Oil and gas fields in the Carpathians and the Carpathian Foredeep

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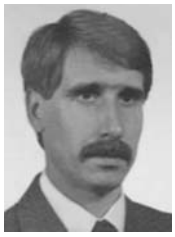

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A b s t r a c t . *Southeastern Poland is one of the oldest petroleum provinces in the world. Although hydrocarbon production has been conducted in this region since the middle of 19th century, there is still a good potential for more discoveries. 9 billion cubic meters of high methane gas reserves reported in the years 2000-2006, when combined with the previously discovered gas fields, essentially satisfy gas demand for this area. Currently, Miocene deposit of the Carpathian Foredeep is the most prolific exploration target area with more than 100 discoveries of high methane gas. The total reserves of these fields are 138 billion cubic meters, and the cumulative production is more than 90 billion cubic meters of natural gas. Large gas fields in terms of area and reserves that have already been discovered are followed by present discoveries of fields with relatively smaller area, their reserves are up to 2 billion cubic meters. Current exploration efforts are focused on good understanding of the sub-miocene basement configuration as well as detecting of seismic anomalies directly related to natural gas accumulations. Another very important element of exploration strategy for Southern Poland is the Mesozoic and Paleozoic deposits of the Carpathian Foredeep. The most prospective for discovering of sizeable hydrocarbon fields are Cretaceous (Cenomanian) sandstones and Upper Jurassic carbonates, locally also Middle Jurassic sandstone as well as Lower Carboniferous and Devonian carbonates. So far 13 gas fields and 10 oil fields have been discovered in the Mesozoic and Paleozoic of the Carpathian Foredeep and the sub-Carpathian basement with booked reserves of 7.5 billion cubic meters of natural gas and 4.7 million tons of oil. The cumulative production amounts to 6.1 billion cubic meters of gas and 4.3 million tons of oil. Different exploration problems have been encountered in the Carpathians. Most of the fields which have been discovered in the Flysch Carpathians occur in shallow, steep, narrow, commonly thrusted and faulted folds. Oil and gas fields discovered so far in the Carpathians have small reserves. Additionally, discovered and booked reserves of existing oil and gas fields are depleted to a large extent. 17 gas fields and 67 oil fields have been discovered in the Carpathians. Booked reserves amount to 16.6 billion cubic meters of natural gas and 12.3 million tons of oil. Cumulative production has been 15.2 billion cubic meters of gas and 11.9 million tons of oil. To sum up, it should be emphasized that the bulk of gas reserves discovered, booked and developed recently in Southern Poland comes from the autochthonous Miocene deposits. This trend, which involves high methane gas, is expected to continue for the next few years. Potential oil discoveries can be attributed mainly to the flysch Carpathians and Paleozoic, but requires more research and further exploration on a larger scale.*

Key words: *gas fields, oil fields, Carpathian Foredeep, Carpathians, sub-miocene basement, reserves.*

The geological and drilling efforts carried out for many years in the Carpathian Foredeep and the Flysch Carpathians have been marked by exploration success in discovery and documentation of new natural gas fields.

In the years 2000–2006, the volume of high-methane gas reserves documented in the South of Poland was around 9 billion cu. m, which together with earlier discoveries effectively covers the volume of gas produced in this area.

The Miocene deposits of the Carpathian Foredeep are the main, and currently the most prolific exploration target, especially in the eastern and central part, although positive results have been also achieved in the remaining part of the basin (Fig. 1).

To date, over 100 high-methane gas fields have been discovered in the Miocene deposits of the Carpathian Foredeep (Karnkowski, 1993b). The proven gas reserves from these fields amount to approx. 138 billion cu. m, and the cumulative production exceeds 90 billion cu. m of natural gas.

After large field discoveries, in terms of area and natural gas reserves, the currently discovered fields are characterised by relatively smaller area and amplitudes. Nevertheless, these features are characterised by multiple horizons and their reserves may be as high as 2 billion cu. m of natural gas (e.g. Jasionka near Rzeszow) and can be produced selectively from multiple reservoirs, which results in satisfactory production rates from a single well.

