

## OIL INDUSTRY IN THE CARPATHIAN AREA – AN OUTLINE HISTORY, CURRENT STATE AND DEVELOPMENT PROSPECTS<sup>1</sup>

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### Summary

The article presents an outline history, current state and development prospects of oil industry of the Carpathian area in Poland as compared to the Carpathian petroleum province. Polish part of The Carpathian Flysch Belt is considered to be a cradle of oil industry, the beginnings of which are related to mass distillation of oil and its industrial extraction. After dynamic development at the turn of 19<sup>th</sup> and 20<sup>th</sup> centuries there was a period of regression, which lasts till the present day. It was related to the exhaustion of old deposits and lack of discovery of the new ones. The prospects of further development of the industry depend on identifying deeper beds of the Carpathian orogen and of eastern and southern part of the Carpathian Foredeep, and on the development of exploration and extraction methods of the so-called unconventional deposits of hydrocarbons.

### Keywords

Flysch Carpathians • Carpathian Foredeep • oil industry • history • production

### 1. Introduction

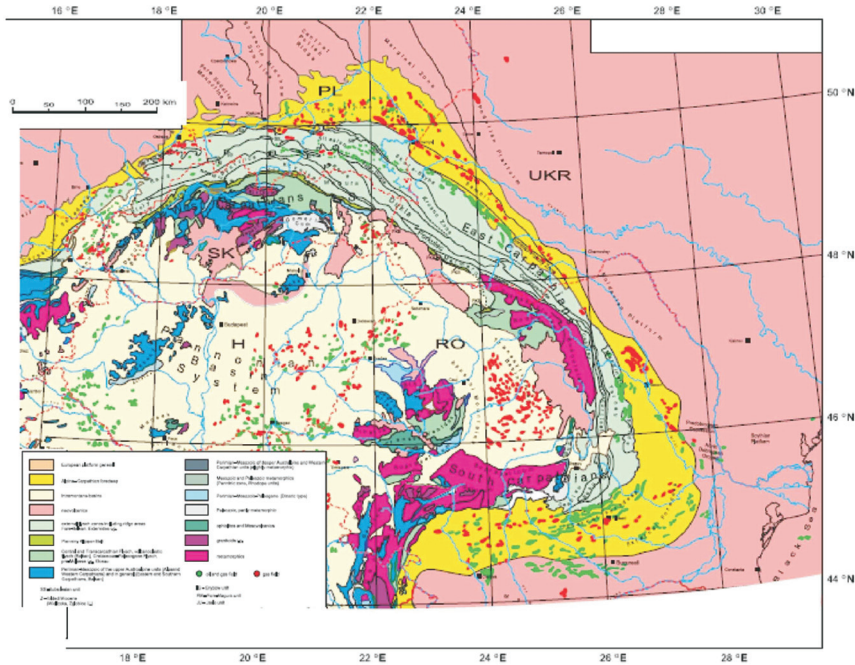
The Carpathian orogen stretches out along a wide arc reaching from Vienna at the border of Alps to the Iron Gate on the Danube in Romania. The orogen consists of an inner crystalline core and outer belts composed of sedimentary rocks. Mountain ranges are accompanied by inner and outer foredeeps usually filled with Neogen molasse sediments. In most of sedimentary parts of orogen the hydrocarbon deposits have been discovered (Figure 1). The Outer Carpathians fold zone in Krosno-Gorlice region, situated in the north-east part of orogen, went down in history of civilization as the cradle of oil industry. In this region in the mid-19<sup>th</sup> century the industrial extraction and refining of “rock oil” began. In the second half of the 19<sup>th</sup> century and at the beginning of

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the 20<sup>th</sup> century folded sedimentary formations encompassing deposits of the Silesian and Boryslav-Pokuttya units of the north-east Carpathians belonged to four mean oil regions in the world. The total production from the Carpathian deposits: Galician and Romanian gave the region the leading place in the world at the turn of the centuries. Unfortunately, extraction in Krosno-Gorlice and Boryslav deposits reached its peak in 1909. From this time on the scale of extraction started to drop. In 1930 a history of gas deposits extraction began, which was intensely developed in the post-war years, as gas deposits were discovered in the Polish part of the Carpathian Foredeep.

