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Polish Hydrogeological Survey

HYDROCARBON PROSPECTIVE OF POLAND

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KARTUZY
TENDER AREA
GEOLOGICAL PACKAGE ENGLISH ABSTRACT

LICENSING ROUND V
FOR CONCESSIONS FOR HYDROCARBON
PROSPECTION, EXPLORATION AND PRODUCTION
IN POLAND

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and Water Management

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1. GENERAL INFORMATION
1.1. LOCATION

The “Kartuzy” tender area of 900.35 km^2 is located onshore N Poland, in the concession block 49 (Fig. 1.1). The precise location is defined by geographical coordinates listed below.

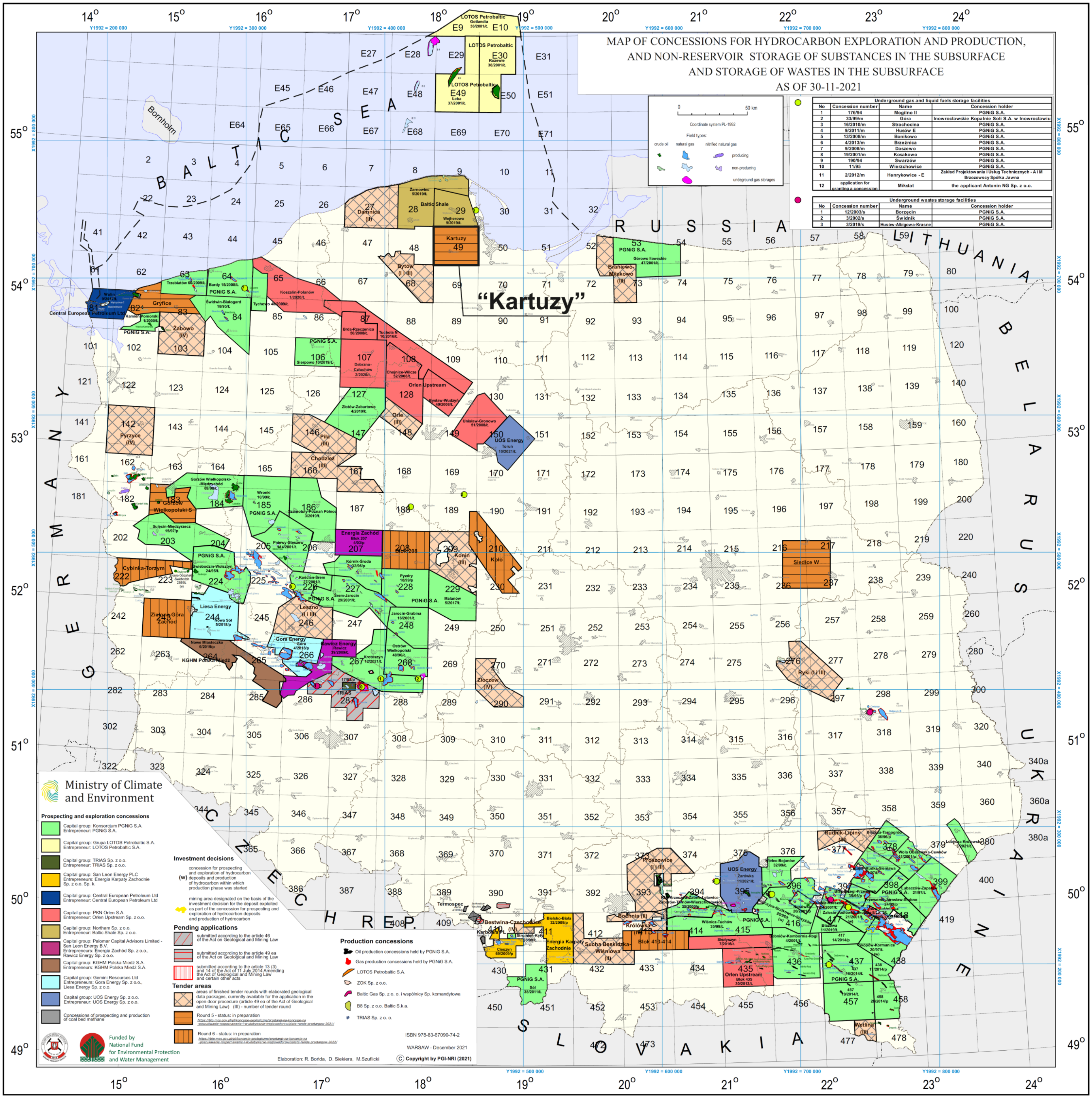
Border points	1992 coordinate system	
	X	Y
1	709648.50	467438.93
2	709994.91	434842.34
3	737770.93	435133.01
4	737259.22	467502.29
5	720361.13	467514.79

Tab. 1.1. Border points coordinates of the “Kartuzy” tender area (Fig. 1.2).

The “Kartuzy” tender area was previously subjected to hydrocarbon prospection and exploration concessions „Kartuzy-Szemud” No. 72/2009/p (PGNiG S.A.), and „Gdańsk W” No. 71/2009/p (Oculis Investments/Talisman Energy/Baltic Oil&Gas LLC).

The main exploration target of the “Kartuzy” tender area is related to unconventional accumulations of gas and oil in the Lower Paleozoic shale formations, as well as to conventional accumulations of oil and gas in the Middle Cambrian.

→**Fig. 1.1.** Location of the “Kartuzy” 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 30-11-2021.


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 30-11-2021
"Kartuzy"
BALTIC SEA
RUSSIA
LITHUANIA
BELARUS
UKRAINE
SLOVAKIA
CZECH REP.
GERMANY
Ministry of Climate and Environment
Prospecting and exploration concessions
Investment decisions
Pending applications
Tender areas
Production concessions
Underground gas and liquid fuels storage facilities
Underground wastes storage facilities
Funded by National Fund for Environmental Protection and Water Management
ISBN 978-83-67090-74-2
WARSAW - December 2021
Elaboration: R. Bońda, D. Siekiera, M.Szuflicki
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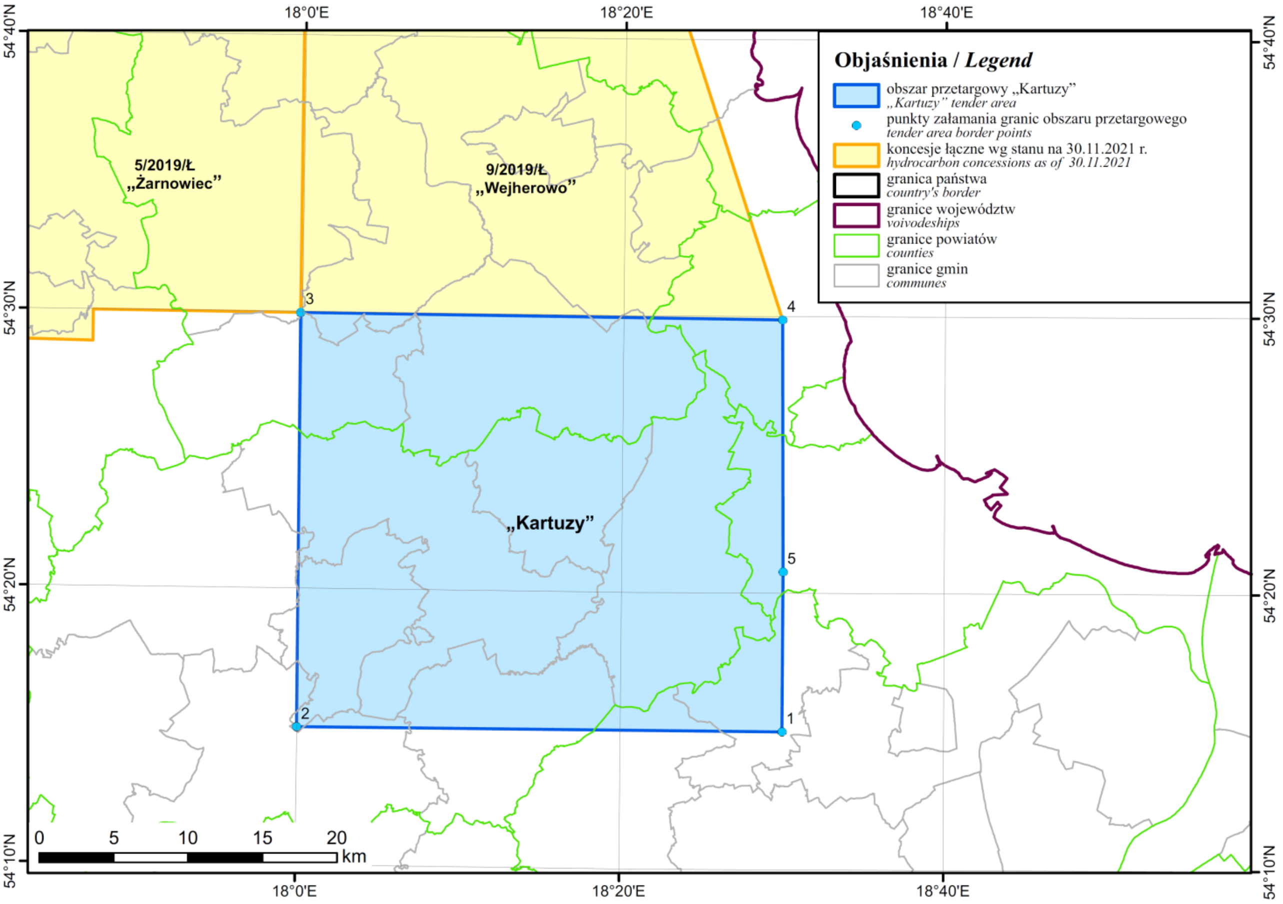


Fig. 1.2. Border points of the "Kartuzy" tender area and location of the hydrocarbon concessions in the neighborhood as of 30-11-2021 (CGDB, 2021).

1.2. ENVIRONMENTAL CONDITIONS

The “Kartuzy” tender area is located in 16 communes within the Pomeranian Voivodeship. Four communes, including Szemud, Kartuzy, Przodkowo and Żukowo, cover over 64% of the area. The eastern part of the area includes a fragment of the Tri-City agglomeration, which is one of the most important metropolitan centers in Poland. Therefore, the area has a very well-developed road network with the most important S6 expressway, being the Tri-City bypass. It connects with the S6 national road in the north at latitude of Gdynia. In the south, starting at the Rusocin junction, the road continues as the A1 motorway. In 2021, the section of the S6 Szemud-Gdynia road (a part of the Tri-City expressway to Szczecin) will be completed. Others roads passing through the area are voivodeship, county and commune roads, as well as DK 7 and 20 national roads. An important infrastructure element of this area is the railway network, including the most important national line 201, reaching the port of Gdynia. Other railways are usually not electrified, but locally important such as line 248 connecting the Tri-City to the international Gdańsk Lech Wałęsa Airport in the eastern part of the area. The technical infrastructure consists of 3 high voltage power lines (400 kV) and 2 high-methane gas pipelines with diameters of 500 and 150 mm, respectively.

The area is located entirely within the Kashubian Lakeland mesoregion, which is part of the East Pomeranian Lakeland macroregion. It is an area of varied topography, dominated by moraine sediments cut by ribbon lakes and river valleys. In this area is the Wieżyca Hill - the highest hill in this part of Poland with an elevation of 329 m above sea level. The entire area is located in the Lower Vistula water region, and the main rivers are Radunia and Łeba. The hydrographic network is completed by small rivers, canals and drainage ditches, as well as by a number of ponds and lakes. An important hydrogeological element of this area is the presence of the principal aquifer No. 111 "Gdańsk Subbasin" (GZPW 111). There are the Kaszubski and Trójmiejski landscape parks in the area, which together with their buffer zones cover 43% of the tender area. In addition, the following protected areas were inventoried: 11 nature reserves of various types (forest, landscape and peat bogs) covering approximately 0.7% of the area, 5 protected landscape areas constituting a total of approximately 19% of the area, and 7 nature and landscape complexes covering 9% of the area. Nature 2000 sites cover approximately 7% of the area, and consist of 9 sites specified according to the Habitats Directive, and 1 according to the Birds Directive. Other forms of nature protection include 21 ecological areas and 682 natural monuments, dominated by single-growing trees or their clusters. In terms of nature, of high values are also agricultural lands covering 16.7% of the area, meadows developed on organic soils, and dense forest complexes, some of which with the status of protective forests.

There are 63 mineral deposits in the area, with 58 aggregate deposits, 4 deposits of clay raw materials of construction ceramics, and 1 quartz sand deposits for the production of sand-lime bricks. Moreover, within the boundaries of this area, several tens of prospective areas for various types of natural aggregate have been specified, as well as numerous prognostic areas, including 38 for peat, 4 for sands, and 1 each for rock salt, clay, and clay shale for construction ceramics.

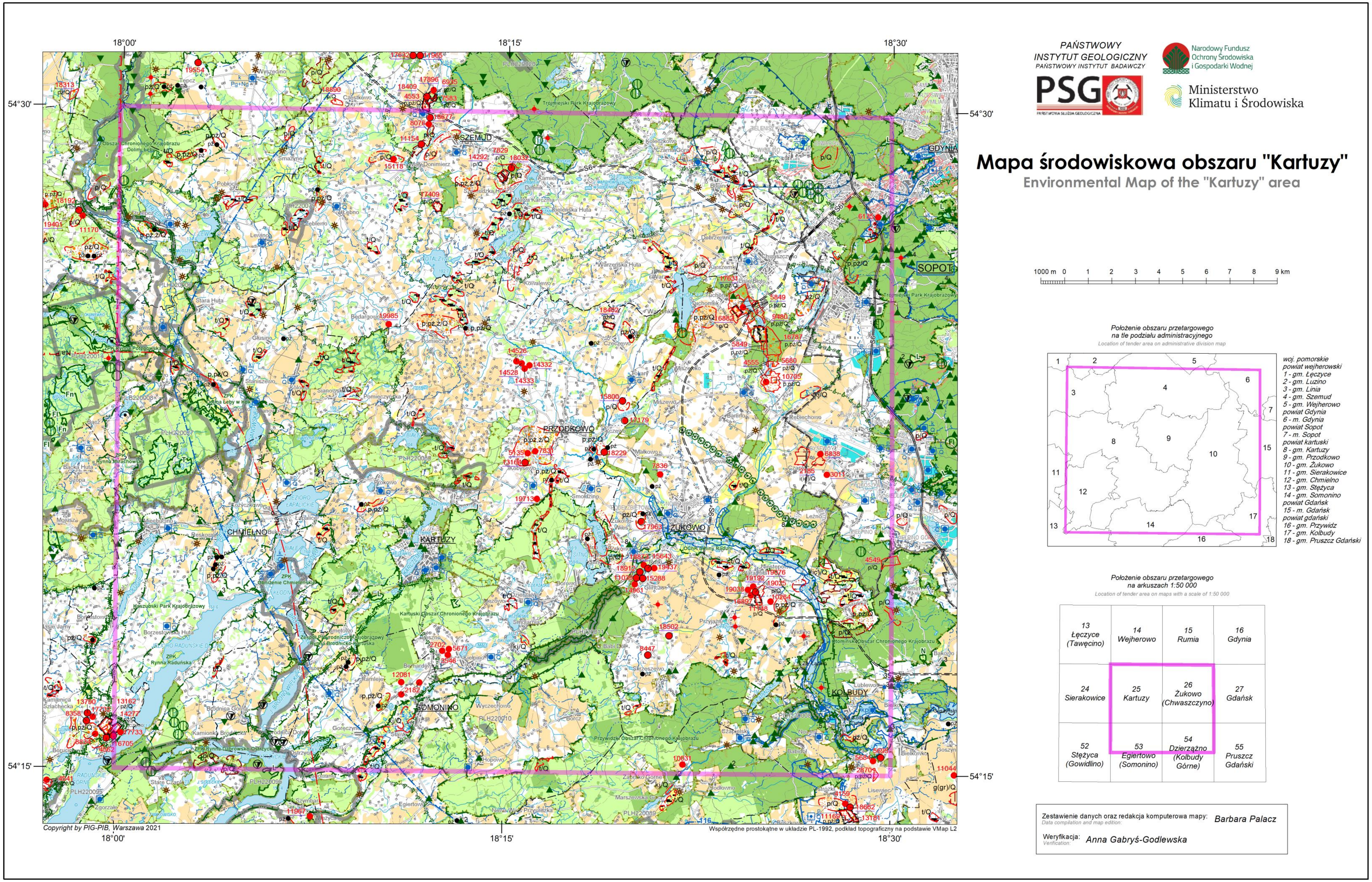
The environmental conditions for the “Kartuzy” tender area are summarized in Tab. 1.2.

THE ENVIRONMENTAL CONDITIONS DATASHEET FOR THE "KARTUZY" TENDER AREA				
1.	LOCATION OF THE TENDER AREA ON THE MAP	Name and number of the map sheet at a scale 1: 50 000	Sierakowice 24, Kartuzy 25, Chwaszczyno 26, Gdańsk 27, Gowidlino 52, Somonino 53, Kolbudy Górne 54, Pruszcz Gdański 55	
2.	ADMINISTRATIVE LOCATION	**Voivodeship**	**Pomorskie**	
		County	**Gdynia City**	
		The commune and % of the area within the tendering area	Gdynia City (3.89%)	
		County	**Gdańsk City**	
		Commune	Gdańsk City (4.26%)	
		County	**Gdańsk**	
		Commune	Kolbudy (3.63%), Przywidz (1.33%)	
		County	**Kartuzy**	
		Commune	Żukowo (18.18%), Stężyca (0.84%), Chmielno (8.13%), Kartuzy (20.21%), Sierakowice (0.12%), Somonino (6.90%), Przodkowo (9.46%)	
		County	Wejherowo	
		Commune	Linia (5.44%), Szemud (16.61%), Wejherowo (0.12%), Łęczyce (0.0006%), Luzino (0.88%)	
3.	PHYSIOGRAPHIC REGIONALIZATION (after KONDRACKI, 2013 and SOLON et al., 2018)	Macroregion	Pojezierze Wschodniopomorskie (314.5)	
		Mesoregion	Pojezierze Kaszubskie (314.51)	
4.	COORDINATES OF THE TENDER AREA BORDER POINTS	PL-1992 coordinate system [X, Y]	709648.50	467438.93
			709994.91	434842.34
			737770.93	435133.01
			737259.22	467502.29
			720361.13	467514.79
5.	ACREAGE	[km^2]	900.35	
6.	CONCESSION TYPE		prospecting, exploration and production of hydrocarbons	
7.	AGE OF HYDROCARBON FORMATION		Cambrian, Ordovician, Silurian	
8.	PROTECTED NATURAL AREAS:	[yes/ no] if "yes": the name of the tender area and its % within the total area		
	National Parks		no	
	Natural Reserves		Zamkowa Góra (<1%), Stare Modrzewie (<1%), Ostrzycki Las (<1%), Kacze Łęgi (<1%), Jar Rzeki Raduni (<1%), Jar Reknicy (<1%), Lubygość (<1%), Staniszewskie Zdroje (<1%), Żurawie Błota, (<1%) Staniszewskie Błoto (<1%), Leśne Oczko (<1%)	
	Landscape Parks		Kaszubski Park Krajobrazowy (19.3%) wraz z otuliną (10.1%), Trójmiejski Park Krajobrazowy (2.7%) wraz z otuliną (10.8%)	
	Protected landscape areas		Kartuski OChK (7.4%), Otomiński OChK (1.4%, OChK Doliny Łeby (2%), Przywidzki OChK (5.4%), OChK Doliny Raduni (2.6%)	
	(Special Area of Conservation, SAC)		PLH220010 Hopowo (<1%), PLH220014 Kurze Grzędy (<1%), PLH220080 Prokowo (1%), PLH220027 Staniszewskie Błoto (1%), PLH220075 Mechowiska	

THE ENVIRONMENTAL CONDITIONS DATASHEET FOR THE "KARTUZY" TENDER AREA			
			Zęblewskie (<1%), PLH220008 Dolina Reknicy (<1%), PLH220006 Dolina Górnej Łeby (2%), PLH220011 Jar Rzeki Raduni (<1%), PLH220095 Uroczyska Pojezierza Kaszubskiego (1.4%)
	(Special Bird Protection, SPA)		PLB220008 Lasy Mirachowskie (3.1%)
	Nature and landscape complexes		Dolina Łeby w Kpk (3.3%), Rynna Dąbrowsko-Ostrzycka (<1%), Rynna Brodnicko-Kartuska (1%), Rynna Mirachowska (<1%), Obniżenie Chmieleńskie (1.3%), Rynna Raduńska (2%), Rynna Potęgowska (<1%)
	Ecological area	[yes (quantity) / no]	yes (21)
	Nature monuments		yes (682)
	Documentation positions		no
9.	PROTECTED SOIL	[yes / no]	yes
10.	FOREST COMPLEXES	[yes / no]	yes
11.	PROTECTIVE FORESTS	[yes (% of the total tender area) / no]	yes (104.8 km^2, 11.6%)
12.	CULTURAL HERITAGE FACILITIES Archaeological monuments	[yes (quantity) / no]	yes (57)
		Hillfort	9
		Hamlet	8
		Cemetery	36
		others	4
13.	MAJOR GROUNDWATER RESERVOIRS	[yes (number, name and age of the aquifer) / no]	tak (GZWP nr 111 „Subniecka Gdańska", Upper Cretaceous)
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, clays, quartz sand for lime-sand products manufacture)
18.	PROGNOSTIC AND PROSPECTIVE AREAS OF OCCURRENCE OF MINERAL RESOURCES (excluding hydrocarbons)	[yes (type of mineral deposit) / no]	yes (sand, sand and gravel, peat, chalk, clays, salt)
19.	NATURAL GAS PIPELINES	[yes / no]	yes
20.	UNDERGROUND GAS STORAGE	[yes / no]	no
21.	DATA COLLECTION AND ELABORATION	08.03.2021 Barbara Palacz, Dominika Kafara	

Tab. 1.2. The environmental conditions datasheet for the "Kartuzy" tender area.

→**Fig. 1.3.** Environmental Map of the "Kartuzy" area.


PAŃSTWOWY INSTYTUT GEOLOGICZNY
PAŃSTWOWY INSTYTUT BADAWCZY
PSG
Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej
Ministerstwo Klimatu i Środowiska
Mapa środowiskowa obszaru "Kartuzy"
Environmental Map of the "Kartuzy" area
1000 m 0 1 2 3 4 5 6 7 8 9 km
Położenie obszaru przetargowego na tle podziału administracyjnego
Location of tender area on administrative division map
woj. pomorskie
powiat wejherowski
1 - gm. Łęczyce
2 - gm. Luzino
3 - gm. Linia
4 - gm. Szemud
5 - gm. Wejherowo
powiat Gdynia
6 - m. Gdynia
powiat Sopot
7 - m. Sopot
powiat kartuski
8 - gm. Kartuzy
9 - gm. Przodkowo
10 - gm. Żukowo
11 - gm. Sierakowice
12 - gm. Chmielno
13 - gm. Stężyca
14 - gm. Somonino
powiat Gdańsk
15 - m. Gdańsk
powiat gdański
16 - gm. Przywidz
17 - gm. Kolbudy
18 - gm. Pruszcz Gdański
Położenie obszaru przetargowego na arkuszach 1:50 000
Location of tender area on maps with a scale of 1:50 000
13 Łęczyce (Tawęcino)
14 Wejherowo
15 Rumia
16 Gdynia
24 Sierakowice
25 Kartuzy
26 Żukowo (Chwaszczyno)
27 Gdańsk
52 Stężyca (Gowidlino)
53 Egiertowo (Somonino)
54 Dzierżążno (Kolbudy Górne)
55 Pruszcz Gdański
Zestawienie danych oraz redakcja komputerowa mapy: Barbara Palacz
Data compilation and map edition:
Weryfikacja: Anna Gabryś-Godlewska
Verification:
18°00'
18°15'
18°30'
54°30'
54°15'
SZEMUD
PRZODKOWO
KARTUZY
CHMIELNO
ŻUKOWO
SOMONINO
KOLBUDY
GDYNIA
SOPOT
Copyright by PIG-PIB, Warszawa 2021
Współrzędne prostokątne w układzie PL-1992, podkład topograficzny na podstawie VMap L2

Objaśnienia do Mapy środowiskowej obszaru "KARTUZY"

Legend of the Environmental Map of the "KARTUZY" 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

- kreda jeziorna i gytia – lacustrine chalk and gyttja
- piaski i żwiry – sands and gravels
- iły i łupki ilaste – clay and claystone
- piaski – sands
- gliny – tills
- torfy – peat
- granica złoża – deposit boundary
- granica obszaru prognostycznego – prognostic area boundary
- granica zweryfikowanego obszaru prognostycznego – verified prognostic area boundary
- granica obszaru perspektywicznego – perspective area boundary
- złoże o powierzchni ≤ 5 ha – deposit with area ≤ 5 ha
- 2182 – identyfikator z bazy MIDAS złoża małokonfliktowego – ID from the MIDAS database of the small environmental conflict
- 2185 – identyfikator z bazy MIDAS złoża konfliktowego – ID from the MIDAS database of the environmental conflict

GÓRNICTWO I PRZETWÓRSTWO KOPALIN

MINING AND MINERAL PROCESSING

- granica obszaru górniczego – boundary of the mining area
- granica terenu górniczego – boundary of the mining terrain
- obszar i teren górniczy złoża o powierzchni ≤ 5 ha – area and terrain of the deposit with area ≤ 5 ha
- pż – punkt niekoncesjonowanej eksploatacji kopaliny (pż - rodzaj kopaliny) – point of unlicensed exploitation of a mineral (type of mineral)

Symbol kopaliny: / Mineral symbol:

- Na - sole kamienne – rock salt
- kj - kreda jeziorna i gytia – lacustrine chalk and gyttja
- i(ic) - surowce ceramiki budowlanej – building ceramics raw materials
- g(gr) - gliny o różnym zastosowaniu – clayey raw materials for varius applications
- ż - żwiry – gravels
- pż - piaski i żwiry – sands and gravels
- p - piaski – sands
- t - torfy – peat

Symbol jednostki stratygraficznej: / Symbol of the stratigraphic unit:

- Q - czwartorzęd – Quaternary
- Ng - neogen – Neogene
- Pg - paleogen – Paleogene
- Cr - kreda – Cretaceous
- P - perm – Permian

WODY POWIERZCHNIOWE I PODZIEMNE

SURFACE AND UNDERGROUNG WATERS

- obszary dolinne zagrożone podtopieniami – valley flood hazard area
- granica działu wodnego pierwszego rzędu – water divide of first rank
- granica działu wodnego drugiego rzędu – water divide of second rank
- granica działu wodnego trzeciego rzędu – water divide of third rank
- granica działu wodnego czwartego rzędu – water divide of fourth rank
- 111 – granica głównego zbiornika wód podziemnych wraz z jego numerem – principle boundary aquifer with ID number
- granica strefy ochronnej "C" uzdrowiska – boundary of "C" protected area within resort
- granica strefy ochrony ujęcia wód – water intake protected area boundary
- Q – granica leja depresyjnego wywołanego eksploatacją wód podziemnych (Q - wiek eksploatowanych utworów) – boundary of a cone depression caused by water exploitation (Q - age of exploited rocks)
- źródło – spring
- Zb. Goszyński – zbiornik retencyjny wraz z jego nazwą – water reservoir with its name
- SOPOT – uzdrowisko – resort
- kp – ujęcie wód powierzchniowych (k - komunalne, p - przemysłowe) – surface water intake (k - municipal, p - industrial)
- p/Q – ujęcie wód podziemnych o wydajności 25 - 50 m³/h* (k - komunalne, p - przemysłowe, Q - wiek ujmowanych utworów) – underground water intake with capacity 25 - 50 m³/h* (k - municipal, p - industrial, Q - age of exploited rocks)
- k/Q – ujęcie wód podziemnych o wydajności ≥ 50 m³/h – underground water intake with capacity ≥ 50 m³/h

* tylko ujęcia posiadające ustanowioną strefę ochrony pośredniej

* applies to intakes with an established intermediate protection zone

WARUNKI PODŁOŻA BUDOWLANEGO

BUILDING SUBSTRATE CONDITIONS

- tereny osuwiskowe i zagrożone ruchami masowymi – landslides and mass movements hazard area
- granice opracowań atlasów geologiczno-inżynierskich aglomeracji miejskich – boundaries of studies of geological and engineering of urban agglomerations

OCHRONA PRZYRODY, KRAJOBRAZU I DZIEDZICTWA KULTUROWEGO

PROTECTION OF NATURE, LANDSCAPE AND CULTURAL HERITAGE

- grunty orne (klasy I-IVa użytków rolnych) – arable land (class I-IVa)
- łąki na glebach pochodzenia organicznego – meadows on organic soils
- lasy – forests
- lasy ochronne – protected forests
- zieleń urządzona – urban greenery
- granice terenów zarządzanych przez Dyrekcję Generalną Lasów Państwowych – boundary of areas managed by General Directorate of the State Forests
- granica parku krajobrazowego; nazwa parku – boundary of landscape park; park name
- granica strefy ochronnej (otuliny) parku krajobrazowego – boundary of buffer zone of landscape park; park name
- granica obszaru chronionego krajobrazu; nazwa obszaru – boundary of protected landscape area; area name
- granica zespołu przyrodniczo-krajobrazowego, nazwa zespołu – boundary of nature and landscape complex; complex name
- Fl – granica rezerwatu przyrody (Fl - florystyczny, Fn - faunistyczny, K - krajobrazowy, L - leśny, N - przyrody nieożywionej, T - torfowiskowy) – boundary of natural reserve (Fl - floristic, Fn - faunistic, K - landscape, L - forests, N - inimate nature, T - peat)
- granica strefy ochronnej (otuliny) rezerwatu przyrody – boundary of buffer zone of natural reserve
- aleja drzew pomnikowych – avenue of monumental trees
- Obszary Europejskiej Sieci Ekologicznej Natura 2000; kod obszaru – Natura 2000 ecological network; area code
- Fl – rezerwat przyrody lub obszar ochrony ścisłej (os) w obrębie parku narodowego o powierzchni ≤ 5 ha – boundary of natural reserve or strict nature reserve within national park with area ≤ 5 ha
- n – pomnik przyrody żywej (n - liczba obiektów) – animate nature monument (n - number of objects)
- pomnik przyrody nieożywionej – inanimate nature monument
- użytek ekologiczny – ecological use
- użytek ekologiczny o powierzchni ≤ 5 ha – ecological use with area ≤ 5 ha
- geostanowisko o znaczeniu krajowym – geosite of national importance
- geostanowisko o znaczeniu regionalnym – geosite of regional importance
- jaskinia niezakwalifikowana jako pomnik przyrody – cave, not qualified as natural monument
- głaz narzutowy o średnicy >1,5 m niezakwalifikowany jako pomnik przyrody – glacial eratic less than 1.5m in diameter, not qualified as natural monument
- n – stanowisko archeologiczne (n - liczba obiektów) – archeological site (n - number of objects)

INFORMACJE DODATKOWE

ADDITIONAL INFORMATIONS

- granica powiatu – county boundary
- granica gminy, miasta – commune or town boundary
- S6 – oś autostrady lub drogi szybkiego ruchu – highway or express route
- S6 – oś projektowanej autostrady lub drogi szybkiego ruchu – planned highway or express route
- KOLBUDY – siedziba urzędu gminy, miasta – commune or town office headquarter
- sieć gazociągów przesyłowych – natural gas pipeline network
- sieć elektroenergetyczna najwyższych napięć – high-voltage power network
- granica obszaru przetargowego – boundary of tender area

* *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 stratigraphic succession of the “Kartuzy” tender area is divided into four units. These are: Precambrian crystalline basement, Caledonian Lower Paleozoic succession, Laramide Permian-Mesozoic sedimentary succession, and Cenozoic cover (Żelaźniewicz et al., 2011; Nawrocki and Becker, 2017; Figs 2.1–2.2).

The Precambrian crystalline basement of the “Kartuzy” tender area belongs to the Fennoscandian part (Dobrzyń Domain) of the East European Craton (Bogdanova et al., 2005; Krzemińska and Krzemiński, 2017), and is built of Mesoproterozoic monzonite intrusions and Paleoproterozoic paragneisses (Figs 2.3–2.5, Fig. 2.17). These rocks were drilled in the surroundings. New seismic research (Kasperska et al., 2019; Fig. 2.5) shows the top surface of the Precambrian crystalline rocks occur at depths between 3600 m b.s.l. and 4100 m b.s.l., slightly descending to the SW, and being thrust by the NW-SE and SW-NE fault systems.

The oldest part of the sedimentary cover is composed of Ediacaran and Lower Paleozoic rocks of the Peribaltic Syneclise (Żelaźniewicz et al., 2011; Nawrocki and Becker, 2017; Figs 2.1–2.2, Figs 2.6–2.12, Fig. 2.17). This succession dips towards SW, their thickness increases in the same direction. Some folds related to the TTZ were interpreted within (Mazur et al., 2016; Konon et al., 2018).

The Caledonian succession is covered discordantly by the Permian-Mesozoic rocks of the Mazury-Podlasie Monocline (Nawrocki and Becker, 2017; Fig. 2.2; Figs 2.13–2.17). The Permian base surface occurs at depths between 1200 m b.s.l. and 1600 m b.s.l. and dips towards SE. The Laramide succession is thrust by NW-SE and NWW-SEE fault systems. The succession is separated from the overlying Cenozoic cover by an angular unconformity.

The stratigraphy and lithology of the sedimentary succession are recognized in several boreholes located in the “Kartuzy” tender area and its close neighborhood. These are: Borcz-1, Gapowo B-1, B-1A, Lewino-1G2, Miłoszewo ONZ-1, Miłowo-1, Niestępowo-1, and Tępcz-1. Their location is shown in Fig. 5.1.

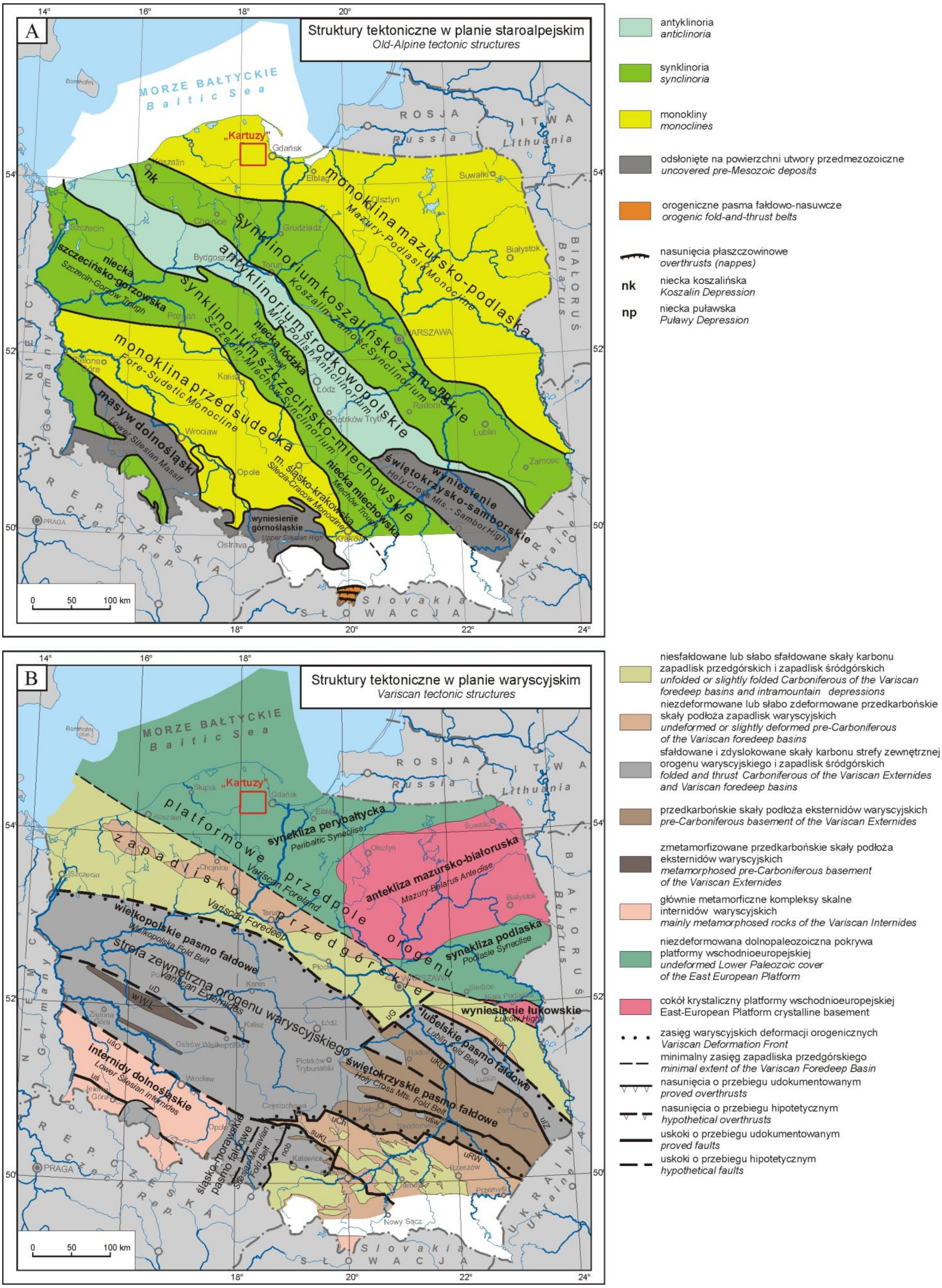


Fig. 2.1.A. Position of the "Kartuzy" tender area in relation to the Old-Apline tectonic structures in the Polish Lowland (Nawrocki and Becker, 2017). **B.** Position of the "Kartuzy" tender area in relation to the Variscan tectonic structures in the Polish Lowland (Nawrocki and Becker, 2017).

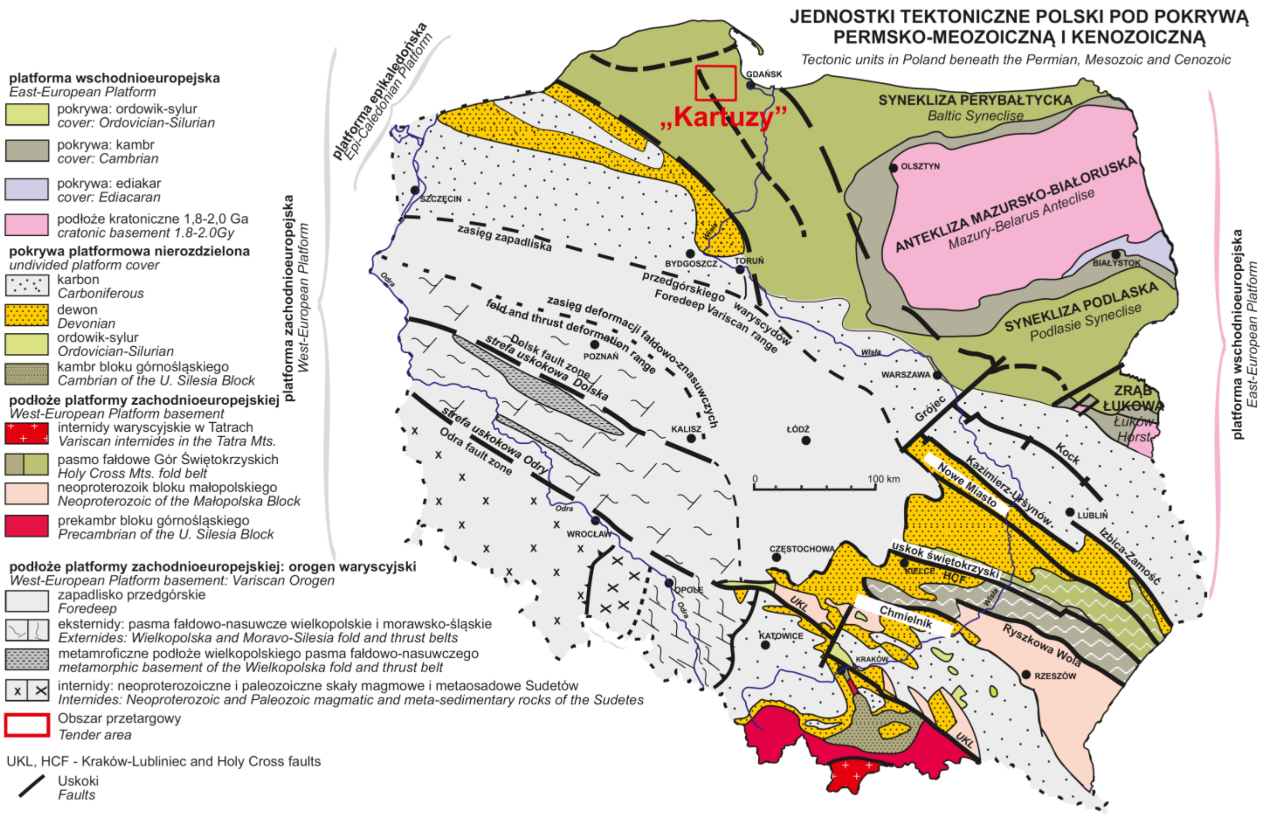


Fig. 2.2. Position of the "Kartuzy" tender area in relation to the main tectonic units in Poland beneath the Permian, Mesozoic and Cenozoic (Żelaźniewicz et al., 2011).

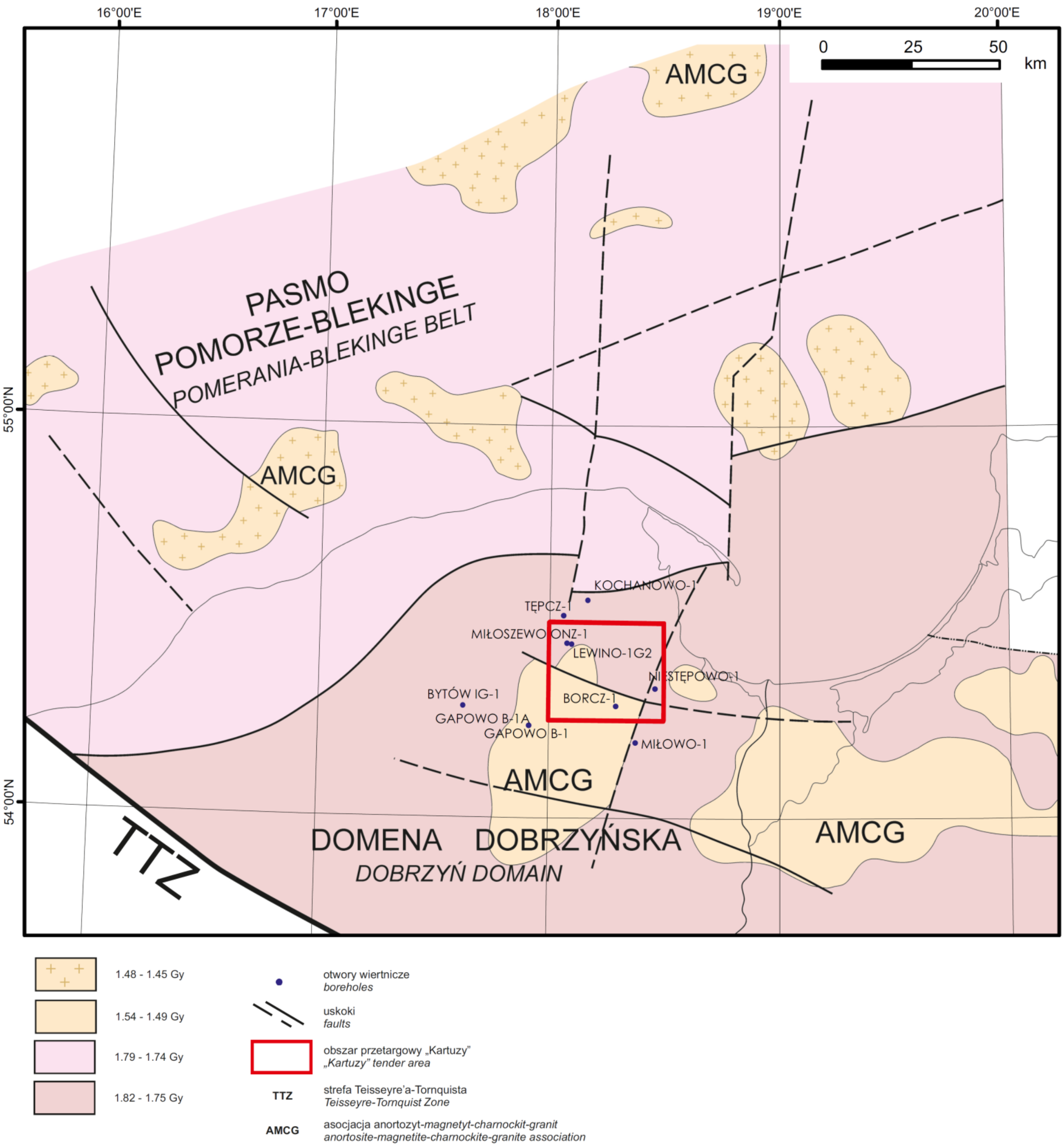


Fig. 2.3. Location of the "Kartuzy" tender area in relation to the crustal structure of the crystalline basement of the East European Craton (Krzemińska and Krzemiński, 2017).

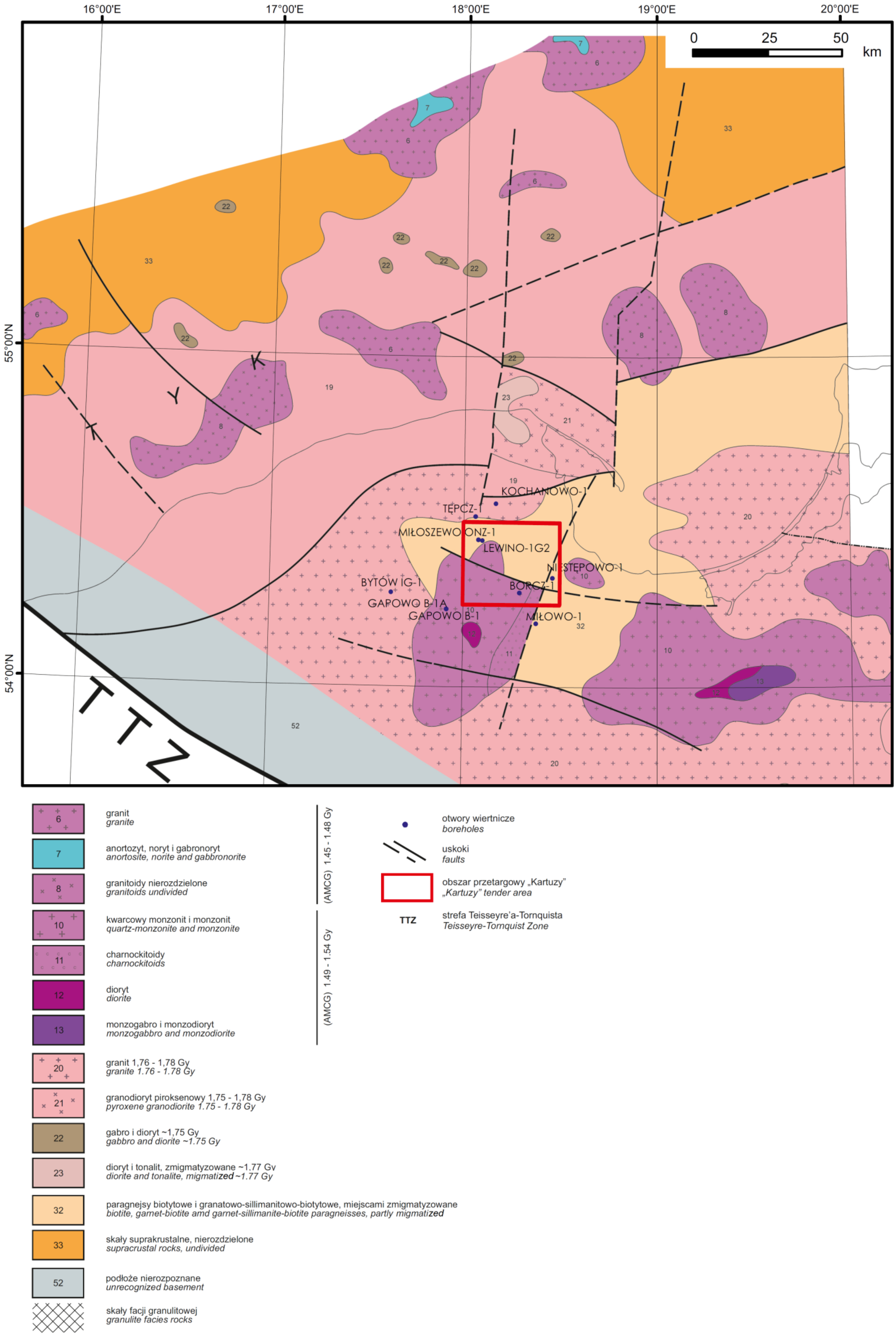
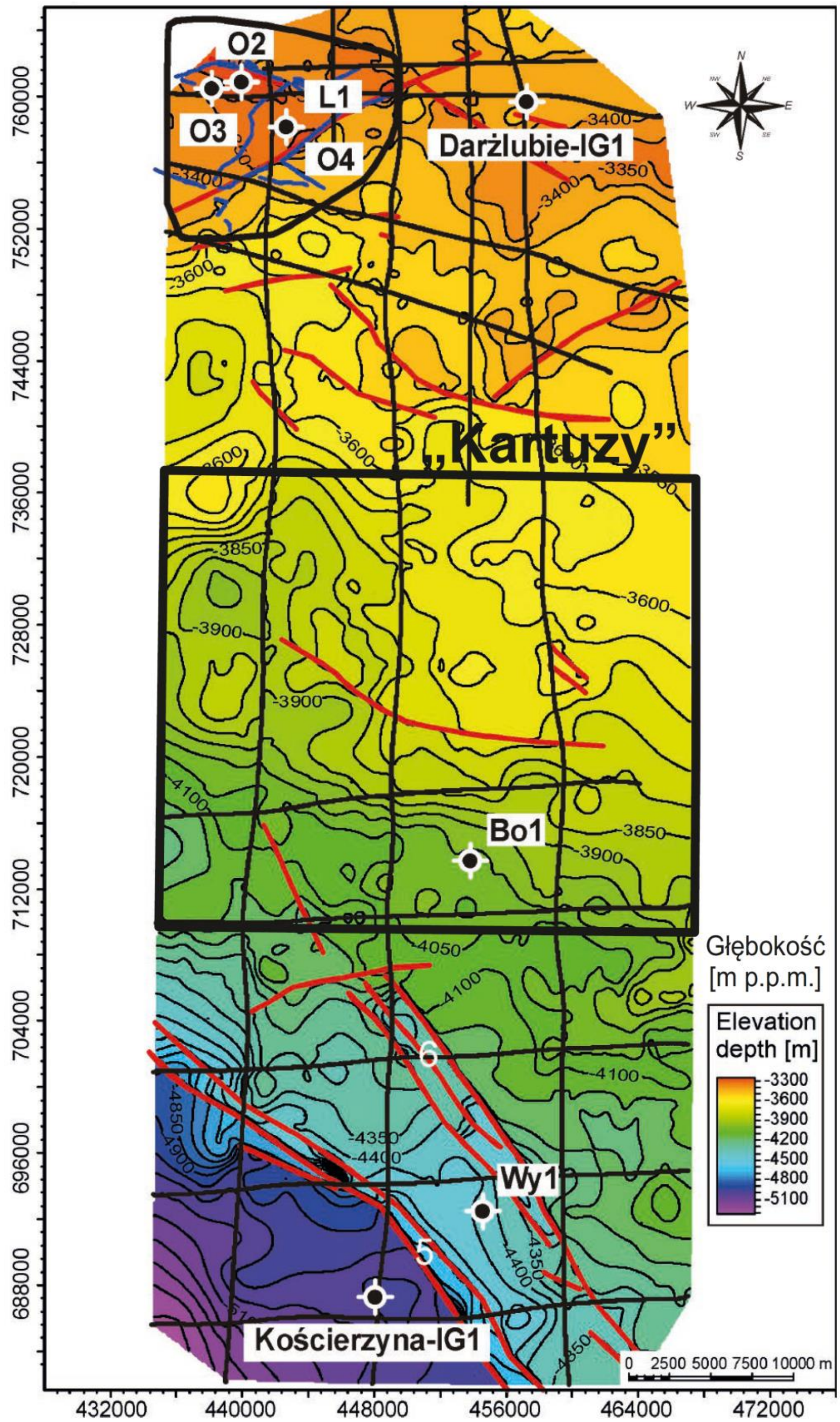


Fig. 2.4. Location of the "Kartuzy" tender area in relation to a geological map of the crystalline basement of the East European Craton (Krzemińska and Krzemiński, 2017).



