Hydrocarbon Accumulations in Poland

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The territory of Poland extends across three main structural units, which are: the Precambrian East European Platform, the Paleozoic West European Platform and the Alpine folded belt. The boundary between the East European and the West European Platforms runs along the Teisseyre-Tornquist Zone (NW–SE). The East European Platform forms the basement of the north-eastern and eastern part of the country, and is not folded. The West European Platform forms the basement of western and north-western part of the Country, covered with a thick sequence of Paleozoic trough Mesozoic sediments, folded during the Variscan and Alpine orogenies. In the south of the country, the Alpine movements formed the Carpathians and the Carpathian Foredeep. The Outer (Flysch) Carpathians are built of strongly folded Late Cretaceous trough Paleogene deep-marine siliciclastic sediments. The Carpathian Foredeep is filled-up with thick sequence of Miocene clastics and evaporties, which accumulated on the Mesozoic, Palaeozoic and Precambrian strata (Fig. 1).

Main prospective formations

Rotliegend. The Rotliegend (Fig. 2) sediments played a key role in the distribution and accumulation of hydrocarbons, although they were not recognized as a source rock. The deposition environment of the Rotliegend was mostly influenced by the dry and hot climate, terrestrial sedimentation, significant morphological gradient resulting from the Variscan orogeny and syngenetic tension movements stretching the basin, which resulted in volcanism and change of the erosion base (Wolnowski, 2004). The local tension-displacement movements coincided with slow epeirogenic movements, and subsidence of the basin by over 1000 m, which led to Zechstein transgression. A number of sedimentary facies can be discerned within the Rotliegend Group. Their extent depends on the prevailing climate conditions and the distance from the alimentation areas, which changed along with the basin subsidence and the progressing erosion of the uplifted areas: Consequently:

- ❑ the distal zones of the basin and the lowest parts of the section are characterized by alluvial-fluvial sediments (coarse and medium-grained sandstones, clayey breccias);
- ❑ in the central parts of the Zielona Góra and Poznań Troughs — at the top, and within the Danish–Polish Trough — at the bottom of the section, sedimented aeolian well-sorted fine- and medium-grained sandstones, with the best reservoir properties;
- ❑ in the most immersed part of the basin, within the Szczecin and Mogilno–Łódź Troughs dominated playa sediments (fine-grained clastics — mudstones and claystones).

Zechstein Limestone. Apart from the Rotliegend, the Zechstein Limestone (Fig. 3) is the next main gas bearing horizon of the Foresudetic Monocline. Zechstein Limestone (Ca1) developed in two different facies: the shallow-water zone, which is dominated by thick organogenic light-brownish limestones and dolomites, and the deep-water 1 to 5 meters thick grey limestones and marly dolomites. At the boundary of these two facies, developed the barrier facies of Zechstein Limestone with good reservoir properties and thickness from 50 to 100 meters. The 5–10 kilometers wide coastal barrier zone stretches from Ostrzeszów to Lubin. A number of fields with good reservoir properties have been discovered in this area. Gas fields in Zechstein Limestone are often in hydraulic communication with Rotliegend substrata and produce from both formations simultaneously. A number of hydrocarbon accumulations have also been discovered north of the barrier, in the fore-barrier zone. In the northern part of the Foresudetic Monocline, application of new exploration methods resulted in discoveries of fields within the reef formations of the shallowest zones of the Wolsztyn Swell. The reef development in this zone was driven mainly by the paleomorphology and the subsidence equal to the growth rate of the reef structures. The thickness of reef formations varies from 40 to 90 m. They are characterized by very good reservoir properties and are deposited directly on the Carboniferous substrata.

Main Dolomite

The Main Dolomite (Fig. 4) formation is another important petroliferous horizon, including oil, oil and gas, gas and condensate fields. The Main Dolomite occurs in the north-western and northern part of the Polish Lowland.

It forms a closed hydrodynamic system, sealed at the top and the bottom by the evaporite series. The system includes both the source and the reservoir series. The presence of these series depends on the paleomorphology, which was closely related to the sedimentation of Werra Anhydrite.

In the paleogeography of the Main Dolomite three major zones can be discerned: the carbonate platform, the platform slope and the basin plane where lagoon, barrier, fore-barrier and deep basin facies developed.

The occurrence of fields is conditional on the source rock, reservoir rock and trap presence. The source rock strata are made of dark, micrite sediments rich in organic matter developed in a quiet anoxic environment, in shallow — as well as deep-water zones.