The current exploration efforts within new prospects are focused on understanding properly the configuration of the top of the Miocene basement and identifying seismic anomalies that are directly associated with natural gas accumulations.

The 2D and 3D seismics carried out in the Carpathian Foredeep provide a basis for gradual development of new exploration opportunities. This ensures regular replenishment of the production in the South and a high percentage of successful exploration wells drilled (approx. 70% in 2006).

However, in order to maintain this high level of drilling success the latest seismic techniques have to be used on a regular basis (e.g. high-frequency 3C P-wave and S-wave surveys,) and advanced interpretation methods using at the same time multifunctional geological analyses, including sedimentation, lithologic and facial, petrophysical, geochemical and other aspects.

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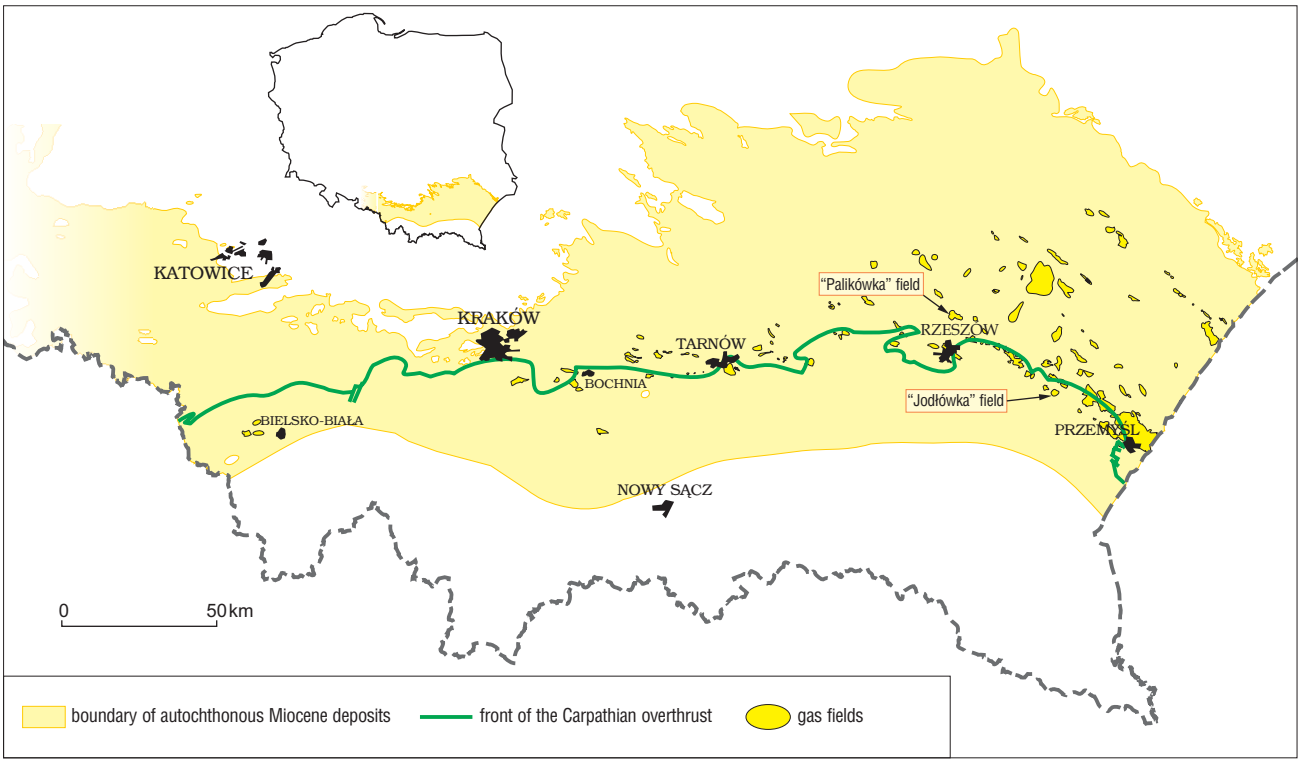

Fig. 1. Occurrence of gas fields in Miocene deposits

Identification of lithologic and stratigraphic traps is a challenge in the Carpathian Foredeep. The traps are mainly associated with intra-Miocene beds and the onlap of Sarmatian and Upper Badenian sands onto the basement.