Regrettably, lack of economically significant discoveries in recent years led to a decline of oil industry in the area. New development prospects and opportunities appeared after technology of extraction and exploration of the co-called unconventional accumulations of hydrocarbons, had been invented. The next years and possible discovery of such deposits will determine the future of oil industry in the north-east fragment of The Outer Carpathians.



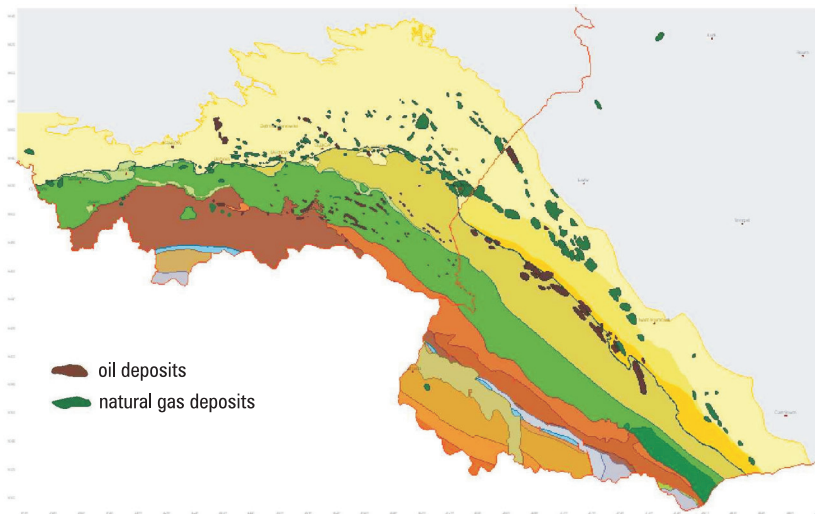
Source: Ślęczka et al. 2006

**Fig. 1.** Hydrocarbon deposits in the Carpathians and their geological structure

## 2. Outline of geological structure of the Carpathians

The Carpathian orogen consists of two zones: inner and outer, with their diverse structures and geological history [Golonka et al. 2006] (Figure 1). The Inner Carpathians were formed by Mesozoic tectonic movements and are composed mainly of Mesozoic or older crystalline, igneous and metamorphic rocks. The crystalline basement is covered by younger, usually Cenozoic sediments of depressions and inner foredeeps. Inner, marginal parts of orogen are overlain by younger sediments of the inner Pannonian basin [Tari and Horvath 2006].

The Outer Carpathians are composed of folded and overthrust tectonic-stratigraphic units, formerly regarded as nappes (Figure 2). The Outer Carpathian units are made up with deep-sea sediments that consist mostly of thick complexes of interbedding sandstones, mudstones and claystones that occur in beds of diverse thickness. The rock beds join to create packets of diverse content ratio of particular lithotypes. In spite of an apparent monotony of the structure, flysch complexes were formed in remarkably varied sedimentary conditions, which is reflected in great inner diversity of petrophysical parameters of beds, including reservoir parameters.



Source: U. Baran

**Fig. 2.** Distribution of hydrocarbons deposits in the north-east part of The Carpathian Province

In the Outer Carpathians area five main tectonic-stratigraphic units (nappes) are singled out. From the south it is Magura unit, and then: Dukla, Silesian, Subsilesian and Skole units. Before the frontal Carpathian thrust appear folded deposits of the so-called paraautochthonous Miocene, creating marginal units: Zgólbice and Stebnik. Only small fragment of the Stebnik unit lies in Poland, but it extends considerably towards the east.

The unit is composed of Eocene and Miocene deposits (Figure 2). On the Ukrainian and Romanian territory, in the basement of Skole unit, there is a Boryslav-Pokuttya unit, where oil fields occur. They are rich but today of solely historical significance (Figure 3). Before the front of the Outer Carpathians stretch foreland basins zone, filled with thick packets of molasse deposits with the addition of evaporite levels. In the north part of the Carpathian region it is mainly claystones, sandstones, and conglomerates of the Miocene period. These rocks are frequent in packets of thin beds of considerable facies variability. Total thickness of these deposits exceeds locally 3500 m [Karnkowski 1993].



