Ordovician-Silurian shale gas resources potential in Poland: evaluation of Gas Resources Assessment Reports published to date and expected improvements for 2014 forthcoming Assessment

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A b s t r a c t. The paper comprises a brief history and results of Assessment Reports of shale gas resources for the Polish Ordovician-Silurian Basin. The Reports have been confronted in the context of used criteria of assessing. The comparison shows that the early, most optimistic assessments (Wood Mackenzie, ARI & EIA) were based on very generalized data and different assessment methods than those used in the PGI and USGS Reports. In turn, the PGI and USGS Reports, based on USGS assessment methodology, were not so diverse taking into account the presented extreme low values of recoverable gas resources and the used methods of shale gas occurrence probability. The terms EUR (Estimated Ultimate Recovery) and AU (Assessment Unit), used in the USGS methodology of shale gas and shale oil resources assessment are characterized. The paper also presents assessment methods of technically and economically recoverable shale gas, and the significance of "sweet spots" as areas with the greatest probability for shale gas productivity. Finally, proposals for the reconstruction of future work on the new assessment (at the turn of 2014) of recoverable shale gas resources for the Polish Ordovician-Silurian Basin are recommended. The future assessment of shale gas resources should be more detailed, not only due to new geological input data (including results of exploration wells), but also thanks to segmentation of the whole Ordovician-Silurian assessment area into five smaller regional assessment units. The paper presents the criteria of area segmentation and the characteristics of proposed assessment units. The key geological, geophysical and geochemical criteria, which should be taken into consideration in the methodology of new shale gas resources assessment, are compiled. Moreover, to better understand the peculiarity of the Polish Ordovician-Silurian shales and reservoir attributes, and to fit these to shale gas recovery technology, the lessons coming from the US shale basins are discussed. In summarizing, the authors, presenting the conclusions and recommendations, refer to future shale gas resources assessment that, in their opinion, would help particularize the results and thus make them more authenticated.

Keywords: *shale gas, resources assessment, technically recoverable resources, economically recoverable resources*

On 18 March 2013, the public opinion in Poland was once again thrilled by the news from the Polish Press Agency, PAP: "The Polish Oil and Gas Company, PGNiG, obtained a gas flow from a borehole in the village of Lubocin", informed the company on Monday. "It is good news that should motivate to invest in the exploration of shale gas in this country", said the minister of the State Treasury. "Fracturing fluid is now being collected from the Lubocino 2H borehole. Gas flow was obtained, but it will take a few weeks before tests are completed and then we will be able to answer the question about the real amount of gas in the well", wrote the spokeswomen of the Polish Oil and Gas Company. According to PAP: "One more time, the presence of gas at Lubocin was successfully proved already in a horizontal drilling at a distance of a few hundred meters – so this is good news which should motivate to invest in the exploration shale gas in this country", said the minister of the State Treasury on Monday. "It is – in the minister's opinion – further evidence for the presence of the (shale) gas". That gas "is present" we have known for some time, but we still do not know how big are technically recoverable resources of the gas in terms of technology, nor do we know whether its extraction and production will be economically viable.

The purpose of this paper is briefly outline three issues which relate to the problem: an analysis of the current recoverable gas resource assessments, assessment methodology as well as proposals for future assessments.

To understand (by the state administration in particular) the diversity of gas occurrence both in conventional and unconventional deposits is a key factor in the process of a gas resource assessment. The problem is that conventional deposits within a sedimentary basin have a limited extension (and thus precisely determined size and resources in a given exploration category), while unconventional deposits do not have a limited extension (and thus do not have a determined size) and therefore, precisely defined resources.

THE SUBJECT OF THE GAS RESOURCE ASSESSMENTS

The subject of the gas resource assessments are the Ordovician and Silurian claystone-mudstone rocks which contain dispersed organic matter and are referred to as "shales" due to their characteristic shaly cleave.

The Basic, regional division of the Ordovician-Silurian Basin into the north-western part (Baltic Basin) and the south-east part (Lublin Basin) (Fig. 1) show different significance of individual the Ordovician and Silurian series in terms of their deposit potential which is due to the various values of TOC (the organic matter weight amount remaining after the process of gas generation from organic matter) (Poprawa, 2010a, b, c).

The Ordovician-Silurian Basin in its onshore and offshore part, beside a regional division, is divided into zones which outline the occurrence of gas and oil (Fig. 2) (after the PGI Report, 2012 – Fig. 14). In the PGI Report, the criterion of thermal maturity was adopted for the calculations of gas resources and the value of 3.5% Ro as "the maximal maturity with which natural gas deposits can occur. Additionally, as the arbitrary limit for natural gas and oil

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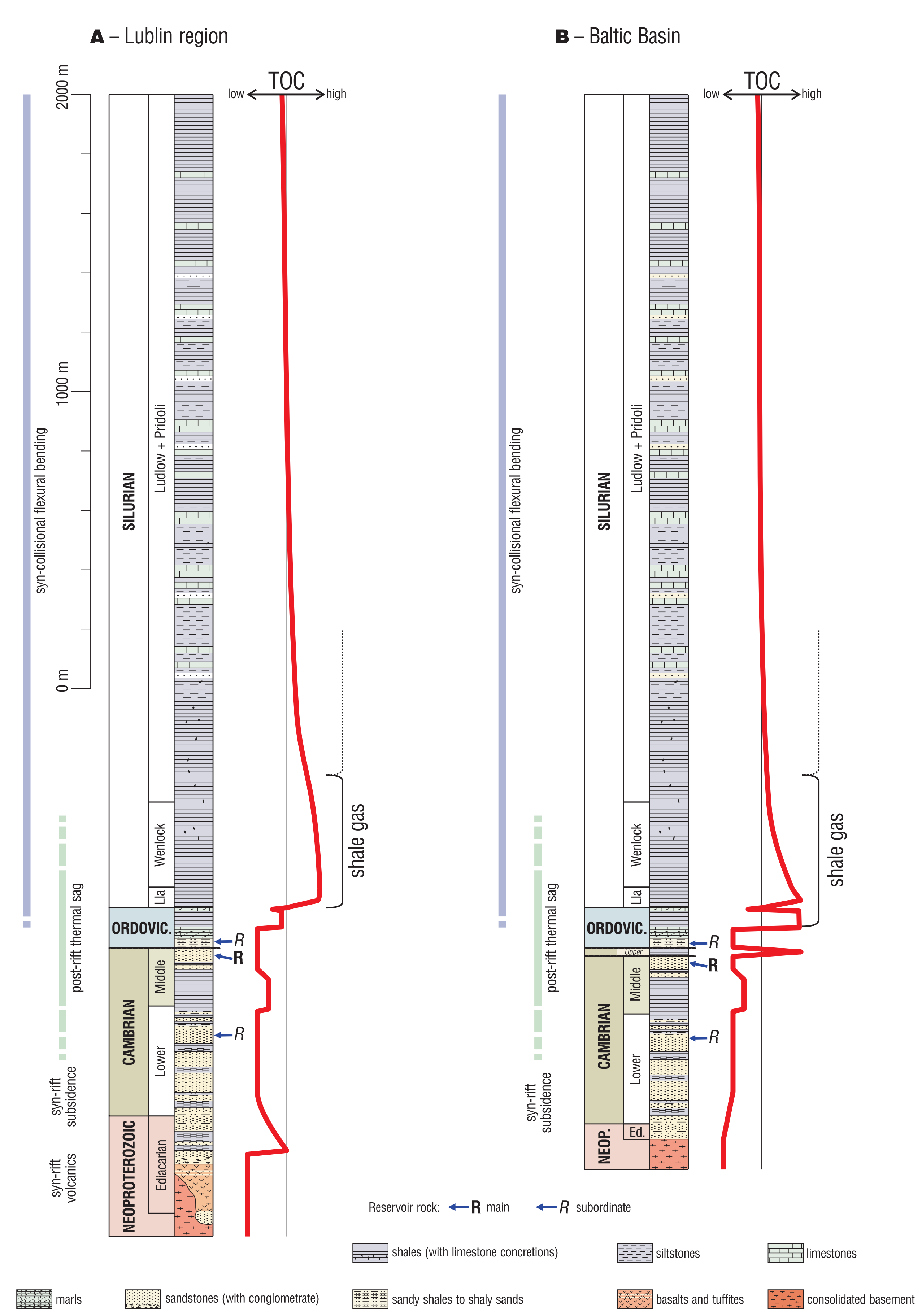


Fig. 1. Simplified lithostratigraphic section of the Lower Paleozoic in the (**A**) Lublin region, and (**B**) Baltic Basin with the position of organic-rich shales that are the potential shale gas/oil formation (PGI Raport, 2012; Poprawa, 2010b)

