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## NEW INSIGHTS INTO UNCONVENTIONAL GAS POTENTIAL OF THE MIKULOV JURASSIC MARLS IN THE MORAVIAN PART OF THE VIENNA BASIN (CZECH REPUBLIC)

The focus of this contribution is twofold: (1) analysis of tectonic patterns of the entire Vienna Basin and its subthrust level which includes autochthonous Jurassic sediments; (2) further geological and palynofacial characterization of Mikulov Upper Jurassic marls with ultimate aim to get new insights into unconventional prospects within the Moravian part of the Basin. The deposition here has been largely controlled by strike-slip reactivations within faults of the principal displacement zone. Liquid and gaseous hydrocarbons generated within the Mikulov source rock formation supplied several conventional oil and gas plays in the Miocene reservoirs mostly laterally but also vertically. Vertical migration of hydrocarbons took place via releasing jogs or "windows" appeared in thrust belt damage zone because of transtensional reactivations of en échelon arranged fragments of the principal displacement zone. Our model suggests presence of considerable unconventional gas resource play existing in deep overpressured Mikulov compartment sealed by impermeable combination of overlapping flysch and multiple the Carpathian thrust belt's sheets.

*Keywords:* autochthonous and allochtonous structural flours, strike-slip faults, releasing jogs, palinofacies, type of kerogen, hydrocarbons, overpressured compartment.

**Introduction.** Over the past decade gas from different types of unconventional reservoirs or simply natural thermogenic gas which can be pried from low-permeable organic-rich formations by combination of stimulation techniques including hydraulic fracturing treatment and horizontal drilling has become an increasingly important source of energy. Commercially successful production of gas from shale and tight sandstones formations is still restricted by the North America terrain. However, now the interest for targeting unconventional gas resource plays is progressively sweeping towards Europe, wherein many countries are attempting to cover gaps between steadily growing energy demand and supply possibilities also taking into account the ultimate aim to ease their dependence on imported fossil fuel by the help of shale gas developments.

**Geology and new structural concept of the Vienna Basin.** Almost all conventional hydrocarbon deposits of the Czech Republic are confined to the Czech part of the highly prolific Vienna basin, wherein the earliest drilling operations in Moravia started in 1900. The Vienna Basin is definitively the one of the most important oil and gas provinces in Europe containing 46 fields in Austrian part of the Vienna Basin [18] and at least 20 oil-bearing structures and gas-producing horizons in the Czech and the Slovak parts of the Vienna Basin (Fig. 1).

Pre-Miocene basin floor is heterogenic. It consists of allochthonous nappes sheets emplaced onto autochthonous pre-folding sequences resting on the pre-Mesozoic basement. The formation of the Vienna Basin fault system is dated by the onset of subsidence in the Vienna Basin in Miocene, which opened as a transtensional pull-apart between two left-stepping segments of the fault zone (Fig. 1), which was later compressionally inverted in the Pliocene.

In structural terms the basin is associated with a classical thin-skinned pull-apart basin of Miocene age, which sedimentary fill is overlying on a top of the Carpathian thrust belt [18, 5]. Deep autochthonous basement in this area comprises Precambrian crystalline and Paleozoic-Mesozoic sedimentary units of the North European Platform [1].

In fact the deposition in the basin and the formation of the Central Moravian depression from our point of view have been largely controlled by strike-slip reactivations within fragments of the principal displacement zone PDZ (Fig. 1) in the Pre-Miocene basement floor.

Recent active strike-slip faulting is kinematically linked to the reactivation of major Miocene normal faults branching off from the wrench fault in the central part of the Vienna Basin [9]. Modern stresses and focal mechanisms from earthquakes along the Vienna Basin mostly indicate sinistral strike-slip faulting along north-east striking subvertical faults.