The reservoir rocks are mainly oolite sands developed in high energy, shallow-waters. Large thickness of these deposits is observed in the barrier zone, and decreases towards the barrier base and the lagoon.

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The thickness of Main Dolomite varies from 5 m in the deep water zone to approximately 100 m in the platform zone.

Hydrocarbon accumulations occur in structural and stratigraphic traps. Structural traps coincide with paleo-elevations of the top of Main Dolomite with subsequent structures developed on salt pillows of the Oldest Halite.

Mesozoic of the Carpathian Foreland

The most prospective Mesozoic (Fig. 5) sediments in terms of petroleum exploration include carbonate formations of Late Jurassic (Oxfordian, Kimmeridgian, Tithonian) and the clastic Cretaceous formations. Similarly as in case of Rotliegend, they do not have generation potential and are treated only as reservoirs for hydrocarbon accumulation. The deposition of Late Jurassic carbonates in the prospective region in the south of Poland corresponds to the epicontinental, shallow-marine, carbonate ramp model. One of the characteristic features of such environment is the presence of organic structures, which in case of Upper Jurassic deposits in the Carpathian Foreland are of the bioherm and reef type. The reef-type structures are mostly found in the upper part of Oxfordian, in Kimmeridgian and Tithonian, while bioherms are associated with the middle Oxfordian. Additionally, the presence of reservoir rock within the Jurassic section can be related to the sedimentation environment and the deposited material, subsequent dolomitization processes (zones adjacent to erosion grooves) as well as karst phenomena, which developed especially at the dislocation zones.

In the Cenomanian, the transgression, which started at the end of Early Cretaceous, is visibly expanding and sea covers a large part of the Carpathian Foreland. The facies development of the Cenomanian within the Carpathian Foreland is emphasized by the presence of glauconitic sandstones in the paleodepressions of the basement, as opposed to conglomerates in the coastal zones. Medium-grained sandstones, most often glauconitic, are prevailing in both in the middle and eastern part of the Carpathian Foreland. The grain diameter of the sandstones increases from the central zone towards the boundaries of the basin and sandstones are gradually replaced with conglomerate facies. The extent of the Cenomanian within the Carpathian Foreland is ragged; very often conglomerate or sandstone bodies form small patches isolated from the main extent.

Ryc. 1. Poland Main Structural Units

Miocene of the Carpathian Foredeep

The sediments of Autochthonous Miocene (Fig. 6) are the most prospective formations in the SE Poland covering the area of approximately 14 000 sq. km. A certain part of potentially attractive Miocene sediments rests also under the Carpathian Overthrust, up to 20 kilometers from the front of the overthrust. This is a classical foreland molasse with well developed deltaic sedimentation. In the Miocene, the complete petroleum system can be observed, including biogenic gas generation. The main reservoir where high-methane gas is found, consists of fine-grained sandstones of Badenian and Sarmatian, and in some cases also mudstones sealed with clayey intercalations. Gas accumulations occur most frequently over basement elevations, and form stacked pool systems in the form of large anticlines. There are also stratigraphic traps formed as a result of pinch-out of sandstone strata in various sedimentary sequences.

Rotliegend, Zechstein Limestone and Main Dolomite formations are the characteristic prospective levels for the Wielkopolska Petroleum Province. In the Pomeranian and Gdańska Provinces, Main Dolomite plays the dominant role in hydrocarbon accumulation, and in the Małopolska Petroleum Province the main hydrocarbon accumulations are located within the Mesozoic rocks of the Foreland and the Miocene beds of the foredeep (Fig. 7).

Crude oil and natural gas fields

Currently, PGNiG SA holds 208 production concessions, including 51 concessions for oil, 22 concessions for oil and gas and 135 concessions for gas production (Fig. 8). The majority of the discovered fields are described in the book *Oil and Gas Deposits in Poland* (Karnkowski, 1999).

The total production of gas from domestic fields comprises the volumes extracted from the gas fields, the oil and gas fields, and the associated gas from the oil fields (Tab. 1).

In addition, the ongoing exploration efforts resulted in a number of further discoveries of hydrocarbon accumulations, which reserves have not been documented yet. This is reflected in the following summary (Tab. 2).