Photo by D. Ilcewicz-Stefaniuk

**Fig. 3.** Exposure of oil-bearing formation in Boryslav

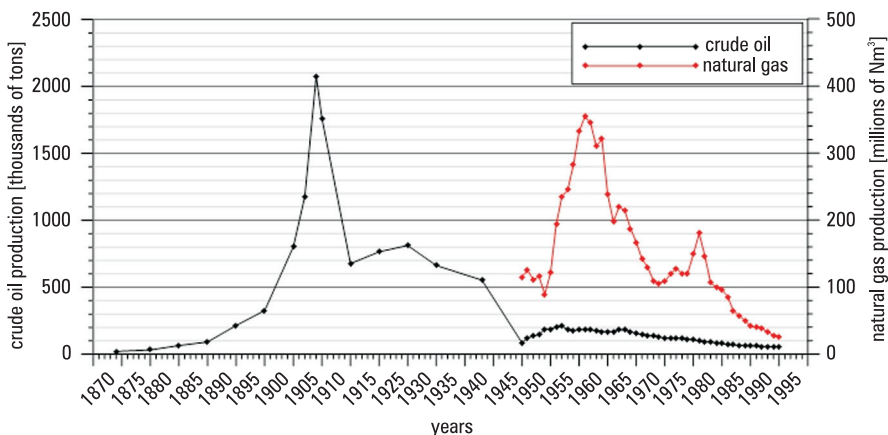
Discovery of hydrocarbons and exploration prospects in Poland are related to sedimentary complexes of fold belts of the Outer Carpathians. They contain both crude oil and natural gas deposits but in Miocene complexes of the foredeep numerous deposits of natural gas are located.

### 3. Outline history of oil industry in the Carpatian area

There is a widespread conviction in Europe that the beginnings of industrial extraction and processing of hydrocarbons are related to the north part of the Flysch Carpathians. It is debatable, however, what event (or series of events) is to be considered the very beginning of the oil industry. In our community such an initial occurrence is the oil distillation (then called rock oil) carried out in 1853 by a Polish pharmacist Ignacy Łukasiewicz [Karnkowski 1993]. The oiled obtained as a result of this process was used as fuel to light a lamp designed by Łukasiewicz. The growing demand for products

of rock oil processing made Łukasiewicz to set up another companies distilling oil: in Ulaszowice, near Jasło (1856), Kłęczany (1858), Polanka (1861) and Chorkówka (1865). Extraction industry also underwent rapid development. The first oil wells had a form of excavation wells of a dozen or several dozen meters and were located near Bóbrka. A rise in oil production and the need to reach for deeper deposits made it necessary to use drilling technology. Rich collection of souvenirs from the early, pioneer era of oil mining can be found in The I. Łukasiewicz Museum of Oil and Gas Industry in Bóbrka.

Another milestone in the history of oil industry in the north-east Carpathians was a discovery of rich oil deposits in the region of Boryslav in 1893, thanks to which the whole region was in its heyday. At the beginning of the 20<sup>th</sup> century the north Carpathian area was mentioned, next to Pennsylvania, Romania and Baku, as one of the four main centres of oil industry. Including the Romanian deposits the Carpathian area, broadly understood, was undoubtedly one of the world leaders in extracting and processing of oil. The hight of development of Borslav and Krosno-Gorlice oil basins fell in 1909, with total annual production level above 2 million tons (Figure 4). From this moment on there is a gradual decline of production down to 0.55 million tons in 1938 and 86 000 tons in 1946 [Karnkowski 1993]. After an initial rise in production from the Carpathian deposits in the post-war Poland up to 200 000 tons there was a slow decline of production due to the depletion of economically viable resources.