Horyzont sejsmiczny prekambru
Precambrian seismic horizon

Fig. 2.5. Location of the "Kartuzy" tender area (black square) in relation to the map of the Precambrian seismic horizon (Kasperska et al., 2019). Wells: O2 – Opalino-2, O3 – Opalino-3, O4 – Opalino-4, L1 – Lewino-1G2, Bo1 – Borcz-1, Wy1 – Wysin-1.

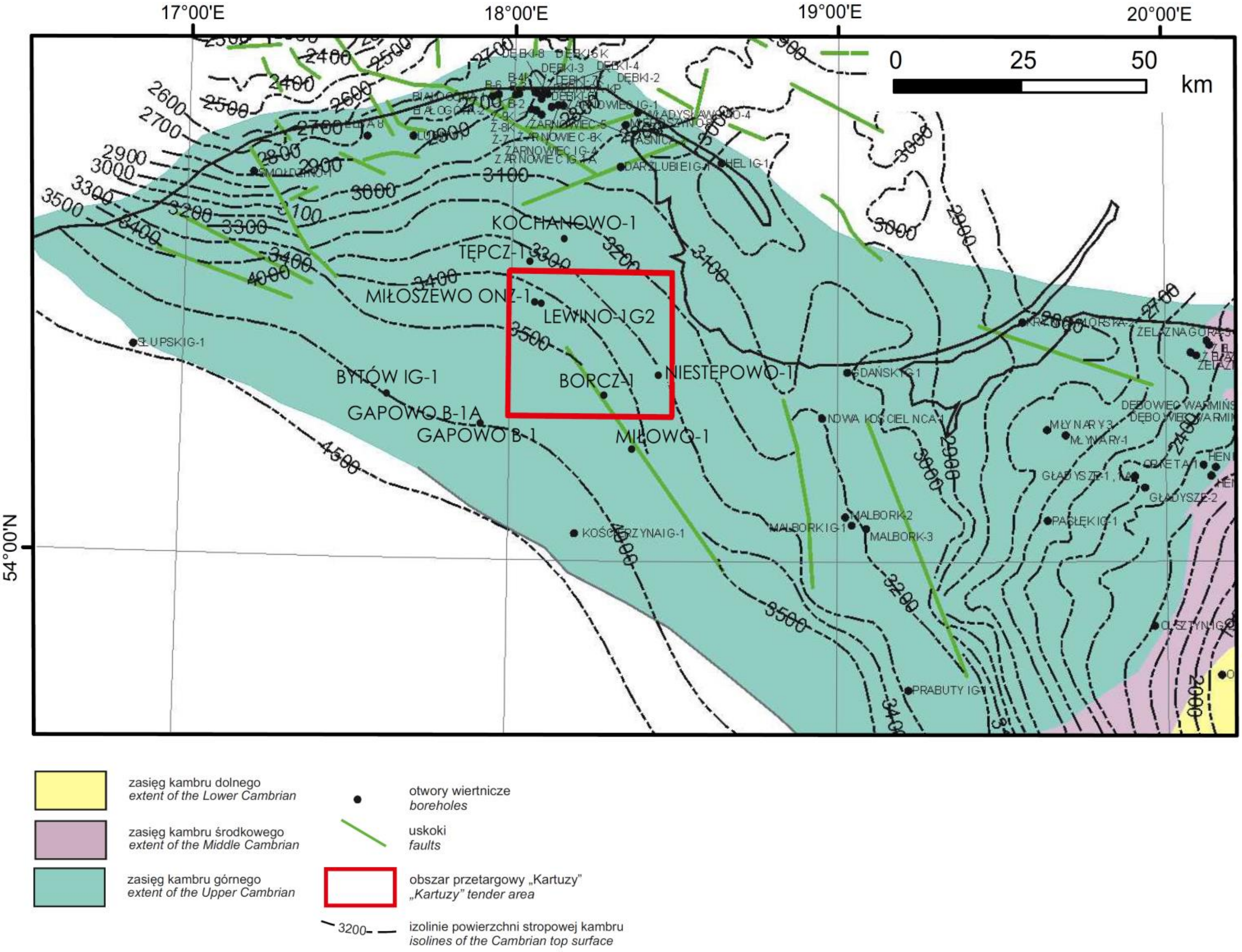


Fig. 2.6. Location of the “Kartuzy” tender area in relation to the structural map of the Cambrian top surface (Poprawa and Kiersnowski, 2010).

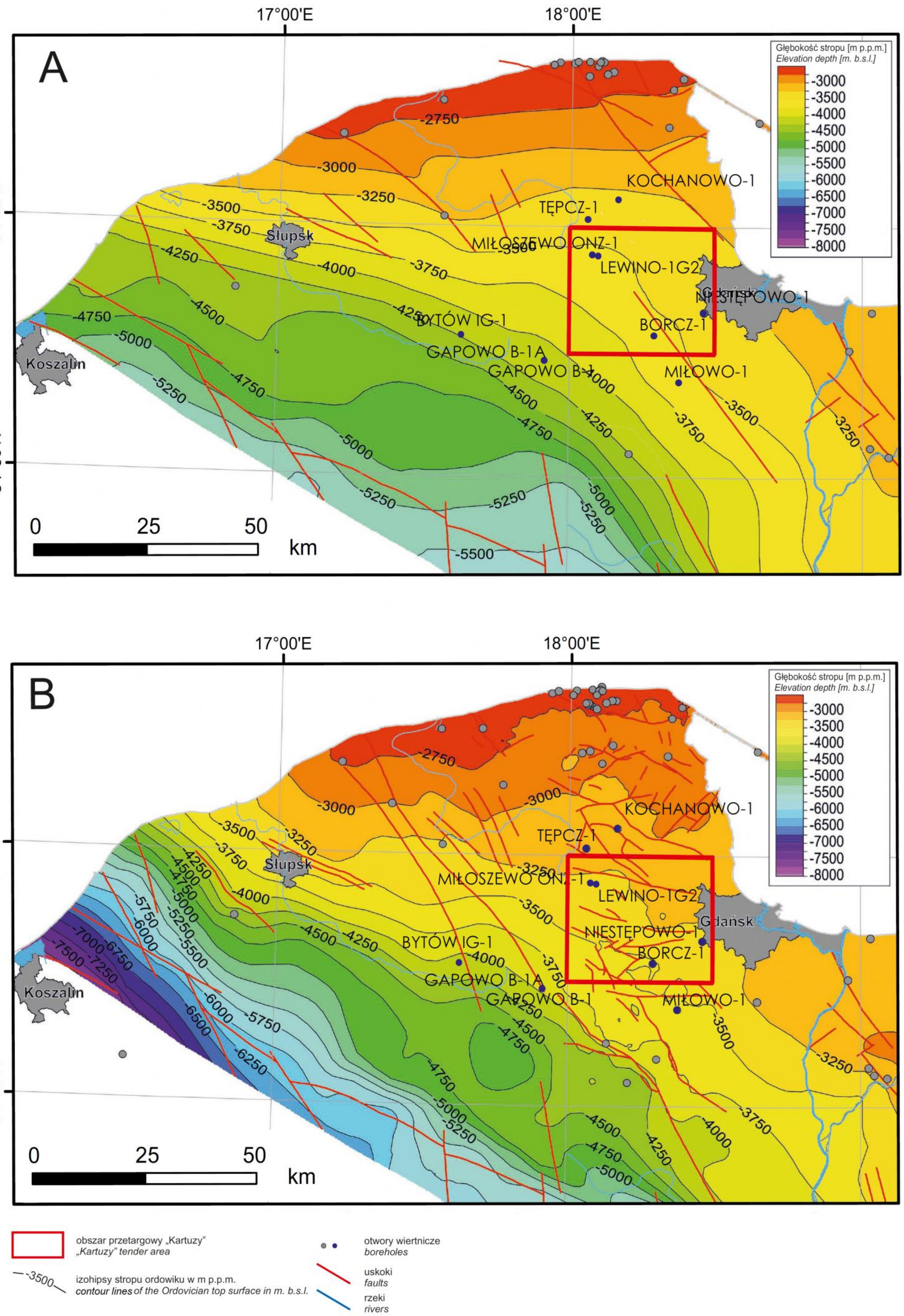


Fig. 2.7. Location of the "Kartuzy" tender area in relation to the structural map of the Ordovician top surface (Papiernik and Michna, 2019). **A**. Original trend map. **B**. Seismic reinterpretation. Wells marked by darker colour are analyzed in this report.

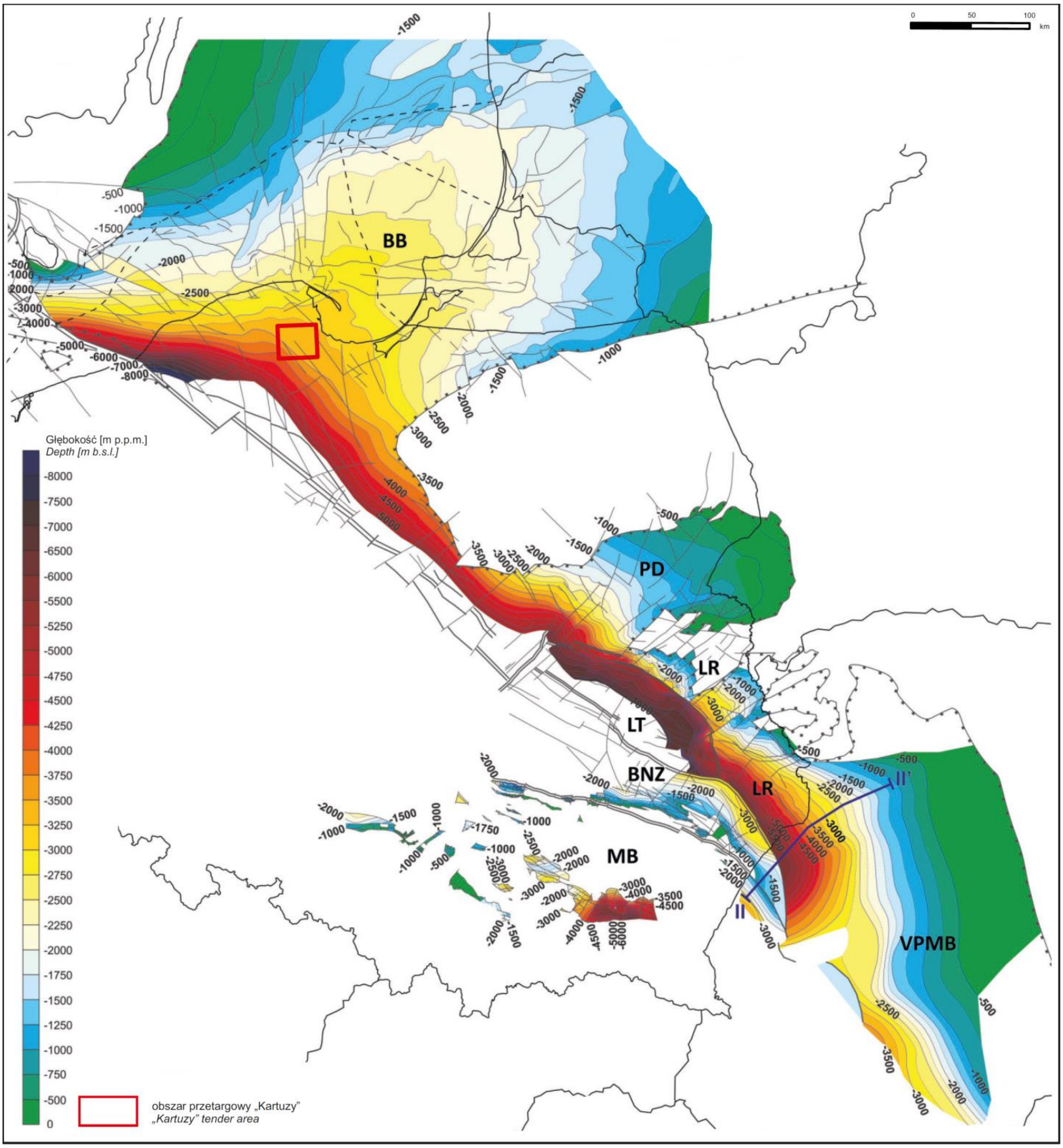


Fig. 2.8. Location of the "Kartuzy" tender area in relation to the structural map of the Caradoc top surface (Poprawa, 2019); BB – Baltic Basin, PD – Podlasie Depression, LR – Lublin Region, LT – Lublin Graben, BNZ – Biłgoraj-Narol Zone, MB – Małopolska Block, VPMB – Volyn-Podole Basin.

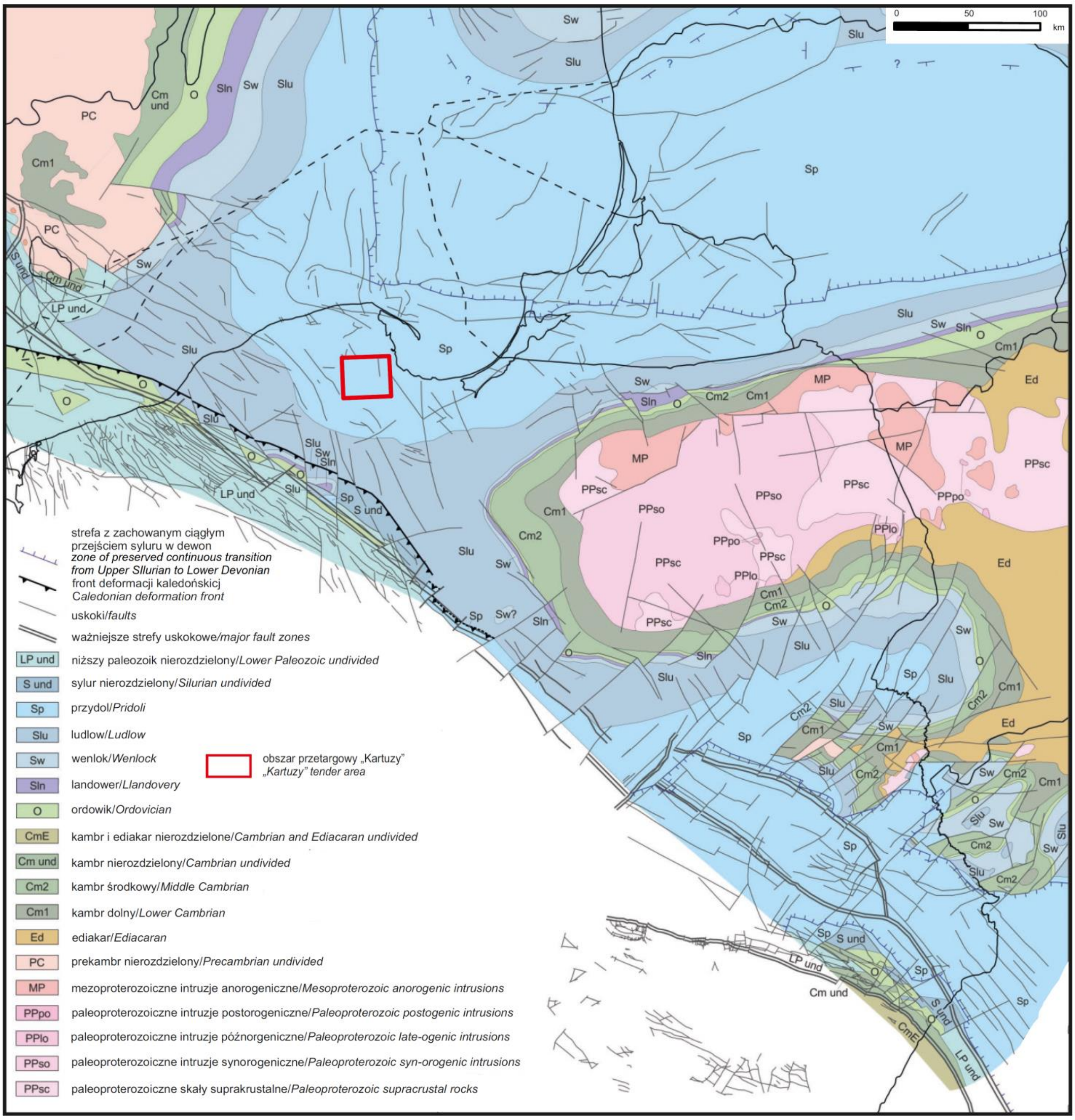


Fig. 2.9. Location of the "Kartuzy" tender area in the geological map of Poland and neighboring countries, without Devonian and younger strata (Poprawa, 2019).

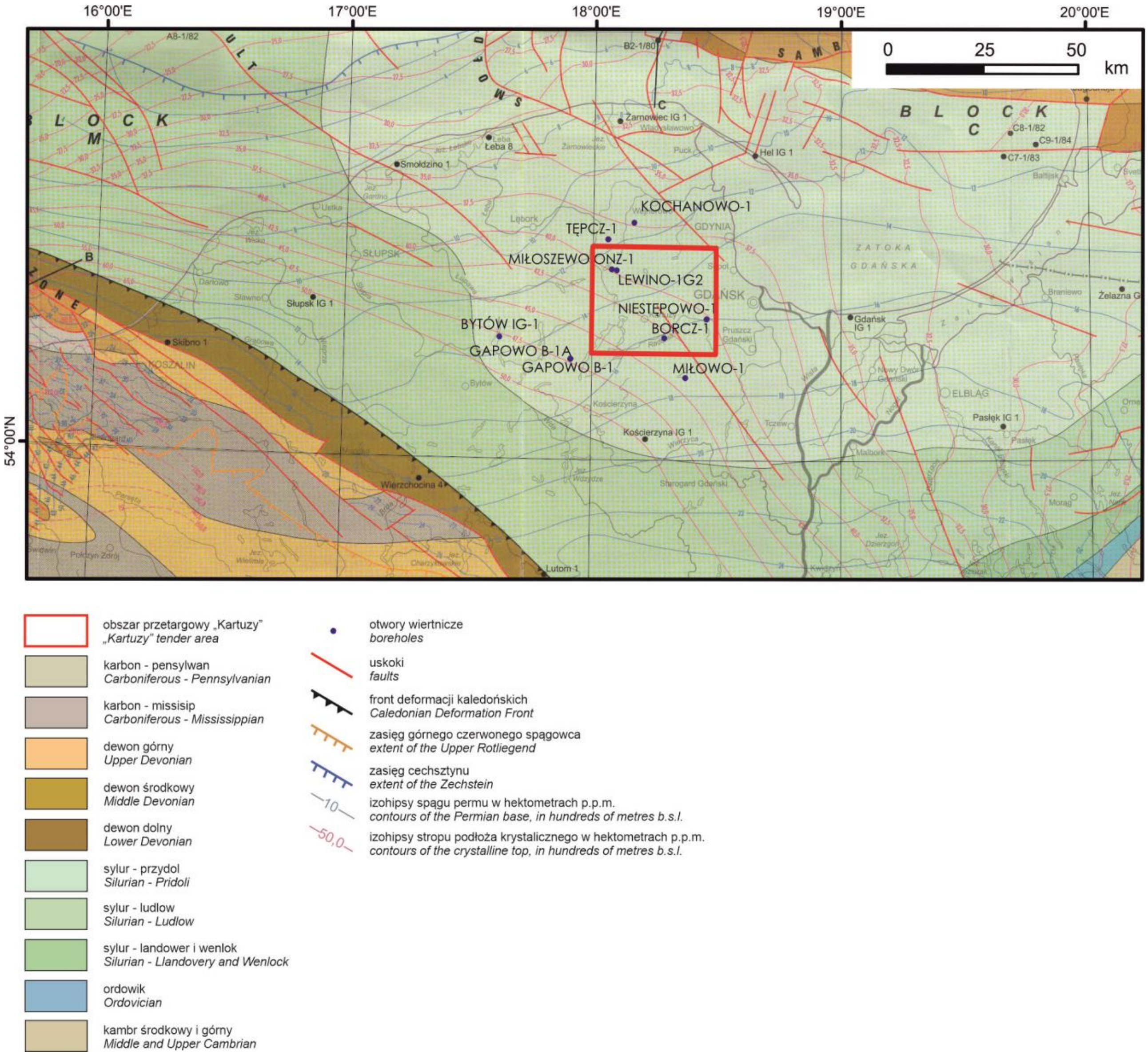


Fig. 2.10. Location of the “Kartuzy” tender area in the geological map of the Peribaltic Syneclise, without Permian and younger strata (Pokorski and Modliński, 2007).

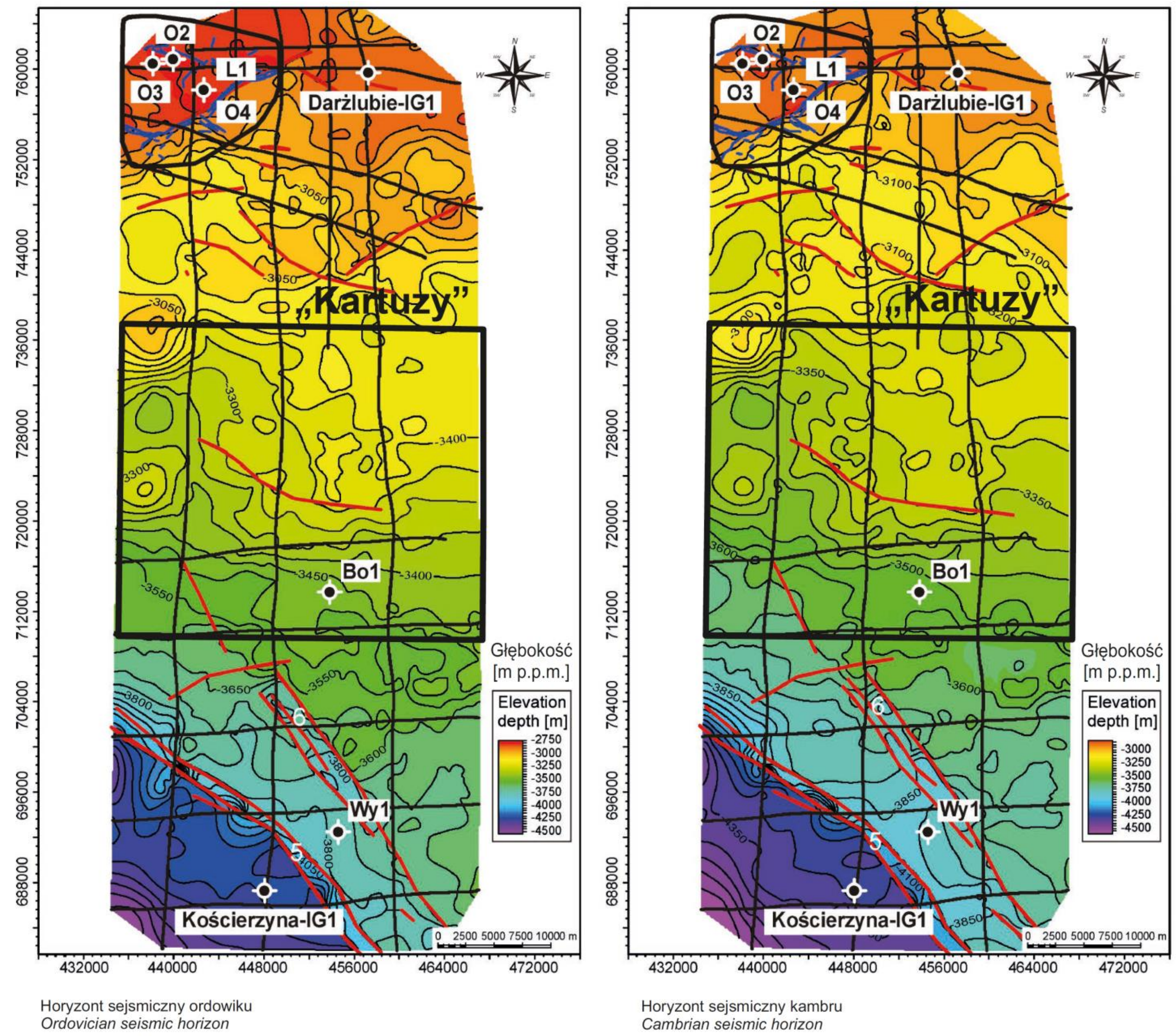


Fig. 2.11. Location of the "Kartuzy" tender area (black square) in relation to the maps of the Cambrian and Ordovician seismic horizons (Kasperska et al., 2019). Wells: O2 – Opalino-2, O3 – Opalino-3, O4 – Opalino-4, L1 – Lewino-1G2, Bo1 – Borcz-1, Wy1 – Wysin-1.

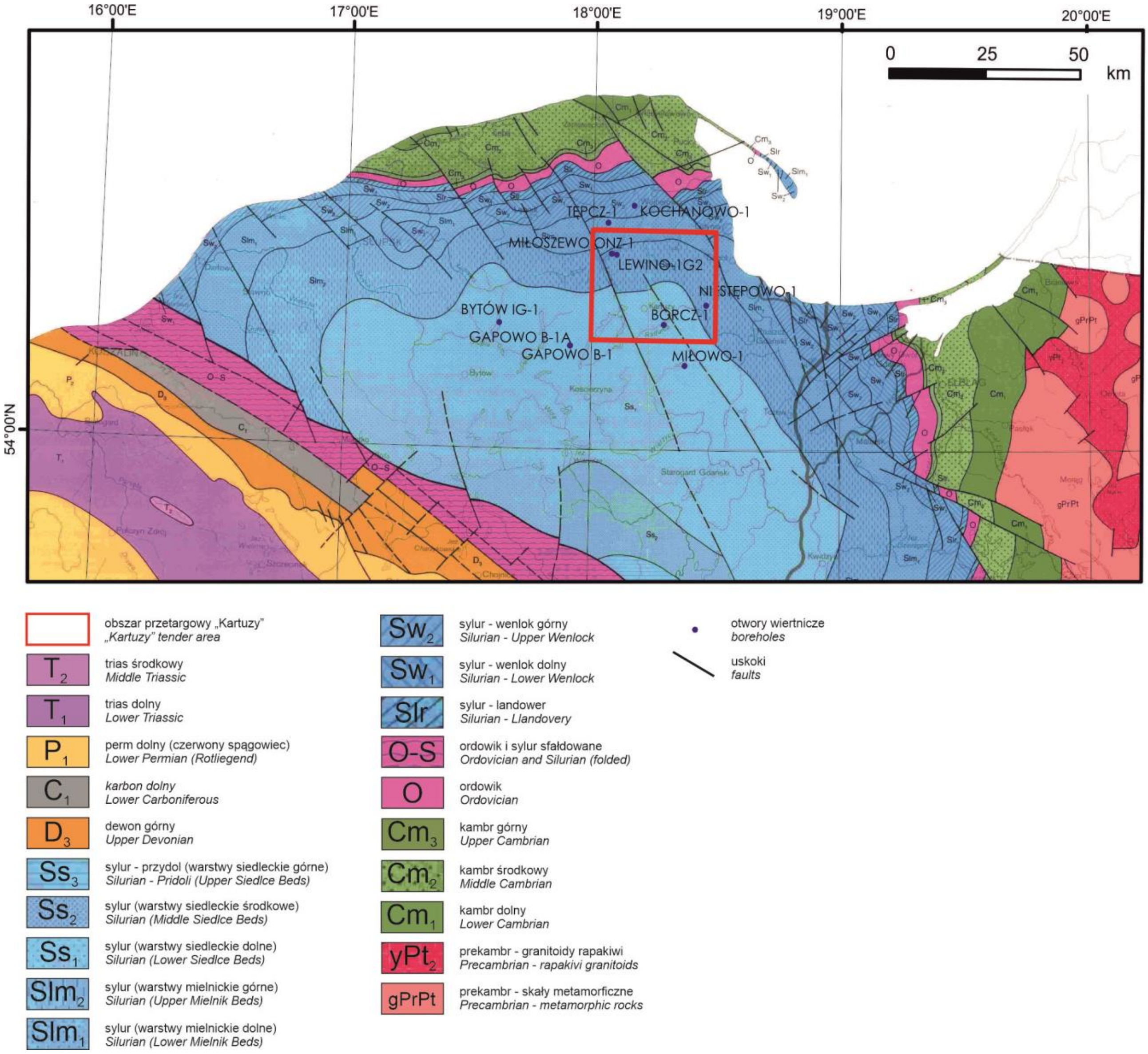


Fig. 2.12. Location of the "Kartuzy" tender area in the geological map of horizontal cutting at 3000 m b.s.l. (Kotański, 1997).

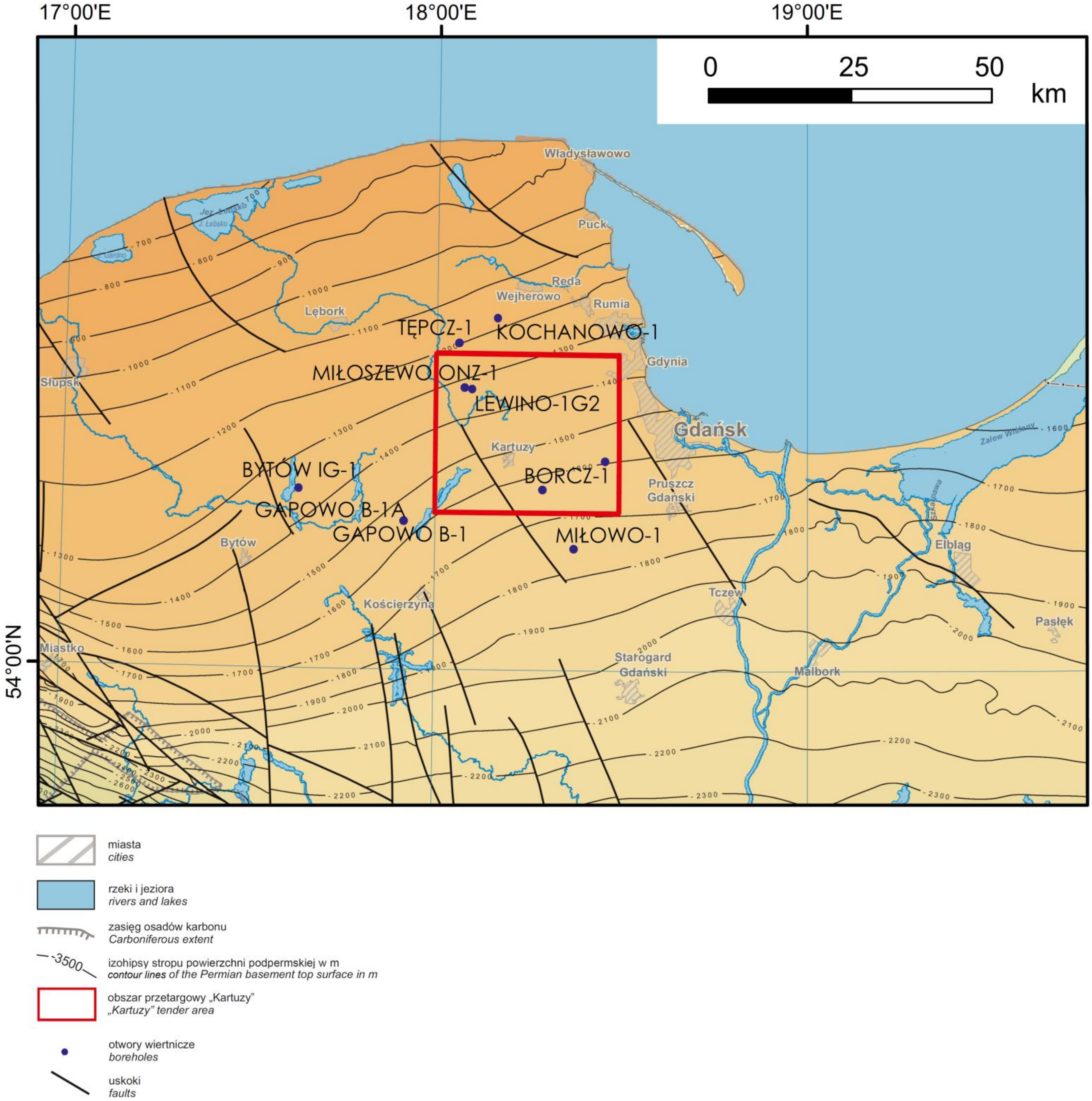


Fig. 2.13. Location of the "Kartuzy" tender area in the structural map of the Permian basement top surface (Kudrewicz, 2008).

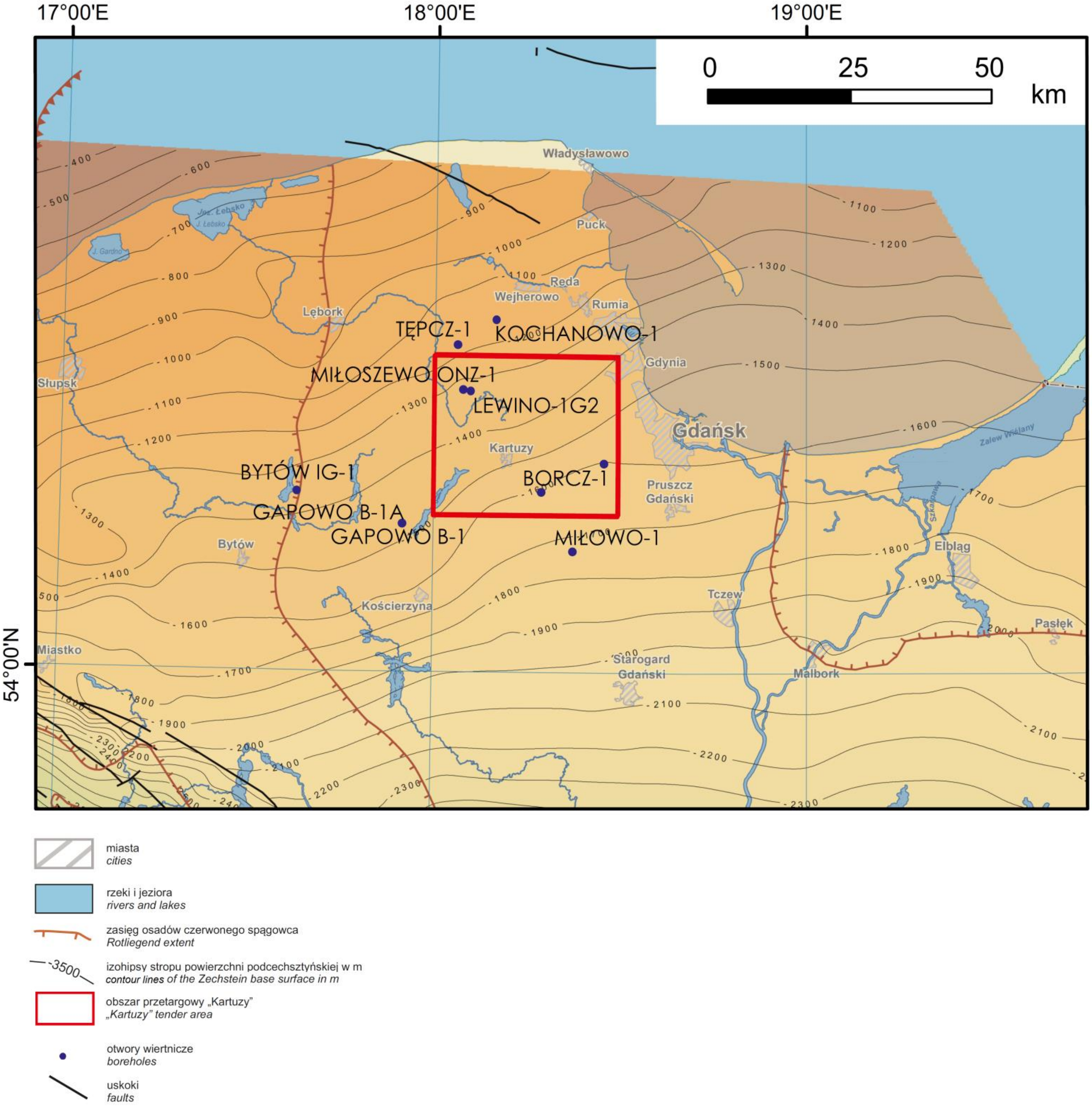


Fig. 2.14. Location of the “Kartuzy” tender area in the structural map of the Zechstein base surface (Kudrewicz, 2008).

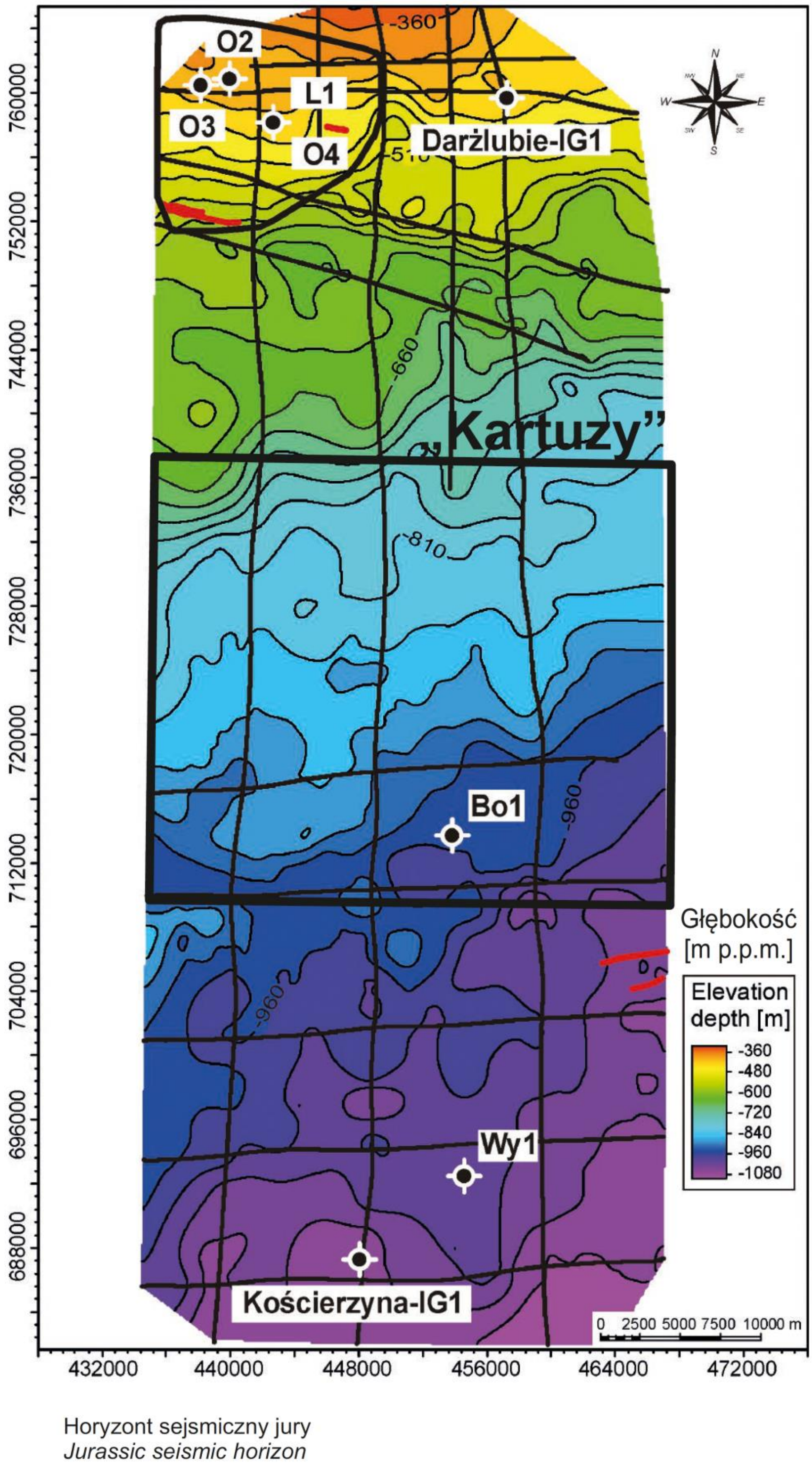


Fig. 2.15. Location of the "Kartuzy" tender area (black square) in relation to the map of the Jurassic seismic horizon (Kasperska et al., 2019). Wells: O2 – Opalino-2, O3 – Opalino-3, O4 – Opalino-4, L1 – Lewino-1G2, Bo1 – Borcz-1, Wy1 – Wysin-1.

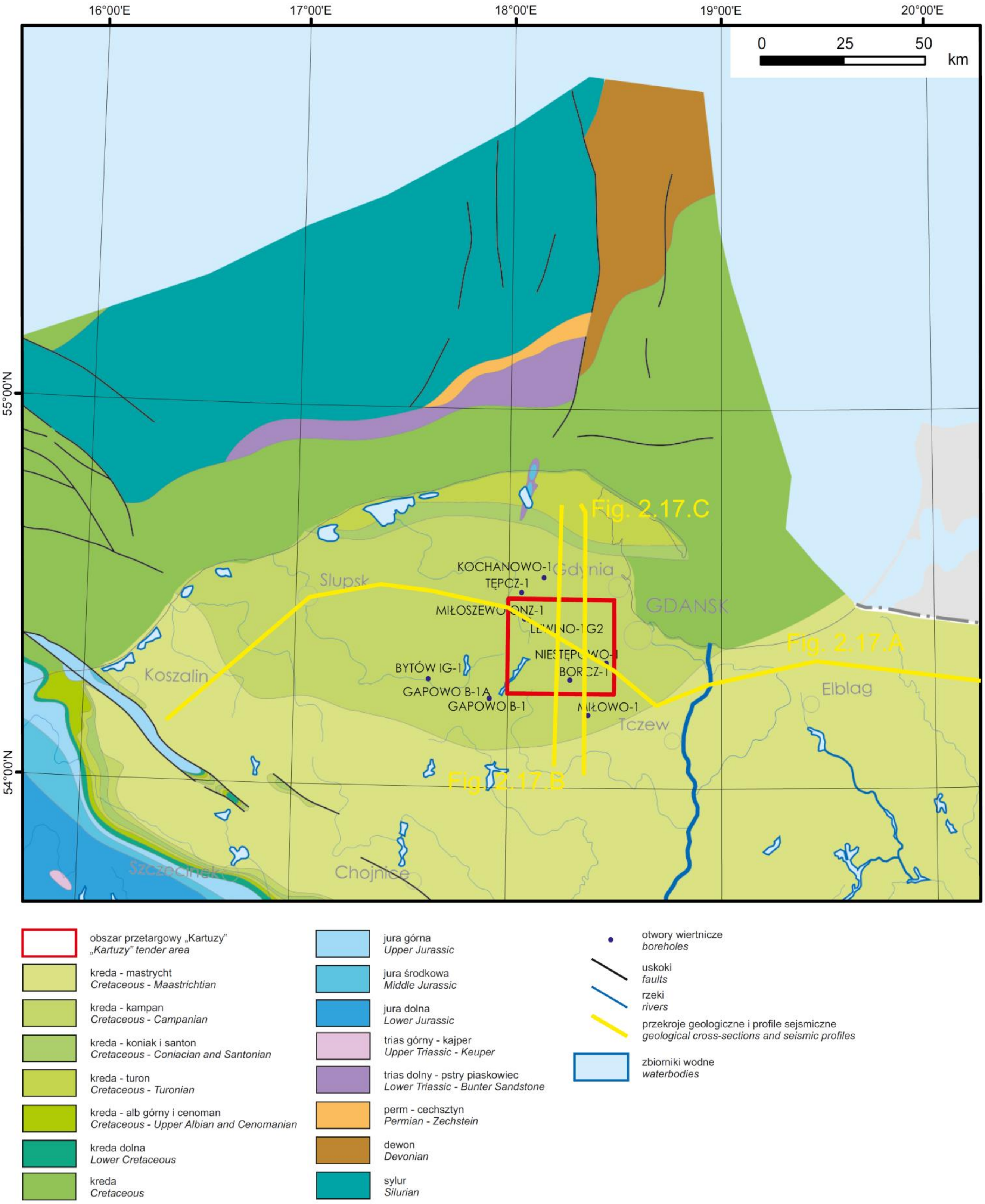


Fig. 2.16. Location of the "Kartuzy" tender area in the geological map of Poland without Cenozoic strata (Dadlez et al., 2000).

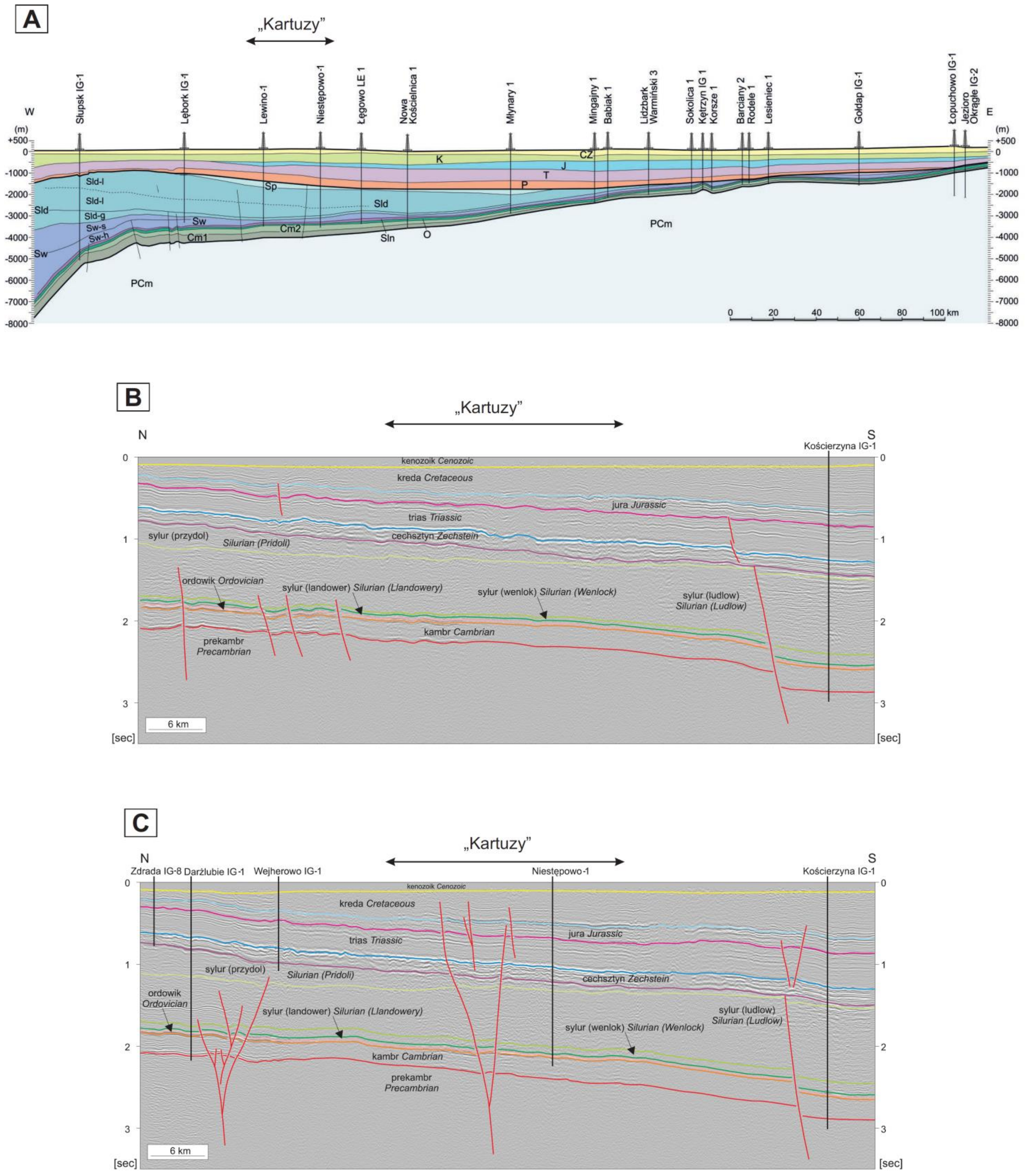


Fig. 2.17. A. Geological cross-section through the Peribaltic Syneclise (Poprawa, 2019). PCm – Precambrian, Cm1 – Lower Cambrian, Cm2 – Middle Cambrian, Cm3 – Upper Cambrian, O – Ordovician, Sln – Llandovery, Sw – Wenlock, Sw-s –Sheinwoodian, Sw-h – Homerian, Sw-g – Gorstian, Sld – Ludlow, Sld-l – Ludfordian, P – Permian, T – Triassic, J – Jurassic, k – Cretaceous, CZ – Cenozoic. **B**. Interpretation of the 13-9-03K seismic section (Krzywiec, 2011). **C**. Interpretation of the 14-9-03K seismic section (Krzywiec, 2011). Location of the A–C sections is shown in Fig. 2.16.

2.2. STRATIGRAPHY
2.2.1. EDIACARAN AND CAMBRIAN

Extent and thickness

None of the wells from the “Kartuzy” tender area drilled through the Early Cambrian strata, therefore the thickness of the Cambrian can be only interpreted (Lendzion, 1983; Modliński et al., 2010). The oldest deposits drilled in the ”Kartuzy” tender area, as well as in the adjacent areas, were dated to the Middle and Upper Cambrian. The depth range of the drilled interval in the wells is as follows (see Chapter 5):

- Borcz-1: 3726.9–3760.0 m,
- Niestępowo-1: 3490.0–3632.9 m,
- Lewino-1G2,
- Miłowo-1: 3810.2–3856.0 m,
- Gapowo B-1: 4257.0–4303.0 m,
- Tępcz-1: 3408.5–3428.5 m.

Because no borehole has been drilled through the Cambrian, the thickness in the tender area could be estimated based on the Cambrian thickness maps (Lendzion, 1983; Modliński et al., 2010). The Cambrian thickness increases towards the marginal zone of the East European Craton, reaching (including the undivided Żarnowiec Formation) approx. 700 m (Lendzion, 1983; Modliński et al., 2010).

Lithology and stratigraphy
Ediacaran – Lower Cambrian

According to the previous studies, the Ediacaran is represented by sandstones and conglomerates of the Żarnowiec/Smołdzino Formation, and sandstones, mudstones and heteroliths of the Kluków and Łeba formations (Terreneuvian). In the “Kartuzy” tender area, the thickness of the Ediacaran strata is estimated between 50 and 75 m and increases to the SW (Fig. 2.18; Lendzion, 1983; Jaworowski and Sikorska, 2010).

Middle Cambrian: Dębki, Sarbsko, Osiek, and Białogóra formations (undivided)

Depth and thickness of Middle Cambrian strata in the wells drilled are as follows:

- Borcz-1: 3727.2–3760.0 m,
- Niestępowo-1: 3492.8–3632.9 m,
- Lewino-1G2,
- Miłowo 1: 3811.0–3856.0 m,
- Gapowo B-1: 4262.0–4303.0 m,
- Tępcz-1: 3408.65–3428.5 m.

