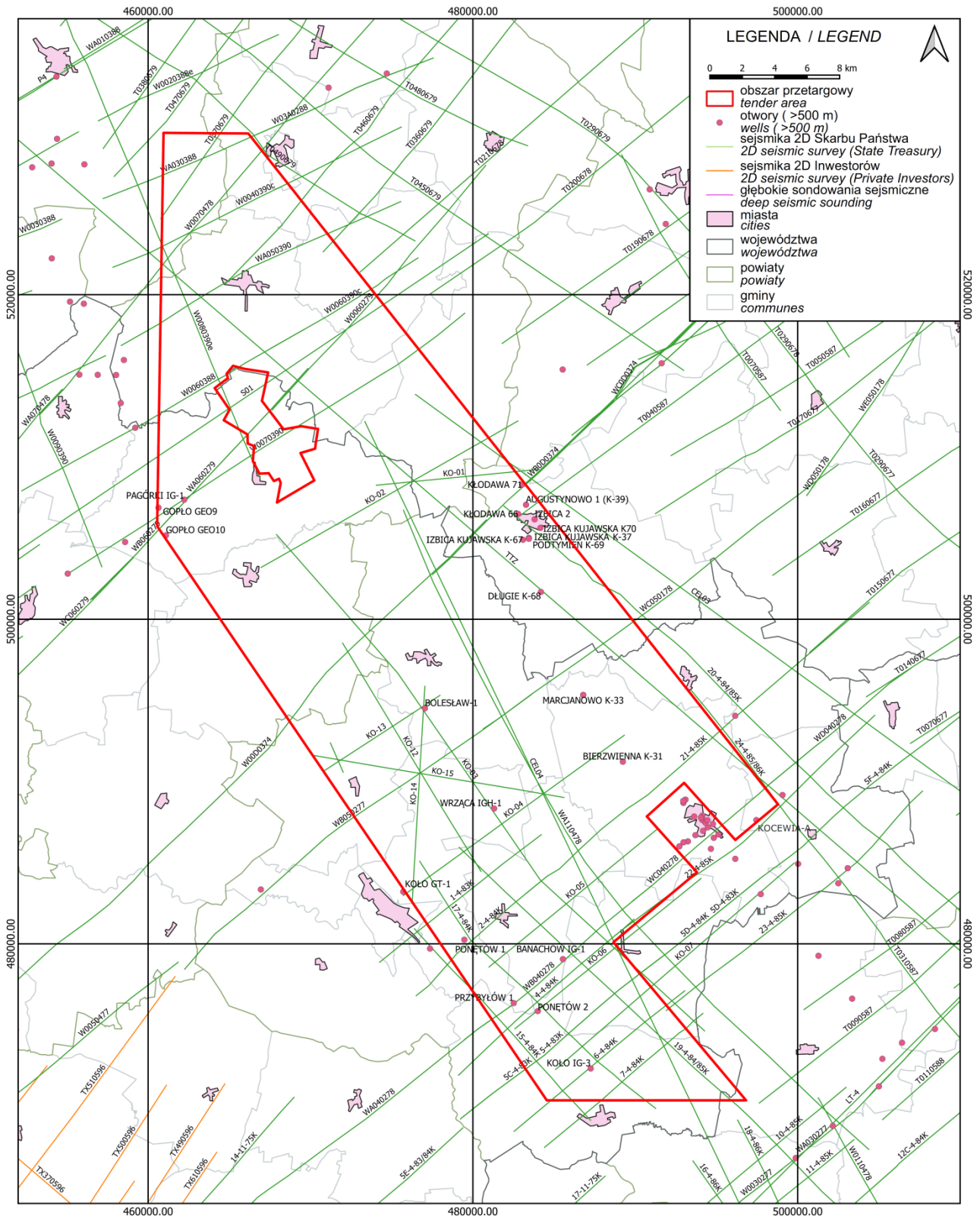


Fig. 6.1. Seismic survey within and in the neighborhood of the Koło tender area (CGDB, 2023).

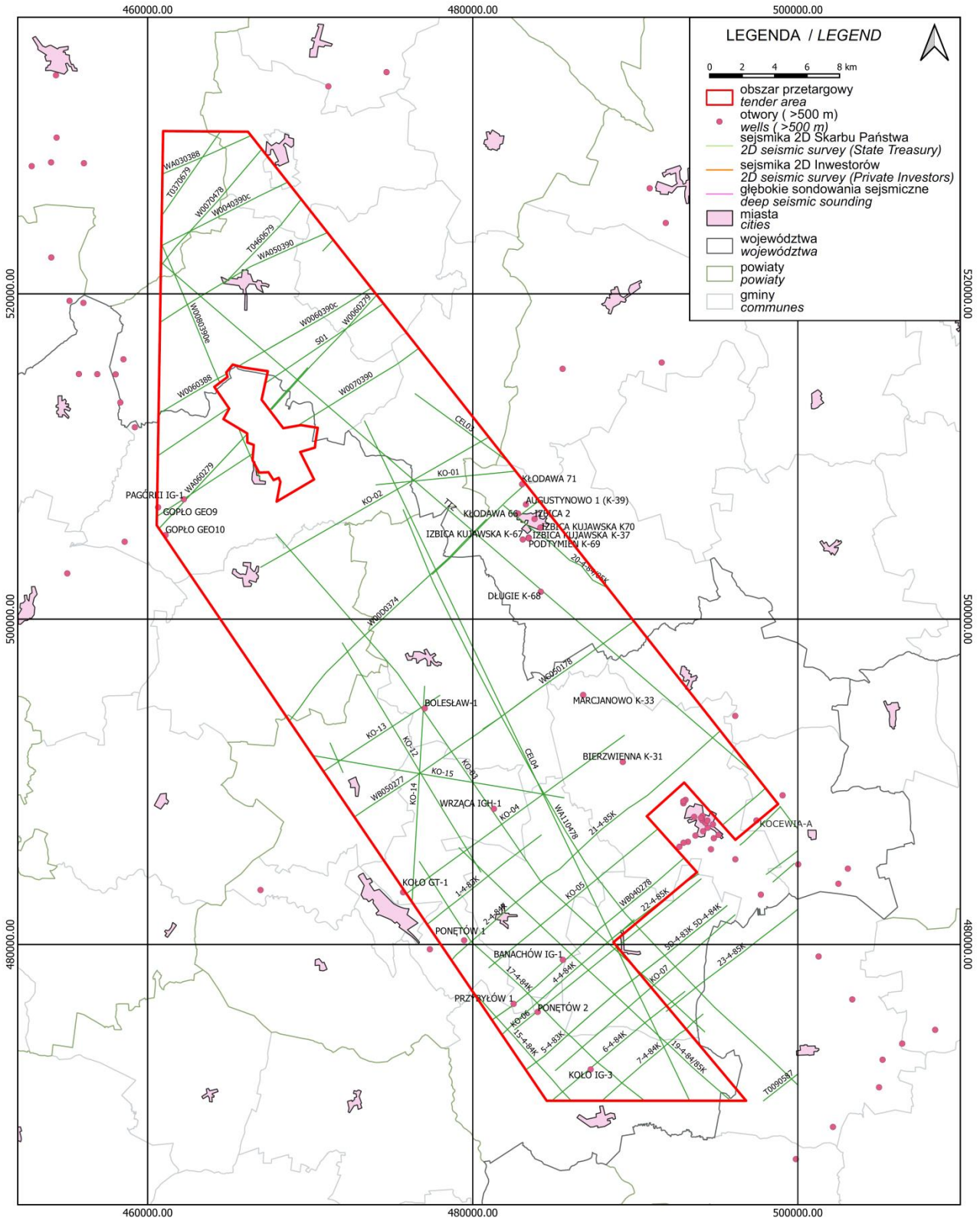


Fig. 6.2. Seismic survey within the Koło tender area (CGDB, 2023).

LINE NAME	YEAR	PROJECT	CONCESSIONS (after 2001)	OWNER	LENGTH [km]	
W00D0374	1974	Profile Regionalne		State Treasury	17.38	
WA0D0374	1974	Profile Regionalne		State Treasury	8.01	
W0070478	1978	Mogilno-Pabianice		State Treasury	9.48	
WA110478	1978	Mogilno-Pabianice		State Treasury	43.42	
WB040278	1978	Mogilno-Pabianice		State Treasury	13.00	
WB050277	1978	Mogilno-Pabianice		State Treasury	13.22	
WC040278	1978	Mogilno-Pabianice		State Treasury	7.69	
WC050178	1978	Mogilno-Pabianice		State Treasury	11.42	
T0370679	1979	Włocławek-Płock		State Treasury	6.31	
T0460679	1979	Włocławek-Płock		State Treasury	7.00	
W0060279	1979	Mogilno-Pabianice		State Treasury	9.56	
WA060279	1979	Mogilno-Pabianice		State Treasury	11.45	
WB060279	1979	Mogilno-Pabianice		State Treasury	9.69	
1-4-83K	1983	Ponętów-Wartkowice		State Treasury	8.91	
5C-4-83K	1983	Ponętów-Wartkowice		State Treasury	10.81	
5D-4-83K	1983	Ponętów-Wartkowice		State Treasury	7.11	
15-4-84K	1984	Ponętów-Wartkowice		State Treasury	9.09	
17-4-84K	1984	Ponętów-Wartkowice		State Treasury	20.36	
2-4-84K	1984	Ponętów-Wartkowice		State Treasury	7.82	
4-4-84K	1984	Ponętów-Wartkowice		State Treasury	10.78	
5-4-83K	1984	Ponętów-Wartkowice		State Treasury	10.85	
5D-4-84K	1984	Ponętów-Wartkowice		State Treasury	6.87	
5F-4-84K	1984	Ponętów-Wartkowice		State Treasury	3.07	
6-4-84K	1984	Ponętów-Wartkowice		State Treasury	10.59	
7-4-84K	1984	Ponętów-Wartkowice		State Treasury	8.19	
19-4-84/85K	1985	Ponętów-Wartkowice		State Treasury	22.85	
20-4-84/85K	1985	Ponętów-Wartkowice		State Treasury	8.25	
21-4-85K	1985	Ponętów-Wartkowice		State Treasury	15.70	
22-4-85K	1985	Ponętów-Wartkowice		State Treasury	9.90	
23-4-85K	1985	Ponętów-Wartkowice		State Treasury	10.25	
T0040587	1987	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	2.68	
W0060388	1988	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	9.50	
WA030388	1988	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	5.95	
W0040390c	1990	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	8.72	
W0060390c	1990	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	7.21	
W0070390	1990	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	15.95	
W0080390e	1990	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	12.62	
WA050390	1990	Ciechocinek-Brześć Kuj.-Wojszyce		State Treasury	11.72	
KO-01	2013	Strzelecki Energia Sp. z o.o.	Koło 53/2011/p	State Treasury	8.64	
KO-02	2013	Strzelecki Energia Sp. z o.o.		State Treasury	16.16	
KO-03	2013	Strzelecki Energia Sp. z o.o.		State Treasury	40.59	
KO-04	2013	Strzelecki Energia Sp. z o.o.		State Treasury	16.57	
KO-05	2013	Strzelecki Energia Sp. z o.o.		State Treasury	13.43	
KO-06	2013	Strzelecki Energia Sp. z o.o.		State Treasury	14.74	
KO-07	2013	Strzelecki Energia Sp. z o.o.		State Treasury	16.34	
KO-12	2013	Strzelecki Energia Sp. z o.o.		State Treasury	16.45	
KO-13	2013	Strzelecki Energia Sp. z o.o.		State Treasury	8.54	
KO-14	2013	Strzelecki Energia Sp. z o.o.		State Treasury	13.29	
KO-15	2013	Strzelecki Energia Sp. z o.o.		State Treasury	15.65	
					State Treasury	603.78

**Tab. 6.1.** 2D seismic surveys (lines longer than 2 km) within the Koło tender area.

## 7. GRAVIMETRY, MAGNETOMETRY AND MAGNETOTELLURICS

### 7.1. GRAVIMETRY

There are three semidetailed surveys in the Koło tender area (Fig. 7.1), with 2330 data points within. The Gostynin-Łowicz-Poneń-tów-Poddebice survey (Soćko, 1966), covering the southern part of the area, was collected with a point density ca. 1.9 stations/km<sup>2</sup>. Two other surveys: Mogilno-Konin-Uniejów (Reczek, 1967) and Kujawy and Rawa-Gielniów Anticlinorium (Łyszkowska and Kruk, 1969) were collected with a point density ca. 2 stations/km<sup>2</sup>. All data are available in the CGDB (2023).