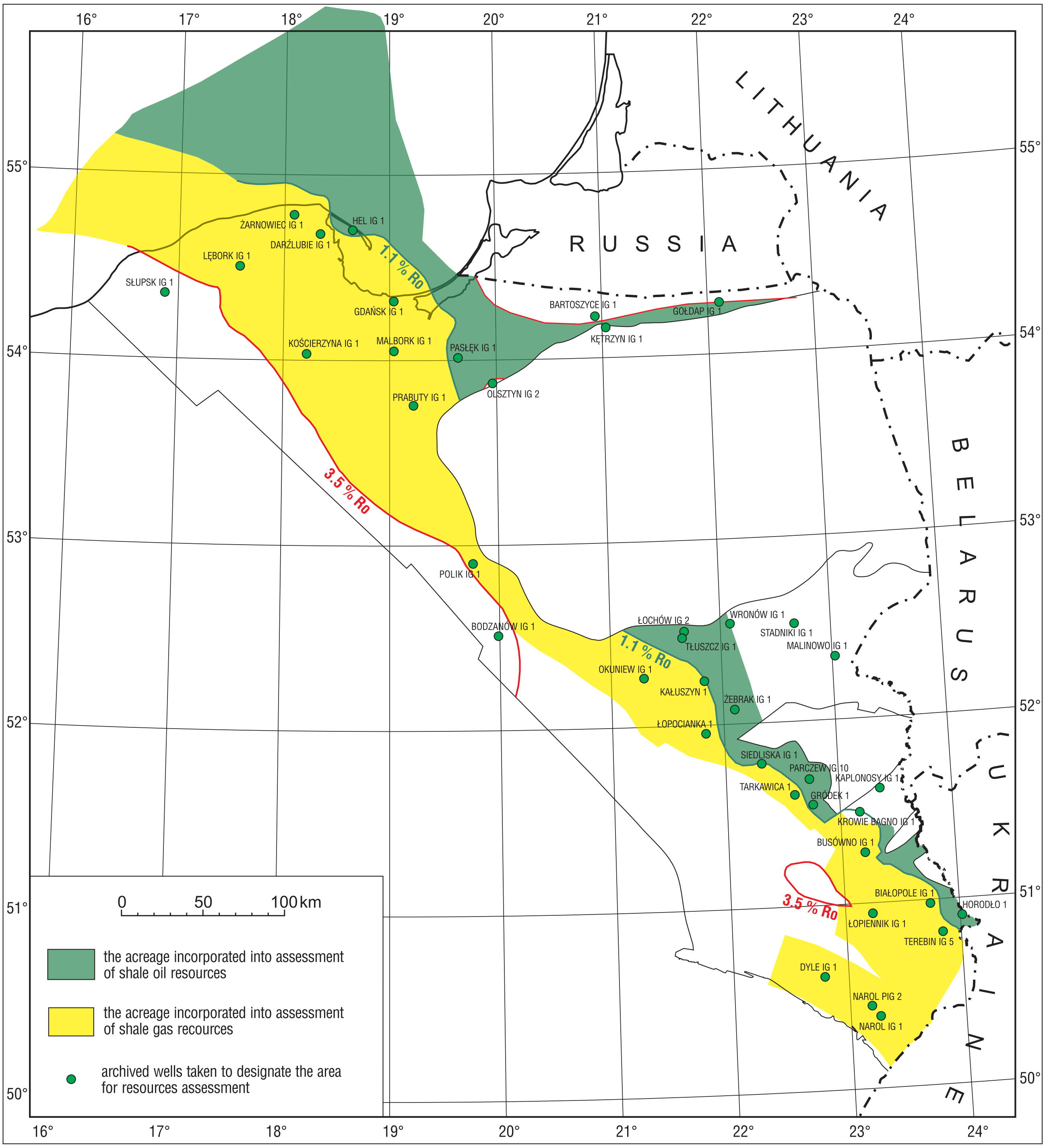


Fig. 2. The acreage incorporated into assessment units and qualified into calculation of resources of shale gas (yellow color) and shale oil (green color) in a model with maximum thickness of shale intervals with TOC contents >2% wt on the basis of 39 exploratory drillings from 1950–1990 (after PGI Raport, 2012 – Fig. 14, modified)

saturation, the thermal maturity isoline of 1.1% Ro was accepted".

SHALE GAS RESOURCE ASSESMENTS TO DATE

Between 2009 and 2012, five Reports on the gas assessment in the Polish part of the Ordovician-Silurian Basin shales were published.

Former Reports: Wood Mackenzie of 2009 and Advanced Resources International Inc. (ARI) of 2009 have been omitted as being outdated and based on less reliable data.

Below, three basic Reports on technically recoverable shale gas resources in Poland are the subject of discussion and comparison, namely, the Reports submitted by the U.S. Energy Information Administration (EIA) (Kuuskraa et al.) of 2011, by the Polish Geological Institute of 2012 and by the United States Geological Survey (USGS) (Gautier et al.), also of 2012.

The EIA Report

In the U.S. Energy Information Administration Report, the highest so far estimation values of the shales resources

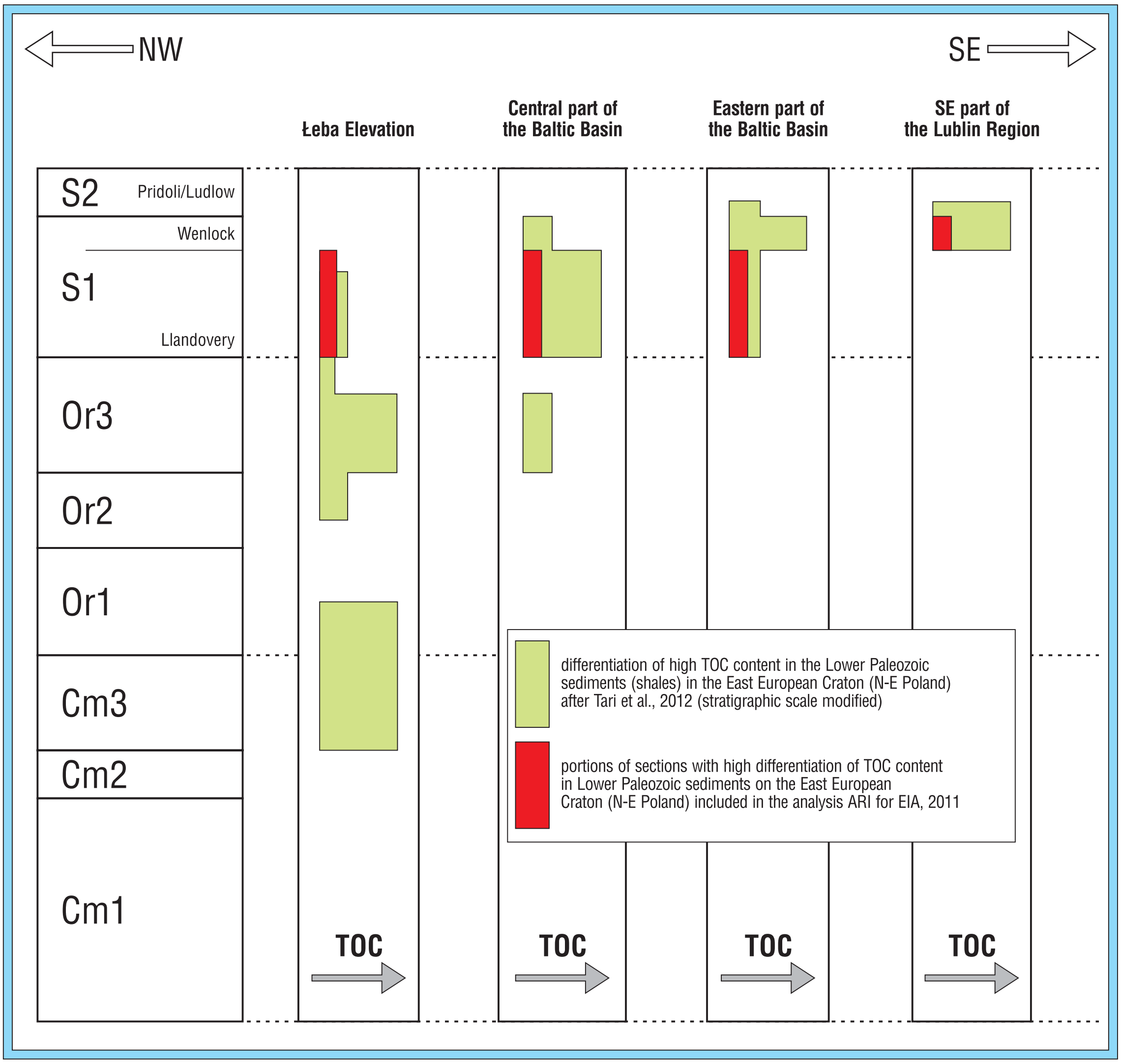


Fig. 3. Simplified scheme illustrating the diachronism of the first appearance of organic-rich shales in sedimentary basins from the western slope of the East European Craton during the Early Paleozoic. S – Silurian; Or – Ordovician, Cm – Cambrian (modified after Tari et al., 2012 – Fig. 5)

in the Polish Ordovician-Silurian Basin of the amount of 5.3 trillion m^3 has been presented.

In the scheme (Fig. 3), three main areas of the appearance of the Cambrian, Ordovician and Silurian gas and oil-bearing shales in a stratigraphic section are shown. In addition, the fragments of the stratigraphic profile with the highest content of TOC are marked. The scheme comprises the sediments (shales) that are included in the assessment of technically recoverable gas resources made by ARI for EIA in 2011. Paradoxically, despite the fact that the estimation of all the Ordovician-Silurian gas shales was not mentioned, the EIA Report gave the highest prognosis for the resources (see Table 1 with comparative material).

Given the fact that the EIA Report significantly differs, in terms of quantity, from the next reports, an analysis of its components was made in order to comprehend such a big disproportion between the results. The component analysis for each individual basin with the view to such a high estimate of the shale gas showed various reasons why the prospective gas resources can be increased and possibly decreased. In case of the Baltic Basin (both onshore and offshore areas), the causes of the resources increase by EIA was that a vast acreage was adopted (larger than that in the other analyses of the Basin), the mean TOC value was overstated for the Silurian shales only, the presence of sufficient overpressure was assumed (and thus it overstated the values of EUR). And in the Podlasie Basin, significantly overstated values of TOC were adopted for the Silurian shales only, and in case of the Lublin Basin it was assumed that there was sufficient overpressure (EUR values were overstated). Moreover, for each basin a relatively high gas recovery factor (of 23.5%) was assumed. The possible decrease in the Baltic Basin gas resources could have been due to the fact that the Silurian and Ordovician potential was not taken into account, since only the Silurian Llandovery shales were included, while those of Wenlock and Ordovician omitted. As regards the other basins, i.e. the Podlasie Basin and the Lublin Basin, also the potential of the other shales, apart from the Llandovery shales, was not taken into consideration, and moreover, the values of the thermally mature organic matter were understated (% Ro).

The PGI Report

The Report by the Polish Geological Institute, announced in March 2012, was based on the methodology of the shale gas assessment that has been used and modified for many years by the United States Geological Survey

Table 1. Reservoir properties of shales and shale gas resources in Poland based on EIA Report, 2011

Basic data	**Basin/Total area [km^2]**		**Baltic Basin 263 172 km^2**	**Lublin Basin 30 774 km^2**	**Podlasie Basin 11 152 km^2**
	Shale formation		Lower Silurian	Lower Silurian	Lower Silurian
	Geologic age		Llandovery	Wenlock	Llandovery
Physical extent of examined area	Prospective area [km^2]		22 911 km^2	30 199 km^2	3432 km^2
	Thickness [m]	Interval	100.6–250 m	100.6–340 m	109.7–219.5 m
		Organic rich	175.3 m	126.5 m	164.6 m
		Net	96.3 m	69.5 m	90.5 m
	Głębokość Depth [m]	Interval	2500–5000 m	2000–4100 m	1750–3460 m
		Average	3750 m	3050 m	2605 m
Reservoir properties	Reservoir pressure		Overpressured	Overpressured	Overpressured
	Average TOC [wt. %]		4.0%	1.5%	6.0%
	Thermal maturity [% Ro]		1.75%	1.35%	1.25%
	Clay content		Medium	Medium	Medium
Resources	GIP concentration [m^3/km^2]		1 585 314 672 m^3/1 km^2	863 723 166 m^3/1 km^2	1 552 515 058 m^3/1 km^2
	Risked GIP, onshore [m^3] 22 427 064 000 000 m^3		14 554 938 000 000 m^3	6 286 374 000 000 m^3	1 585 752 000 000 m^3
	Risked (GIP) recoverable [m^3] 5 295 279 000 000 m^3 = **5.3 trillion m^3**		3 652 893 000 000 m^3	1 245 948 000 000 m^3	396 438 000 000 m^3

(USGS). According to the authors of the document "the Report should be treated as an open-file report because it was based on some vintage data obtained from 39 exploration wells drilled between 1950–1990 and discussed in the previous publications", without taking into consideration the data from new boreholes which were in possession of oil companies. However, the data were included were obtained in shale basins in the USA of known deposit characteristics.