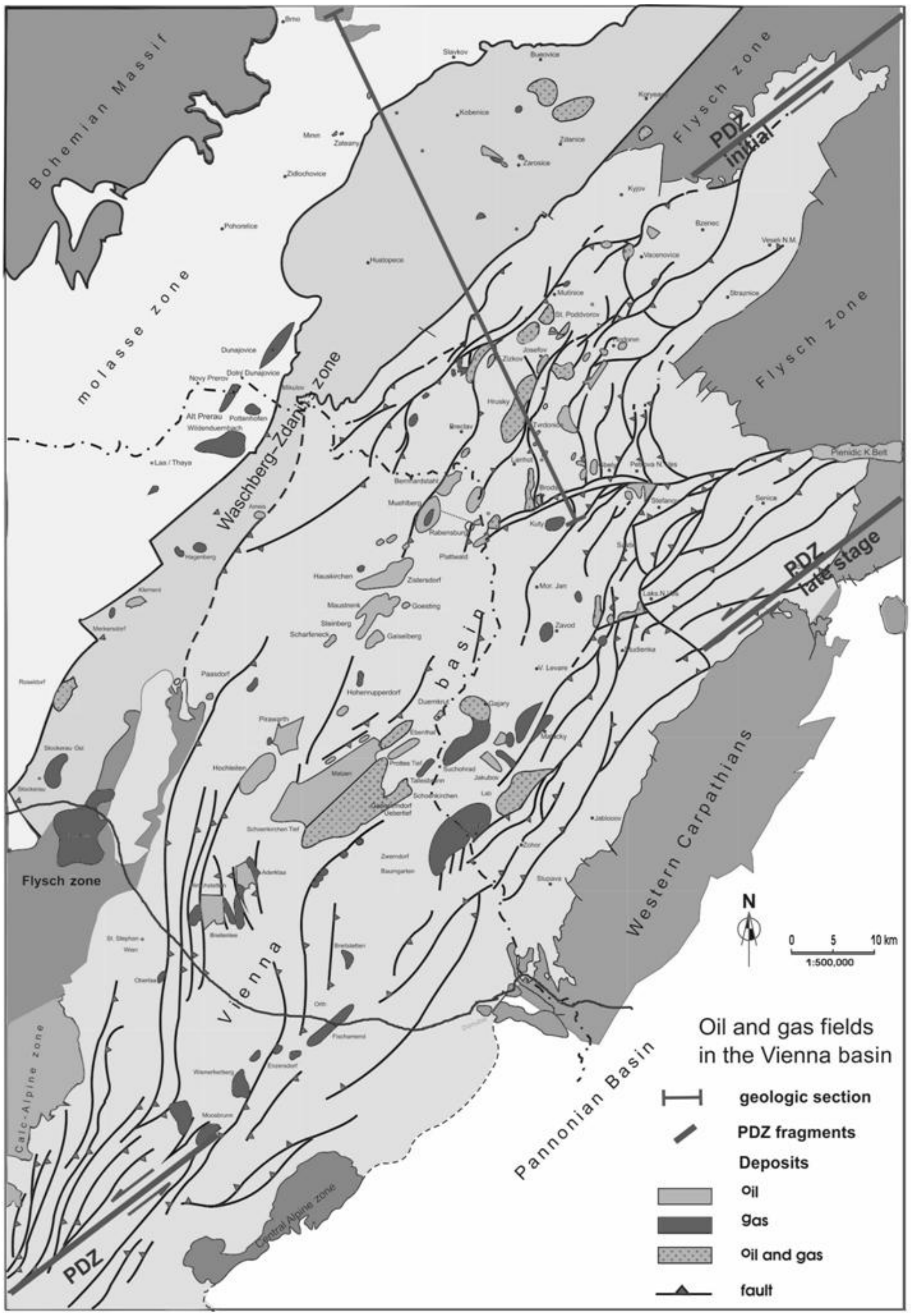


Fig. 1. Oil and gas fields in the Vienna basin (modified after Arzmuller et al. [2], model of principal displacement zone (PDZ) are from Wu et al. [5], however some fragments of the PDZ are missing in this model. Note, that most of hydrocarbon fields are located within offset jogs between adjoining en échelon left-stepping NE-SE striking shears within the PDZ. The geometry of these jogs controls local extensional (dilational) environments during sinistral reactivation pulses within the PDZ

However, 3-D interpretation of seismic sections within the Central Moravian Depression and, more specifically, mapping of paleochannels in the Mid Miocene Badenian sediments did not show significant lateral offsets of across such big faults as the Steinberg fault. It can be interpreted whether as a prove of absence of playing a significant role of strike-slip tectonics since the Late Badenian [15] or alternatively as an evidence of multiple sign-variable sinistral-dextral reactivation of faults with almost zero total displacement.

