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# ASSESSMENT OF SHALE GAS AND SHALE OIL RESOURCES OF THE LOWER PALEOZOIC BALTIC-PODLASIE-LUBLIN BASIN IN POLAND

## FIRST REPORT

Warsaw, March 2012

Polish Geological Institute acknowledges support of team of United States Geological Survey leaded by Donald L. Gautier and Christopher J. Schenk on analysis of data from the Baltic – Podlasie – Lublin Basin, as well as training on shale gas resources assessment.

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## 1. Summary

This is a first Polish report on shale gas and shale oil resources and refers to the Baltic-Podlasie-Lublin Basin only.

The Report is a result of research conducted from October 2010 to February 2012 by Polish Geological Institute – National Research Institute, acting as a geological survey of Poland. Research were conducted thanks to support of U.S. Geological Survey (USGS) in the field of training and data evaluation. USGS completes its own research project on global shale gas resources assessment, which includes also Poland.

The current report might be regarded as a base line for further reevaluations and is based only on archive data collected for 39 key wells throughout years 1950-1990, and discussed in separate publications. As a new data from shale gas/oil exploration wells, drilled since 2010, will become available, the assessment shall be verified and new reports shall be issued every 2 years.

### Assumptions for resources calculation

The Report is an attempt to estimate technically recoverable shale gas and shale oil resources for the Baltic – Podlasie - Lublin Basin in Poland in the region located between Baltic offshore north of Słupsk and Wejherowo towns and the area of Hrubieszów and Tomaszów Lubelski towns.

The Report does not includes hydrocarbon resources from the conventional fields, as well as unconventional resources such as tight gas or Coal Bed Methane. The Report does not includes other perspective regions of Poland, as Lower Silesia or Wielkopolska.

For recoverable shale gas/oil resources assessment a broad range of geological, geochemical, geophysical and geomechanical data is required. For the analyzed basin some of key data are still not available. This refers to such data as porosity and permeability of shale reservoir, gas composition, reservoir pressure or initial production. For this reason the assessment is based partly on assumptions from the analogue basins, resulting with increase of the result's error bars. As the analogues for the Baltic – Podlasie – Lublin Basin data from some of the US with well understood field characteristics were used.

In this Report the recoverable resources were estimated with application of average Estimated Ultimate Recovery (EUR) from each individual well, and average well drainage acreage, both adopted from US analogues. To qualify an individual archive well from the Baltic – Podlasie - Lublin Basin into acreage for which resources were calculated a criteria of net thickness at least of 15 m of shale formation with TOC at least 2 % wt was used, according to USGS procedures.

The key parameters of the assessment do not have a unique value and were adopted for the calculation in a few alternative scenarios. As a result a range of resources estimation results were revealed.

The error bars of the analysis might be systematically limited once new data from the exploration wells, conducted by the concession holders on all the basin, will become available.

**Results of the assessment and interpretation**

**SHALE GAS**

Shale gas recoverable resources of the onshore and offshore Baltic – Podlasie – Lublin Basin are estimated for maximum:

**1920 Bcm (1,92 Tcm)**

Taking into account constraints on key parameters of the calculations the higher probability range of recoverable shale gas resources is:

**346 - 768 Bcm**

These resources are therefore **2,5 to 5,5 times higher than documented** conventional gas fields in Poland (145 Bcm).

With the level of current gas consumption in Poland (14,5 Bcm/y) the shale gas resources together with conventional fields are an equivalent of:

- **35 - 65 years of cumulative gas consumption on Polish market**, or
- **120 – 200 years of gas production in Poland at its current level with no changes in current proportion between domestic production and import**

**SHALE OIL**

Shale oil recoverable resources of the onshore and offshore Baltic – Podlasie – Lublin Basin are estimated for maximum:

**535 MMtons (3905 MMB)**

Taking into account constrains on key parameters of the calculations the higher probability range of recoverable shale oil resources is:

**215 – 268 MMtons (1569 – 1956 MMB)**

These resources are therefore **8,5 to 10,5 times higher than documented** conventional fields in Poland (26 MMtons; 190 MMB).

With the level of current oil consumption in Poland (24 MMtons; 175 MMB) shale oil together with conventional fields are an equivalent of:

- **10 - 12 years of cumulative oil consumption on Polish market**, or
- **360 - 440 years of oil production in Poland at its current level with no changes in current proportions between domestic production and import.**

## 2. Introduction

During the first decade of XXI century USA and the lesser degree also Canada experienced “energetic revolution” related to production of gas and oil from new type of fields in shale formations.

Rapid increase of production of hydrocarbons from such type of fields has significant impact on gas and oil prices, energetic security, as well as stimulates economic recovery. Technologic and economic success of this sector of petroleum industry in North America has inspired attempts to export this concept to other continents, including Europe.

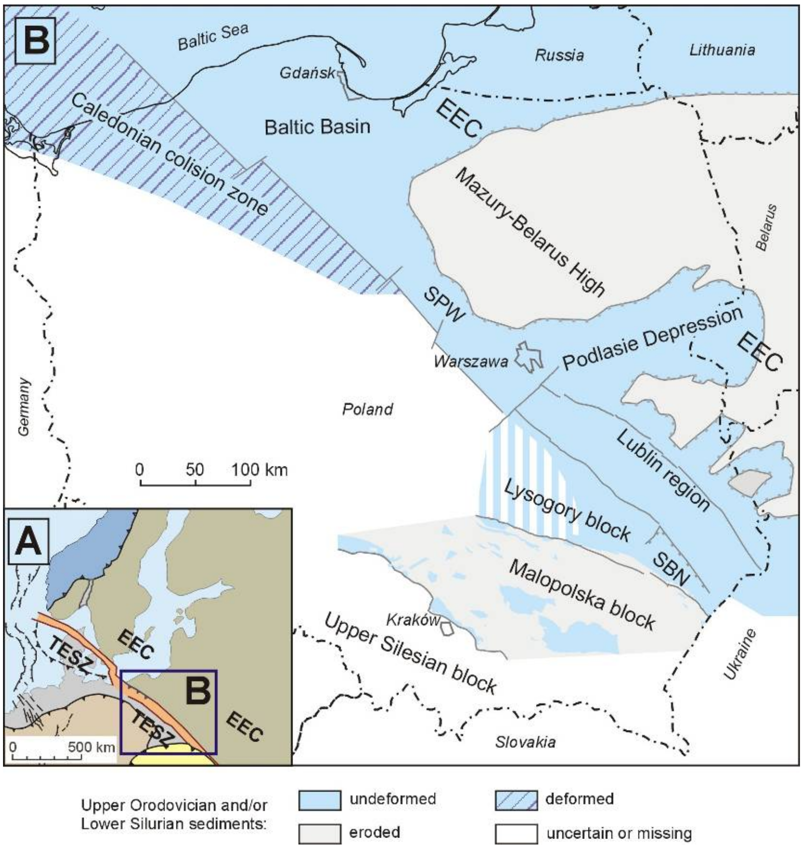


*Figure 1*
*location of the Lower Paleozoic Baltic-Podlasie-Lublin Basin at the western slope of the East European Craton in Poland. After: Poprawa P., 2010b. EEC – East European Craton. SPW –Płock-Warszawa Zone. SBN – Biłgoraj-Narol Zone.*

During last years the most intensive exploration for shale gas and shale oil globally, except of USA and Canada, took place in the Lower Paleozoic Baltic-Podlasie-Lublin Basin in Poland (location: Fig. 1; stratigraphic position: Fig. 2). This region was previously a subject to exploration of conventional oil and gas fields, discovered and producing however only in the northern part of the Baltic Basin (Górecki et al., 1992; Karnkowski, 1993; Kanev et al., 1994; Stolarczyk et al., 1997, 2004; Domżalski et al., 2004).

Since the concept of shale gas was applied to in the Baltic-Podlasie-Lublin Basin (Poprawa, 2006), it was intensively studied based on public domain historical data, gathered through decades of studied conducted for different purposes. Moreover shale oil potential of the same basin was indentify last years (Poprawa, 2010a). However verification of the exploration concepts begun only in the mid 2010 when program of drilling of exploration wells was initiated.

Since the beginning of shale gas and shale oil exploration one of the key issues was to determine unconventional hydrocarbon field resources for the here discussed basin.

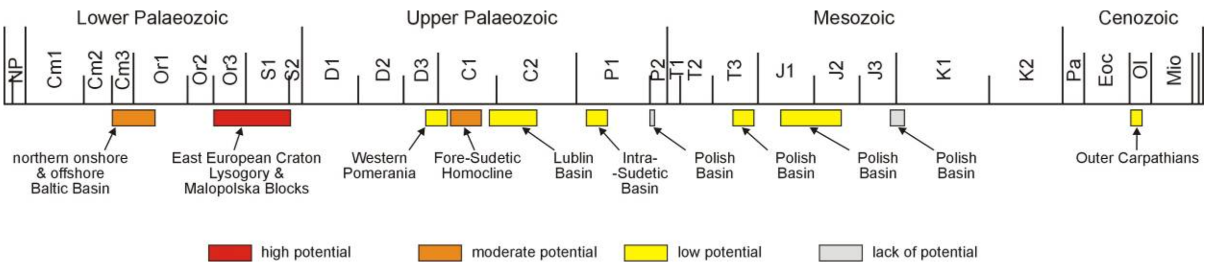


*Figure 2*
*Stratigraphic position and location of the main dark organic rich shale formations in Poland. After: Poprawa P., 2010c.*

During last years there was a few attempts to estimate recoverable shale gas resources for this basin, resulting with a very broad range of values. In 2009 Wood Mackenzie and Advanced Research Institute reported 1400 Bcm and 3000 Bcm, respectively. In 2010 Rystad Energy announced 1000 Bcm. Much higher resources, equal to 5300 Bcm, were presented for the Baltic-Podlasie-Lublin Basin in the global shale gas resources assessment report of the US Energy Information Agency, prepared for the US EIA by Advanced Research Institute in 2011. Also in 2010 Lane Energy Poland reported 1000 Bcm of recoverable gas for their 6 concession blocks in the Baltic Basin only. All these report, irrespective of being inconsistent with relation to each other, presented gas resources much higher than Polish conventional gas resources, and were few tens to few hundred times higher than annual gas consumption in Poland. So far there was not attempts to calculate Polish shale oil resources.