The findings of the Report stirred up a lot of controversy and criticism from some people and opinion-forming environments in the geological and industrial circles. The PGI-NRI was accused of understating the gas resources, especially with respect to "amateur" estimates of some "fathers of shale gas exploration in Poland". The Report was competently judged in the publications by the Institute of Petroleum and Gas (Ciechanowska et al., 2012), and in the later report of the USGS, of July 2012, where its value was confirmed as just optimistic in the most probable variation (Table 2).

The USGS Report

The latest assessment of the Ordovician-Silurian shales in Poland was carried out by the United States Geological Survey in July 2012. It presented the resources of technically recoverable gas on a dramatically low level in comparison with the former estimates. The appraisal of the gas potential made by the USGS in fact proved that there was no technically recoverable gas – 38 Bcm (billion m^3) of gas scattered throughout the Baltic Sea up to the border with Ukraine.

In the USGS's Report (2012), the specificity of the shales in Poland was taken into account which lies in the fact that the gas is accompanied by condensates, associated gas and crude oil. Those types of resources were discussed separately in the Report. This paper is focused on the potential gas resources only as they consist the most essential aspect of resource management.

The United States Geological Survey estimated the resource potential of the technically recoverable shale gas and oil from the shales located in the Polish part of the Polish-Ukrainian Pre-Orogenic Basin (Table 3, USGS Report, 2012). According to the Report (Table 4): "The estimated resources, recoverable with existing technology, range from 0 to 4.086 billion cubic feet of gas (Bcf), with a mean estimate of 1.345 Bcf. The wide range of resource estimates underscores the uncertainty inherent in this assessment".

In the USGS Report (2012), the data from gas and oil assessments in the American deposits were used such as: (1) a parameter of Estimated Ultimate Gas Recovery (EUR) from a borehole, which is obtained from a group of shale gas and shale oil exploitation wells, (2) a mean drainage area for directional drillings, (3) average success ratios for individual boreholes and (4) an Assessment Unit (AU). The minimum, middle and maximum values represent a deviation from the mean value and they do not consist the total deviation from those parameters. The average total recovery is shown in the form of minimum, modal and maximum values, and a calculated mean".

And further, (the data source, as above) "Results shown are fully risked estimates. For gas accumulations, all liquids are included as NGL (natural gas liquids) category. Undiscovered gas resources are the sum of non-associated (gas in gas fields) and associated gas (gas in oil fields). F95 represents a 95 percent chance of at least the amount tabulated-other fractiles (F) are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. AU (Assessment Unit – a unit of the acreage being

Table 2. Recoverable resources of shale gas in the Lower Paleozoic Baltic-Podlasie-Lublin Basin. EUR – Estimated Ultimate Recovery (after PGI Raport, 2012, modified)

Raport PIG, 2012	1.13 mln m^3 (0,04 Bcf) EUR minimum	11.3 mln m^3 (0,4 Bcf) EUR optimum	28.3 mln m^3 (1 Bcf) EUR maximum
Offshore acreage max 7 952.4 km^2	14.8 billion m^3	148.4 billion m^3	371.1 billion m^3
Offshore acreage min. 6 192.4 km^2	11.6 billion m^3	115.6 billion m^3	289.0 billion m^3
Onshore basin acreage max. 33 183.3 km^2	61.9 billion m^3	619.4 billion m^3	1 548.6billion m^3
Onshore basin acreage min. 12 347.3 km^2	23.0 billion m^3	230.5 billion m^3	576.2 billion m^3
Onshore & offshore acreage max. 41 135.7 km^2	76.8 billion m^3	**767.9 billion m^3**	**1 919.7 billion m^3** extreme maximum
Onshore & offshore acreage min. 18 539.7 km^2	**34.6 billion m^3** extreme minimum	**346.1 billion m^3**	865.2 billion m^3

Table 3. Key assessment input data for shale gas assessment units in Poland (After USGS Report, 2012 – Table 1, modified)

Assessment input data	Polish foredeep Lower Paleozoic Gas (assessment units – km^2)			
	Minimum	Mode	Maximum	Calculated mean
Potential production area of AU [km^2]	0	4 856.227	20 234.282	8 363.504
Average drainage area of 1 well [km^2]	0.485622	0.647497	0.809371	0.647497
Average EUR [m^3]	2 831 700 (0.1 Bcf)	5 663 400 (0.2 Bcf)	28 317 000 (1 Bcf)	6 937 663 (0.245 Bcf)
Success ratios [%]*	10	50	90	50
Estimated ultimate gas recovery (EUR) [Bcf/1 km^2]	0.2 Bcf/1 km^2	0.3 Bcf/1 km^2	1.2 Bcf/1 km^2	0.3 Bcf/1 km^2

* Probability values when assessing resources: P90 – 90% chance of success – sure resources; P50 – 50% chance of success – probable resources; P30 – 30% chance of success – possible resources; P10 – 10% chance of success – unreliable resources (very little probable).

evaluated) probability is the chance of at least one well within the AU having a production capacity of the minimum estimated ultimate recovery".

Comparison of the Reports for assessment critera used in them

The findings of the aforementioned Reports about the assessment of technically recoverable gas resources are shown in a compilation (Table 5) which includes a juxtaposition of the one of quantitative aspects, namely the total assessment acreage.

AU AND EUR CRITERIA

The above mentioned assessments of the gas resources in the Ordovician-Silurian Resource Area (O-S RA) cover vast areas which can be referred to as so called LAU (Large Assessment Units).

However, in the USGS methodology, the term AU is used for small units of surface, e.g. a square mile. In order to define the characteristics of the AU, it is necessary to test several elements of an acreage assessment:

Productive Area

The area which is covered by (gas) drainage within an AU (Drainage Areas). In the USA, it is adopted to be of 80–180 acres (0.324–0.728 km^2).

Untested Area

The area that has not been tested for gas production within a given AU.

An area untested from the point of view of the presence or absence of sweet spots, with allowance made for the previous assumptions related to the resource value of the mineral deposits of the acreage (the occurrence of sweet spots). This is connected with the term of a success rate, that means the probability of higher production output in case of coming across sweet spots.

And this, in turn, relates to the determination of a postulated EUR size for better areas (sweet spots) or worse areas (non-sweet spots), including a possible scale of the area covered by gas drainage.

According to the data contained in the PGI Report (2012): "The recoverable resources were determined in the Report as based on an adopted Estimated Ultimate Recovery (EUR) ratio of natural gas from each individual borehole for the whole period of its exploitation, from a certain average area of the zone exploited by the borehole. The basic criterion, that specifies whether each borehole can be qualified in calculations for a resource zone is the presence of a shale formation with the thickness (thickness of a solid layer) of at least 15 m and containing 2% of TOC (Total Organic Carbon) by weight".

In the Polish Report (PGI Report, 2012) about the assessment of the recoverable resources of natural gas from shales, the resources were calculated in three variants. The EUR of 0.04 Bcf (1.13 million m^3) was adopted as the minimal variant, which represents a value below the EUR found in the most of the basins in the USA. In the most likely variant, the EUR equal to 0.4 Bcf (11.3 million m^3) was assumed, which is at the bottom zone of the most American basins of average recovery. As the maximal variant, the EUR amounting to 1Bcf (28.3 million m^3) was adopted which constitutes the value to be found in the most highyield American basins, which in this respect are currently the best shale basins in the world.

Similar values were employed in the USGS methodology related to the shale gas assessment in the Polish Ordovician-Silurian Basin (USGS Report, 2012).

In the USA, it is assumed that the required minimum EUR is 0.02 Bcf (USGS Open-File Report 2011-1167, 2011), although in many basins lower minimal EUR values were obtained (USGS Open-File Report 2012-1118, 2012). In the PGI Report (2012), the EUR ratio was arbitrarily adopted as averaged with relation to the values from the diagram in Fig. 4, and relatively low as compared with American basins (Table 6).

Of some interest are the EUR calculations adopted for the partly depleted Ordovician shale play of Utica (Table 7) in the USA (to some extent resembling the Ordovician-Silurian shales in Poland) where a division was made between the sweet spots EUR and the EUR for deposits deprived of any sweet spots (Kirschbaum et al., Utica Shale Assessment, USGS, 2012).

It seems that the same division as in the Ordovician Utica formation might be used in future for the Ordovician-Sylurian Resource Area (O-S RA), if one recognizes the results of the resource tests as partly representative for the zones deprived of sweet spots. An estimated average value of EUR in the northern part of the O-S RA for the area without sweet spots might reach 0.1 Bcf in the first twelve months of exploitation (including 50% drop in yield). At present, this method is recommended by the USGS (Charpentier & Cook, 2010a and b).

The problem of the occurrence frequency, distribution density and size of sweet spots is one of the key issues of the exploration geology with respect to prospecting for shale gas. According to some experts in the exploration trade, small sweet spots can be expected in the O-S RA which undoubtedly makes it difficult to choose the optimal localization for drilling and fracturing processes to be applied.

To qualify areas of potentially the best productivity of gas or oil as sweet spots does not need to be related to the widely adopted conviction that there must be the highest

Table 4. Assessment results for undiscovered unconventional gas resources in Poland (after USGS Report, 2012 – Table 2, modified)

Provinces, Total petroleum systems (TPS) and assessment units (AU) (acres)	AU probability	Field type	Total undiscovered recources			
			Gas [BCFG]*			
			F95**	F50**	F5**	Mean
Polish foredeep Lower Paleozoic gas AU	0.8	Shale gas	0	908	3 794	1 246
		Gas accompanied in shale oil	0	75	292	99
Total (technically recoverable) shale gas resources [Bcf]			0	983	4 086	**1 345**
Total (technically recoverable) shale gas resources [Bcm]			0	27.836	115.032	**38.086**

*BCFG – billion cubic feet of gas.

** Probability values when assessment resources: F95 – 95% chance of success – sure resources; F50 – 50% chance of success – probable resources; F5 – 5% chance of success – unreliable resources (very less possible).