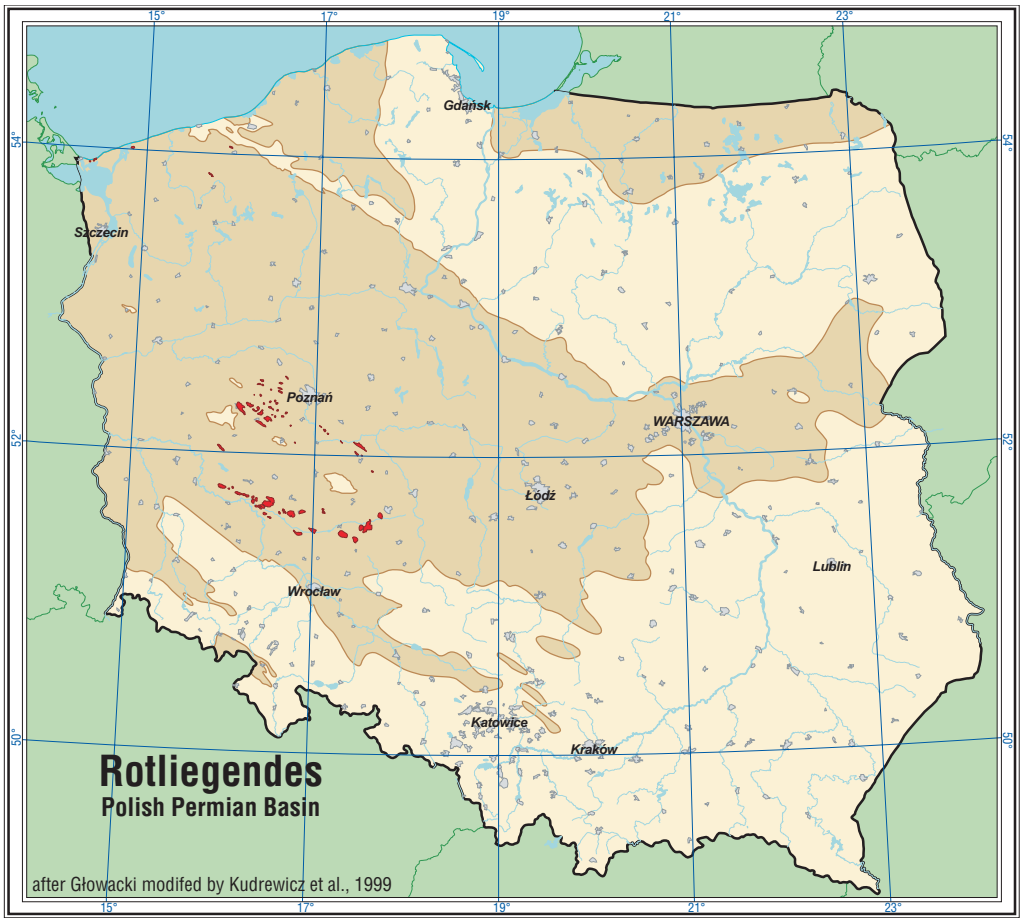
Table 1. Reserves of the producing fields

Field type	Quantity		Initial recoverable reserves*	Cumulative production	Remaining recoverable reserves
natural gas	135	natural gas [BCM]	200.33	106.40	93.93
crude oil	51	crude oil [MM metr. tons]	21.20	12.49	8.71
oil and gas	22	crude oil [MM metr. tons]	20.75	9.96	10.79
		natural gas [BCM]	18.16	9.09	9.07
TOTAL		**crude oil** [MM metr. tons]**	41.95	***22.45***	19.50
		natural gas [BCM]	218.49	***115.49***	103.00

gas recalculated into the high-methane gas
*includes fields with pending concessions — natural gas — 4.3 BCM — crude oil — 2.69 MM metr. tons
**excluding condensate