Research and work carried out with participation of scientific and research institutions (INiG, PIG, AGH, PAN), including sedimentation analyses of clastic formations, contribute to accurate selection of the exploration sites. These areas will certainly be the exploration targets in the following years.

Another exploration problem concerns the Miocene formations before and underneath the front of the Carpathian thrust. Due to the large velocity variations of the rock medium in the flysch formations, objects with small amplitudes and surfaces are difficult to locate based on the seismic data. These difficulties became apparent, for example, in the process of discovery and appraisal of the Jodlowka natural gas field, which despite its contained surface area (2.5 sq. km) offers 24 reservoir horizons accumulating 3 billion cu. m of natural gas (Borys, 1996). Further field discoveries of this type indicate that they should not be seen as an incidental phenomenon in this area.

The Mesozoic deposits of the Carpathian Foredeep are a very important element in the context of hydrocarbon exploration in the South of Poland. The most prospective targets for discovery of sizeable hydrocarbon fields are Cretaceous (Cenomanian) sandstones and Upper Jurassic carbonates. The zone of existing field discoveries and prospective areas stretches between Krakow and Rzeszow and in the southern part of the foredeep, in the region from Lubaczow to the eastern border.

In the Cenomanian, 4 natural gas fields and 4 oil fields have been discovered to date (Jawor & Jawor, 1989) (Fig. 2). The proven recoverable reserves from these fields for natural gas and oil are, respectively, 1.0 billion cu. m and 4.15 million tons. The cumulative production to date totalled 0.3 billion cu. m of gas and 3.9 million tons of crude oil.

Meanwhile, in the Jurassic, the discoveries comprise 6 natural gas fields and 5 oil fields (Fig. 3). The proven recoverable reserves of these fields amount to 6.3 billion cu. m of natural gas and 0.3 million tonnes of crude oil, with cumulative production to date of 5.8 billion cu. m and 0.2 million tonnes, respectively.

However, further development of hydrocarbon fields in these deposits calls for new solutions in terms of methodology and interpretation. The well logging method is both too risky and too costly. Consequently, attempts are being made to identify reservoir trap accumulations using different sorts of advanced geological analyses and seismic data analyses. The Cenomanian sandstones (Fig. 2) with their relatively constant petrophysical parameters in a large part of the reservoir, seem to be a good object for tracking the changes in seismic signal, depending also on the quality of reservoir rock saturation with hydrocarbons. The analyses of this kind (including, attribute analyses, experimental 2D-3C seismic projects) are undertaken with a view to improving the efficiency of the exploration efforts in these formations.

The Upper Jurassic deposits, the most prolific of all Mesozoic stages, are a separate exploration question. They are an important geological feature both in terms of the previous discoveries (including natural gas fields in Tarnow and Lakta) and the exploration prospects (Fig. 3).