In the western part of the East European Platform, the Middle Cambrian is represented by Sarbsko, Dębki, Osiek and Białogóra formations (Bednarczyk and Turnau-Morawska, 1975; Jaworowski, 1998). They are composed of claystones, mudstones, quartz sandstones and heteroliths (Jaworowski, 1998) deposited under marine conditions. The total thickness of the Middle Cambrian succession is approximately 250–300 m (Modliński et al., 2010, Fig. 2.19).

Upper Cambrian (*Furongian*)

The Late Cambrian is represented by the relics of the Piaśnica Formation, which contain conglomerates with carbonate-cemented clayey-silty clasts. The thickness of the Piaśnica Formation varies around 0.15–5 m (Podhalańska et al., 2020, Fig. 2.20). The formation was drilled in the following wells:

- Borcz-1: 3726.9–3727.2 m,
- Niestępowo-1: 3490.0–3492.8 m,
- Lewino-1G2,
- Tępcz-1: 3408.5–3408.65 m,
- Gapowo B-1: 4257.0–4262.0 m,
- Miłowo-1: 3810.2–3811.0 m.

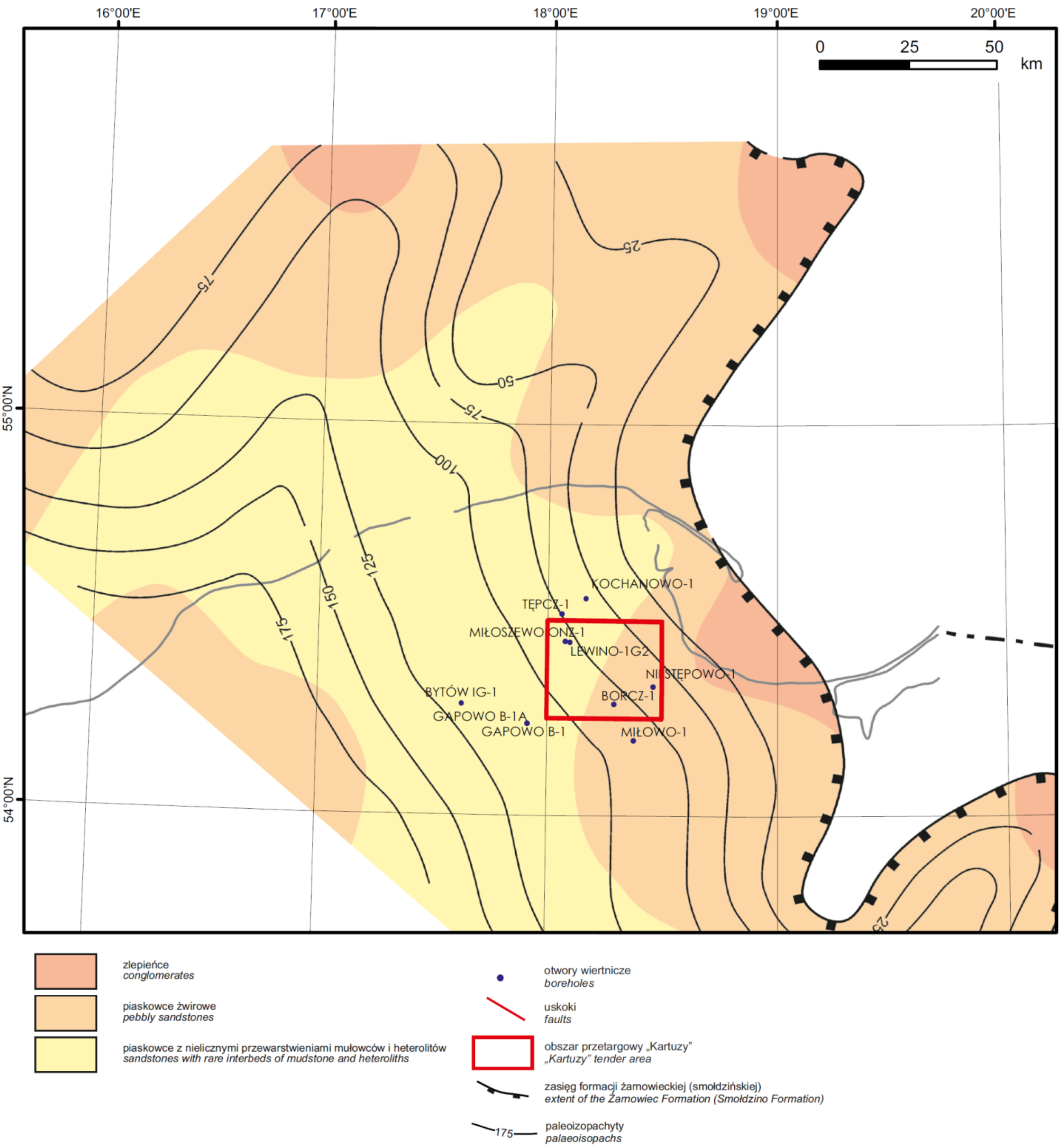


Fig. 2.18. The "Kartuzy" tender area in the lithofacies-palaeothickness map of the Żarnowiec Formation (Modliński et al., 2010; modified).

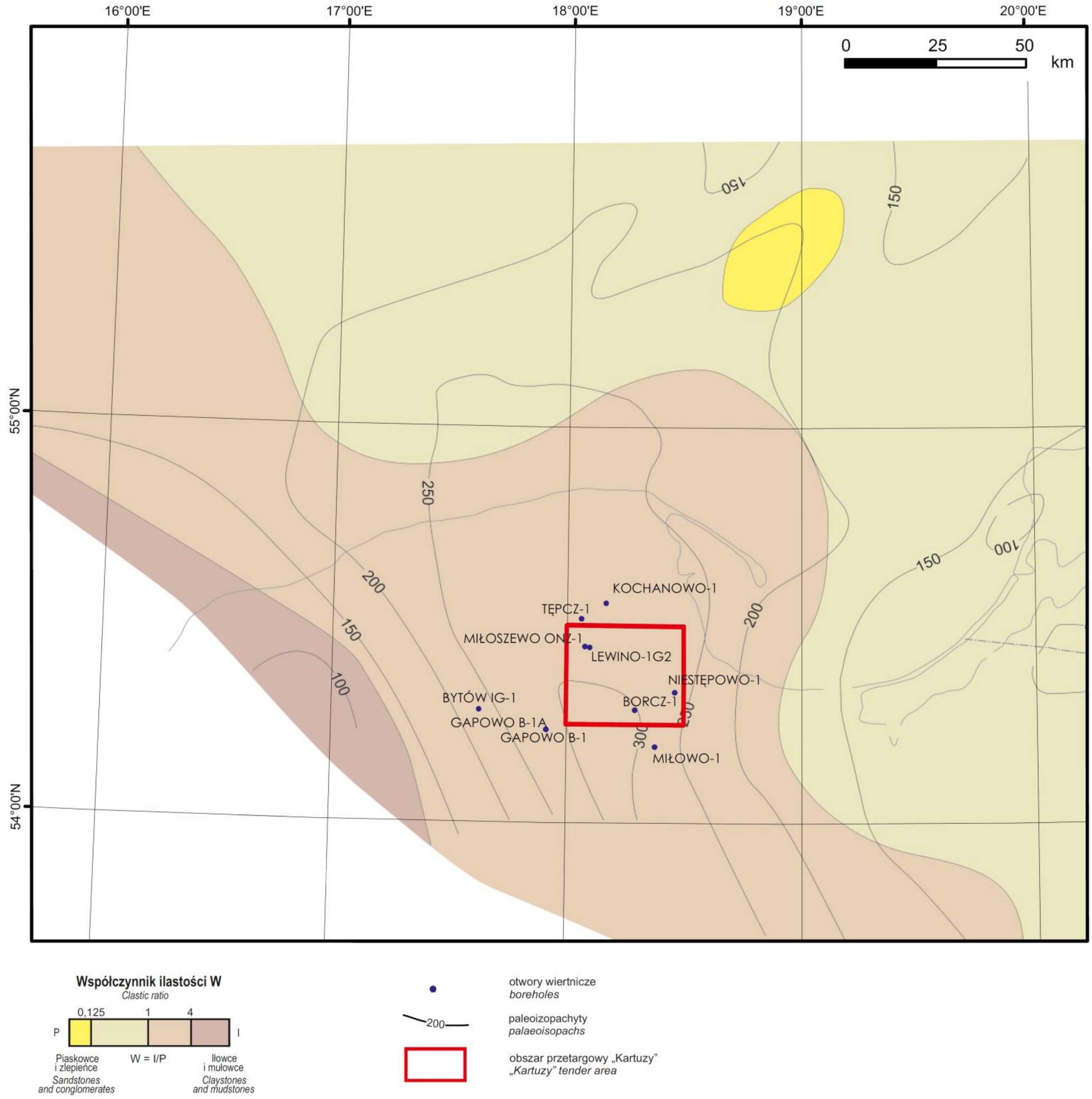


Fig. 2.19. The "Kartuzy" tender area in the lithofacies-palaeothickness map of the Middle Cambrian (Modliński et al., 2010; modified).

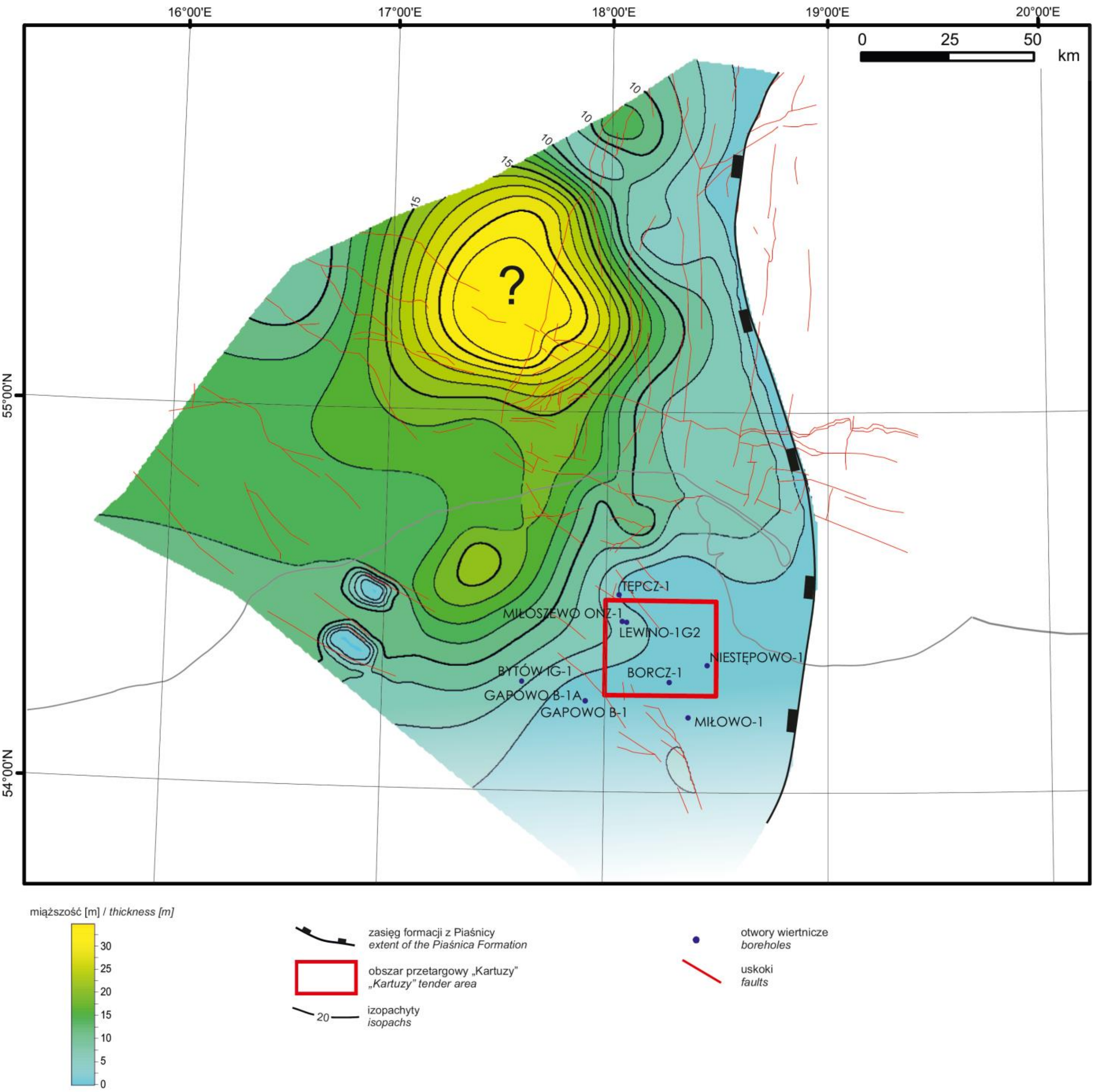


Fig. 2.20. The "Kartuzy" tender area in relation to the Piaśnica Formation thickness (Podhalańska et al., 2020; modified).

2.2.2. ORDOVICIAN

Extent and thickness

The Ordovician sediments have been encountered in all boreholes in the "Kartuzy" tender area, as well as in the adjacent areas between the Miłowo-1 (NW) and Niestępowo-1 (SE) wells (Modliński, 1973, 1982; Modliński and Szymański, 1997; Modliński and Podhalańska, 2010; Podhalańska, 2017, 2019, Podhalańska et al., 2018). The thickness of the Ordovician succession varies from 39.2 to 50 m in individual boreholes (see Chapter 5):

- Borcz-1: 3694.0–3726.9 m,
- Niestępowo-1: 3452.0–3490.0 m,
- Lewino-1G2,
- Miłowo-1: 3775.5–3810.2 m,
- Gapowo B-1: 4207.0–4257.0 m,
- Tępcz-1: 3368.5–3408.5 m.

Lithology and stratigraphy

The Ordovician carbonate-clastic deposits in the Polish part of the Baltic Depression have been distinguished into several formations by Modliński and Szymański (1997) and later verified by Porębski and Podhalańska, (2017, 2019) (Fig. 2.21). In the western part of the Baltic Depression, within the analyzed area, the Ordovician is represented by a continuous full succession from the lower Arenig (Floian) to the upper Ashgill (Hirnantian) and divided into 5 formations.

Słuchowo Glauconitic Mudstone/Claystone Formation

The formation occurs in the following wells:
- Borcz-1: 3725.5–3 726.9 m,
- Niestępowo-1: 3485.0–3490.0 m,
- Lewino-1G2,
- Miłowo-1: 3807.5–3810.2 m,
- Tępcz-1: 3407.5–3408.5 m.

The Słuchowo Formation thickness is from 1 to 5 m (Fig. 2.22). The formation is composed of sandstones, conglomerates, glauconitic breccia, and predominantly mudstones with conchoidal intercalations. The Słuchowo Formation is of lower Arenig (Floian) age. The stratigraphic equivalent of the Słuchowo Formation in the Baltic Basin is the Didymograptus Shales of Tøyen Shale Formation in Scania and Jämtland (Sweden).

Pieszkowo Red Limestones Formation

The formation occurs in one well:
- Niestępowo-1: 3481.0–3485.0 m.

The Pieszkowo Formation has been distinguished only in the Niestępowo-1 well (thickness 4.0 m). However, it is very similar and probably corresponds to the Słuchowo Formation (based on Podhalańska et al., 2018).

Kopalino Limestone Formation

The formation occurs in the following wells:
- Borcz-1: 3715.5–3725.5 m,
- Niestępowo-1: 3478.5–3481.0 m,.
- Lewino-1G2,
- Miłowo-1: 3798.85–3807.5 m,
- Gapowo B-1: 4250.0–4257.0 m,
- Tępcz-1: 3396.0–3407.5 m.

The Kopalino Formation is represented by limestones, marly limestones, occasionally knobby limestones with frequent discontinuity surfaces. The Kopalino Formation corresponds to the upper Arenig and lower Llanvirn. The thickness of this succession is between 7 and 11m (except in the Niestępowo-1 well).

Sasino Claystone Formation

The formation occurs in the following wells:
- Borcz-1: 3700.5–3715.5 m,
- Niestępowo-1: 3459.0–3478.5 m,
- Lewino-1G2,
- Miłowo-1: 3782.5–3798.85 m,
- Gapowo B-1: 4236.0–4250.0 m,
- Tępcz-1: 3375.5–3396.0 m.

The Sasino Formation begins with a sheet of transgressive conglomerate with ferrous and phosphate pisoids, which is underlined by a sharp erosional surface. The Sasino Formation is composed of fine-grained sediments: black, dark grey, and greenish-grey mudstones and claystones with pyrite, intercalated by marly limestones with bioclasts or highly bioturbated mudstones with numerous layers of bentonites. The tripartite composition reflects periodic reducing conditions at the bottom of the basin, which is visible on gamma profiles (for example in the Borcz-1 well), and confirmed by sedimentological studies (Feldman-Olszewska and Roszkowska-Remin, 2016; Kędzior et al., 2017). The graptolite dating indicates the age of the formation as upper Llanvirn – Caradoc (Darriwilian – upper Katian; Modliński and Szymański, 1997; Podhalańska, 2013, 2017, 2019; Podhalańska et al., 2020). The thickness of the Sasino Formation in the “Kartuzy” tender area, as well as in the adjacent areas, varies between 14 and 20.5 m (Podhalańska et al., 2020, Fig. 2.23).

Prabuty Marls and Claystones Formation

The formation occurs in the following wells:
- Borcz-1: 3694.0–3700.5 m,
- Niestępowo-1: 3452.0–3459.0 m,
- Lewino-1G2,
- Tępcz-1: 3368.5–3375.5 m,
- Gapowo B-1: 4207.0–4236.0 m,

- Miłowo-1: 3775.5–3782.5 m.

The thickness of the formation in the analyzed area is 6–9 m, which is consistent with the thickness map of the Ashgill deposits (Modliński et al., 2010; Fig. 2.24). The formation is composed of claystones and marls with benthic fauna of trilobites and brachiopods of the Ashgill (Hirnatian) age (Modliński, 1973; Podhalańska, 2009; Porębski and Podhalańska, 2017).

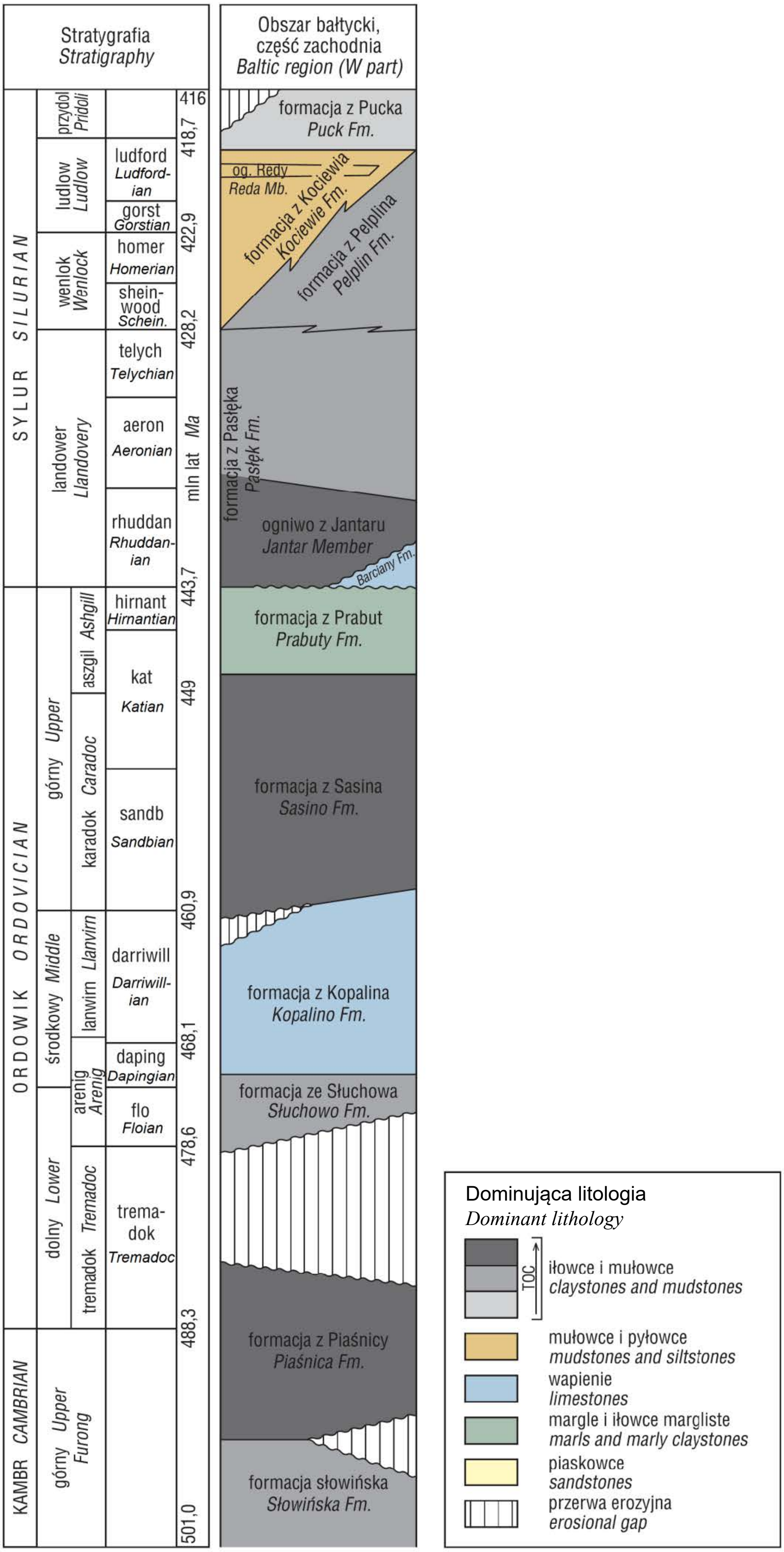


Fig. 2.21. Lower Paleozoic stratigraphy in the western part of the Baltic region (Podhalańska et al., 2016; modified).

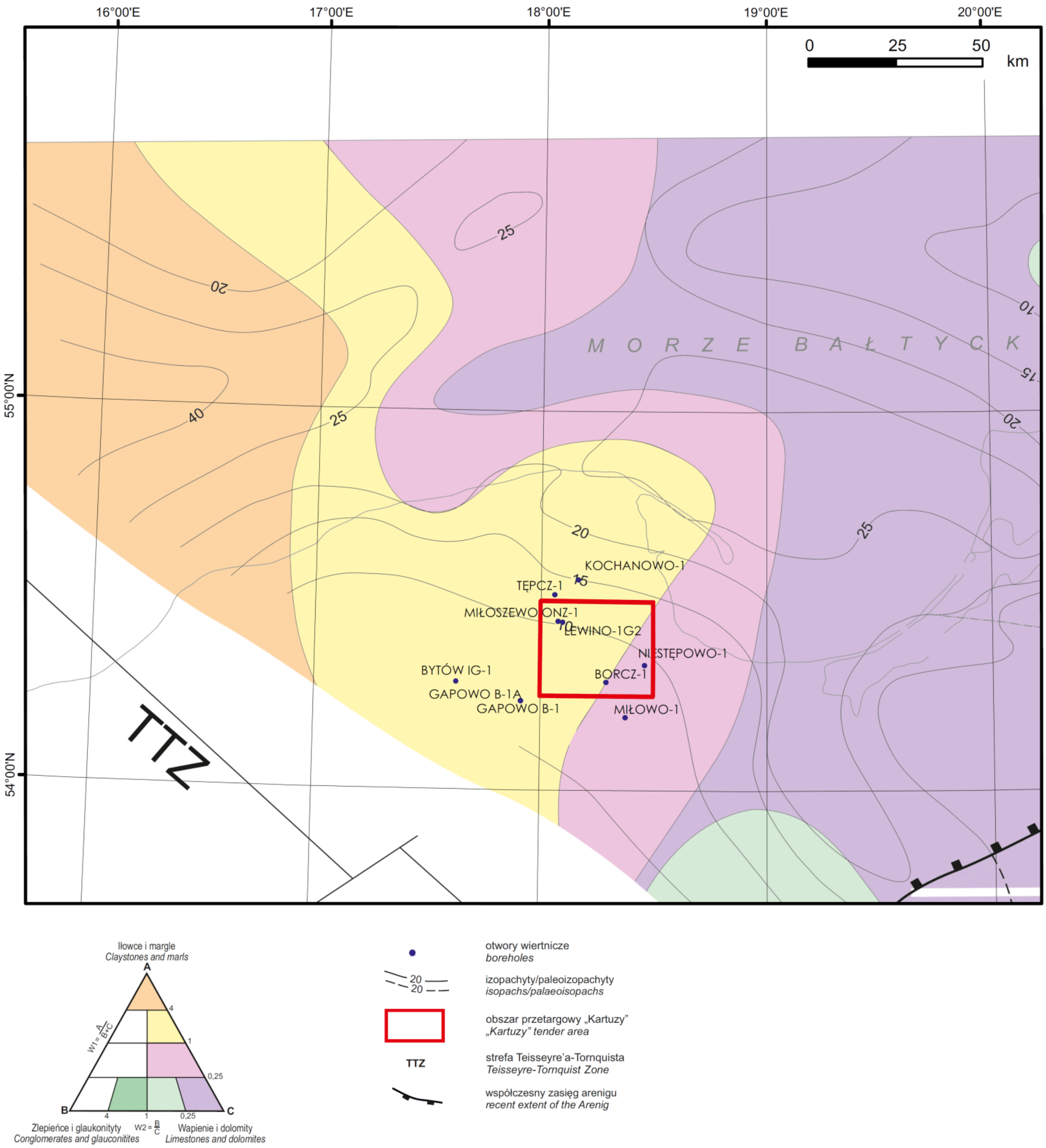


Fig. 2.22. The "Kartuzy" tender area in the lithofacies-palaeothickness map of the Arenig (Modliński et al., 2010; modified).

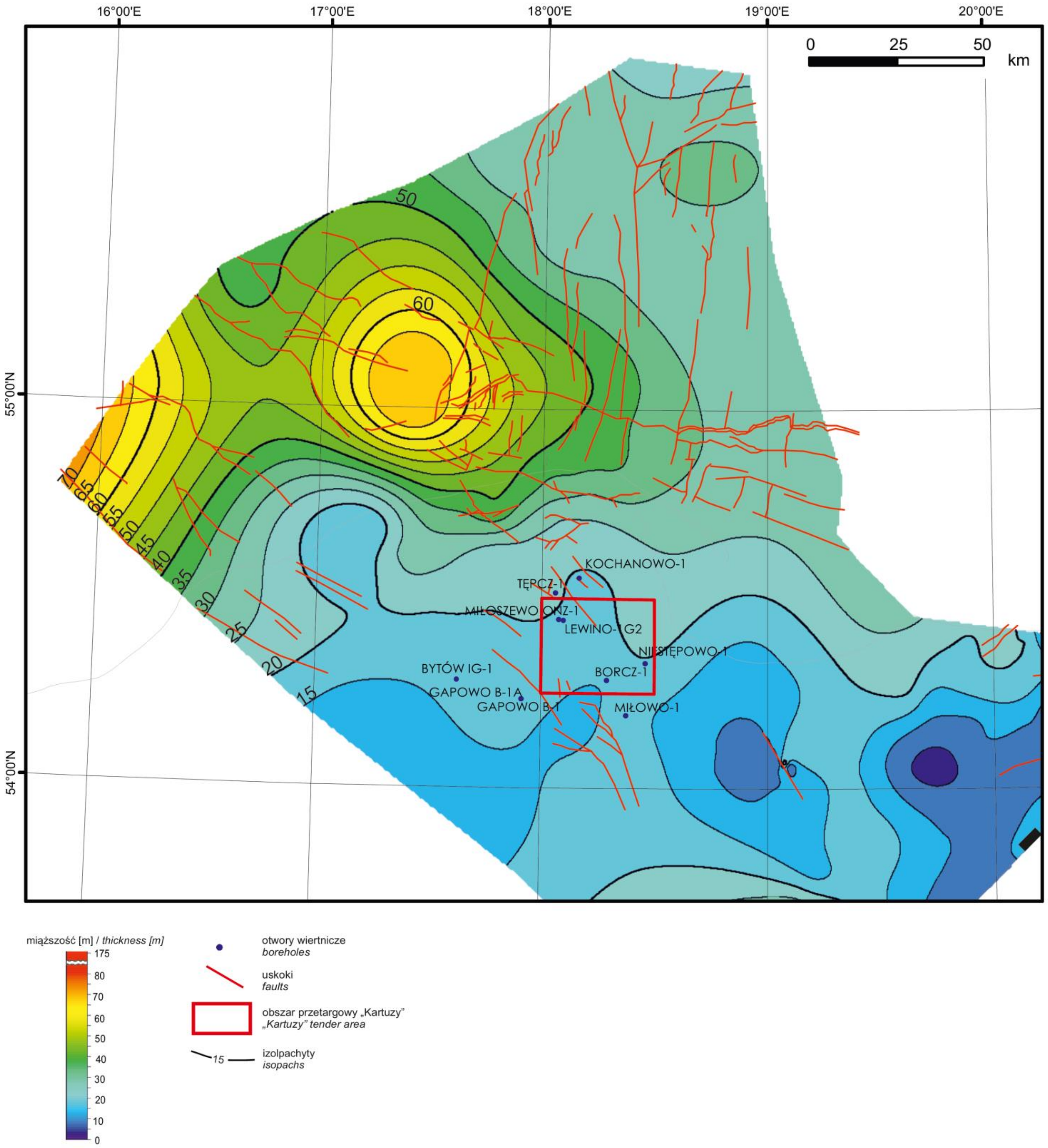


Fig. 2.23. The "Kartuzy" tender area in relation to the Sasino Formation thickness (Podhalańska et al., 2020; modified).

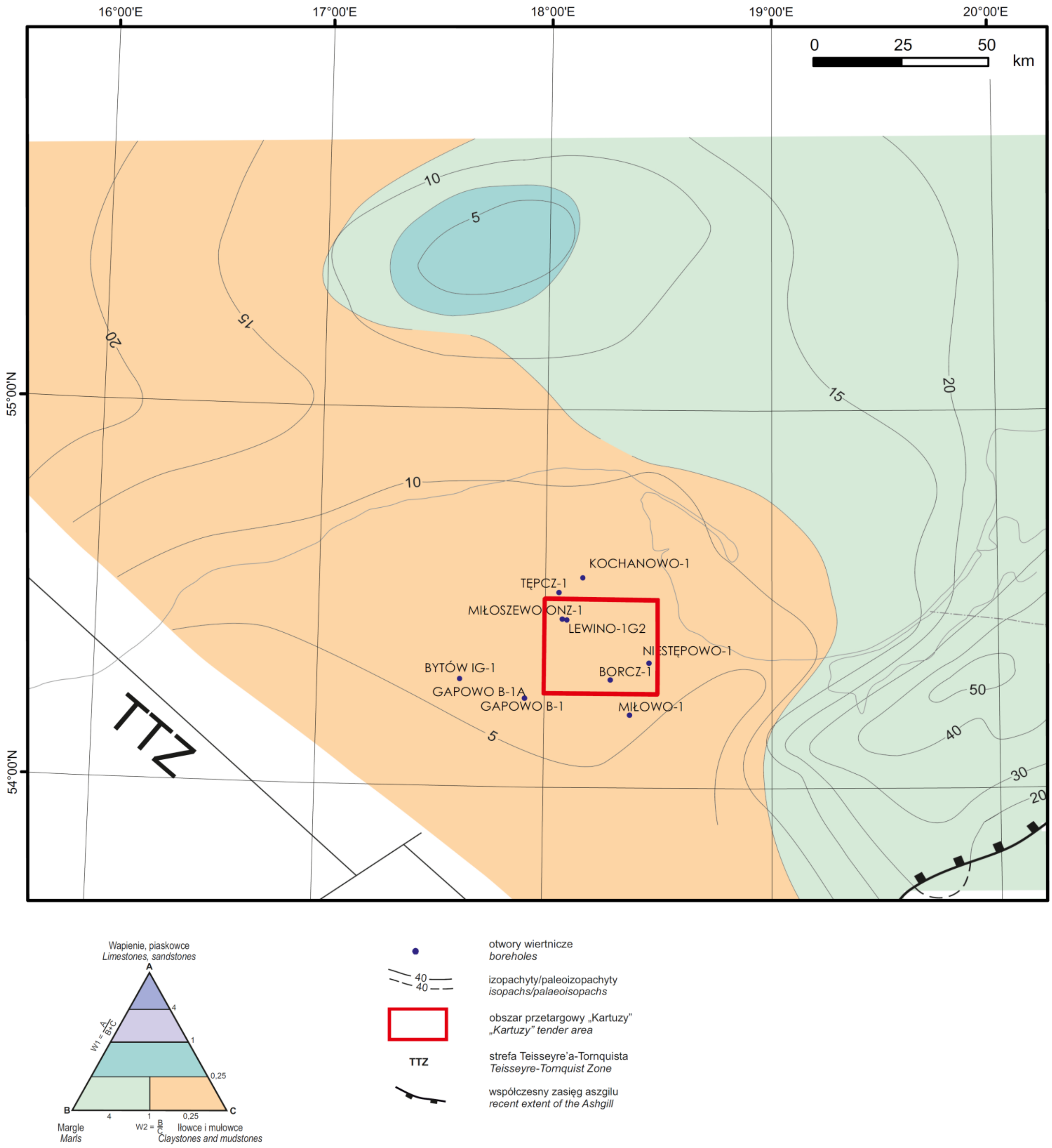


Fig. 2.24. The "Kartuzy" tender area in the lithofacies-palaeothickness map of the Ashgill (Modliński et al., 2010; modified).

2.2.3. SILURIAN

Extent and thickness

Fine-grained siliciclastic Silurian deposits were identified in deep wells in the "Kartuzy" tender area and adjacent areas (Modliński et al., 2010; Podhalańska, 2017, 2019; Porębski and Podhalańska, 2017, 2019; Podhalańska et al., 2020). The thickness of the Silurian succession significantly exceeds the thickness of the Ordovician strata. In the north-eastern part of the "Kartuzy" tender area, the thickness reaches 1730.5 m, increasing to 2312.0 m towards the SW. The Silurian was drilled in the following wells (see Chapter 5):

- Borcz-1: 1834.0–3694.0 m,
- Niestępowo-1: 1717.0–3452.0 m,
- Lewino-1G2,
- Miłoszewo ONZ-1: 1520.0–1558.0 m,
- Miłowo-1: 2045.0–3775.5 m,
- Gapowo B-1: 1895.0–4207.0 m,
- Tępcz-1: 1449.0–3368.5 m.

Lithology and stratigraphy

Formal lithostratigraphy of the Silurian succession was presented by Modliński et al. (2006). The Silurian succession of the western part of the Peribaltic Syneclise was initially divided into 4 formations and 2 members. Recently, this scheme has been modified and the bituminous claystone of the Jantar Member has been elevated to the formation rank (Porębski and Podhalańska, 2017, 2019; Fig. 2.21). This is the reason why there is the Jantar Member instead of the Jantar Formation in most of the analyzed documentations (before 2017).

Jantar Claystone Formation

The formation occurs in the following wells:

- Borcz-1: 3680.5–3694.0 m,
- Niestępowo-1: 3442.0–3452.0 m,
- Miłowo-1: 3767.0–3775.5 m,
- Gapowo B-1: 4192.0–4207.0 m,
- Tępcz-1: 3349.0–3368.5 m.

The Jantar Formation is composed of black and dark grey bituminous mudstones with pyrite and interbeds of laminated mudstones and greenish bioturbated mudstones. The Jantar Formation is characterized by increased gamma curve values in well logs and can be relatively easily identified. Sedimentological analysis performed in the Baltic region showed the dominance of lithofacies L-1A/1B (after Feldman-Olszewska and Roszkowska-Remin, 2016) that is an association of lithofacies consisting of massive claystones and non-calcareous mudstones with rare carbonate laminas and pyrite concretions; occasionally with thin layers of bioturbated deposits. The thickness of the formation in the analyzed and adjacent areas varies from 8.5 to 19.5 m and significantly increases to the N (Fig. 2.25). The age of the Jantar Formation in the “Kartuzy” tender area has been determined by numerous graptolite assemblages as Rhuddanian – lowest Aeronian (*Parakidograptus acuminatus – Demirastrites convolutes* graptolite zones; e.g. Podhalańska, 2019). The Jantar Formation is one of the main prospective horizons in Lower Paleozoic unconventional hydrocarbon systems in Poland (e.g. Poprawa, 2010; Podhalańska et al., 2018; Podhalańska et al., 2020).

Pasłęk Claystone Formation

The formation occurs in the following wells:

- Borcz-1: 3637.0–3680.5 m,
- Niestępowo-1: 3412.0–3442.0 m,
- Lewino-1G2,
- Miłowo-1: 3739.0–3767.0 m,
- Gapowo B-1: 4164.0–4192.0 m,
- Tępcz-1: 3318.0–3349.0 m.

The Pasłęk Formation (Llandovery – Aeronian – Telychian) in the Polish part of the Peribaltic Syneclise is represented by intercalations of dark bituminous mudstones and variably bioturbated light grey to green mudstones. The top of the Pasłęk Formation corresponds to the Llandovery/Wenlock boundary (*centrifugus* to *murchisoni* graptolite zone; Modliński et al., 2006; Porębski and Podhalańska, 2019; Podhalańska, 2017, 2019; Podhalańska et al., 2020). The thickness of the formation varies from 28.0 m to 43.5 m.

Pelpin Claystone Formation

The formation occurs in the following wells:

- Borcz-1: 3510.0–3637.0 m – Wenlock part,
- Niestępowo-1: ?3262.0–3412.0 m – Wenlock part,
- Miłowo-IG: 3608.5–3739.0 m – Wenlock part,
- Gapowo B-1: 4060.0–4164.0 m – Wenlock part,
- Tępcz-1: 3173.0–3318.0 m – Wenlock part.

The age of the Pelplin Formation in this part of the Peribaltic Syneclise is defined as the Wenlock – lower Ludlow (Sheinwoodian – Ludfordian). The dominant lithology of the

Pelplin Formation comprises dark grey mudstones, interbedded with calcareous-clayey mudstones. In the uppermost part, siliciclastic intercalations of shelly detritus and bioclastic limestones are present (Porębski and Podhalańska, 2019). Sedimentological studies show a significant predominance of assemblages of horizontally and lenticularly laminated mudstones of lithofacies association L-4 (after Feldman Olszewska and Roszkowska-Remin, 2016) or association AF3: clayey banded mudstones, often non-bioturbated (after Dziadzio et al., 2017). Both the upper and basal boundaries of the formation are characterized by gradual transition. The basal part of the formation (Wenlock) is characterized by better prospective parameters and thickness of ca. 130 m. The distribution of the Pelplin Formation succession in the analyzed area is shown in Fig. 2.26. The total thickness of the Pelplin Formation with the lower Ludlow (Gorstian) is approximately 255 m.

Puck Claystone and Calcareous Claystone Formation, Kociewie Claystone and Mudstone Formation, upper part of the Pelplin Claystone Formation

This interval occurs in the following wells:

- Borcz-1: 1834.0–3510.0 m,
- Niestępowo-1: 1717.0–2557.0 m – Puck and Kociewie formations,
- Miłowo-1: 2045.0–3739.0 m – Puck, Kociewie and Pelplin formations undivided,
- Gapowo B-1: 1895.0–3210.0 m – Puck and Kociewie formations,
- Tępcz-1: 1449.0–3173.0 m – Puck and Kociewie formations.

The Kociewie and Puck formations represent the greatest thickness (exceeding 2000 m) of the Silurian siliciclastic deposits in the "Kartuzy" tender area, as well as in the whole Peribaltic Syneclise. Most of the Kociewie Formation belongs stratigraphically to the Ludlow (Fig. 2.27). The formation is composed of massive, laminated calcareous mudstones with intercalations of siliciclastic and carbonate siltstones (Mazur et al., 2017; Podhalańska, 2019). In the upper part of the formation, the Reda Member has been separated (Modliński et al., 2006). The Puck Formation (Pridoli) consists of mudstones and claystones with mainly benthic fauna.

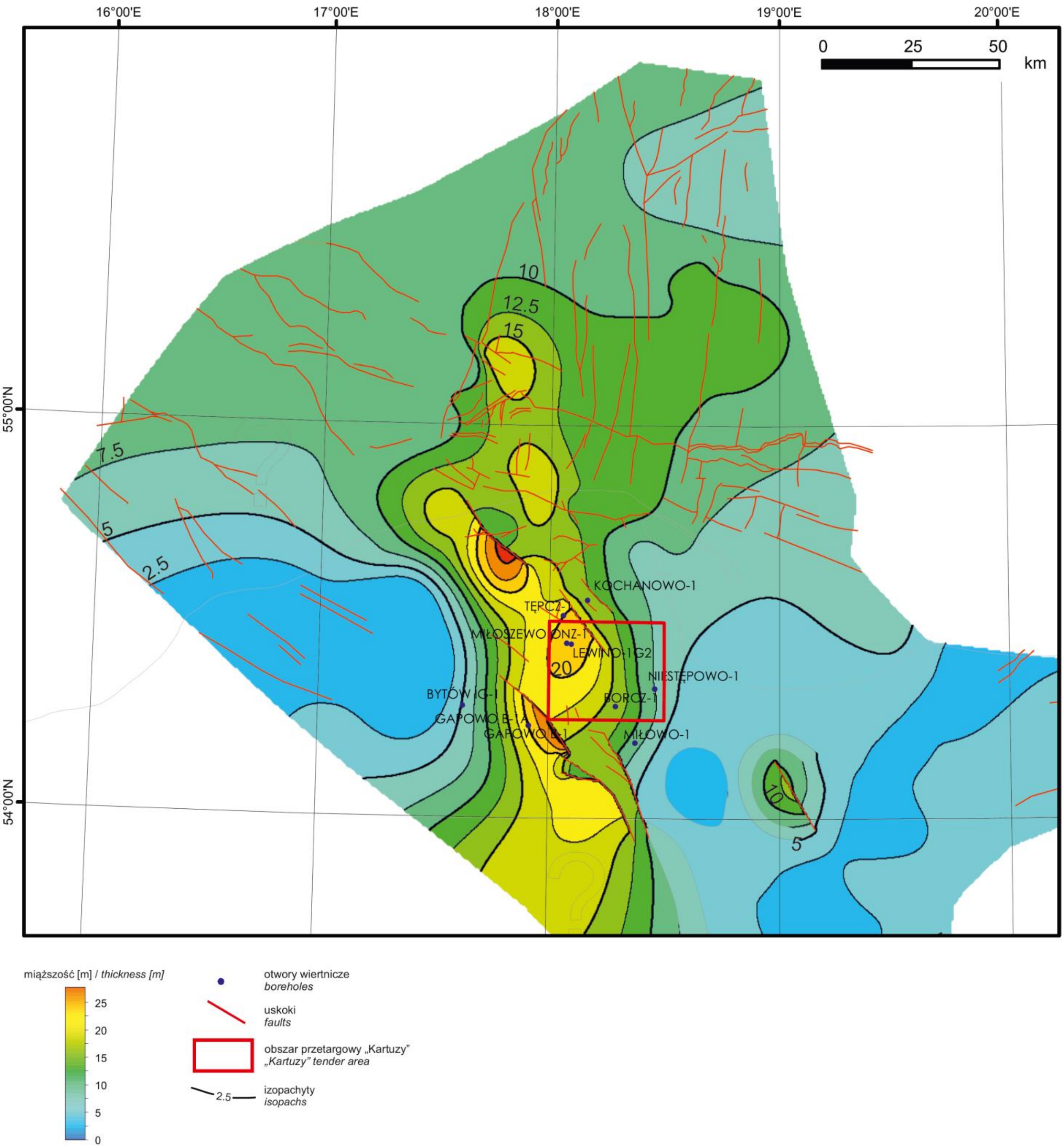


Fig. 2.25. The "Kartuzy" tender area in relation to the Jantar Formation thickness (Podhalańska et al., 2020; modified).

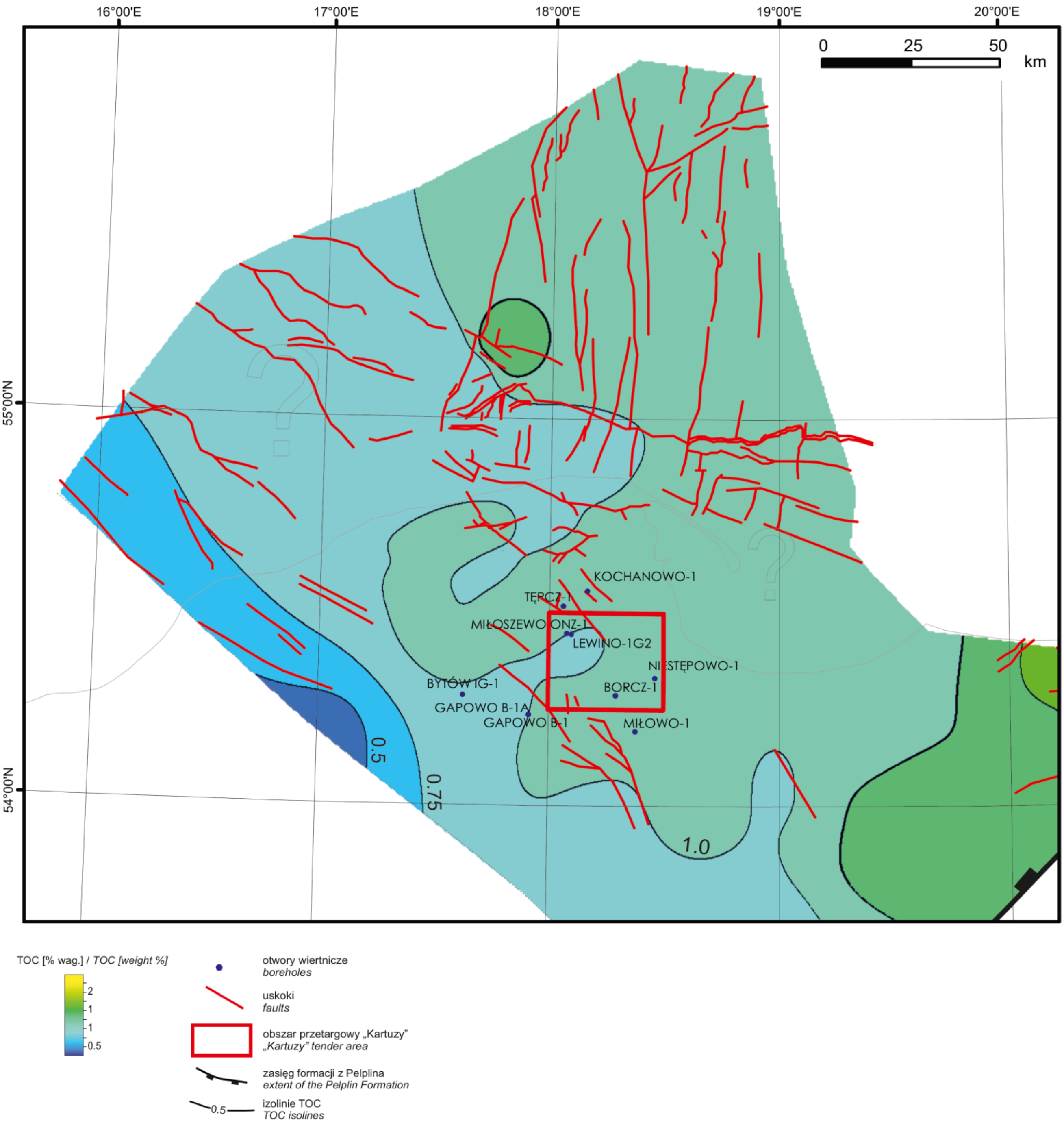


Fig. 2.26. The "Kartuzy" tender area in relation to the Pelplin Formation thickness (Podhalańska et al., 2020; modified).

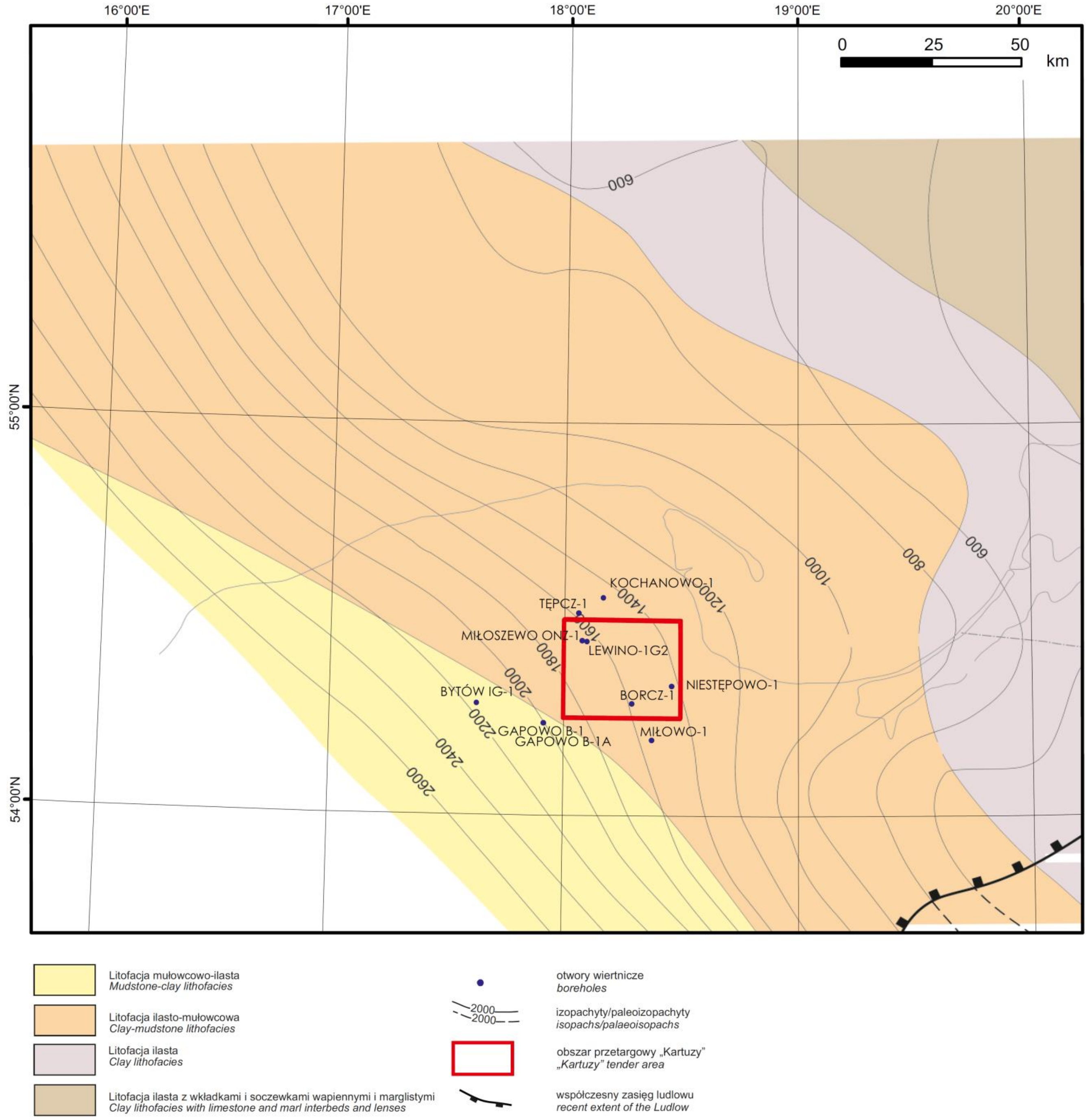


Fig. 2.27. The "Kartuzy" tender area in the lithofacies-palaeothickness map of the Ludlow (Modliński et al., 2010; modified).