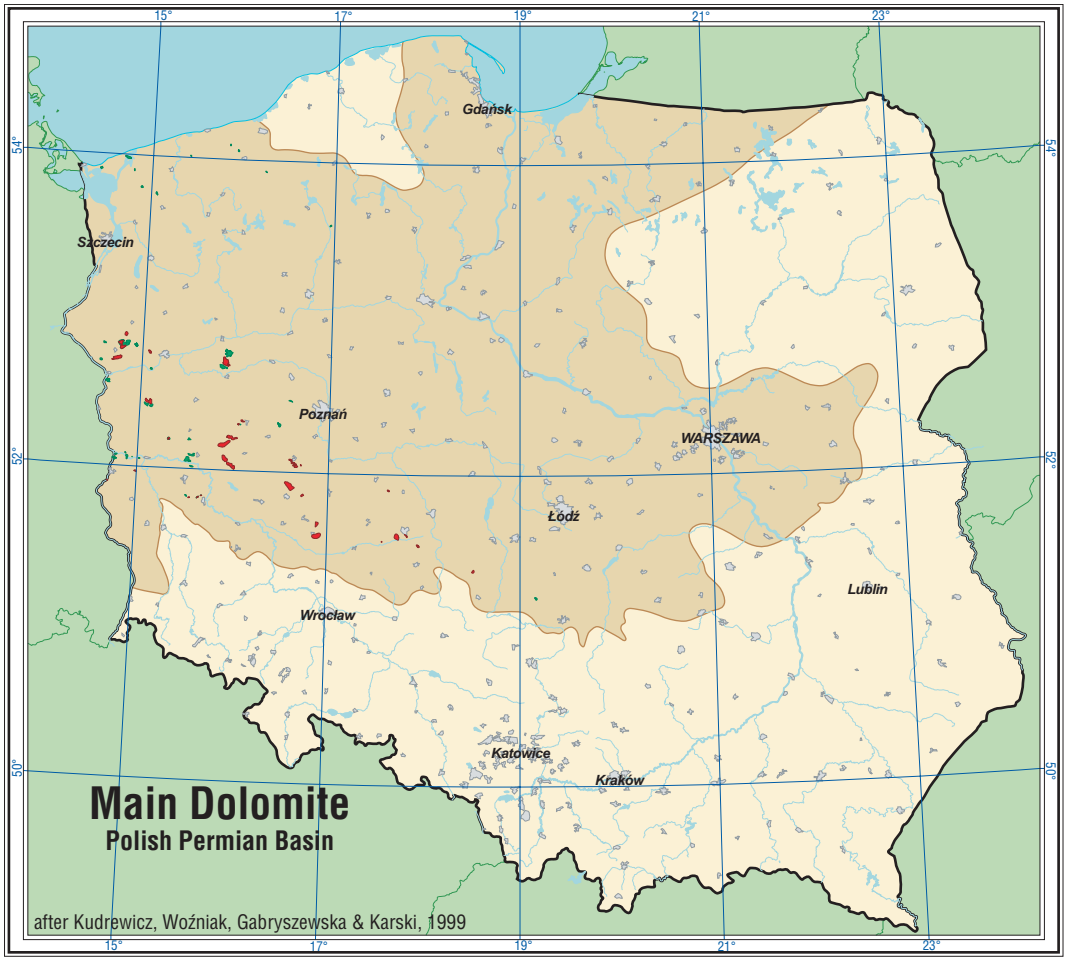
Table 2. Hydrocarbon accumulations, which reserves have not been documented yet

Geological region	Formation	Number of fields		In-placereserves		Recoverable reserves	
		Oil	Gas	Oil MM metr. t	Gas BCM	Oil MM metr. t	Gas BCM
Szczecin Trough	Main Dolomite	1	4	19.7	9.27	3.9	2.36
Foresudetic Monocline	Rotliegend		3		6.94		4.78
	Zechstein Limestone		1		7.58		6.46
	Main Dolomite	2	2	1.5	0.56	0.18	0.35
Carpathian Foredeep	Miocene		13		3.51		2.76
Carpathian Foreland	Upper Jurassic		2		1.45		1.15