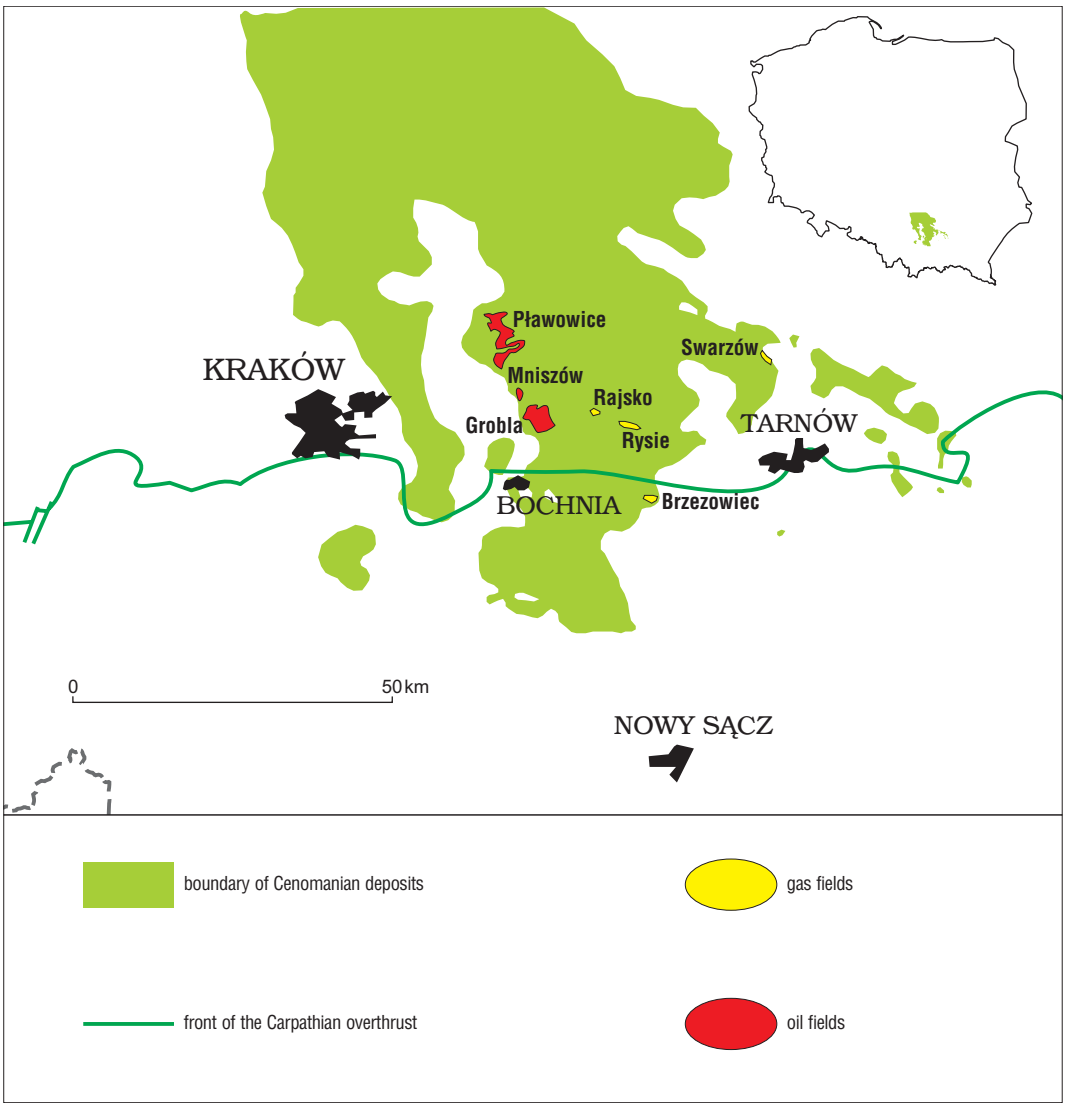

Fig. 2. Occurrence of gas and oil fields in Cenomanian deposits

Due to the complexity of traps and geological processes that determine the presence of hydrocarbon fields in Jurassic deposits, further analyses and new seismic inputs are required.

The reservoir traps in the Jurassic in principle do not lend themselves to clear classification. Frequently, they are combination of different conditions — structural, tectonic, facial changes, dolomitisation processes, karst phenomena with additional involvement of organic bioherm structures and reefs.

These complicated exploration conditions in the Jurassic require advanced surveying methods, ranging from e.g. sedimentation analyses to modern seismic methods used to survey the density of the rock medium, both the reservoir rock and the sealing. The recent results of these efforts, as well as the recent field discoveries suggest a progress in the research, which should translate into further success in hydrocarbon exploration. The analyses and surveys indicate that there are high chances of reservoir traps formation and preservation of the reservoirs.

The exploration efforts in the Carpathian Foredeep, apart from the Miocene and Mesozoic, have also focused on the Palaeozoic. To date, 3 natural gas fields and 1 crude oil field have been discovered in the Palaeozoic in the South of Poland (Fig. 4). The proven recoverable reserves from these fields are 0.2 billion cu. m of natural gas and 0.25 million tons of crude oil, with cumulative production of 0.2 million tons of crude oil. The discoveries of Nosowka oil field in Vizean carbonates and Lachowice-Stryszawa and Trzebownisko natural gas fields in Devonian carbonates indicate that there might be more such accumulations.