Table 5. Comparison of assessment reports of technically recoverable shale gas resources in terms of size of surface area used for the assessment

PGI Raport, 2012			ARI Report for EIA, 2011	USGS Report, 2012
Total acreage of O-S shales with oil and gas potential [km²]/ (onshore & offshore)	**Oil prone acreage (onshore & offshore) (km²)**	**Gas prone acreage (onshore & offshore) (km²)**	**Baltic, Podlasie and Lublin basins (gas prone area in km²) (onshore)**	**Baltic, Podlasie and Lublin basins (gas prone acreage [km²] (onshore)**
Total acreage max. 64 867 km²	Total acreage max. 23 731.3 km²	Total acreage max. 41 135.7 km²	Total perspective acreage 56 542 km²	Acreage max. 20 234 km²
Total acreage min. 37 630 km²	Total acreage min. 19 090.3 km²	Total acreage min. 18 539.7 km²		Most useful acreage, calculated mean 8365.5 km²
Assessments of gas resources (average results) [Tcm*]		Most probable range of recoverable shale gas resources (for O-S Basin):	Technically recoverable shale gas resources for Polish onshore (only Silurian):	Technically recoverable shale gas resources for Polish onshore (Silurian-Ordovician Basin):
		346.1 to 767.9 billion m³ 0.346–0.768 Tcm	5295.279 billion m³ 5.3 Tcm	38.086 billion m³ 0.038 Tcm

* Tcm – trillion cubic metres.

percentage of TOC ("residual" TOC in thermally mature rocks). It may also concern the areas of the best parameters of susceptibility to fracturing, with a view to brittleness of the rock centre, that enables it to achieve a higher EUR value.

Apart from an increased level of TOC, the areas of favourable resource parameters, sweet spots, have to meet several requirements. According to Laind (2012), a higher coefficient of rock brittleness combined with its low plasticity results in a higher complexity of cracks and much bigger area covered by them. In addition, the effect of secondary crack closure is reduced. Such areas are characteristic of increased effective porosity and thus a bigger proportion of so called free gas that is not bounded by absorption with organic matter.

Preferably, the rock centre being analyzed is isotrophic in terms of regular stratification (lamination) that results in low VTI (Vertical Transverse Isotropy) anisotrophy in a seismic image. It is also desirable that there occur natural cracks (microfissures) in the rock centre being examined that result in high HTI (Horizontal Transverse Isotropy) anisotrophy in a seismic image (Castillo et al., 2012).

Some studies being carried out prove that anisotrophy of a rock centre elastic properties (shales) is the function of a rock which contains organic matter (Tyczkowska-Jedrzejowska, 2012), and therefore, it makes it possible to outline areas with a sweet spot potential. The geological importance of seismic anomalies that may be correlated with one another and constitute symptoms of potential locations of sweet spots is emphasized.

Predicting the occurrence of sweet spots also consists in analyzing the spatial distribution of the sorptive capacity in shales. The content of gas in shales depends, among others, on the capacity of methane adsorption on organic particles, subject to pressure, not necessarily directly related to a litho- or hydrostatic gradient.

Additionally, when the most of gas is adsorbed in and on organic matter, the type and distribution of the preserved organic matter may be of a key importance for defining sweet spot areas.

The amount of the methane adsorbed (Scf/t – Standard cubic feet per ton) depend on the total organic carbon (%TOC) in the function of pressure value (PSI) (Bentley, 2013).

Overpressure in the whole Basin enables it to keep up overpressure in the source rocks. Overpressure in the porespace increase permeability and mobility of fluids. These are favourable conditions for microfissures to be formed and bitumens to migrate to the adjacent layers.

Therefore, the presence of overpressure in a mineral deposit is a desirable factor that can guarantee an increased production volume. A pressure drop, while in the course of production, leads to the release of gas adsorbed.

This formed a basis for the calculations of the total content of gas in place (GIP) in the shale rock with reference made to a resource area surface unit (Table 8A). The distribution and percentage of potential sweet spots within the O-S RA are unexplored. Drillings to date (43 until April 2013) are insufficient to define areas of the highest probability of sweet spots occurrence. After Charpentier & Cook (2010 a and b), only when one obtains EUR results from hundreds of drillings, as in the example of the Fayetteville shale deposit (USA), it is possible to determine a drilling cluster that means the occurrence of sweet spots.

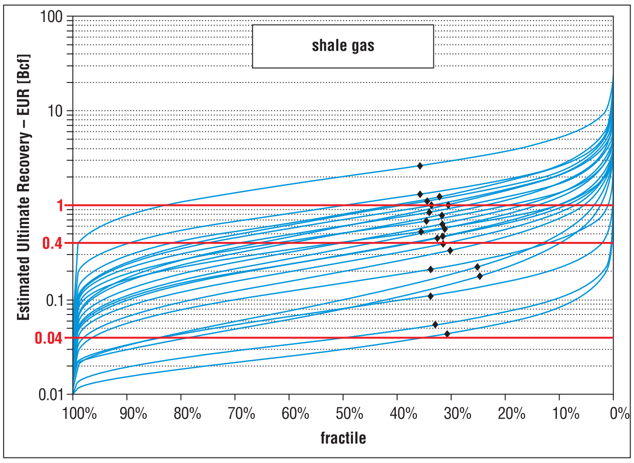


Fig. 4. Distribution of Estimated Ultimate Recovery from a single well for 26 U.S. sedimentary basins or areas analyzed at angle of USGS resources. Each blue line represents distribution of EUR in a certain U.S. sedimentary basin. Black diamonds indicate the mean value for each curve. Red line indicates EUR values adopted in the assessment of shale gas in Poland by the PGI-NRI in the minimum, optimum and maximum variants. (after U.S. Geological Survey Open-File Report 2012–1118, 2012, modified)

From the above mentioned compilation (the content of gas in cubic meters or cubic feet per a square kilometer), interesting conclusions can be drawn. Firstly, the very low estimates of the technically recoverable gas resources in the USGS Report of 2012, amounting to 38 Bcm (Billion cubic meters) (including 35.2 Bcm of "pure" gas not connected with oil) coincide with the lowest extreme assessments presented in the PGI Report of 2012 (34.6 Bcm). This is why the USGS results which were published after the PGI's Report should not be a surprise for the public opinion in Poland. The very low quantitative parameters of the recoverable gas content (especially as compared with those from the best basins in the USA – Table 8A) prove a potentially very low EUR, probably locally below the limits of profitability.

Uncertainty of such assumptions as those accepted in the PGI Report PIG (2012) and the USGS Report (2012), results from the fact that when the same value of Bcf per 1 km^2 is adopted for the whole area of interest (Table 8B), the EUR (Bcf) values are subject to excessive averaging. The EUR value can be higher than the postulated one on the basis of the content of technically recoverable resources (Bcf) per 1 km^2 or per another AU (e.g. drainage area of a single well – Table 3). A higher EUR, than that resulting from the gas content calculations (GIP and the recovery percentage assumed), might be due to the process of repeated fracturing and a bigger percentage of gas drainage then it was assumed.

With the averaged measurements like these, it is not possible to determine areas which are potentially richer in gas and are more productive. In each shale basin in the USA, analyses are carried out in order to outline the most productive and optimal, in terms of economy, parts of the basin which are called cores. This term should not be mixed up with the expression sweet spot that relates to smaller acreages showing the best reservoir parameters.

It should be a priority for the O-S Basin to identify the core area. Such areas need to be determined for each regional assessment unit which are discussed further in the paper.

Table 6. EUR adopted for some U.S. basins and Polish Ordovician-Silurian basin

After Hughes, 2013			After USGS Open-File Report 2012-1118		
Shale Gas Basins in United States "Big Six" (Year of assessment)		Shale rocks age	Minimum EUR [Bcf]	Median EUR [Bcf]	Maximum EUR [Bcf]
1	Haynesville, Gulf Coast (2010)	Late Jurassic	0.02	2	20
2	Barnett (Bend Arch – Fort Worth Basin) Greater Newark East Frac-Barrier (2003)	Early Carboniferous and early Late Carboniferous	0.02	0.7	10
	Barnett (Extended)		0.02	0.2	5
3	Marcellus, Appalachian Basin (interior) (2011)	Middle Devonian	0.02	0.8	12
	Marcellus (foldbelt)		0.02	0.1	5
	Marcellus (Western Margin)		0.02	0.05	5
4	Fayetteville, Arkoma Basin (High GR Depocenter) (2010)	Early Carboniferous	0.02	0.8	10
	Fayetteville (W Arkansas Basin Margin)		0.02	0.3	6
5	Eagle Ford, Gulf Coast (2010)	Late Cretaceous	0.02	0.8	10
6	Woodford, Anadarko Basin (2010)	Late Devonian – Early Carboniferous	0.02	0.8	15
	Woodford, Arkoma Basin (2010)		0.02	0.5	10
Poland			EUR after Raport PGI, 2012		
Ordovician-Silurian resource area onshore & offshore		Late Ordovician – Early Silurian	Minimum EUR	Optimum EUR	Maximum EUR
			0.04 Bcf	0.4 Bcf	1 Bcf
			1.13 mln m^3	11.3 mln m^3	28.3 mln m^3

1 Bcf = 1 000 000 000 ft^3 = 28 317 000 m^3.

Table. 7. EUR adopted for Utica shale in the U.S. (after Kirschbaum et al.; Utica Shale Assesment, USGS, 2012 – Table 1, modified)

Assessment input data	Assessment of Utica Shale Play			
	EUR minimum	EUR mode	EUR maximum	EUR calculated mean
Input data for sweet spots				
Average EUR [BCFG]	5.6 0.2	16.9 0.6	31.1 1.1	17.5 0.619
Success ratios [%]	75	85	95	85
Input data for non sweet spots				
Average EUR [BCFG]	1.1 0.04	2.8 0.1	16.9 0.6	3.6 0.128
Success ratios [%]	10	40	70	40

BCFG – billion cubic feet of gas, AU – assessment unit.

TECHNICALLY RECOVERABLE RESOURCES

In the process of assessment of shale gas resources, also the term, Technically Recoverable Resources (TRR) is used.

In the ARI (US EIA, 2011) Reports: a risked technically recoverable shale gas resource and the USGS (2012) Report: potentially technically recoverable gas terms can be found. Also, in the PGI (2012) Report one can read: "the assessments of technically recoverable resources of shale gas and shale oil in Poland in the Baltic-Podlasie-Lublin Basin", although in each summary of the Report, the expression "recoverable resources" is used. This diversity of the terms does not seem to be of much significance, as it is not possible to exploit hydrocarbons without technology. However, the striking differences in the assessments of the O-S Basin resources made in the same place result not only from the different area of the O-S RA, with the similar resource area assessment parameters, but also from the evaluation of the real possibilities of the gas extraction, while taking into account the current price of the technology being used with respect to the various types of resource areas (in the USA and Canada).

At present, the shale gas recovery ratio is within the range from 15% to 35% of the total gas in place (GIP). According to ARI (EIA, 2011), there are three basic factors that are decisive when one evaluates the shale gas recovery factor. These include: shale mineralogy, their reservoir properties and geological structure complexity.

