Where is There Chance to Find Deep Prospects Below the Outer Western Carpathian Thrust Belt?

To cite this article: Lubomil Pospíšil et al 2020 IOP Conf. Ser.: Earth Environ. Sci. 609 012101

View the article online for updates and enhancements.
Where is There Chance to Find Deep Prospects Below the Outer Western Carpathian Thrust Belt?

Lubomil Pospíšil¹, Dalibor Bartoněk², Pavel Černota¹

¹Department of Geodesy and Mine Surveying, Faculty of Mining and Geology, VŠB-
Technical University of Ostrava, Ostrava-Poruba, Czech Republic
²Institute of Geodesy, Faculty of Civil Engineering, Brno University of Technology,
Czech Republic

bartonek.d@fce.vutbr.cz

Abstract. In the period of 80 and 90th, the intensive deep drilling and seismic profiling
program in the Outer Western Carpathian belt has been realized for confirming the idea about
the existence and opening of new promising plays beneath some of these thin-skinned belts.
Many trans-Carpathian 2D seismic transects opened discussion on the understanding of the
complex structure of thrust belts and its basement. The recent development of exploration,
based on the new modern play concepts, has brought new light on this problem. The new 3D
and the reprocessed 2D seismic sections from Czech and Slovak part of the Western
Carpathian Flysch Belt disclosed several potentially new prospects, combined with the cover of
the foreland of European plate. New significant reserves of hydrocarbons may occur in
subthrust autochthonous and parautochthonous series buried below the frontal zones of thin-
skinned thrust belts. The study of the deepest parts of the Carpathian Flysch belt has been
based on the complex geochemical, structural analyses and geophysical Data reprocessing,
supplied by verification along the chosen balanced sections. Four examples of 2D seismic
transects, with registration up to 9-12 seconds, that present different tectonic style of structures
of Flysch Belt and its platform basement, influenced by older large-scale faults, is presented
from the western, northern and eastern parts of the Outer Western Carpathians. From point of
view of hydrocarbon prospection, the most important features of the seismic profiles are the
anticline structures of the North European Platform (NEP) below the thrust stack of the Flysch
Belt. From the west to east the Týnec-Cunin, Drietoma, Orava and Zbudza elevations can be
distinguished, created by a passive margin of the European plate, in the second and third
structures probably by parautochthonous blocks of the same plate.

1. Introduction

The territory of the Western Carpathians was subject of increased interest of hydrocarbon exploration
during 1980-90s, not only in the traditional hydrocarbon basins (Vienna Basin, Danube Basin,
Transcarpathian Basin) formed by the Late Tertiary extensional processes but also in the regions
affected by compressional tectonics, first of all in the Flysch Belt (FB). The large exploration program
has been concentrated on the deepest horizons below flysch complexes, created by molasse sediments
and the platform covers. Many 2D reflection seismic transects with prolonged registration up to 12
seconds have been measured in Czech and Slovak Republics and supplied by tens of deep wells (> 6000 m). The actual results of seismic exploration indicate the presence of many hydrocarbon
prospective structures in these areas. However, these structures can be reached only in the deeper structural levels.

The arcuate thin-skinned Carpathian orogenic belt, which evolved during the Mesozoic and Cenozoic, is thrust tens of kilometers over its Neogene foredeep and the underlying European plate (Figure 1). Various structural and stratigraphic settings and potential hydrocarbon plays have been recognized within the buried margins of the European plate, including a late Paleozoic Hercynian compressional system, Mesozoic rifted margins of the Tethys and a Cenozoic synorogenic foreland-type fault system. Possibly, deeper parautochthonous structures may also be present below the thin-skinned frontal zone of the Carpathian thrust belt. In addition to these structural settings, large Paleogene valleys/submarine canyons have been found within the margins of the European plate. These structural and morphologic features, if combined with source rocks, reservoirs, and proper burial history, represent potential hydrocarbon plays. Generation of hydrocarbons from sources within the sub-thrust plate was greatly enhanced by emplacement of the wedge-shaped thrust belt, which may also provide a regional seal; therefore, the combination of the long and complex geological history of the European plate with the impact of the Alpine thrusting and foreland deformation created unique conditions for generation, entrapment, and preservation of hydrocarbons in sub-thrust settings.

2. Method of research

For the definition of lithospheric and crustal relationships in the collisional zone of the Western Carpathians block and the NEP were chosen migrated reflection seismic profiles with deep registration. These seismic profiles have been reprocessed by Geofyzika, a.s. Brno company in the years 1997-2002. Our main method of the research was to gain knowledge (from reprocessed seismic profiles) of conditions and structure of the southern distal parts of the NEP, which were components of the passive margin of the Eurasian continent for the whole Tertiary. The results of reprocessing show expressive advances in identification of deep geological structures. Quality of reprocessed seismic profiles also enables a better understanding of the internal structure of the FB.