The Palaeozoic deposits in the South of Poland have been identified between Cieszyn, Krakow, Busko, Rzeszow and the eastern border of the country, and before and underneath the Carpathian thrust (Fig. 4).

The entire are should be considered prospective, although the current understanding based geological, seismic and drilling data indicates that it is relatively poorly developed.

The exploration potential in these deposits can be mostly associated with the Lower Devonian sandstones and the limestones and dolomites of the Middle and Upper Devonian and the Lower Carboniferous. The geochemical analyses of gas composition from Trzebownisko field

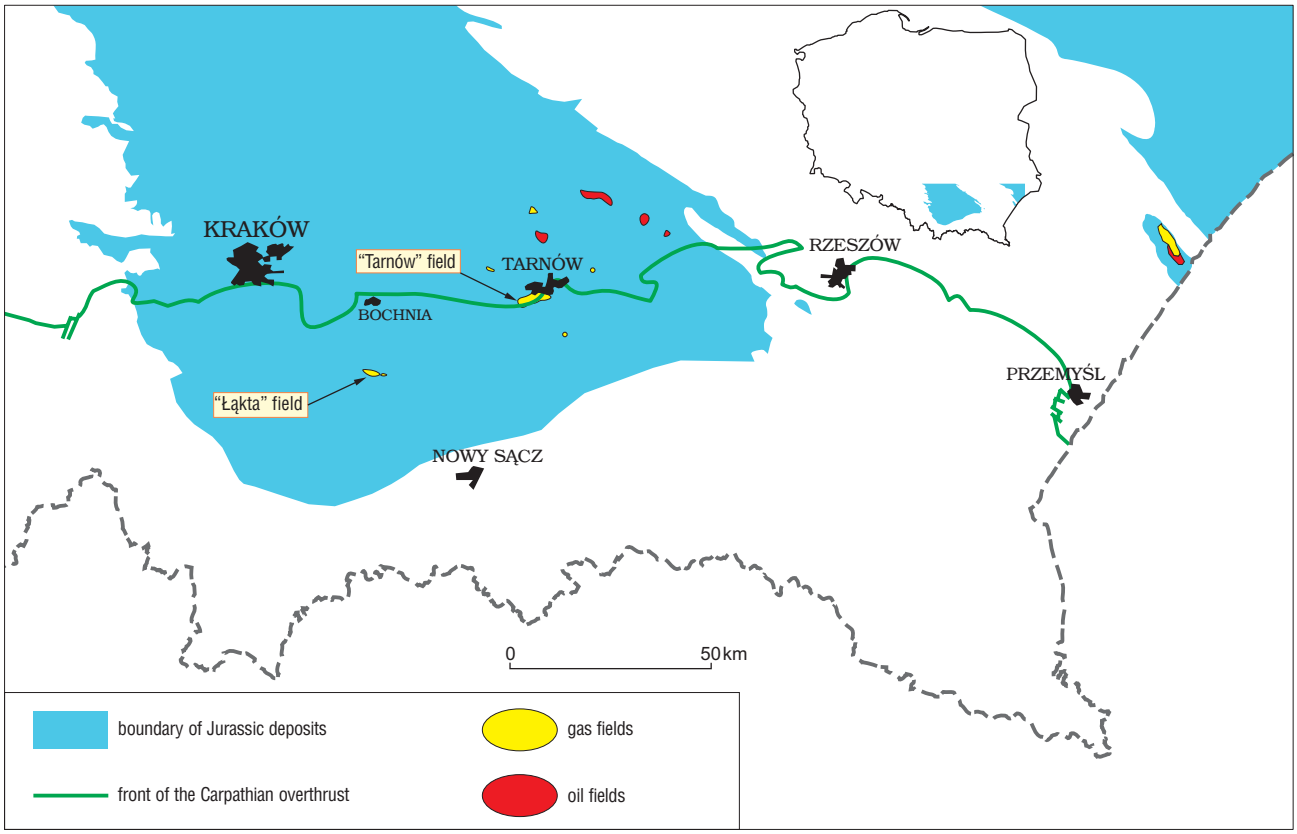

Fig. 3. Occurrence of gas and oil fields in Jurasic deposits

confirmed the genetic relationship of this gas with both the Miocene and Palaeozoic (Matyasik et al., 2003). This discovery broadens up the exploration prospects for reservoir traps saturated with hydrocarbons in Palaeozoic beds.