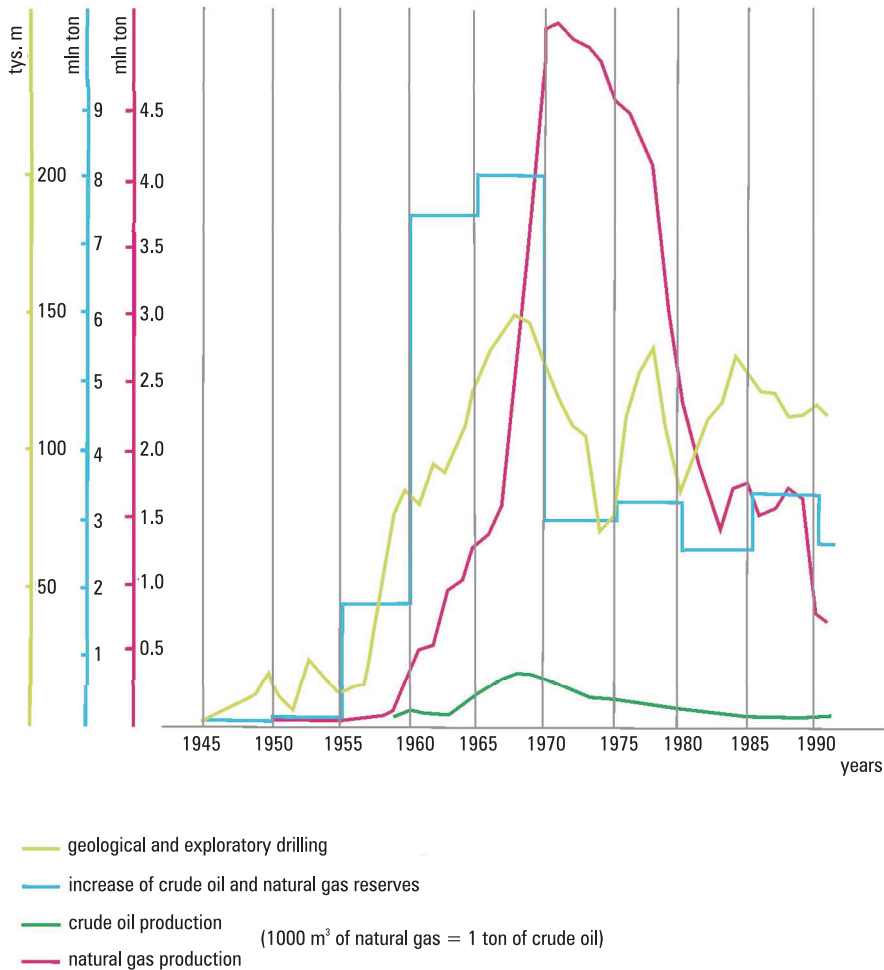
Source: authors' study based on Karnkowski 1993, Buczyński 2006, Marcinkowski and Szewczyk 2008

**Fig. 4.** Annual hydrocarbons production from the Carpathian deposits in Poland

Another strong impetus for the development of the industry was a discovery of natural gas deposits in 1930. In the post-war period the exploration works were extended into the area of the Carpathian Foredeep, where numerous gas deposits were found, mainly in Miocene deposits, and crude oil and natural gas deposits in Mesozoic-Paleozoic complexes of Miocene and Carpathian basement. Gas produced from the Carpathian Foredeep still makes up a large share of Poland's total gas supply (Figure 5).

It is noteworthy that the emergence and development of oil and gas industry in the vicinity of Krosno and Jasło were not accidental or surprising. The rock oil, with its numerous natural flows in the area, was used for economic and medicinal purposes from time immemorial. First mentions of oil medicinal come from 1534 and can be found in Stefan Falimirz work *O ziołach i mocy ich* ("About herbs and their powers") in a chapter called: "How to mix oils good for healing". There are also many pieces of information on the oil extraction in literature of 17<sup>th</sup>, 18<sup>th</sup> and 19<sup>th</sup> centuries. Stanisław Staszic, among others, writes about it in his work *O ziemiorództwie Karpatów i innych gór i równin Polski* ("Carpathian and other Polish mountains' and plains' geology") [Karnkowski 1993]. One can therefore conclude that industrial extraction and refinery of oil developed in a region where this resource had been known, appreciated and used for centuries. The reasons of appearance of the oil industry and of its impressive development in the vicinity of Krosno, Jasło, Gorlice and Sanok, as well as oil industry development at the end of the 19<sup>th</sup> century in the region of Boryslav (in Ukraine) and its later decline are worth considering. The reasons are certainly based on fundamental geological premises.

Specific, still not fully known geological structure of the north Carpathian oil basin is defined by intensive tectonics and diverse sediments that form flysch sediments. As a result, numerous, emerging to the Earth surface, pathways accompanying equally numerous and diverse reservoir traps have formed, in zones close to the surface of the Earth. Reaching organic matter maturity (so called source rock) initiated the process of generation and movement of hydrocarbons toward the surface and thus filling of the above-mentioned small and not very effective reservoir traps and numerous flows to the surface. That is why our predecessors did not have to use practically no exploration techniques – oil was just spontaneously flowing at their feet. Later the surface manifestations also led to shallow sources of these flows, and accessibility was the reason of the boom of the extractive industry. Unfortunately, after several dozen years of intensive extraction shallow sources were exhausted, and the pace of oil extraction from rocks of relatively poor reservoir properties was the cause of the inability to meet the fast growing demand for oil. Expensive explorations of deposits at larger depths have been so far unsuccessful, leading to a continuing decrease in production and marginalization of this oil basin.