In 2010 Polish Geological Institute – National Research Institute (PGI), acting as a geological survey of Poland, established cooperation with Unites States Geological Survey (USGS) aiming common study on assessment of hydrocarbon resources for the Lower Paleozoic shale formation in Poland using methodology of USGS.

The current report of PGI, being a result of above mentioned cooperation, presents a geological model and resources estimates based on public data gathered prior to beginning of exploration drilling. Once drilling shall proceed and a new data will become available, the PGI assessment shall be reevaluated every 2 years.

From the USGS stand point the cooperation with PGI was a part of USGS global shale gas resources assessment, and shall be reported separately according to internal USGS procedures. Cooperation between PGI and USGS was performed during a few work shops at PGI headquarter in Warsaw (10.2010, 09.2011) and USGS headquarter in Denver (04.2011, 09.2011, 02.2012). Cooperation was financed by each party separately from its internal sources.

It is important to notice that resources assessment conducted by PGI and USGS was limited to the Baltic-Podlasie-Lublin Basin only. However on the territory of Poland there are other formations possibly being unconventional gas and/or oil reservoirs, which could be subject for resources assessment.

In the Wielkopolska region (western Poland) tight gas accumulations in the Rotliegend sandstone are anticipated (Buniak et al., 2008; Poprawa & Kiersnowski, 2008, 2010; Kiersnowski et al., 2010). A few first vertical and lateral wells were drilled in there and their results are encouraging.

In the northern and eastern part of the Lower Silesia the Lower Carboniferous formations might be hybrid reservoir for the co-occurring shale gas and tight gas (Fig. 2; Poprawa, 2006; 2010c; Poprawa & Kiersnowski, 2008, 2010). One exploration well was drilled on this target in 2011. There are indications for possible presence of tight gas in the Upper Silesia region.

In the case of the Menilite shale in the Outer Carpathians (Fig. 2) existence of accumulations of shale oil, and to lesser degree also shale gas, is very probable. The same region might contain tight gas accumulations.

Currently the subject for analysis of unconventional oil and gas potential is also the Lower and Middle Jurassic shale in the Polish Basin and the Lower Permian shale in the Intra-Sudetic Basin.

Yet another separate issue are Coal Bed Methane resources of the Upper Silesian Basin and Lublin Basin (Kotas, 1994; Kotarba, 2001; Kędzior et al., 2007).

The above additional exploration targets attracts presently less attention than the shale gas and shale oil the Baltic-Podlasie-Lublin Basin. However their further analysis and possible development might promote diversification of exploration targets and possibly also diversification of gas and oil sources in Poland.

## 3. Geological characteristics of the basin

Characteristic feature of the Lower Paleozoic Baltic-Podlasie-Lublin Basin is a presence of shale formations enriched in organic matter, possibly being unconventional reservoir for gas and oil accumulations (Fig. 1). The shale contains organic matter with the II type of kerogen (Kanev et al., 1994; Klimuszko, 2002; Poprawa, 2010b; Więcław et al., 2010). Development of this formations was caused by interaction of several processes, with the main being basin's subsidence, relative sea level changes, basin's bathymetry, organic productivity, rate of detritus supply, geochemical conditions at the sea bottom, mainly oxygenation, activity of organisms penetrating soft sediment, presence of topographic barriers at the sea bottom favoring development of isolated zones with anoxic conditions, sea current configuration and paleoclimatic conditions.

Tectonic processes had a key control on development of the gas saturated shale formation. During late Ordovician and Silurian the Baltic-Podlasie-Lublin Basin was a flexural foredeep of Caledonian collision zone (Poprawa et al., 1999). At the early stage of its development flexural subsidence together with low rate of detritus deposition created an accommodation space and caused anoxic conditions at the sea bottom, allowing for deposition of organic rich shale. During the later stage of the basin's evolution, mainly in late Silurian, increasing rate of deposition of detritus derived from collision zone ceased that type of deposition.

The oldest formations, located in the lower part of the basin's section, are the Upper Cambrian to Tremadocian bituminous shale (Figs. 2, 3), developed only in the northern part of the onshore Baltic Basin and in its offshore part (Szymański, 2008). This shale is a source rock for conventional hydrocarbon fields in the Middle Cambrian reservoir (Górecki et al., 1992; Karnkowski, 1993; Schleicher et al., 1998; Kowalski et al., 2010). Its thickness is however limited, particularly in the onshore part of the basin were equals to several meters at maximum, while in the Polish offshore sector reaches 34 m (Szymański, 2008; Więcław et al., 2010). This shale is characterized by high contents of organic matter, being equal in individual wells at average to 3–12 % TOC (Więcław et al., 2010).

The next organic rich shale formation up section is the Upper Ordovician shale, mainly Caradoc (Fig. 2), developed in the central and western part of the Baltic Basin, as well as in the western part of the Podlasie Depression. In the north-western part of the Baltic-Podlasie-Lublin Basin, i.e. at the Łeba Elevation, the onset of organic rich sediment deposition was even earlier, during late Llanvirn. Such a deposition was diachronically expanding in time towards east and south-east, systematically replacing laterally limestone and marl deposition (Modliński & Szymański, 1997; Poprawa, 2010b). During Ashgill time eustatic sea level drop caused expansion of the carbonate sedimentation on all the here discussed basin, except of the Łeba Elevation where organic rich shale deposition continued.

Thickness of the Upper Ordovician shale increases from the east towards the west and north-west: in the Baltic Basin onshore from 3,5 m to 37 m and offshore from 26,5 m to 70 m (Modliński & Szymański, 1997), while in the Podlasie Depression and the basement of Płock-Warszawa Trough from 1,5 m to 52 m (Modliński & Szymański, 2008). In the central part of the Baltic Basin for the individual wells the average TOC contents of this shale formation ranges from 1 % to 3 % (Poprawa, 2010b; Kowalski et al., 2010). In the western and central part of the Podlasie

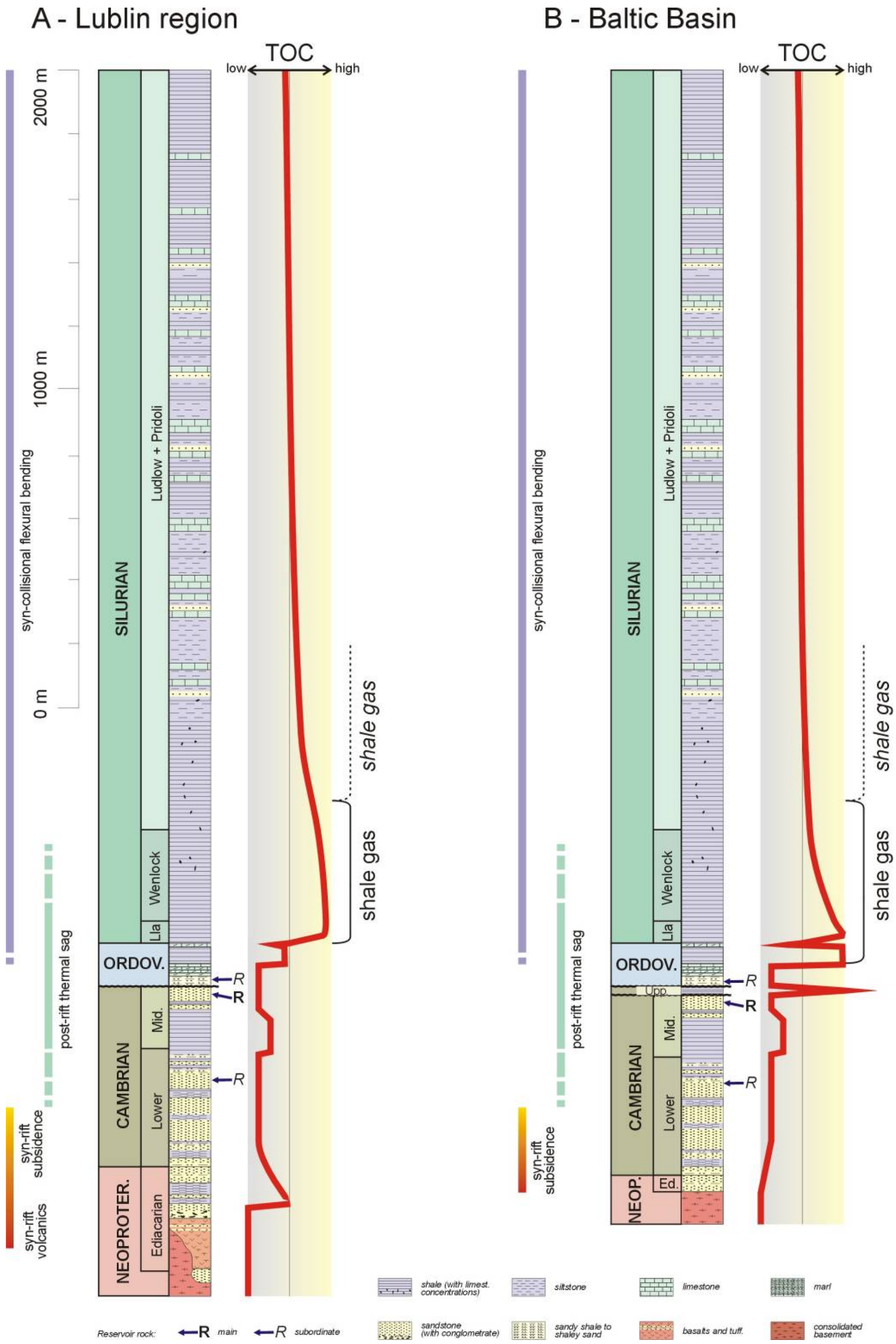


Figure 3
Simplified lithostratigraphic section of the Lower Paleozoic at the (A) Lublin region, and (B) Baltic Basin with position of organic rich shales, being potential shale gas/oil formation. After: Poprawa P., 2010b.