There are some detailed surveys in the tender area, as well. Most of them were focused on lignite exploration. There are 13 profiles at Lubstów deposit (Jakubiak et al., 1979) collected with 20 m step. The others were collected with 100 m step (Ostrowska and Pisula, 1990; Wasiak, 1990).

The Gopło Anticline survey (Bochnia and Duda, 1961), at the western border of the tender area, was collected with an irregular point distribution, with density of ca. 15 stations/km<sup>2</sup>. 25 profiles with 300 m step were collected, as well.

Królikowski and Petecki (1995) proposed a division of Poland into several gravity regions. Thus, the Koło tender area is placed within the north-eastern part of the Szczecin-Mogilno-Miechów Low. The border of the tender area goes along gradient zone separating this low from the Kuyavian Low (visible at Bouguer anomaly map as a relatively positive anomaly – Fig. 7.2). Królikowski and Petecki (1995) suggest the dominant role of the crystalline basement in the formation of the Szczecin-Mogilno-Miechów Low, but the Variscan orogeny could play a significant role, as well, since it could produce significant amounts of rock material with reduced densities.

At the background of the regional anomalies described above, the relatively negative anomalies associated with the Kłodawa and Łanięta Salt Diapirs, as well as the relatively positive anomaly associated with the Gopło Anticline, are clearly visible.

### 7.2. MAGNETOMETRY

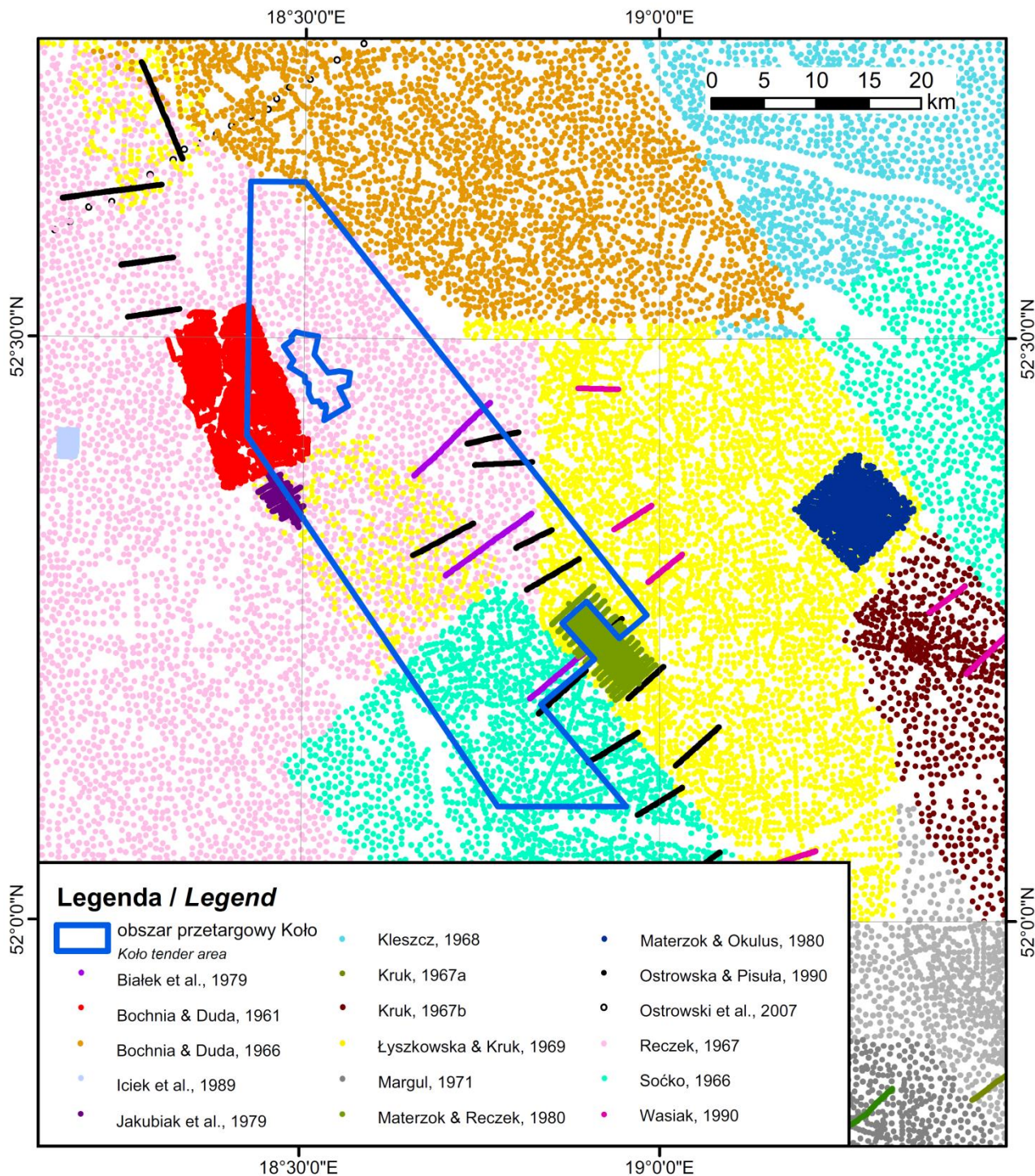
First magnetic survey at the Koło tender area was a the regional vertical component Z survey (Kozera, 1954, Fig. 7.3), collected with a density ca. 0.18 stations/km<sup>2</sup>. A semidetailed survey of total intensity T (Kosobudzka and Paprocki, 1997) is collected with density ca. 2 stations/km<sup>2</sup>.

An image of magnetic anomalies presented in Fig. 7.4 is taken from magnetic map of Poland (Petecki and Rosowiecka, 2017). The map is divided into several regions with different magnetic characteristic. The Koło tender area is located within the Central and Western Poland domain (CWPd), which from the north is limited by the gradient zone Szczecin-Stargard Szczeciński-Piła-Inowrocław (Petecki, 2008).

There is lack of strong magnetic local anomalies in the Koło tender area, which suggests either a reduced magnetization of the rocks of the crystalline basement or a tectonically undisturbed and deeply lying top of it. CWPd is characterized by the presence of a thicker upper crust with reduced seismic velocities (Guterch and Grad, 2006), which may also be responsible for the generally lower values of magnetic field anomalies (Petecki and Rosowiecka, 2017).

### 7.3. MAGNETOTELLURICS

So far, no magnetotelluric works have been carried out directly within the Koło tender area. There is Zgorzelec-Wizajny regional profile (Ostrowski et al., 2007) to the north-west of the area (Fig. 7.5). 2D inversion results are presented in Fig. 7.6. The measurement step of about 4 km does not allow for a detailed analysis of the sub-Zechstein structures, in the depth interval of 4–8 km, and it also does not allow tracing the continuity of certain resistance boundaries, e.g. in the area of advanced salt tectonics. Hence, the study proposes a concentration of measurements, which, however, has not been the case so far.



**Fig. 7.1.** Distribution of gravimetric measurements in the Koło tender area (based on CGDB, 2023).

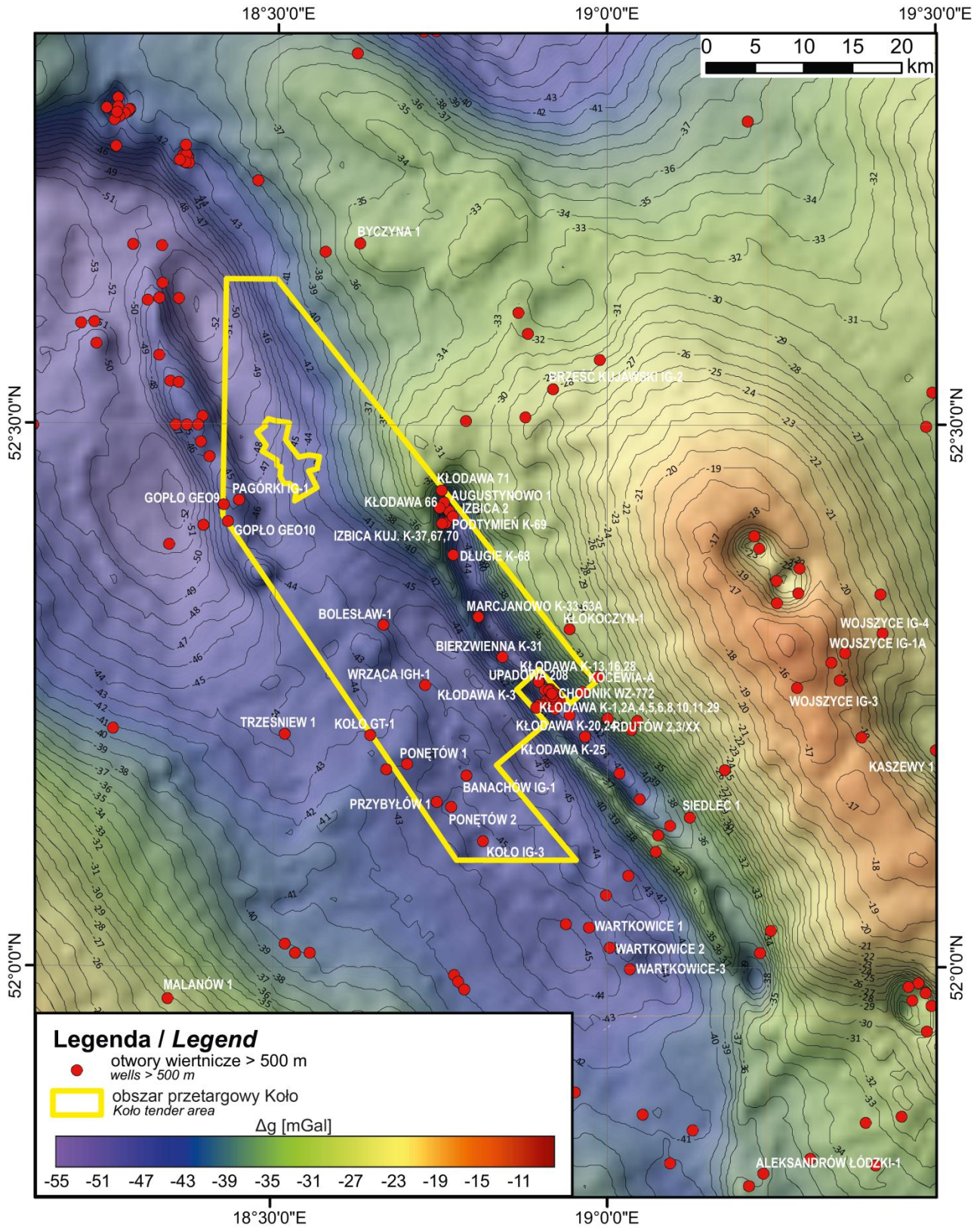


Fig. 7.2. Location of the Koło tender area on the Bouguer gravity anomaly map of Poland (Królikowski and Petecki, 1995).