**The petroleum systems of the study area and discussion on its unconventional gas potential.** The petroleum systems of the Vienna basin Miocene sedimentary carapace and entire the Carpathian region in Moravia are mostly associated with the Jurassic source rocks and only partially with Paleogene source rocks [13]. However, taking into account our special interest to unconventional resource plays [3,16] we focused on the subthrust zone which includes autochthonous the Upper Jurassic Mikulov Formation. It represented by organic-rich Malmian dark marls which are considered to be qualified as world-class source rock [10,14,7].

Oils and gases generated within formation supplied several oil and gas fields in the Miocene reservoirs mostly laterally via several major fault and fracture zones and episodically vertically through locally released domains in the thrust belt damage zone during discrete episodes of sinistral reactivations of the PDZ. Actually dilatational jogs located within offsets between adjoining en échelon left-stepping NE-SE striking shears within the PDZ served as conduits for vertically migrated liquid and gaseous hydrocarbons to reach areas of their favorable accumulation in the uppermost conventional reservoirs.

The Mikulov Formation is buried under the flysch units of argillaceous lithology and these together with heavily faulted base of the Carpathian thrust belt have served as some kind of regional seal restricting an active vertical migration of gaseous hydrocarbons from deep generation levels (Fig. 2).

Actually the most of generated hydrocarbons might be still locked within the place of their generation in the Mikulov beds.

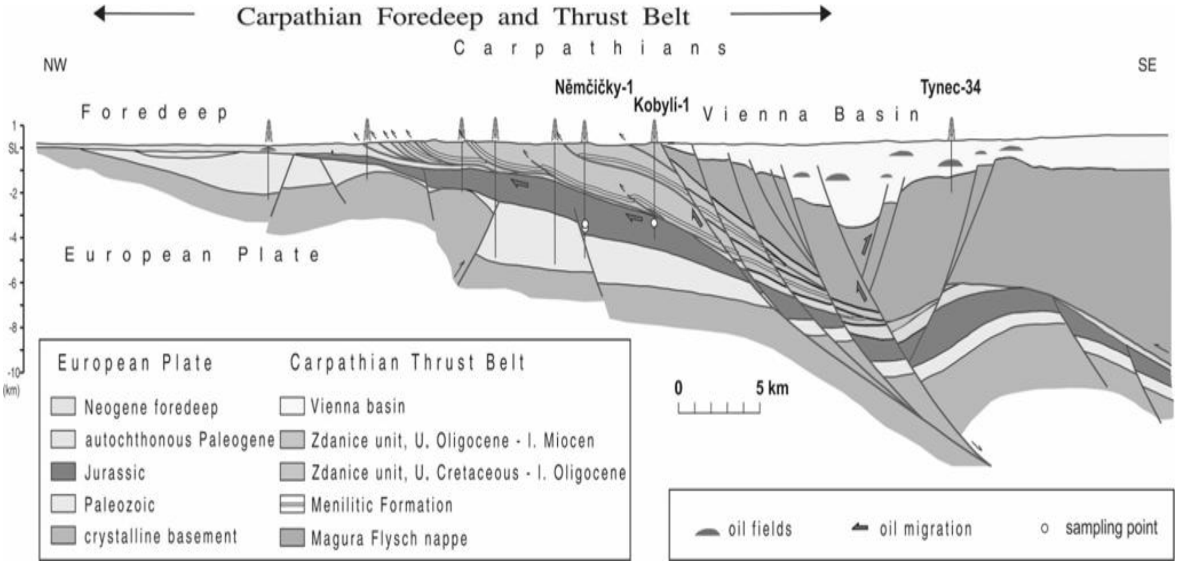


Fig. 2. Regional cross section through the West European plate, the overlying Outer Western Carpathian thrust belt, and the successor Vienna basin (modified after Picha and Peters [13]). Location of the section is shown on Fig. 1. In fact the Carpathian thrust belt consists of multiple thrust sheets and associated nappes. It would appear that several of the thrust imbricate sheets have a strong detachment folding overprint and after their soling into the base level may represent some of the most important structural traps and exploratory targets in the Basin

Previous geochemical studies [10,6,14] demonstrated that organic matter of the Mikulov marls is composed of a kerogen type II -III with total organic carbon TOC in range of 0.2-10 %. According to Krejčí et al. [10], the reactive part of kerogen in the Mikulov marls is type II, while the abundant inertinite makes the bulk hydrogen index lower.

The presence of mixed kerogen of II-III types also have confirmed by our palynofacial analysis (Fig. 3, 4) and numerous documentations of remains of terrestrial organic matter in grains of vitrinite and inertinite (Fig. 5).