Depression the average TOC contents of the Upper Ordovician shale is equal to 1 % to 1,25 %, while in the basement of Płock-Warszawa Trough it ranges between 2,1 to 3, 76 % TOC. In the Lublin region the average TOC of these sediments is lower than 1 %. The average TOC contents of the Ashgill deposits usually is below 0,5 %, except of the Łeba Elevation where it reaches 4,5 %.

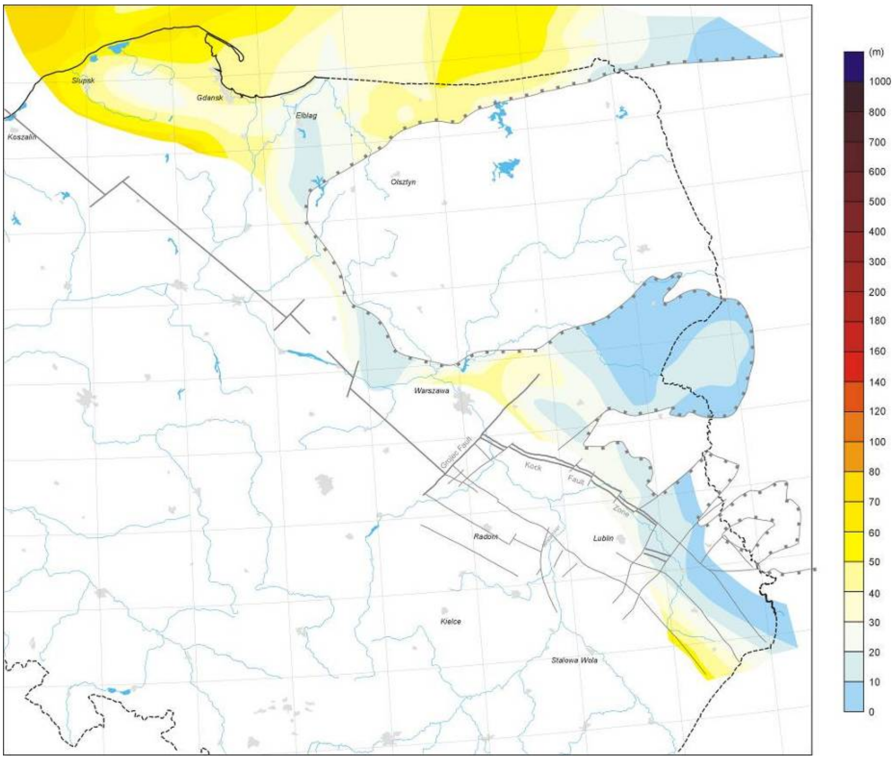


Figure 4A
Thickness of the Llandovery sediments (Lower Silurian) in the Baltic-Podlasie-Lublin Basin.

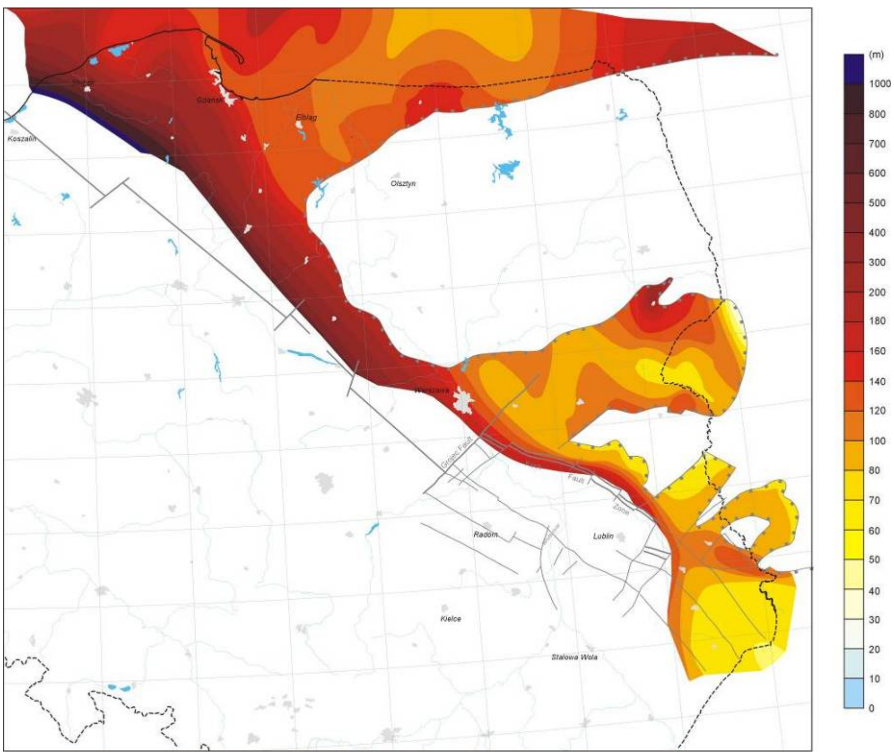


Figure 4B
Thickness of the Wenlock sediments (Lower Silurian) in the Baltic-Podlasie-Lublin Basin.

With the beginning of Silurian eastwards and south-eastwards expansion of organic rich shale sedimentation took place as a result of eustatic sea level rise. The Llandovery siltstone and claystone are present on nearly all the discussed area, except of south-eastern Lublin region. The bottom part of the Llandovery is often represented by bituminous shale. In the eastern part of the Baltic Basin the lower Llandovery bituminous shale is locally replaced by black nodule limestone (Jaworowski & Modliński, 1968). Fine grained sedimentation continued during Wenlock, Ludlow and Pridoli, however with time mudstone, marl and even sandstone share increased up-section.

Thickness of the Llandovery sediments commonly rages between 20-70 m (Fig. 4A), with a general tendency for the westwards increase (Modliński et al., 2006). The lower part of the Llandovery section on major part of the basin is characterized by high TOC contents (Klimuszko, 2002). The highest measured TOC contents reaches 20 %, while average TOC contents of the Llandovery shale usually equals to 1 % to 3 % (Poprawa, 2010b). Thickness of the Wenlock section is significantly varies laterally from less than 100 m in the eastern part of the Podlasie Depression and Lublin region, to more than 1000 m I the western part of the Baltic Basin (Fig. 5B). Average TOC contents in a range of 1 % to 2 % are characteristic to the Wenlock sediments in the eastern Baltic Basin, as well as in a part of Podlasie Depression and Lublin region. In a remaining part of the discussed area average TOC contents of the Wenlock is less than 1 %.

Burial depth of the Upper Ordovician and Lower Silurian shale increases in general from the east to the west (Fig. 5). In the Polish part of the Baltic Basin the recent burial depth of these formations increases from approximately 1000 m in its eastern part to more than 4500 m in its western part. In the Podlasie Depression the recent depth to this formation also increases from the east, were it equals to approximately 5000 m, towards the west were near Warsaw reaches 4000 m. In the Lublin region lateral changes of burial depth to the Lower Paleozoic shale are more complex due to presence of a system of faults with significant offsets limiting individual tectonic blocks, as well as due to considerable lateral differences in the thickness of younger sediments resting above the analyzed complex. In this part of the Lublin region were the Lower Paleozoic section is reached and documented by boreholes depth to these sediments increases from some 1000 m in the eastern zones to 3000-3500 m in vicinity of the Kock fault zone. The deepest position of this sediments in this region is documented in Łopiennik IG 1 well, where bottom of the Llandovery is reached at the depth of 4330 m. In the Lublin Trough burial depth of the Lower Paleozoic shale is too deep from economic point of view to allow for exploration for shale gas. In the Biłgoraj-Narol zone further to the west burial depth of the Lower Paleozoic shale decreases, locally even to less than 1000 m.

Determination of thermal maturity for the Upper Ordovician to Lower Silurian shale is difficult since this sediments do not contain Vitrinite, which did not existed prior to Devonian. Therefore thermal maturity measurements were conducted on zooclasts, alginate and bitumen, what leads to higher error bars of the analysis (Grotek, 2006). Revealed thermal maturity of the Lower Paleozoic shale in the Baltic-Podlasie-Lublin Basin increases from the east and north-east to the west and south-west, similarly as burial depth (Fig. 6) (Nehring-Lefeld et al., 1997; Swadowska & Sikorska, 1998; Grotek, 2006).