![Figure 1](image_url). Situation of the studied area in the framework of the Western Carpathian arc. Heavy dashed line is high conductivity zone (HCZ)
3. Source rocks

The geochemical characteristics as total organic carbon, pyrolytic hydrocarbons, and hydrogen index control the initial source potential of the rocks. Hydrocarbons are generated, however, only if the source rocks are buried to depth and heated to sufficient temperature so that maturation reactions may start. This is the essence of the method of basin evolution analysis with the "total-heatpulse model" applied in the Czech Republic in 1985 to 1986 [1]. It is based on diagenetic and catagenetic zonation used by Russian petroleum geologists of the Vassoyevitch school.

This earlier model was improved and supported by numerous geochemical analyses in the research project "Oil and gas prospecting in the structural zones of the Bohemian Massif's eastern margin". In 1992 the subsidence and erosional history was remodeled and revised cross-sections and maps [2].

As shown by the models, several geologic events played a role in hydrocarbon generation. The first deep burial was induced by the deposition of the thick Lower (Figure 2 – source rocks) to Upper Carboniferous formations with coal-bearing Ostrava Formation on top. The Devonian basal clastic sequence, the overlying carbonates, and the lower part of the Myslejovice Formation were among those the most affected by heating and maturation. Particularly the sediments occurring in the N of the area (approximately north of the Nesvačilka-Ždánice line) were exposed to high temperatures and kerogen reached maturity (catagenetic alteration) that was never exceeded since then. The catagenetic zones contouring the organic maturity were later frozen as a relic of the Variscan tectogenesis, and no hydrocarbons have been generated since the Paleozoic.

The next stage of organic maturation was induced by the burial of Paleozoic sequences due to the Jurassic sedimentation. It affected the entire area of the Upper Carboniferous in the Nesvačilka and Nemčičky blocks, the Myslejovice Formation in the S, and the Paleozoic carbonate sediments. In the sediments buried to depth of about 2,000 m kerogen was converted to liquid hydrocarbons ("early oil window" stage) and between 2,000 and 3,000 m or more, the condensate was generated.

The most important volume of oil and gas in the region was generated during the overthrust of the Carpathian Flysch nappes during the Savic and Styrian orogenies, which started some 22 million years ago. Deep burial below the nappes heated up most of the autochthonous lithostratigraphic units in the area. Only in the N this process was less intensive. Most of the Mesozoic and Paleozoic sediments entered the early and main oil window for the first time in their geologic history.

The approximate total amount of hydrocarbons generated from kerogen during the Miocene burial was calculated using the geochemical data and modeling. Total source rocks volume exceeds 200 km3 and contains kerogen mass of over 12 thousand million tons. It has generated more than 850 million tons of hydrocarbons in the Pavlov block and in the adjacent autochthonous formations below the Vienna basin. A fraction of the hydrocarbons formed could have migrated to a potential trap in the Zaječí-Podivín structural area on the E of the Pavlov block [3]. Paleogene source rocks in the Nesvačilka depression could have generated a volume of gas and oil that exceeds at least 10 times the total hydrocarbon production in the Czech Republic.

Biomarker analyses indicate that at least two petroleum systems operate in the Vienna basin, Carpathian thrust belt and the European foreland plate in Moravia - one associated with Jurassic and the other with Palaeogene organic-rich rocks. Four oils from the sub-Carpathian foreland plate and one sample from the Vienna basin were analyzed and geochemically compared to extracts from the Jurassic and Palaeogene source rocks. Two oils from the sub-thrust foreland plate (Lubna-18 and Dolní Lomná-1) are genetically related based on similar geochemical compositions. These oils show high oleanane and 24-nordiacholestane ratios, age-related biomarker ratios that are consistent with an origin from Palaeogene organic-rich rocks. These rocks are inferred to be either the menilitic shales of the Carpathian
thrust belt or autochthonous Palaeogene deposits buried below the thrust belt. Two other oils from the sub-thrust plate (Ždanice-7 and Damborice-16) correlate geochemically with extracts from Jurassic source rocks in the Sedlec-1 and Nemčičky-1 wells. Like the oil extracts, these oils lack alcanane and show low 24-nordiacholestane ratios, supporting an origin from Jurassic organic-rich marls.