Source: Chytla et al. 1992

**Fig. 5.** Annual production of hydrocarbons from deposits of the Carpathian Foredeep

#### 4. The current state of oil industry in the Polish Carpathian region and the Carpathian Foredeep

During over 150 year in the region of the Carpathian orogen about seventy oil and almost twenty natural gas deposits were documented [Karnkowski 1993, Buczyński 2006]. The distribution of these resource is shown on a geological map of the region in Figure 2. Straight majority of this accumulations, 46 oil, oil and gas, and seven gas deposits, is located within the Silesian unit, mainly in the area of the Central Carpathian Depression and on its edges (Figure 6). Three of them are both oil and gas deposits.

Within the Skole unit ten deposits are exploited [Karnkowski 1993]. In the Magura unit seven oil and two gas deposits were found. The remaining deposits occur within the following units: Subsilesian, Dukla and in the Mesozoic-Paleozoic basements of the Carpathians. The source rocks of the folded Carpathians are frequent organic-rich shale complexes [Karnkowski 1993, Kuśmierek et al. 2009, Matyasik and Dziadzio 2006, Matyasik 1994]. Black Menilite shales are especially noteworthy, often organic-rich (20%). Organic matter is characterized by diverse degree of maturity, which is a result of complex tectonics of the area, and consequently varied subsidence history of particular rock complexes.

The reservoir rocks are mainly sandstone complexes, usually of not very good reservoir properties [Karnkowski 1993, Kuśmierek et al. 2009].



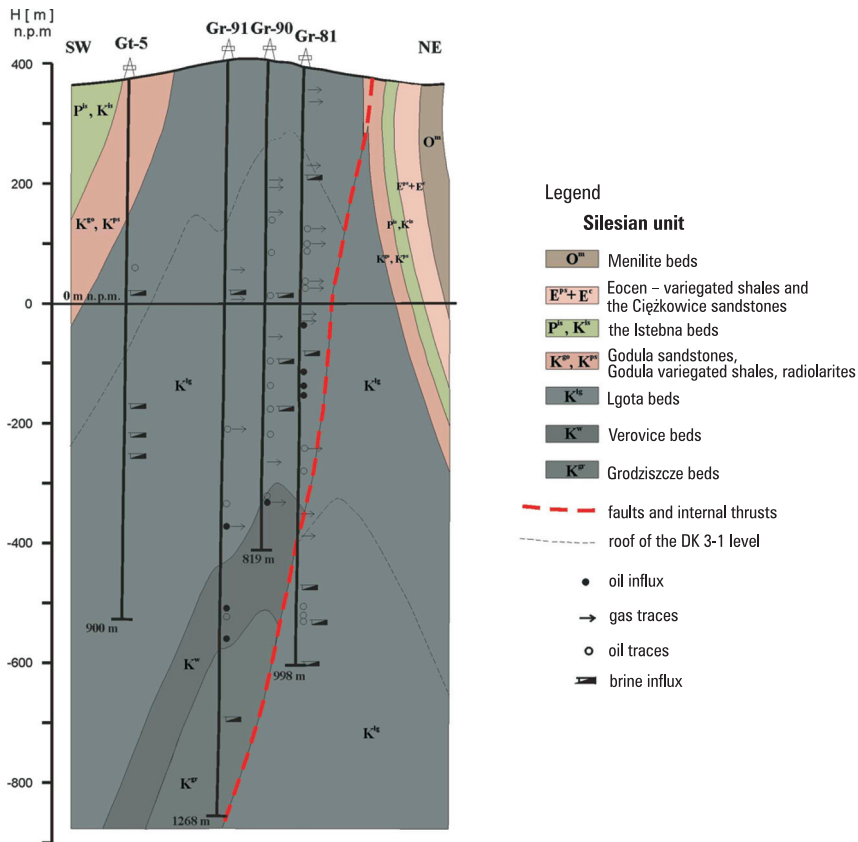
Source: Karnkowski 1993

**Fig. 6.** Location of hydrocarbon deposits in the area of the east part of the Polish Carpathians and the Carpathian Foredeep



The most significant in this respect are Kliwa sandstones, within Menilite beds, which in some places show high porosity and good permeability. Figure 7 presents an example of cross-section of the Grabownica hydrocarbon deposit.