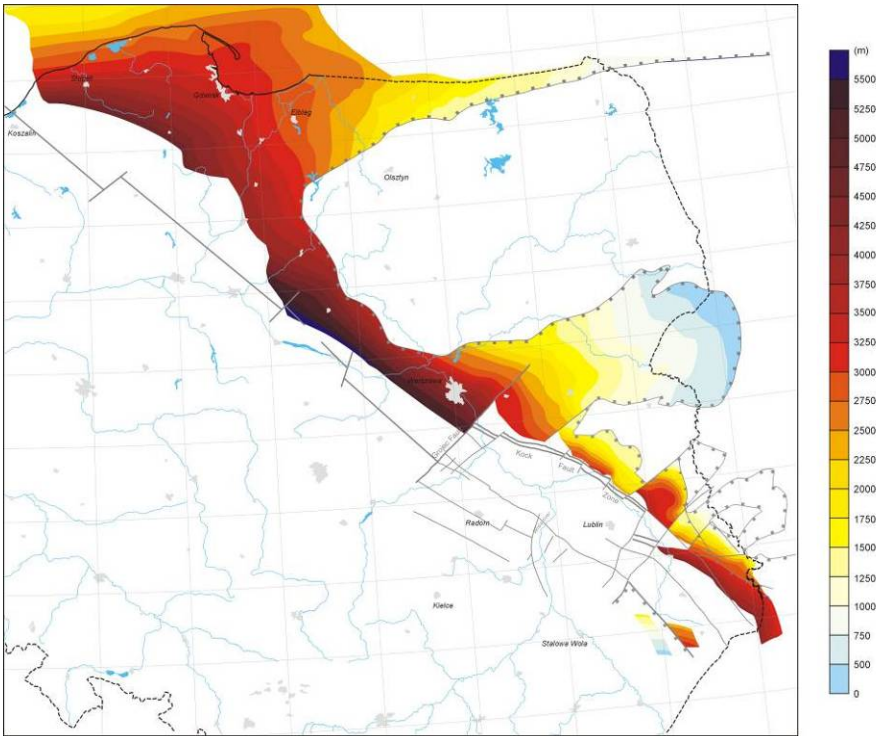


Figure 5
Burial depth of the bottom of Llandovery (Lower Silurian) in the Baltic-Podlasie-Lublin Basin. After: Poprawa P., 2010b.

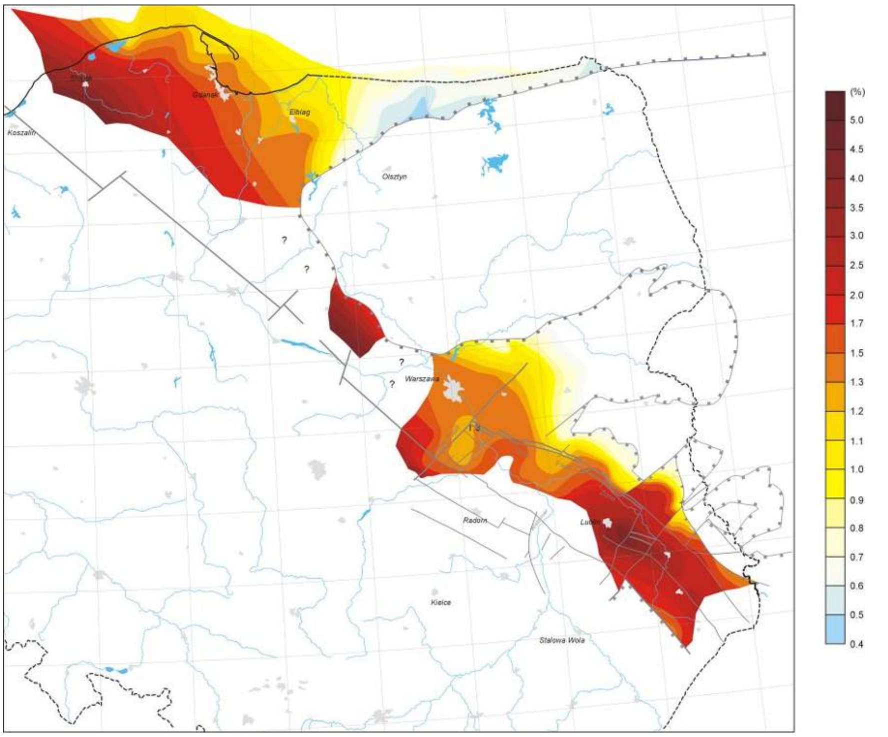


Figure 6
Thermal maturity (Vitrinite reflectance %Ro) of the Llandovery (Lower Silurian) in the Baltic-Podlasie-Lublin Basin. After: Poprawa P., 2010b.

Thermal maturity of the Upper Ordovician to Lower Silurian shale changes in this direction from being an equivalent of immature, through oil window, wet gas window to dry gas window or even overmature near the western margin of the East European Craton. In the Biłgoraj-Narol zone thermal maturity is relatively high (dry gas window), irrespective of relatively low burial depth.

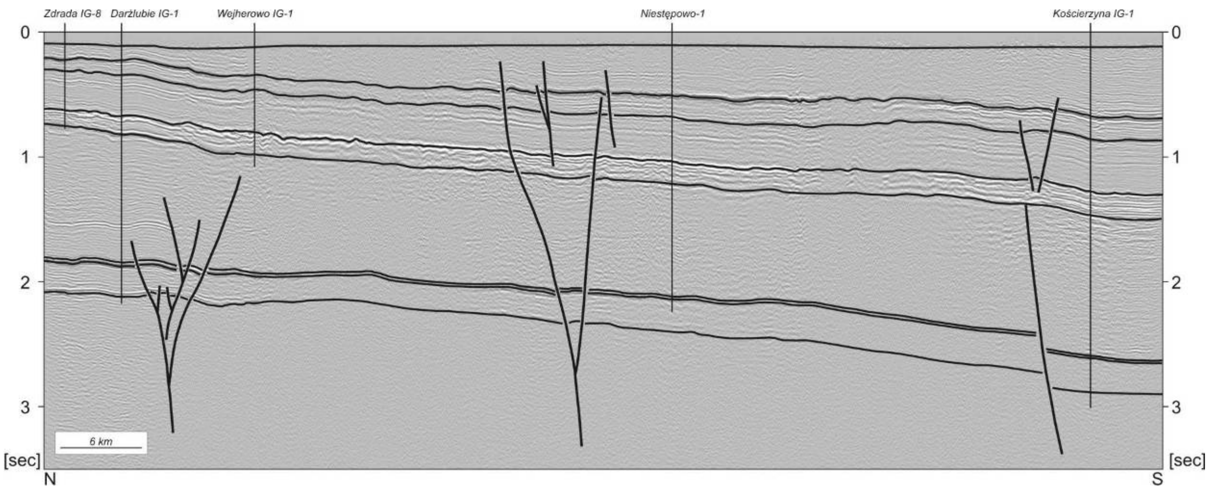


Figure 7A
Seismic cross section illustrating tectonic style of the geological setting of the Baltic Basin. After: Krzywiec P., 2011.

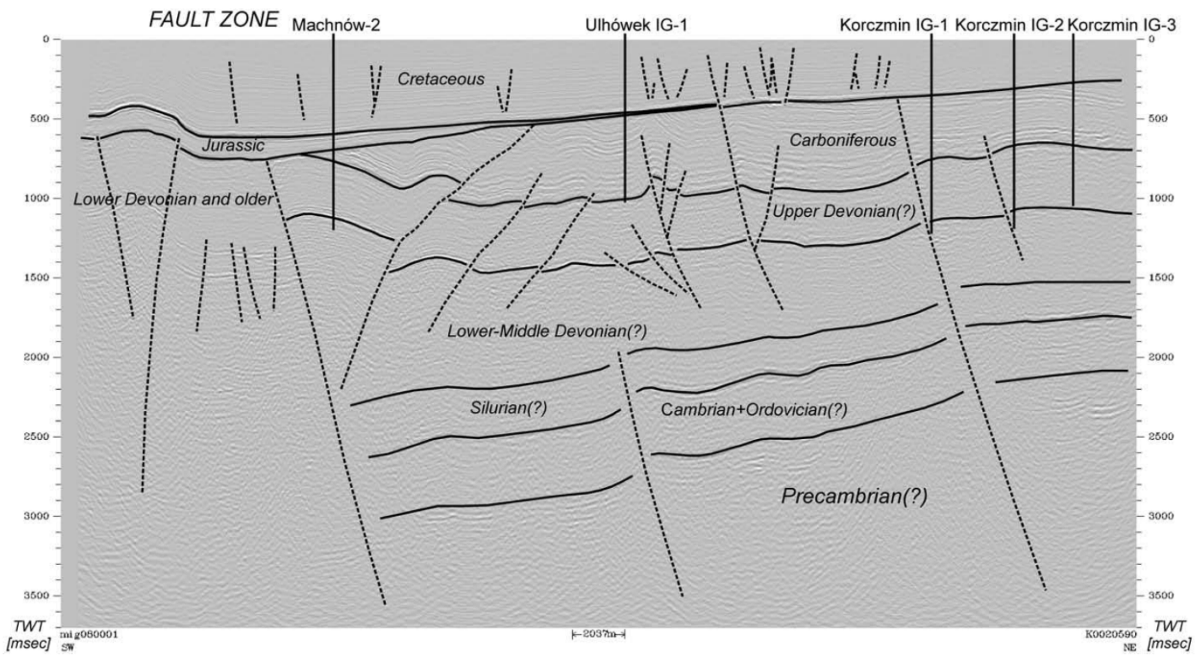


Figure 7B
Seismic cross section illustrating tectonic style of the geological setting of the Lublin region. After: Krzywiec P., 2009.

The Lower Paleozoic of the Baltic-Podlasie-Lublin Basin is characterized by relatively simple tectonic setting, suitable for shale gas and shale oil exploration and production. In a case of Baltic Basin and Podlasie Depression the main characteristics is a flexural bending towards the west (Fig. 7A). Density of faults is low and their offsets are very limited. More complex tectonic setting is observed in the Lublin region, where structural setting is defined by fault-block tectonics Fig. 7B), active in time period between late-most of Devonian and early Visean. During that time a system of tectonic blocks limited with the major fault zones developed, and was as subject to differential tectonic uplift and erosion (Żelichowski & Kozłowski, 1983; Krzywiec, 2011). Nonetheless, within an individual block degree of internal tectonic deformation and faulting is relatively limited.