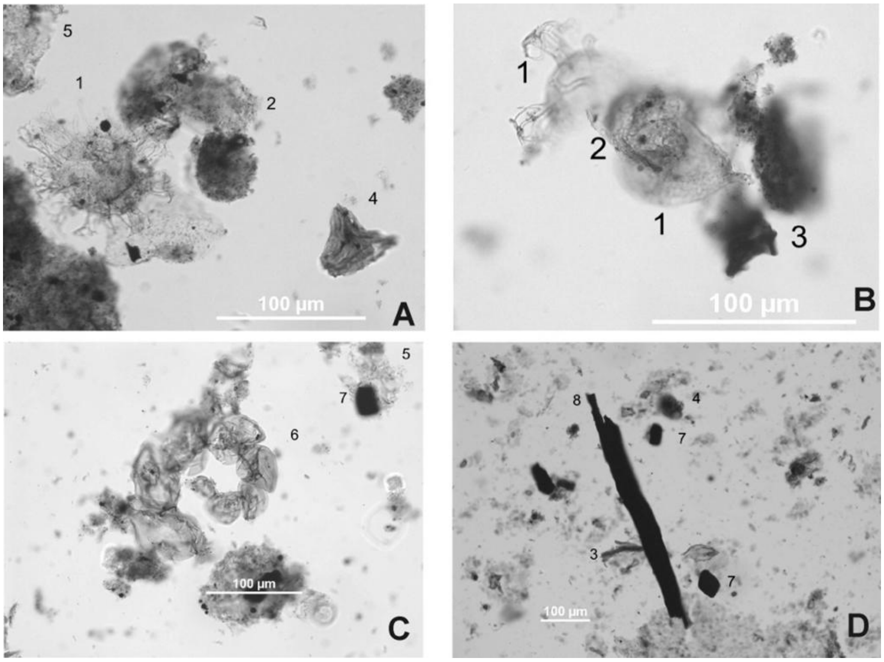


Fig. 3. Palynofacies of samples from wells Sedlec 1, Nové Mlýny 1 and Kobylí 1: A – palynofacie of sample Sedlec; B – palynofacie of sample Nové Mlýny; C, D – palynofacie of sample Kobylí; details: 1 – dinoflagellate, 2 – algae, 3 – brown particles, 4 – spore, 5 – cuticle, 6 – forameniferal assemblage, 7 – amorphous black particle, 8 – sharp-edged black particle

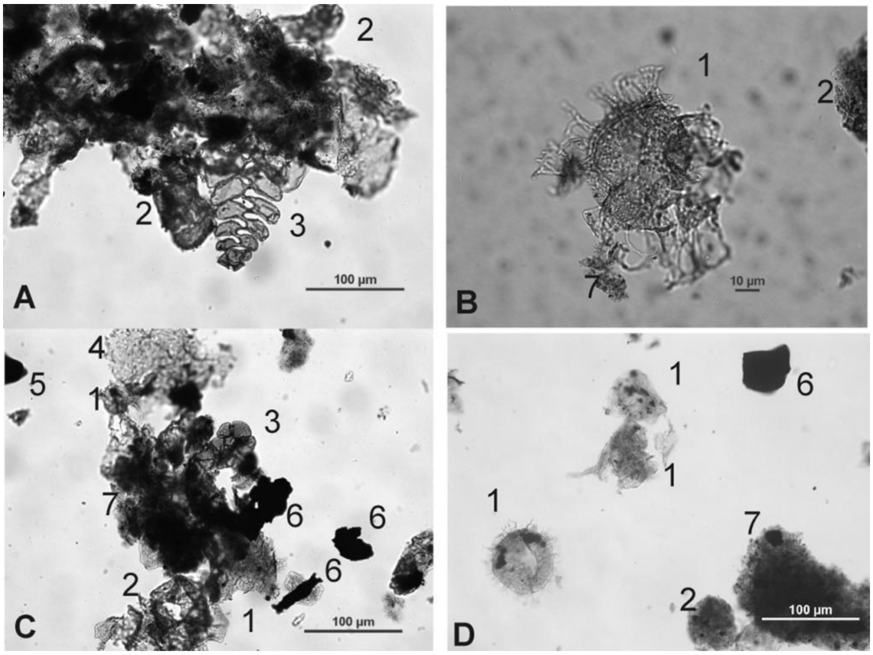


Figure 4 - Palynofacies of samples from wells Němčičky 1, Morkuvky 1: A, B – palynofacie of sample Němčičky; A – algae assemblage and algogenic organic matter , B – cyst of dinoflagellate; C, D – palynofacie of sample Morkuvky; details: 1 – dinoflagellate, 2 – algae, 3 – forameniferal assemblage, 4 – cuticle, 5 –spherical black particle, 6 – sharp-edged black particle, 7 – algogenic organic matter.