2.2.4. PERMIAN

Extent and thickness

The Permian deposits were drilled in the following wells (see Chapter 5):

- Borcz-1: 1448.5–1834.0 m,
- Niestępowo-1: 1340.0–1717.0 m,
- Lewino-1G2,
- Miłoszewo ONZ-1: 1169.0–1520.0 m,
- Miłowo-1: 1685.5–2045.0 m,
- Gapowo B-1: 1495.0–1895.0 m,
- Tępcz-1: 1098.0–1449.0 m.

In the "Kartuzy" tender area, the Silurian sediments are covered by the Permian deposits of 350–385 m thickness (Wagner, 1998, Fig. 2.28).

Lithology and stratigraphy
Rotliegend – Darłowo Formation

The Gapowo B-1 well is the only one where the Rotliegend deposits (Darłowo Formation, 43 m thick) were encountered at a depth of 1852.0–1895.0 m.

Zechstein

The Zechstein deposits in the "Kartuzy" and adjacent areas include the PZ1–PZ3 cyclothems (Werra, Stassfurt, Leine) and the residual part of the PZ4 (Aller). The PZ1 Werra cyclothem is represented by a continuous succession starting with the Basal Conglomerate (Zp1), Zechstein Limestone (Ca1) or Kupferschiefer (T1; Figs 2.29–2.31). The PZ2 Stassfurt and PZ3 Leine cyclothems are highly reduced (Figs 2.32–2.35). The Main Dolomite (Ca2) is an important lithostratigraphic level, as it contains hydrocarbon accumulations in the Polish Lowlands. The "Kartuzy" tender area is located within the Main Dolomite carbonate platform and its slope (Fig. 2.34). Lithological analysis of the Main Dolomite succession in the Borcz-1 well shows the presence of mudstone and wackestone rocks that were accumulated on a low-energy carbonate platform. The upper part of the succession is dominated by grainstones and packstones of a platform-interior shoal (Strzelecka, 2017).

In the analyzed area, the Leine (PZ3) cyclothem was deposited on a carbonate platform (Fig. 2.35). The Main Anhydrite (A3), Platy Dolomite (Ca3), and Grey Salt Clay (T3) were divided into particular boreholes, as well as residual deposits of the Aller cyclothem (PZ4) (Fig. 2.36). The thickness of the individual lithostratigraphic units is presented in Tab. 2.1.

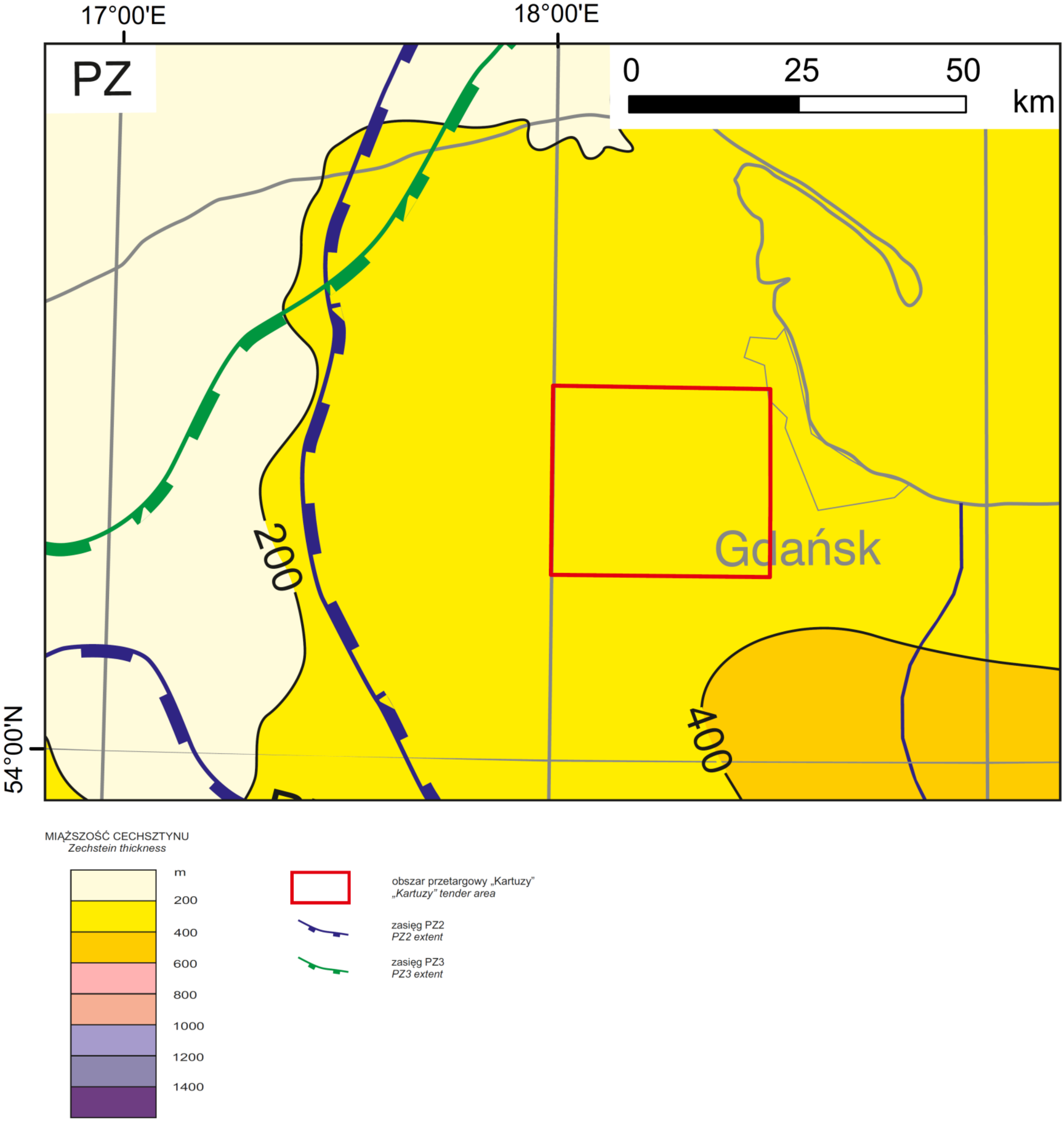


Fig. 2.28. Location of the "Kartuzy" tender area in the Zechstein thickness map (Wagner, 1998; modified).

Lithostratigraphy		Depth [m] (thickness) [m]						
PZ4		**Borcz-1**	**Niestępowo-1**	**Lewino-1G2**	**Miłoszewo ONZ-1**	**Miłowo-1**	**Gapowo B-1**	**Tępcz-1**
[PZt]			1340.0–1358.0 (18)	Until 29-11-2022 the entity has exclusive right to use geological information	1169.5–1194.0 (24.5)		1495.0–1500.0 (5)	
PZ3								
A3	**Main Anhydrite**	1448.5–1488.0 (39.5)	1358.0–1392.5 (34.5)		1194.0–1205.5 (11.5)	1685.5–1726.5 (41)	1500.0–1525.0 (25)	1098.0–1119.0 (21)
Ca3	**Platy Dolomite**	1488.0–1490.5 (2.5)	1392.5–1396.0 (3.5)		1205.5–1209.2 (3.7)	1726.50–1729.50 (3)	1525.0–1530.0 (5)	1119.0–1125.0 (6)
T3	**Grey Pelite**		1396.0–1396.5 (0.50)		1209.2–1209.5 (0.3)			
PZ2								
A2r	**Screening Anhy-drite**		1396.5–1398.5 (2)					
Na2	**Older Halite**		1398.5–1404.0 (5.5)					
A2	**Basal Anhydrite**	1490.5–1501.0 (10.5)	1404.0–1422.5 (18.5)		1209.5–1214.0 (4.5)	1729.5–1740.0 (10.5)	1530.0–1537.0 (7)	1125.0–1128.5 (3.5)
Ca2	**Main Dolomite**	1501.0–1535.5 (34.5)	1422.5–1451.5 (29)		1214.0–1255.5 (41.5)	1740.0–1768.0 (28)	1537.0–1580.0 (43)	1128.5–1170.0 (41.5)
PZ1								
A1g	**Upper Anhydrite**	1535.5–1564.0 (28.5)	1451.5–1475.5 (24)		1255.5–1283.5 (28)	1768.0–1870.0 (102)	1580.0–1614.0 (34)	1170.0–1195.5 (25.5)
Na1	**Oldest Halite**	1564.0–1767.5 (203.5)	1475.5–1577.5 (102)		1283.5–1443.0 (159.5)	1870.0–1938.5 (68.5)	1614.0–1700.0 (86)	1195.5–1390.5 (195)
A1d	**Lower Anhydrite**	1767.5–1825.0 (57.5)	1577.5–1705.5 (128)		1443.0–1510.0 (67)	1938.5–2036.0 (97.5)	1700.0–1836.0 (136)	1390.5–1436.0 (45.5)
Ca1 + T1	**Zechstein Limestone and Kupferschiefer**	1825.0–1834.0 (9)	1705.5–1716.5 (11)		1510.0–1520.0 (10)	2036.0–2045.0 (9)	1836.0–1852.0 (16)	1436.0–1449.0 (13)
Zp1	**Basal Conglomerate**		1716.5–1717.0 (0.5)					
Zechstein thickness		**385.50**	**377.0**		**350.5**	**359.5**	**357.0**	**351.0**

Tab. 2.1. Lithostratigraphy of the Zechstein deposits in the wells located within the "Kartuzy" tender area and in its close neighborhood (CGDB, 2021; Szpetnar-Skierniewska and Krajewski, 2018; Kubala, 2013; Chruścińska and Sikorska-Piekut, 2018).

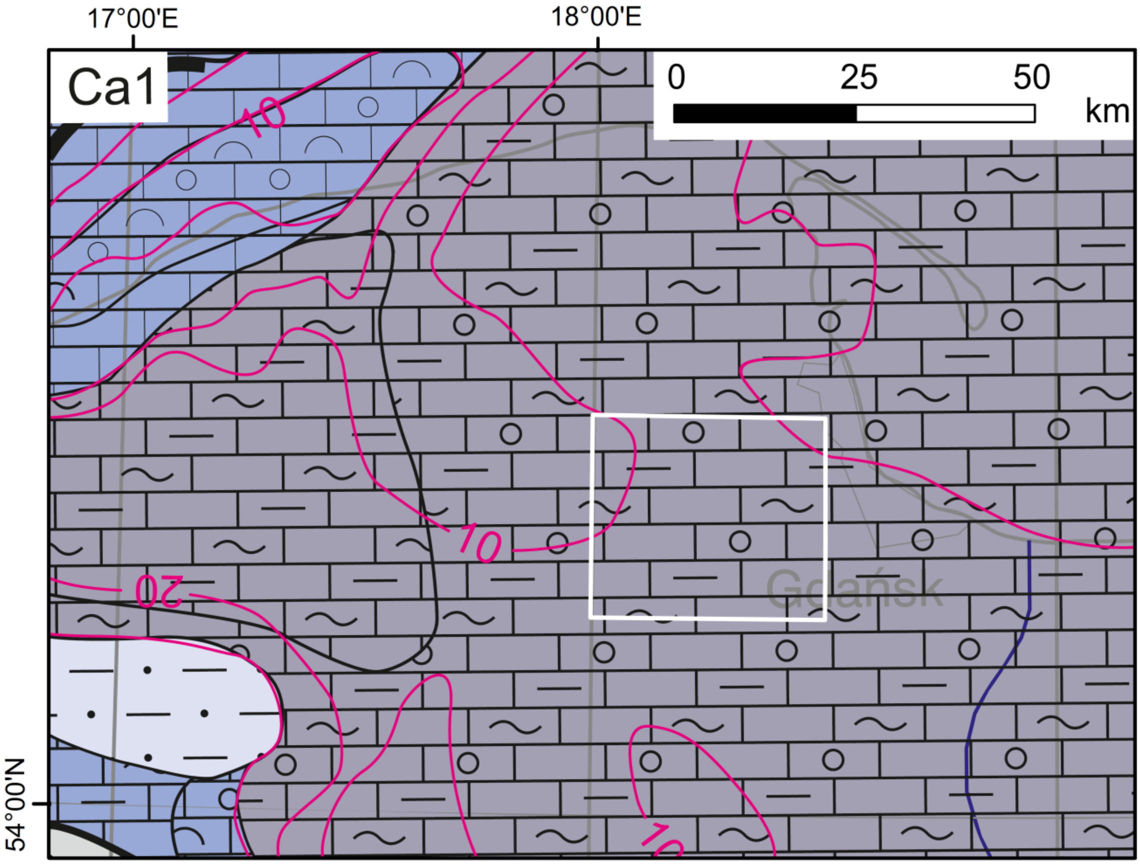


Fig. 2.29. Location of the "Kartuzy" tender area in the palaeogeographic map of the Zechstein Limestone Ca1; explanations in Fig. 2.31 (Wagner, 1998; modified).

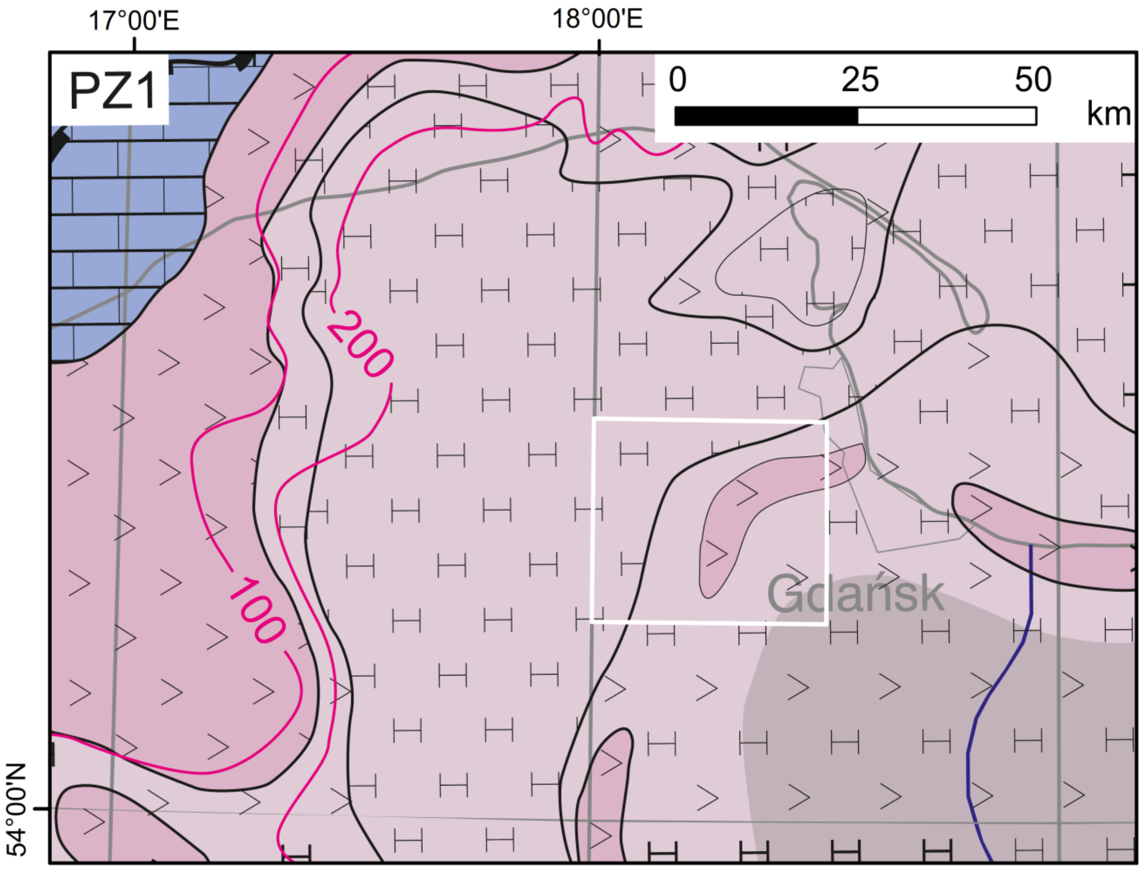


Fig. 2.30. Location of the "Kartuzy" tender area in the palaeogeographic map of the PZ1 cyclothem; explanations in Fig. 2.31 (Wagner, 1998; modified).

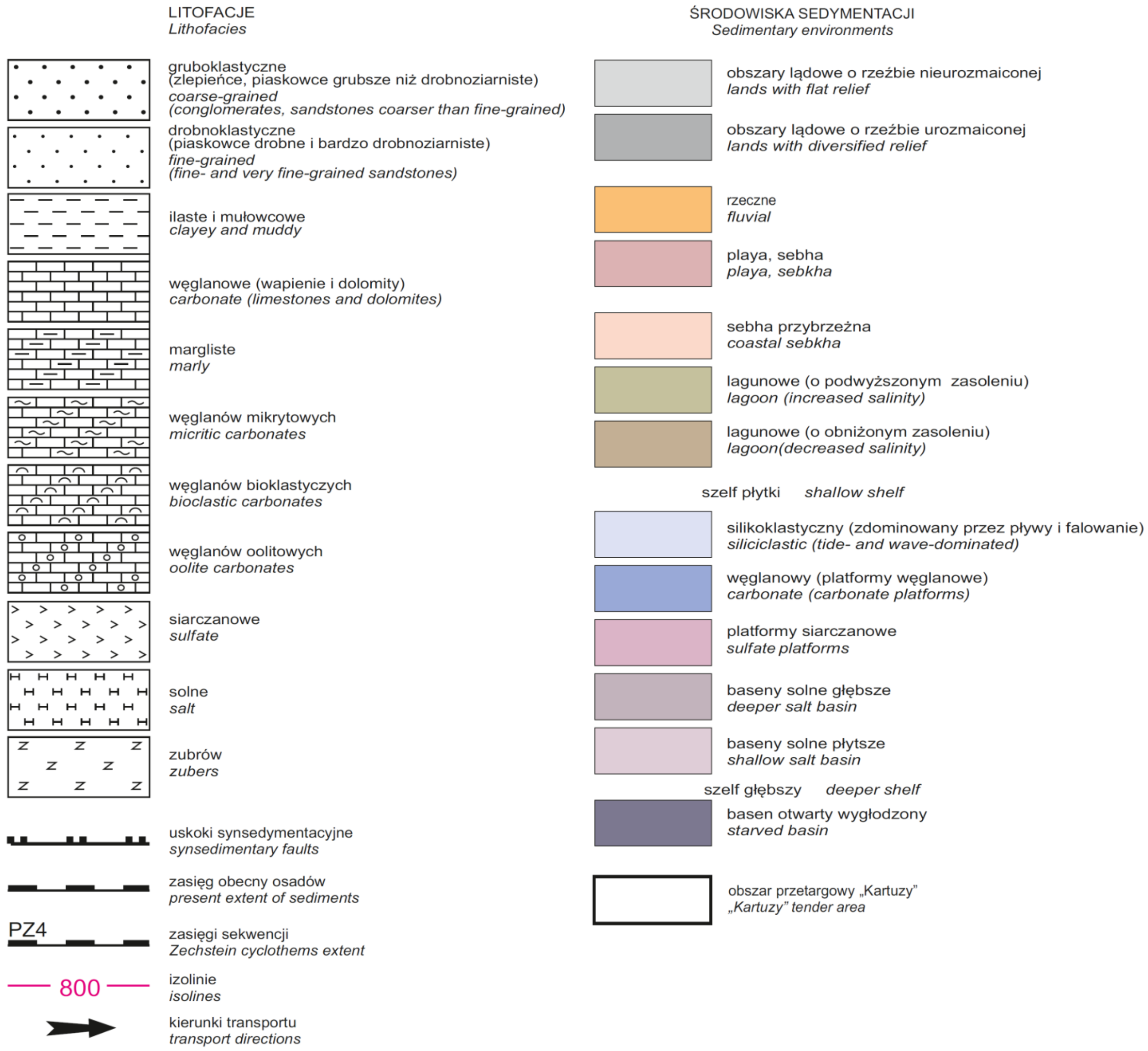


Fig. 2.31. Explanations to the palaeogeographic maps of the Zechstein: Zechstein Limestone Ca1, PZ1 cyclothem, PZ2, PZ3 cyclothems, Main Dolomite Ca3 and PZ4 cyclothem (Wagner, 1998; modified).

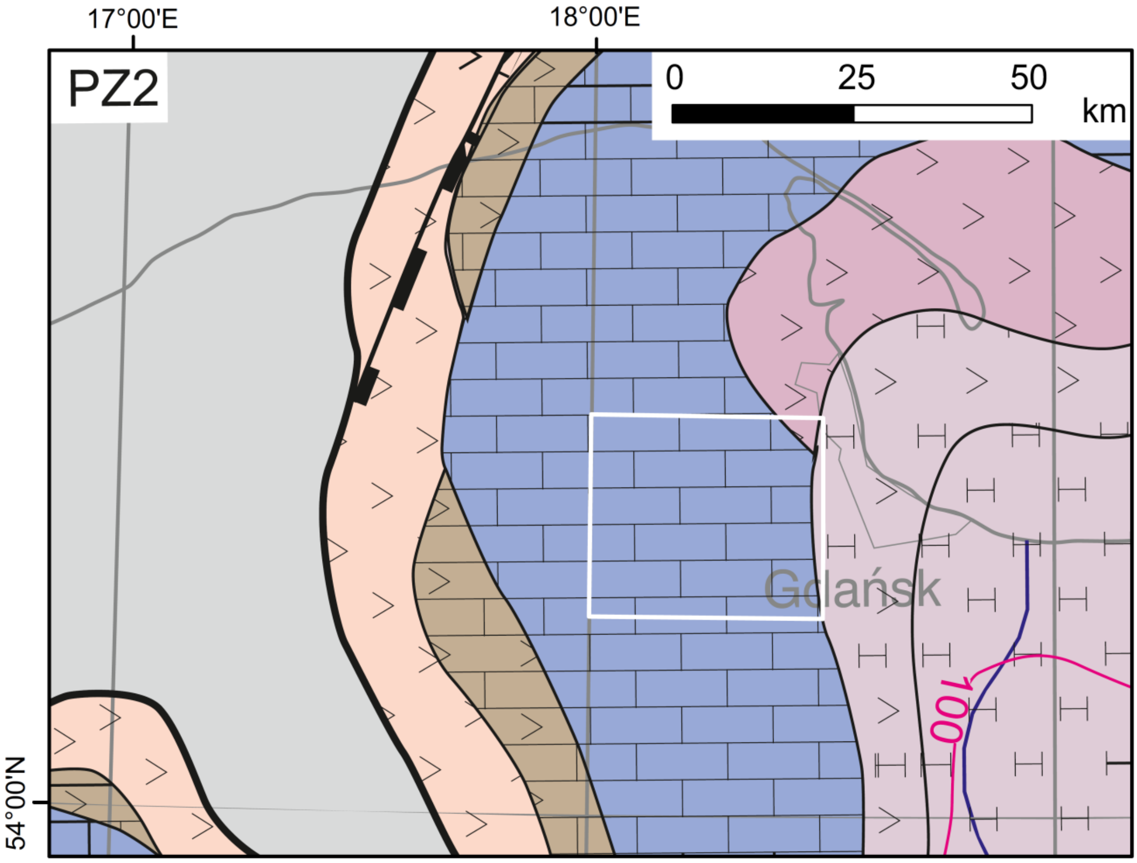


Fig. 2.32. Location of the "Kartuzy" tender area in the palaeogeographic map of the PZ2 cyclothem; explanations in Fig. 2.31 (Wagner, 1998; modified).

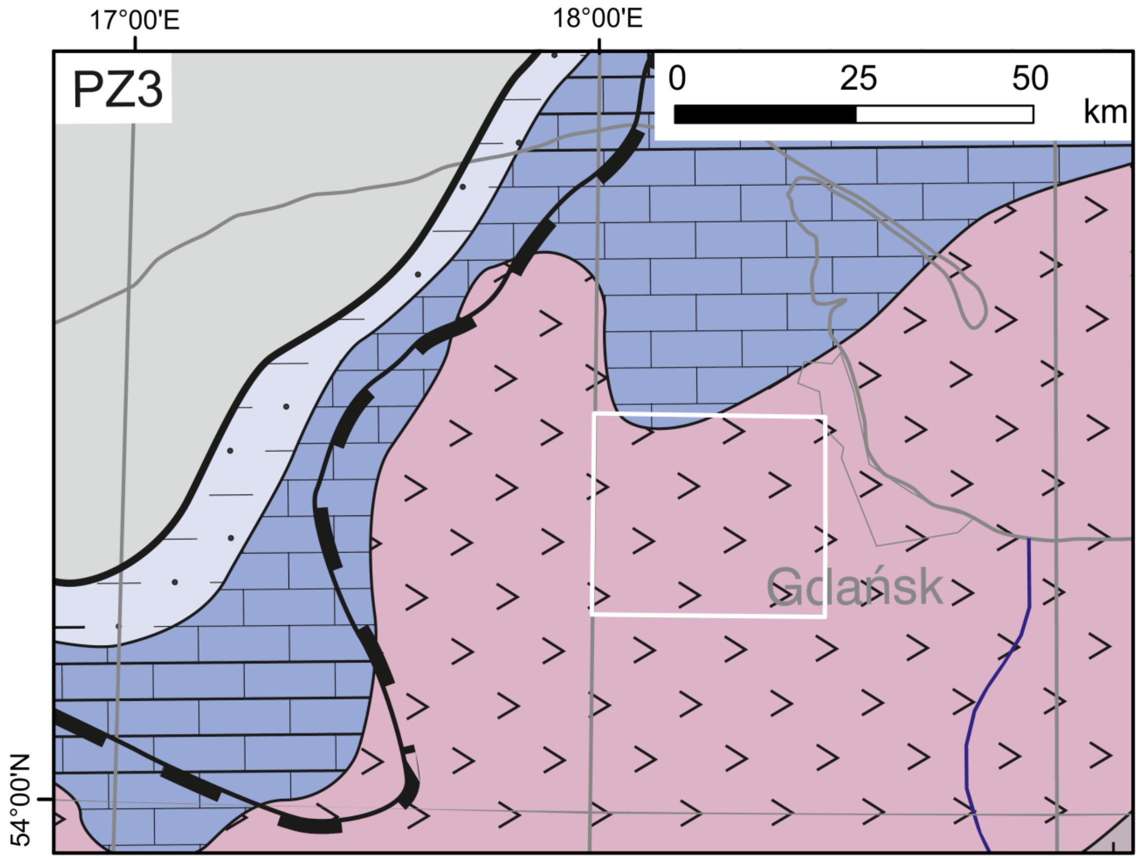


Fig. 2.33. Location of the "Kartuzy" tender area in the palaeogeographic map of the PZ3 cyclothem; explanations in Fig. 2.31 (Wagner, 1998; modified).

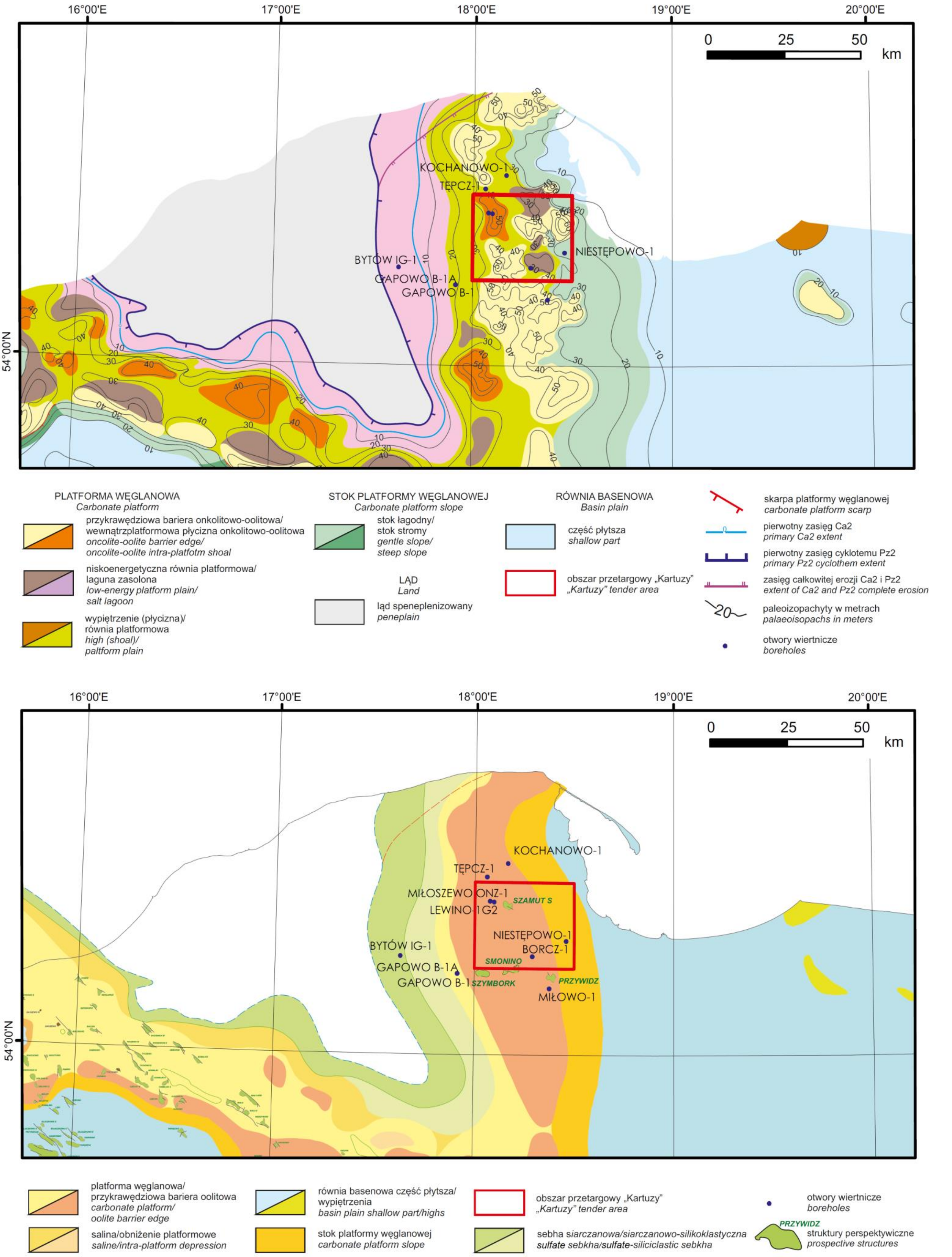


Fig. 2.34. Location of the "Kartuzy" tender area in the palaeogeographic map of the Main Dolomite Ca2 (upper map – Wagner, 2012; modified; lower map – Buniak et al., 2013; modified).

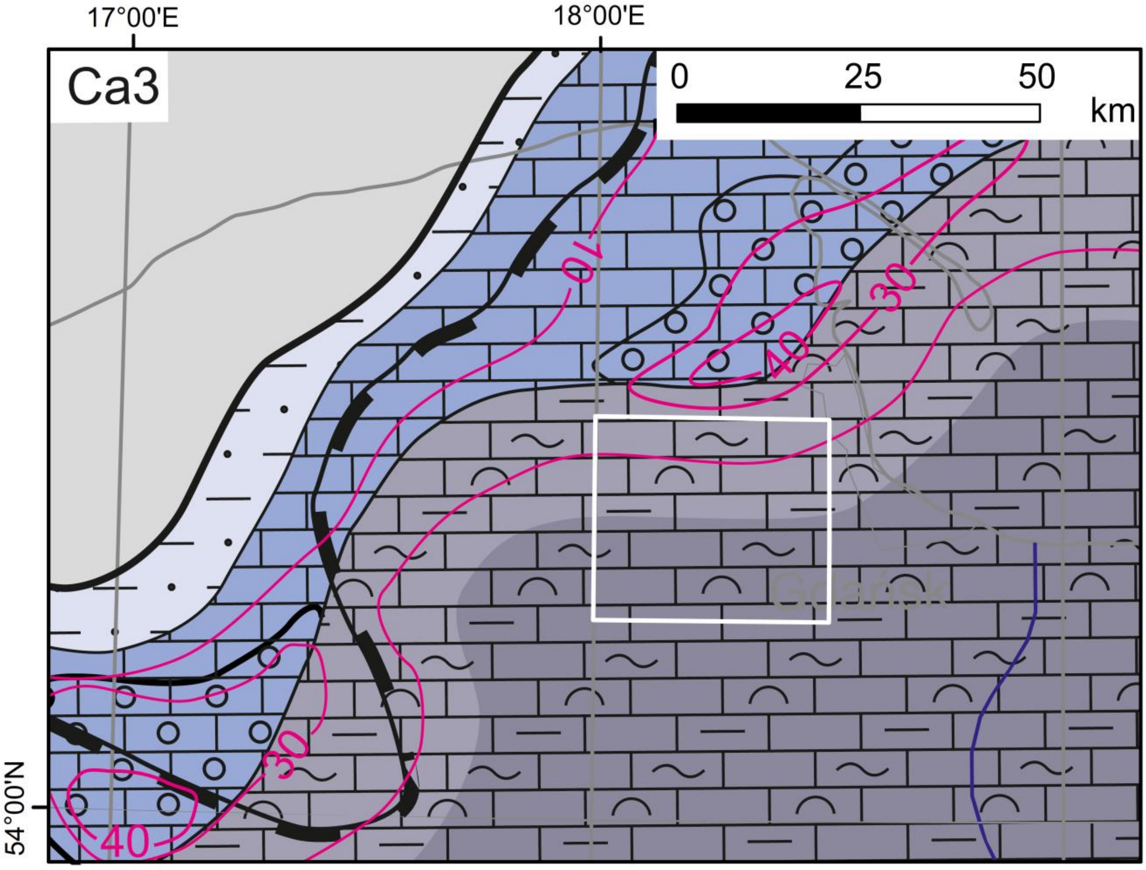


Fig. 2.35. Location of the "Kartuzy" tender area in the palaeogeographic map of the Platy Dolomite Ca3; explanations in Fig. 2.31 (Wagner, 1998; modified).

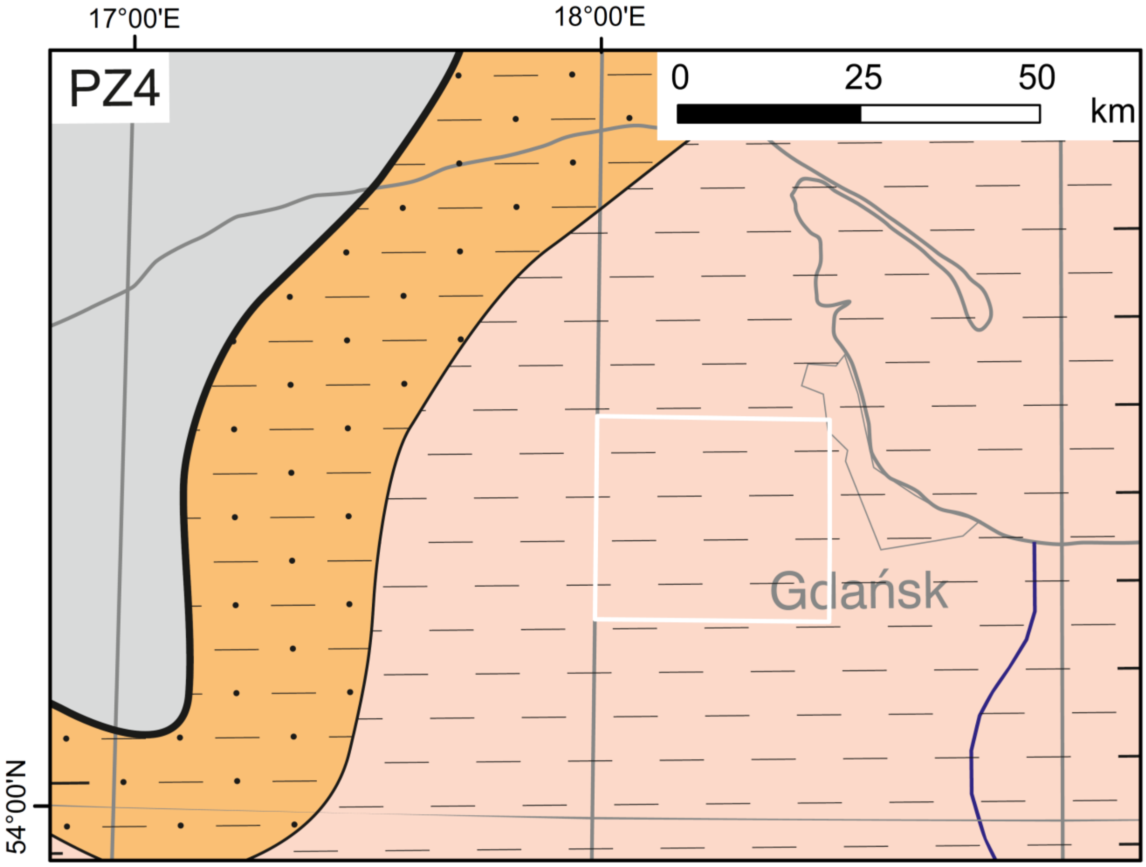


Fig. 2.36. Location of the "Kartuzy" tender area in the palaeogeographic map of the PZ4 cyclothem; explanations in Fig. 2.31 (Wagner, 1998; modified).

2.2.5. TRIASSIC

Extent and thickness

The Triassic deposits were drilled in the following wells (see chapter 5):

- Borcz-1: 894.0–1448.5 m,
- Niestępowo-1: 792.0–1340.0 m,
- Lewino-1G2,
- Miłoszewo ONZ-1: 770.0–1169.5 m,
- Miłowo-1: 1092.0–1685.0 m,
- Gapowo B-1: 953.0–1495.0 m,
- Tępcz-1: 812.5–1098.0 m.

In the "Kartuzy" tender area, there is only the Lower Triassic – Bunter Sandstone present, attaining a thickness of 395.5–593.0 m. A continuous full succession of the Lower Triassic of the greatest thickness is observed in the Borcz-1, Niestępowo-1, Miłoszewo ONZ-1 and Gapowo B-1 boreholes.

Lithology and stratigraphy

The Lower Triassic – Bunter Sandstone succession is thick in the "Kartuzy" tender area. Deposition of the Bunter Sandstone deposits took place in the epicontinental Central European Basin. Middle and Upper Triassic deposits are absent due to erosion of the marginal part of the Triassic basin (Deczkowski et al., 1997; Iwanow, 1998).

The Bunter Sandstone is divided into three parts – lower (the thickest), middle, and upper (Röt) with predominant mudstone, claystone, and sandstone assemblages. Because of the lack of both drill cores and petroleum prospects, the interval has not been investigated in detail.

Lower Bunter Sandstone

- Borcz-1: 1181.5–1448.5 m,
- Niestępowo-1: 1090.0–1340.0 m – Baltic Formation,
- Miłoszewo ONZ-1: 920.0–1169.0 m – Baltic Formation,
- Miłowo-1: 1381.5–1685.0 m,
- Gapowo B-1: 1212.0–1495.0 m – Baltic Formation,
- Tępcz-1: 856.0–1098.0 m.

Middle Bunter Sandstone

- Borcz-1: 997.0–1181.5 m,
- Niestępowo-1: 1038.0–1090.0 m,
- Miłoszewo ONZ-1: 872.0–920.0 m – Pomerania Formation,
- Miłowo-1: 1197.5–1381.5 m,
- Gapowo B-1: 978.0–1212.0 m – Pomerania and Połczyn formations
- Tępcz-1: 812.5–856.0 m.

Upper Bunter Sandstone (Röt)

- Borcz-1: 894.0–997.0 m,
- Niestępowo-1: 792.0–812.0 m – Elbląg Formation and Bartoszyce Beds,
- Miłowo-1: 1092.0–1197.5 m,
- Gapowo B-1: 953.0–978.0 m – Barwice Formation.

2.2.6. JURASSIC

Extent and thickness

The Jurassic succession was drilled in the following wells (see Chapter 5):

- Borcz:1 735.0–894.0 m,
- Niestępowo-1: 625.5–792.0 m,
- Lewino-1G2,
- Miłoszewo ONZ-1: 612.5–770.0 m,
- Miłowo-1: 864.0–1092.0 m,
- Gapowo B-1: 857.0–953.0 m,
- Tępcz-1: 604.5–812.5 m.

In the "Kartuzy" tender area, the Jurassic is represented by a discontinuous succession of variable thickness between 96 and 262 m.

Lithology and stratigraphy

In the "Kartuzy" tender area, the Lower Jurassic deposits are absent. The Middle Jurassic (Bathonian and Callovian) is represented by sandy and clayey deposits with ferruginous ooids in the basal part of the profile, passing to mudstones and marls deposited inland with periodic offshore influence (Dayczak-Calikowska, 1976). Carbonate-clastic deposits of the Upper Jurassic occasionally occur in the analyzed area (Niemczycka, 1997). The lower Oxfordian consists mainly of sandstones and mudstones, but the upper part of the profile is represented by sandstones with limestone intercalations, overlain by limestones.

Lower/Middle Jurassic

- Borcz-1: 857.0–894.0 m,
- Niestępowo-1: 655.0–792.0 m,
- Miłoszewo ONZ-1: 651.0–770.0 m,
- Miłowo-1: 1036.5–1092.0 m,
- Gapowo B-1: 904.0–953.0 m,
- Tępcz-1: 682.0–812.0 m.

Upper Jurassic

- Borcz-1: 735.0–857.0 m,
- Niestępowo-1: 625.5–655.0 m,
- Miłoszewo ONZ-1: 612.5–651.0 m,
- Miłowo-1: 864.0–1036.5 m,
- Gapowo B-1: 857.0–953.0 m,
- Tępcz-1: 604.5–682.0 m.

2.2.7. CRETACEOUS

Extent and thickness

The Cretaceous deposits occur in the following wells (see Chapter 5):

- Borcz-1: 205.0–735.0 m,
- Niestępowo-1: 217.0–625.5 m,
- Lewino-1G2,
- Miłoszewo ONZ-1: 274.0–612.5 m,
- Miłowo-1: 230.0–864.0 m,
- Gapowo B-1: 323.0–857.0 m,
- Tępcz-1: 215.0–604.5 m.

In the "Kartuzy" tender area and in the adjacent areas the Cretaceous is represented by a discontinuous sedimentary succession of variable thickness between 337 and 634 m.

Lithology and stratigraphy

In the "Kartuzy" tender area the Lower Cretaceous is probably absent. In the new shale gas exploration wells, the Cretaceous has not been divided into stages. The thickness of the Cretaceous varies to more than 600 m in the Miłowo-1 well. More details on the Upper Cretaceous stratigraphy can be found in Tab. 2.2.

The Upper Cretaceous succession is represented by clastic sediments passing into gaize and marls. The deposition took place in a shallowing epicontinental basin during a high global sea level.

Stage	Niestępowo-1 [m]	Miłoszewo ONZ-1 [m]	Gapowo B-1 [m]
Upper Campanian	217.0–379.0	274.0–321.0	323.0–453.0
Lower Campanian	379.0–430.0	321.0–389.5	323.0–453.0
Santonian	430.0–497.0	389.5–428.0	453.0–622.0
Coniacian	497.0–528.0	428.0–455.0	453.0–622.0
Turonian	528.0–606.0	455.0–541.0	622.0–795.0
Cenomanian	606.0–625.5	541.0–612.5	795.0–857.0

Tab. 2.2. Upper Cretaceous stratigraphy in the selected wells from the "Kartuzy" tender area (CGDB, 2021).

2.3.8. CENOZOIC

Extent and thickness

The Cenozoic was drilled in the following wells (see Chapter 5):

- Borcz-1: 0–205.0 m,
- Niestępowo-1: 0–217.0 m,
- Lewino-1G2,
- Miłoszewo ONZ-1: 0–274.0 m,
- Miłowo-1: 0–230.0 m,
- Gapowo B-1: 10.0–332.0 m,
- Tępcz-1: 0–215.0 m.

The Cenozoic succession, comprising the Paleogene and Neogene, is 205–322 m thick and overlain by Quaternary deposits.

Lithology and stratigraphy

The Paleogene, Neogene and Quaternary deposits are not subdivided and are represented by siliciclastic sediments of variable grain size distribution (see Chapter 2.3).

2.3. HYDROGEOLOGY

The “Kartuzy” tender area is located in the Lower Vistula water region and belongs to GWBs 11 and 13. According to the regional classification of fresh groundwater, it is situated in the East Sea Region of the Coastal Baltic Province.

In the “Kartuzy” area, fresh groundwater is found within regional hydrogeological system (Gdansk Subtrough) and consists of Quaternary, Neogene-Paleogene and Upper Cretaceous multiaquifer complexes (Figs 2.40–2.41). Only the first of these complexes occurs continuously throughout the area and meets the parameters of usable aquifers according to the MhP criteria. The Neogene-Paleogene complex is relatively poorly recognized and its utilitarian nature has only been found locally. The Upper Cretaceous hydrogeological complex is continuous; however, in the western part of the area, it does not have appropriate usable parameters. These multi-aquifer complexes are in hydraulic contact with each other. The groundwater recharge takes place in the upland of the Kashubian Lakeland District, within which the ‘Kartuzy’ area is located, and the groundwater drainage base is the Gulf of Gdańsk along with the coastal lowlands and Żuławy. The recognition of deeper aquifers is regional in nature. They contain salty (mineralized) water, and its mineralization increases with depth.

The Quaternary groundwater complex, associated with sandy-gravelly sediments of intermoraine and buried glacial valleys, is essential for water supply. Within it, there are two water-bearing horizons. The upper intermoraine horizon represented by sediments of the North Polish Glaciation occurs in the majority of the area, but it is not continuous. It is recognized at depths of several to 60 meters and its groundwater surface remains under low hydrostatic pressure or is unconfined (water table). The aquifer thickness is generally between 10 and 30 meters and the well’s potential discharge is from 30 to 70 m^3/h. The varied confined bed’s thickness may cause the medium or high, less frequently low, risk of anthropogenic pollution flow to aquifer. The groundwater recharge is carried out mainly by infiltration of precipitation and inflow from surface water. The second intermoraine aquifer associated with sandy-gravelly sediments of the Middle and South Polish glaciations occurs throughout the whole “Kartuzy” area, at depths of 30 to more than 100 meters. The level thickness generally ranges from 20 to 50 meters and the well’s potential discharge varies from 50 to 120 m^3/h. The most favorable hydrogeological conditions occur within deeply buried glacial valleys, where the sediments attain a thickness of up to 100 meters and remain in hydraulic contact with the Neogen aquifer. The groundwater table is sub-Artesian, but locally also Artesian. It is recharged by percolation from the layers above. The large thickness of the overlying aquitard layers cause low or very low risk for groundwater quality.

The Quaternary groundwater table is generally located at elevations from 180 m a.s.l. in the upland of the Kashubian Lakeland District to 60 m a.s.l. in the Radunia River valley. The direct water drainage base is the Gulf of Gdańsk and the intermediate bases are the valleys of Radunia and Łeba and the Reda-Łeba buried glacial valley.

The groundwater quality of Quaternary aquifers is generally good or average due to increased content of iron and manganese compounds. In order to protect the quality of the groundwater, outer protection zones have been designated around the major intakes of Gdańsk and Gdynia.

The Neogene-Paleogene and Cretaceous aquifers in the 'Kartuzy' tender area are of minor importance for groundwater supply and only the former is sporadically exploited in a few intakes. The latter one is a very precious groundwater reservoir for which MGWB No. 111 (GZWP nr 111) has been designated to protect.

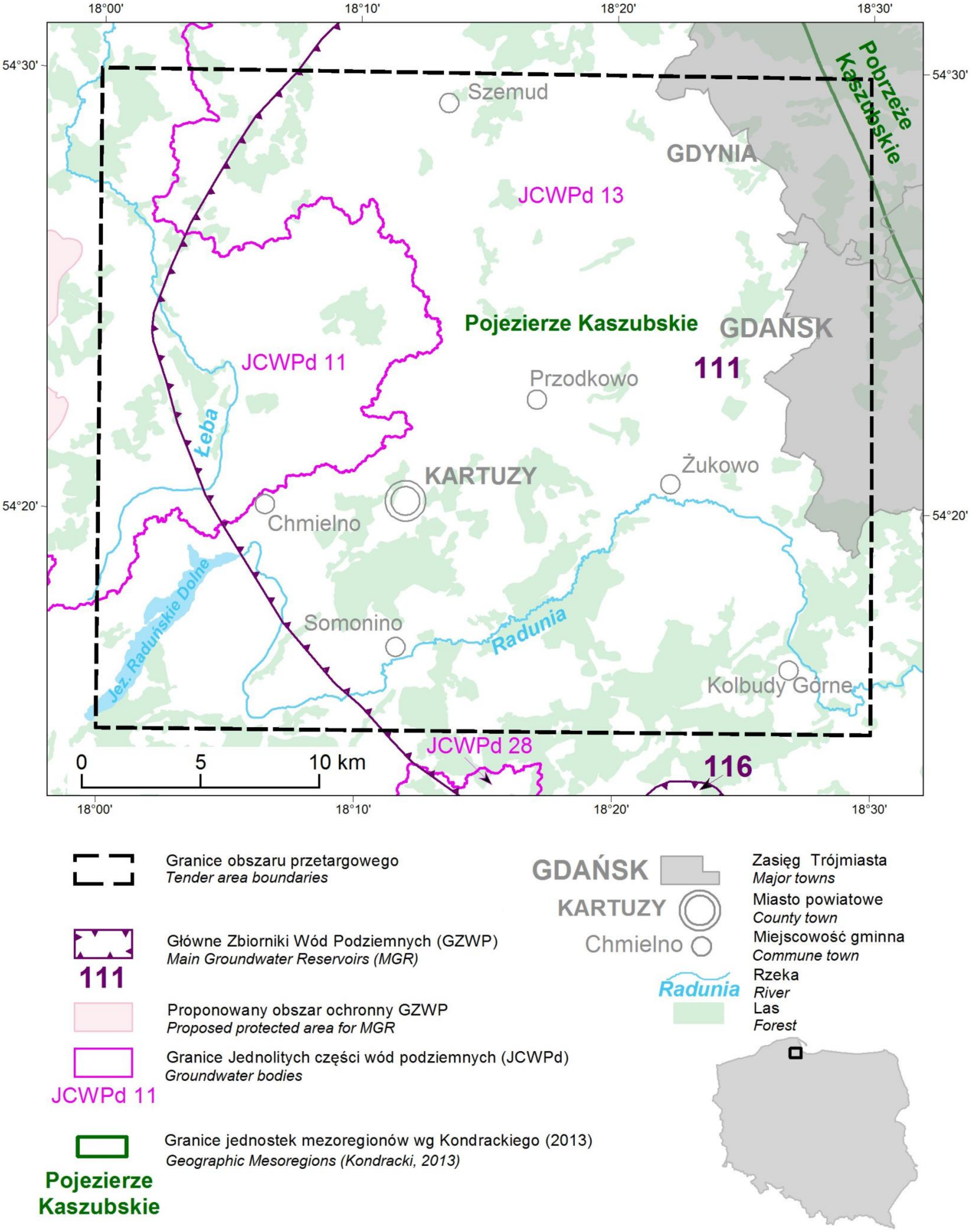


Fig. 2.40. Location of the ”Kartuzy” tender area in the map of geographic regions, main groundwater reservoirs, and groundwater bodies.