4. Reservoir rocks
The part of the European plate adjacent to the Carpathian system during the Phanerozoic thus passed through two full plate tectonic cycles: the Paleozoic Hercynian and the Mesozoic-Cenozoic Alpine cycles. Both cycles started with rifting and ended with compressive deformation. During this long and complex history, conditions favorable for deposition of organic-rich source rocks occurred in the Middle Devonian, Late Carboniferous, Jurassic, and Palaeogene. Also, good reservoir rocks were deposited and their porosity preserved or enhanced during the complex geological history of the region. Hydrocarbons have been found at various stratigraphic levels, including the weathered and fractured surface of the crystalline basement, Devonian and Jurassic clastics and carbonates, and Palaeogene and Neogene clastics (Figure 2).

The hydrocarbon potential of the sub-thrust European plate was greatly affected by its burial beneath the thickening wedge of the Carpathian belt. The superposition of the thrust belt not only enhanced the maturation of source rocks and generation of hydrocarbons but also improved the trapping mechanism by providing a good regional seal. The increasing thickness of the thrust belt, however, limits the extent of the sub thrust plate accessible to exploration. Considering the economic and technical feasibility of drilling at 6-7 km depth, the width of the drillable zone typically would not exceed 5 km. However, the relatively low heat flow in the Carpathian foreland allows for liquid hydrocarbons to be generated and preserved at depths of 5 km and dry gas at depths of 9 km [4]. Thus, both oil and gas may be found in deep sub-thrust plays.

[Diagram: Play Types in the area of the Southeastern slopes of the Bohemian Massif]
Of prime importance for the accumulation of oil and gas in the region under study are the lithostratigraphic units of the sedimentary cover of the NEP. These reservoir rocks are represented by Devonian to Lower Carboniferous carbonates and by clastics of the autochthonous Paleogene and Neogene formations. A favorable assessment can also be made for the fractured and weathered surface of the crystalline basement, the terrigenous Upper Carboniferous, carbonate development of the Mesozoic and for the psammitic and psephitic sequences of the Flysch Zone.

Oil and gas have been generated in source rocks of the Paleozoic and younger autochthonous cover of the platform and in the Mesozoic and Paleogene sediments of all the allochthonous nappes. This is also supported by the proven reserves Neogene reservoirs of the Vienna Basin, which considerably exceed the potential reserves of the Miocene basin fill.

Structural traps are the primary objective in areas where the European platform has been deeply buried; they consist of large, locally faulted anticlines. Stratigraphic traps associated with weathered and fractured crystalline basement form secondary objectives.

5. 2D Seismic sections
In the region studied, regional reflection-seismic surveys revealed uplifted structures in the areas of Týnec (section 8HR/86; t - 3,2 s – Figure 3); Holíč (section 563/72; t - 3,1 sec), Starý Hrozenkov - Drietoma (section 176A/74, t - 2,3 s; 124/75-77– Figure 4), Horní Bečva (section 221/77; t - 2,0 s), Oravská Polhora (section 2T/83, 2AT/84; t - 2,6 s; 512/84/99) and Zborov (section 80/87; t – 3,4s – Figure 5). The majority of these structures have been related to the autochthonous-parautochthonous platform cover underlying Flysch nappes.

As shown by the data obtained by seismic well logging in Jarošov-1 well, the top of the Týnec structure corresponds to a depth of 5,800 m, that of the Holíč structure to 6,100 m and that of the Starý Hrozenkov - Drietoma structure to a depth of 4,500 m. On the basis of the seismic well logging data from Vizovice-1 well, the top of the undrilled Horní Bečva structure has been prognosed at a depth of 4,400m, the top of the Oravská Polhora structure at 5,900 m and that Zborov prospective horizons at depth of 4500 m to 6200 m. The refinement of the geologic setting of the above structures and the discovery of other oil and gas prospects will be the subject of subsequent deep reflection-seismic measurements.
Figure 3. Deep seismic reflection profile 8HR/86 that enables to evaluate prospectivity of deeper horizons between Bohemian Massif and the Inner Western Carpathians [5]

6. Results
For the identification of the NEP below the Western Carpathian Flysch Belt and for the definition of the lithospheric and crustal relationships in the collisional zone between the Western Carpathian block and the NEP were chosen in the western and eastern sectors of the Western Carpathians several migrated reflection seismic profiles with deep registration (Figure 3, 4 and 5). All of them were new-reprocessed (1998-2002), deep and composite seismic profiles, which define some new geological features in the collisional zone of the Western Carpathians.
Figure 4. The Drietoma structure captured by the reflection profile 124 / 75-77, according to [1].
Explanations: 1- magnetic curve, 2- gravity curve, 3- strike-slip, 4- seismic horizon, 5- interpreted fault, 6- borehole, 7- platform (Bohemian Massif), 8- Inner Carpathians crystalline, 9- thrusted parts of former passive continental margin (platform with Mesozoic and Tertiary cover), 10- Mesozoic of Inner Western Carpathians, 11- Klippen Belt one, 12- Neogene sediments, HCL – high conductivity zone.