Table 8A. Calculations of total gas content (GIP) in shales in relation to the acreage unit of deposit area

Data after D. Bentley; European Unconventional, Schlumberger, 2013				
Gas deposit	**The total content of gas in Bcf per a one-square-mile area**	**The total content of gas per 1 km^2 area**		**Recoverable gas (e.g. 25%) in m^3 per 1 km^2 area (per Bcf)**
		Bcf	m^3	m^3 (Bcf)
Core Barnett	139 Bcf	53.67	1 519 773 390	379 943 347.5 (13.4 Bcf)
Marcellus	60 Bcf	23.17	656 104 890	164 026 222.5 (5.8 Bcf)
Haynesville	129 Bcf	49.81	1 410 469 770	352 617 442.5 (12.4 Bcf)

1 Bcf = 1 000 000 000 ft^3 = 28 317 000 m^3.

Table 8B. Recalculations from EUR dedicated for Polish O-S shales on recoverable gas in the established acreage unit of deposit area

Reports on Polish Ordovician-Silurian basin		
Report PGI, 2012	**Technically recoverable gas volume per 1 km^{2}area (per Bcf) Assumed recovery factor within the limits of 25%**	
Maximum recoverable resources for total minimum acreage – 18 539.7 km^2 (865.2 Bcm) and total maximum acreage – 41 135.7 km^2 (1 919.7 Bcm)		~46 667 446.0 m^3 (1.65 Bcf)
Most probable recoverable resources in the lowest range (346.1 Bcm) for total minimum acreage – 18 539.7 km^2 and in the in the highest range (767.9 Bcm) for total maximum acreage – 41 135.7 km^2		~18 667 422.0 m^3 (0.66 Bcf)
The lowest recoverable resources in the lowest range (34.6 Bcm) for total minimum acreage – 18 539.7 km^2 and resources in the highest range (76.8 Bcm) for total maximum acreage – 41 135.7 km^2		~1 866 265.0 m^3 (0.06 Bcf)
Maximum recoverable resources for onshore minimum acreage – 12 347.3 km^2 (576.2 Bcm) and onshore maximum acreage – 33 183.3 km^2 (1 548.6 Bcm)		~46 666 073.0 m^3 (1.65 Bcf)
Most probable recoverable resources for onshore minimum acreage – 12 347.3 km^2 (230.5 Bcm) and onshore maximum acreage - 33 183.3 km2 (619.4 Bcm)		~18 668 049.0 m^3 (0.66 Bcf)
The lowest recoverable resources for onshore minimum acreage – 12 347.3 km^2 (23.0 Bcm) and onshore maximum acreage – 33 183.3 km^2 (61.9 Bcm)		~1 862 755.0 m^3 (0.06 Bcf)
USGS Report, 2012	maximum acreage of potential gas production area (20 234.3 km^2)	5 309 612.0 m^3 (0.19 Bcf)
	most useful acreage for potential production area, calculated mean (8 363.5 km^2)	4 218 686.0 m^3 (0.15 Bcf)
ARI Report for U. S. Energy Information Administration, 2011	Acreage for most perspective area for gas prospecting (56 542 km^2)	93 642 197.8 m^3 (3.31 Bcf)

O-S OZ – Ordovician-Silurian resource area.

A shale gas recovery factor of 30% is adopted for the basins and geological settings with a low content of clay minerals, and low or middle complexity of geological structure, favourable reservoir properties, such as the presence of overpressure and high porosity (in the rocks attributable to shales) with pores filled in with gas.

A shale gas recovery factor of 25% is applied for the basins and geological settings with a middle (quantitatively) content of argillaceous minerals, middle complexity of geological feature and average formation pressure and reservoir properties.

A shale gas recovery factor of 20% is accepted for the basins and geological settings with a middle (quantitatively) content of argillaceous minerals, middle complexity of geological structure and reservoir properties below the average value.

A shale gas recovery factor of 35% is used in exceptional cases where the rate of gas outlet from a well is high and stable. And a shale gas recovery factor of 15% is adopted in exceptional cases where the basin geological structure is extremely complex and underpressure is present.

The estimated EUR for an individual borehole depends on the gas recovery factor assumed for the resource area. A new term, High Technically Recoverable Resource (HTRR), has been introduced which is a sort of grouping high EUR (Staub, 2012) for boreholes located very close to one another (it cover the areas of 80 acres = 0.32375 km^2 per a borehole, i.e. three wells per 1 km^2).

GAS PRODUCTION AND ECONOMICALLY RECOVERABLE RESOURCES

For the purpose of shale gas assessment, also the expression ERR (Economically Recoverable Resources) is used, with an additional remark, "with the current technology being applied".

From the example of the comparison shown in Fig. 5 (Hughes, 2013), it can be seen that the daily shale gas production in the USA in May 2012, was covered in 66% from three resource areas (Haynesville, Barnett and Marcellus), and the production at the level of 88%, additionally, from the resource areas of the basins Fayettville, Eagle Ford and

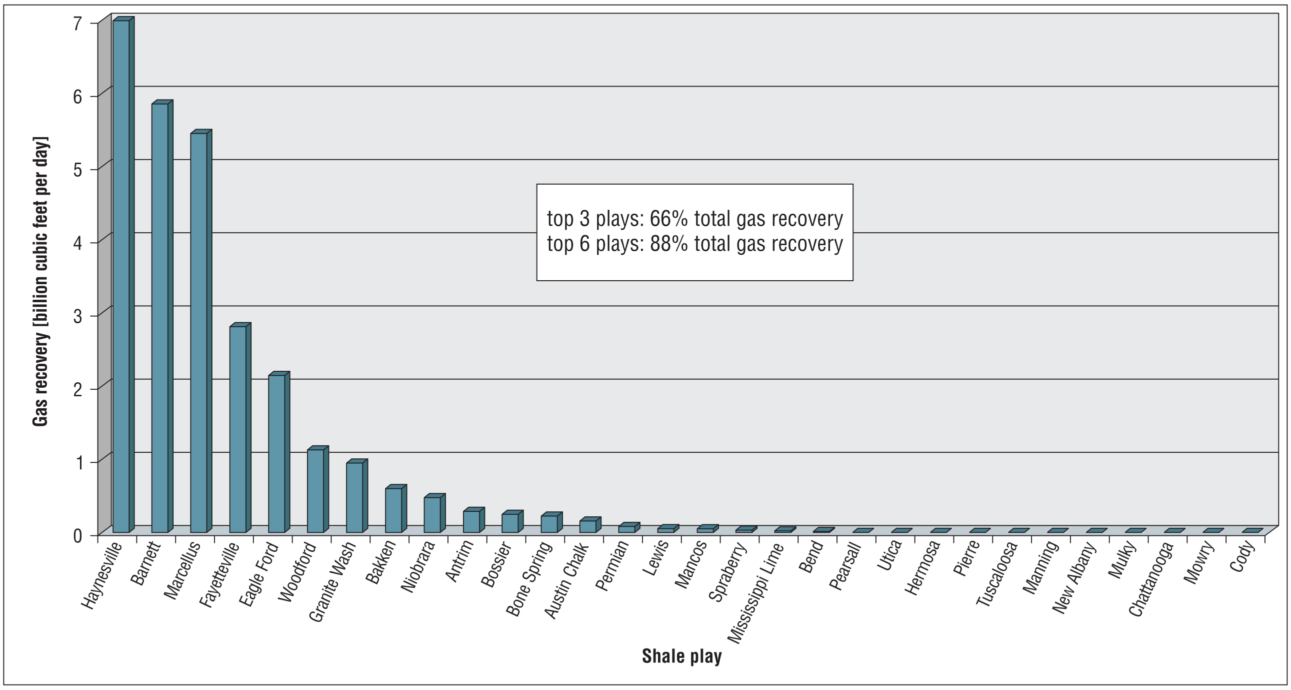


Fig. 5. Daily gas production in 30 selected U.S. basins in May 2012 (after Hughes, 2013 – Fig. 41)

Woodford. The other twenty-four resource areas shown in the compilation accounted for the production output of 12%.

From among the thirty resource areas in the USA, presented in the comparison (Fig. 5), six has stable production, six is at a production increase stage, and eighteen in a production decline phase.

The Polish Ordovician-Silurian Resource Area (O-S RA) belongs to the category of emerging basins at present, with its unspecified potential and undetermined size of potential production output. Therefore, it is not known whether it will be classified under a high-productivity resource area, irrespective of the resource potential assessed.

Key determinants include time and production output volume, expenditure on prospecting, production process and return on investment as well as predicted trends in changes of prices of the gas, drilling and service markets.

The time interval of the potential exploitation of gas from a well (production) determines the production output (EUR). From a point of view of production profitability, the time can be extended if the gas selling price is on the increase and the drilling and service costs are going down at the same time. By analogy, the time can be shortened if the IP (Initial Productivity) decreases due to incorrect geological exploration and fewer new drillings (Hughes, 2013). In such circumstances, economically recoverable resources can be less than technically recoverable ones.

Bearing in mind the experience from the shale gas extraction in the USA, one should be aware of the fact that to maintain a stable or increasing productivity of a given exploitation area it requires a constant increase in the number of boreholes drilled. With the lack of increase in the number of production wells, the gas productivity tends to decrease. However, a general trend in productivity drop is predicted, even despite a significant increase in production wells (Figs. 6A, C; see Comparative table p. 651).

Because of the significant drop in a well productivity as early as in the initial test period, IHS (Energy Information, Software & Solutions) suggests that the 24-hour bore well initial productivity test (IP), which is applied at present as a key index, should be replaced by a 30-day measurement reduced by 40%, as an initial productivity value.

These data provide essential information, namely that to assess (technically) recoverable resources is inevitably connected with economics. In other words, economic profitability of gas recovery is to be included in an assessment process and a category of economically recoverable resources assessment created. On the basis of the history of the resource area exploitation in the USA, a lesson can be drawn that there is a hiatus between the production and expenditure on new drillings (including fracturing).

In case of a stable or decreasing gas price, the scenario shown in Fig. 6B is not likely to happen since the price of well drillings and services will not decline and both lines will not cross each other. Some predictions are made that the prices of gas might drop owing to the market liberalization and after the import of liquefied natural gas (LNG) to Poland is launched. According to such a scenario, it will not be profitable to exploit shale gas, with an assumption made that EUR values expected are low.

The lack of a gradual decrease in the well drilling and service prices will result from the lack or low gas production which will be unprofitable or at a break-even point due to economic reasons. This example shows that the lack of profitability might be a key factor responsible for the lack of production, and thus the shale gas assessed, regardless of its volume, will not constitute an added value, apart from us being aware that gas actually "exists".