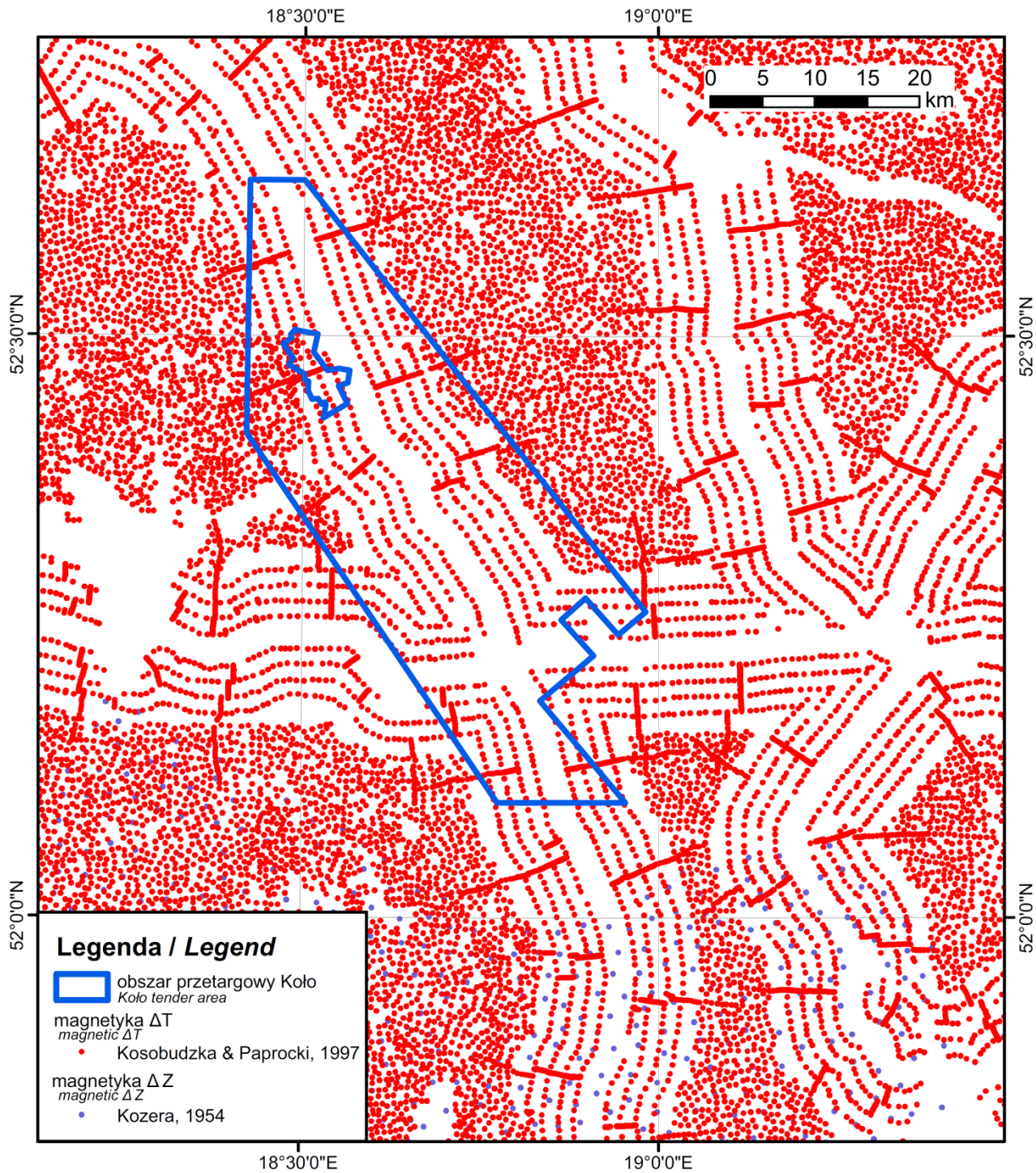


Fig. 7.3. Distribution of magnetic stations in the Koło tender area (based on CGDB, 2023).

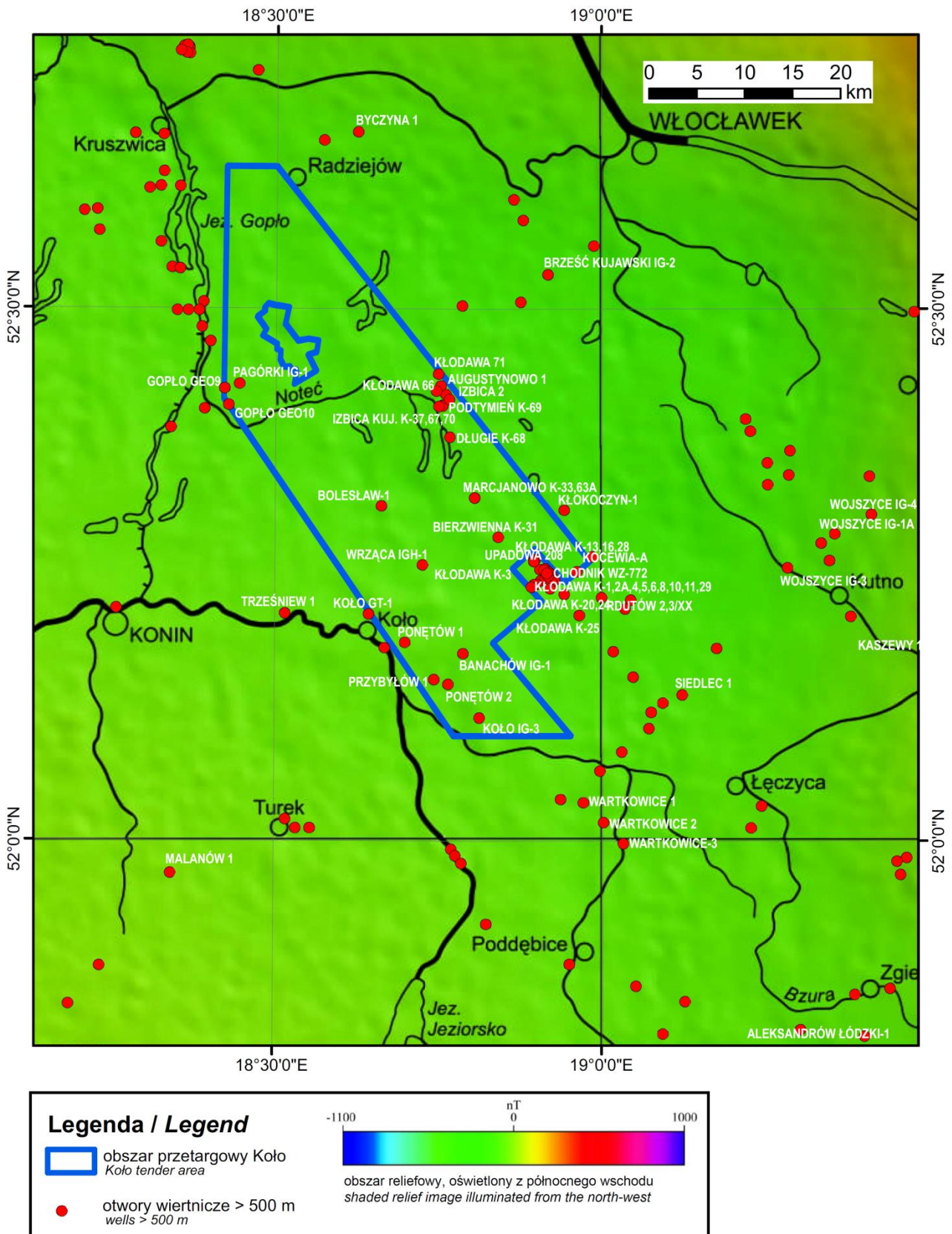
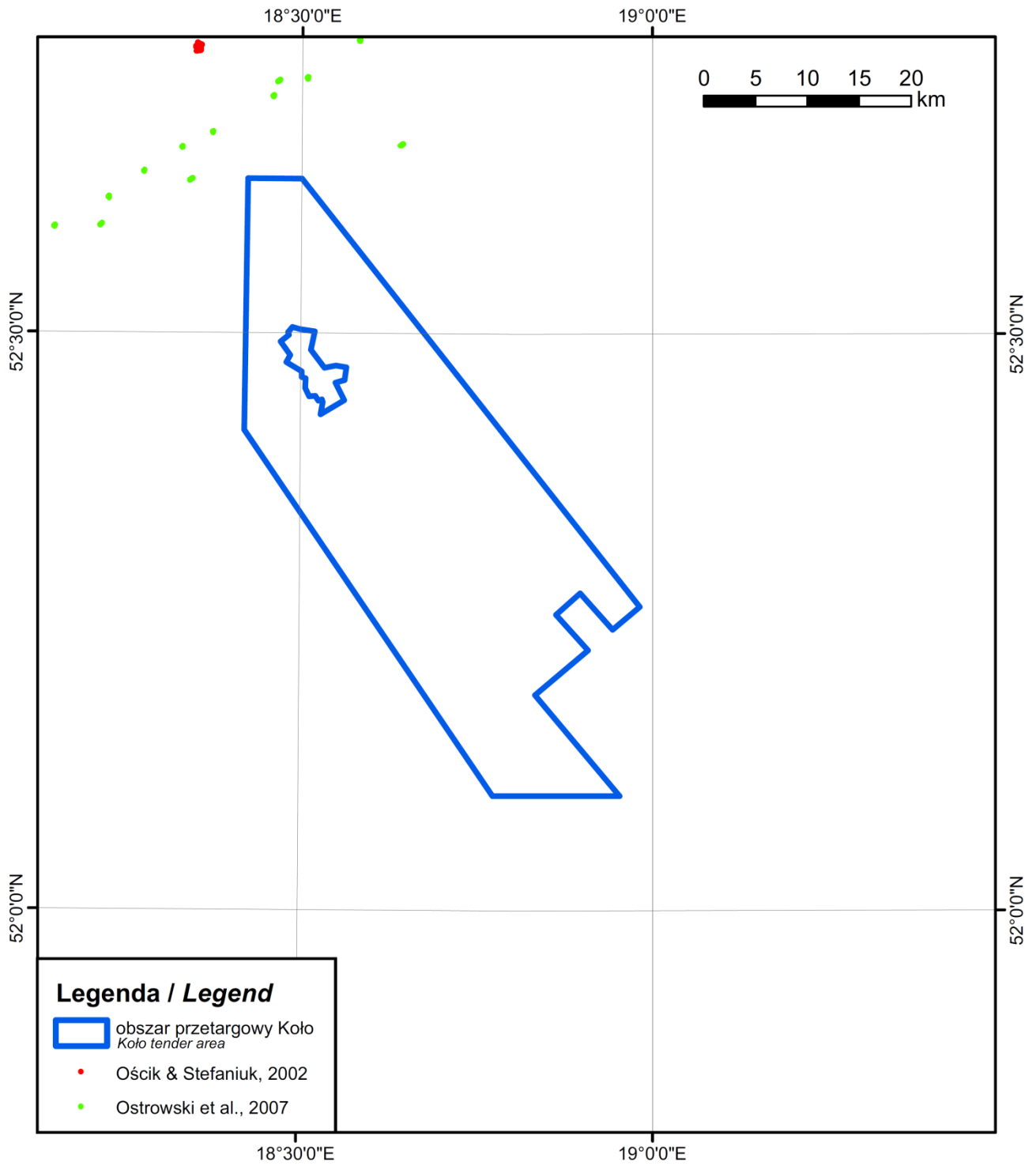
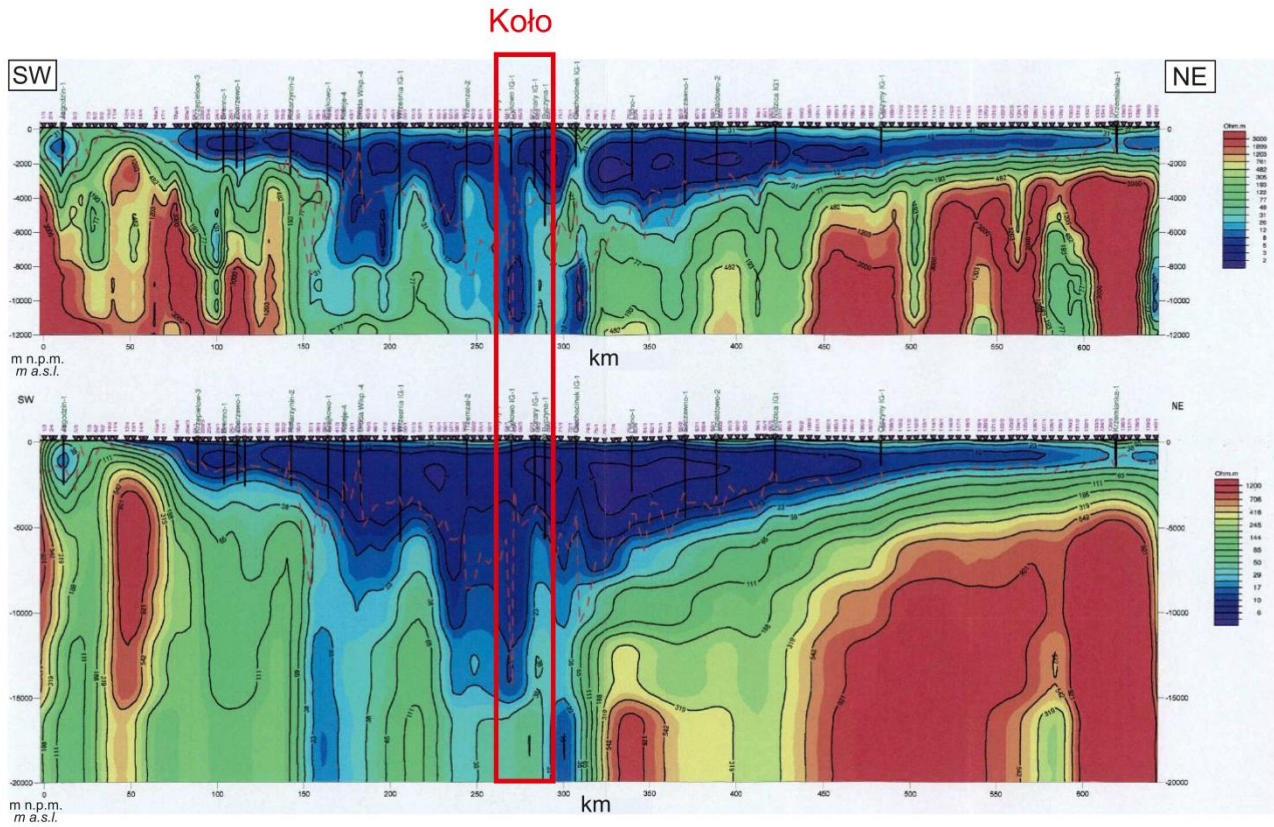