The majority of the Carpathian deposits are extracted for several dozen and sometimes even more than one hundred years, and so they are largely depleted [Karnkowski 1993, Buczyński 2006]. Extraction of some of these deposits have already been closed, and closure of many others is planned for economic reasons. Figure 8 shows extraction facilities used at one of the old oil deposits near Krosno.



Source: Lejkowska 1975, after: Luczejko and Nycz 1988

**Fig. 7.** Geological cross-section of the Grabownica oil deposit

Oil production from the Carpathian deposits is several dozen tons per year and shows a downward trend (Figure 4). The natural gas production is 30 million Nm<sup>3</sup> and it diminishes too [Buczyński 2006]. A decrease in extraction is related to the exhaustion of economically profitable deposits, and so to the closure of old mines, and also to the lack of new effective discoveries. Closing of mines that have been functioning for

decades is also an acute social problem. It is most clearly visible in Podkarpatie, where Polish Oil and Gas Company (PGNiG) is one of the biggest employers. For the region deprived of other significant natural resources, characterized by poor conditions for farming, it can mean growing impoverishment and outflow of people.



Photo by M. Stefaniuk

**Fig. 8.** Oil wells in the east of the Polish Carpathians

Within the Carpathian Foredeep 123 natural gas and nine crude oil deposits were located [Karnkowski 1993, Buczyński 2006]. Location of deposits in the area is shown in Figure 6. The majority of natural gas deposits is situated within Miocene molasse formation. They are present inside heterolithic clastic complexes, filling sandstone beds of diverse thickness. Natural gas filling reservoir traps is produced in claystone lithotype and clay-mudstone through bacterial processes [Kotarba 1992, Kotarba and Koltun 2006]. Oil deposits are related to the Mesozoic and Paleozoic basement formations. The genesis of hydrocarbons saturating reservoir traps in the Mesozoic-Paleozoic basement is not clear and still remains debatable. In usually monotonous landscape of Sandomierz Basin, characteristic nodding donkeys pumping oil (Figure 9) and heads of boreholes making gas deposits available (Figure 10) are the region's frequent variety. Though intensive exploration works are in progress, the level of gas production in the foredeep region stays low (Figure 5). However, the gas production from the Carpathian foredeep still makes up a large share of Poland's total gas supply.

From the above considerations a conclusion can be drawn that crude oil mining in the Carpathian area is in the declining state and there are no clear signs that the situation will get better in the nearest future. The level of natural gas extraction is quite significant, especially in the Carpathian Foredeep deposits. Unfortunately the results of recent exploration works have not been satisfactory, which certainly proves the current method of exploration, which previously had been successful, is no longer effective. Therefore it is necessary to analyse the methodology and devising a new way of explorations.



Photo by M. Stefaniuk

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**Fig. 9.** Oil well in an oil deposit in the area of the Carpathian Foredeep



Photo by D. Ilcewicz-Stefaniuk

**Fig. 10.** Natural gas well in the area of the Carpathian Foredeep

#### 4. Development prospects

As stated above, extraction industry in the Carpathian area, is in stagnation. The cause of this is a gradual exhaustion of deposits, the extraction of which are in the last stages, and a deadlock in explorations for new, economically profitable deposits [Kuśmierk et al 2006, Marcinkowski and Szewczyk 2008, Buczyński 2006]. Oil exploration impasse in the Flysch Carpathians, in the opinion of many specialists, is related to complicated geological structure of the Carpathians orogen. The structure is determined by both variable sedimentation conditions of flysch formations and their intensive tectonics. Considerable facies and lithologic variability overlaps paradoxically with monotonous series of sand- and clay-mudstone sediments of variable mutual thickness relations, causing on the one hand great variability of petrophysical parameters, and on the other – limited amount or even lack of important seismic horizons that can be tracked in larger areas. Locally intensive tectonic deformations or even destruction of the primary structure of rock mass generate strong diffraction waves or deprives large areas of sources of a reflected wave. The situation gets worse by the presence of abrupt outcrops of stratigraphic and tectonic boundaries, that are hard or impossible to register by means of seismic reflection method, which is a basic research method in oil explorations. That is why there are no reliable interpretations of geological research and as a result there are no successful boreholes. Another difficulty is, confirmed by many