It is not known where is the deep conviction is taken from, which is published in many a European reports (e.g. JRC Report, 2012), that the American economic phenomenon (Fig. 6B) will take place in Poland and which will cause the prices of gas to fall and bring about a geopolitical reconfiguration of the gas import and export trends in Europe, including Poland. It seems that the above mentioned scenarios of shale gas (IEA Report, 2012, Golden Age) are affected by the models of continuous and steady increase in the recovery and production of gas as well as by an

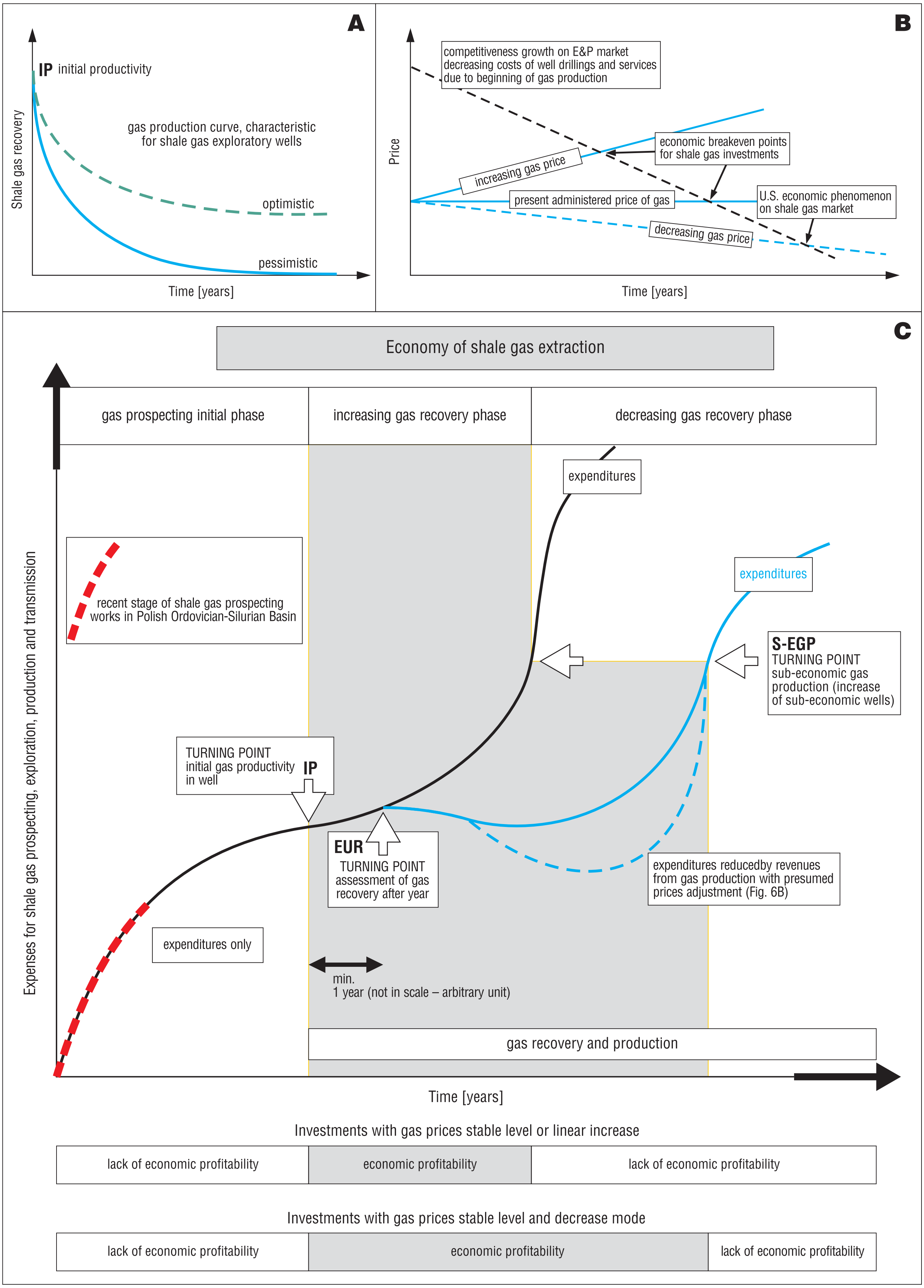


Fig. 6. A – diagram of shale gas production decline during well exploitation; **B** – diagram of critical factors relationships (time and costs) during shale gas exploration and exploitation; **C** – diagram showing the possible scenarios of shale gas production based on the experience and lessons learned from shale gas production in the USA (after Hughes, 2013; Baker Institute, 2011)

analogy with the exploitation models of conventional gas resources.

According to the assessments in the IEA Report (2012), as based on the ARI Report (2011) and PGI Report (2012), the production of shale gas is to be launched around 2017 in Poland and it will reach its apogee in about 2027. The scenario of the shale gas production stretches up to 2035.

In the Baker Institute Report (2011), some scenarios of shale gas production are projected for Europe (Poland is estimated to account for 55% of the production output) which show that the production is going to start around 2020 and it will continue to rise or it will not be launched at all or on a small scale. This shale gas production scenario reaches 2040. It is assumed, in these scenarios, that the break-even point is obtained with the production level of 60% of technically recoverable resources (which is not to be confused with the shale gas recovery factor).

In the diagram (Fig. 6C), the Polish O-S RA is now in the phase of prospecting and this is why the economically recoverable resources can be evaluated on the basis of a simulation and extrapolation. This diagram can be modified by an increase in expenditures and a decrease in profitability caused by additional fiscal charges at the stage of gas production. However, scale economies should be taken into account with reference to the comparisons (USA) and forecasts (Poland) for the E&P sector. The economic aspect of opening out and extraction of shale gas in Poland was focused on in a report by the Institute of Petroleum and Gas (Ciechanowska et al., 2012).

There must have been some misunderstanding as regards the data published in the report of a Polish foundation, CASE (CASE Report, 2012) about the economic potential of shale gas production in Poland which were based on an assumed number of production wells, expected production output from a single borehole as well as the resulting economic scenarios for Poland until 2025 or even to 2034 which are referred to by Polish members of the European Parliament at present.

As an example, in the above mentioned report, in its the most modest variant of moderate increase in the gas extraction, an assumption was made that in order to obtain the production level of 2.160 Bcm of shale gas in 2020, 215 boreholes (all of production type) are to be drilled with a high EUR of 1.6 Bcf. According to the CASE report (2012) within the 10-year production period (from 2015 to 2024) those wells are going to reach EUR of from 1.8 up to 2.25 Bcf! (compare Table 6 – EUR median from the most productive basins in the USA).

PROPOSALS FOR RE-ASSESSMENT OF THE RECOVERABLE RESOURCES OF SHALE GAS IN THE ORDOVICIAN-SILURIAN BASIN

So far, the reports about the shale gas resources have been based on various criteria and showed a different degree of probability. Some analysts and advisers to proper government departments do not seem to have understood enough well the scale and probability ranges related to the assessments. Moreover, insufficient understanding of the differences between conventional and unconventional resources can lead to irresponsible declarations, kind of "in two years, we are going to produce x Bcm of shale gas" (Golden Age Report, 2012).

However, if the PGI (Polish Geological Survey) is to carry out the task of re-assessment of the recoverable shale gas resources in the Ordovician-Silurian Basin in 2014, it needs, in our opinion, a partly changed approach to the issue.

For the Polish Ordovician-Silurian Basin, the only reference for a comparison of differences and similarities as well as reservoir parameters is to be found in the US-Canadian basins.

It is essential to be aware of the fact that any conclusions deduced from such juxtapositions do not necessarily need to bring about an expected successful production. This comes from the fundamental cardinal message: "Every Shale is Different – due to the unique nature of shale, every basin, play, well and pay zone may require a unique treatment" (Halliburton, 2008).

What should we know about shales in terms of their reservoir value (gas potential?) The basic factors that characterize a shale rock, that affect the possibility and size of shale gas recovery, include: the range and thickness of organic matter (present and primary); type of organic matter (gas-bearing, oil-bearing); content of clay minerals and their types; history of burial and maturity; fracturing susceptibility or lack of it (brittleness and fragility of the rocks or their plasticity and ability to deform); natural fissuring. These factors (exogenic and endogenic) may be subject to changes within a shale formation in a sedimentation basin.

The basic objective of the exploration is, first of all, horizons enriched with organic matter of an increased content of TOC, that are referred to as sweet spots in the oil industry.

Below, a comparative table is presented of some selected assessment criteria and parameters which are considered important for shale gas production.

Comparative table:

Geological factors that are essential for continuous accumulation of gas in shale having reservoir properties (based on different data sources)	**Specification of the Ordovician-Silurian Resource Area shales**
Basic geological structure explored: stratigraphy, tectonics, lithofacies and occurrence ranges	Good, but non-uniform geological exploration. New data modify the O-S deposits range, their thickness and reveal tectonic faults that have not been recognized before
Depth from the surface to the shales (potentially productive series) Burial of deposits and ensuing mechanical and chemical compaction (transitions from smectite to illite due to the submergence in progress) (Jędrzejowska-Tyczkowska, 2012)	Baltic Basin: from 1000 m (E part) to 4500 m (W part) Podlasie Basin: from 500 m (in E) to 4000 m (W part) Lublin Basin: 1000 m (E part) to 3500 m (4330 m) in W part Biłgoraj – Narol Zone to >1000 m