Fig. 7.4. Location of the Koło tender area on the magnetic anomaly map of Poland (Petecki and Rosowiecka, 2017).



**Fig. 7.5.** Distribution of magnetotelluric survey in the Koło tender area (based on CGDB, 2023).



**Fig. 7.6.** 2D inversion results along Zgorzelec-Wizajny profile (Ostrowski et al., 2007). The segment adjacent to the Koło tender area is marked with purpled.

8. SUMMARY CHART

Tender area:		KOŁO
General information:	Location:	<p><u>Onshore</u>  <u>Hydrocarbon concession blocks:</u> 189, 190, 209, 210 ,230  <u>Administrative location:</u> Kujawsko-Pomorskie Voivodeship, Inowrocław country, commune Kruszwica (2,.8%); Radziejów country, communes: Bytoń (2.70%), Piotrków Kujawski (11.22%), Radziejów City (0.14%), Radziejów (1.69%), Topólka (4.66%); Włocławek county, communes: Izbica Kujawska (7.18%), Lubraniec (0.04%); Łódzkie Voivodeship, Łęczyca country, commune Grabów (0,06%); Wielkopolskie Voivodeship, Koło country, communes: Babiak (12.91%), Chodów (0.48%), Dąbie (5.69%), Grzegorzew (7.07%), Kłodawa (9.09%), Koło City (0,09%), Koło (6.84%), Olszówka (4.46%), Osiek Mały (4.13%), Przedecz (1.15%); Konin country, communes Sompolno (8.39%), Wierzbiniek (9.43%)</p>
	Concession type:	prospection and exploration of hydrocarbon deposits and production of hydrocarbons from a deposit
	Time:	concession for 30 years, including: prospection and exploration phase (5 years), production phase – after investment decision
	Participation:	winner of the tender 100%
Acreage [km <sup>2</sup> ]:	1035.32	
Accumulation type:	(I) unconventional (shale gas) in the Jurassic (II) conventional (oil and gas) in the Mesozoic	
Structural stages:	Cenozoic, Laramide, Variscan?	
Petroleum plays:	(I) unconventional in the Jurassic fine-grained clastic rocks (II) conventional in the Mesozoic	
Reservoir rocks:	(I) Middle and Upper Jurassic black shales and siltstones and marly carbonates (II) Reed Sandstone and Lower and Middle Jurassic coarse- and medium-grained clastic rocks; Upper Jurassic carbonate rocks, Cretaceous sandstones	
Source rocks:	(I) Middle and Upper Jurassic black shales and siltstones and marly carbonates (II) Carboniferous? fine-grained clastic rocks, Middle and Upper Jurassic fine-grained clastic rocks and marls	
Seal rocks:	(I) Middle and Upper Jurassic black shales and siltstones and marly carbonates (II) Triassic clays and evaporites, Lower and Middle Jurassic clays, Lower Cretaceous siltstones and evaporites, Upper Cretaceous carbonates and silicicarbonates	
Trap type:	(I) unconventional, continuous (II) conventional traps in Triassic, Jurassic and Cretaceous	
Oil and gas fields:	no	
Seismic surveys (owner):	1974 Profile Regionalne 2D, 2 lines (State Treasury) 1978-1979 Mogilno-Pabianice 2D, 9 lines (State Treasury) 1979 Włocławek-Płock 2D, 2 lines (State Treasury) 1983-1985 Ponętów-Wartkowie 2D, 17 lines (State Treasury) 1987-1990 Ciechocinek-Brześć Kuj.-Wojszyce 2D, 8 lines (State Treasury) 2013 Strzelecki Energia Sp. Z o.o. 2D, 11 lines (State Treasury)	
Wells (depth):	<p>AUGUSTYNOWO 1 (630.0 m)  BANACHÓW IG-1 (3403.0 m)  BIERZWIENNA K-31 (1020.4 m)  BOLESŁAW-1 (1550.0 m)  DŁUGIE K-68 (627.0 m)  GOPŁO GEO9 (751.5 m)  GOPŁO GEO10 (507.1 m)  IZBICA 2 (1200.0 m)  IZBICA KUJAWSKA K-37 (1212.3 m)  IZBICA KUJAWSKA K-67 (521.0 m)  IZBICA KUJAWSKA K-70 (590.5 m)  KŁODAWA 66 (500.7 m)  KŁODAWA 71 (510.0 m)  KOCEWIA-A (542.7 m)  KOŁO GT-1 (3905.0 m)  KOŁO IG-3 (3905.0 m)  MARCJANOWO K-33 (1002.7 m)</p>	

	PAGÓRKI IG-1 (1562.1 m) PODTYMIEN K-69 (600.1 m) PONEŹÓW 1 (3007.0 m) PONEŹÓW 2 (2937.0 m) PRZYBYŁÓW 1 (3857.0 m) WRZAŹA IGH-1 (2934.8 m)
--	--

*Possible minimum work program for the prospection and exploration phase*

- Archival data reinterpretation and analysis
- Conducting of 2D seismic survey (at least 100 km) or 3D seismic survey (at least 50 km<sup>2</sup>)
- Drilling of one well to the maximal depth 5000 m TVD with obligatory coring of prospective intervals