## 4. Methodology

For the analysis of shale gas/oil potential and assessment of its resources a broad range of geological, geochemical, geophysical and mechanical data is required (Fig. 8). However in the basins were there was yet no exploration drilling for shale gas and shale oil some of the key data for understanding the potential and resources are usually missing. This is refers particularly to such data as shale porosity and permeability, gas composition, reservoir pressure, initial production (IP) and estimated ultimate recovery (EUR), mineralogical composition, including clay, silica and carbonates contents, mechanical properties, etc (Fig. 8). For this reason any attempts to calculate hydrocarbon resources of the basin can not avoid high analytical error bars. This limitations characterize any of previously released reports on resources of the basin, as well as here presented report.

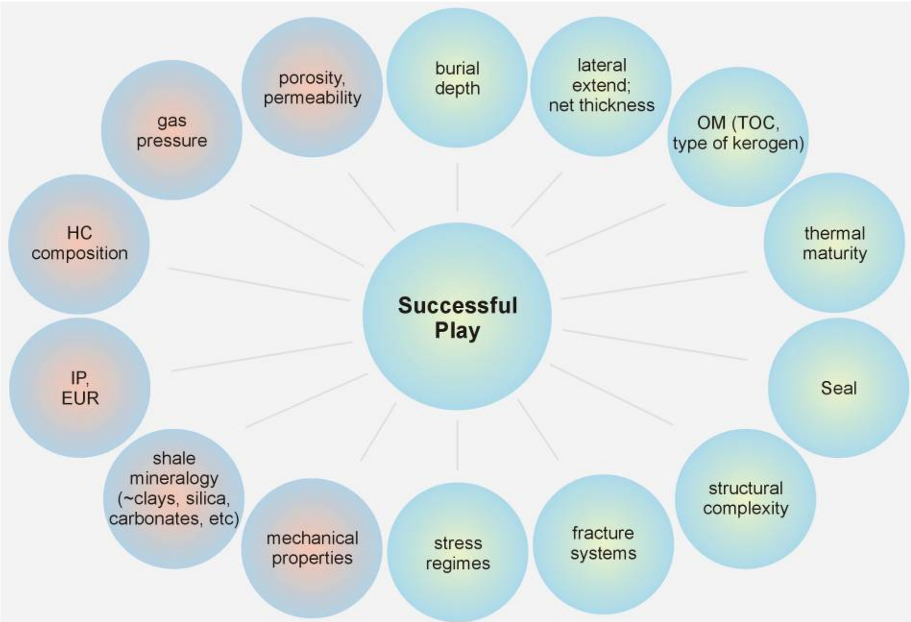


Figure 8
Typical set of geological required for analysis of shale gas and shale oil potential, as well as for resources assessment. Blue – data available in public domain in Poland. Fiolet – data currently not available in public domain in Poland.

Lack of some of the key data does not exclude possibility for preliminary assessment of resources. This requires however use of the American producing basins as analogues to constrain the reservoir characteristics. So far resources calculation for the Lower Paleozoic basin in Poland were performed mainly with a volumetric method. In such calculation certain surface of a field is adopted together with parameters characterizing the reservoir, such as porosity, permeability, gas saturation, etc. Recoverable gas is then determined with use of certain recovery factor, for shale reservoirs being usually equal to 10-25 % of geological gas reserves.

The approach used in here presented assessment is different. Recoverable resources were calculated with use of a certain average Estimated Ultimate Recovery (EUR) of an individual well, as well as with use of a certain average acreage drainaged by an individual well, both based on American analogues (Fig. 9). This characteristics was then applied to a certain acreage of the basin, were shale have proper geological characteristics. In a case of each individual historical well the major criteria allowing to include or not its location into acreage for which resources are calculated is a presence of shale formation with TOC contents of at least 2 % wt. at interval at least 15 m thick. The other criteria limiting assessment units is thermal maturity (Fig. 6). As a maximum maturity for presence of shale gas a value of 3,5 % Ro field was adopted. Moreover as a limit between shale gas and shale oil assessment unit a thermal maturity isoline of 1,1 % Ro was adopted.

At a current stage of knowledge on geological setting of the Lower Paleozoic Basin in Poland no unique value of individual parameters of resources assessment can be identify. For this reason both the key parameters, i.e. EUR and acreage of the basin qualified for calculations, were adopted in a few alternative scenarios. As a result the Report does not conclude one certain value of the resources, but results with a ranges of alternative solutions.

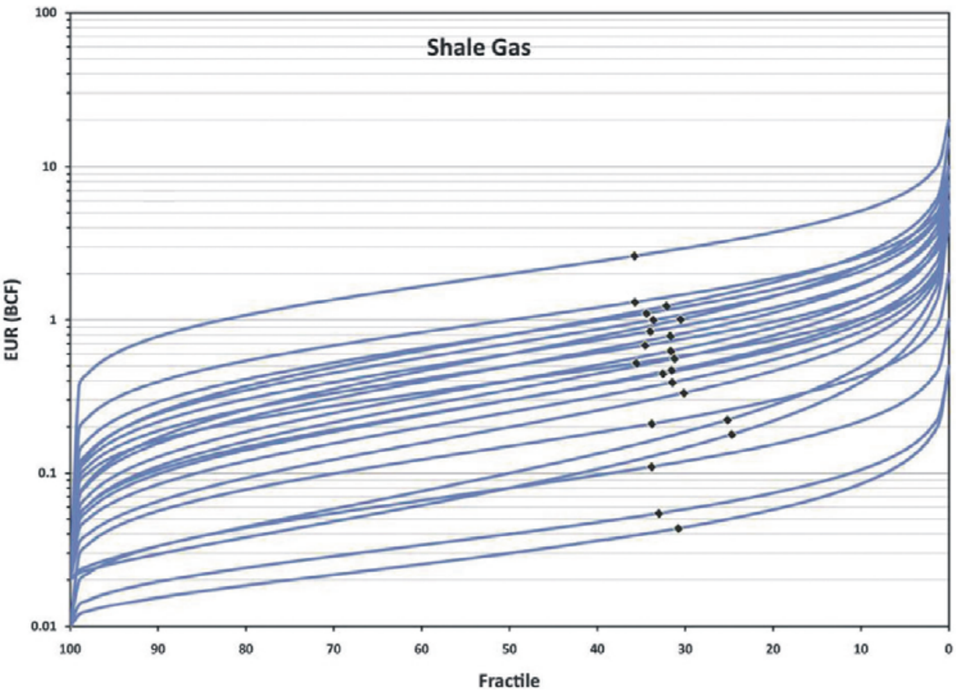


Figura 9
Dystrybucja rozkładów przewidywanego całkowitego wydobycia gazu ziemnego z pojedynczego otworu wiertniczego (EUR) dla 26 amerykańskich basenów sedymentacyjnych lub ich stref analizowanych pod kątem zasobów przez USGS. Poszczególna pojedyncza niebieska linia reprezentuje rozkład EUR w określonym basenie sedymentacyjnym. Według: USGS Marcellus Shale Assessment Team, 2011.

Methodology used by USGS for assessment of shale gas and shale oil resources was described in details in Marcellus Shale Assessment Report (USGS Marcellus Shale Assessment Team, 2011). Specific of this method is that it bases on quantitative shale gas and shale oil production historical experience.

## 5. Geological constraints and assumptions for resources calculation

With the currently used method the key parameters for shale gas/oil recoverable resources assessment, which solely impact obtained results, are primarily the average EUR (Estimated Ultimate Recovery) adopted for the basin and the acreage of the basin qualified for calculations. The range of EUR documented by USGS for basins in United States are presented on Figure 9. Each of the blue lines stands for the individual wells EUR distribution in the single sedimentary basin. This documents for each basin present of limited amount of wells with exceptionally poor and exceptionally good performance, and a plateau of EURs being more representative as average. The average values are marked with black chevrons. EURs average for individual basins create a very broad spectrum of values from as low as 0,03 Bcf (~0,85 MMcm), to as high as 2 Bcf (~56,7 MMcm). Mmoreover the figure is a good illustration how inadequate might be application of the best EURs in a basin (e.g. in range of 5-10 Bcf), which are sometimes documented, however statistically are by far not representative for the basin.

Adaptation of the proper EUR analogue from US for the calculation requires identification of American basin, being the closet geological are reservoir equivalent of the Lower Paleozoic Baltic-Podlasie-Lublin Basin in Poland. With the current level of understanding of shale gas/oil characteristics of the basin in Poland this is rather difficult and ambiguous. Stratigraphic age criteria would allow to suggest the Ordovician Utica shale from the NE USA and SE Canada as possible analogue. This is currently the only Lower Paleozoic shale producing gas at the industrial scale. However Utica shale are characterized by higher thermal maturity, thickness and to some extend higher TOC. Taking into account depositional environment and sedimentological model, the Woodford shale from Arcoma Basin were considered as a analogue (personal communication: P. Lis). The Upper Ordovician part of the section of the Baltic-Podlasie-Lublin Basin, characterized by elevated contents of carbonates, would point to for example Eagle Ford shale from the SW Texas as analogue for that interval of the basin section. This kind of analogue identification is however in general difficult since many of USA shale basins differ from the one in Poland with higher TOC and lower clay mineral contents.

Important leads for selection of proper EUR for the analayzed basin are related to first results of vertical well fracturing and two lateral wells with multifracturing in the Baltic-Podlasie-Lublin Basin. Relatively low initial gas flows does not allow to adopt EURs from the most productive US (e.g. Haynesville or Barnett).

Base on the above considerations for here conducted calculations three alternative EURs were incorporated. For the most probable scenario EUR equal to 0,4 Bcf (~11,3 MMcm) was adopted, being equivalent of the lower range of the main cluster of EURs from the US basins (Fig. 9). As a maximum EUR a value of 1 Bcf (~28,3 MMcm) was used, being documented in the some of the best performing basins in US. As a minimum EUR equal to 0.04 Bcf (~1,13 MMcm) was adopted, which might be observed e.g. in poorly performing Ohio shale.