The current understanding of these deposits indicates the potential for hydrocarbon exploration in the local and, in the longer term, also in the regional scale.

The preparation of these deposits for further reasonable exploration will, however, have to be preceded with an analysis of the Palaeozoic sedimentation basin in the southern Poland in the context of petroleum exploration. This process is currently underway with the participation of, among others, the Polish Geological Institute.

The analysis of questions related to the deep geological structure of the sub-flysch formations reveals an important problem of the time and depth conversion along the seismic profiles originating from the flysch Carpathians. This is being currently resolved through performance of prestack depth migration, but the effectiveness of this method depends on building of an accurate velocity model of the rock medium. Therefore, additional geological surveys are also performed, such as detailed surface cartography and magnetotelluric and gravimetric methods used to predetermine the geological structure of the exploration zone.

Different exploration problems are encountered in the Carpathians. The majority of the fields discovered to date in the flysch Carpathians are found in shallow, steep, narrow, frequently laminated and dislocated folds (Fig. 5).

Generally, oil and gas field discoveries to date are characterised by rather modest reserves and the bulk of documented hydrocarbon discoveries have been already depleted. Overall, 17 gas fields and 67 oil fields have been discovered to date in the Flysch Carpathians. The documented recoverable reserves are estimated at 16.6 billion m^3 of natural gas and 12.3 million tonnes of crude oil (Karnkowski, 1993a), whereas the volumes produced from these fields are, respectively, 15.2 billion m^3 of natural gas and 11.9 million tonnes of crude oil. This situation, i.e. the comparison of discovered and produced hydrocarbon volumes illustrates the current stagnation of the petroleum exploration in the Carpathians.

The unsuccessful exploration in the Carpathians manifests itself with the lack of major commercial discoveries in the recent years. In addition, the projects in the Carpathians are costly and exposed to considerable risk due to the fact that the seismic surveys performed so far have not provided sufficiently reliable interpretation of the geological structure and the projections of reservoir rock occurrence remain too general. The evaluation of exploration prospects in the Western Carpathians is highly contentious. This leads to the conclusion that the exploration in the Flysch Carpathians requires methodological progress in petroleum prospecting, new technologies in exploration geophysics and seismic data interpretation. Perhaps, new exploration concepts are necessary. Discussion is needed on the idea of re-activating deep research wells, which used to be drilled by the Polish Geological Institute and were instrumental for the scientific advancement and the industry. Also a question to be asked is whether the Carpathians offer the potential