## 9. REFERENCES

- **Andrews I.J. 2013.** The Carboniferous Bowland Shale gas study: geology and resource estimation: British Geological Survey for Department of Energy and Climate Change, London, UK.
- **Anthonsen K.L., Frykman P., Nielsen C.M. 2016.** Mapping of the CO<sub>2</sub> storage potential in the Nordic region. *Geological Survey of Denmark and Greenland (GEUS) Bulletin*, **35**, 87–90.
- **Białek A., Midura A., Okulus H. 1979.** Dokumentacja sejsmicznych badań refleksyjnych oraz badań grawimetrycznych; temat: Mogilno-Pabianice, 1977-78. [Mogilno-Pabianice 1977-1978 seismic and gravimetric survey report]. Inw. 20540, Arch. CAG PIG, Warsaw. [in Polish]
- **Bloch J., Nocoń W., Jastrząb M. 1984.** Dokumentacja wynikowa otworu badawczego Byczyńska-1 [Byczyńska-1 final well report]. Inw. 129635, Arch. CAG PIG, Warsaw. [in Polish]
- **Bochnia N., Duda H. 1966.** Dokumentacja półszczegółowych badań grawimetrycznych. Temat: Paraantyklinorium Kujawskie, rejon Brześćcia Kujawskiego, 1965. [Kuyavian Para-Anticlinorium Brześć Kujawski 1965, semidetailed gravimetric survey report]. Inw. 1242, Arch. CAG PIG, Warsaw. [in Polish]
- **Bochnia N., Duda W. 1961.** Sprawozdanie – Szczegółowe badania grawimetryczne na obszarze Antykliny Gopła, 1960. [Gopło 1960, detailed gravimetric survey report]. Inw. 1397/61, Arch. CAG PIG, Warsaw. [in Polish]
- **Botor D., Papiernik, B. Maćkowski T., Reicher B., Kosakowski P., Machowski G., Górecki W. 2013.** Gas generation in Carboniferous source rocks of the Variscan foreland basin: implications for a charge history of Rotliegend deposits with natural gases. *Annales Societatis Geologorum Poloniae*, **83**, 353–383.
- **Burliga S., Kolonko P., Misiek G., Czapowski G. 1995.** Kłodawa Salt Mine. Upper Permian (Zechstein) profile from basin center, salt tectonics, mineral transformations, salt mining problems. XIII International Congress on Carboniferous-Permian Guide to Excursion A3. Polish Geological Institute, Warsaw, 45–54.
- **Burliga S., Koyi, H. A., Chemia, Z. 2012.** Analogue and numerical modelling of salt supply to a diapiric structure rising above an active basement fault. *Geological Society, London, Special Publications*, **363**, 395–408.
- **CGDB 2023.** Central Geological Database. baza.pgi.gov.pl
- **Charysz W. 1973.** Cechsztyńskie piętro soli młodszych (Z3) w regionie kujawskim. [Zechstein Younger Salt stage Z3 in the Kuyavian Region]. *Prace Geologiczne PAN Oddz. w Krakowie*, **75**, 1–68. [in Polish]
- **Czapowski G. 1994.** Facies characteristics and distribution of the Zechstein (Upper Permian) salt deposits of PZ3 (Leine) Cycle in Poland. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, **41**, 229–237.
- **Czapowski G., Tomassi-Morawiec H. 2018.** Wykształcenie i geochemia bromu utworów solnych pogranicza cyklotemów PZ1 i PZ2 cechsztynu w kłodawskim wydzie solnym (środkowa Polska). [Deposits from the transition of Zechstein PZ1 to PZ2 cyclothems in the Kłodawa salt dome (central Poland)]. *Przegląd Geologiczny*, **66**, 303–308. [in Polish with English summary]
- **Czapowski G., Antonowicz L., Peryt T. 1991.** Facies and paleogeography of the Zechstein (Upper Permian) Older Halite (Na<sub>2</sub>) in Poland. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, **38**, 45–55.
- **Czapowski G., Peryt T.M., Antonowicz L. 1994.** Facies and paleogeography of the Zechstein (Upper Permian) Oldest Halite (Na<sub>1</sub>) in Poland. *Bulletin of the Polish Academy of Sciences, Earth Sciences*, **41**, 217–227.
- **Dadlez R. 1997.** Tektonika kompleksu permsko-mezozoicznego. Ogólne rysy tektoniczne bruzdy środkowopolskiej. [Tectonic of the Permian-Mesozoic complex. General tectonic framework of the Mid-Polish Trough]. *Prace Państwowego Insty-*

- tutu Geologicznego* **153**, 410–414. [in Polish with English summary]
- **Dadlez, R., Franczyk, M. 1976.** Palaeogeographic and palaeotectonic significance of the Wielkopolska Ridge (central Poland) in the Lower Jurassic epoch. *Biuletyn Instytutu Geologicznego*, **295**, 27–55.
  - **Dadlez R., Narkiewicz M., Stephenson R. A., Visser M. T. M., Van Wees J. D. 1995.** Tectonic evolution of the Mid-Polish Trough: modelling implications and significance for central European geology. *Tectonophysics*, **252**, 179–195.
  - **Dadlez R., Marek S., Pokorski J. 1998.** Atlas paleogeograficzny epikontynentalnego permu i mezozoiku w Polsce: 1 : 2 500 000. [Palaeogeographic atlas of the Epicontinental Permian and Mesozoic in Poland, 1 : 250 000]. Wydawnictwo Kartograficzne Polskiej Agencji Ekologicznej. [in Polish]
  - **Dadlez R., Marek S., Pokorski J. 2000.** Geological Map of Poland without Cenozoic deposits, 1 : 1 000 000. Polish Geological Institute, Warsaw. [in Polish with English abbreviations]
  - **Dayczak-Calikowska K. 1990.** Wyniki badań litologiczno-stratygraficznych. Jura środkowa. [Results of lithological and stratigraphic studies. Middle Jurassic]. (In): Koło IG 3, Koło IG 4, Poddebice IG 1. (Eds.): Dembowska J., Marek S. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **69**, 70–74. [in Polish]
  - **Dayczak-Calikowska K. Moryc W. 1988.** Rozwój basenu sedymentacyjnego i paleotektonika jury środkowej na obszarze Polski. [Evolution of sedimentary basin and palaeotectonics of the Middle Jurassic in Poland]. *Geological Quarterly*, **32**, 117–136. [in Polish with English summary]
  - **Dębski J., Czapowski G., Tarka R. 1989.** Dodatek nr 2 do dokumentacji geologicznej złoża soli kamiennej (perm) w kopalni Kłodawa, kat. C2+C1, woj. bydgoskie. [Kłodawa salt deposits geological documentation, Add. 2]. Inw. 1155/91, Arch. CAG PIG, Warsaw. [in Polish]
  - **Dembowska J. 1979.** Systematyzowanie litostratygrafii jury górnej w Polsce północnej i środkowej. [Systematization of lithostratigraphy of the Upper Jurassic in Northern and Central Poland]. *Geological Quarterly*, **23**, 617–630. [in Polish with English summary]
  - **Dembowska J. 1990.** Wyniki badań litologiczno-stratygraficznych. Jura górna. [Results of lithological and stratigraphic studies. Upper Jurassic]. (In): Koło IG 3, Koło IG 4, Poddebice IG 1. (Eds.): Dembowska J., Marek S. *Profile Głębokich Otworów Wiertniczych Instytutu Geologicznego*, **69**, 74–81.
  - **Doornenbal H., Stevenson A. 2010.** Petroleum geological atlas of the Southern Permian Basin area. EAGE.
  - **Dravis J.J., Yurewicz D.A. 1985.** Enhanced carbonate petrography using fluorescence microscopy. *Journal of Sedimentary Research*, **55**, 795–804.
  - **Espitalié J., Deroo G., Marquis F. 1985.** La pyrolyse Rock-Eval et ses applications. Deuxième partie. *Revue de l'Institut français du Pétrole*, **40**, 755–784.
  - **Feldman-Olszewska A. 1997a.** Depositional architecture of the Polish epicontinental Middle Jurassic basin. *Geological Quarterly*, **41**, 491–508.
  - **Feldman-Olszewska A. 1997b.** Depositional systems and cyclicity in the intracratonic Early Jurassic basin in Poland. *Geological Quarterly*, **41**, 475–490.
  - **Feldman-Olszewska A. 1998.** Palaeogeographic maps of Middle Jurassic, pl. 36–47. [In]: Palaeogeographic Atlas of the Epicontinental Permian and Mesozoic in Poland. [Red.]: Dadlez R., Marek S., Pokorski J. Państwowy Instytut Geologiczny, Warszawa.
  - **Feldman-Olszewska A. 2008a.** Wyniki badań litologicznych i stratygraficznych utworów jury dolnej. [Results of lithological and stratigraphic studies of the Lower Jurassic deposits]. (In): Brześć Kujawski IG 1, Brześć Kujawski IG 2, Brześć Kujawski IG 3. (Ed.): Feldman-Olszewska A. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **125**, 139–140. [in Polish with English summary]
  - **Feldman-Olszewska A. 2008b.** Wyniki badań litologicznych i stratygraficznych utworów jury środkowej. [Results of litho-

- logical and stratigraphic studies of the Middle Jurassic deposits]. (In): Brześć Kujawski IG 1, Brześć Kujawski IG 2, Brześć Kujawski IG 3. (Ed.): Feldman-Olszewska A. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **125**, 150–151. [in Polish with English summary]
- **Feldman-Olszewska A. 2012a.** Stratygrafia i litologia utworów jury dolnej na tle rozwoju paleotektonicznego strefy Ponętów-Wartkowice. [Stratigraphy and lithology of the Lower Jurassic in relation to palaeotectonic development of the Ponętów-Wartkowice zone]. (In): Poddebice PIG 2. (Ed.): Leszczyński K. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **133**, 84–87. [in Polish with English summary]
  - **Feldman-Olszewska A. 2012b.** Stratygrafia i litologia utworów jury środkowej na tle rozwoju paleotektonicznego strefy Ponętów-Wartkowice. [Stratigraphy and lithology of the Middle Jurassic in relation to palaeotectonic development of the Ponętów-Wartkowice zone]. (In): Poddebice PIG 2. (Ed.): Leszczyński K. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **133**, 94–96. [in Polish with English summary]
  - **Feldman A., Marek S. 1988.** Dokumentacja wynikowa otworu badawczego Banachów IG-1. [Banachów IG-1 final well report]. Inw. 131366, CAG PIG, Warszawa. [in Polish]
  - **Gast R., Dusar M., Breikreutz Ch., Gaupp R., Schneider J.W., Stemmerik L., Geluk M., Geissler M., Kiersnowski H., Glennie K., Kabel S., Jones N. 2010.** Chapter 7, Rotliegend. (In): Petroleum Geological Atlas of the Southern Permian Basin Area. (Eds): Doornenbal H., Stevenson A., TNO, The Netherlands, 101–122.
  - **Gawenda P. 2012.** Germany – Overview about Renewed Petroleum Activities. AAPG-European Region Newsletter, 4–9.
  - **Gaździcka E. 2012.** Badania litologiczno-stratygraficzne utworów jury górnej i beriasu dolnego. [Lithological and stratigraphic study of the Upper Jurassic and Lower Beriasian deposits]. (In): Poddebice PIG 2. (Ed.): Leszczyński K. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **133**, 101–103. [in Polish with English summary]
  - **Gondek B. 1980.** Geochemistry of normal alkanes encountered in sedimentary rocks of the Polish Lowlands. *Prace Instytutu Geologicznego*, **97**. [in Polish with English summary]
  - **Górecki W., Hajto M. 2006.** Atlas zasobów geotermalnych na Niżu Polskim. [Atlas of geothermal resources, Polish Lowlands]. Katedra Surowców Energetycznych Akademii Górniczo-Hutniczej, Cracow. [in Polish with]
  - **Grotek I. 2012.** Charakterystyka petrograficzna oraz dojrzałość termiczna materii organicznej rozproszonej w utworach mezozoiku. [Petrographic characteristics and thermal maturity of the organic matter dispersed in the Mesozoic]. (In): Poddebice PIG 2. (Ed.): Leszczyński K. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **133**, 132–136. [in Polish with English summary]
  - **Guterch A., Grad M. 2006.** Lithospheric structure of the TESH in Poland based on modern seismic experiments. *Geological Quarterly*, **50**, 23–32.
  - **Guterch A., Wybraniec S., Grad M., Chadwick R., Krawczyk C., Ziegler P., De Vos W., Thybo H. 2010.** Crustal structure and structural framework. (In): Petroleum Geological Atlas of the Southern Permian Basin Area. (Eds): Doornenbal J., Stevenson A. Houten, EAGE Publications, 11–23.
  - **Hanczke T. 1969.** Mineralogia i petrografia soli cechsztyńskich w kopalni Kłodawa. [Mineralogy and petrography of the Zechstein salts in the Kłodawa mine]. *Prace Muzeum Ziemi*, **16**, 3–52. [in Polish]
  - **Iciek A., Królikowski C., Linowski H., Midura A., Oleksiak J., Piwocki M., Soćko A. 1989.** Budowa geologiczna Polski i poszukiwanie złóż surowców mineralnych. Cel nr 28. Opracowanie kompleksu nowoczesnych metod geofizycznych do poszukiwania i rozpoznawania złóż węgla brunatnych. [Geology of Poland and mineral resources. Target 28. Development of new geophysical methods for prospecting and exploration of brown coals]. Kat.