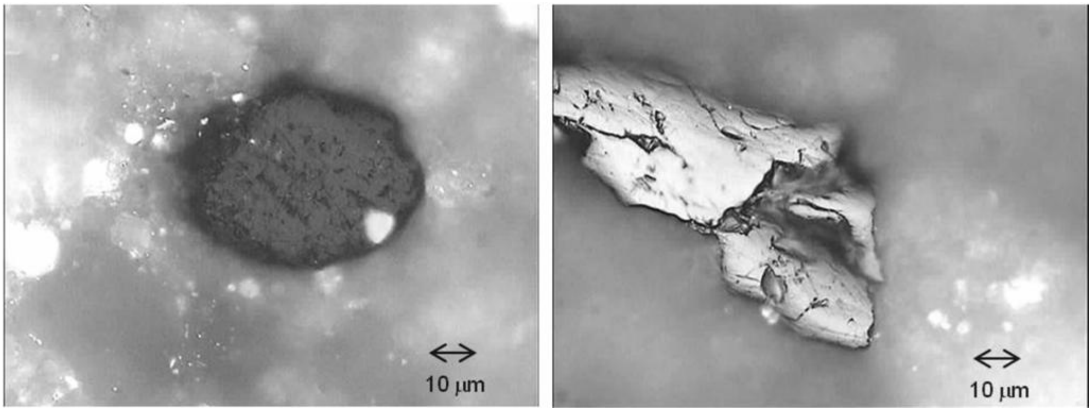


Figure 5. Grains of vitrinite (left) and inertinite (right) within sample from the well Nové Mlýny 1.

The presence of an inertinite is important geological record, because it indicates at least oxidation due to an atmospheric exposure for the Mikulov Formation during deposition.

In the northwest–southeast-trending Dyje–Thaya depression, which was formed during the Jurassic rifting [14], a set of subthrust antiformal structures, e.g. Tynec, Holic, and Lednice, have been delineated on seismic data with depths to the tops of these structures in range from 4 km (Lednice antiform) to 6 –7 km (Tynec and Holic antiforms) and these are already in condensate-gas window. These structures were formed as tilted blocks and horsts during the Jurassic rifting with further reactivation as local restraining bends during the strike-slip faulting.

At such depths fractured marls of the Mikulov Formation may be overpressured because of sedimentary loading and recent tectonic stresses. One of reason to consider this option is the fact that this pelitic-carbonatic unit at the deep levels is tectonically enlarged [1] by multiple duplications. Such kind of structural thickening related with thrust cleavage duplexes occur in the Marcellus Shale [11], which is up to now the most successful exploration reservoir for commercial shale gas production. These duplexes are interpreted as manifestations of the progressive transfer of slip from floor to roof through a disturbed zone that serves as a shear boundary between large, more internally passive, thrust sheets [11]. In case of the Vienna basin tectonically thickened weak pelitic-carbonatic marls of the Mikulov Formation could serve as the accommodation rock volume for development of ductile deformations associated with intensive folding and faulting in the overlying competent layers of allochtonous structural flour. Ductile duplexes and associated thrust-related subhorizontal fracturing related with abnormal fluid pressure [8] now are widely recognized as positive signal for targeting productive shale gas reservoirs [12,4].

**Conclusions**. Fractured intervals with gas kicks in the Mikulov Formations have been observed at great depths (7.5 km scale) in Austrian part of the Vienna basin [19]. We propose that this fracturing could be resulted from the same mechanism of formation of compressional duplexes and gives hopes for good potential of preservation here the subthrust levels of the basin significant unconventional gas resource in deep overpressured compartment.