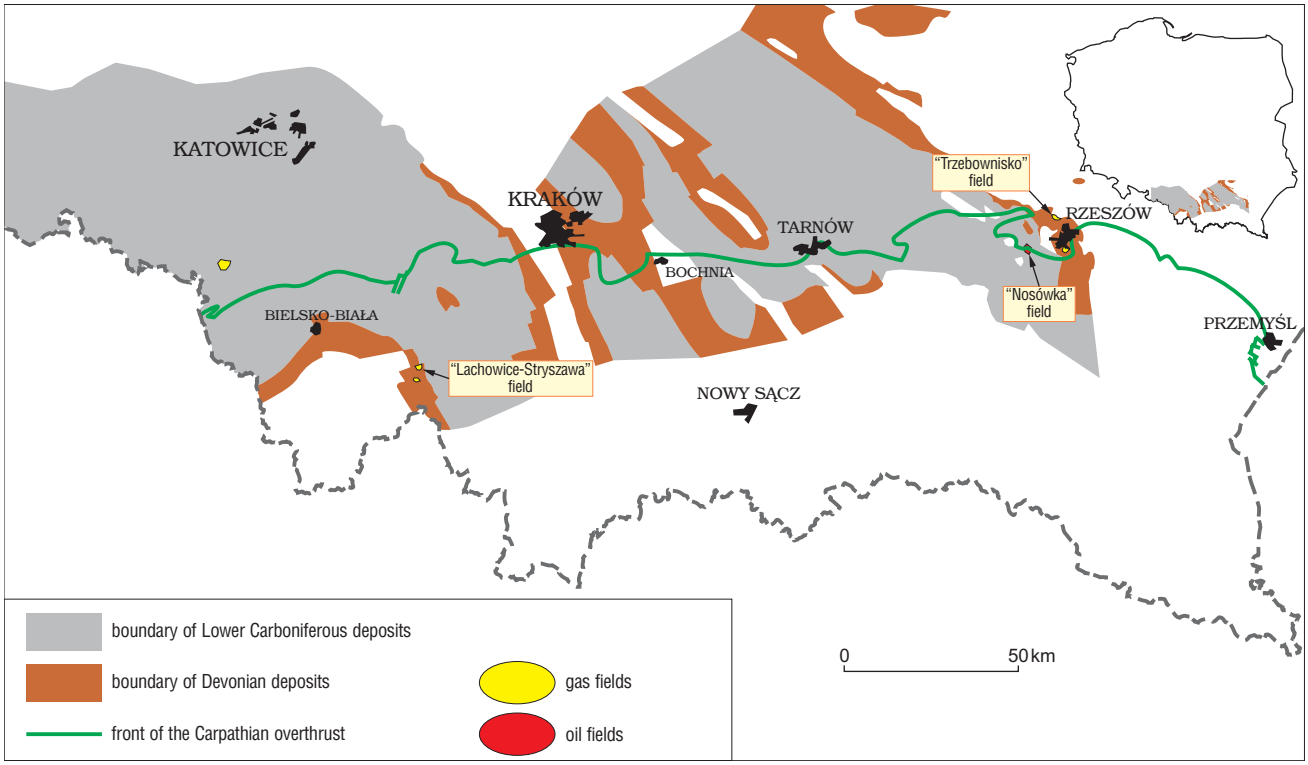

Fig. 4. Occurrence of gas and oil fields in Lower Carbniferous deposits

for discovery of relatively large hydrocarbon fields, e.g. 5 million tones of oil, 5 billion cu. m of natural gas?

Based on the hitherto results of the exploration of the Carpathian oil and gas fields, the best reservoir rocks are: Ciężkowice and Istebna sandstones in the Silesian unit, Wierzowskie i Lgota sandstones in the Sub-Silesian unit and Kliwskie and Kuźmina sandstones (Early Cretaceous) in the Skole unit. It is worth recalling the proposition that the lack of large hydrocarbon discoveries in the Carpathians is due to limited recognition of the deeper "structural stage" of the flysch formation. This is due to limited seismic date from the area and the small number of completed deep wells such as Paszowa–1, Kuźmina–1, Gorlice–13, Sieklówka–1 in the eastern part and Słopnice–1, Leśniówka–2, Chabówka–1, Zawoja–1, Sól–8 in the west.

The majority of the hitherto discoveries are found at the depth of approx. 1,500 metres, in complex geological conditions, which determines the volume of documented reserves in these structures. Nevertheless, for several fields the production exceeded 1 million tones of crude oil. The largest fields are: Dominikowice–Kryg–Lipinki, Bóbrka–Rogi and Grabownica in the Silesian unit and Węglówka in the Sub-Silesian unit. The largest natural gas production was achieved from Potok and Strachocina folds.