Ryc. 2. Rotliegendes: Polish Permian Basin

Ryc. 3. Zechstein Limestone: Polish Permian Basin

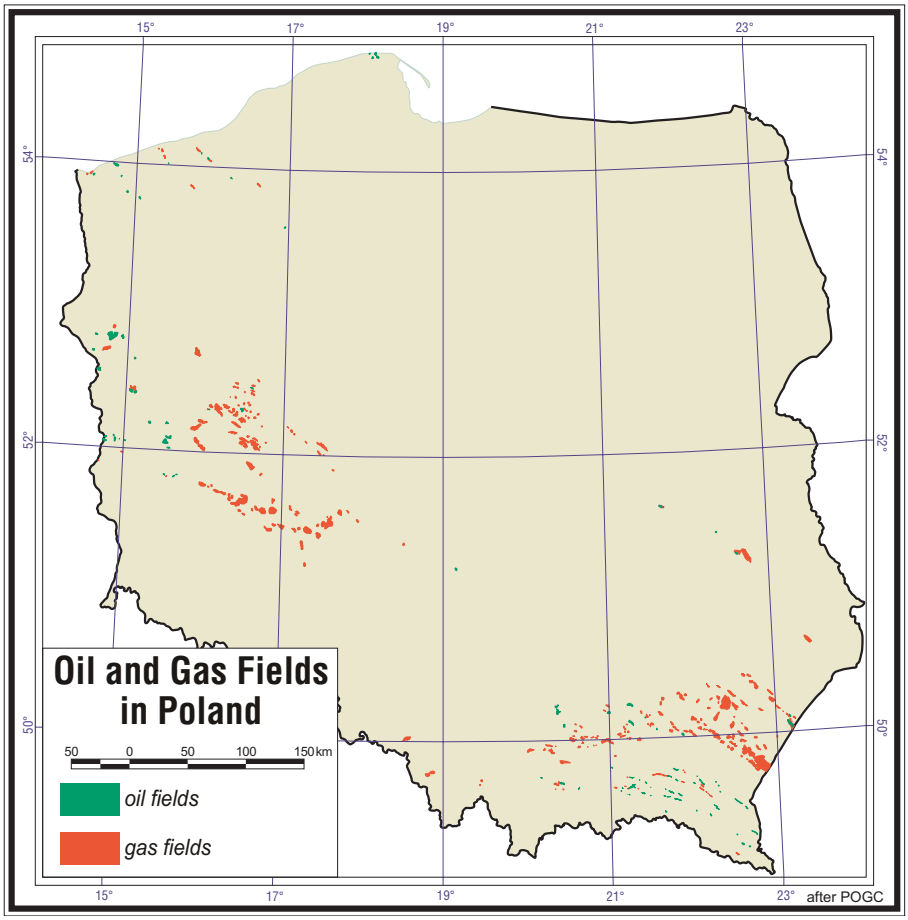


Ryc. 4. Main Dolomite: Polish Permian Basin

Ryc. 5. Jurassic & Cretaceous: Carpathian Foredeep

Ryc. 6. Miocene Carpathian Foredeep

Ryc. 7. Petroleum Provinces in Poland



Ryc. 8. Oil and Gas Fields in Poland

Recoverable reserves of PGNiG SA

The above figures show the current level of recoverable hydrocarbon reserves of PGNiG SA:

Crude oil 22.2 [MM metr. tons]
of which condensate 2.4 [MM metr. tons]
Natural gas 140.6 [BCM]
Gas converted into high-methane gas 107.3 [BCM]

Resources

Until 1990, the resources in Poland were estimated using the volumetric method. According to the calculations performed by the Polish Geological Institute, the resources were, respectively, 107 million metric tons of oil and around 665 BCM of gas (Depowski, 1984).

As of 1992, the Oil and Gas Institute and at the University of Mining and Metallurgy in Kraków estimation of the resources is provided with application of the genetic method. At this point, geodynamic analysis of sedimentation and petroleum basins was applied for the first time. It is the fundamental method of resources evaluation with respect to undiscovered potential. The analysis combined, in a standardized physical system, the geodynamic conditions of the petroleum system, i.e., the distribution of source, reservoir rocks and seals with thermodynamic conditions of hydrocarbon expulsion and migration leading to accumulation of oil and gas fields.

The volumes of initial resources for the territory of Poland, based on the assessment of independent scientific and research institutions, are estimated as follows:

- 509.6 million metric tons of oil (which with confidence level of 50% gives a range from 254.8 to 764.4 million metric tons)
- 1,966.2 BCM of gas (which with confidence level of 50% gives a range from 983.1 to 2,706.6 BCM)

After subtraction of the cumulative oil and gas production and the documented reserves, the undiscovered potential was estimated, as the resources to be discovered in Poland, which as at 31.12.2005 stood at:

- 469.5 million metric tones of oil (which with confidence level of 50% gives a range from 234.8 to 704.3 million metric tons)
- 1,586.5 BCM of gas (which with confidence level of 50% gives a range from 793.3 to 2,379.8 BCM).

The prospectivity

The presented figures demonstrate that the projections for the resources are relatively high. However, major part of these resources is related to deep (below 5,000 m) Permian strata within the Polish Lowland, Mesozoic and Paleozoic formations underneath the Carpathian Overthrust, at similar depths, and Paleozoic formations in Tarnów, Rzeszów, Lublin and Warsaw areas. So far, these horizons are rather poorly recognized with seismics and drilling. The investigation of their petroleum potential requires application of modern technologies and substantial financial investments. With its team of specialists and advanced exploration technologies, PGNiG is ready for such undertaking and expects it to result in the discovery of further major hydrocarbon accumulations in Poland.