**REFERENCES**

1. Adámek J. The Jurassic floor of the Bohemian Massif in Moravia – geology and paleogeography / J. Adámek // Bulletin of Geosciences. – 2005. – Vol. 80 (4). – P. 291 – 305.
2. Arzmuller G. The Vienna basin. / G. Arzmuller, S. Buchta, E. Ralbovsky, G. Wessely // The Carpathians and their Foreland: Geology and Hydrocarbon Resources [J. Golonka & F. J. Picha, eds]: AAPG Memoir. – 2006. – Vol. 84. – P. 191 – 204.
3. Bujok P. Břidlicový plyn, současnost a perspektivy možné těžby / P. Bujok, P. Skupien, M. Klempa, K. Labus, T. Třasoň, V. Zeman / Shale gas: the present and future prospects of potential exploitation // Uhlí rudy geologický průzkum. – 2012. – Vol. 19 (2). – P. 3 – 7.
4. Cook B.S. Ductile duplexes as potential natural gas plays: an example from the Appalachian thrust belt in Georgia, USA / B. S. Cook , W. A. Thomas // Geological Society, Special Publications. – London, 2010. – 1986. – Vol. 3488. – P. 57–70.
5. Decker K. Miocene tectonics at the Alpine-Carpathian junction and the evolution of the Vienna Basin / K. Decker // Mitt. Ges. Geol. Bergbaustud. Oesterr. – 1996. – Vol.41. – P. 33 – 44.

6. Francu J. Oil-oil and oil-source rock correlations in the northern Vienna basin and adjacent Carpathian Flysch zone (Czech and Slovak area) / J. Francu, M. Radke, R. G. Schaefer, H. S. Poelchau, J. Caslavsky, Z. Bohacek // Oil and Gas in Alpine Thrustbelts and Basins of Central and Eastern Europe [G. Wessely and W. Liebl, eds]: EAGE Special Publication. – London, 1996. – Vol. 5. – P. 343–353.
7. Golonka J. The Carpathians and their foreland: Geology and hydrocarbon resources/ J. Golonka, F. Picha // The American Association of Petroleum Geologists. – 2006. – Vol. 84. – P. 1 – 600.
8. Hathaway T. M. Thrust-related permeability in the South Wales Coalfield / T. M. Hathaway, R. A. Gayer // Geological Society, Special Publications. – London, 1996. – Vol. 109. – P. 121 – 132.
9. Hinsch R. 3-D mapping of segmented active faults in the southern Vienna Basin / R. Hinsch, K. Decker, M. Wagreich //Quaternary Science Reviews. – 2005. – Vol. 24. – P. 321 – 336.
10. Krejčí O. Tectonic evolution and oil and gas generation at the border of the North European Platform / O. Krejčí, J. Francu, H. S. Poelchau, P. Müller, Z. Stráník // Oil and Gas in Alpine Thrustbelts and Basins of Central and Eastern Europe [G. Wessely and W. Liebl, eds]: EAGE Special Publication.– London, 1996. – Vol. 5. – P. 177 – 186.
11. Nickelsen R. P. Cleavage duplexes in the Marcellus shale of the Appalachian foreland / R. P. Nickelsen // Journal of Structural Geology. – 1986. – Vol. 8. – P. 361 – 371.
12. Pashin J. C. Shale gas plays of the southern Appalachian thrust belt / J. C. Pashin: International Coalbed & Shale Gas Symposium Proceedings / University of Alabama. – Alabama: University of Alabama, 2009. – Paper 0907. – 14 p.
13. Picha F.J. Biomarker oil-to-source rock correlation in the Western Carpathians and their foreland, Czech Republic / F. J. Picha, K. E. Peters // Petroleum Geoscience.– 1998. – Vol. 4. – P. 289 – 302.
14. Picha F. J. Geology and hydrocarbon resources of the Outer Western Carpathians and their foreland, Czech Republic. / F. J. Picha, Z. Stranik, O. Krejčí // The Carpathians and their foreland: Geology and hydrocarbon resources [J. Golonka and F. J. Picha, eds.]: AAPG Memoir. – 2006. – Vol. 84. – P. 49 – 175.
15. Prochác R. Tectono-sedimentary features in 3D seismic data from the Moravian part of the Vienna Basin / R. Prochác, M. Pereszlényi, B. Sopková // First break. – 2012. – Vol. 30. – P. 49 – 56.
16. Pryvalov V. A. Potential for Unconventional Deep Gas Accumulation in the Donets Basin, Ukraine / V. A. Pryvalov, O. A. Panova, R. Sachsenhofer, A. Izart: 73rd EAGE Conference & Exhibition incorporating SPE EUROPEC 2011 at Vienna. – 2011. – Paper P174. – 6 p.
17. Wessely G. Geological results of deep exploration in the Vienna basin / G. Wessely // Geologische Rundschau. – 1990. – Vol. 79. – P. 513 – 520.
18. Wu J. E. 4D analogue modelling of transtensional pull-apart basins / J. E. Wu, K. McClay, P. Whitehouse, T. Dooley // Marine and Petroleum Geology. – 2009. – Vol. 26 (8). – P. 1608 – 1623.