Presence of a shale formation with the thickness (thickness of a solid layer) of at least 15 m. Sections of a high GR (Gamma Ray) are thought to have thickness of > 20 m	Sections of such characteristics and thickness are found in the O-S profiles
TOC % by weight at least 2%	Sections of profiles of such parameters were found many times in the Ordovician and Lower Silurian shales
Organic matter maturity (reflection ceofficient of vitrinite Ro%) and alternatively TAI (Thermal Alteration Index)	In the Polish O-S Basin, a gas window was determined (wet and dry gas) in the interval 1.1–3.5% Ro. There is a relatively large number of measurements Necessity to recount (VRE – vitrinite equivalent value) Ro due to the occurrence of alginites in the O-S shales (kerogen type II)
Shale gas content > 100 SCF/ton* (~2.8 m^3/ton) Shale gas content (GIP) of 30 Bcf per 1 sq. mile is considered a good result Kerogen hydrogene index (HI) higher than 250 mg HC/g	After BNK Polska for Lębork S-1well the gas content is: for Lower Silurian 1.1 m^3 per ton (~40 SCF per ton), in the Ordovician and Silurianw deposits 7.58 m^3 per ton (~268 SCF per ton) reaching in some intervals 12.76 m^3 per ton (~451 SCFper ton)
Nanoscale pore spaces in mature kerogen with increased TOC Preferable porosity > 4%, permeability higher than 100 nanoDarcy	Nanoporosity was found probablly as a predominant feature First analyses of pore space in the Silurian shales in Poland (Such, 2012)
Water saturation below 45% (Sw)	No data available
Zones (within a shale rock complex) with the presence of overpressure. Highly-productive shales in the American basins show overpressure of >0.45 psi/ft	In many drillings no significant overpressure was found. However, in Pomerania overpressure of 0.57 psi/ft was recorded which is > 30% of "natural" pressure at given depth
Occurrance of natural fractures (microfractures) and porosity related to the geomechanical properties of a rock (Leśniak, 2012) determined by acoustic impedance values (preferably low), Poisson's ratio (preferably low), Young's modulus (preferably high) and regional tectonic stress direction	Results from single drillings. No data for a bigger group of wells that might help indicating areas of better reservoir properties. Shales that occur in the Pomeranian part show intense natural cleavage combined with a high ratio of rock brittleness. There are measurements of reginal tectonic stress
Relatively small content of clay mienrals below 40% (Barnett shales contain only 27% of clay minerals). Especially preferable low content of clay minerals that swell upon contact with water. High ratio of rock brittleness due to quartz appearance	No analogues to the parameter of percentage clay mineral content in the Barnett shales have been found so far
Generally, lack of lithologic barriers (mostly limestones) which form an obstacle to proper fracturing („Mechanical stratigraphy") In some cases barriers like those are desired to increase gas production (according to McKeon, Halliburton, 2011)	In the Polish O-S basin, the shales of Ordovician and partly Lower Silurian are separated by limestone levels that are barriers to the propagation of cracks (an example, Lubocino well profile)
Preferably, the shales lie horizontally in orogenic edge foreland basins or on cratons and are not tectonically faulted. However, shales in orogenic belt zones (e.g. the Conasauga productive shales in Alabama that lie in the Appalachian overthtust external zone) should be taken into consideration as well	The O-S RA shales occur on a craton where tectonic deformations are insignificant. In the rim zone of the East European Craton, there occur continuous and discontinuous tectonic deformations of shales, including tectonic horsts. These zones have not been tested for their resource potential yet
Occurrence of conventional gas fields connected with occurrence of shale gas. Such an interrelation was found in some basins in the USA	In the Polish O-S Basin, such interdependence with respect to gas has not been found so far.However, it may exist with respect to the Cambrian sandstone oil fields

* SCF/ton = Gas in place (GIP) is calculated frim the geochemical determination of standard cubic feet per ton.

More information from the aforementioned scope is to be obtained for a more probable assessment of the shale gas potential.

We propose that in a new attempt to assess the shale gas resources the subject of an analysis should not be the entire Ordovician-Silurian Basin located in Poland (PGI Report, 2012 in the onshore and offshore parts), but only its segments (Fig. 7). By duplicating the PGI Report in which the results of new drillings would be included, only the scope of a resource prognosis might be changed to higher of lower values, up or down, for the Ordovician-Silurian Basin in Poland. What would be more valuable for the individual segments of the Basin is an analysis of prognoses. Firstly, it would show where the prognoses are more reliable on the basis of more data obtained. A reliability factor would be attached to each segment (as in the USGS Report, 2012). Secondly, it would show a rating of the areas for their degree of exploration risk. This might back up a concession policy which is based on the assessment of concession blocks for their exploration risk (e.g. a tax abatement for companies that enter more risky and difficult areas).

We propose that the Polish Ordovician-Silurian Basin (both onshore and offshore) should be divided into segments (Assessment Units) in order to assess the potential of gas content in shales.

To the numerous geological-geochemical parameters which are needed at the initial study on the assessment of the prospectivity of a given area for the presence of shale gas and its potential economical extraction one can include: thermal maturity (% Ro), content of organic matter (% TOC), thickness, depth of burial, tectonic pattern or possible presence of conventional gas in a basin. These parameters have been chosen to characterize some selected areas of assessment.

Here is a list of selected regions (assessment units):

1. Baltic Basin (offshore);
2. Baltic Basin (onshore);
3. Płock-Warszawa Zone;
4. Podlasie Basin and North Lublin Basin;
5. South Lublin Basin and Narol Basin.

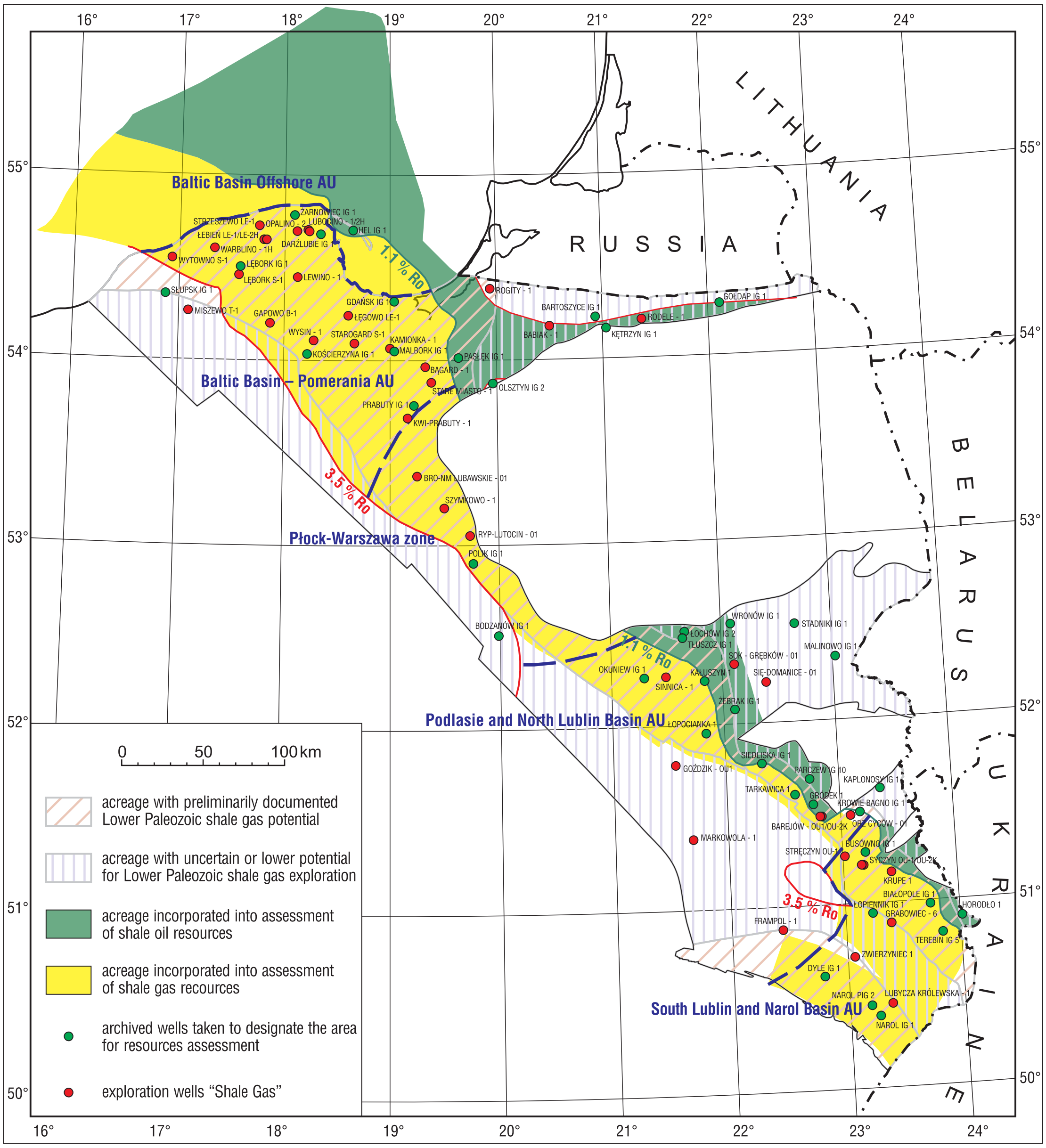
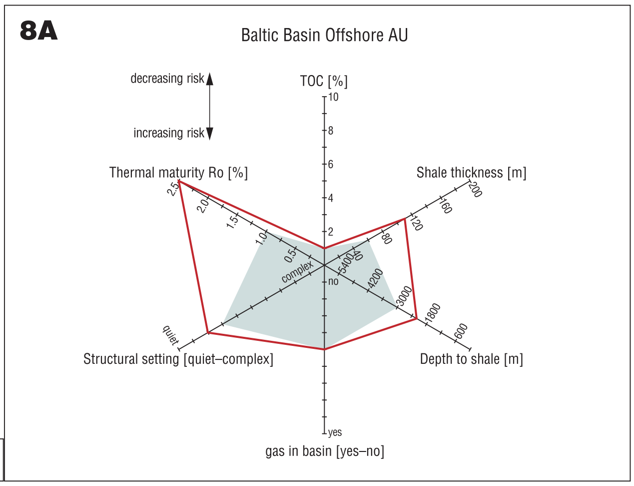


Fig. 7. Distribution map of oil- and gas-prone areas in the Ordovician-Silurian basin divided into segments representing separate assessment units

Below is the characteristics of the individual proposed regions (new units of assessment) and selected geological and geochemical parameters defining their reservoir quality.

Offshore Baltic Basin (Fig. 8A) – seems to be the most prospective, however, with the small amount of data used to construct the diagram, this thesis may be encumbered with a grave error. Yet, each value acquired is beyond a high-risk area. To the disadvantages a rare occurrence of conventional gas and poor content of organic substance in this area can be included. This results from the fact that the Ordovician and Silurian deposits pass from a clay into carbonate facies that is characteristic of a smaller content of organic matter. Despite the fact that the area seems to be just enough prospective, it must be emphasized that nowhere in the world have the prospecting and extracting of offshore shale gas been carried out so far.



values in high risk zone | values typically average observed in the basin

Onshore Baltic Basin – the Pomeranian Ordovician-Silurian shales (**Fig. 8B)** are characterized by the organic matter content of 1–2% TOC. It occurs between zones of a too low thermal maturity degree and too big depth of the burial the Lower Paleozoic shales, forming a wide belt of an increased prospecting potential (Poprawa, 2010b and c). Due to the increased degree of thermal maturity of the deposits , the presence of dry gas can be expected.The Pomerania area potential is affected by natural gas shows, mainly of methane-rich type, obtained from the Middle Cambrian deposits in the villages of Żarnowiec, Łeba and Kościerzyna. The increasing depth of the shales occurrence and the tectonic structure that becomes more and more complicated towards the Teisseyre-Tornquist zone lead to a higher prospecting risk and costs of drillings.

