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AN UNCONVENTIONAL GAS FUTURE FOR THE DONETS COAL BASIN

НЕТРАДИЦІЙНИЙ ГАЗ – МАЙБУТНЄ ДОНЕЦЬКОГО ВУГІЛЬНОГО БАСЕЙНУ

Донецький кам'яновугільний басейн має багатовікову історію досліджень, зумовлену унікальною вугільною сировинною базою і економічними викликами, пов'язаними з його великомасштабною експлуатацією. У Донбасі ідентифікована єдина вуглеводнева система, що охоплює увесь розріз осадових порід карбону та включає традиційні і нетрадиційні поклади газоподібних вуглеводнів. Велетенська маса органічної речовини у вугільних пластах і вміщуючих породах (від 1 до 6 трильйонів тонн), достатній ступінь його термального дозрівання (вуглефікації) обумовлюють необхідність розглядати Донбас як найбільше родовище центральнобасейнового типу з нетрадиційними колекторами. Зроблено висновок про добрі можливості збереження вуглеводневих газів у породах вугленосної товщі на глибоких горизонтах (пластичних сланцевих товщах і пісковиках), де низька проникність відкладів зумовила збіг зон генерації і акумуляції газу. Концентрація вуглеводневих газів у вуглевміщуючих породах значно менша, ніж у вугіллі і в природних газових родовищах. Проте за рахунок об'єму цих відкладень видобуток метану за умови використання сучасних технологій стає економічно доцільним.

НЕТРАДИЦИОННЫЙ ГАЗ – БУДУЩЕЕ ДОНЕЦКОГО УГОЛЬНОГО БАССЕЙНА

Донецкий каменноугольный бассейн имеет многовековую историю исследований, обусловленную уникальной угольной сырьевой базой и экономическими вызовами, связанными с его крупномасштабной эксплуатацией. В Донбассе идентифицирована единая углеводородная система, которая охватывает весь разрез осадочных пород карбона и включает традиционные и нетрадиционные залежи газообразных углеводородов. Гигантское количество органического вещества в угольных пластах и вмещающих породах (от 1 до 6 триллионов тонн), достаточная степень его термального созревания (углефикации) обуславливают необходимость рассматривать Донбасс как крупнейшее месторождение центральнобассейнового типа с нетрадиционными коллекторами. Сделан вывод о хорошей сохранности углеводородных газов в породах угленосной толщи на глубоких горизонтах (пластичных сланцевых толщах и песчаниках), где низкая проницаемость отложений обусловила совпадение зон генерации и аккумуляции газа. Концентрация углеводородных газов в углевмещающих породах значительно меньше, чем в угле и в природных газовых месторождениях. Однако за счет объема этих отложений добыча метана при условии использования современных технологий становится экономически целесообразной.

Ключові слова: *Донецький басейн, вугільний метан, вуглеводнева система, низькопроникні вугленосні породи, пісковики, розсіяна органічна речовина, нетрадиційні газові поклади.*
Ключевые слова: *Донецкий бассейн, угольный метан, углеводородная система, низкопроницаемые угленосные породы, песчаники, рассеянное органическое вещество, нетрадиционные газовые залежи.*
Keywords: *Donets Basin, coal, methane, hydrocarbon, system, low-permeable coal-bearing rocks, sandstones, dispersed organic matter, unconventional gas accumulations.*

The energy policy of Ukraine is in a large part dependent on domestic coal production. The Donets Basin, also known as the Donbas, is a major coal-mining district in eastern Ukraine and adjacent portions of Russia. Needless to say, those both, conventional and unconventional hydrocarbon recourses are vital to our future. Because of the enormous coal resource base and the economical challenges associated with its large-scale exploitation, the Donets Basin has a centuries-long history of coal exploration. The Carboniferous section of the extremely thick sedimentary fill of the Donets Basin hosts one of the major coal fields in the world. The coal, subbituminous to meta-anthracite in rank contains variable, but generally very high methane contents.

The Donets coal Basin (Donbas) covers an area of 60.000 km^2 and it is located immediately southeast of the Dnieper-Donets Basin, one of the most mature oil and gas provinces of Ukraine. Both basins, the Donbas and the

Dnieper-Donets, are adjoining segments of large Late Devonian Pripyat-Dnieper-Donets-Karpinsky (PDDK) rift system situated at the southern part of the Eastern European craton. No doubts, that the Donbas is the most anomalous segment of the rift. Geologically, the basin stands out by its up to 20–24 km sedimentary column containing prolific coal-bearing measures and within domain of the Donbas Foldbelt (to east from the Donetsk-Kadievka deep fault), it is also characterized by prominent inversion-folding-thrusting patterns. Because of the enormous coal resource base and the economical challenges associated with its large-scale exploitation, the Donets Basin has been a major focus of coal exploration in former Russian Empire and Soviet Union, recent Ukraine and Russia for more than two centuries. Although the broad features of the Donbas are fairly well known, and despite fascinately growing commercial interest in coalbed methane resources, surprisingly little is known about the distribution of gas-prone low-permeability argillaceous and tight sandstone formations which have to be present over broad areas in the deeper part of the basin. In fact, these formations acted as both a source of gas and as its reservoir and maintained free gas in rock pores, natural fractures, and adsorbed gas on organic matter and mineral surfaces.