- 3921/287, Arch. CAG PIG, Warsaw. [in Polish]
- **Jakubiak H., Wojas A., Okulus H. 1979.** Dokumentacja badań geofizycznych. Temat: Złoże węgla brunatnego „Lubstów”. Rok badań 1978. [Lubstów brown coal, 1978, Geophysical documentation]. Inw. 12546c CUG, Arch. CAG PIG, Warsaw. [in Polish]
  - **Jaskowiak-Schoeneichowa M. 1977.** Kreda górna. Budowa geologiczna wschodniej części niecki mogileńsko-łódzkiej (strefa Gopło-Ponętów-Pabianice). [Upper Cretaceous. Geology of the eastern part of the Mogilno-Łódź Synclinorium (Gopło-Ponętów-Pabianice area)]. *Prace Instytutu Geologicznego*, **80**. [in Polish with English summary]
  - **Karnin W.-D., Gast R., Bärle C., Clever B., Kühn M., Sommer J. 2006.** Play types, structural history and distribution of Middle Buntsandstein gas fields in NW Germany: observations and their genetic interpretation. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, **157**, 121–134.
  - **Karnkowski P.H. 1991.** Zagadnienie ruchów tektonicznych w czerwonym spągowcu. [Problems of tectonic movements in the Rotliegendes]. *Przegląd Geologiczny*, **39**, 352–356. [in Polish with English summary]
  - **Karnkowski P.H. 1999.** Stratygrafia sekwencji czerwonego spągowca w basenie polskim: relacje między tektoniką a klimatem. [Sequence stratigraphy of the Rotliegend deposits in the Polish Basin: relations between climate and tectonic]. *Przegląd Geologiczny*, **47**, 473–474. [in Polish]
  - **Kiersnowski H., Buniak A., Waśkiewicz K. 2020.** Mapa litofacji stropu osadów czerwonego spągowca górnego. [Lithofacies map of the top of the Upper Rotliegend]. Polish Geological Institute – National Research Institute, Warsaw. [in Polish with English abbreviations]
  - **Kilhams B., Kukla P. A., Mazur S., McKie T., Mijnlief H. F., Van Ojik K. 2018.** Mesozoic resource potential in the Southern Permian Basin. *Geological Society of London, Special Publications*, **469**, 1–18.
  - **Kleszcz T. 1968.** Dokumentacja badań grawimetrycznych, temat: „Synklinorium Pomorskie”, 1967. [Pomerania Synclinorium, 1967, Gravimetric survey report]. Kat. G-231 PBG, Arch. CAG PIG, Warsaw. [in Polish]
  - **Klimuszko E. 2012.** Charakterystyka geochemiczna materii organicznej. [Geochemical characteristics of the organic matter]. (In): Poddębice PIG 2. (Ed.): Leszczyński K. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **133**, 137–144. [in Polish with English summary]
  - **Kondracki J. 2013.** Geografia regionalna Polski. [Regional geography of Poland]. PWN, Warsaw. [in Polish]
  - **Kosakowski P., Wójcik-Tabol P., Kowalski A., Zacharski J. 2015.** Jurassic Petroleum System in the Polish Lowlands (Central Poland)-Organic Geochemical and Numerical Modelling Approach. 77th EA-GE Conference and Exhibition. European Association of Geoscientists & Engineers.
  - **Kosobudzka I., Paprocki A. 1997.** Wykonanie półszczegółowych badań magnetycznych „T” w Polsce zachodniej, centralnej i południowo-wschodniej w latach 1995-1997. [Semidetailed magnetic T research in Western, Central, and South-Western Poland, 1995-1997]. Inw. 812/98, Arch. CAG PIG, Warsaw. [in Polish]
  - **Kotański Z. 1997.** Budowa geologiczna Polski na mapach ścięcia poziomego. [Geology of Poland on the maps of horizontal cutting]. *Przegląd Geologiczny*, **45**, 605–618. [in Polish]
  - **Kotarba M., Lewan M. D. 2004.** Characterizing thermogenic coalbed gas from Polish coals of different ranks by hydrous pyrolysis. *Organic Geochemistry*, **35**, 615–646.
  - **Kotarba M., Lewan M.D. 2013.** Sources of natural gases in Middle Cambrian reservoirs in Polish and Lithuanian Baltic Basin as determined by stable isotopes and hydrous pyrolysis of Lower Palaeozoic source rocks. *Chemical Geology*, **345**, 62–76.

- **Kotarba M., Piela J., Żolnierczuk T. 1992.** Geneza gazu ziemnego akumulowanego w permsko-karbońskich pułapkach litologicznych złoża "Paproć" w świetle badań izotopowych. [Origin of natural gas in Permo-Carboniferous lithological traps of Paproć field (Western Poland) in light of isotope studies]. *Przegląd Geologiczny*, **40**, 260. [in Polish with English summary]
- **Kotarba M., Grelowski C., Kosakowski P., Więclaw D., Kowalski A., Sikorski B. 1999.** Potencjał węglowodorowy skał macierzystych i geneza gazu ziemnego akumulowanego w utworach czerwonego spągowca i karbonu w północnej części Pomorza Zachodniego. [Hydrocarbon potential of source rocks and origin of natural gas accumulated in the Rotliegend and Carboniferous deposits in northern part of the Western Pomerania]. *Przegląd Geologiczny*, **47**, 480. [in Polish]
- **Kotarba M., Pokorski J., Grelowski C., Kosakowski P. 2005.** Geneza gazu ziemnego akumulowanego w utworach karbonu i czerwonego spągowca w nadbałtyckiej części Pomorza Zachodniego. [Origin of natural gases accumulated in Carboniferous and Rotliegend strata on the Baltic part of the Western Pomerania.] *Przegląd Geologiczny*, **53**, 425–433. [in Polish with English summary]
- **Kozera A. 1954.** Sprawozdanie z badań magnetycznych rejonu Niecki Nidziańskiej i Niecki Łódzkiej przeprowadzonych przez Grupę Magnetyczną II Przedsiębiorstwa Poszukiwań Geofizycznych w roku 1953 zgodnie z Planem Technicznym IG. [Magnetic survey report from Nida Trough and Łódź Trough, 1953]. Inw. 5442, Arch. CAG PIG, Warsaw. [in Polish]
- **Królikowski C., Petecki Z. 1995.** Atlas grawimetryczny Polski. [Gravimetric Atlas of Poland]. Polish Geological Institute, Warsaw. [in Polish]
- **Kruk B. 1967a.** Dokumentacja półszczełowych badań grawimetrycznych, tematy: 1. Antyklina Justynowa – Jeżowa, 1966-67, 2. Antyklinorium Kujawskie i Rawsko-Gielniowskie, 1967. [Semidetailed gravimetric survey report, Justynów-Jeżów Antycline 1966-1967, Kuyavian and Rawsko-Gielniów Antyclinorium, 1967]. Inw. 1432, Arch. CAG PIG, Warsaw. [in Polish]
- **Kruk B. 1967b.** Dokumentacja półszczełowych badań grawimetrycznych. Temat: Paraantyklinorium Kujawskie, rejon Wojszyc, 1966. [Semidetailed gravimetric survey report, Kuyavian Para-Antyclinorium, Wojszyce region, 1966]. Inw. 1303, Arch. CAG PIG, Warsaw. [in Polish]
- **Krystkiewicz E. 1996.** Środowiska sedymentacji i diagenetyzacji jury dolnej w centralnej Polsce na podstawie wybranych otworów wiertniczych. [Sedimentary environments and diagenesis of the Lower Jurassic in Central Poland based on selected wells]. Inw. 170/99, Arch. CAG PIG, Warsaw. [in Polish]
- **Krzywiec P. 2002.** Mid-Polish Trough inversion—seismic examples, main mechanisms and its relationship to the Alpine–Carpathian collision. *EGU Stephan Mueller Special Publication Series*, **1**, 151–165.
- **Krzywiec P. 2004a.** Triassic evolution of the Kłodawa salt structure: basement-controlled salt tectonics within the Mid-Polish Trough (Central Poland). *Geological Quarterly*, **48**, 123–134.
- **Krzywiec P. 2004b.** Basement vs. salt tectonics and salt-sediment Interaction—case study of the Mesozoic evolution of the Intracontinental Mid-Polish Trough. GCS-SEPM Foundation 24th Annual Research Conference "Salt – Sediment Interactions and Hydrocarbon Prospectivity: Concepts, Applications and Case Studies for the 21st Century", 5–8.12, 343–370.
- **Krzywiec P. 2012.** Mesozoic and Cenozoic evolution of salt structures within the Polish basin: An overview. *Geological Society of London, Special Publications*, **363**, 381–394.
- **Kudrewicz R. 2007.** Mapy strukturalne powierzchni podcechsztyńskiej i podpermskiej, 1 : 500 000. [Structural maps of the Permian and Zechstein basement surfaces]. (In): Zasoby prognostyczne, nieodkryty potencjał gazu ziemnego w utworach czerwonego spągowca i wapienia cechsztyńskiego w Polsce – badania geologiczne. [Prognostic resources, undiscovered gas