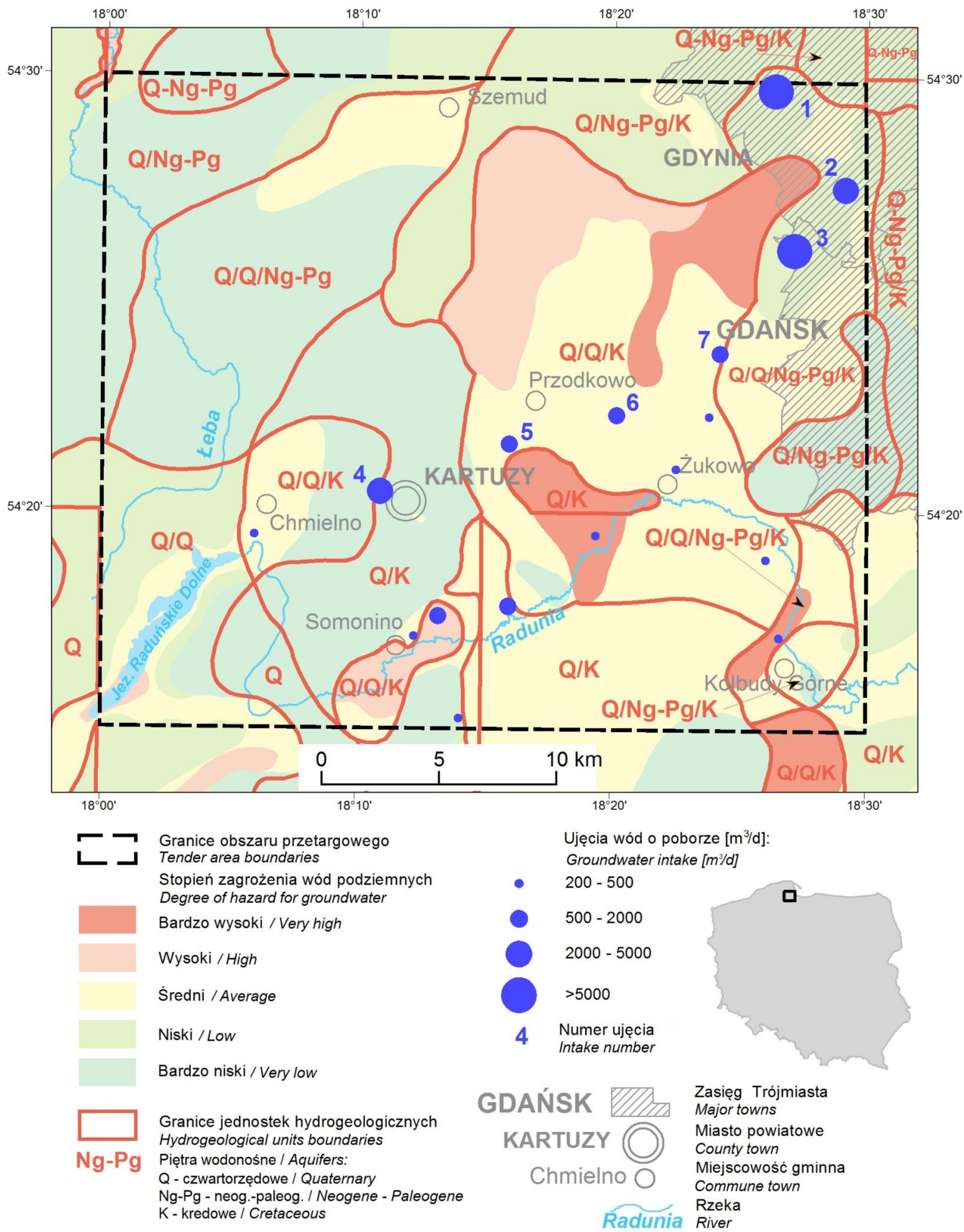


Fig. 2.41. Location of the ”Kartuzy” tender area in relation to the hydrogeological units boundaries.

3. PETROLEUM PLAY
3.1. GENERAL CHARACTERISTICS

The “Kartuzy” tender area is located in the Northern Petroleum Province, within the Baltic Subprovince. The general characteristics of the petroleum play are shown in Fig. 3.1.

A small part of the “Kartuzy” tender area reaches the prospective zone of hydrocarbon exploration in the Middle Cambrian (Fig. 3.2; Stolarczyk et al., 2004). The area is also situated within the prospective zones for unconventional hydrocarbon accumulation in Lower Paleozoic shales (Figs 3.3–3.4; Podhalańska et al., 2018, 2020). Additionally, few prospective structures in the Main Dolomite occur within the tender area (Fig. 2.34).

The three following petroleum plays can be considered in the “Kartuzy” tender area:

- Lower Paleozoic petroleum play in the Middle Cambrian deposits (conventional and unconventional – „tight gas“ type)
- Lower Paleozoic unconventional petroleum play – „shale gas/shale oil“ type.
- Permian conventional petroleum play in the Zechstein (Main Dolomite).

The Permian (Main Dolomite) interval is not the main target for this tender area and is not described in detail, although it is worth underlining that the “Kartuzy” area is located within the Main Dolomite carbonate platform (Fig. 2.34) and coarse-grained carbonates with good reservoir parameters are expected here (oolitic-oncolitic grainstones and packstones; Mikołajewski, 2015; Szpetnar-Skierniewska and Krajewski, 2018). Only in the Borcz-1 borehole, the Main Dolomite was considered a potential reservoir. During the mudlogging, in the 1531.5–1536.0 m depth interval, an increase of gas content was noted in the well logs. Laboratory analyses of cuttings and interpretation of the well logs indicated good reservoir parameters (mean porosity ~18%, mean permeability ~0.434 mD). However, the analyses showed also that the investigated Main Dolomite interval is water-saturated, which excludes it from further investigations.

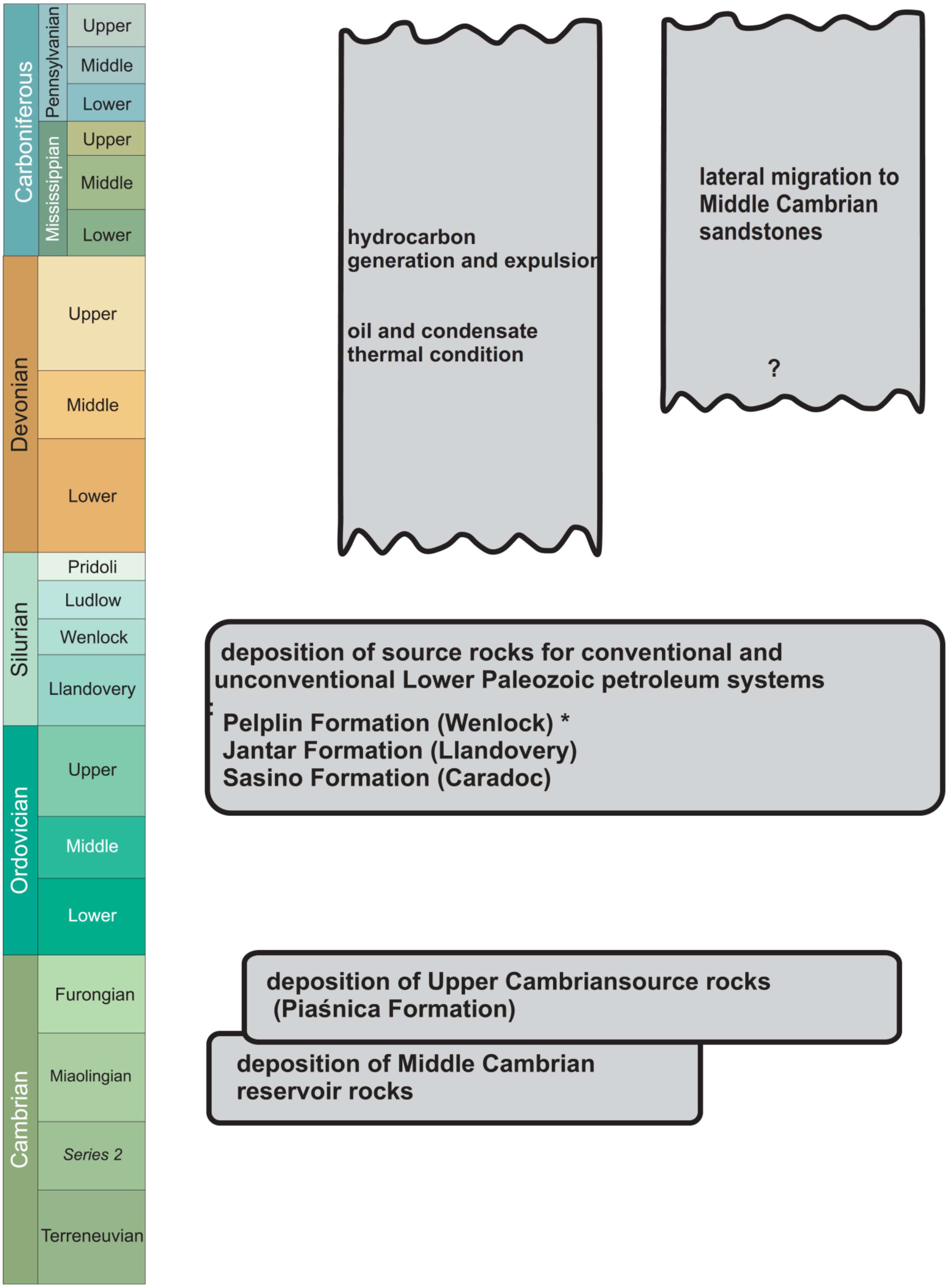


Fig. 3.1. Schematic diagram of petroleum play evolution in the "Kartuzy" tender area.

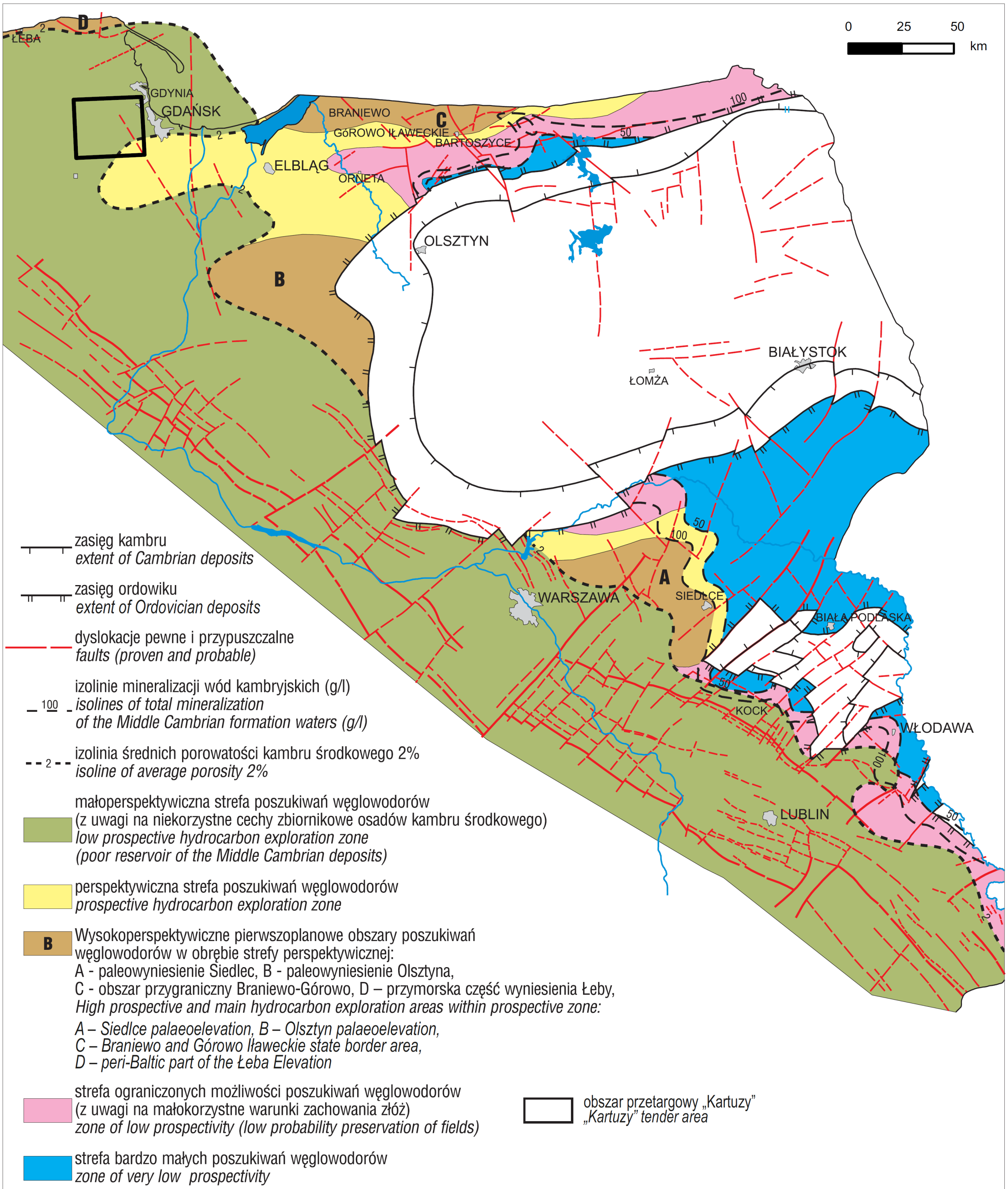


Fig. 3.2. The "Kartuzy" tender area in the map of prospectivity for hydrocarbon exploration zones in the Middle Cambrian (Stolarczyk et al., 2004, modified).

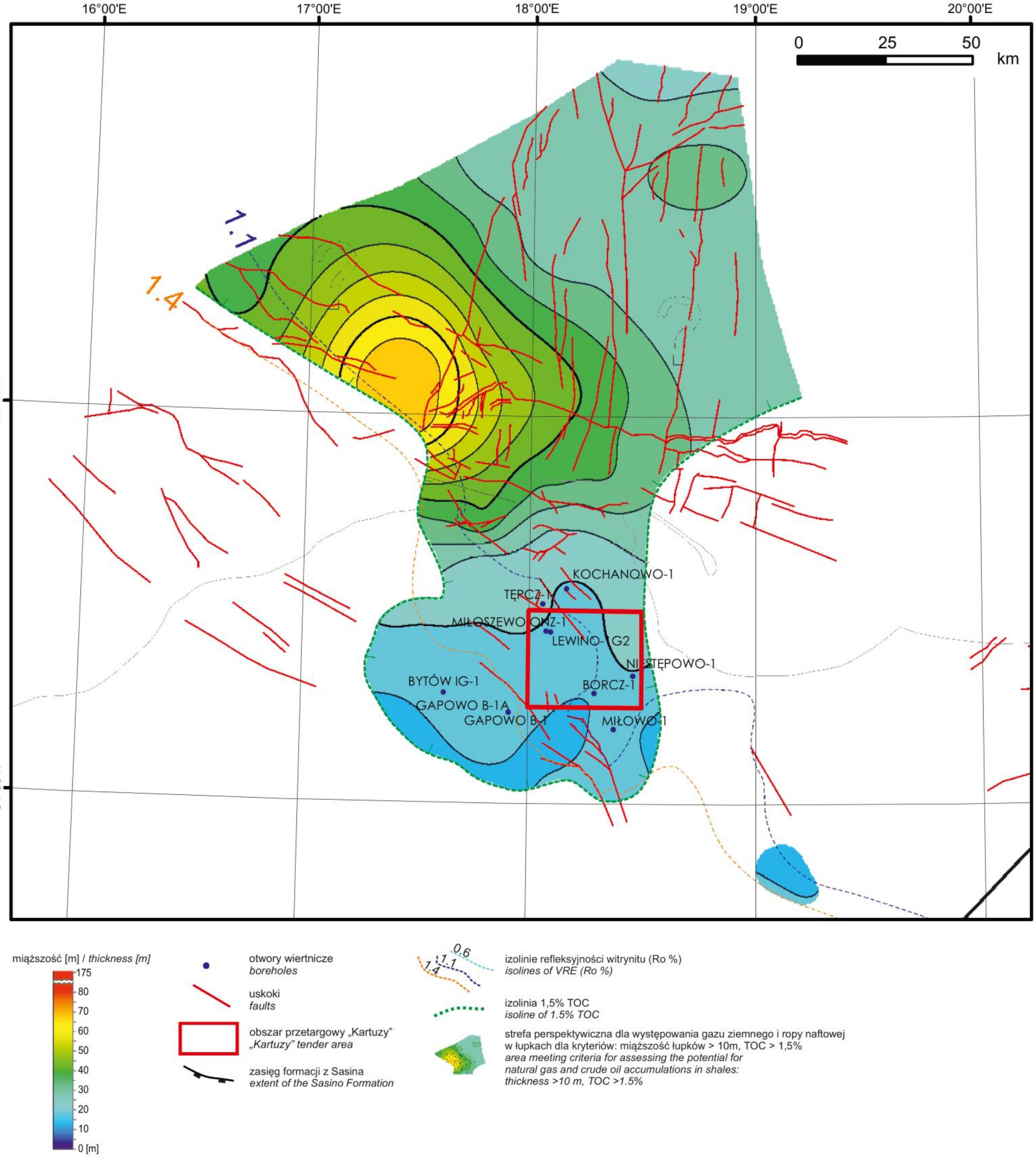


Fig. 3.3. The "Kartuzy" tender area in the map of the prospective hydrocarbon exploration zone in the Sasino Formation (Ordovician; Podhalańska et al., 2020, modified).

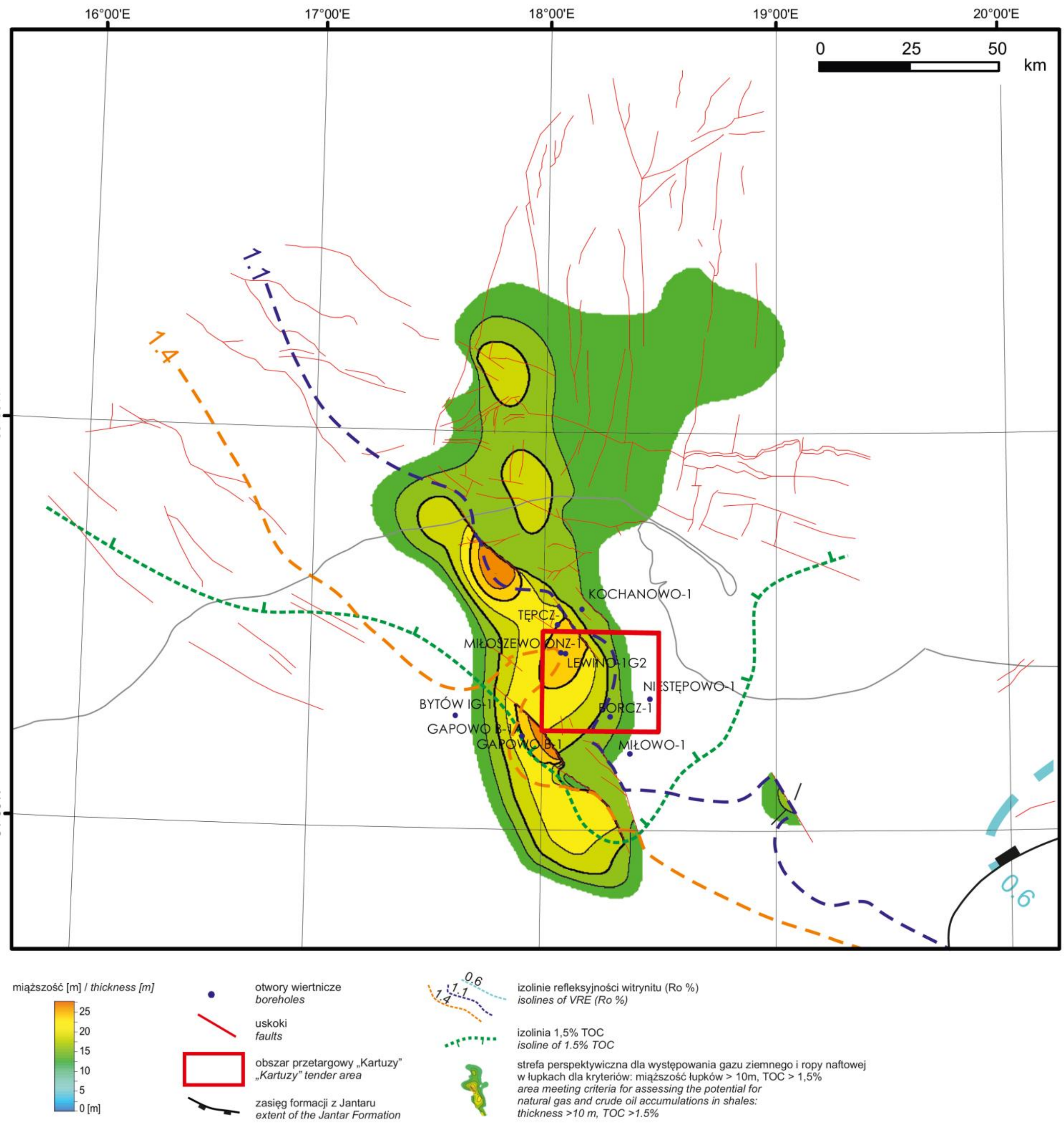


Fig. 3.4. The “Kartuzy” tender area in the map of the prospective hydrocarbon exploration zone in the Jantar Formation (Silurian; Podhalańska et al., 2020, modified).

3.2. LOWER PALEOZOIC PETROLEUM PLAY IN THE MIDDLE CAMBRIAN DEPOSITS (CONVENTIONAL AND UNCONVENTIONAL PLAY)

3.2.1. SOURCE ROCKS

Upper Cambrian (Furongian)
Piaśnica Formation

Lithology: Organic matter-enriched black claystones and mudstones, conglomerates with claystone, and mudstone clasts cemented with carbonates

Characteristics: In the “Kartuzy” tender area, the thickness and organic matter content of the Piaśnica Formation are very low (Fig. 3.5;

Podhalańska et al., 2020). This is the reason why this interval has not been investigated in detail in all wells within the tender area.

The analyses of oil and gas (Więcław et al., 2010, Kotarba, 2010) accumulated in the Middle Cambrian sandstones in the Baltic area indicate that their source rocks are organic matter-enriched shales from the Upper Cambrian, Ordovician and Silurian. Hydrocarbons vertically and laterally migrated to the Middle Cambrian sandstones during Variscan inversion.

The TOC median for the Piaśnica Formation in the Peribaltic Syneclise is in the range of 0.92 - 13.15 wt%, which indicates a high hydrocarbon potential of those rocks (Janas, 2018). The highest values of TOC content in the Piaśnica Formation onshore were noticed at the Łeba High (3–8 wt%), together with the highest thickness of this formation (10–15 m; Fig. 3.5; Karcz and Janas, 2016; Podhalańska et al., 2018, 2020).

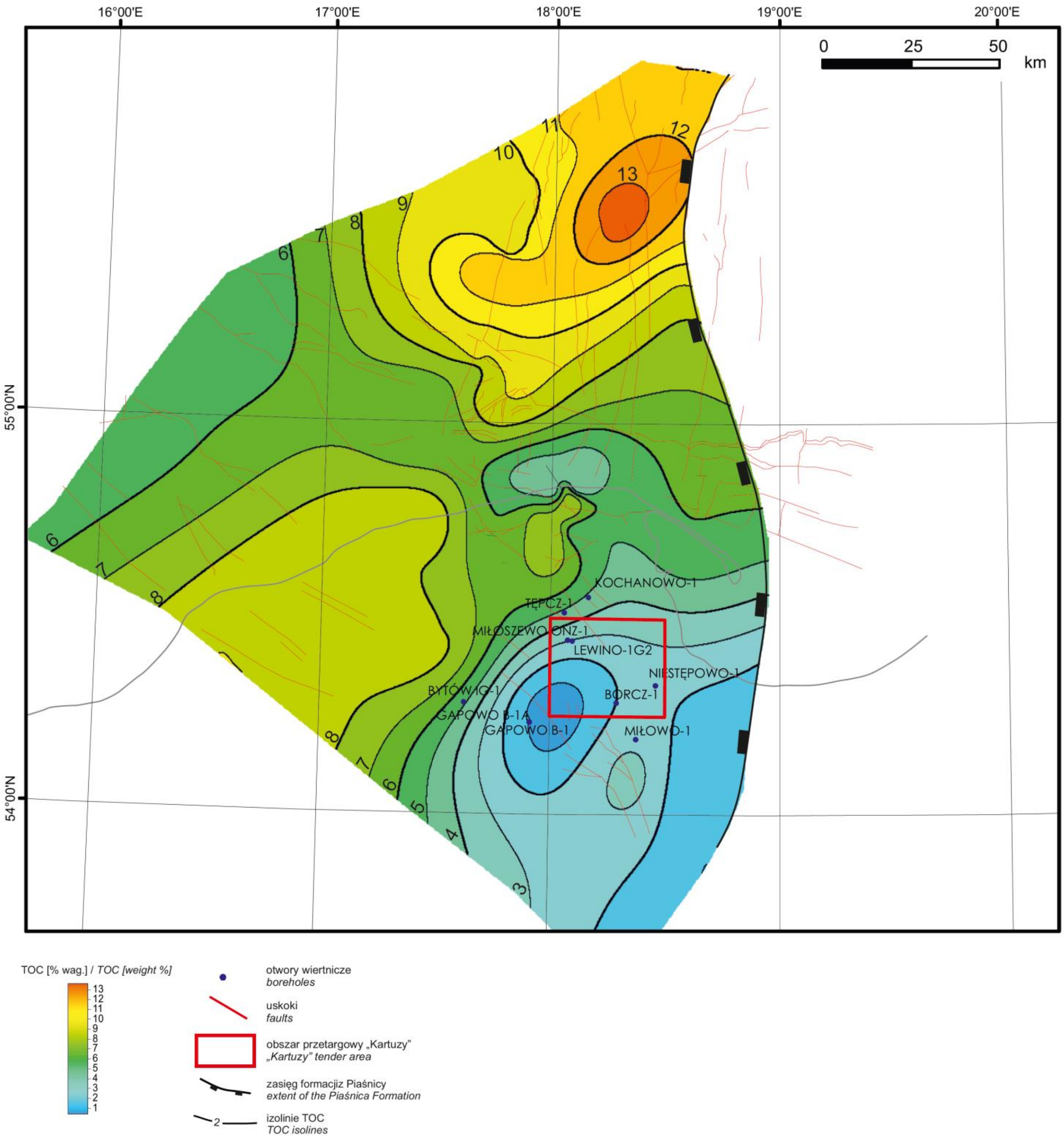


Fig. 3.5. The "Kartuzy" tender area in the map of TOC (median) distribution in the Piaśnica Formation (Podhalańska et al., 2020, modified).

3.2.2. RESERVOIR ROCKS

Middle Cambrian sandstones

Lithology: Quarzitic sandstones with silica cement, sometimes carbonate cement, intercalated with mudstones and heteroliths.
Age: Middle Cambrian; sandstones from the *Paradoxides paradoxissimus and Parradoxides forchhammeri* zones (Dębki and Białogóra formations, respectively) display the best reservoir characteristics.
Thickness: No borehole pierced the Middle Cambrian interval in the tender area and surroundings. Supposed thicknesses in the “Kartuzy” area are in the range of 250–300 m. (Modliński et al., 2010).
Characteristics: Generally, the quality of reservoir parameters decreases at the depth 2500–3000 m; however, the tectonic processes might increase the secondary porosity combined with microfissures (Reicher, 2006). The regional analyses of the Middle Cambrian porosity (Fig. 3.6) indicate that poor reservoir properties are expected in the tender area. The porosity and permeability parameters from the “Kartuzy” tender area wells and the neighborhood are summarized in Tab. 3.1.
Hydrocarbon shows:

Niestępowo-1
Source: Kalbarczyk and Śliwiński, 1974.
Mudlogging: during drilling, an increase in hydrocarbon content was noticed at 3500.4–3620.0 m on the gas curves. At a depth of 3562.6 m, the gasification of drilling mud was noticed.
Well tests: in the Middle Cambrian interval, well tests were applied during and after drilling, however, only gasification of the drilling mud was observed.

Borcz-1
Source: Mikołajewski, 2015; Strzelecka, 2017.
Mudlogging: maximal gas shows during the gas profiling at 3759.0 m depth. In the interval of 3726.0–3737.0 m – small gas shows on core fissures.
No well test was applied in the Middle Cambrian interval.

Lewino-1G2
Source: Szpetnar-Skierniewska, Krajewski, 2018, 2019.

Miłowo-1
Source: Chruścińska et al., 2018; Mikołajewski, 2015; Strzelecka, 2017.
Mudlogging: increasing hydrocarbon content in the gas profiling in the intervals: 3815.0–3816.5 m, 3822.0–3826.0 m, 3845.5–3846.5 m, 3852.0–3854.0 m. Gas shows on the core was observed in the following intervals: 3813.0–3819.0 m, 3837.0–3846.0 m, 3846.0–3855.0 m.
Well tests: after drilling well test of 3795.0–3855.0 m interval was applied with a negative outcome.

Gapowo B-1
Source: Kubala, 2013.
Middle Cambrian was not investigated during the drilling.
No well test in the Middle Cambrian interval was applied.

Tępcz-1
Source: Chruścińska and Sikorska-Piekut, 2018.
Middle Cambrian was not investigated during the drilling.
No well test in the Middle Cambrian interval was applied.

Wells	Top of the Middle Cambrian [m]	Thickness of the Middle Cambrian [m]	Total porosity range [%]	Total porosity mean [%]	Effective porosity mean (range) [%]	Permeability mean (range) [mD]
Borcz-1	3727.0	>33.1	< 6% (lab.) 0.0–6.2 (geoph.)	2.19 (lab.); 2.8 (geoph.)	2.8 (0–6.2)	no data
Niestę–powo-1	3492.8	>140.0	0.28–5.27	1.84	no data	0.39 (0.00–2.42)
Lewino-1G2	Until 29-11-2022 the entity has exclusive right to use geological information					
Tępcz-1*	3408.65	>19.35	0.42–5.6 (lab.) 1.48–6.8 (geoph.) 0.29–4 (resonance)	2.36 (lab.) 3 (geoph.) 1.72 (resonance)	no data	14.1 (0–132.44)
Gapowo B-1	4262.0	>41	0.85–4.36	2.94	2.0 (0.78–4.33)	0.00
Miłowo-1	3811.0	>45	0.41–7.06 %	3.2 (0.41–7.06) (geoph.)	2.93 (0.07–6.56)	1.43 (0–14.5)

Tab. 3.1. Reservoir parameters of Middle Cambrian deposits in the boreholes located in the “Kartuzy” tender area and its surroundings. Based on the final well reports and regional studies (CGDB, 2021, Szpetnar-Skierniewska and Krajewski, 2018, Chruścińska and Sikorska-Piekut, 2018; Kubala, 2013; Mikołajewski 2015); *parameters only for the most prospective Dębki Formation (Podhalańska et al., 2018); blue colour: wells located within the “Kartuzy” tender area, lab. – laboratory measurements; geoph. – geophysical interpretation.

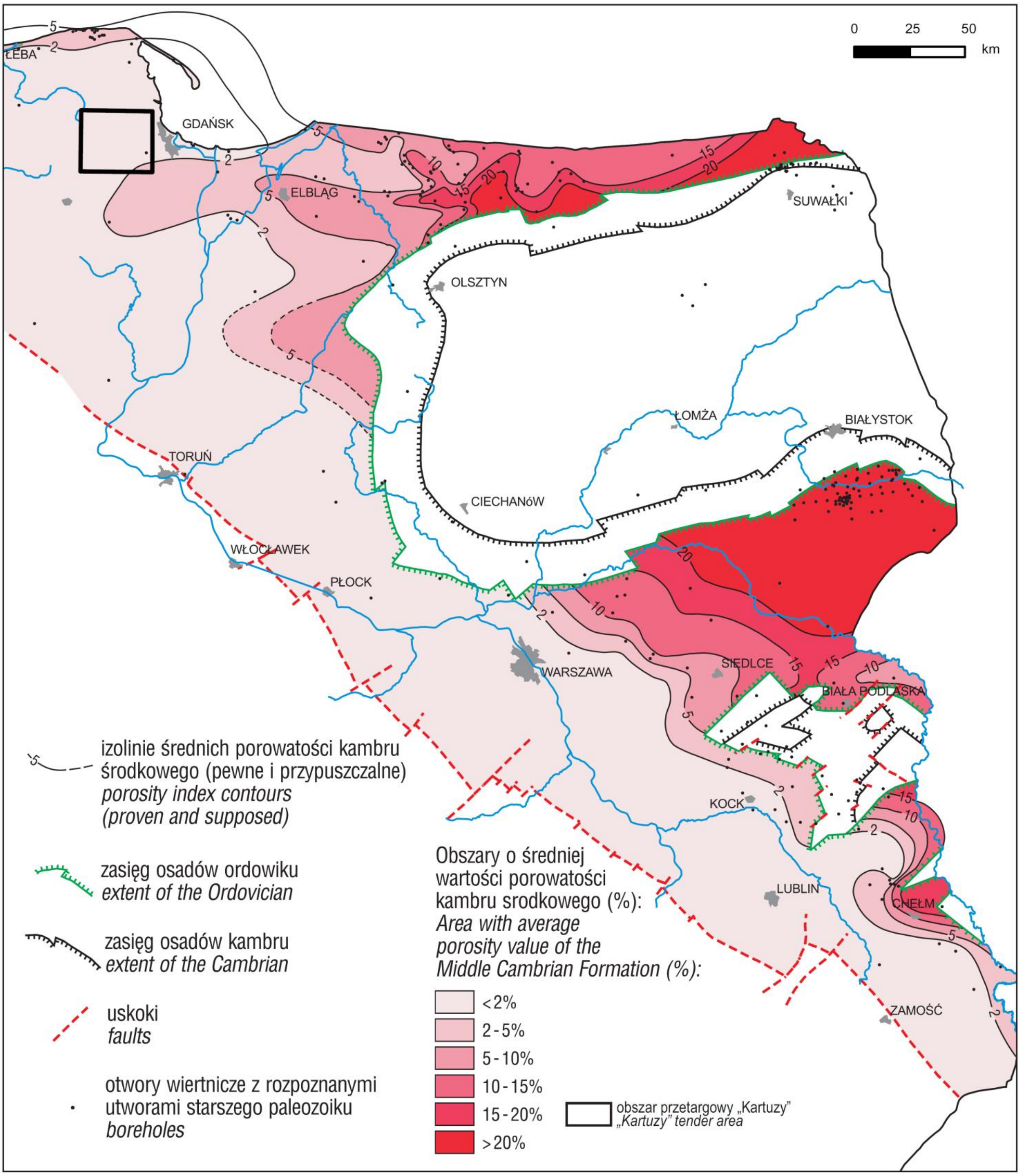


Fig. 3.6. The **"**Kartuzy" tender area in the map of porosity distribution (mean) in the Middle Cambrian deposits (Stolarczyk et al., 2004, modified).

3.2.3. SEAL ROCKS

The main seal rocks for the Middle Cambrian petroleum play are impermeable claystones and mudstones of the Upper Cambrian, Ordovician and Silurian (Silurian has the greatest thickness, which can exceed 1900 m in the tender area). The Zechstein evaporites constitute an additional, regional seal level. A high level of Middle Cambrian water mineralization suggests good seal for reservoir intervals in the tender area (Fig. 3.7).

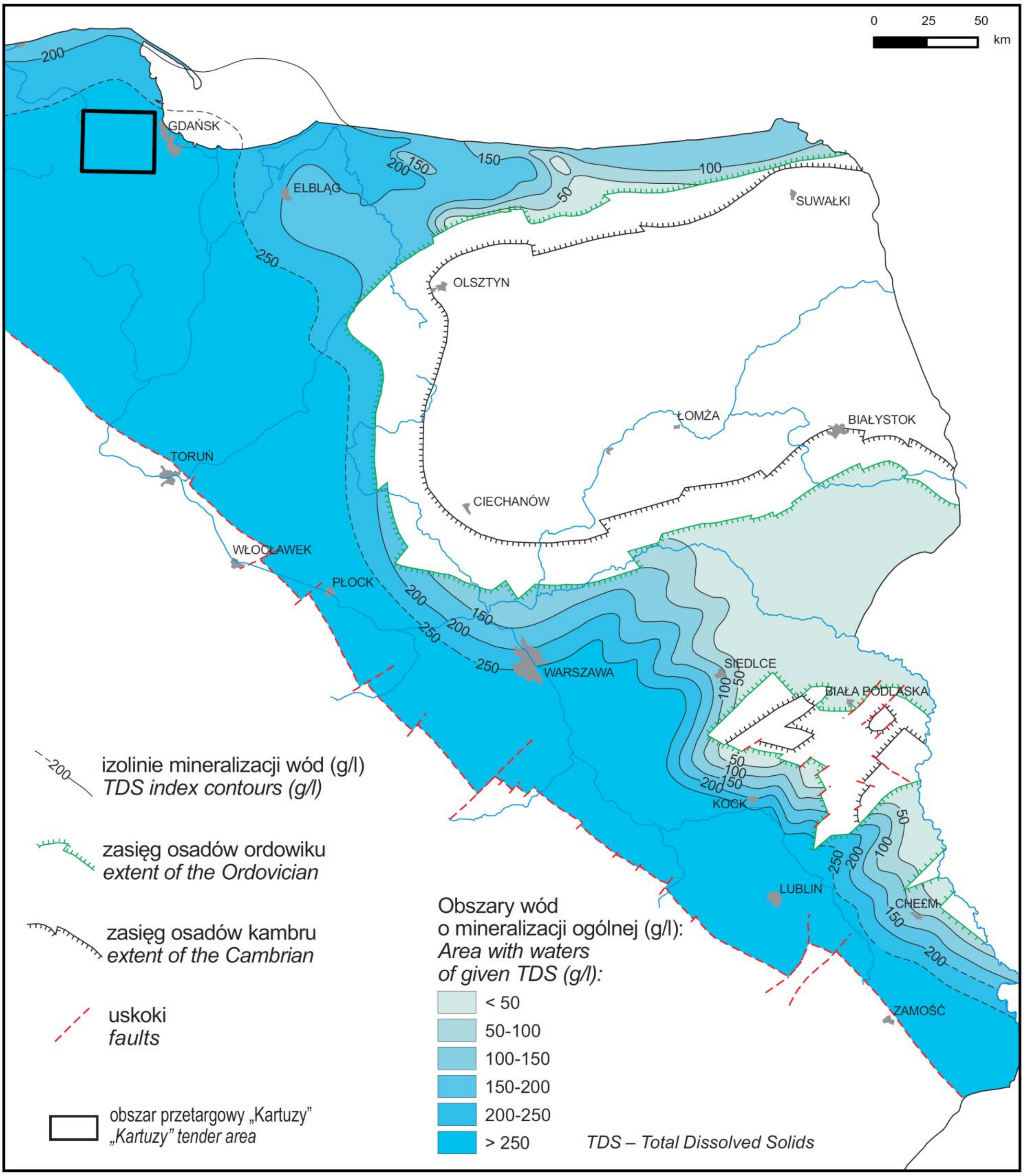


Fig. 3.7. The "Kartuzy" tender area in the map of mineralization of the Cambrian waters (Stolarczyk et al., 2004, modified).

3.3. LOWER PALEOZOIC UNCONVENTIONAL PETROLEUM PLAY – SHALE GAS/SHALE OIL TYPE

Prospective rocks for unconventional petroleum exploration in the Kartuzy tender area are mudstones and clayey mudstones enriched in organic matter from the Piaśnica Formation (Upper Cambrian), Sasino Formation (Middle Ordovician – Caradoc), Jantar Formation (Silurian – Llandovery), and the lower part of the Pelplin Formation (Silurian – Wenlock).

3.3.1. ARE LOWER PALEOZOIC SHALES SOURCE ROCKS?

Piaśnica Formation

Due to the small thickness in the "Kartuzy" tender area, the Piaśnica Formation is not prospective for unconventional petroleum exploration. The area is located outside the prospective zone of the Piaśnica Formation (Fig. 3.9; Podhalańska et al., 2020).

Sasino Formation

Lithology: mudstones and claystones.
Age: Caradoc and Upper Llanvirn.
Thickness:

- Borcz-1: 15 m,
- Niestępowo-1: 19,5 m,
- Miłowo-1: 16.35 m,
- Gapowo B-1: 14 m,
- Tępcz-1: 20.5 m.

Depth:

- Borcz-1: 3700.5–3715.5 m,
- Niestępowo-1: 3459.0–3478.5 m,
- Miłowo-1: 3782.5–3798.85 m,
- Gapowo B-1: 4236.0–4250.0 m,
- Tępcz-1: 3375.5–3396.0 m.

Characteristics:
The TOC content (median) in the Sasino Formation in the whole Peribaltic Syneclise is in the range of 0.3 - 3.64 wt%. The highest measured value was 9.11 wt%. The median of TOC in the onshore part of Peribaltic Syneclise (over 2%) was calculated in the Gapowo and Kościerzyna area (Fig. 3.10; Karcz and Janas, 2016; Janas, 2018; Podhalańska et al., 2020), as well as in the "Kartuzy" tender area – in the Borcz-1 well (Tab. 3.2). It is worth noting that the Sasino Formation is lithologically heterogeneous, which implies different source rock characteristics. The upper and lower parts are enriched in organic matter, while the middle part is depleted in TOC (Podhalańska et al., 2018, 2020).

The alternating values of generation potential (S2 = 0.06–10.8 mg HC/g rock; Tab. 3.2) and TOC (0.18– 6.90 wt%) classify the hydrocarbon potential of the Sasino Formation in the Kartuzy area in a wide range from barren to excellent source rocks. Except for isolated horizons, in which the TOC is below 0.5 wt%, almost the entire Sasino Formation succession meets the criteria of hydrocarbon source rock (TOC > 0.5 wt%; S2 > 2.5 mg HC/g rock; Dembicki, 2017).

Relatively low oil saturation index (average OSI = 36–64 mg HC/g TOC; Tab. 3.2) suggests that the generated hydrocarbons remained within the source rock to a greater extent. Elevated OSI values (> 100 mg HC/g TOC) in some samples imply local migration of the liquid hydrocarbons.

The vitrinite reflectance measurements (average Ro = 0.92–1.28%), as well as average Tmax (450–475 ˚C), and production index (average PI = 0.26–0.53) values indicate that the thermal maturity of the Sasino Formation in the "Kartuzy" area is at the boundary between the oil window and the wet gas window. The degree of thermal maturation increases with the depth of burial, towards the SW (Janas, 2018).

Jantar Formation

Lithology: claystones and mudstones.
Age: Llandovery.
Thickness:

- Borcz-1: 13.5 m,
- Niestępowo-1: 10 m,
- Gapowo B-1: 15 m,

- Tępcz-1: 19.5 m,
- Miłowo-1: 8.5 m.

Depth:

- Borcz-1: 3680.5–3694.0 m,
- Niestępowo-1: 3442.0–3452.0 m,
- Miłowo-1: 3767.0–3775.5 m,
- Gapowo B-1: 4192.0–4207.0 m,
- Tępcz-1: 3349.0–3368.5 m.

Characteristics:

The Jantar Formation is lithologically more homogenous than the Sasino Formation, and the content of organic matter in the whole formation interval is constant. The highest TOC value from the Jantar Formation in the Peribaltic Syneclise is 15 wt% (Fig. 3.11). However, the mean TOC for the formation is between 0,.5–10.5 wt%.

Despite the mean Hydrogen Index values (HI = 80–120 mg HC/g TOC) due to high thermal maturity of rocks (compare to Figs 3.12–3.13), most of the investigated samples contain type II kerogen (Tab. 3.3).

The main source of organic matter is the remains of graptolites (i.e. in the Borcz-1 well graptolites are more than 90%mass of organic matter). Among the remaining organic components, bitumen-type organo-mineral associations prevail and take the form of amorphous organic remains mixed with clay material. Solid bitumen and vitrinite-like macerals (likely sourced from algal remains) are among other significant contributors to the maceral composition of the rock (Strzelecka, 2017; Grotek, 1999). In the group composition of extracted bitumen, aliphatic hydrocarbons predominate (58.8–70.6 wt%). The maximum contribution from the aromatic fraction is 18.5 wt%, and from the non-hydrocarbon components (asphaltenes and resins) it is 23% in total (Strzelecka, 2017).

Oil saturation index (OSI) values below 50 g HC/g TOC in most samples (Tab. 3.3) indicate that the free hydrocarbons present in the rock (S1) remained in place of their generation. The measured TOC values (Tab. 3.3; ranging from below 0.5 up to 7.08 wt%) classify the hydrocarbon potential of the Jantar Formation form the “Kartuzy” area in a wide range between barren and excellent source rocks. Samples with high total organic carbon content also show elevated values of generation potential (average S2 = 2.68–3.69 mg HC/g rock), confirming their further ability to generate hydrocarbons. Source rocks of good and very good hydrocarbon potential dominate in the Jantar Formation (Strzelecka, 2017).

The degree of thermal maturity of organic matter is relatively high. Average Tmax parameter values measured in the “Kartuzy” area (Tab. 3.3) oscillate within a narrow range between 453 and 463˚C, and the average vitrinite reflectance is from 1.15 to 1.21%, which is equivalent to thermal conditions between the oil and wet gas windows. Production index values (0.31–0.32) confirm the maturity of Jantar Formation source rocks. According to the analysis performed for the Polish part of the East European Craton (Podhalańska et al., 2020), thermal maturity of the Jantar Formation in the terrestrial part of the Baltic Lowland changes axially. A lower degree of thermal maturation is characterized of Jantar Formation rocks in areas located NE of the “Kartuzy” tender area, whereas to the SW, the thermal maturity level significantly increases (Figs 3.12–3.13).

According to Botor et al. (2019b), due to the degree of thermal transformation of the kerogen, the initial generative potential of the Jantar Formation was significantly higher and has been already realized to a large extent. The Jantar Formation is the most organic matter-rich layer of the entire Lower Paleozoic shale complex in the “Kartuzy” area. Due to its significant TOC content, the oil-prone character of the kerogen, and its thermal maturity ranging from the oil to wet gas windows, the Jantar Formation is a prospective source rock for hydrocarbons in the unconventional shale oil-type system (Strzelecka, 2017; Karcz and Janas, 2016; Podhalańska et al., 2018, 2020).

Pelplin Formation (Wenlock part)

Lithology: mudstones and claystones.

Age: Wenlock.

Thickness (Wenlock part):

- Borcz-1: 127 m,
- Niestępowo-1: ~150 m,
- Miłowo-1: 130.5 m,
- Gapowo B-1: 104 m,

- Tępcz-1: 145 m.

Depth (Wenlock part):

- Borcz-1: 3510.0–3637.0 m,
- Niestępowo-1: ?3262.0–3412.0 m,
- Miłowo-1: 3608.5–3739.0 m,
- Gapowo B-1: 4060.0–4164.0 m,
- Tępcz-1: 3173.0–3318.0 m.

Characteristics:

The “Kartuzy” tender area is lying within the prospective zone for hydrocarbon occurrence in the Pelplin Formation. However, during the intensive exploration of this area, the Wenlock interval was one of the exploration targets, and the rich data from the wells gave rise to many analyses from this interval.

The mean TOC values in the Wenlock part of the Pelplin Formation is about 1 wt%. (Podhalańska et al., 2018). The organic geochemistry of the Pelplin Formation is summarized in Tab. 3.4.

The results from the wells located within and in the neighborhood of the “Kartuzy” tender area are comparable with regional analyses of maturity in the Pelplin Formation of the Baltic region (Fig. 3.14; Podhalańska et al., 2020).

The main source of organic matter is the remains of graptolites. Among the remaining organic components, bitumen-type organo-mineral associations prevail and take the form of amorphous organic remains mixed with clay material. Solid bitumen and vitrinite-like macerals (likely sourced from algal remains) are among other significant contributors to the maceral composition of the rock (Strzelecka, 2017; Grotek, 1999). In the group composition of extracted bitumen, aliphatic hydrocarbons predominate. The contribution of asphaltenes and resins does not exceed 4%. Despite the lower mean Hydrogen Index values (25–139 mg HC/g TOC, Tab. 3.4), due to high thermal maturity of rocks, most of the investigated samples contain type II kerogen (Tab. 3.4).

The oil saturation index (OSI) values, close to 50 g HC/g TOC in most samples (Tab. 3.4), indicate that the free hydrocarbons present in the rock (S1) remained in place of their generation. The measured TOC values (Tab. 3.4) classify the hydrocarbon potential of the Pelplin Formation from the “Kartuzy” area in a range between poor and good source rocks.

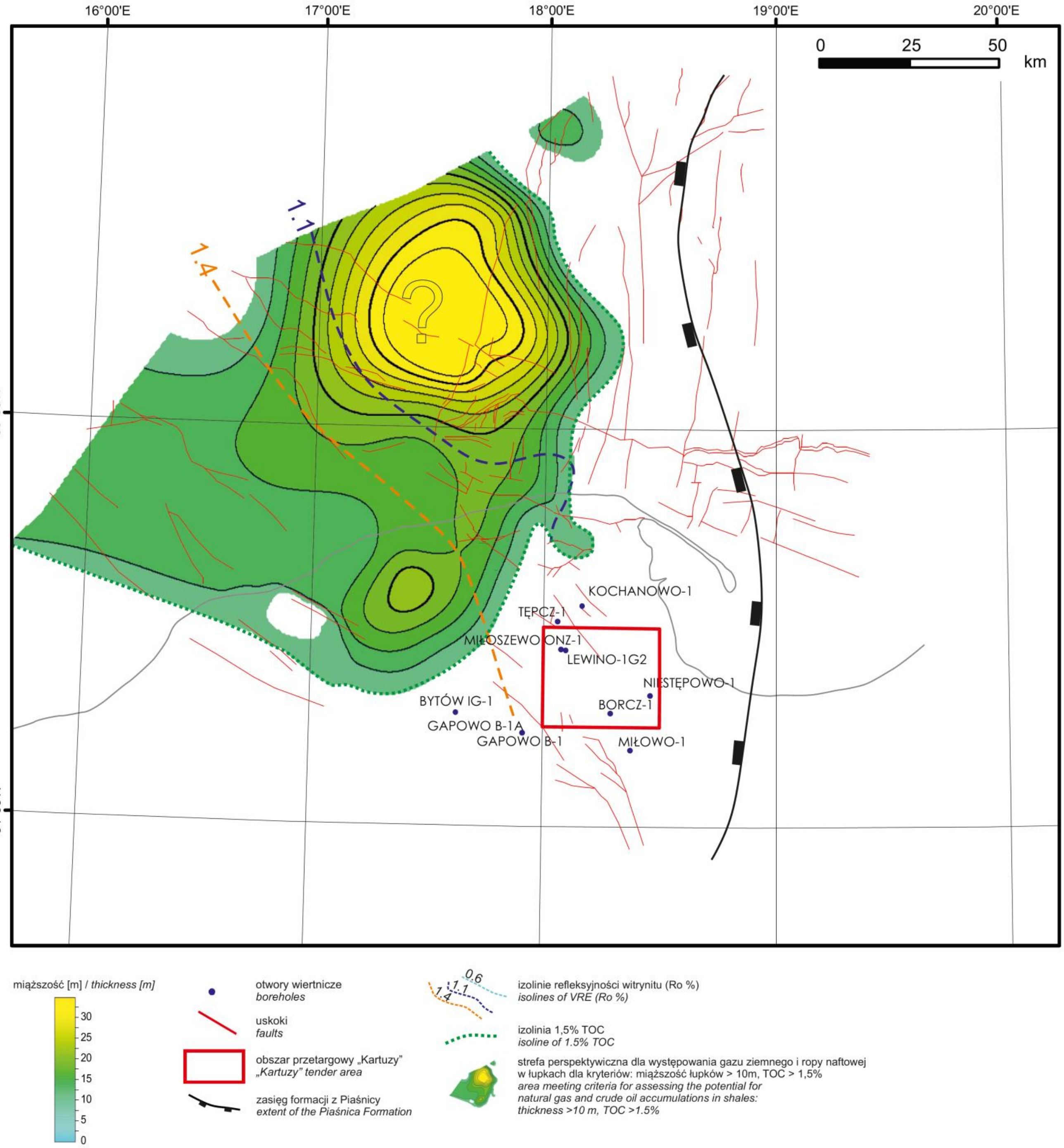


Fig. 3.9. Location of the "Kartuzy" tender area in the map of prospective zone for unconventional hydrocarbon exploration in the Piaśnica Formation (Podhalańska et al., 2020, modified).