Płock-Warszawa Zone (Fig. 8C) – is distinguished from the other areas by the highest content of organic content TOC. Too big depth at which the shales appear, above 4000 m, is a significant limitation. With a deeper depth, the thermal maturity increases and reaches the value of above 2.5% Ro, which results in the shales generation potential being depleted. In the Płock–Warszawa Zone no signs of hydrocarbons have been fund so far, and it should be stressed that gas shale formations are also very good conventional source rocks. In this segment, the Ordovician and Silurian deposits appear around the western rim of the Mazury-Suwałki Elevation (tectonic and/or erosional boundaries). This means the possibility of additional production of biogonic gas due to deep weathering of the shales in combination with the circulation of meteoric waters during Permian time on the rim of the Mazury Elevation, later sealed by the Zechstein deposit cover.

Podlasie Basin and North Lublin Basin (Fig. 8D) – the geological-geochemical conditioning of these Basins, as it appears from the diagram, result in a higher prospecting risk. This is mainly because of the complicated tectonic framework and lower thermal maturity of the shales that often appears here within the range of the wet gas generation window. Moreover, only few signs of gas were found in this area. It is possible that the Ordovician-Silurian shales complex has a more complicated tectonic pattern within the T-T zone in this area.

South Lublin Basin and Narol Basin (Fig. 8E) – the potential of these Basins is significantly complicated by the structural setting in the form of a block tectonics. Individual blocks dislocated between one another may cause the potential shale formations, chiefly of Wenlock, to occur at a too deep depth. However, generally the average depth fluctuates around 3000 m. The above mentioned Wenlock shales, unlike those in the other Basins, are the most prospective, as the Upper Ordovician mostly occurs in carbonate facies. Apart from this, the area in comparison with the others is characteristic of a large thickness of the prospective shales and thermal maturity which corresponds to a dry gas generation window. Low permeability of the shale rocks may be additionally caused by the Caledonian and Variscan compaction (orogenie stress?) in a deeper submerged part of the Basin, unlike the shale rocks located on the platform (craton).

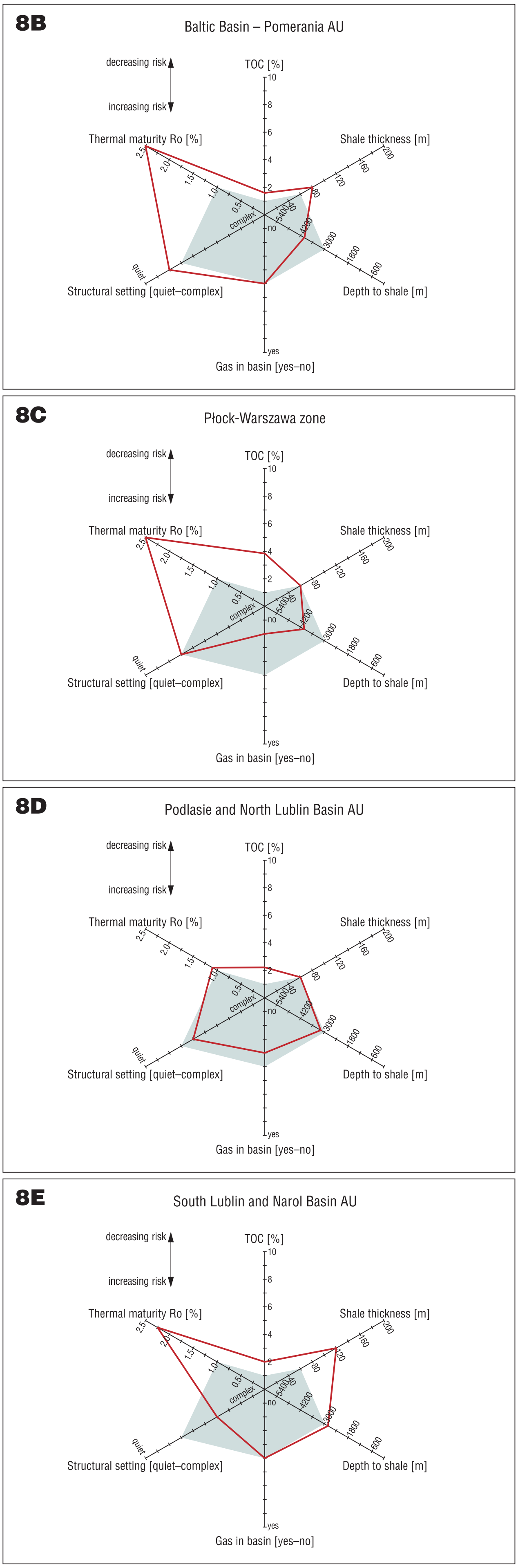


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Fig. 8. Geological and geochemical risk parameters of shale gas exploration for proposed future assessment units

The basic geological-geochemical parameters of individual Basins (segments) show that they clearly differ from one another. This characteristics proves that the division proposed by the authors of this paper is appropriate and so is the conclusion that the next assessment of shale gas should be carried out separately for each unit.

Lesson from Experience

For the purpose of the assessment of gas reserves in the Polish Ordovician-Silurian resource area, the experience from the American shale gas basins should be taken into consideration.

Method of basin comparison. After Charpentier & Cook (Open-File Report 2010-1309), an improved method of shale gas assessment consists in analysing the data from analogues. In case of the Polish O-S RA, such benefits can be obtained from a comparison with the Utica shales from the Appalachian Basin, USA (Kirschbaum et al., 2012). According to the current opinions, the Middle Ordovician shales from Utica in the States of Ohio and Pennsylvania most probably bear the clearest analogy with the Ordovician- Silurian shales in Poland (see Table 7). The Utica shales can ensure that gas is produced although they are poorly explored as they underlie much better drilled Devonian Marcellus shales. The methods employed in the Utica and Marcellus deposits should be thoroughly analyzed in Poland.

Companies that carry out exploration work in the Polish O-S RA often refer to searching for sweet spots. Despite the obvious sense of pursuing such activities, this also results from an arising confidence that areas of a sweet spot type have more chance to produce gas than other acreages whose parameters are perhaps not sufficient to reach a commercial production level. It is just the opposite to what happens in many American basins where poorer results, however such ones that can guarantee production, can be found in the vast area of basins, whereas sweet spots consist the best, the most productive parts of them.

Methods of adaptation of proper technologies to be applied for the conditions of the Ordovician-Silurian Resource Area. Companies from the shale gas exploration and exploitation sector are constantly running a "technological race" in order to increase the percentage of technologically recoverable resources and decrease the cost of gas recovery. The importance of the development of a fracturing technology for increasing the production from the existing ("vintage") boreholes and of a multi-stage fracturing technology in the same well. The benefits in terms of the recovery volume – EUR – are shown in Figure 9.

Denis McKee (a partner of George P. Mitchell, the forerunner of hydraulic fracturing and horizontal drilling in shale rocks in the USA), the president of the board of directors and of the American company, United Oilfield Services, based in Poland, says (oral information, 2012) that the geological shale data can give reason for optimism and offer a chance to launch commercial production. In his opinion, the shales occurring in Poland are in some respects similar to the Marcellus shales and, with reference to the depth of burial, to the Haynesville shales in the northern Texas and northern Louisiana. The United Oilfield Services has brought to Poland the best American experience with the shale fracturing, equipment used for deep depth

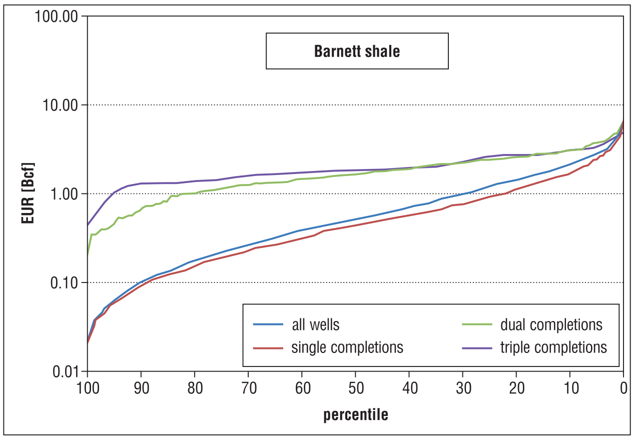

Fig. 9. Example of EUR increase calculated for the Barnett field wells for which a single completion (1240), dual completion (156), and triple completion (21) were made (after Charpentier & Cook, 2010b; Open-File Report 2010-1309)

operations and technology adopted to the conditions of the resources Ordovician-Silurian shales in Poland explored up till now. According to Denis McKee and other American experts from the shale gas exploration trade in Poland, it is necessary to drill at last hundreds of wells with completions carried out mostly in vertical sections. Such a method has been used and is still being applied in the American basins at the stage of prospecting and exploration of shale gas resources.

The key to the issue is not only the recovery of the shale gas itself, but also how to increase its effectiveness (percentage of recovery) in order to meet the commercial target. Perhaps, an analysis of the assessment of Technically Recoverable Resources (TRR) of gas should include a rate of technological innovation. A similar approach was adopted by Weijermars & Van der Linden (2012), who introduced to the economic assessment of gas recovery a Technology Factor (TF).

CONCLUSIONS AND RECOMMENDATIONS ON THE NEXT SHALE GAS RESOURCE ASSESSMENTS

We propose that in the next assessment, the methodology adopted the PGI Report of 2012 is not directly repeated with allowance made for new data. Such a report would have only partly modified figures related to the assessment of (technically) recoverable shale gas for the whole Basin, just confirming the opinion that the "gas is present". Therefore, we suggest that uncertainty of such an assessment should be reduced by dividing it into smaller territorial units having a higher or lower gas resource assessment uncertainty factor.

In addition, we propose that the next shale gas resource assessment in Poland will be carried out separately for the five Assessment Units postulated, and that in each unit the shale potential will be assessed separately for shales with sweet spots and shales without sweet spots. This will enable it to determine the Assessment Units more precisely and reject areas without a clear resource potential.

Moreover, we are of the opinion that it would be worthwhile determining for each of the territorial units a separately assumed EUR with a probability (success) factor being emphasized.

Additionally, it would be sensible to create a model AU around the existing wells both with production tests and without them (older boreholes) (hypothetical or poorly explored AU).

An assessment of technically recoverable shale gas might be also considered for the AU's that are now or will be in future (by being put out to tender) the areas of prospecting concessions. This would make it easier for the concession authority to fix the value of a concession and outline a resource area, when production is obtained and a concession for extraction granted.

In case of so called Continuous Petroleum Resources, it is pointless outlining a hydrocarbon resource area, at an early stage of exploration, since the entire area of shale rock appearance (in the interval of e.g. a gas window) actually is a potential shale play. We suggest that the shale play is defined as an area of a sweet spot character that is determined and contoured by many wells and which can prognosticate long-term production (economic EUR).

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