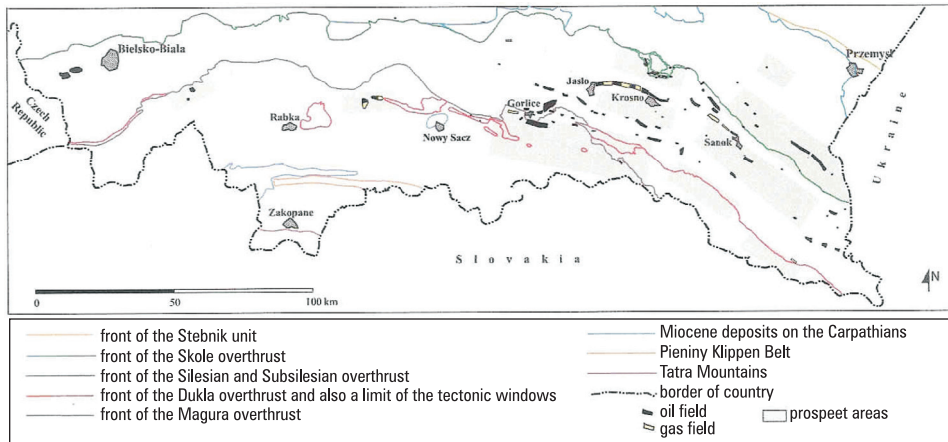
researchers, dissonance of the deformations in the Carpathians flysch cover. The upper part, intensely folded and faulted, creates an effective barrier against identification of lower flysch levels, which probably have more stable geological structure, and against identification of potentially prospective Mesozoic-Paleozoic bed levels.

Many researches carried out in a dozen or so years are an attempt to break this impasse. Apart from geophysical works, geological research analyses are done and oil modellings are performed, usually aimed at estimation of the potential of undiscovered hydrocarbon deposits, with the use of simulation of their generation and migrations in definite or predicted lithostratigraphic and structural conditions [Kuśmierek et al. 2009, Dziadzio et al. 2006, Marcinkowski and Szewczyk 2008].

For most of the researchers, both academic and practitioners, the greatest potential for new discoveries lies in flysch complexes submerged at larger depths, at 3–6 thousand metres. The deposits found so far are located in the intense and complex tectonic subsurface zone, making the identification of deeper complexes extremely difficult. The intensity of surface manifestations and frequent occurrence of shallow deposits, confirm the existence of deep-seated zone, where processes of hydrocarbon generation take place, and later hydrocarbons migrate to higher located reservoir traps. Assuming that there are good reservoir rocks in deeper complexes, the probability of discovering large deposits in this zone is high. Some deep drilling (e.g. Kuźmina-1, -2), though they did not detect hydrocarbon accumulations, they confirmed the presence of good reservoir rocks at large depths [Dziadzio et al. 2006, Marcinkowski and Szewczyk 2008, Kuśmierek et al. 2009]. Predicted distribution of prospective zones, indicated by a team working at the Polish Oil and Gas Company, is shown in Figure 11 [Dziadzio et al. 2006]. Selected prospective zones are related to areas of frequent occurrence of hydrocarbon deposits within the Silesian, Subsilesian units and Skola unit, in the direct forefield of Silesian unit, and within the Dukla unit, in areas bordering on the Silesian one. The prospective areas, probably like the discovered deposits, are concentrated in places close to main tectonic boundaries, that is deeply submerged faults and thrusts. This observation confirm the old idea of deeply submerged generative “hydrocarbon kitchen”, from which hydrocarbons migrate through zones of tectonic fractures towards the surface, filling reservoir traps on their way [Karnkowski 1993, Marcinkowski and Szewczyk 2008, Dziadzio et al. 2006].

A separate issue is how prospective are the hydrocarbon deposits explorations in the Carpathian Foredeep. The deposits discovered here are mainly located within thick packets of molasse deposits, often composed with thin alternating layers of sandstones, claystones and mudstones. Since sandstones, which are reservoir rocks, have usually some clay content, the contrast of physical properties between main lithotypes is small and it impairs the effectiveness of geophysical research. Thin reservoir horizons only partially saturated with hydrocarbons are especially hard to detect with the use of surface geophysical research. In spite of these problems in recent years a number of discoveries (e.g. multifaceted deposits) have been made. In the opinion of many experts of the Polish Oil and Gas Company the autochthonous Miocene formations should still be regarded as prospective [Myśliwiec et al. 2006, Buczyński 2006]. The biggest chances

for discoveries are related to the south-east and east part of the Carpathian Foredeep, in zones above horsts in the basement, and to south part of the foredeep close to the contact with front of the Carpathian-Stebnik overthrust and below the marginal zone of this overthrust. The potential of Mesozoic-Paleozoic formations – being the basement of the Miocene complex, both within the foredeep and in zone located below the Carpathian-Stebnik overthrust – is still little known.