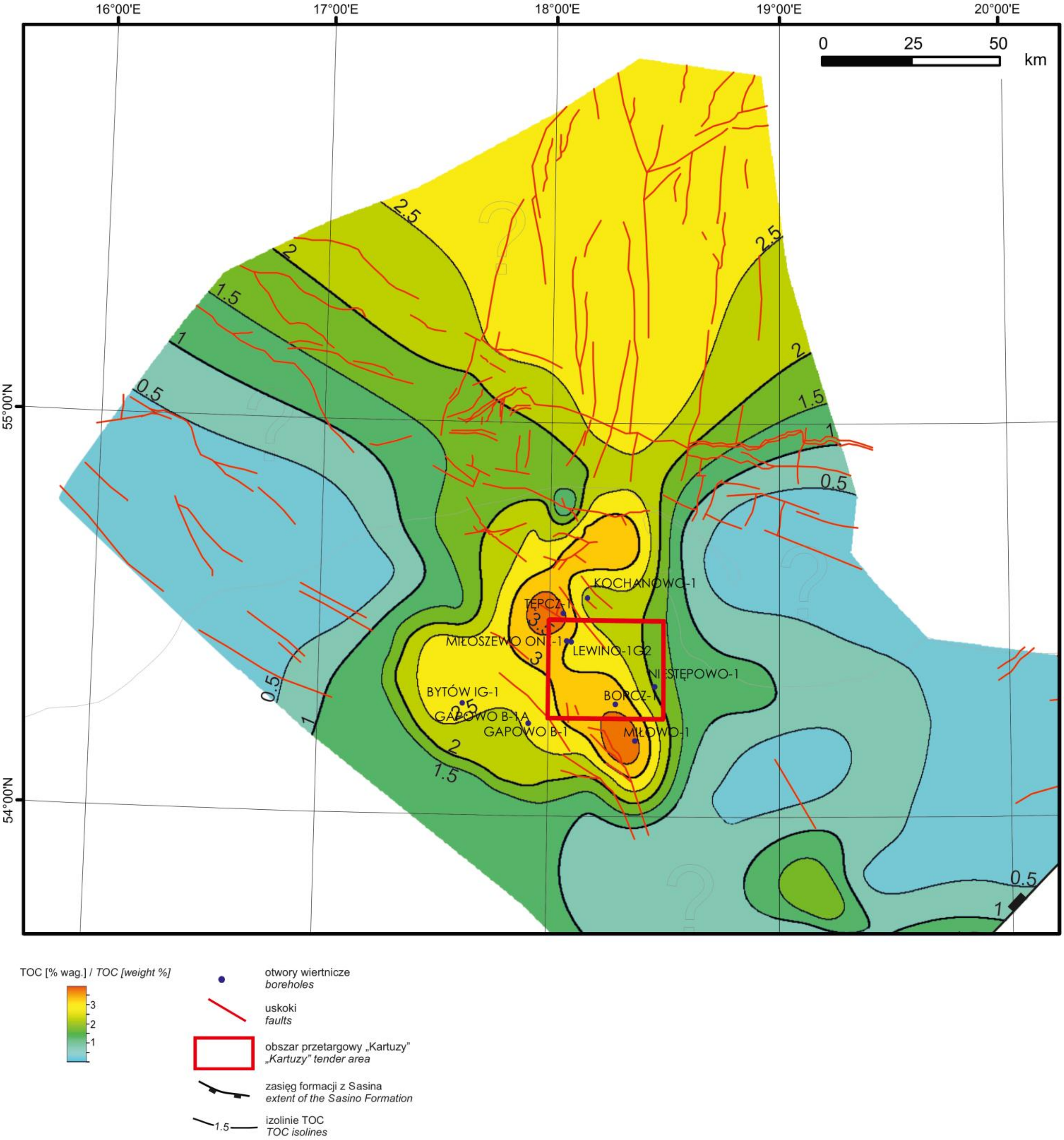


Fig. 3.10. Location of the "Kartuzy" tender area in the map of TOC distribution (median) in the Sasino Formation (Podhalańska et al., 2020, modified).

Organic geochemistry parameters	Borcz-1	Lewino-1G2	Niestępowo-1	Miłowo-1
TOC [wt%]	2.68	Until 29-11-2022 the entity has exclusive right to use geological information	2.79 (0.32–6.90)	3.23 (0.21–6.81)
T_{max} [°C]	465		450 (441–456)	457 (451–463)
R_o	1.23		0.92	0.99
S1 [mg HC/gRock]	0.88		1.35 (0.24–3.42)	1.21 (0.02–2.26)
S2 [mg HC/gRock]	1.94		4.64 (0.46–10.8)	3.77 (0.12–8.48)
HI [mg HC/gTOC]	71.5		171 (122–236)	119 (57–160)
PI	0.36		0.26 (0.13–0.39)	0.27 (0.05–0.47)
Kerogen type	II		II	II

Tab. 3.2. Organic geochemistry of the Sasino Formation (Strzelecka, 2017; Szpetnar-Skierniewska and Krajewski, 2018; Podhalańska et al., 2018).

Organic geochemistry parameters	Borcz-1	Miłowo-1
TOC [wt%]	3.29	3.38 (0.81–7.08)
T_{max} [°C]	463	453 (432–460)
R_o	1.21	1.15
S1 [mg HC/gRock]	1.18	1.38 (0.77–2.09)
S2 [mg HC/gRock]	2.68	3.69 (1.13–7.73)
HI [mg HC/gTOC]	80	120 (83–180)
PI	0.32	0.31 (0.18–0.41)
Kerogen type	II	II

Tab. 3.3. Organic geochemistry of the Jantar Formation (Strzelecka, 2017; Podhalańska et al., 2018.

Organic geochemistry parameters)	Borcz-1	Lewino-1G2	Niestępowo-1	Miłowo-1
TOC [wt%]	0.90	Until 29-11-2022 the entity has exclusive right to use geological information	0.84 (0.09–1.32)	1.13 (0.78–1.44)
T_{max} [°C]	428		448 (440–470)	440 (434–443)
R_o	1.11–1.20		no data	no data
S1 [mg HC/gRock]	0.32		0.57 (0.04–0.82)	0.72 (0.49–0.94)
S2 [mg HC/gRock]	0.41		1.10 (0.14–1.52)	0.94 (0.79–1.09)
HI [mg HC/gTOC]	45.5		139 (66–200)	86 (74–110)
PI	0.43		0.32 (0.20–0.39)	0.43 (0.37–0.48)
Kerogen type	II		II	II

Tab. 3.4. Organic geochemistry of the Pelplin Formation (Strzelecka, 2017; Szpetnar-Skierniewska and Krajewski, 2018; Podhalańska et al., 2018).

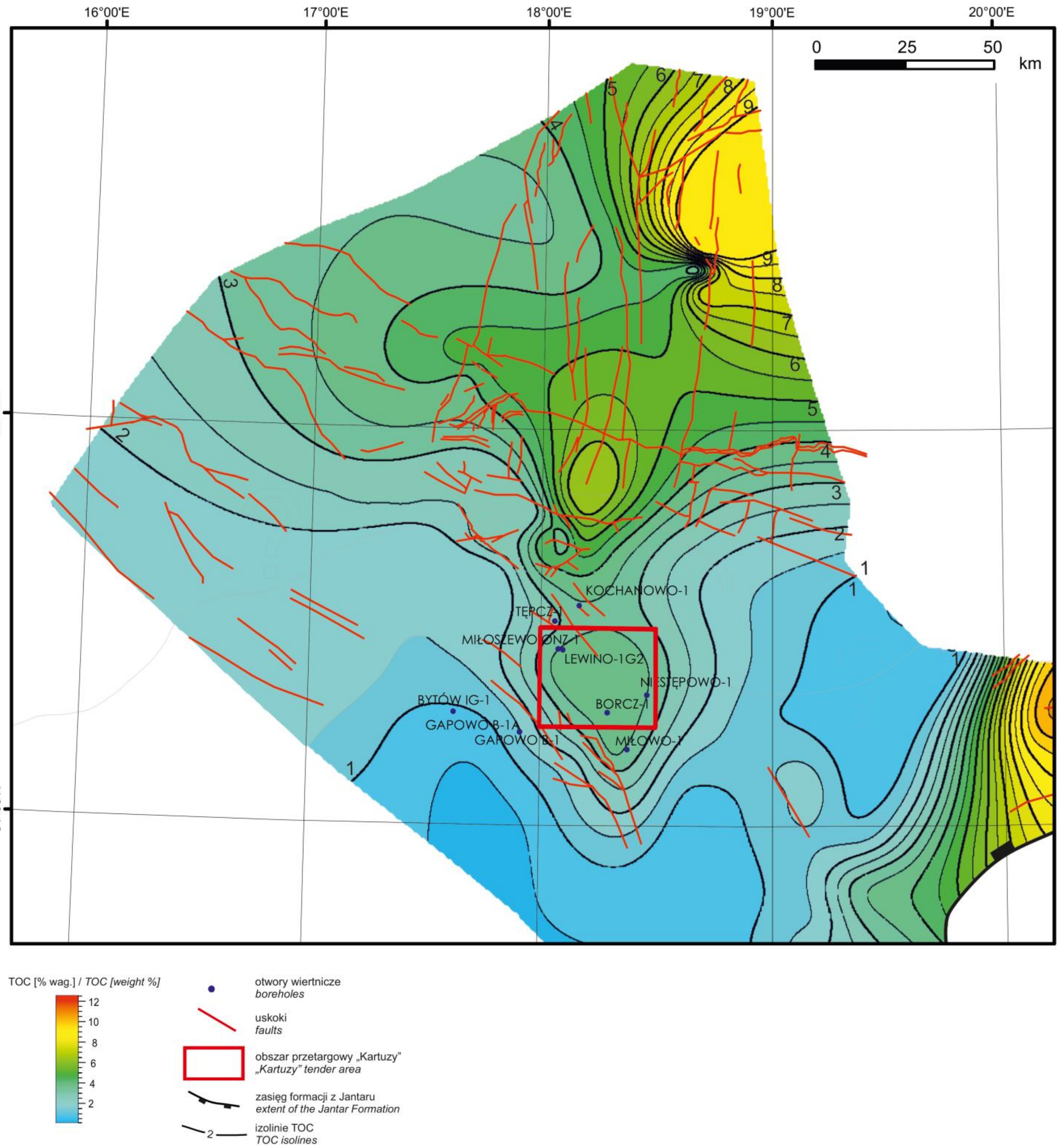


Fig. 3.11. Location of the "Kartuzy" tender area in the map of TOC distribution (median) in the Jantar Formation (Podhalańska et al., 2020, modified).

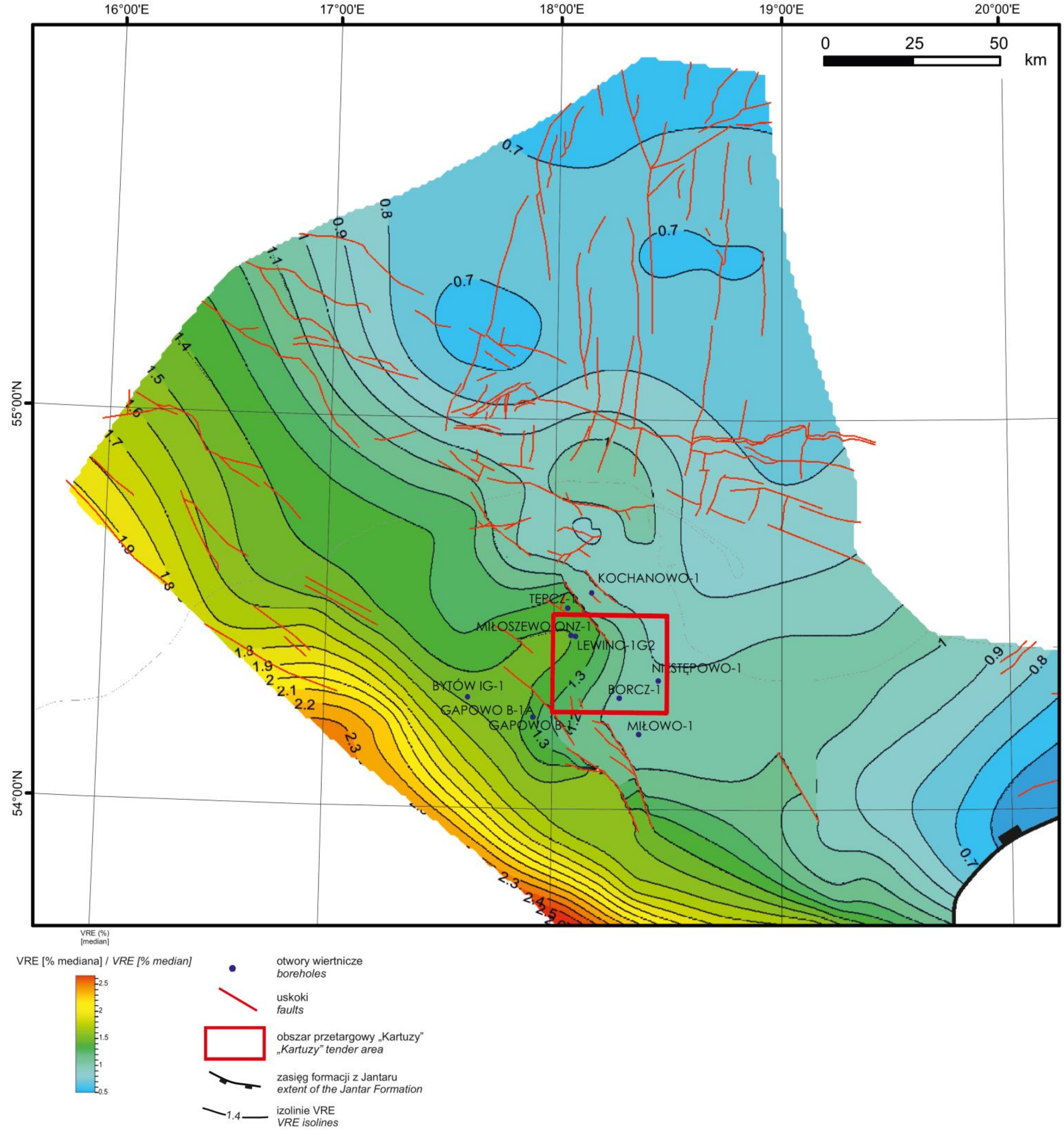


Fig. 3.12. Location of the "Kartuzy" tender area in the map of vitrinite reflectance (median) in the Jantar Formation (Podhalańska et al., 2020, modified).

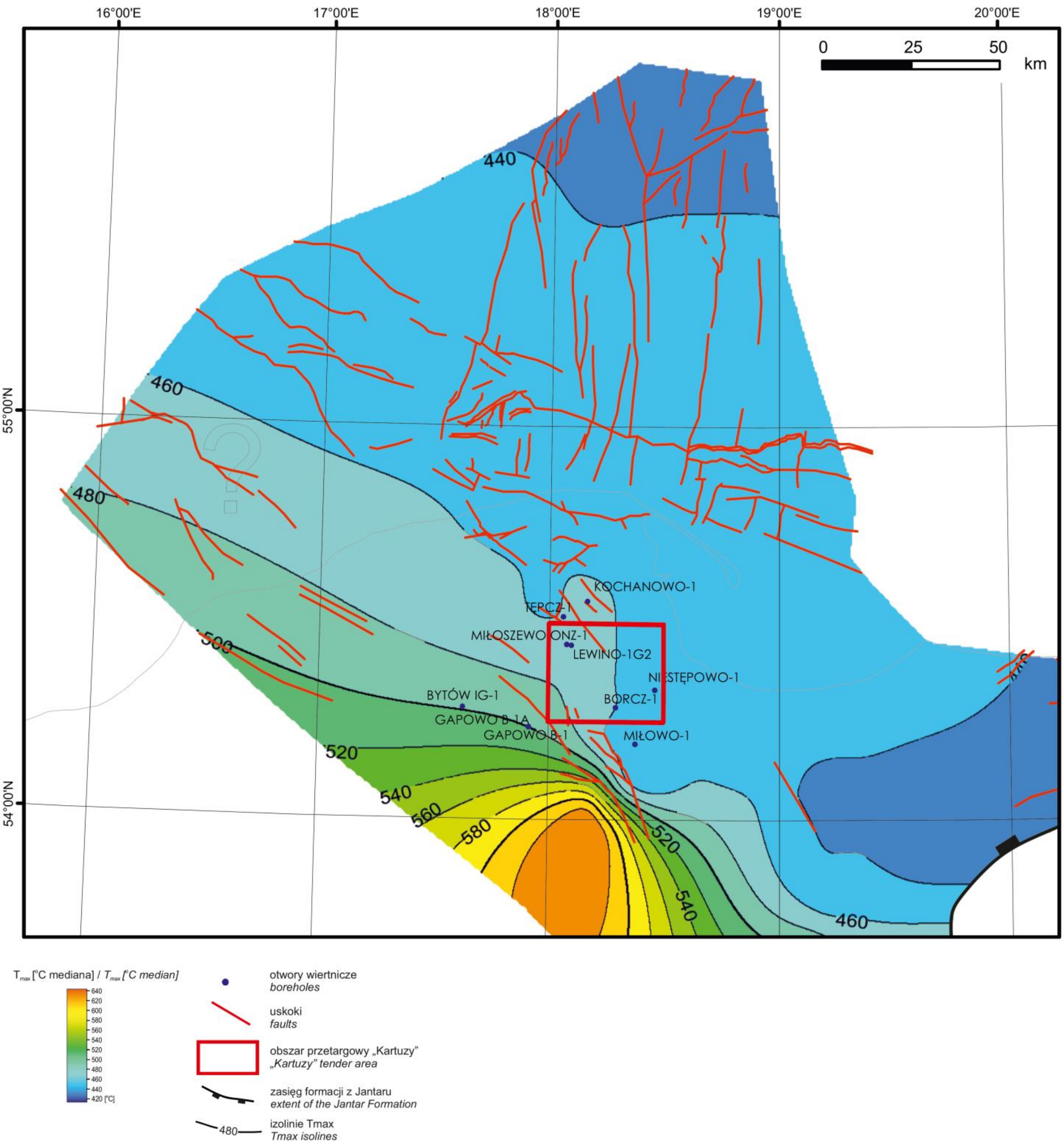


Fig. 3.13. Location of the "Kartuzy" tender area in the map of Tmax distribution (median) in the Jantar Formation (Podhalańska et al., 2020, modified).

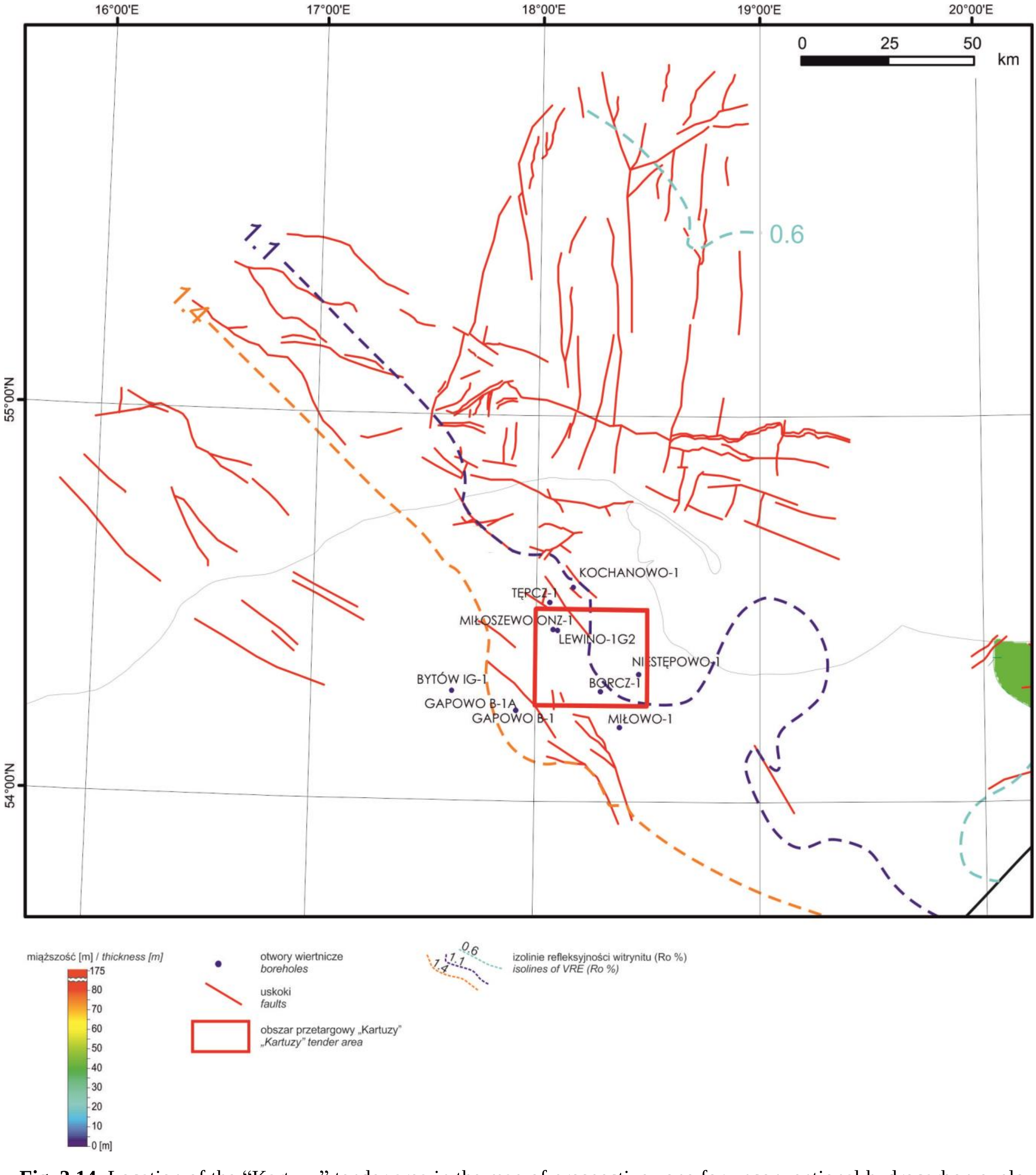


Fig. 3.14. Location of the “Kartuzy” tender area in the map of prospective zone for unconventional hydrocarbon exploration in the Pelplin Formation (Podhalańska et al., 2020, modified).

3.3.2. MINERAL CHARACTERISTICS AND BRITTLENES ANALYSES FOR PROSPECTIVE INTERVALS OF LOWER PALEOZOIC SHALE FORMATIONS

The Lower Paleozoic Piaśnica, Sasino and Jantar formations, as well as the lower part of the Pelplin Formation, are composed mostly of mudstones and claystones enriched in organic matter. Fine-grained sediments contain quartz and clay minerals, with minor carbonates. In the “Kartuzy” tender area, the total mineral clay content is very variable in the Sasino Formation, and it may reach even 80% (Fig. 3.15). The Jantar Formation is characterized by a lower amount of total clay (between 40 and 70%; Fig. 3.16). Mean values of the sum of quartz and total clay in the tender area and surrounding areas are listed in Tab. 3.5.

Brittleness

The Pelplin Formation is the most homogeneous in terms of brittleness in the entire Baltic region. The brittleness parameter calculated on a regional scale (mineralogical brittleness index BI – see Pachytel, 2018; Podhalańska et al., 2020 and the citations therein) indicates that these rocks bear medium to good susceptibility to fracturing. The median of the brittleness index is 0.54 (Pachytel, 2018).

The Jantar and Sasino formations show internal heterogeneity, which can be also noticed in brittleness and susceptibility to fracture propagation parameters. The Jantar Formation in the tender area is characterized by constant heterogeneity. Zones of higher/lower brittleness, which can be tracked even over several tens of kilometers within the basin, can be distinguished. (Fig. 3.17). The constant, low carbonate content causes the brittleness to be ruled mainly by the ratio of clay minerals to quartz and feldspar. The BIBB values for the perspective zone were calculated at 0.464. Heterogeneity is also noticeable in the scatter of the minimum (0.09) and maximum (0.91) values.

It is worth noting that, in the Łeba High, especially in the tender area, the Sasino Formation is characterized by high mineralogical and geochemical heterogeneity (Fig. 3.18). In the Borcz-1, Kochanowo-1 and Lubocino-1 wells, the formation is divided into three sections, with the top and bottom parts enriched with organic matter and clay minerals, and the middle part visibly depleted in TOC. In many samples, an increase in carbonate content was observed, which suggests that the brittleness is created mainly by three variables (quartz + feldspar, carbonates, clay minerals). Within the formation, there are both carbonate inserts, which cause a significant increase in brittleness, and thin layers of bentonite material, inducing the decrease in BI.

The average BIBB for the prospective zone of the Sasino Formation was calculated as 0.544 (Pachytel, 2018; Fig. 3.19). In the “Kartuzy” area, the average brittleness ranges from 0.46 (in the Borcz-1 well) to 0.56 (in the Gapowo B-1 well). Bentonite layers, often occurring as layers with a thickness from a few mm to several meters, constitute zones of significantly reduced brittleness, extremely important in the analyses of drilling companies. These zones are very difficult to fracture – low BI, combined with a low coefficient of friction on successively lying layers, may cause "sliding", a change in the direction of the vertical fracture propagation to a horizontal one, and its "arrest", as well as the end of propagation on one of the layers, even in the case of the normal or strike-slip fault tectonic regime.

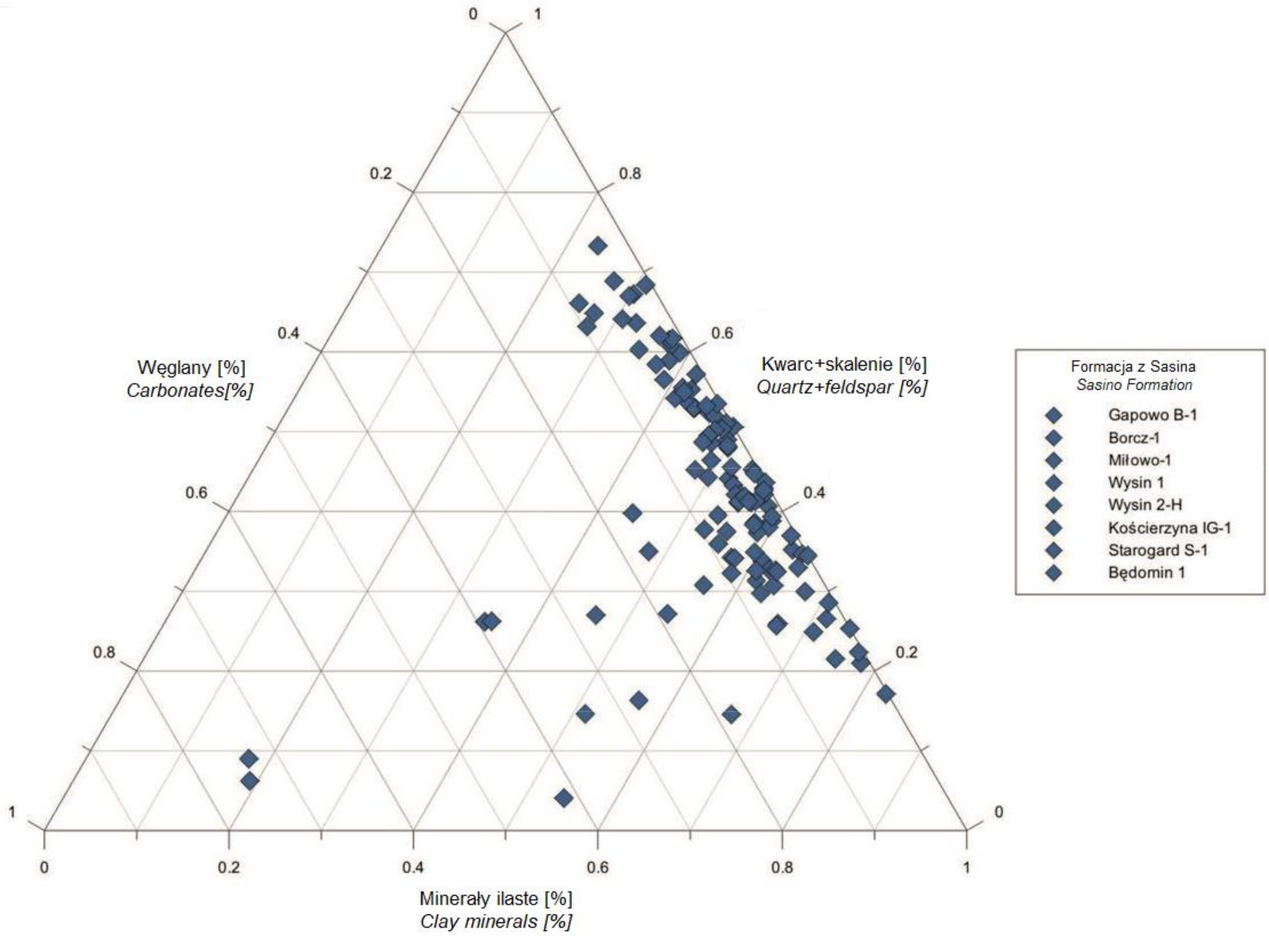


Fig. 3.15. Mean values of carbonates, quartz and feldspars, and total clay in the Sasino Formation in selected wells located within and in the neighborhood of the tender area (Podhalańska et al., 2018).

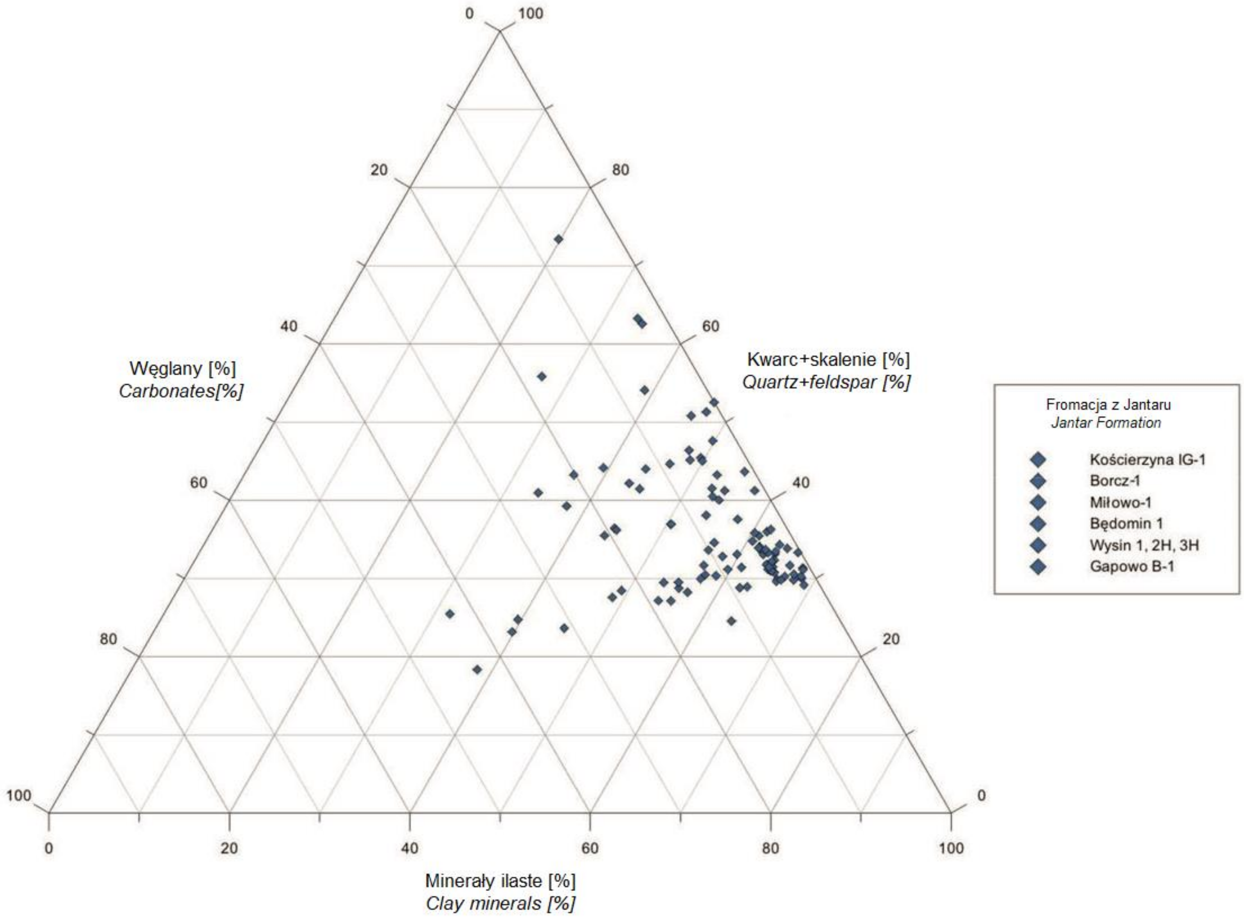


Fig. 3.16. Mean values of carbonates, quartz and feldspars, and total clay in the Jantar Formation in selected wells located within and in the neighborhood of the tender area (Podhalańska et al., 2018).

Wells	Lithostratigraphy	Quartz - median (standard deviation/ number of samples) [%]	Total Clay - median (standard deviation/ number of samples) [%]
Borcz-1	Sasino Formation	27.5 (11/14)	54.5 (7.69/14)
	Jantar Formation	22.7 (3.21/13)	57.2 (6.74/13)
	Pelplin Formation (Wenlock part)	24.45 (3.4/36)	50.75 (5.9/36)
Miłowo-1	Sasino Formation	33.0 (12.7/19)	49.0 (10.8/19)
	Jantar Formation	21.4 (4.6/12)	52.1 (6.8/12)
	Pelplin Formation (Wenlock part)	25.4 (3.4/7)	47.5 (2.5/7)
Gapowo B-1	Piaśnica Formation	31.0 (2/3)	54.0 (4/3)
	Sasino Formation	41.0 (17/14)	45.0 (16/14)
	Jantar Formation	32.0 (9/13)	47.0 (9/13)
	Pelplin Formation (Wenlock part)	31.0 (4/20)	44.0 (4/20)

Tab. 3.5. Amount of quartz and total clay from laboratory samples (XRD) in selected wells located within (blue colour) and in the neighborhood of the tender area (Podhalańska et al., 2018).

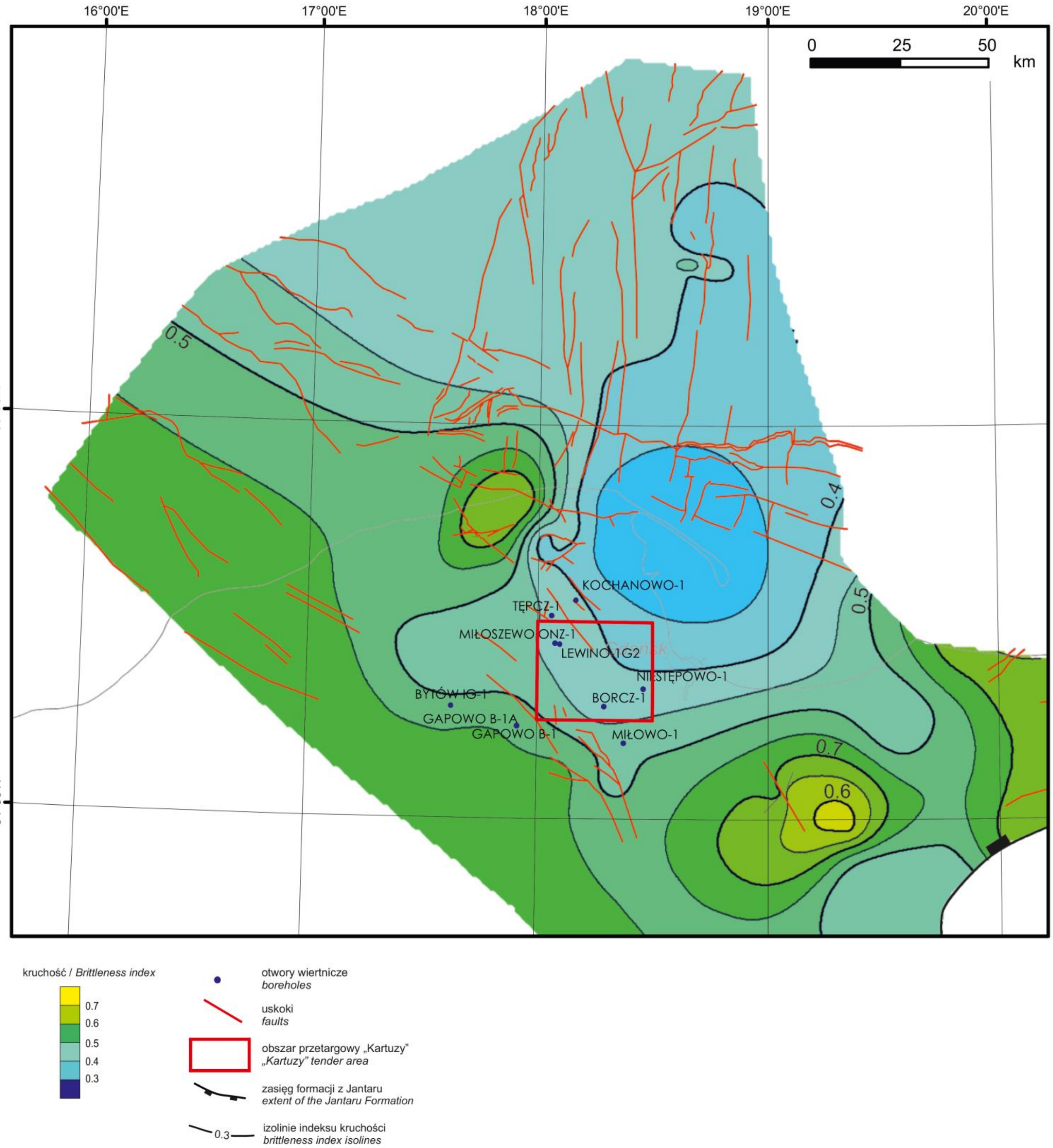


Fig. 3.17. Location of the "Kartuzy" tender area in the map of brittleness index distribution in the Jantar Formation (Podhalańska et al., 2020, modified).

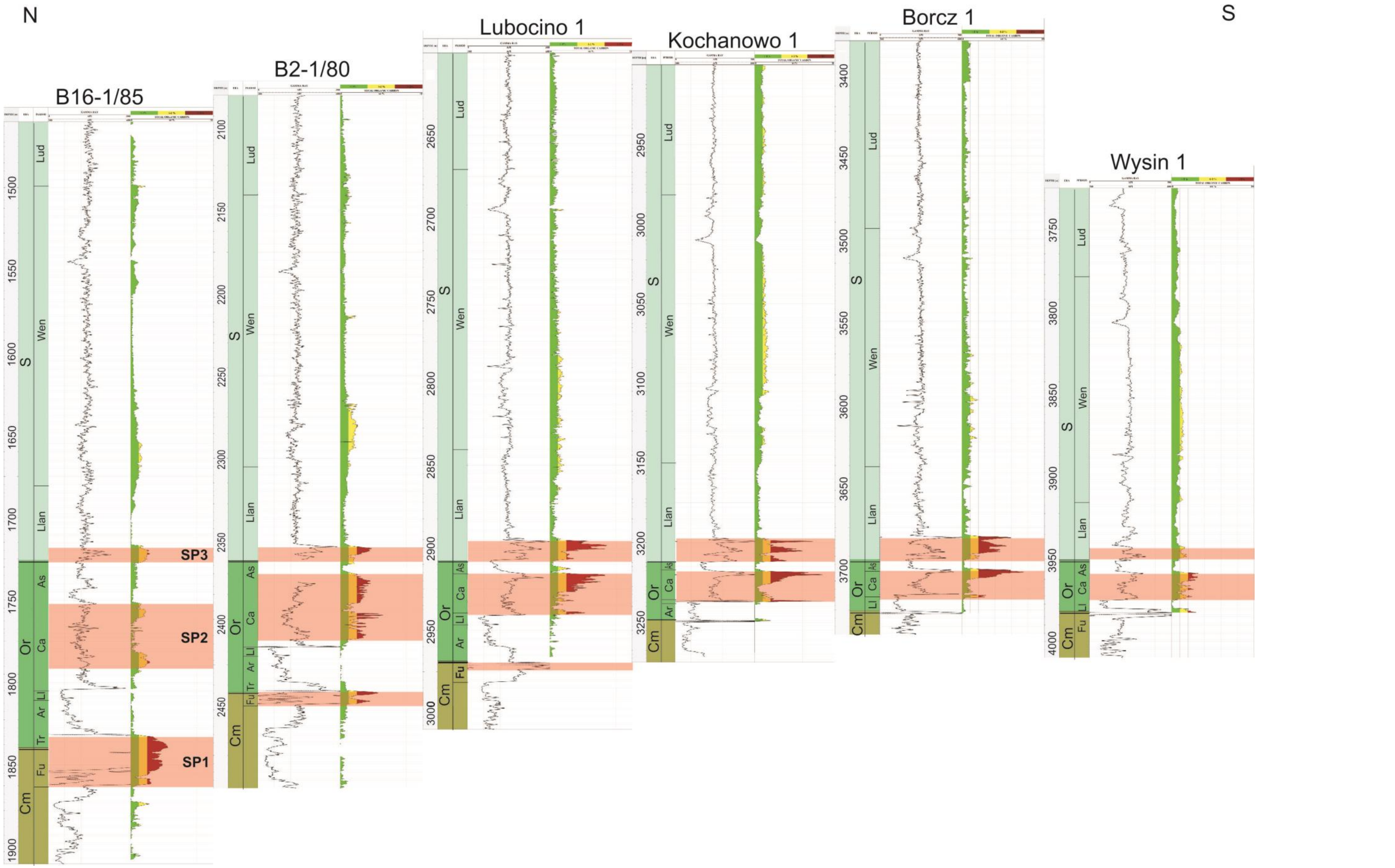


Fig. 3.18. Correlation of the Lower Paleozoic in the Łeba High (Podhalańska et al., 2020). Cm – Cambrian, Or – Ordovician, S – Silurian, Fu – Furongian, Tr – Tremadocian, Ar – Arenig, Ll – Llanvirn, Ca – Caradoc, As – Ashgill, Llan – Llandovery, Wen – Wenlock, Lud – Ludlow, SP1, SP2 – SP3 – prospective shale intervals.

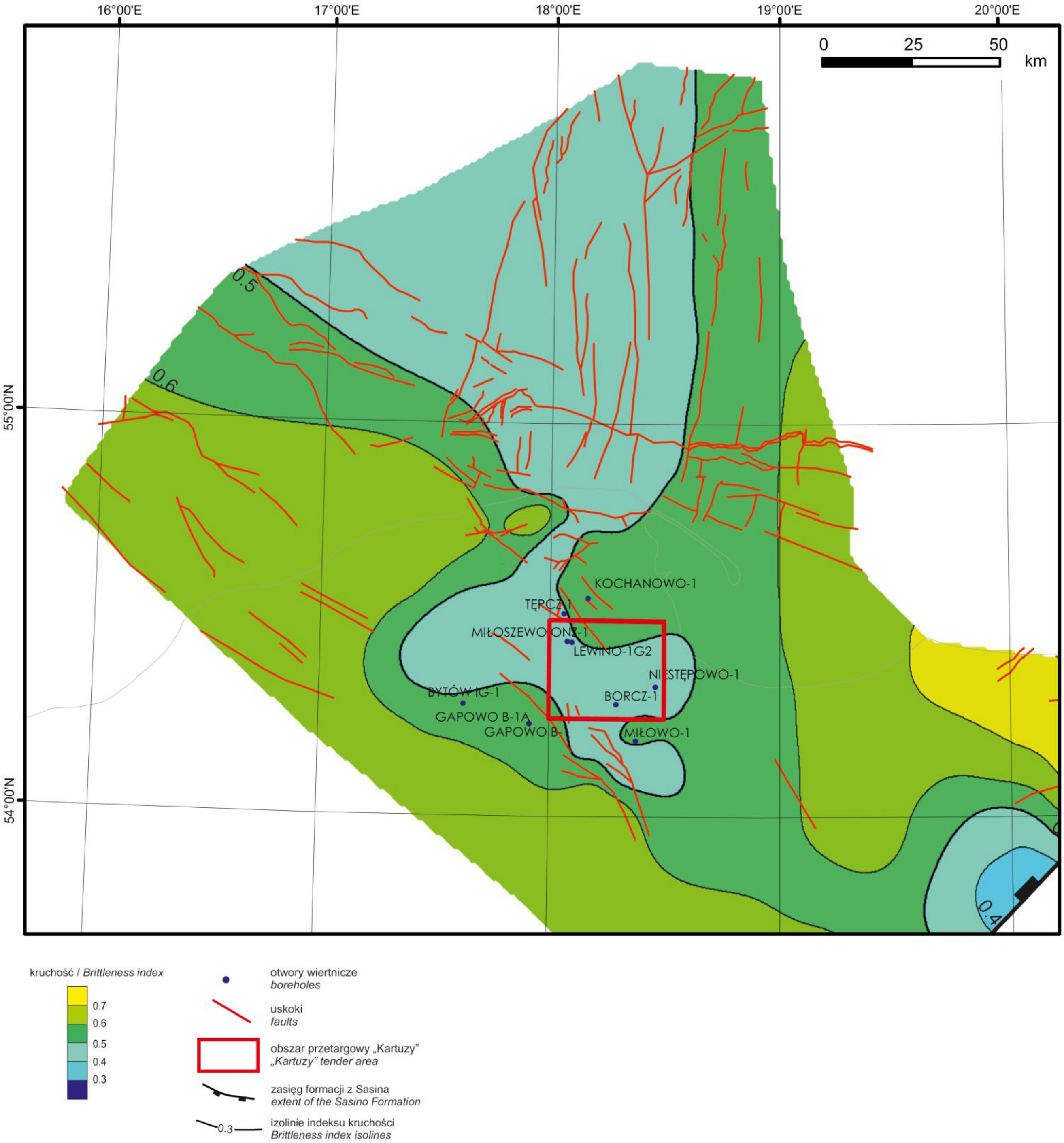


Fig. 3.19. Location of the "Kartuzy" tender area in the map of brittleness index distribution in the Sasino Formation (Podhalańska et al., 2020, modified).

3.3.3. PETROPHYSICAL CHARACTERISTICS OF LOWER PALEOZOIC SHALES

Available data indicate that the porosity and permeability of shales from the Ordovician and Silurian are not satisfactory. Because of different methods that were applied by different operators, the petrophysical parameters from wells are be presented separately (Tabs 3.6–3.8).

No petrophysical analysis in Ordovician and Silurian shales were applied during the drilling of the Niestępowo-1 well. In 2018 (Podhalańska et al., 2018), analyses of geophysical logs were applied to establish effective porosity and TOC content.

Calculated parameters are as follows:
Sasino Formation: total porosity 0–9%,
Jantar Formation: total porosity 0–5%,
Pelpin Formation (Wenlock part): total porosity ~4%.

Lithostratigraphy	Mean total porosity [%]	Mean open porosity [%]	Mean porosity from NMR [%]	Mean porosity based on interpretation of geophysical logs [%]
Sasino Formation	9.58	8.31	5.07	4.7
Jantar Formation	9.75	8.93	4.25	4.1
Pelplin Formation (Wenlock part)	5.86	5.60	no data	no data

Tab. 3.6. Petrophysical parameters in the Borcz-1 well (Mikołajewski, 2015; Strzelecka, 2017).

Lithostratigraphy	Mean total porosity (range) [%]	Mean open porosity (range) [%]	Mean fissure porosity (range) [%]	Mean fissure permeability (range) [mD]
Sasino Formation	6.98 (4.02–13.1)	2.42 (0.18–4.85)	1.68 (0.89–0.74)	1.25 (0.11–4.45)
Jantar Formation	5.69 (2.72–10.58)	1.70 (0.22–3.57)	2.09 (1.11–3.89)	1.77 (0.23–4.25)
Pelplin Formation (Wenlock part)	6.8 (0.33–9.18)	0.52 (0.14–1)	2.25 (1.51–4.10)	1.66 (1.12–2.71)

Tab. 3.7. Petrophysical parameters in the Miłowo-1 well (Mikołajewski, 2015; Strzelecka, 2017).

Lithostratigraphy	Mean total porosity (range) [%]	Mean effective porosity (range) [%]	Mean permeability [mD]
Sasino Formation	5.53 (0.79–16.57)	2.96 (0.56–11.28)	0.00
Jantar Formation	5.47 (3.63–6.15)	3.29 (1.55–4.40)	0.00
Pelplin Formation (Wenlock part)	4.46 (3.20–5.75)	3.02 (2.02–3.71)	0.00

Tab. 3.8. Petrophysical parameters in the Gapowo B-1 well (Kubala, 2013).

3.3.4. HYDROCARBON SHOWS, WELL TESTS, HYDRAULIC FRACTURING RESULTS

Borcz-1
Source: Mikołajewski, 2015.
Mudlogging:
In the following intervals, increases in gas content were noticed:

- Silurian – Wenlock
  3516.0–3521.5 m, 3524.0–3531.5 m, 3535.0–3541.0 m, 3572.5–3574.0 m, 3598.0–3602.0 m, 3619.5–3620.0 m;
- Silurian – Llandovery
  3644.0–3645.0 m, 3679.5–3687.5 m;
- Ordovician – Caradoc/Llanvirn:
  3700.5–3705.0 m, 3710.5–3713.5 m.

Gas shows in drilling cores:

- 3405.0–3414 m (Silurian – Ludlow/Pridoli)
- 3432.0–3530.5 m (Silurian – Ludlow/ Wenlock – Pelplin Formation)
- 3539,5–3566,0 (Silurian – Wenlock – Pelplin Formation)

- 3575.0–3620.0 m (Silurian – Wenlock – Pelplin Formation)
- 3629.0–3647.0 m (Silurian – Wenlock/ Llandovery – Pelplin Formation/Pasłęk Formation)
- 3664.0–3717.0 m (Silurian/Ordovician – Llandovery/Ashgill/Caradoc – Pasłęk Formation, Jantar Formation, Prabuty Formation, Sasino Formation)

Hydraulic fracturing, well tests:
Not applied.

Lewino-1G2
Source: Szpetnar-Skierniewska et al., 2019.
Until 29-11-2022 the entity has exclusive right to use geo-logical information.

Niestępowo-1
Source: Kalbarczyk and Śliwiński, 1974.
Mudlogging:
Increases in methane content were noticed at depths 2955.0 m, 2958.5 m, and 3958.5–2977.3 (Silurian).
Gas shows in mud:
Gas in mud was observed at depths 2958.5–2974.0 m (Silurian – Pridoli and Wenlock) and 3562.6 m (Ordovician – Caradoc).
Gas shows in drilling cores:
2963.5–2968.0 m and 2968.0–2974.3 m.
Hydraulic fracturing, well tests:
Negative results of well tests applied in the Lower Silurian – Ordovician – Middle Cambrian interval.