From a general point of view, all seismic profiles are dominated by a „fan-wise“ („flower-like“) structure. However, we define this structure as „fan-wise“ (Figure 4, 5) since it looks like a classic „flower structure“ in many features. The described “fan-wise“ structure has a great impact on the final form of the collisional zone with the NEP, at least in the eastern part of the Western Carpathians.

The Pieniny Klippen Belt (PKB) is a major tectonic unit at the surface, where it separates the Outer West Carpathians and Inner West Carpathians. However, all seismic lines from the studied area reveal that the PKB has no continuous depth prolongation as a tectonostratigraphic unit [1], [6]. The seismic image allows the interpretation of older subhorizontal structure of laterally wedging-out and inter-fingering rock units that originated by collision processes in a wider zone associated with the PKB. Younger and steep brittle structures that accompany PKB and its surroundings may be traced to a great depth where they merge into a sub-vertical fault zone. This fan-wise fault zone closely resembles a transpressional flower structure.
Figure 5. Time-migrated deep reflection seismic profile 79A, 79, 64, 80/87, and its geological interpretation after [7], [8]. Explanations: TWT = two-way traveltime; PKB = Pieniny Klippen Belt. 2- Inner Carpathian Paleogene, 3- basal Paleogene clastic, 4- Mesozoic complex, 5- Klippen Belt, 6- Magura unit, 7- Obidowa-Slopnic unit, 8- unknown complex, 9- crystalline of NEP

Figure 6. Map of hydrocarbon perspective structures and areas in contact zone of the Bohemian Massif and the Inner Western Carpathians
7. Conclusions
From point of view of hydrocarbon prospection, the most important feature of many seismic profiles is the anticline/uplifted structures of the NEP below the thrust stack of FB (flysch belt) as it is demonstrated on the presented seismic profile (Figure 6 – map of perspective structures and areas). Strong reflections package below the thrust stack of FB probably indicates the presence of Mz-Pz carbonates of NEP cover of larger thickness. In our opinion, these types of structures could be most attractive for hydrocarbon exploration in the Czech and Slovakian parts of the accretionary prism.

References
[1] J. Kadlečík, et al., Reflection seismic survey of Flysch Belt and Inner Carpathian units. Manuscript, Geofyzika a.s. Brno, 1-98, 1988 (in Czech).
[2] M. Pereszlényi, J. Milička, R. Vitáloš, and P. Trgiňa, Prieskum uhľovodíkov v Podunajskej nížine - Geochemické práce. MS, archív SPP š.p. - OZ VVNP, Bratislava, 13, 1993.
[3] O. Krejčí, J. Francú, H. Poelauch, P. Muller, and Z. Straník, Tectonic evolution and oil and gas generation at the border of the North European Platform with the West Carpathians (Czech Republic) – In: Wessely, G. & Liebl, W. (1996): Oil and Gas in Alpidic Thrustbelts and Basins of Central and Eastern Europe. — EAGE Special Publication No. 5, Geological Society, London, 1996.
[4] Z. Stránik, E. Menčík, M. Eliaš, and J. Adamek, Flyšove pasmo Zapadnich Karpat, autochtonní mesozoikum a paleogen na Moravě a ve Slezsku. – In: Přichystal, A. – Obstova, E. & Suk, M. (1993): Geologie Moravy a Slezska. — Moravské zemské muzeum a Sekce geologických věd PřF MU. Brno, 1993.
[5] P. Roštinský, L. Pospíšil, O. Švábenský, M. Kašing and E. Nováková, Risk faults in stable crust of the eastern Bohemian Massif identified by integrating GNSS,figevelling, geological, geomorphological and geophysical data. Tectonophysics, Volume 785, p.1-24, 2020.
[6] L. Pospíšil, Verification of the Remote sensing results from the surrounding of the Orava part of the Flysch Belt on the bases of the geological/geophysical data. Manuscript, GUDS Bratislava, 1-39, 1989 (in Czech).
[7] L. Pospíšil, I. Hruščeky and V. Fejdi, Opening of the new deep prospect opportunities on the base of the reprocessed seismic Data in the Eastern Slovakia. Exploration Geophysics, Remote Sensing and Environment Journal, 1-2/2005, Brno, 2005, ISSN1211-339X.
[8] I. Hruščeky, D. Plašienka and L. Pospíšil, Identification of the North European Platform bellow the West Carpathian Flysch belt, Chapter in J. Golonka and F. J. Picha, eds., The Carpathians and their foreland: Geology and hydrocarbon resources: AAPG Memoir 84, p.717-727, 2006.