- potential in the Rotliegend and Zechstein Limestone in Poland – geological research]. (Eds): Wagner R. et al., 2008. Inw. 2293/2009, Arch. CAG PIG, Warsaw. [in Polish]
- **Kutek J., Głazek J. 1972.** The Holy Cross area, Central Poland, in the Alpine cycle. *Acta Geologica Polonica*, **22**, 603–653.
  - **Leszczyński K. 1990.** Wyniki badań litologiczno-stratygraficznych. Kreda górna z albem górnym. [Results of the lithological and stratigraphic studies. Upper Cretaceous with Upper Albian]. (In): Koło IG 3, Koło IG 4, Poddębice IG 1. (Eds): Dembowska J., Marek S. *Profilę głębokich otworów wiertniczych Państwowego Instytutu Geologicznego*, **69**, 85–69. [in Polish with English summary]
  - **Leszczyński K. 1997.** The Upper Cretaceous carbonate-dominated sequences of the Polish Lowlands. *Geological Quarterly*, **41**, 521–532.
  - **Leszczyński K. 2000.** The Late Cretaceous sedimentation and subsidence south-west of the Kłodawa Salt Diapir, central Poland. *Geological Quarterly*, **44**, 167–174.
  - **Leszczyński K. 2002.** Ewolucja geologiczna strefy Ponętów-Wartkowice w kredzie. [The cretaceous evolution of the Ponętów-Wartkowice zone]. *Prace Państwowego Instytutu Geologicznego*, **176**. [in Polish with English summary]
  - **Leszczyński K. 2012.** The internal geometry and lithofacies pattern of the Upper Cretaceous-Danian sequence in the Polish Lowlands. *Geological Quarterly*, **56**, 363–386.
  - **Lokhorst A. 1997.** NW European Gas Atlas (EC JOULE Programme). Haarlem: Netherland Geological Survey.
  - **Łyszowska J., Kruk B. 1969.** Dokumentacja półszczełowych badań grawimetrycznych; temat: Antyklitorium Kujawskie i Rawsko-Gielniowskie, 1968. [Semi-detailed gravimetric survey report. Kuyavian and Rawicz-Gielniów Anticlinoria]. Kat. 43/157, Arch. CAG PIG, Warsaw. [in Polish]
  - **Maliszewska A. 1999.** Jura środkowa. [Middle Jurassic]. (In): Diagenesa osadów permu górnego i mezozoiku Kujaw. [Diagenesis of the Upper Permian and Mesozoic of the Kuyavian region]. (Eds): Maliszewska A. *Prace Państwowego Instytutu Geologicznego*, **167**, 78–93. [in Polish with English summary]
  - **Marek S. 1997.** Tektonika kompleksu permsko-mezozoicznego. Ogólne wnioski o ewolucji tektonicznej. [Tectonic of the Permian-Mesozoic complex. General remarks on tectonic evolution]. (In): Epikontynentalny perm i mezozoik w Polsce. [The epicontinental Permian and Mesozoic in Poland]. (Eds): Marek., Pajchłowa M. *Prace Państwowego Instytutu Geologicznego*, **153**, 414–415. [in Polish with English summary]
  - **Marek S., Raczyńska A. 1979.** Obecny podział litostratygraficzny epikontynentalnej kredy dolnej w Polsce i propozycje jego uporządkowania. [Lithostratigraphic subdivision of epicontinental Lower Cretaceous in Poland and proposals for its rearrangement]. *Geological Quarterly*, **23**, 631–637. [in Polish with English summary]
  - **Margul B. 1971.** Dokumentacja półszczełowych badań grawimetrycznych temat: Synklinorium łódzkie, 1970 r. [Semidetailed gravimetric survey report. Topic: Łódź Synclinorium, 1970]. Inw. 1636, Arch. CAG PIG, Warsaw. [in Polish]
  - **Materzok W., Okulus H. 1980.** Dokumentacja badań geofizycznych w rejonie wysadu solnego Łanięta, 1980. [Geophysical survey report of the Łanięta salt diapir, 1980]. Inw. 21266, Arch. CAG PIG, Warsaw. [in Polish]
  - **Materzok W., Reczek J. 1980.** Dokumentacja badań geofizycznych; temat: Wysad solny „Kłodawa”, rok 1979. [Geophysical survey report, topic: Kłodawa salt diapir, 1979]. Inw. 2067, Arch. CAG PIG, Warsaw. [in Polish]
  - **Matyasik I. 1998.** Charakterystyka geochemiczna skał macierzystych karbonu w wybranych profilach wiertniczych obszaru radomsko-lubelskiego i pomorskiego. [Geochemical characteristics of Carboniferous source rocks in selected boreholes from the Radom-Lublin and Pomerania areas]. *Prace Państwowego Instytutu Geologicznego*

- icznego*, **165**, 215–226. [in Polish with English summary]
- **Mazur S., Scheck-Wenderoth M., Krzywiec P. 2005.** Different modes of inversion in the German and Polish basins. *International Journal of Earth Sciences*, **94**, 5–6.
  - **Mazurek S., Burliga S., Wiśniewski A., Staszczak W., Misiak Ł., Kurdek D., Bartłomiejczak G. 2016.** Dodatek nr 2 do Dokumentacji geologicznej złoża soli kamiennej „Kłodawa 1”. [Kłodawa 1 rock salt field documentation, Add. 2]. Inw. 3420/2017, Arch. CAG-PIG, Warsaw. [in Polish]
  - **Misiak G. 1997.** Stratygrafia i wykształcenie utworów cechsztynu w wysadzie solnym Kłodawy. Tektonika solna regionu kujawskiego. [Stratigraphy and lithology of the Zechstein in the Kłodawa Salt Diapir. Salt tectonic of the Kuyavian region. Conference Materials]. Uniejów 23-25.10.1997. WIND, Wrocław, 20–23. [in Polish]
  - **Nawrocki J., Becker A. 2017.** Geological Atlas of Poland. Polish Geological Institute – National Research Institute, Warsaw.
  - **Niemczycka T. 1997.** Jura górna. Formalne i nieformalne jednostki litostratigraficzne. [Upper Jurassic. Formal and informal lithostratigraphic units]. (In): Epikontynentalny perm i mezozoik w Polsce. [The epicontinental Permian and Mesozoic in Poland]. (Eds): Marek S., Pajchłowa M. *Prace Państwowego Instytutu Geologicznego*, **153**, 309–322. [in Polish with English summary]
  - **Obarowski M., Rosowski T., Mulińska M. 2015.** Dokumentacja prac geologicznych niekończących się udokumentowaniem zasobów złoża kopaliny lub zasobów wód podziemnych na obszarze koncesji "Koło" (części bloków koncesyjnych 189, 190, 209, 210 i 230). [Final concession report. Koło area, concession blocks 189, 190, 209, 210 and 230]. Inw. 2721/2015, Arch. CAG PIG, Warsaw. [in Polish]
  - **Osika R. 1959.** Osady dolnokredowe w okolicach Izbicy i w wierceniach Pagórki (Kujawy). [Lower Cretaceous sediments in the region of Izbica and in the Pagórki borehole (Central Poland)] *Geological Quarterly*, **3**, 339–358.
  - **Ostrowska K., Piśula M. 1990.** Dokumentacja szczegółowych badań grawimetrycznych dla tematu: Poszukiwanie złóż węgla brunatnego w obrębie anomalii grawimetrycznych, II faza, 1990 rok. [Detailed gravimetric survey report for recognition of brown coal deposits on gravimetric anomalies, stage II, 1990]. Inw. 1281/91, Arch. CAG PIG, Warsaw. [in Polish]
  - **Ostrowski C., Stefaniuk M., Wojdyła M., Kosobudzka I. 2007.** Dokumentacja badań geofizycznych. Temat: Pomiar polowe magnetotelluryczne, magnetyczne i grawimetryczne wzdłuż profilu Zgorzelec–Wiżajny wraz z ich przetworzeniem i interpretacją, 2005-2007. [Geophysical survey report. Field magnetotelluric, magnetic and gravimetric measurements along Zgorzelec–Wiżajny line with its processing and interpretation]. Inw. 3093/2014, Arch. CAG PIG, Warsaw. [in Polish]
  - **Oszczepalski S., Rydzewski A. 1987.** Paleogeography and sedimentary model of the Keuperschiefer in Poland. Oszczepalski S., Rydzewski A. 1987. Paleogeography and sedimentary model of the Keuperschiefer in Poland. *Zentralblatt für Geologie und Paläontologie*, **4**, 975–999.
  - **Oszczepalski S., Rydzewski A. 1991.** The Keuperschiefer mineralization in Poland. *Lecture Notes in Earth Sciences*, **10**, 189–205.
  - **Peryt T. M., Antonowicz L. 1990.** Facje i paleogeografia cechsztyńskiego anhydrytu dolnego (A1d) w Polsce. [Facies and paleogeography of the Zechstein Lower Werra Anhydrite (A1d) in Poland]. *Przeгляд Geologiczny*, **38**, 173–180. [in Polish with English summary]
  - **Peryt T. M., Peryt D. 2012.** Geochemical and foraminiferal records of environmental changes during Zechstein Limestone (Lopingian) deposition in Northern Poland. *Geological Quarterly*, **56**, 187–198.
  - **Peryt T. M., Wagner R. 1998.** Zechstein evaporite deposition in the Central European Basin: cycles and stratigraphic sequences. *Journal of Seismic Exploration*, **7**, 201–218.