Miłowo-1
Source: Mikołajewski, 2015.
Mudlogging:
Increases in methane content were noticed in the following intervals:

- Upper Silurian: 3545.0–3551.0 m, 3584.0–3600.0 m,
- Silurian – Wenlock: 3614.0–3618.5 m, 3643.5–3648.0 m., 3658.0–3663.5 m, 3671.0–3680.0 m., 3687.0–3691.5 m, 3704.5–3729.5 m, 3757.0–3760.0 m,
- Silurian – Llandovery: 3768.0–3775.0 m,
- Ordovician: 3782.0–3789.0 m, 3790.5–3792.0 m, 3795.5–3797.5 m,
- Upper Cambrian: 3809.5–3811.5 m.

Gas shows in drilling cores:

- 3680.0–3698.5 m (Silurian – Wenlock – Pelplin Formation),
- 3698.5–3716.0 m (Silurian – Wenlock – Pelplin Formation),
- 3762.0–3780.0 m (Silurian/Ordovician – Llandovery/Ashgill),
- 3780.0–3789.0 m (Ordovician – Ashgill/Caradoc – Prabuty/Sasino Formation),
- 3789.0–3807.0 m (Ordovician – Caradoc/Llanvirn/Arenig – Sasino/Kopalino/ Słuchowo Formation).

Hydraulic fracturing and well tests:
Not applied.

Tępcz-1
Source: Chruścińska and Sikorska-Piekut, 2018.
Mudlogging:
Increases in methane content were noticed in the following intervals:

- Silurian – Pridoli/Ludlow: 1662–2089.0 m,
- Silurian – Ludlow/Wenlock: 3043.0 m, 3058.,0–3270.0 m, 3166.0 m,
- Silurian – Wenlock: 3270.0–3288.0 m, 3288.0–3348.0 m,
- Silurian – Llandovery 3348.0–3362.0 m,
- Ordovician – Ashgill/Caradoc: 3375.0–3384.0 m.

Gas shows in drilling cores:

- 3270.0–3288.0 m (Silurian – Wenlock – Pelplin Formation)
- 3330.0–3348.0 m (Silurian – Llandovery – Pasłęk Formation)
- 3348.0–3366.0 m (Silurian - Llandovery – Jantar Formation)
- 3366.0–3384.0 m (Ordovician - Caradocian – Sasino Formation)
- 3392.0–3410.0 m (Ordovician – Llanvirn – Kopalino Formation)

Hydraulic fracturing and well tests:
Not applied.

Gapowo B-1 and Gapowo B-1A
Source: Kubala, 2014, Miłaczewski and Poprawa, 2015.
Mudlogging:
Increase of hydrocarbons content during the mudlogging was observed from the top of the

Silurian. In the horizontal well Gapowo B-1A, increase in hydrocarbons occurred at the bottom of the Ludlow, in the whole Wenlock, and in the lower Llandovery

Gas shows in drilling cores:

Lack of detailed depth information; however, gas shows in the Silurian and Ordovician were noticed.

Hydraulic fracturing and well tests:

Hydraulic fracturing and production tests were performed in the horizontal Gapowo B-1A well. The length of the perforated section was 1541 m (4409.0–5860.0 m interval) and comprised mainly the Jantar Formation. Twenty stages of hydraulic fracturing were performed, but after analyzing the results, it was found that only 8 were performed effectively (Kubala, 2014; Miłaczewski and Poprawa, 2015). The production test showed the hydrocarbon flow around 5600–11,300 m^3/day. There were no traces of heavy hydrocarbons. The content of C1–C6 hydrocarbons was in the range of 29–85% (Kubala, 2014).

3.4. GENERATION, MIGRATION, ACCUMULATION AND HYDROCARBON TRAPS

Lower Paleozoic petroleum plays

Source rocks: Upper Cambrian, Ordovician (Caradoc) and Silurian (Llandovery and Wenlock) fine-grained sediments enriched in organic matter.

Reservoir rocks: Middle Cambrian sandstones in the Lower Paleozoic petroleum play (conventional and unconventional play); Upper Cambrian, Ordovician (Caradoc) and Silurian (Llandovery and Wenlock) fine-grained sediments enriched in organic matter in the Lower Paleozoic unconventional petroleum play of shale gas/shale oil type.

Seal: Ordovician and Silurian fine-grained sediments, Zechstein evaporites.

Traps: structural, lithological and stratigraphic or combined traps in the Lower Paleozoic petroleum play in the Middle Cambrian deposits (conventional and unconventional plays). All of the discovered reservoirs are related to the structural elevations (Vosilius, 1987; Reicher, 2006); continuous traps in the Lower Paleozoic unconventional petroleum play.

Age and mechanism of traps formation: In the Lower Paleozoic petroleum play in the Middle Cambrian deposits (conventional and unconventional play), the bases of structures originated at the end of the Proterozoic and in the Early Cambrian, but they were formed in the Cambrian and Silurian – Devonian stages of structural evolution of the Peribaltic Syneclise (Reicher, 2006).

Petroleum generation, expulsion, migration, and accumulation of hydrocarbons: Maturity modeling of the Lower Paleozoic indicates that the shale source rocks are at present in the transition zone of generation/occurrence of wet gas, condensate (Ro: 1.1–1.4%; Podhalańska et al., 2020). The results of thermal and burial history show that the Lower Paleozoic shales reached the highest paleotemperatures in the Paleozoic – from the end of the Silurian to the Late Carboniferous/Early Permian (Botor et al., 2017a,b, 2019a,b).

Generation of hydrocarbons in the Baltic region began in the Caledonian stage of deposit burial, when it exceeded 2000 m (Witkowski, 1989; Reicher, 2006). In the “Kartuzy” tender area, the process of generation started in the Late Silurian/Early Devonian and lasted until the end of the Carboniferous. Data from the Gdańsk IG-1 well (Fig. 3.20), which is located about 20 km from the tender area, suggest that generation of oil in the Ordovician and Silurian could start in the Early Devonian (Botor et al., 2017b, 2019b). Generation of hydrocarbons in the Baltic region finished with Variscan inversion of the Paleozoic strata. In the Mesozoic and Cenozoic, the Lower Paleozoic deposits were cooled and there was no generation activation at those times (Botor et al., 2017b, 2019b).

In the “Kartuzy” tender area, the kerogen transformation ratio at the end of the Paleozoic could be over 90% for Caradoc and Llandovery HC-source shales, and over 80% for Wenlock shales (Fig. 3.21 A–C). It also confirms that generation processes in the Mesozoic and Cenozoic have not been resumed.

The gas generation potential calculated for the Ordovician (Caradocian) shales of the Late Paleozoic stage in the Baltic region increases towards the SW, and may reach 20–40 mg HC/g TOC in the tender area (Fig. 3.22 C). The oil generation potential is higher and may reach 450 mg HC/g TOC (Fig. 3.23 C).

The hydrocarbon generation potential calculated for the Llandovery and Wenlock shales also increases towards the SW and may reach the range of 30–80 mg HC/g TOC for gas (Fig. 3.22 A–B) and over 450 mg HC/g TOC for oil (Fig. 3.23 A–B) in the tender area.

The generation processes occurred from the Late Silurian to the end of the Carboniferous. The rate of gas expulsion for Ordovician and Silurian shales did not reach the values of 10 Mton/km^2/Ma (Fig. 3.24 A–C). The rate of oil expulsion reached 50 Mton/km^2/Ma for the Caradoc, 10–150 Mton/km^2/Ma for the Llandovery, and 300 Mton/km^2/Ma for the Wenlock shales (Fig. 3.25A–C; Botor et al., 2017b, 2019b).

Based on Reicher (2006), the main phase of migration and accumulation of hydrocarbons in the Lower Paleozoic petroleum play in the Middle Cambrian deposits was in the Early/Middle Devonian and was related to the Variscan inversion. The hydrocarbons have been migrated towards the north and northeast of the Baltic Basin. The hydrocarbon plays started to form before the Carboniferous erosion. A schematic diagram of the evolution of petroleum systems in the "Kartuzy" area is illustrated in Fig. 3.26.

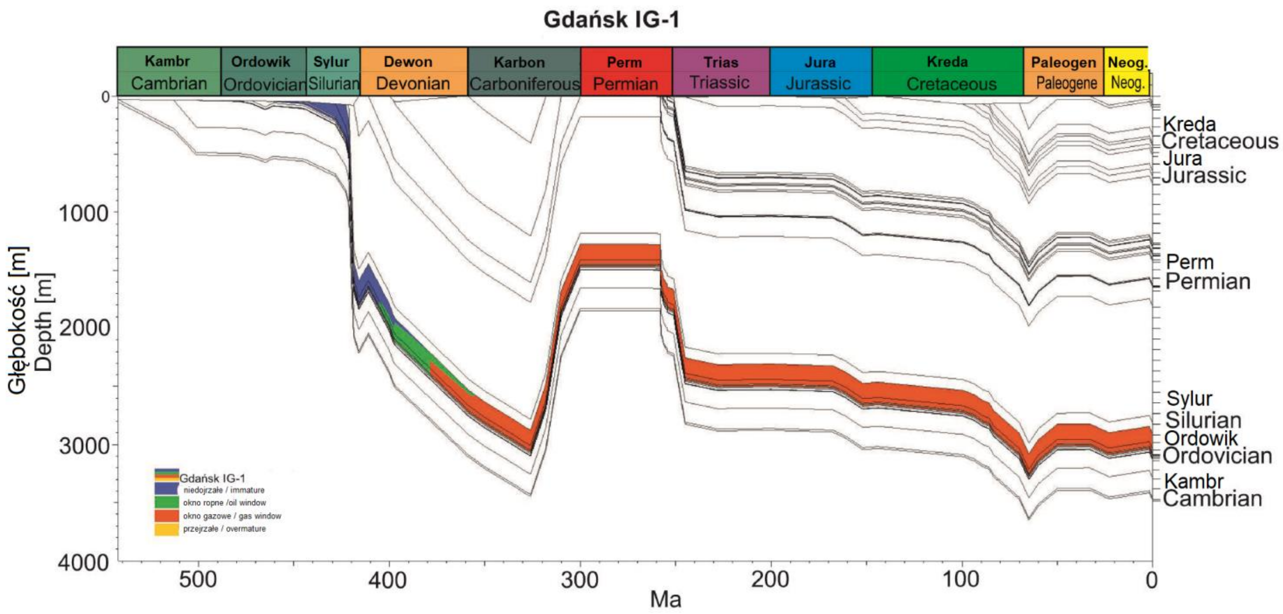


Fig. 3.20. Burial and thermal history model for the Gdańsk IG-1 well (Botor et al., 2019b, after Botor et al., 2017b)

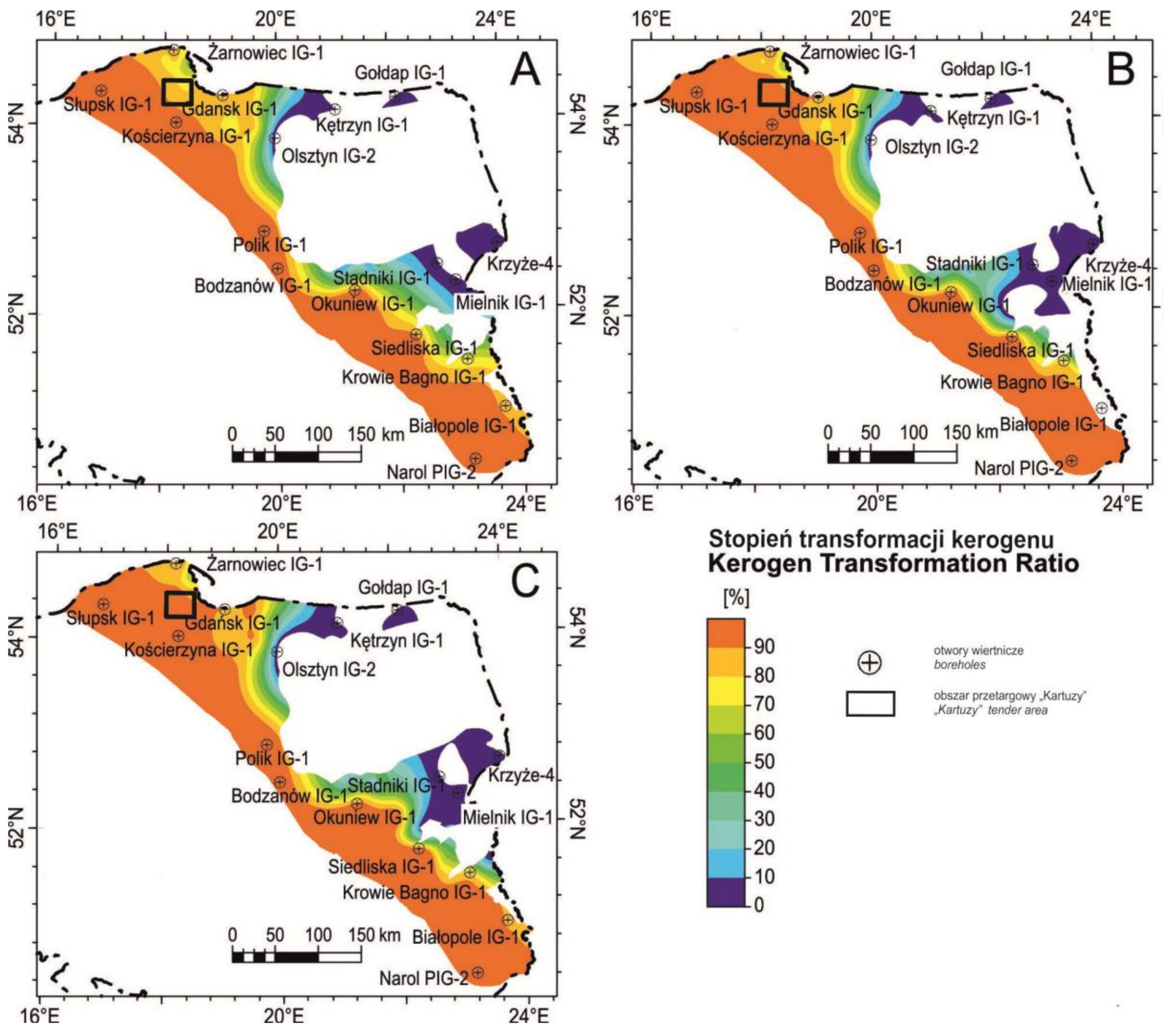


Fig. 3.21. Location of the "Kartuzy" tender area in the map of kerogen transformation ratio in the Wenlock (A), Llandovery (B) and Caradoc (C; Botor et al., 2019b, modified after Botor et al., 2017b).

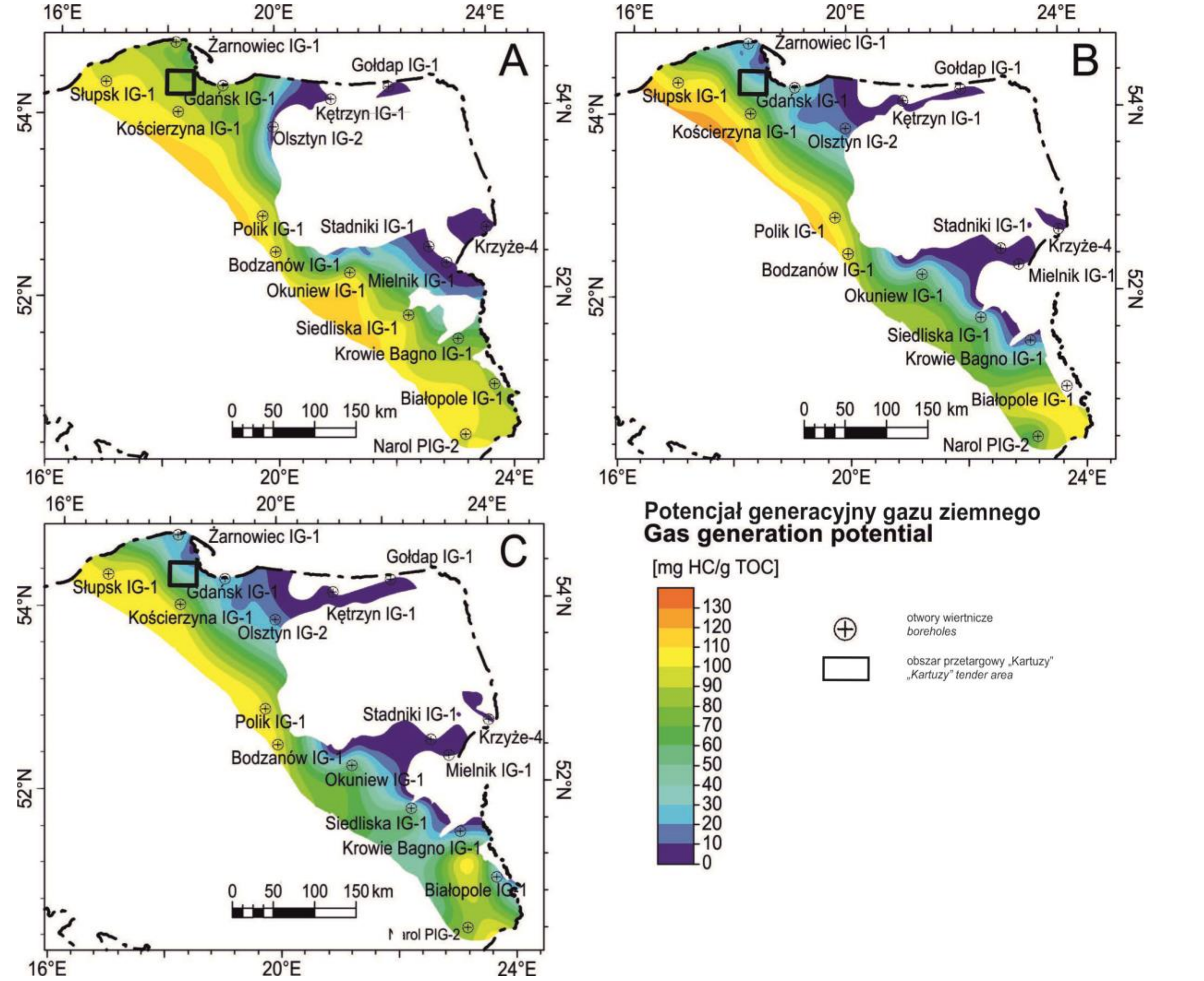


Fig. 3.22. Location of the "Kartuzy" tender area in the map of gas generation potential in the Wenlock (A), Llandovery (B) and Caradoc (C; Botor et al., 2019b, modified after Botor et al., 2017b).

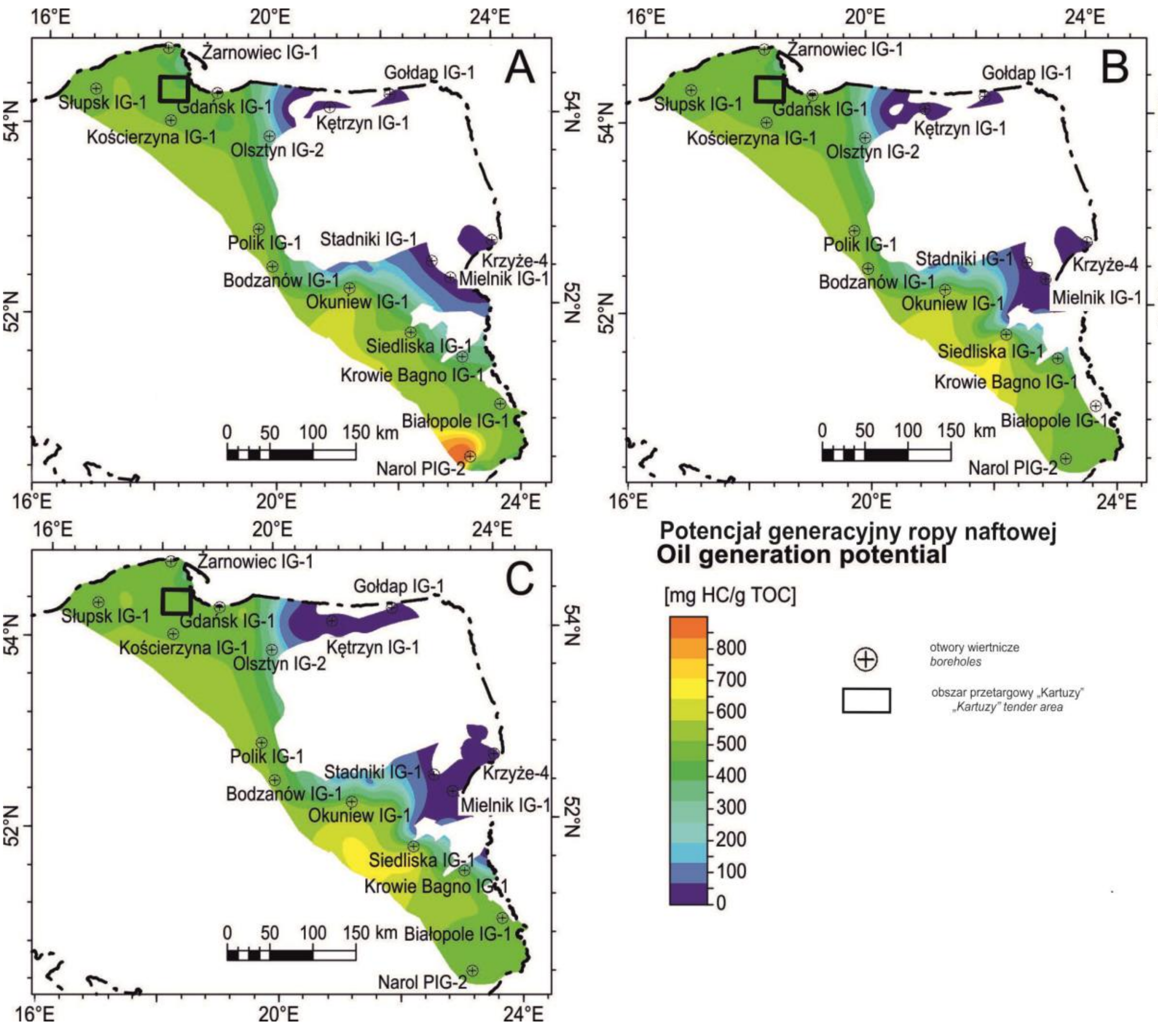


Fig. 3.23. Location of the "Kartuzy" tender area in the map of oil generation potential in the Wenlock (A), Llandovery (B) and Caradoc (C) estimated for the Paleozoic stage (Botor et al., 2019b, modified after Botor et al., 2017b).

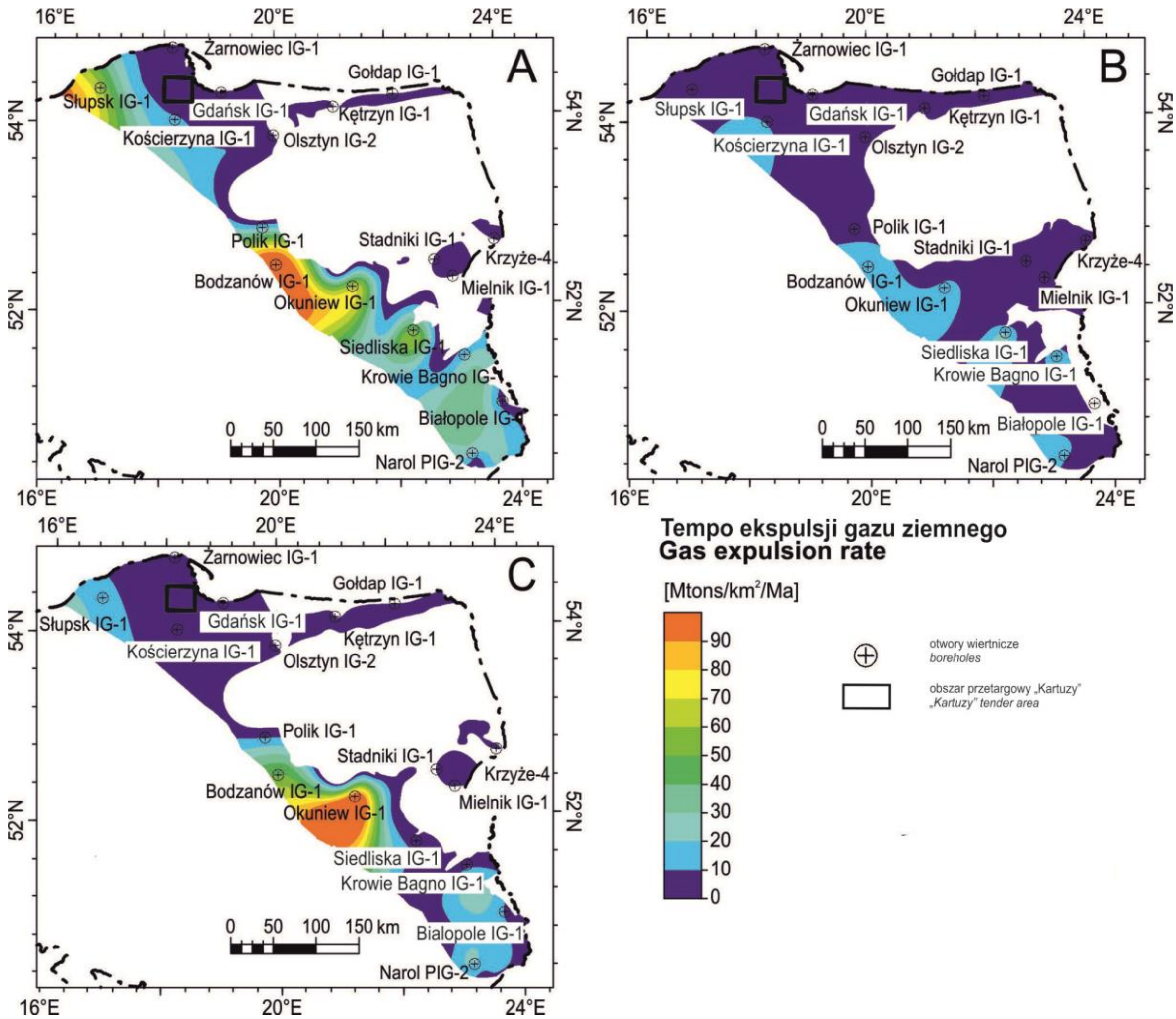


Fig. 3.24. Location of the "Kartuzy" tender area in the map of gas expulsion rate from the Wenlock (A), Llandovery (B) and Caradoc (C) estimated for the Paleozoic stage (Botor et al., 2019b, modified after Botor et al., 2017b).

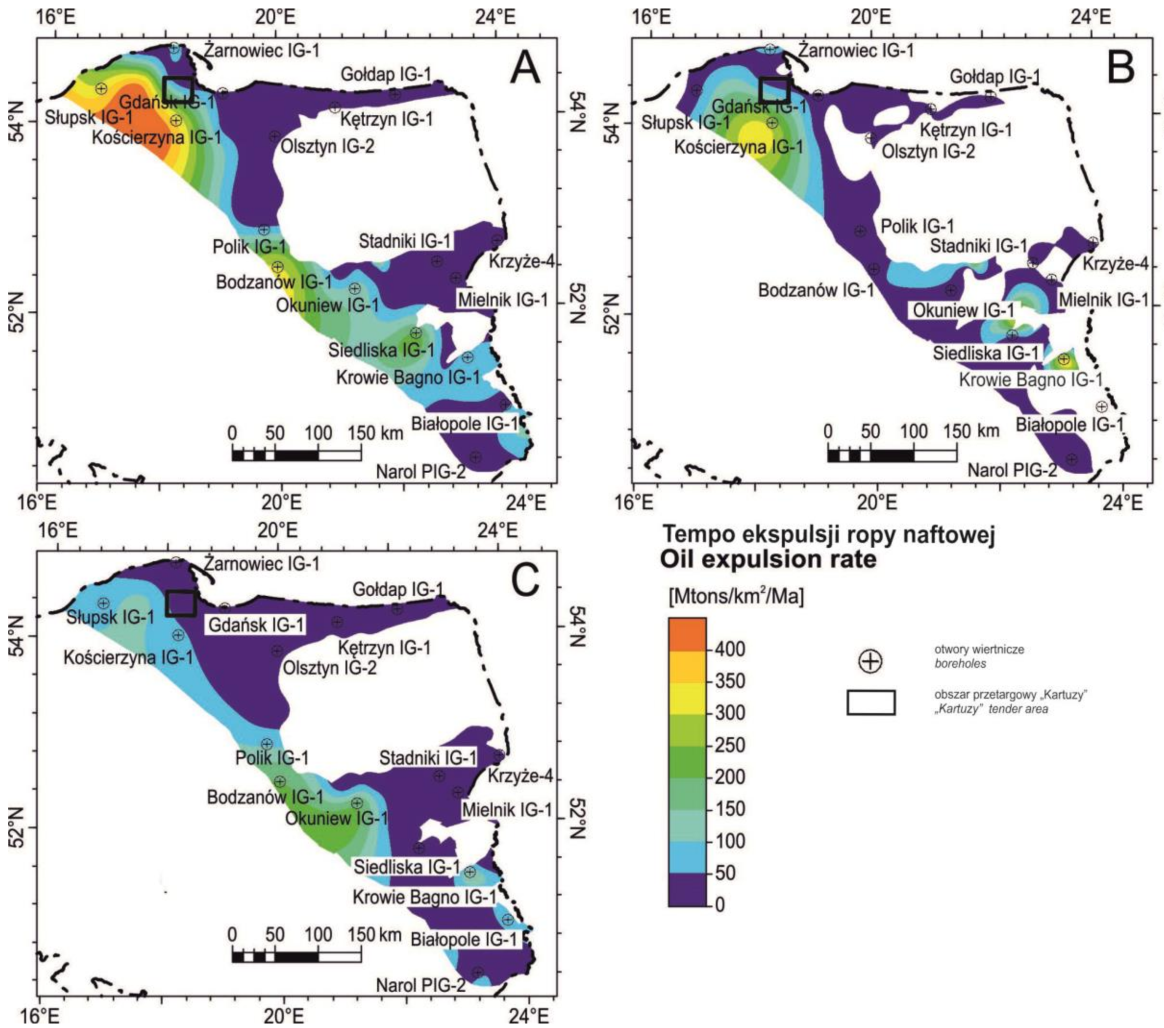


Fig. 3.25. Location of the "Kartuzy" tender area in the map of oil expulsion rate from the Wenlock (A), Llandovery (B) and Caradoc (C) estimated for the Paleozoic stage (Botor et al., 2019b, modified after Botor et al., 2017b).

4. HYDROCARBON FIELDS

Neither conventional nor unconventional oil and gas fields have been documented within the “Kartuzy” tender area and in its vicinity. Some analogues related to the conventional accumulations in the Middle Cambrian – Żarnowiec, Dębki and Białogóra fields are located about 30 km north of the “Kartuzy” area. The detailed descriprion of these accumulations can be found at, e.g.:
https://bip.mos.gov.pl/fileadmin/user_upload/bip/koncesje_geologiczne/ogloszenia/przetargi_weglowodorowe/runda_3_2018/pakiety_2/PDG%20WEJHEROWO.pdf

5. WELLS

Four deep wells (> 500 m MD) are located within the "Kartuzy" tender area (Fig. 5.1). Another three wells, located in the neighborhood, should be investigated in terms of unconventional petroleum play modelling.

Well name	Year	Owner	Concession (for wells after 1994)	Depth [m]	Stratigraphy at the bottom
Borcz-1	2013	State Treasury	Kartuzy-Szemud 72/2009/p	3760.0	Middle Cambrian
Lewino-1G2	2011	State Treasury	Gdańsk W 71/2009/p	3760.0	Middle Cambrian
Niestępowo-1	1973	State Treasury		3632.9	Middle Cambrian
Miłoszewo ONZ-1	1969	State Treasury		1558.0	Pridoli
Wells located in the neighborhood of the tender area					
Gapowo B-1/ B-1A	2012/2014	State Treasury	Bytów 17/2010/p	4303.0/ 6058.0	Cambrian/Ordovician
Miłowo-1	2014	State Treasury	Kartuzy-Szemud 72/2009/p	3856.0	Middle Cambrian
Tępcz-1	2014	State Treasury	Wejherowo 4/2009/p	3428.0	Middle Cambrian

The general characteristics of the listed above wells, including hydrocarbon shows and inflows, as well as petrophysical properties of gas-and-oil bearing intervals, are shortly summarized in Tab. 5.1. The Niestępowo-1 well is illustrated as an example in Fig. 5.2.

The original data from 8 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 5th tender round. In the case of Lewino-1G2 well, until 29-11-2022 the entity has exclusive right to use geological information

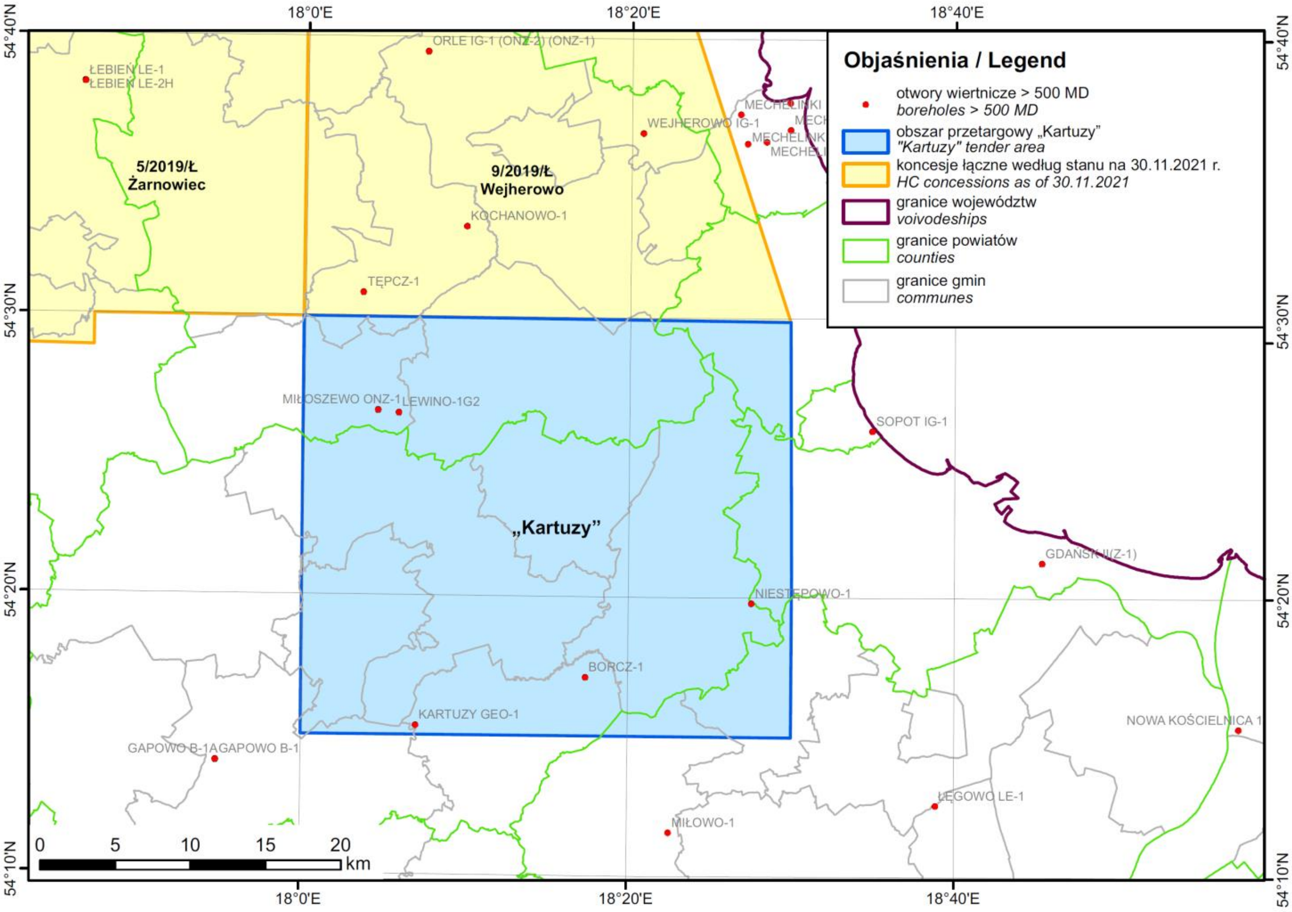


Fig. 5.1. Deep wells (>500 m MD) located within the "Kartuzy" tender area and in its close neighborhood.

→ **Tab. 5.1.** Summary of stratigraphy, petrophysical properties, hydrocarbon shows, hydrocarbon inflows, and well logs in deep wells located within the "Kartuzy" tender area and in its close neighborhood.

STRATIGRAPHY	BORCZ-1		2013	LEWINO-1G2		2011		NIESTĘPOWO-1		1973	
	Depth from [m]	Depth to [m]	Average porosity [%]/ Average permeability [mD]/ Average TOC [%]	Depth from [m]	Depth to [m]	Average porosity [%]/ Average permeability [mD]/ Average TOC [%]	HC Inflow	Depth from [m]	Depth to [m]	Average porosity [%]/ Average permeability [mD]/ Average TOC [%]	HC Inflow
Cenozoic	0	205.0						0	217.0		
Cretaceous	205.0	735.0		Until 29-11-2022 the entity has exclusive right to use geological information				217.0	625.5		
Jurassic	735.0	894.0						625.5	792.0		
Triassic	894.0	1448.5						792.0	1340.0		
Permian	1448.5	1834.0						1340.0	1717.0		
Top Terrigenous Series PZt								1340.0	1358.0		
Main Anhydrite A3								1358.0	1392.5		
Platy Dolomite Ca3								1392.5	1396.0		
Grey Pelite T3								1396.0	1396.5		
Screening Anhydrite A2r								1396.5	1398.5		
Older Halite Na2								1398.5	1404.0		
Basal Anhydrite A2								1404.0	1422.5		
Main Dolomite Ca2			17.2/-/-					1422.5	1451.5	6,43/33,90/-	
Upper Anhydrite A1g								1451.5	1475.5		
Oldest Halite Na1								1475.5	1577.5		
Lower Anhydrite A1d								1577.5	1705.5		no inflow
Zechstein Limestone Ca1								1705.5	1716.0	2,80/0,35/-	
Kupferschiefer T1								1716.0	1716.5		
Basal Conglomerate								1716.5	1717.0		
Rotliegend											
Silurian	1834.0	3694.0						1717.0	3452.0		
Puck Fm	1834.0	3637.0									
Kociewie Fm											
Pelplin Fm			5.86-8.31/-/0.9								
Pasłęk Fm	3637.0	3680.5	7.61/-/1.49					3412.0	3442.0	-/-/0,48	
Jantar Fm	3680.5	3694.0	9.75/-/3.29					3442.0	3452.0		
Ordovician	3694.0	3726.9						3452.0	3490.0		drilling fluid with gas
Prabuty Fm	3694.0	3700.5	7.41/-/0.19					3452.0	3459.0		
Sasino Fm	3700.5	3715.5	9.58/-/2.68					3459.0	3478.5	-/-/2,79	
Kopalino Fm	3715.5	3725.5	2.51/-/0.91					3478.5	3481.0	-/-/2,52	
Pieszkowo Fm								3481.0	3485.0	-/-/3,25	
Słuchowo Fm	3725.5	3726.9						3485.0	3490.0		
Upper Cambrian	3726.9	3727.2						3490.0	3492.8	2,09/-/-	
Piaśnica Fm	3726.9	3727.2									
Middle Cambrian	3727.2	3760	2.19/-/0.19					3492.8	3632.9	1,84/0,39/0,35	
Sarbsko Fm											
Białogóra Fm											
Osieck Fm	3727.2	3760.0									
Dębki Fm											

STRATIGRAPHY	MIŁOSZEWO ONZ-1, 1969		GAPOWO B-1		2012	
	Depth from [m]	Depth to [m]	Depth from [m]	Depth to [m]	Average porosity [%]/ Average permeability [mD]/ Average TOC [%]	HC Inflow
Cenozoic	0	274.0	0	323.0		
Cretaceous	274.0	612.5	323.0	857.0		
Jurassic	612.5	770.0	857.0	953.0		
Triassic	770.0	1169.0	953.0	1495.0		
Permian	1169.0	1520.0	1495.0	1895.0		
Top Terrigenous Series PZt	1169.0	1194.0	1495.0	1500.0		
Main Anhydrite A3	1194.0	1205.5	1500.0	1525.0		
Platy Dolomite Ca3	1205.5	1209.2	1525.0	1530.0		
Grey Pelite T3	1209.2	1209.5				
Screening Anhydrite A2r						
Older Halite Na2						
Basal Anhydrite A2	1209.5	1214.0	1530.0	1537.0		
Main Dolomite Ca2	1214.0	1255.5	1537.0	1580.0		
Upper Anhydrite A1g	1255.5	1283.5	1580.0	1614.0		
Oldest Halite Na1	1283.5	1443.0	1614.0	1700.0		
Lower Anhydrite A1d	1443.0	1510.0	1700.0	1836.0		
Zechstein Limestone Ca1	1510.0	1519.3	1836.0	1852.0		
Kupferschiefer T1	1519.3	1520.0				
Basal Conglomerate						
Rotliegend			1852.0	1895.0		
Silurian	1520.0	1558.0	1895.0	4207.0		
Puck Fm	1520.0	1558.0	1895.0	2080.0		
Kociewie Fm			2080.0	3210.0		
Pelplin Fm			3210.0	4164.0	4,46/0/0,91	
Pasłęk Fm			4164.0	4192.0	3,88/0/0,63	
Jantar Fm			4192.0	4207.0	5,47/0/1,55	
Ordovician			4207.0	4257.0		
Prabuty Fm			4207.0	4236.0	3,89/0/1,76	
Sasino Fm			4236.0	4250.0	5,53/0/1,23	
Kopalino Fm			42500	4257.0	3,52/0/0,53	
Pieszkowo Fm						
Słuchowo Fm						
Upper Cambrian			4257.0	4262.0		
Piaśnica Fm			4257.0	4262.0	2,28/0/0,52	
Middle Cambrian			4262.0	4303.0		
Sarbsko Fm			4262.0	4303.0	2,94/0/0,20	
Białogóra Fm						
Osieck Fm						
Dębki Fm						

STRATIGRAPHY	GAPOWO B-1A		2014		MIŁOWO-1		2014		TĘPCZ-1, 2014	
	Depth from [m]	Depth to [m]	Average porosity [%]/ Average permeability [mD]/ Average TOC [%]	HC Inflow	Depth from [m]	Depth to [m]	Average porosity [%]/ Average permeability [mD]/ Average TOC [%]	HC Inflow	Depth from [m]	Depth to [m]
Cenozoic					0	230.0			0	215.0
Cretaceous					230.0	864.0			215.0	604.5
Jurassic					864.0	1092.0			604.5	812.5
Triassic					1092.0	1685.5			812,5	1098.0
Permian					1685.5	2045.0			1098.0	1449.0
Top Terrigenous Series PZt										
Main Anhydrite A3									1098.0	1119.0
Platy Dolomite Ca3									1119.0	1125.0
Grey Pelite T3										
Screening Anhydrite A2r										
Older Halite Na2										
Basal Anhydrite A2									1125.0	1128.5
Main Dolomite Ca2									1128.5	1170.0
Upper Anhydrite A1g									1170.0	1195.5
Oldest Halite Na1									1195.5	1390.5
Lower Anhydrite A1d									1390.5	1436.0
Zechstein Limestone Ca1									1436.0	1449.0
Kupferschiefer T1										
Basal Conglomerate										
Rotliegend										
Silurian	3710.0	6044.0			2045.0	3775.5			1449.0	3368.5
Puck Fm					2045.0	2618.0			1449.0	1902.0
Kociewie Fm					2618.0	26420			1902.0	31730
Pelplin Fm					2642.0	3608.5			3173.0	3318.0
Pasłęk Fm					3739.0	3767.0			3318.0	3349.0
Jantar Fm	4255.4	6058.0		**hydraulic fracturing: gas**	3767.0	3775.5	2,09-5,69/1,77/3,38		3349.0	3368.5
Ordovician					3775.5	3810.2			3368.5	3408,5
Prabuty Fm					3775.5	3782.5			3368.5	3375.5
Sasino Fm					3782.5	3798.85	1,68-6,98/1,25/3,23		3375.5	3396.0
Kopalino Fm					3798.85	3807.5			3396.0	3407.5
Pieszkowo Fm										
Słuchowo Fm					3807.5	3810.2			3407.5	3408.5
Upper Cambrian					3810.2	3811.0			3408.5	3408.65
Piaśnica Fm					3810.2	3811.0				
Middle Cambrian					3811.0	3856.0		week air flow	3408.65	3428.0
Sarbsko Fm										
Białogóra Fm										
Osieck Fm										
Dębki Fm										

	BORCZ-1	LEWINO-1G2	NIESTĘPOWO-1	MIŁOSZEWO ONZ-1	GAPOWO B-1	GAPOWO B-1A	MIŁOWO-1	TĘPCZ-1
GEOPHYSICS	BS: 25.0–3759.0 m; PSr: 340.0–3759.0 m; DTP: 345.0–3757.9 m; NPHI: 335.8:3757.0 m; PG: 345.0–3758.0 m; POst: 341.5–3754.7 m; RHOB: 341.6–3760.0 m.	ADJS1: 0–3577 m; DTCO: 533–3577 m; DTSM: 533–3577 m; PG: 533–3577 m; PSr: 533–3577 m; NPHI: 533–3577 m; PR: 533–3577 m; RHOZ:–533–3577 m; PS: 533–3577 m.	BS: 10–3610 m; gPS: 1020–3612 m; mPO: 235–1072 m; mPSr: 100–3615 m; PA:–1350–3515 m; PAdt: 1344,25–3611,25 m; PG: 5–3613 m; PGaz: 2640–3620,5 m; PK: 25–3600 m; PNG: 5–3613 m; PO: 16–3621 m; POst: 1020–3613 m; EL: 950–1650 m; PS: 235–3515 m; PSr: 10–3612 m; PT: 1000–3050 m; Tx2: 20–3600 m; TW: 20–3600 m; Tr_PW1: 75–3600 m; Tr_PO: 75–3600 m; DT_VSP: 20–3600 m; DT_VSP: 20–2000 m.	PA: 1552–905 m; PAT: 110–1528 m; PG: 22–1552 m; PGG: 40–1552 m; PK: 900–900 m; PNG: 22–1551 m; PO: 73–1551,5 m; POpl: 905,5–1545,5 m; POst: 905,5–1551,5 m; PS: 73–1545,5 m; PSr: 73–1543 m; PTn: 73–1550 m.	ASO: 1913–4303 m; DPA: 800–1913 m; ECS: 1913–4303 m; HRLA:800–1913 m; PG: 10–4303 m; BHC: 38–800 m; ECS: 800–1913 m; TLD: 800–4303 m; AIT: 38–4303 m; CNL: 1913–4303 m; HGNS: 800–1913 m; PS: 38–800 m; PSr: 800–4303 m; EMS: 38–800 m; FMI: 1913–4303 m; HNGS: 1913–4303 m; USIT-CBL: 10–1911.3 m.	PG: 1911–4141 m; PGA: 4679–6058 m; PKA: 1911–6058 m; Mudlogging: 0–6058 m.	BS: 0–3858 m; PSr: 332–3857 m; CS: 2050–3818 m; CSP: 31–3855 m; DEVI: 2050–3856 m; DT: 344–3850 m; FLOC: 31–3855 m; FLOW: 31–3855 m; PG: 0–3851 m; HBHK: 1–1973 m; ICV: 0–3858 m; MTI, MTO, MWI, MWO: 31–3855 m; NPOR: 2050–3853 m; PEFZ: 332–3855 m; PHI, PHO: 31–3855 m; PV: 31–3855 m; RHOZ: 332–3855 m; SLOANI: 3072–3850 m; THOR: 1–2053 m; TPRA: 1–2053 m; TURA: 1–2053 m; URAN: 1–2053 m; VPVS: 2072–3850 m.	BSAT: 329.5–1473 m; CSNG: 329.5–1466 m; CSNG: 1475–3417 m; D4TG: 329.5–3410 m; DLL: 329,5–3425 m; DSN II: 329.5–1469 m; DSN: 1475–3425 m; FIAC: 329,5–3418 m; GEM: 1475–3421 m; GR: 29–355 m; MRIL: 2416–3417 m; MSFL: 329.5–3428 m; PK: 329.5–3416 m; PSr: 15–3420 m; SDLT: 329.5–1475.5 m; SDLT: 1475–3428.5 m; WS: 1475–3425 m; XRMI: 1475–3428.5 m; XYCAL: 29–355 m.
DOCUMENTATIONS	Chruścińska, J. 2018. Borcz-1 final well report. Inv. 3642/2019, Arch. CAG PIG, Warsaw. [In Polish]	Szpetnar-Skierniewska, A., Krajewski, D. 2018. Gdańsk W No. 71/2009/p final concession report. Inv. 5747/2020, Arch. CAG PIG, Warsaw. [In Polish]	Kalbarczyk, R., Śliwiński, J. 1974. Niestępowo-1 final well report. Inv. 118511, Arch. CAG PIG, Warsaw. [In Polish]	Miłoszewo ONZ-1 well chart. 1969. Inv. 111061, Arch. CAG PIG, Warsaw. [In Polish]	Kubala, P. 2013. Gapowo B-1 well report. Inv. 10040/2017, Arch. CAG PIG, Warsaw. [In Polish]	Kubala, P. 2014. Gapowo B-1A well production test and hydraulic fracturing report. Inv. 10041/2017, 10042/2017, Arch. CAG PIG, Warsaw. [In Polish]	Chruścińska, J., Puchalski, A., Twarduś, E., Majdosz-Lenart, M., Mikołajewski, Z. 2018. Miłowo-1 well liquidation report. Inw. 4714/2019, Arch. CAG PIG, Warsaw. [In Polish]	Chruścińska, J., Sikorska-Piekut, W. 2018. Tępcz-1 well liquidation report. Inv. 1968/2020, Arch. CAG PIG, Warsaw. [In Polish]
	Mikołajewski, Z. 2015. Kartuzy-Szemud concession report. Inv. 2298/2016, Arch. CAG PIG, Warsaw. [In Polish]	Szpetnar-Skierniewska, A., Krajewski, D. 2019. Lewino-1G2 well liquidation report. Inv. 2492/ 2020, Arch. CAG PIG, Warsaw. [In Polish]	Klecan A. 1973. Niestępowo-1 well velocity survey report. N28 VS, Arch. CAG PIG, Warsaw. [In Polish]		Kubala, P. 2014. Gapowo B-1A well production test and hydraulic fracturing report. Inv. 10041/2017, 10042/2017, Arch. CAG PIG, Warsaw. [In Polish]	Miłaczewski, L., Poprawa, P. 2015. Bytow No. 17/2010/p final concession report. Inv. 9282/2017, Arch. CAG PIG, Warsaw. [In Polish]	Podhalańska, T., et al. 2018. Recognition of prospective zones for unconventional hydrocarbon accumulations inPoland, stage II, final report. Inv. 9051/2019, Arch. CAG PIG, Warsaw. [In Polish]	
	Strzelecka, D. 2017. Kartuzy-Szemud No. 72/2009/p final concession report. Inv. 9901/2017, Arch. CAG PIG, Warsaw. [In Polish]		Podhalańska, T., et al. 2018. Recognition of prospective zones for unconventional hydrocarbon accumulations inPoland, stage II, final report. Inv. 9051/2019, Arch. CAG PIG, Warsaw. [In Polish]		Miłaczewski, L., Poprawa, P. 2015. Bytow No. 17/2010/p final concession report. Inv. 9282/2017, Arch. CAG PIG, Warsaw. [In Polish]		Mikołajewski, Z. 2015. Kartuzy-Szemud concession report. Inv. 2298/2016, Arch. CAG PIG, Warsaw. [In Polish]	
							Strzelecka, D. 2017. Kartuzy-Szemud No. 72/2009/p final concession report. Inv. 9901/2017, Arch. CAG PIG, Warsaw. [In Polish]	

(blue shading)	hydrocarbon shows

ADJS1: acoustic velocity GL; AIT: induction log; ASO: acoustic scanner; BHC: acoustic log; BS: nominal diameter; BSAT: interval time of acoustic wave; CNL: neutron porosity log; CS: cable velocity; CSP: drilling fluid pressure; D4TG: gamma-ray log; DEVI: deviation log; DLL: dual laterolog; DPA: dipole acoustic log; DSN: neutron log; DT: wave derivation time; DT_VSP: velocity survey, gradient of interpolated time; DTCO: compressional wave delay tim; DTP1: P-wave slowness; DTSM: shear wave delay time; ECS: mineralogical Schlumberger log; EL: electromagnetic log; EMS: shape log; FIAC: diameter; FLOC: pump efficiency; FLOW: flow meter; FMI: imaging log; GEM: geochemical log; gPS: gradient spontaneous potential log; HBHK: Potassium log; HGNS: gamma ray neutron sonde; HNGS: high resolution spectroscopy; HRLA: high resolution laterolog; ICV: cement volume; mPO: micro resistivity log; mPSr: caliper micrologog; MRIL: magnetic resonance log; MSFL: micro-spherically focused log; MTI, MTO, MWI, MWO: drilling fluid parameters; NPHI: neutron porosity log; NPOR: neutron porosity log; PA: acoustic log; PAdt: interval transit time log; PAT: sonic attenuation; PEFZ: pholoelectric log; PG: gamma-ray log; PGA: azimuth-gamma log; PGaz: gas log; PGG: gamma-gamma density log; PHI, PHO: pH; PK: deviation log; PKA: deviation and azimuth log; PNG: neutron-gamma log; PO: electrical survey (resistivity log); POpl: mud resistivity log; POst: laterolog; PR: Poissona ratio; PS: spontaneous potential log; PSr: diameter; PT: temperature log; PTn: temperature log, unstable thermal equilibrium; PV: drilling fluid volume; RHOB: density log; RHOZ: density log (saturated state); SDLT: spectral density log; SLOANI: slowness based anisotropy; THOR: Thorium log; TLD: density log; TPRA: Th/K log; Tr_PO: velocity survey, observed average time; Tr_PW1: velocity survey, observed travel time of SP1; TURA: Th/U log; TW: velocity survey, interpolated time; Tx2: velocity survey, doubled interpolated time; URAN: Uranium log; USIT-CBL: cement bond log; VPVS: P-velocity/S-velocity; WS: dipole acoustic log; XRMI: X-tended range micro imager; XYCAL: diameter log.