Source: Dziadzio et al. 2006

**Fig. 11.** Location of prospective areas for hydrocarbons explorations in the Carpathian area

New hydrocarbon exploration prospects have been opened thanks to a development of effective technologies of exploring the so-called unconventional deposits. The fundamental difference between conventional and unconventional deposits is determined by the mobility of reservoir fluids. In conventional deposits good permeability of the geological medium allows for hydrocarbons and water movement towards a borehole under the influence of deposit energy or artificially induced pressure. Hydrocarbons in unconventional deposits are chemically or physically related to mineral skeleton of rocks (so-called shale gas) or enclosed in pore space (so-called tight gas). Shale gas can be usually found in source rocks as the part of gas, which has not undergone the process of expulsion, and tight gas tends to accumulate in reservoir rocks (e.g. sandstones) of poor permeability.

At the Department of Fossil Fuels of the AGH University of Science and Technology an analyses and modelling of the Carpathian area were made aimed at estimating prospects of discovery of unconventional deposits [Kuśmierk et al. 2009]. As a result of the studies four main prospective areas were chosen, located in the east part of the Polish Carpathians. The first area covers a lithofacies of Menilite beds in the south part of the Silesian unit, between the Oślawa valley in the east and the Jasiołka valley in the west. This zone has the highest thickness of Menilite beds and transformation of organic

matter at the edge of gas window. In this zone packets of Menilite shales are interbedded with clay and sandy shale interlayers of Cergowa lithofacies of poor reservoir properties that make the expulsion of generated hydrocarbons difficult. Therefore this zone can hide deposits of shale gas and shale oil.

The second prospective zone is related to lithofacies of poor permeability, thick-bedded lower Krosno sandstones (tight gas) stretching within the Central Carpathian Synclinorium, from the Krosno meridian up to the east border of Poland. Blocks of thick-bedded sandstones of total thickness 200–1000 metres were saturated with gas generated in Menilite shales and a series of source rocks of Cretaceous and Paleocene age [Kuśmierek et al. 2009].

The third zone is located between Sanok and Dwernik in Bieszczady Mountains. This complex is possible location of unconventional deposits of tight gas and of conventional deposits. It is built with lithofacies of thick-bedded Istebna sandstone of predicted thickness of 100–400 metres and with pore and crack type of reservoir rocks.

The fourth zone is situated in the Skole unit, between the San Valley in the north and west, and internal synclinorium in the Skole nappe. This prospective complex is composed of lithofacies of thick- and medium-bedded Inoceramus sandstones. The source rock is built with clay sediments of Spas beds, characterized with considerable hydrocarbon potential of gas-prone type. The academic and implementation researches planned in the next years can break the current exploration impasse in the Carpathian area and open a new chapter in the history of oil and gas industry in this important region.

## 5. Conclusions

Oil industry in a region considered to be its cradle is going through a deep regression related to the exhaustion of old deposits and absence of new, economically efficient discoveries of accumulations. The prospective changes of this state of affairs involve breaking the impasse in the exploration works and developing new technologies and exploration methods and identifying new formations with undiscovered oil potential. The chances of new discoveries of crude oil and natural gas deposits in the Flysch Carpathians are determined by examining the deeper beds of orogen, more than 3000 metres bsl, that is below the location of currently extracted deposits. The south and east part of the Carpathian Foredeep, within Miocene formations, have also good prospects of new discoveries of gas deposits.

Completely new prospects of oil industry revival in the Carpathian region are related to explorations and potential extraction of unconventional gas deposits. As a result of the analyses and modellings one prospective area of potential shale gas deposits was singled out, and three areas of potential occurrence of tight gas. The south part of the Carpathian Foredeep, bordering on the frontal part of the Carpathian-Stebnik overthrust and locations below this overthrust, can also become an area of potential occurrence of unconventional deposits.

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