The other parameter, having major impact on obtained results of resources assessment, is a acreage of the area classified for the calculations. According to adopted geological criteria, defined by USGS, this is a cumulative acreage of that part of the basin, which is characterized by thickness is shale interval with TOC > 2 % being higher than 15 m. Within the basin this criteria is relevant only in the location of historical key boreholes with laboratory measurements of TOC and wire logs being available.

In each of the historical wells determination of the net thickness of section with TOC > 2 % is not easy and straight forward. By a rule the TOC measurements are available only for the cored intervals, being usually a small part of the whole well section (Figs. 10-13). For intervals with no core wire logs were used for indirect determination of TOC contents.

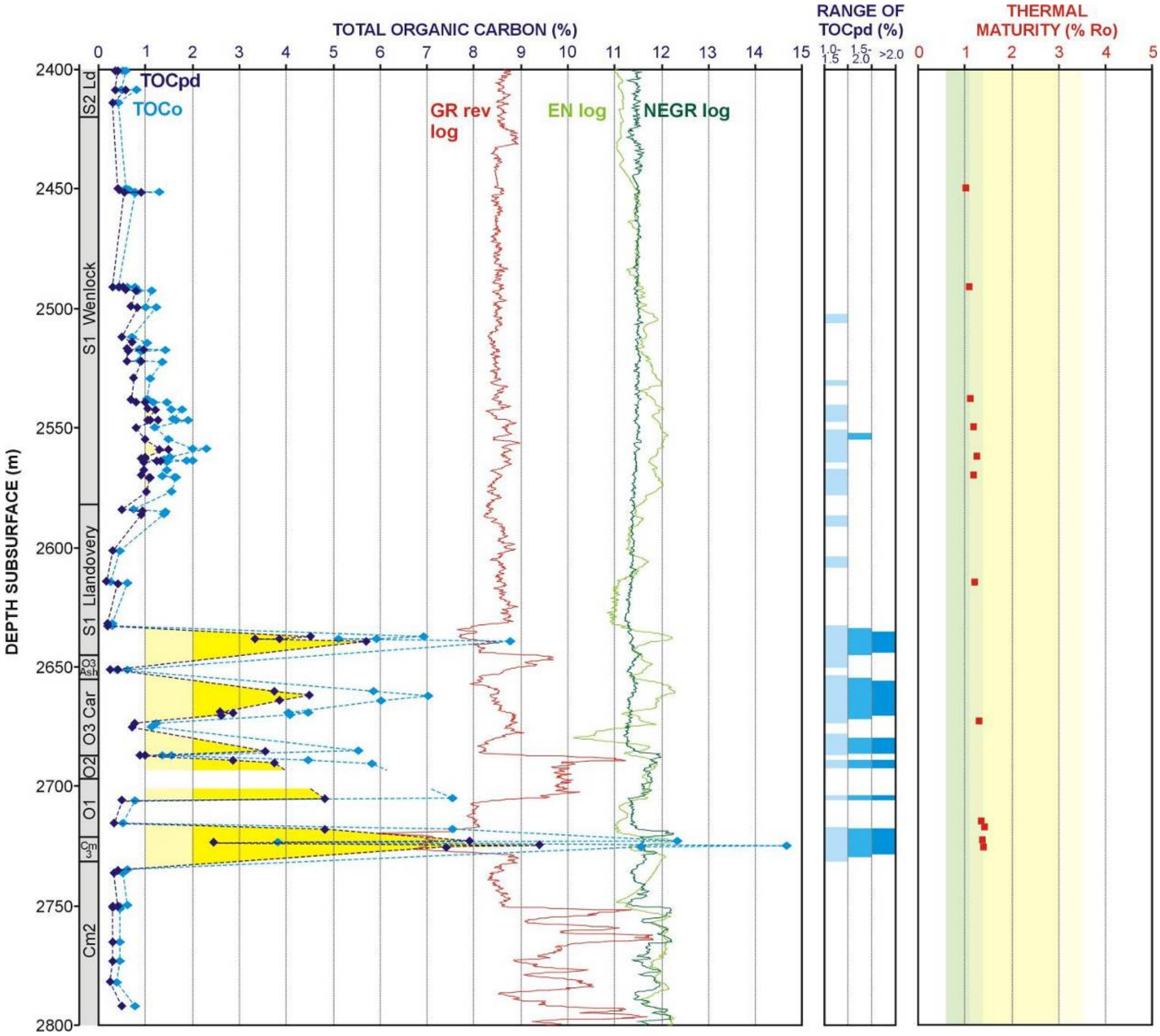


Figure 10
Compilation of geological, geochemical and geophysical data, characterizing shale gas/oil potential of the Lower Paleozoic shale interval in a given exemplary well from the Baltic Basin (Żarnowiec IG 1). TOCpd – measured present day TOC contents. TOCo – reconstructed original TOC contents. GR – gamma ray (increasing towards left-hand side). EN, EL – resistivity log (increasing towards right-hand side). NEGR –neutron log (increasing towards right-hand side).

The most useful for this reason was gamma log, as well as neutron log related to resistivity log. This is important to notice, that TOC measurements were conducted through decades on core samples collected mainly in 60-ties and 70-ties. These are often partly weathered and measurements have therefore higher terror bars.

The analysis of well data devoted to determination of the thickness of high TOC interval were conducted for cumulative number of 39 historical boreholes. In the Baltic Basin these were wells: Bartoszyce IG 1, Darżlubie IG 1, Gdańsk IG 1, Gołdap IG 1, Hel IG 1, Kętrzyn IG 1, Kościerzyna IG 1, Lębork IG 1, Malbork IG 1, Olsztyn IG 2, Pasłęk IG 1, Prabuty IG 1, Słupsk IG 1 and Żarnowiec IG 1. For the basement of Płock-Warsaw Trough the wells Bodzanów IG 1 and Polik IG 1 were analyzed. For the Podlasie Depression following wells were studied: Kałuszyn 1, Łochów IG 2, Malinowo IG 1, Okuniew IG 1, Stadniki IG 1, Tłuszcz IG 1, Wronów IG 1 and Żebrak IG 1. Than for the Lublin region boreholes Białopole IG 1, Busówno IG 1, Gródek 1, Horodło 1, Kaplonosy IG 1, Krowie Bagno IG 1, Łopacianka 1, Łopiennik IG 1, Parczew IG 10, Siedliska IG 1, Tarkawica 1 and Terebin IG 5 were analyzed. In the Biłgoraj-Narol these were wells Dyle IG 1, Narol IG 1 and Narol PIG 2.

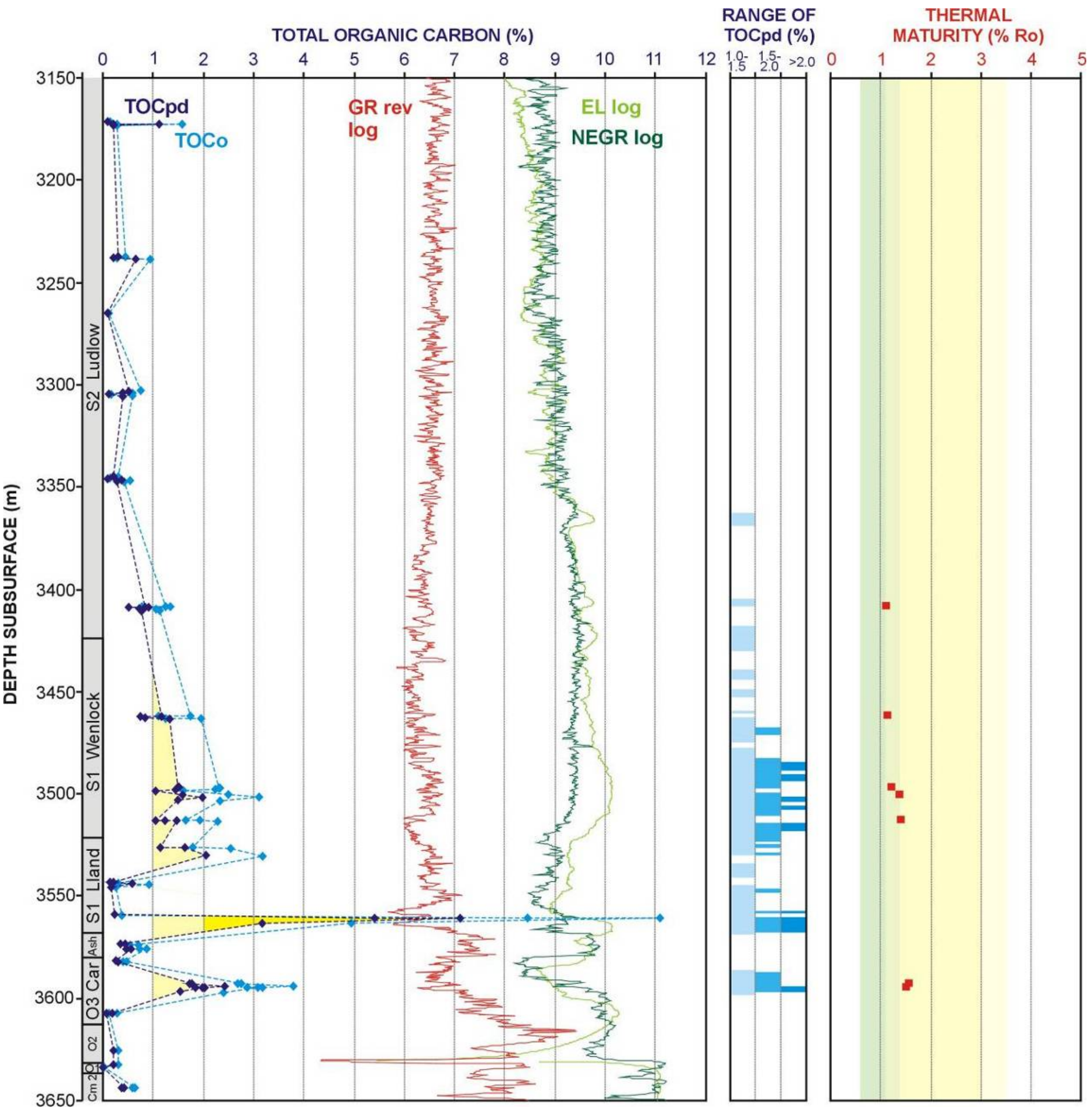


Figure 11
Compilation of geological, geochemical and geophysical data, characterizing shale gas/oil potential of the Lower Paleozoic shale interval in a given exemplary well from the Podlasie Depression (Okuniew IG 1). Explanations as on Figure 10.