- **Pharaoh T., Dusar M., Geluk M., Kockel F., Krawczyk C., Krzywiec P., Scheck-Wenderoth M., Thybo H., Vejbaek O., Van Wees J.D. 2010.** Tectonic evolution (In): Petroleum geological atlas of the Southern Permian Basin Area. (Eds): Doornenbal J.C., Stevenson A.G. EAGE Publications, Houten, 25–57.
- **Pieńkowski G. 2004.** The epicontinental lower Jurassic of Poland. *Polish Geological Institute Special Papers*, **12**, 5–154.
- **Pierson B.J. 1981.** The control of cathodoluminescence in dolomite by iron and manganese. *Sedimentology*, **28**, 601–610.
- **Pletsch T., Appel J., Botor D., Clayton C.J., Duin E.J.T., Faber E., Górecki W., Kombrink H., Kosakowski P., Kuper G., Kus J., Lutz R., Mathiesen A., Ostertag C., Papiernik B., Van Bergen F. 2010.** Petroleum generation and migration. (In): Petroleum Geological Atlas of the Southern Permian, Basin Area. (Eds): Doornenbal H., Stevenson A. EAGE Publications b.v., Houten, 225–253.
- **Pokorski J. 1981.** Propozycja formalnego podziału litostratygraficznego czerwonego spągowca na Niżu Polskim. [Formal lithostratigraphic subdivision proposed for the Rotliegendes of the Polish Lowlands]. *Geological Quarterly*, **25**, 41–58. [in Polish with English summary]
- **Pokorski J. 1988.** Rotliegendes lithostratigraphy in north-western Poland. *Bulletin of the Polish Academy of Sciences*, **36**, 99–108.
- **Pokorski J. 1997.** Perm dolny (czerwony spągowiec). Litostratygrafia i litofacje. Formalne i nieformalne jednostki litostratygraficzne. [Lower Permian (Rotliegend). Lithostratigraphy and lithofacies. Formal and informal lithostratigraphic units]. (In): Epikontynentalny perm i mezozoik w Polsce. [The epicontinental Permian and Mesozoic in Poland]. (Eds): Marek S., Pajchłowa M. *Prace Instytutu Geologicznego*, **153**, 35–38. [in Polish with English summary]
- **Požaryski W., Brochwicz-Lewiński W., Jaskowiak-Schoeneich M. 1978.** Geologiczna mapa Bałtyku. [Geological Map of the Baltic]. *Przegląd Geologiczny*, **26**, 1–5. [in Polish with English summary]
- **Raczyńska A. 1961.** Stratygrafia osadów dolnokredowych okolic Sompolna. [Stratigraphy of Lower Cretaceous sediments of the region of Sompolno] *Geological Quarterly*, **5**, 353–371.
- **Raczyńska A. 1973.** Dokumentacja wyników wiercenia strukturalnego Strzelno IG-1. [Strzelno IG-1 final well report]. Inw. 78200, Arch. CAG PIG, Warsaw. [in Polish]
- **Radlicz K. 1972.** Litologia osadów górnourajskich w północno-wschodniej Polsce. [Lithology of the Upper Jurassic deposits in north-eastern Poland]. *Biuletyn Instytutu Geologicznego*, **261**, 55–150. [in Polish with English summary]
- **Radlicz K. 1997.** Jura górna. Charakterystyka petrograficzna i sedymentologiczna. [Upper Jurassic. Petrographic and sedimentological characteristics]. (In): Epikontynentalny perm i mezozoik w Polsce. [The epicontinental Permian and Mesozoic in Poland]. (Eds): Marek S., Pajchłowa M. *Prace Państwowego Instytutu Geologicznego*, **153**, 322–327. [in Polish with English summary]
- **Radlicz K. 2008.** Petrografia, mikrofacje i diagenetyzacja utworów jury górnej w otworach wiertniczych Brześć Kujawski IG 2 oraz IG 3. [Petrography, microfacies and diagenesis of the Upper Jurassic deposits in the Brześć Kujawski IG2 and IG 3 boreholes]. (In): Brześć Kujawski IG 1, IG 2, IG 3. (Eds): Feldman-Olszewska A. *Profile Głębokich Otworów Wiertniczych Państwowego Instytutu Geologicznego*, **125**, 173–178. [in Polish with English summary]
- **Reczek J. 1967.** Dokumentacja półszczegółowych badań grawimetrycznych, temat: Mogilno – Konin – Uniejów, 1965/66. [Semidetailed gravimetric survey report. Topic: Mogilno – Konin – Uniejów, 1965/66]. Kat. G-215 PBG, Arch. CAG PIG, Warsaw. [in Polish]
- **Resak M., Narkiewicz M., Littke R. 2008.** New basin modelling results from the Polish part of the Central European Basin system: implications for the Late Cretaceous–Early Paleogene structural inversion. *International Journal of Earth Sciences*, **97**, 955–972.
- **Sadowski A., Poborska-Młynarska K., Czapowski G. 2007.** koncepcja wykorzy-

- stania i zagospodarowania wyrobisk poeksploatacyjnych Kopalni Soli „Kłodawa”. [The possibilities of reuse and utilization of underground voids on "Kłodawa" salt mine]. *WUG*, **6**, 12–15. [in Polish with English summary]
- **Scheck-Wenderoth M.Y.C.M.S.R., Maystrenko Y., Hübscher C., Hansen M., Mazur S. 2008.** Dynamics of salt basins. *Dynamics of Complex Intracontinental Basins: The Central European Basin System*. Springer, Berlin, 307, 322.
  - **Schovsbo N.H., Goode T., Beuthin J., Derbez E., Parkin K. 2017.** Method and Data-Acquisition Workflow for Rock-Type Definitions in the Lower Carboniferous Resource Play, NW England. *AAPG Search and Discovery Article*, #10964.
  - **Sikorska-Jaworowska M., Jaworowski K. 1997.** Charakterystyka petrograficzna i sedymentologiczna osadów wapienia muszlowego. [Petrographic and sedimentological characteristics of the Muchelkalk]. (In): Epikontynentalny perm i mezozoik w Polsce. [The epicontinental Permian and Mesozoic in Poland]. (Eds): Marek S., Pajchłowa M. *Prace Państwowego Instytutu Geologicznego*, **153**, 136–144. [in Polish with English summary]
  - **Solon J., Borzyszkowski J., Bidlasik M., Richling A., Badora K., Balon J., Brzezińska-Wójcik T., Chabudziński Ł., Dobrowolski R., Grzegorzczak I., Jodłowski M., Kistowski M., Kot R., Krąż P., Lechnio J., Macias A., Majchrowska A., Malinowska E., Migoń P., Myga-Piątek U., Nita J., Papińska E., Rodzik J., Strzyż M., Terpilowski S., Ziaja W. 2018.** Physico-geographic mesoregions of Poland – verification and adjustment of boundaries on the basis of contemporary spatial data. *Geographia Polonica*, **91**.
  - **Soćko A. 1966.** Dokumentacja półszczełowych badań grawimetrycznych. Temat: Gostynin – Łowicz – Ponętów – Poddebice, 1965. [Semidetailed gravimetric report. Topic: Gostynin – Łowicz – Ponętów – Poddebice, 1965]. Inw. 1252, Arch. CAG PIG, Warsaw. [in Polish]
  - **Tomassi-Morawiec H., Czapowski G., Toboła T., Iwasińska-Budzyk I., Narzekiewicz W., Misiek G., Janiów S., Chęciński R. 2008.** Wzorcowe profile bromowe jako obiektywne narzędzie dla ustalenia wieku i podziału wewnętrznego ogniw solnych cechsztynu z obszaru Polski. [Opracowanie merytoryczne z realizacji projektu badawczego. [Reference Br profiles as an objective tool for determining the age and internal subdivision of the Zechstein salts of the Polish area. Final report]. KBN Project No. 4T12B 002 29. Polish Geological Institute, Warsaw. [in Polish]
  - **Tomassi-Morawiec H., Czapowski G., Bornemann O., Schramm M., Misiek G. 2009.** Wzorcowe profile bromowe dla solnych utworów cechsztynu w Polsce. [Standard bromine profiles of the Polish zechstein salts]. *Gospodarka Surowcami Mineralnymi*, **25**, 75–143. [in Polish with English summary]
  - **Tomassi-Morawiec H., Wachowiak J., Czapowski G. 2019.** Geochemia i wykształcenie skał zuberowych górnego permu (cechsztynu) z obszaru Polski. [Comparative geochemistry and development of the Upper Permian (Zechstein) zuber rocks from Poland]. *Biuletyn Państwowego Instytutu Geologicznego*, **477**, 69–122. [in Polish with English summary]
  - **Wagner R. 1995.** Stratygrafia i rozwój basenu cechsztyńskiego na Niżu Polskim. [Stratigraphy and evolution of the Zechstein Basin in the Polish Lowland]. *Prace Państwowego Instytutu Geologicznego*, **146**, 1–71. [in Polish with English summary]
  - **Wagner R., Buniak A., Dadlez R., Grotek I., Kiersnowski H., Kuberska M., Kudrewicz R., Lis P., Maliszewska A., Mikołajewski Z., Papiernik B., Pokorski J., Poprawa P., Skowroński L., Słowakiewicz M., Szewczyk J., Wolnowski T. 2008.** Zasoby prognostyczne, nieodkryty potencjał gazu ziemnego w utworach czerwonego spągowca i wapienia cechsztyńskiego w Polsce – badania geologiczne. [Prognostic resources, undiscovered potential of natural gas in the Rotliegend and Zechstein Limestone in Poland – geological investigations]. Inw. 2293/2009, Arch. CAG PIG, Warsaw. [in Polish]
  - **Wasiak J. 1990.** Dokumentacja szczełowych badań grawimetrycznych, temat:

- Poszukiwanie złóż węgla brunatnego w obrębie anomalii grawimetrycznych, II faza – 1989 r. [Detailed gravimetric survey report. Topic: Searching for brown coal deposits on gravimetric anomalies, stage II, 1989]. Kat. G-570, Arch. PBG, Warsaw. [in Polish]
- **Werner Z. 1972.** Dokumentacja geologiczna zasobów złoża soli kamiennej kopalni soli „Kłodawa” w Kłodawie kat. A + B + C1. [Geological documentation of the Kłodawa rock salt field in the A+B+C categories]. Inw. 39-28/542, Arch. CAG PIG Warsaw. [in Polish]
  - **Werner Z., Poborski J., Orska J., Bąkowski J. 1960.** Złoże solne w Kłodawie w zarysie geologiczno-górnictw. [Rock salt deposits in Kłodawa in relation to geology and mining]. *Prace Instytutu Geologicznego*, **30**, 467–512. [in Polish]
  - **Więclaw D. 2016.** Habitat and hydrocarbon potential of the Kimmeridgian strata in the central part of the Polish Lowlands. *Geological Quarterly*, **60**, 192–210.
  - **Wierzbowski A., Wierzbowski H. 2019.** Ammonite stratigraphy and organic matter of the Pałuki Fm. n (Upper Kimmeridgian–Lower Tithonian) from the central-eastern part of the Łódź Synclinorium (Central Poland). *Volumina Jurassica*, **17**, 49–102
  - **Wilczek T. 1986.** Ocena możliwości powstania węglowodorów w mezozoicznych skałach macierzystych Niżu Polskiego. [Evaluation of possibilities of generation of hydrocarbons in Mesozoic source rocks in the Polish Lowlands]. *Przegląd Geologiczny*, **34**, 496–502. [in Polish with English summary]
  - **Wójcicki A., zespół. 2013.** Rozpoznanie formacji i struktur do bezpiecznego geologicznego składowania CO<sub>2</sub> wraz z ich programem monitorowania raport końcowy – segment I (regionalny). [Identification of formations and structures for safe geological storage of CO<sub>2</sub> with their monitoring program final report – segment I]. Polish Geological Institute – National Research Institute, Warsaw. [in Polish]  
<https://skladowanie.pgi.gov.pl/twiki/bin/view/CO2/WynikiPrac>
  - **Zakrzewski A., Waliczek M., Kosakowski P. 2022.** Geochemical and petrological characteristics of the Middle Jurassic organic-rich siliciclastic sediments from the central part of the Polish Basin. *International Journal of Coal Geology*, **255**, 103986.
  - **Zhao X., Liu W., Fu J., Cai Z., O'Reilly S. E., Zhao D. 2016.** Dispersion, sorption and photodegradation of petroleum hydrocarbons in dispersant-seawater-sediment systems. *Marine pollution bulletin*, **109**, 526–538.
  - **Ziegler P.A. 1990.** Collision related intra-plate compression deformations in Western and Central Europe. *Journal of Geodynamics*, **11**, 357–388.
  - **Zijp M.H.A.A., Nelskamp S., Doornenbal J.C. 2017.** Resource estimation of shale gas and shale oil in Europe. Report T7b of the EUOGA study (EU Unconventional Oil and Gas Assessment) commissioned by European Commission Joint Research Centre to GEUS.
  - **Żelaźniewicz A., Aleksandrowski P., Buła Z., Karnkowski P.H., Konon A., Ślaczka A., Żaba J., Żytko K. 2011.** Regionalizacja tektoniczna Polski. [Tectonic subdivision of Poland]. Komitet Nauk Geologicznych PAN, Wrocław. [in Polish]