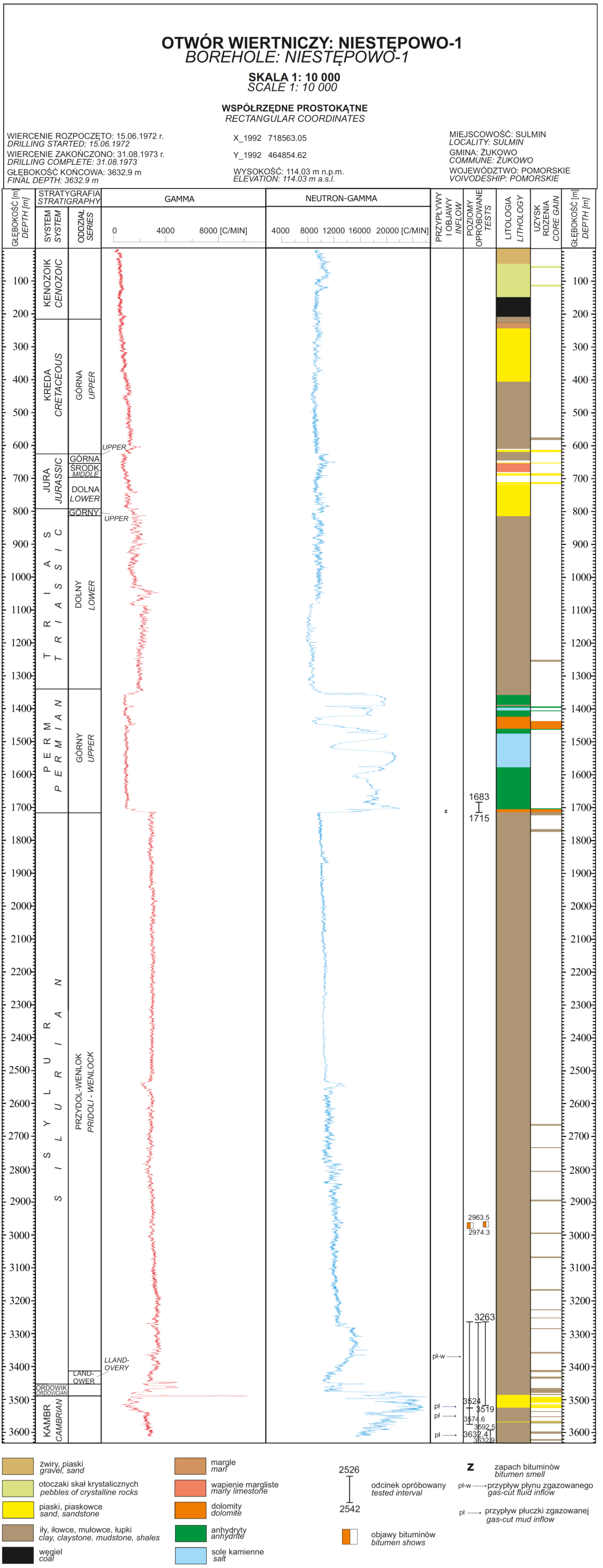


Fig. 5.2. Stratigraphy, lithology, selected well logs and hydrocarbon shows in the Niestępowo-1 well (Kalbarczyk and Śliwiński, 1974).

6. SEISMIC SURVEYS

The "Kartuzy" tender area is explored by a sparse grid of seismic lines and therefore requires further exploration (Figs 6.1–6.3). First surveys were acquired in the 1960s with analog type seismics. The contemporary seismic technology highly affected the seismic quality, e.g. sub-Zechstein reflectors have not been achieved. Further surveys were acquired in 2003 and 2007. The Kościerzyna – Gdańsk survey was conducted first by the Geofizyka Kraków (Fig. 6.3). The survey goal was to recognize the Main Dolomite traps, related to an oolitic barrier, and the Middle Cambrian traps. Then, the survey was completed by the Geofizyka Toruń to supplement previous results. The most up-to-date seismic data within the "Kartuzy" tender area was acquired in 2010 and 2011. These are the Somonino – Przywidz and Baltic Basin 2D projects. Furthermore, the NE and E part of the "Kartuzy" area was investigated by the PolandSpan survey.

Although much of the area requires further investigation, past work allowed identifying several structural objects (Fig. 6.4):

Structure	Horizon
Somonino	Middle Cambrian, Ordovician
Chmielno	Middle Cambrian
Hopowo	Ordovician
Lublewo	Ordovician

The 2D seismic surveys conducted in the "Kartuzy" tender area are summarized in Tab. 6.1.

Name	Year	Topic	Region	Concession (for surveys after 2001)	Owner	Length [km]
12-9-03K	2003	Kościerzyna – Gdańsk		Wejherowo 50/2001/p, Kartuzy 51/2001/p, Kościerzyna 44/2001/p	State Treasury	28.53
13-9-03K	2003	Kościerzyna – Gdańsk			State Treasury	28.04
14-9-03K	2003	Kościerzyna – Gdańsk			State Treasury	28.2
5-9-03K	2003	Kościerzyna – Gdańsk			State Treasury	28.09
6-9-03K	2003	Kościerzyna – Gdańsk			State Treasury	27.17
7-9-03K	2003	Kościerzyna – Gdańsk			State Treasury	30.12
8-9-03K	2003	Kościerzyna – Gdańsk			State Treasury	33.03
T0084307	2007	Kościerzyna – Gdańsk			State Treasury	3.92
T0094307	2007	Kościerzyna – Gdańsk			State Treasury	4.59
T0114307	2007	Kościerzyna – Gdańsk			State Treasury	28.66
T0124307	2007	Kościerzyna – Gdańsk			State Treasury	23.92
T0134307	2007	Kościerzyna – Gdańsk			State Treasury	26.41
T0144307	2007	Kościerzyna – Gdańsk			State Treasury	30.64
T0154307	2007	Kościerzyna – Gdańsk			State Treasury	21.66
T0164307	2007	Kościerzyna – Gdańsk			State Treasury	27.78
T0174307	2007	Kościerzyna – Gdańsk			State Treasury	16.41
T0204307	2007	Kościerzyna – Gdańsk			State Treasury	2.97
16-9-10K	2010	Baltic Basin 2D	Peribaltic Syneclise	Gdańsk W 71/2009/p	State Treasury	11.07
17-9-10K	2010	Baltic Basin 2D			State Treasury	7.56
1-9-10K	2010	Baltic Basin 2D			State Treasury	28.73
2-9-10K	2010	Baltic Basin 2D			State Treasury	15.77
3-9-10K	2010	Baltic Basin 2D			State Treasury	23.42
4-9-10K	2010	Baltic Basin 2D			State Treasury	18.3
5-9-10K	2010	Baltic Basin 2D			State Treasury	15.56
6A-9-10K	2010	Baltic Basin 2D			State Treasury	12.43
6B-9-10K	2010	Baltic Basin 2D			State Treasury	15.79
7-9-10K	2010	Baltic Basin 2D			State Treasury	16.61
8-9-10K	2010	Baltic Basin 2D			State Treasury	8.5
T0029011	2011	Somonino – Przywidz 2D		Kartuzy-Szemud 72/2009/p, Stara Kiszewa 1/2011/p	State Treasury	7.62
T0039011	2011	Somonino – Przywidz 2D			State Treasury	4.45
T0049011	2011	Somonino – Przywidz 2D			State Treasury	5.96
T0059011	2011	Somonino – Przywidz 2D			State Treasury	5.41
T0069011	2012	Somonino – Przywidz 2D			State Treasury	9.97
T0079011	2012	Somonino – Przywidz 2D			State Treasury	2.96
PL1-1200	2012	PolandSPAN			State Treasury	24.23
					Total:	**624.48**

Tab. 6.1. 2D seismic survey (limited to the lines longer than 2 km) in the “Kartuzy” tender area.

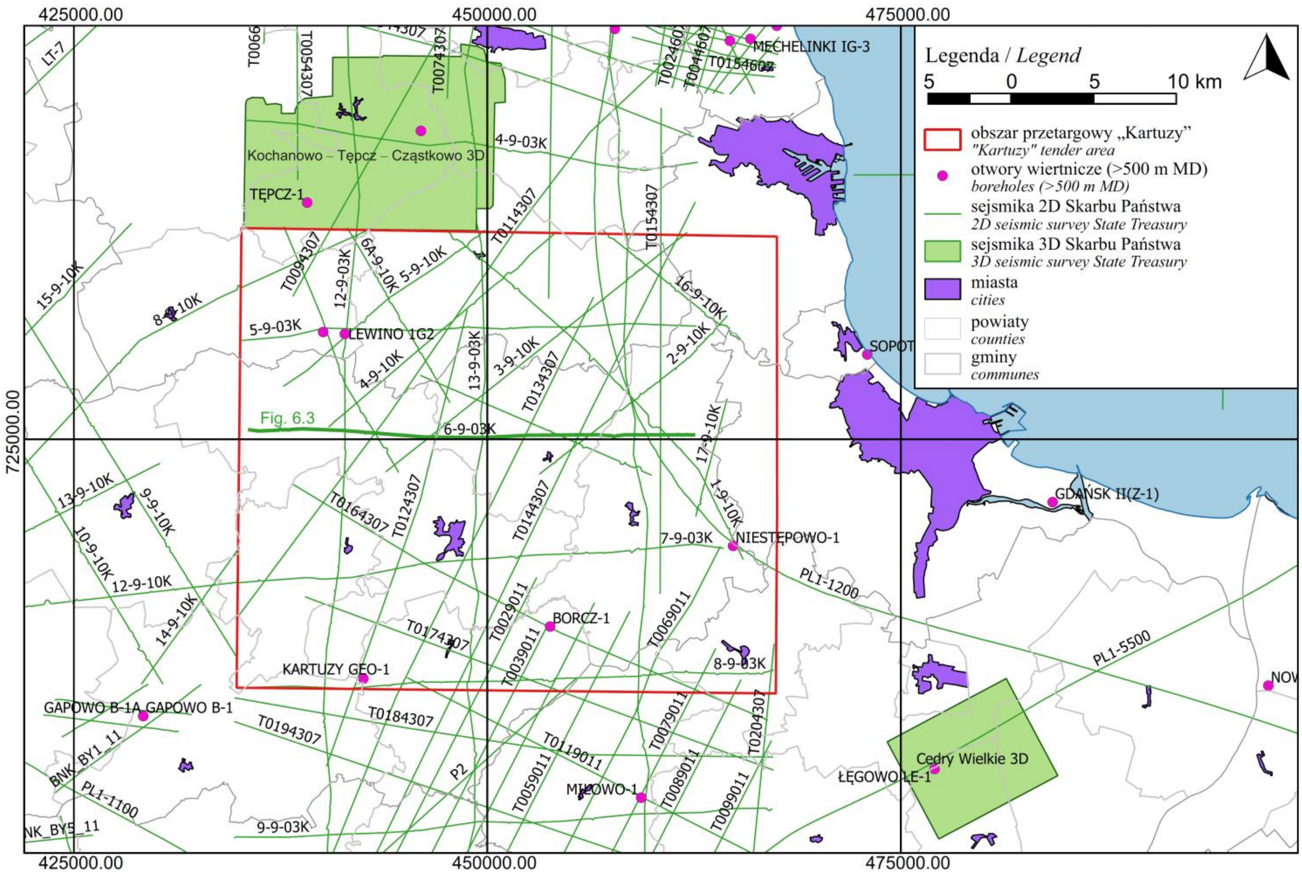


Fig. 6.1. Seismic surveys within the "Kartuzy" tender area and in its neighborhood and location of deep wells (CGDB, 2021).

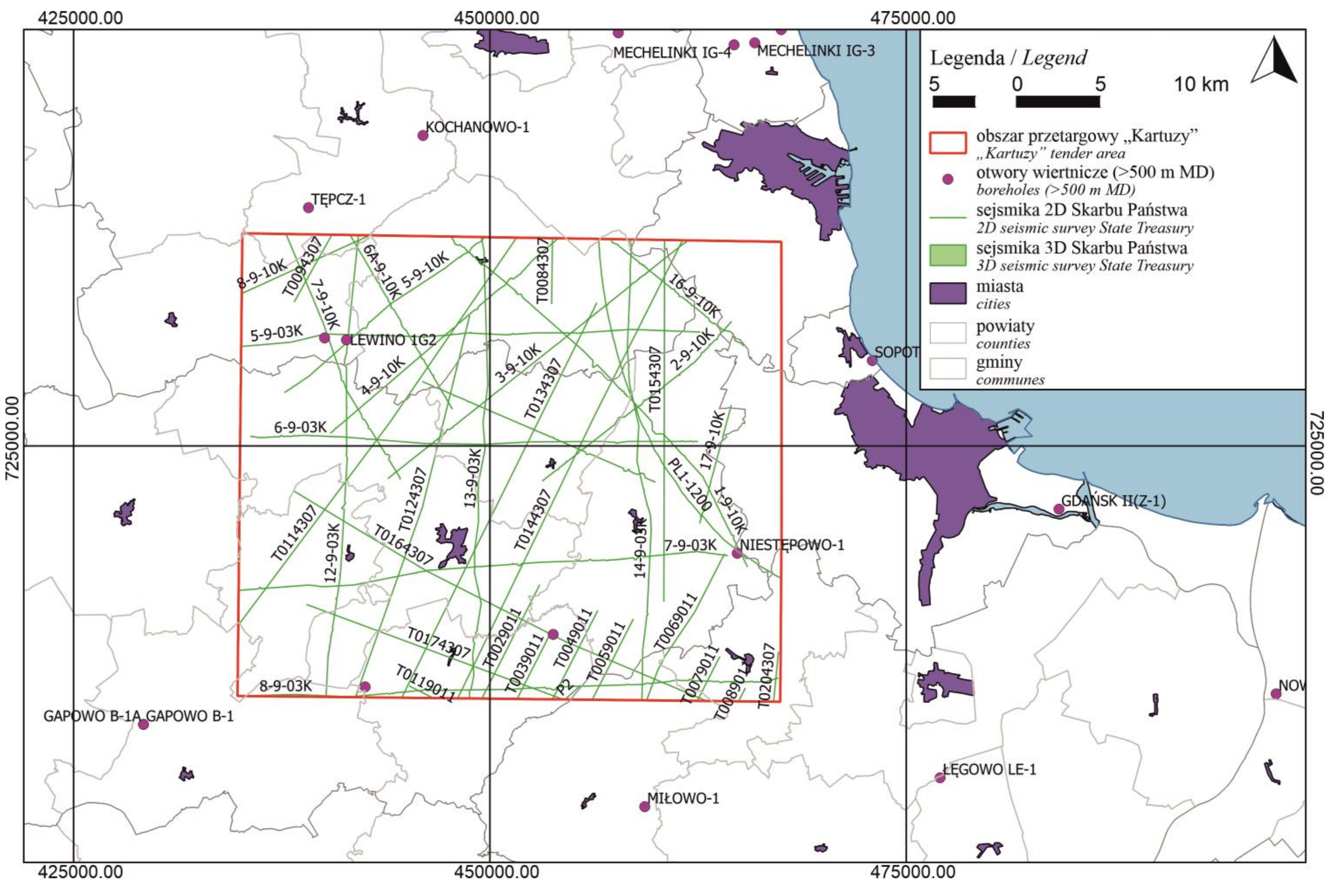


Fig. 6.2. Seismic surveys within the "Kartuzy" tender area and location of deep wells (CGDB, 2021).

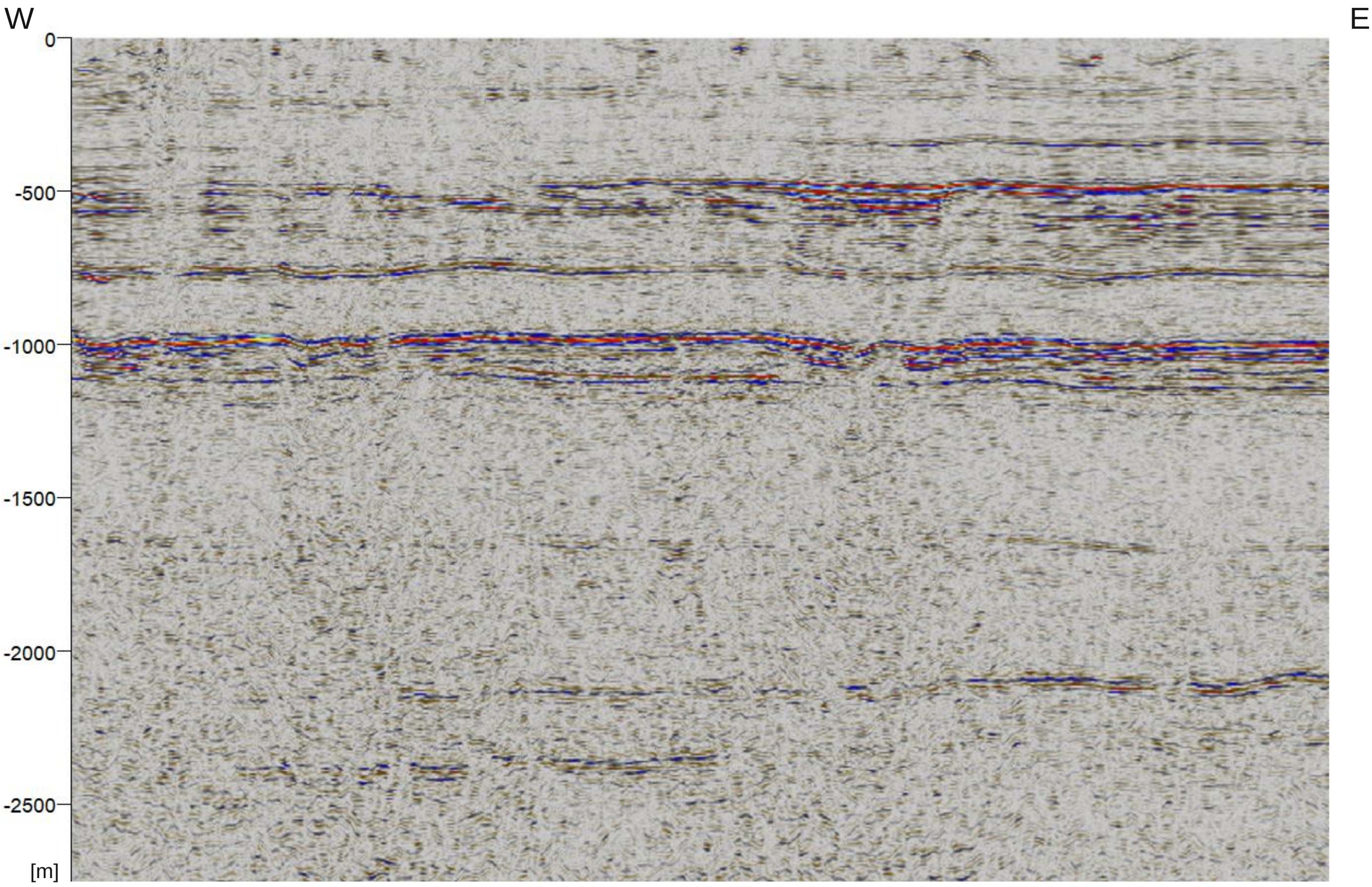


Fig. 6.3. 6-9-03K seismic line as an example of 2D seismic survey from the "Kartuzy" tender area (Wnuk, 2009).

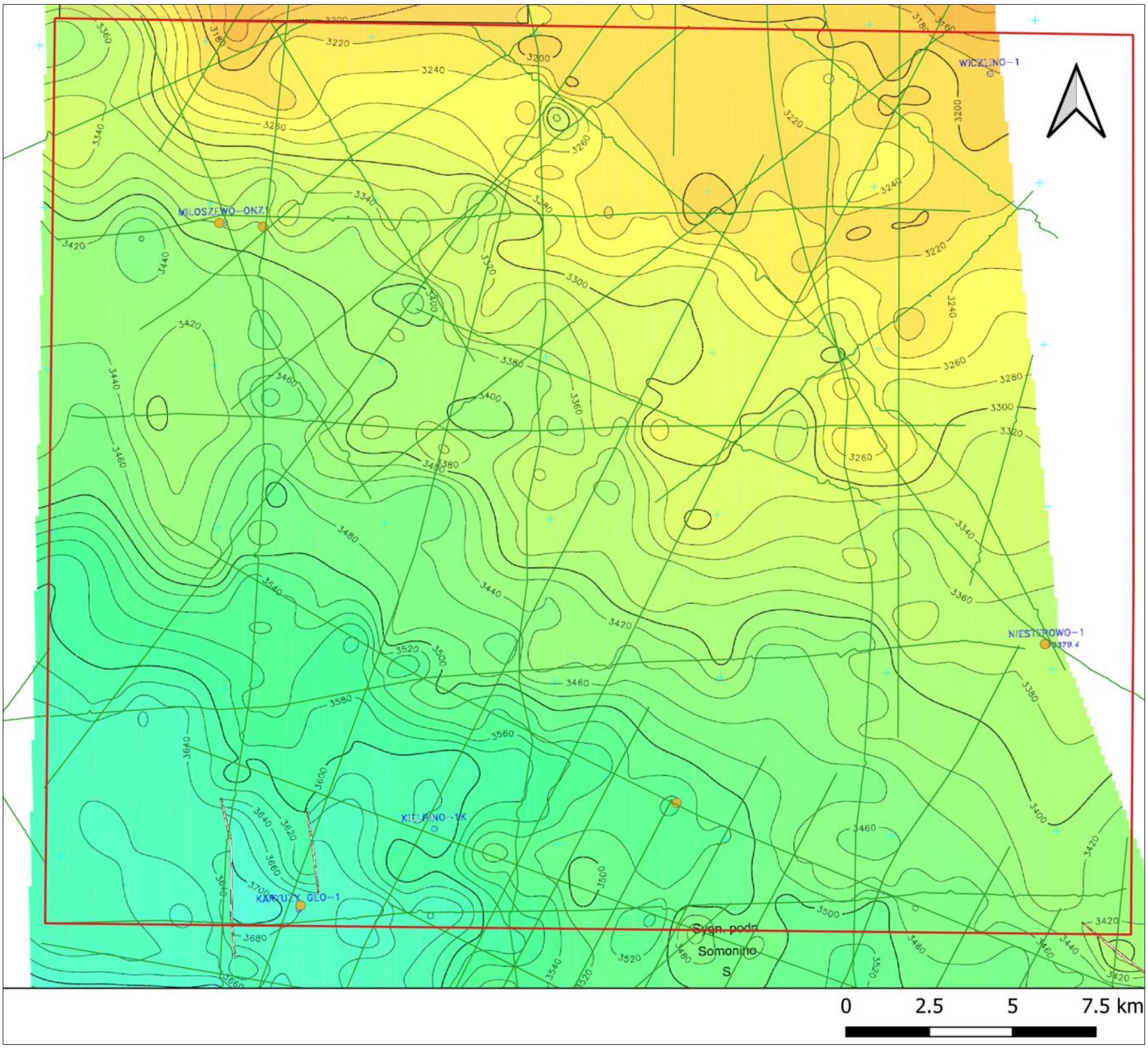


Fig. 6.4. Middle Cambrian top surface seismic horizon (Wnuk, 2009) and location of the “Kartuzy” tender area (red square).

7. GRAVIMETRY, MAGNETOMETRY AND MAGNETOTELLURICS
7.1. GRAVIMETRY

Semidetailed gravimetric survey in the "Kartuzy" tender area and in its close neighborhood was collected with a point density of ca. 1.75 stations/km^2 (Fig. 7.1). All data are available in the CGDB (2021). There are 1668 data points within the tender area, coming from the Łeba Elevation and Peribaltic Syneclise survey (Okulus and Wasiak, 1970). To the south-west, the survey adjoins the Darłowo – Bytów – Starogard Gdański survey (Bochnia and Duda, 1969). There are 285 data points of detailed survey, collected along 2 profiles. The survey was focused on brown coal exploration, and profiles were collected with a 40 m step (Okulus, 1981).

The most recent gravimetric surveys are two Kościerzyna – Gdańsk projects. Interpretation of the first of them (Ostrowski et al., 2004) allowed for the determination of the density boundaries occurring within the Permian (including the boundary related to the Main Dolomite) and Cambrian deposits. Additionally, tectonically disturbed zones are presented. Measurements were made both in a scattered mesh (4 stations/km^2) and along selected lines of seismic profiles (with a 250 m step). Basic and transformed maps were developed, and a preliminary qualitative interpretation was carried out. The second survey (Stefaniuk et al., 2008) was performed to identify the so-called low velocity zone. Gravimetric measurements were made along the seismic and magnetotelluric lines, and the interpretation attempted to find the relationship between the petrophysical parameters resulting from all three methods.

Królikowski and Petecki (1995) proposed a division of Poland into several gravity regions. Thus, the "Kartuzy" tender area is placed within the Mazury – Mazovia High (Fig. 7.2). The region is a gravimetrically very disturbed area, because of the shallow crystalline basement and relatively flat, undisturbed deposition of sedimentary rocks (Królikowski and Petecki, 1995).

7.2. MAGNETOMETRY

A semidetailed ground survey of the total magnetic field intensity was conducted in the "Kartuzy" tender area (Kosobudzka, 2002). The survey has an average density of 2 stations/km^2. All data are available in the CGDB (2021). There are 1893 data points within the Kartuzy tender area (Fig. 7.3).

An image of magnetic anomalies presented in Fig. 7.4 is taken from a magnetic map of Poland (Petecki and Rosowiecka, 2017). The map is divided into several regions with different magnetic characteristics. The "Kartuzy" tender area is located within the Pomerania – Mazury domain (PMd). The domain has a complicated structure and a highly diversified magnetic pattern. The source of magnetic anomalies here are mainly rocks of the anorthosite-mangerite-charnockite-granite association (AMCG). Among such anomalies is the one visible in Fig. 7.4, covering the south-western part of the "Kartuzy" tender area. The anomaly is in close correlation with the positive gravimetric anomaly (Fig. 7.2).

7.3. MAGNETOTELLURICS

At the beginning of the 21st century, two magnetotelluric surveys were taken in the Kościerzyna – Gdańsk area. In the first study (Stefaniuk and Wojdyła, 2004), a set of soundings and two continuous profiles were made, running along selected seismic profiles, so that their results complemented the interpretation of seismic and gravimetric data. The research was focused on stratification and lithological recognition of Paleozoic deposits, as well as on examining the tectonics of the Zechstein complex. It was found that the Precambrian top relief is diverse, the Cambrian formation is not uniform, and the zones of sandstone lithotype dominance are probably related to Precambrian basement elevations. The Zechstein complex is characterized by diverse and relatively low resistance, so its interpretation is uncertain. A clear geoelectric boundary appears at the contact of carbonate and possibly clastic Cretaceous and Upper Jurassic formations with lower Jurassic and Upper Triassic clay-mud formations. The aim of the second study (Stefaniuk et al., 2008) was to develop a methodology and data interpretation for the recognition of the seismic wave velocity distribution in shallow parts of seismic cross-sections based on detailed gravimetric and magnetotelluric data. This goal has been achieved.

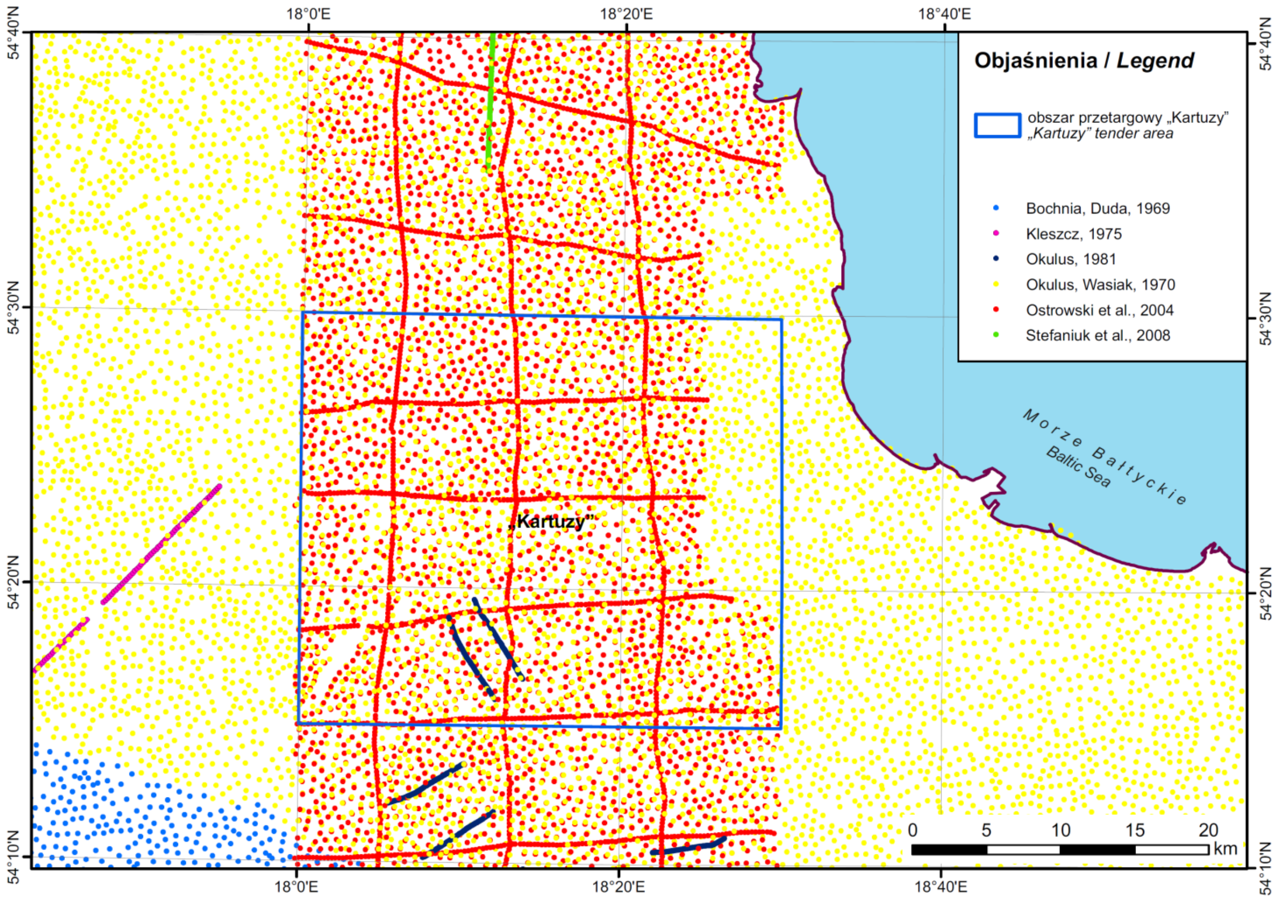


Fig. 7.1. Distribution of gravimetric measurements in the “Kartuzy” tender area (based on CGDB, 2021).

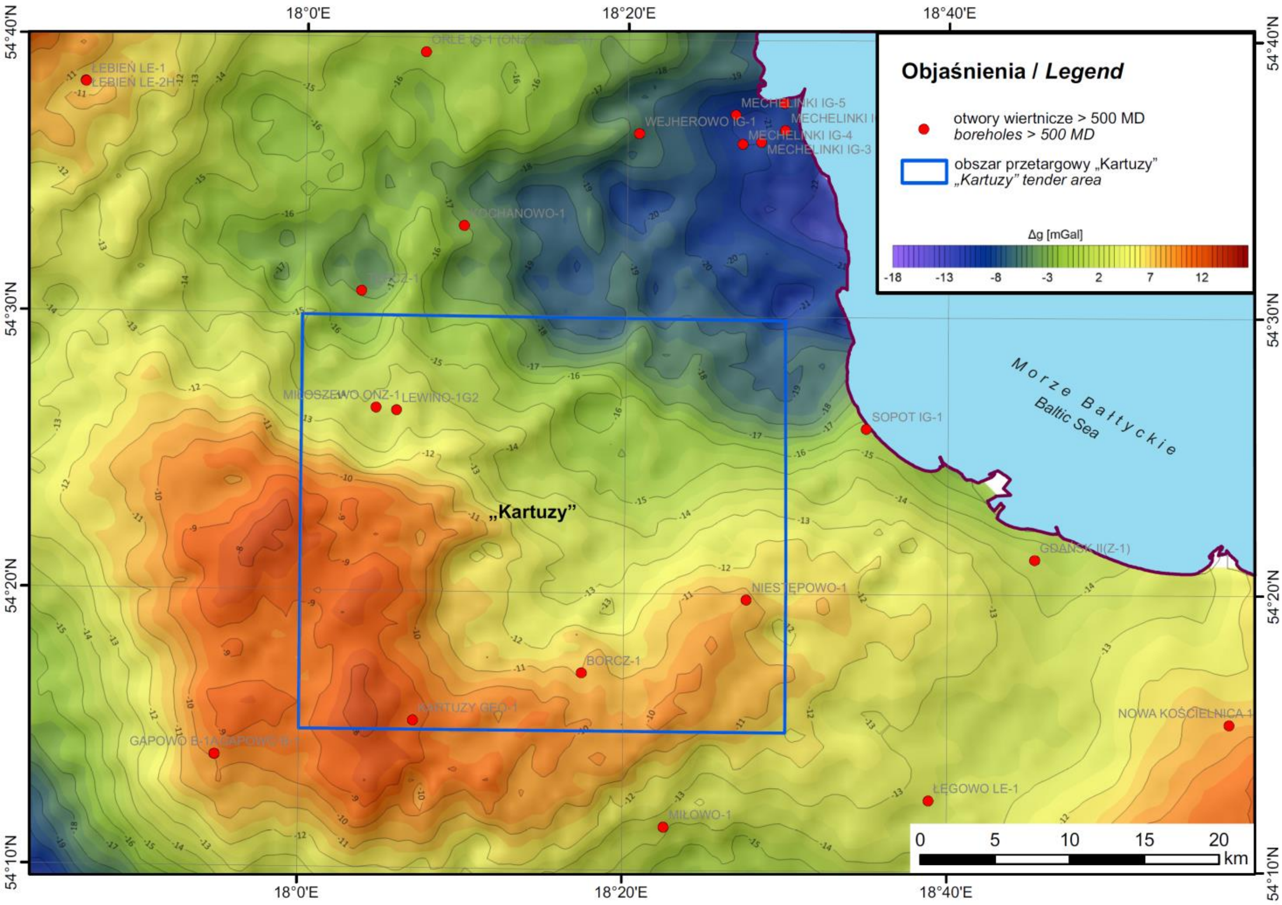


Fig. 7.2. Location of the “Kartuzy” tender area in the Bouguer gravity anomaly map of Poland (Królikowski and Petecki, 1995).

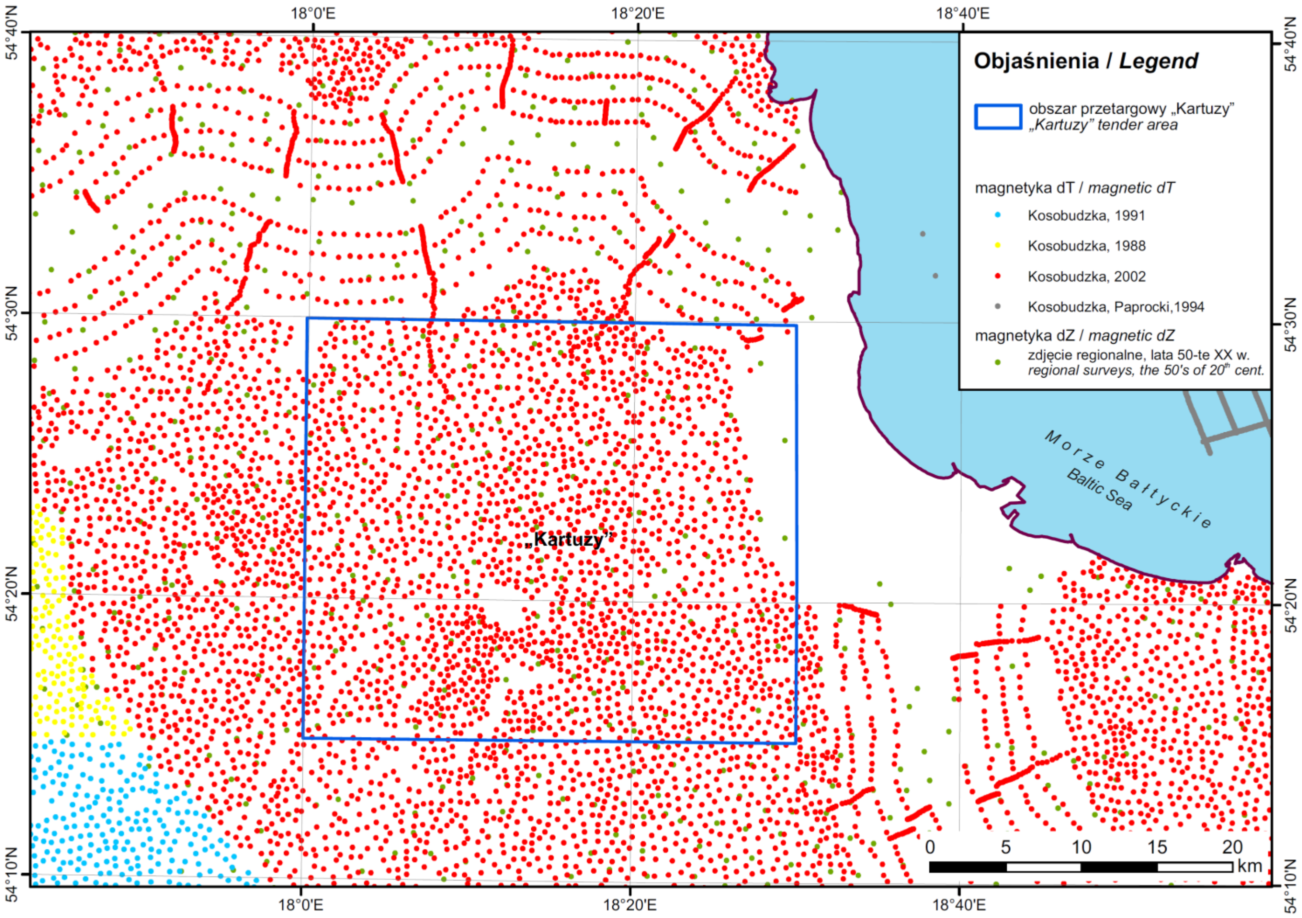


Fig. 7.3. Distribution of magnetic stations in the “Kartuzy” tender area (based on CGDB, 2021).

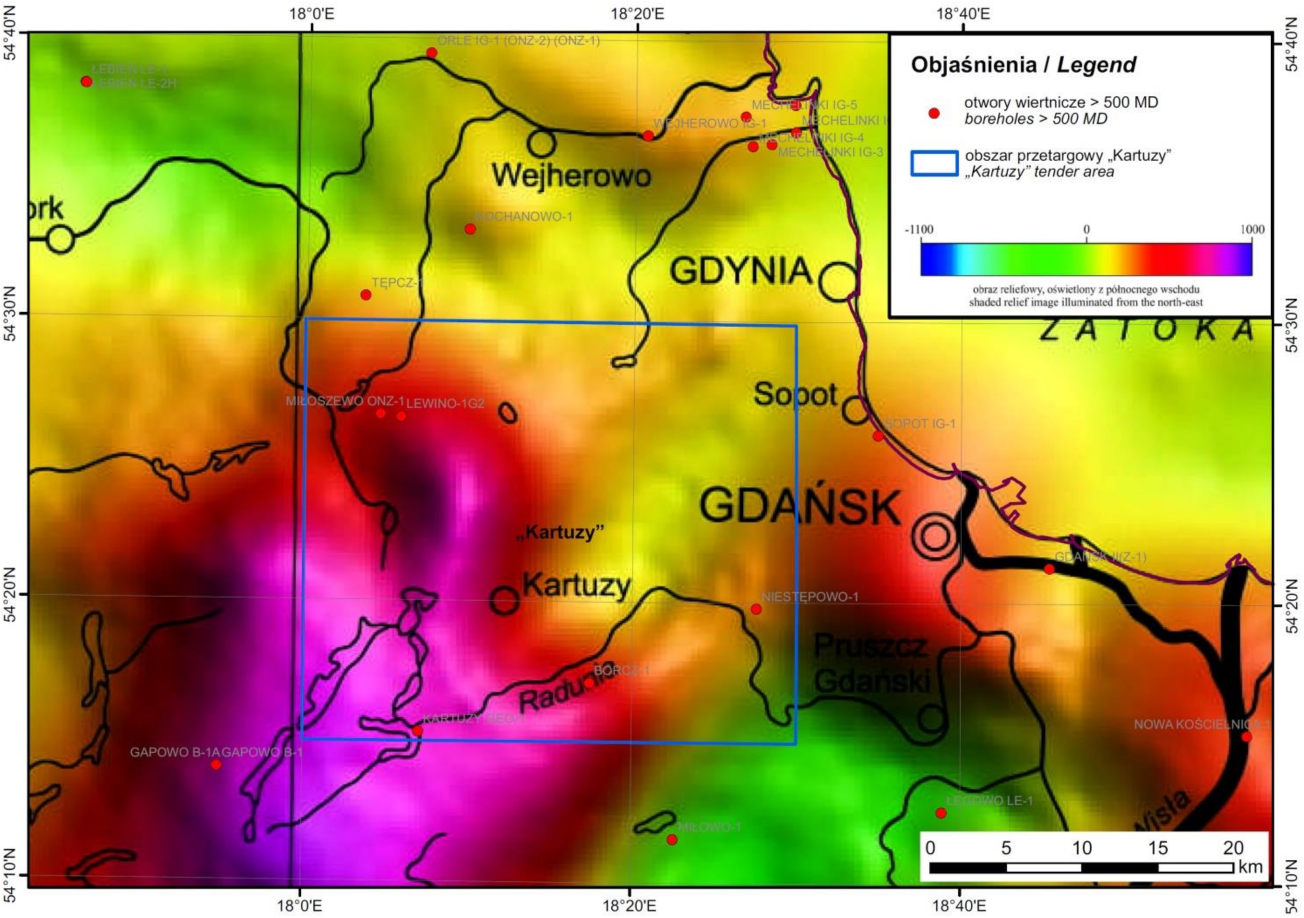


Fig. 7.4. Location of the “Kartuzy” tender area in the magnetic anomaly map of Poland (Petecki and Rosowiecka, 2017).

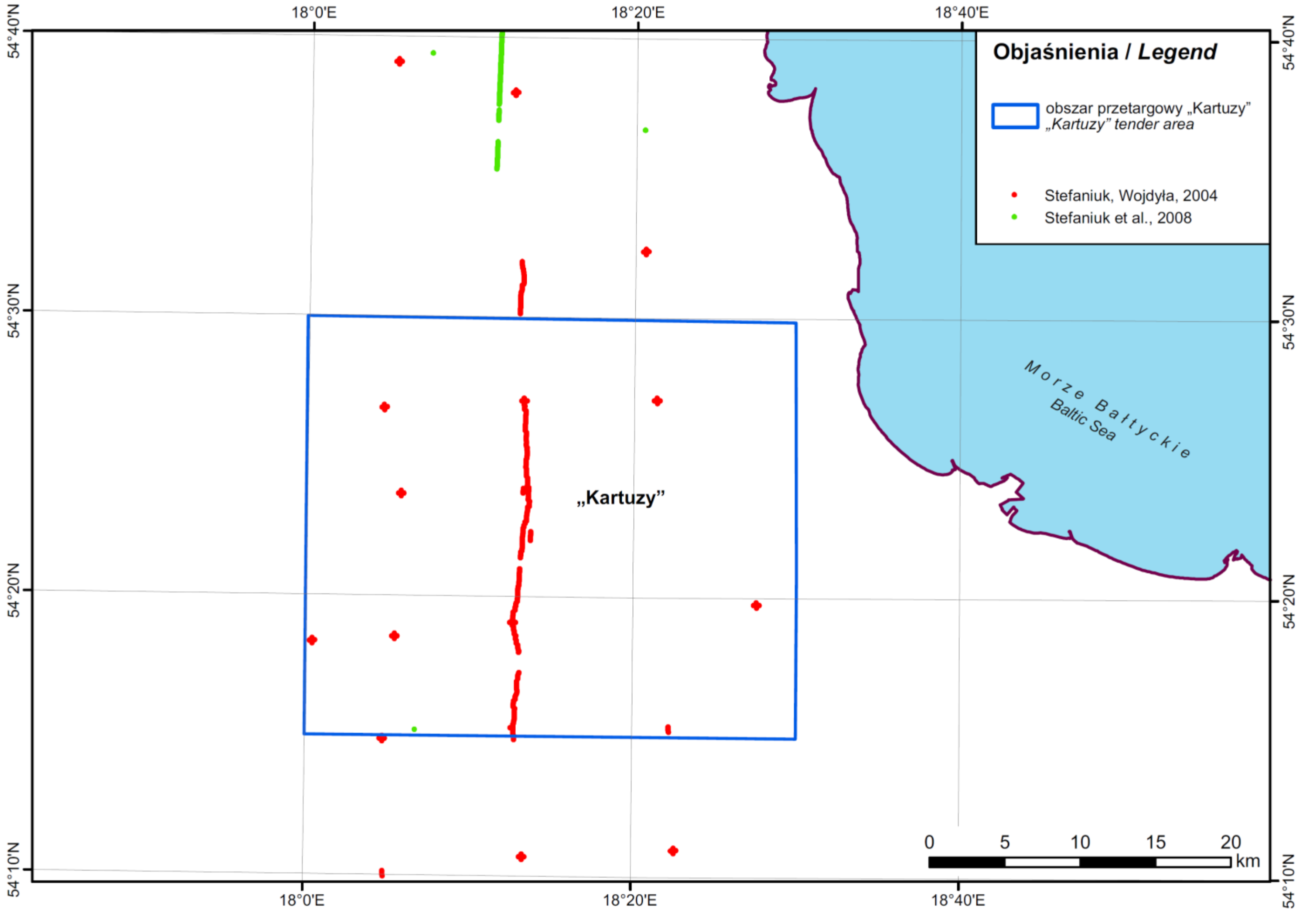


Fig. 7.5. Distribution of magnetotelluric survey in the "Kartuzy" tender area (based on CGDB, 2021).

8. SUMMARY CHART

General information:	Tender area:	**"KARTUZY"**
	Location:	Onshore Hydrocarbon concession blocks: 49 Administrative location: Pomorskie voivodeship, county: Gdynia City, commune: Gdynia (3.89%); county: Gdańsk City, commune: Gdańsk (4.26%); county: Gdańsk, communes: Kolbudy (3.63%), Przywidz (1.33%); county: Kartuzy, communes: Żukowo (18.18%), Stężyca (0.84%), Chmielno (8.13%), Kartuzy (20.21%), Sierakowice (0.12%), Somonino (6.90%), Przodkowo (9.46%); county: Wejherowo, communes: Linia (5.44%), Szemud (16.61%), Wejherowo (0.12%), Łęczyce (0.0006%), Luzino (0.88%)
	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^2]:		900.35
Accumulation type:		conventional for oil and gas unconventional for shale-oil, shale-gas and tight-gas
Structural stages:		Cenozoic Laramide Caledonian Precambrian
Petroleum plays:		I. Middle Cambrian (conventional and unconventional tight gas) II. Lower Paleozoic shale gas and shale oil (unconventional)
Reservoir rocks:		I. Middle Cambrian sandstones II. Ordovician and Silurian claystones and mudstones
Source rocks:		I, II. Upper Cambrian, Ordovician and Silurian fine-grained clastic rocks
Seal rocks:		I, II. Ordovician and Silurian fine-grained clastic rocks; Zechstein evaporites
Trap type:		I. Structural, lithological, stratigraphic, mixed, continuous II. continuous
Oil and gas fields in the neighborhood:		none (Żarnowiec, Dębki, and Białogóra as analogues)
Seismic surveys (owner):		2003 Kościerzyna – Gdańsk 2D, 7 lines (State Treasury) 2007 Kościerzyna – Gdańsk 2D, 10 lines (State Treasury) 2010 Baltic Basin 2D Gdańsk-W, 11 lines (State Treasury) 2011-2012 Somonino – Przywidz 2D, 6 lines (State Treasury) 2012 PolandSPAN, 1 line (State Treasury)
Reper wells (depth):		Borcz-1 (3760.0 m), Lewino-1G2 (3600.38 m), Niestępowo-1 (3632.9 m), Miłoszewo ONZ-1 (1558.0 m) Gapowo B-1/B-1A (4303.0/6058.0 m), Miłowo-1 (3856.0 m), Tępcz-1 (3428.0 m)

Possible minimum work program for prospection and exploration phase

- Archival data reinterpretation and analysis
- Conducting seismic survey 2D (100 km SP) or 3D (50 km^2)
- Drilling of one well of max. depth 5000 m TVD reaching the Cambrian deposits with obligatory coring of prospective intervals

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