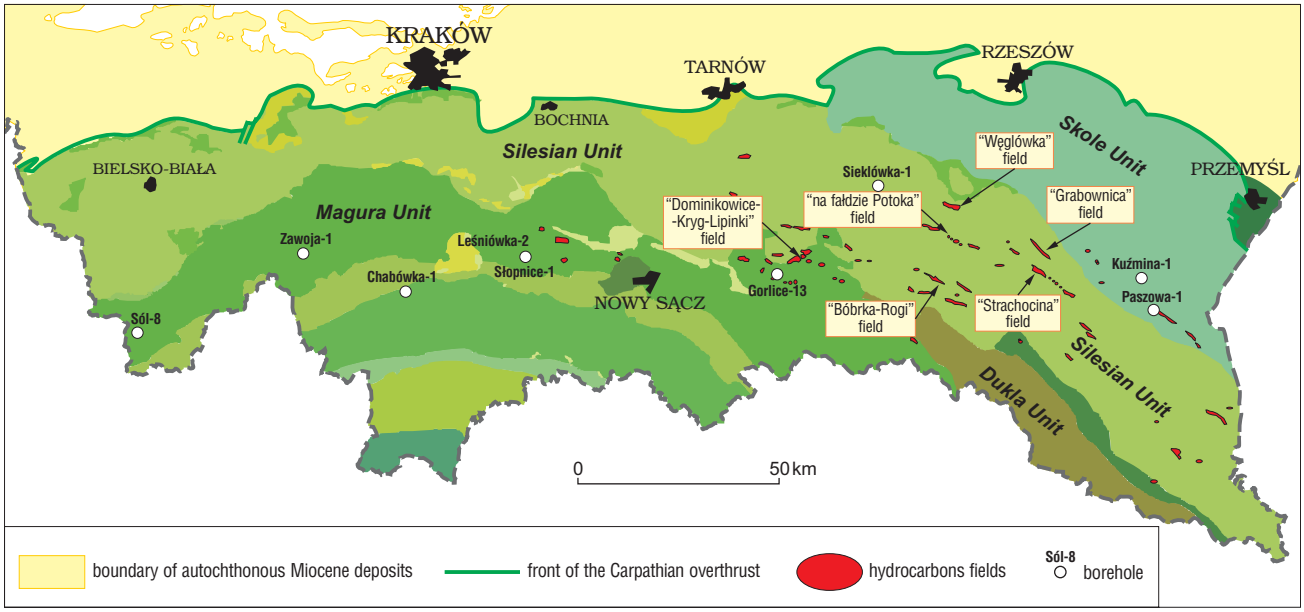

Fig. 5. Occurrence of hydrocarbons fields in Carpathian area

This "shallow" structural stage is relatively well recognised and it is difficult to expect major field discoveries in this zone. More sizable hydrocarbon deposits may, however, exist in deeper, open fold structures of the Carpathian nappes but their exploration involves a significant scope of preparatory seismic work, as well as research and exploration drilling.

Based on the current understanding of the geology and reservoirs of the Carpathians, positive exploration results in some zones that are considered most prospective may be helpful in definition for further exploration programs on the regional level. Such prospective zones include, among others, the region of Kostarowce–Zahutyń south of Sanok and the region of Iwonicz fold and its extensions.

In order to resolve exploration issues in the flysch formation, the concept of comprehensive definition of the geodynamic model of the Carpathians should be revisited. The model should be linked with generation-migration-accumulation studies in the subsequent series of the Flysch Carpathian structural units. The preliminary work completed so far identified large generation potential in the Flysch Carpathian related to Oligocene Menilite beds and Lower Cretaceous formations (Matyasik et al., 2005).

Development of new exploration concept in respect of the above-mentioned regions, supported with adequate seismic methodology (for both data logging and processing) should contribute to the progress of petroleum exploration in the Flysch Carpathians.

In conclusion, it should be underlined that the bulk of the natural gas reserves potential, which was documented and put in production in the South of Poland in the recent years originates from the autochthonous Miocene. This trend oriented at high-methane natural gas from these formations can be expected to continue during the coming years.

With respect to crude oil, the potential for discovery of new fields should be associated mainly with the Flysch Carpatians and the Palaeozoic but this requires further research studies and undertaking broader-scale exploration efforts.

At the same time, further concept, research and exploration work is underway with a view to progressive development of subsequent prospects in the Mesozoic (Jurassic and Cretaceous), Palaeozoic and the Flysch Carpathians in order to secure the current and future exploration and production activity in the South of Poland.

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