The examples of conducted analysis and their interpretation are illustrated on Figures 10-13. In each case present day laboratory measurements of TOC contents (TOCpd – deep blue chevrons) and measurements of thermal maturity (Ro – red chevrons) were assembled original TOC contents (TOCo), i.e. TOC from before beginning of hydrocarbon generation, were reconstructed, and wire logs (GR, NEGR, EL, EN) were compiled. The data were analyzed and interpreted to identify intervals of the section with TOC contents > 1 %, > 1,5 % and > 2 %, respectively.

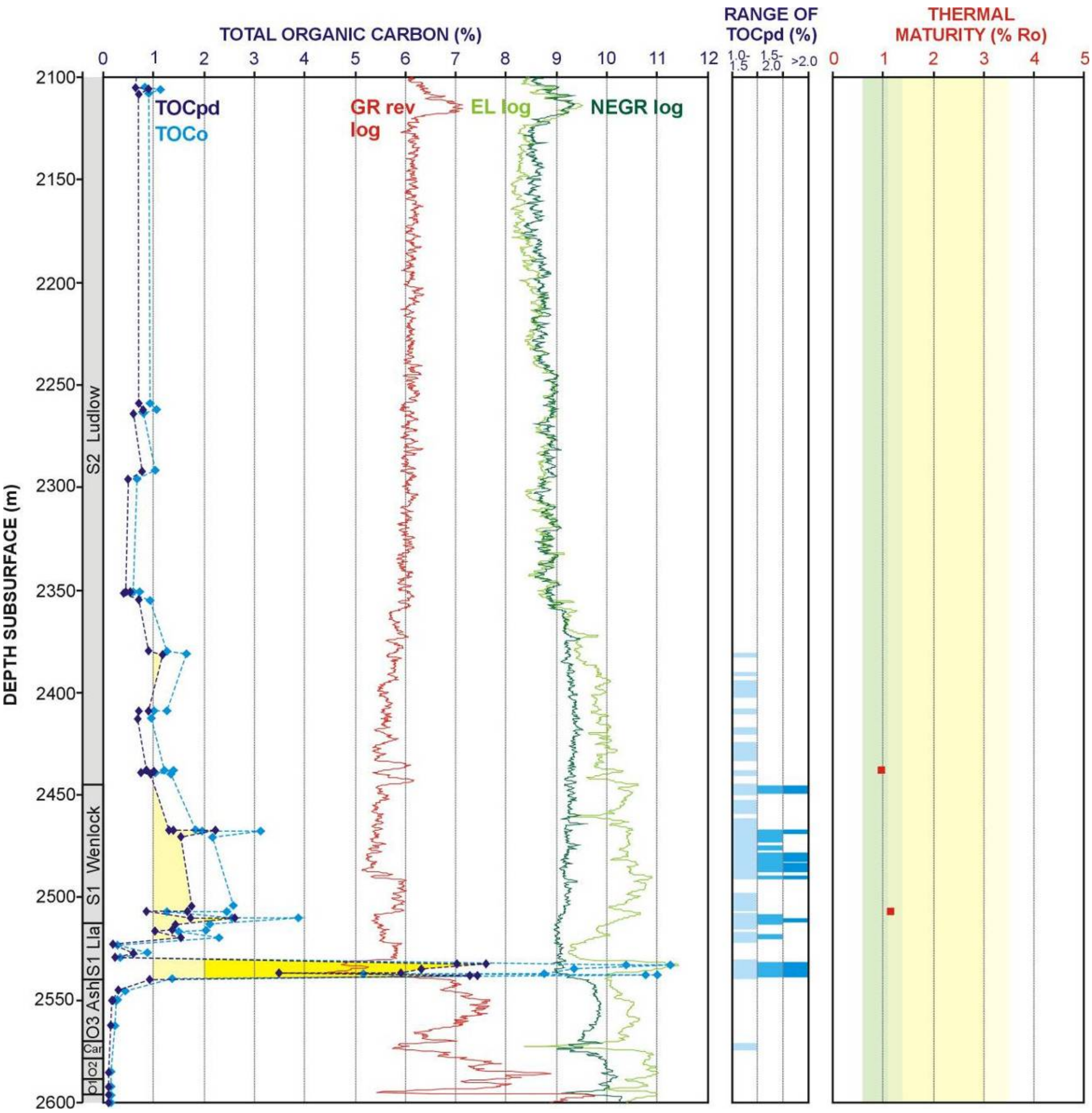


Figure 12
Compilation of geological, geochemical and geophysical data, characterizing shale gas/oil potential of the Lower Paleozoic shale interval in a given exemplary well from the Lublin region (Siedliska IG 1). Explanations as on Figure 10.

The acreage qualified for the resources calculation was limited more over by maximum excepted thermal maturity being equal to 3,5 % Ro, as well as by borders of Poland and limits of Polish territorial waters on Baltic Sea. The assessment units with gas resources were arbitrary limited from the ones with oil resources by thermal maturity isoline 1,1 % Ro. In nature in a broad zone along this limit both oil and gas coexist in laterally changing proportions.

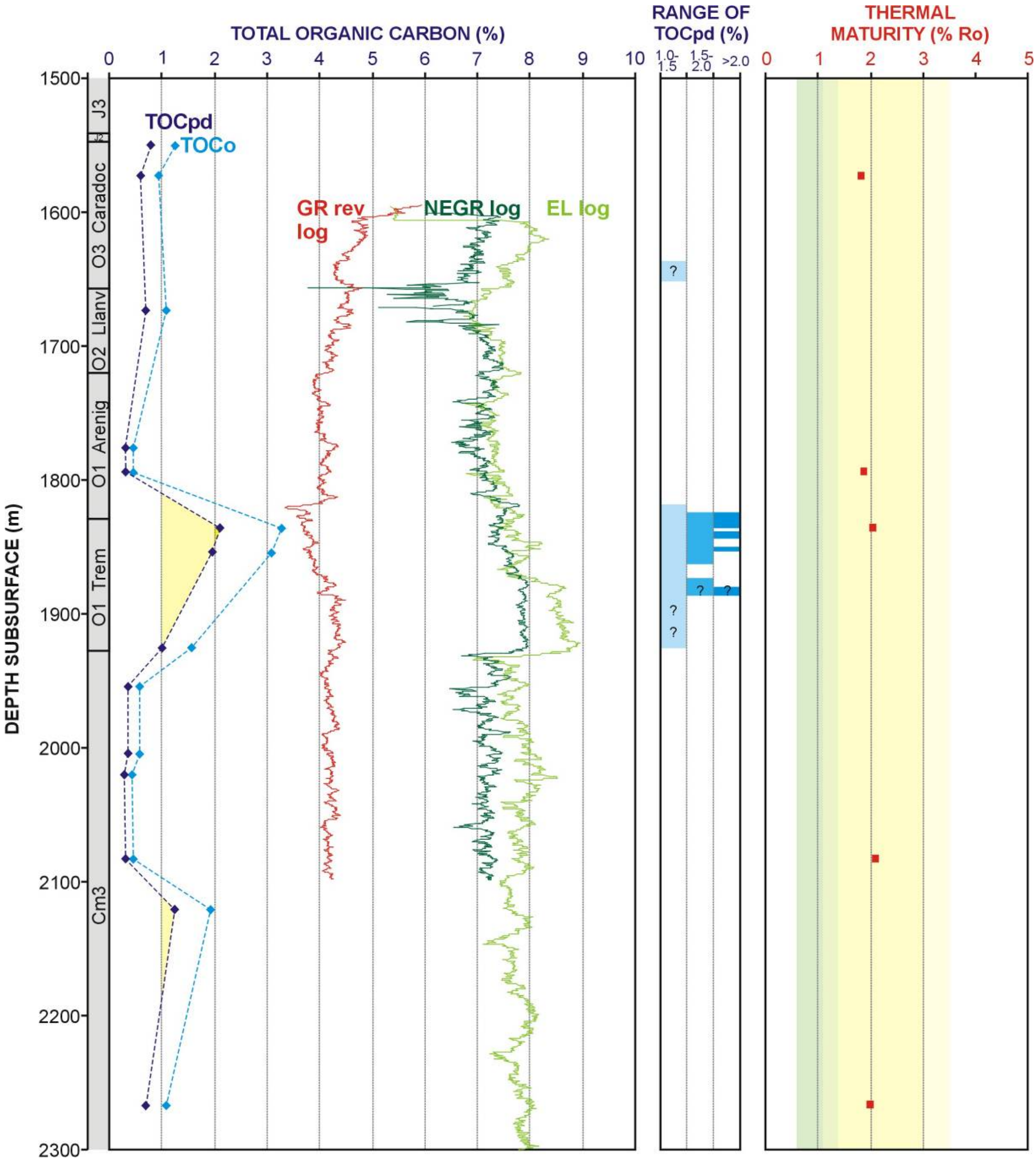


Figure 13
Compilation of geological, geochemical and geophysical data, characterizing shale gas/oil potential of the Lower Paleozoic shale interval in a given exemplary well from the Biłgoraj-Narol Zoned (Dyle IG 1). Explanations as on Figure 10.