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**НОВІ ІДЕЇ ОЦІНКИ ПОТЕНЦІАЛУ НЕТРАДИЦІЙНИХ ГАЗОВИХ РЕСУРСІВ У МИКУЛІВСЬКИХ ЮРСЬКИХ МЕРГЕЛЯХ У МОРАВСЬКІЙ ЧАСТИНІ ВІДЕНСЬКОГО БАСЕЙНУ (ЧЕСЬКА РЕСПУБЛІКА)**

Ця публікація сфокусована на двох аспектах: 1) аналізі тектонічних особливостей Віденського басейну, в цілому, і його піднасувного комплексу, що включає автохтонні юрські відкладення; 2) подальшої геологічної та палінофаціальної характеристиці верньоюрських Микулівських мергелів. Кінцева мета досліджень - отримати нові знання про перспективи нетрадиційної вуглеводневої сировини в межах моравської частини басейну. Обстановки осадконагромадження тут значною мірою контролювалися зсувною активізацією окремих розривів у складі принципової дислокаційної зони. Рідкі й газоподібні вуглеводні, генеровані в нафтогазоматеринських Микулівських верствах, призвели до формування ряду традиційних родовищ нафти і газу в міоценових колекторах не тільки за рахунок переважної латеральної, а й вертикальної міграції. Вертикальна міграція відбувалася в умовах зсувної активізації принципової дислокаційної зони крізь періодично відкриті в непроникній зоні дроблення Карпатського насувного поясу «вікна» на ділянках локального розтягу у межах кулісоподібного вигину або зчленування зсувів. Наша модель передбачає наявність на глибоких горизонтах Микулівської формації значного скупчення нетрадиційного газу, який знаходиться в специфічних умовах аномально високого пластового тиску.

*Ключові слова:* алохтонні та автохтонні структурні поверхи, зсувні дислокації, ділянки локального розтягу, палінофації, кероген, вуглеводні, зона аномально високого пластового тиску.

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**НОВЫЕ ИДЕИ В ОЦЕНКЕ ПОТЕНЦИАЛА НЕТРАДИЦИОННЫХ ГАЗОВЫХ РЕСУРСОВ В МИКУЛОВСКИХ ЮРСКИХ МЕРГЕЛЯХ МОРАВСКОЙ ЧАСТИ ВЕНСКОГО БАССЕЙНА (ЧЕШСКАЯ РЕСПУБЛИКА)**

Настоящая публикация сфокусирована на двух аспектах: 1) анализе тектонических особенностей Венского бассейна, в целом, и его поднадвигового комплекса, включающего автохтонные юрские отложения; 2) дальнейшей геологической и палинофациальной характеристике вернеюрских Микуловских мергелей. Конечная цель исследований - получить новые знания о перспективах нетрадиционного углеводородного сырья в пределах Моравской части бассейна. Обстановки осадконакопления здесь в значительной степени контролировались сдвиговыми активизациями отдельных разрывов в составе принципиальной дислокационной зоны. Жидкие и газообразные углеводороды, генерированные в нефтегазоматеринских Микуловских слоях, привели к формированию ряда традиционных месторождений нефти и газа в миоценовых коллекторах не только за счет преобладающей латеральной, но и вертикальной миграции. Вертикальная миграция происходила в условиях сдвиговой активизации принципиальной дислокационной зоны сквозь периодически открывавшиеся в непроницаемой зоне дробления Карпатского надвигового пояса «окна» на участках локального растяжения в пределах кулисобразного сочленения отдельных разрывов. Наша модель предполагает наличие на глубоких горизонтах Микуловской формации значительного скопления нетрадиционного газа, который находится в специфических условиях аномально высокого пластового давления.

*Ключевые слова:* аллохтонные и автохтонные структурные этажи, сдвиговые дислокации, участки локального растяжения, палинофации, кероген, углеводороды, зона аномально высокого пластового давления.

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