Thicknesses of the intervals with TOC contents > 2 % interpreter for the individual wells were further used to map extend of the area incorporated into assessment units and qualified for resources calculation. Acreage of such area was subsequently determined. For non of analyzed wells such procedure is straight forward and results with unit results and often different alternative interpretation approaches are acceptable. As a consequence for the conducted resources assessment the two alternative models of the acreage of the field were adopted. In the first model, regarded here as a minimum, acreage of the area qualified into assessment units was determined as 37630 km$^2$. Within this area some 18539,7 km$^2$ are identified as mainly gas saturated (with 6192,4 km$^2$ offshore and 12347,3 km$^2$ onshore) and 19090,3 km$^2$ as mainly oil saturated (with 14767 km$^2$ offshore and 4323,3 km$^2$ onshore).

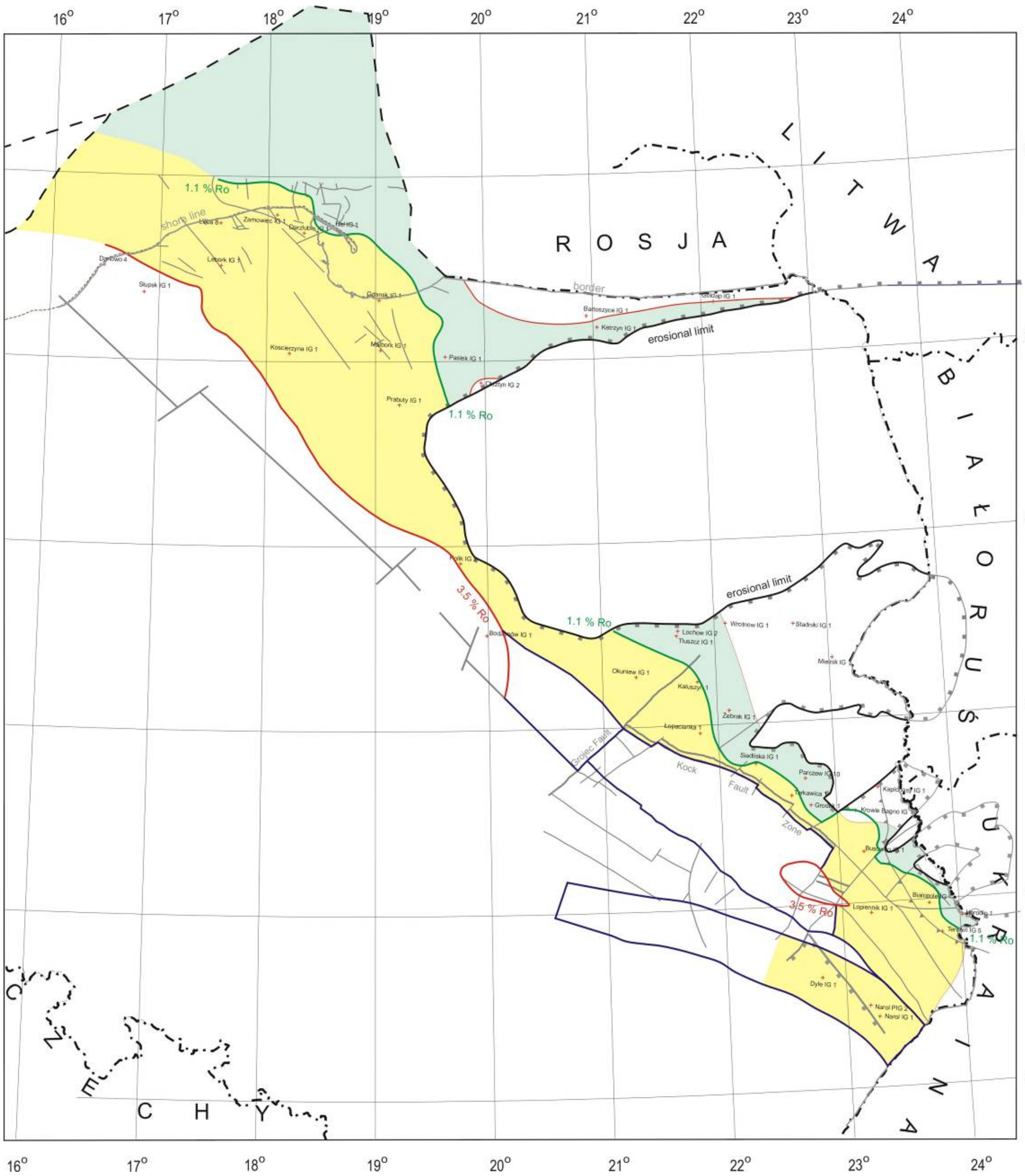


Figure 14.
The acreage incorporated into assessment units and qualified into calculation of resources of shale gas (yellow color) and shale oil (green color) in a model with maximum thickness of shale intervals with TOC contents > 2 % wt on the basis of 39 exploratory drillings from 1950-1990

In the second alternative model (Fig. 14), regarded as maximum, acreage of the area qualified into assessment units was determined as 64867 km$^2$. Within this area some

41135,77 km$^2$ are identified as mainly gas saturated (with 7952,4 km$^2$ offshore and 33183,3 km$^2$ onshore) and 23731,3 km$^2$ as mainly oil saturated (with 14767 km$^2$ offshore and 8964,3 km$^2$ onshore).

The above discussed alternative values of the assessment units acreage and alternative average EUR were used to calculated in a few alternative approaches the recoverable resources of shale gas and shale oil for the Lower Paleozoic Baltic-Podlasie-Lublin Basin.

## 6. Recoverable shale gas resources

Unconventional hydrocarbon resources assessment was conducted in a few alternative models of assumed values of key parameters, including in particular surface of the acreage incorporated into calculations and adopted EUR. This resulted with a few alternative models of the resources of shale gas (Tab. 1) and shale oil (Tab. 2). Revealed recoverable resources of shale gas for the both onshore and offshore part of the basin are covering very broad ranges of values from 37,9 Bcm at minimum to 1 919,7 Bcm at maximum. However these extremes are characterized by low probability. If to apply to conducted calculations the key parameters values regarded here as the most probable, the shale gas recoverable resources for the both onshore and offshore part of the basin are in a range of 346,1 Bcm to 767,9 Bcm (Tab. 1).

***Table 1***
***Recoverable resources of shale gas in the Lower Paleozoic basin. Bcf – billion cubic feet. Bcm – billion cubic meters. EUR – Estimated Ultimate Recovery.***

| | **EUR minimum 0.04 Bcf = 1,13 MMcm),** | **EUR optimum (0,4 Bcf = 11,3 MMcm)** | **EUR maximum (1 Bcf = 28,3 MMcm),** |
|---|---|---|---|
| **offshore acreage max. 7 952,4 $km^2$** | 14,8 Bcm | 148,4 Bcm | 371,1 Bcm |
| **offshore acreage min. 6 192,4 $km^2$** | 11,6 Bcm | 115,6 Bcm | 289,0 Bcm |
| **onshore basin acreage max. 33 183,3$km^2$** | 61,9 Bcm | 619,4 Bcm | 1 548,6 Bcm |
| **onshore basin acreage min. 12 347,3$km^2$** | 23,0 Bcm | 230,5 Bcm | 576,2 Bcm |
| **onshore & offshore acreage max. 41 135,7 $km^2$** | 76,8 Bcm | 767,9 Bcm | 1 919,7 Bcm |
| **onshore & offshore acreage min. 18 539,7 $km^2$** | 34,6 Bcm | 346,1 Bcm | 865,2 Bcm |

## 7. Recoverable shale oil resources

Cumulative recoverable resources of shale oil for the both onshore and offshore part of the basin, calculated with alternative assumptions as for key parameters of the assessment, also are covering broad ranges of values from58,5 MMt at minimum to 535,5 MMt at maximum. These extremes are also characterized by low probability. If to apply to conducted calculations the key parameters values regarded here as the most probable, the shale oil recoverable resources for the both onshore and offshore part of the basin are in a range of 215,4 MMt to 267,8 MMt (Tab. 2).

***Table 2***
***Recoverable resources of shale oil in the Lower Paleozoic basin. MMB – millions of barrels. MMt – millions of tons. EUR – Estimated Ultimate Recovery.***

| | **EUR minimum (0.03 MMB = 4,11 tys. ton),** | **EUR optimum (0,05 MMB = 6,85 tys. ton)** | **EUR maximum (0,1 MMB = 13,7 tys. ton),** |
|---|---|---|---|
| **offshore acreage max. 14 767 km$^2$** | 100,0 MMt | 166,6 MMt | 333,2 MMt |
| **offshore acreage min. 14 767 km$^2$** | 100,0 MMt | 166,6 MMt | 333,2 MMt |
| **onshore basin acreage max. 8 964,3 km$^2$** | 60,7 MMt | 101,1 MMt | 202,3 MMt |
| **onshore basin acreage min. 4 323,3 km$^2$** | 29,3 MMt | 48,8 MMt | 97,6 MMt |
| **onshore & offshore acreage max. 23 731,3 km$^2$** | 160,7 MMt | 267,8 MMt | 535,5 MMt |
| **onshore & offshore acreage min. 19 090,3 km$^2$** | 58,5 MMt | 215,4 MMt | 430,8 MMt |

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