The primary focus of this contribution is to describe the potential for unconventional deep gas accumulation in the Donets coal Basin of eastern Ukraine.

In 3-D view, the Donbas is a deformed prismatoidal block located on the intersection of the NNW striking Early Proterozoic weak zone bracketed by MK (Mariupol-Kursk) and Lipetsk-Konstantinovsk (LK) lineaments within the Sarmatian segment of the East European Craton and the Late Devonian PDDK rift (Fig. 1).

Deep tectonic framework of the basin includes a set of NE striking basement transverse zones of lazy Z-shape geometry. The most prominent Donetsk-Kadievka and Elantchik-Rovenki transverse zones are expressed in a sedimentary cover by intensive shallow (2.5–3.5 km) faulting. Total thickness of Devonian pre- and syn-rift rocks is 750 m at the margins of the Donets Basin, but may reach 5 km along the basin center.

The Carboniferous sequence is subdivided into lithostratigraphic units named as suites. Most of suites, e.g. B (C_1^2), C (C_1^3), D (C_1^4), E (C_2^0 = former index C_1^5), F (C_2^1), G (C_2^1), F (C_2^2), I (C_2^4), K (C_2^5), L (C_2^6), M (C_2^7), N (C_3^1), O (C_3^2), P (C_3^3), consist of typical coal-bearing paralic measures, but the lowermost suite A (C_1^1) is represented entirely by Tournaisian-Early Viséan carbonate-dolomite strata.

The wide-scale industrial underground coal mining began in the Donets Basin in 1796. The Carboniferous basin fill hosts 330 identified coal seams and layers to a depth of 1800 m. The most of them are typically thin, but have a wide lateral distribution. Many charged up sandstones. Principal coal reserves are accumulated in seams 0.6 to 1.0 m thick. However, about 36% of coal reserves were identified in 12 seams more than 1.0 m thick. About 95.5% of annual Ukraine's hard coal production (72.22 Mt in 2009) is from the Donets Basin.

The coal-bearing strata consist of cyclic successions of marine, continental and transitional facies. An elementary sequence (20 to 40m thick) is composed of fluvial sandstone, coal seam, marine limestone or mudstone, and deltaic claystone or siltstone (Izart et al., 2006). Lower Serpukhovian coal accumulated in a relatively narrow shore-zone. It is rich in inertinite and liptinite and very low in ash. Bashkirian and Moscovian coal has a significantly wider lateral extension. Donbas coals are generally rich in vitrinite, with average contents of 81%. Inertinite and liptinite macerals have mean contents of 12 and 7%, respectively. Some Serpukhovian samples exhibit higher inertinite (up to 58%) and liptinite (26%) percentages (Sachsenhofer et al., 2003). High hydrogen and volatile matter contents suggest that the coal is oil-prone (Alsaab et al., 2007), an assumption which has been confirmed for Serpukhovian coals in the western part of the Dniepr-Donets Basin characterized by similar maceral compositions (Sachsenhofer et al., 2010).

Domal fault-breached structures along the northern marginal fault of the Donets Basin host conventional gas deposits in Bashkirian and Moscovian levels, whereas conventional gas occurs in Serpukovian levels in the southern Krasnoarmeisk and the Southern Donbas (Yuzhno-Donbassky) regions (Fig. 2).

There are large areas with high rank coals within the Donets Basin where no methane, but significant amounts of CO_2 occur (inset, Fig. 2). In the Dolzhansky-Rovenetsky region (most uplifted domain) the CO_2 content in some mines is up to 35 m^3/t coal.

Lower Visean deep seated black anoxic shales and carbonates are considered as principal source-rocks intervals for the Dnieper-Donets hydrocarbon system formation, however, the role of the Carboniferous coals as source rocks is still uncertain. The majority of discovered fields are in salt-cored anticlines or in drapes over uplifted blocks. Whereas oil deposits occur in its northwestern part of DDB, gas deposits prevail in the deeper central and southeastern sections (Ulmishek, 2001). Law et al. (1998) emphasize a significant potential for unconventional (basin-centered) gas.

Based on comparisons with the neighboring Pripyat Basin and limited available source rock data (e.g. Ulmishek, 2001), source rocks are located probably in the Devonian and Lower Carboniferous section of the basin fill. However, because these rocks are at considerable depth, information is rare (Ulmishek, 2001).

Recent studies (Sachsenhofer et al., 2010) have shown Serpukhovian horizons in the Dnieper-Donets Basin (DDB) include highly oil-prone source rocks with high TOC contents (up to 16 %) and HI values (up to 550 mgHC/gTOC). Biomarker characteristics argue for organic matter production and preservation due to planktonic blooms and the evolution of photic zone anoxia. Results of Rock-Eval experiments in the Donets basin (Privalov et al., 2005) have shown that the effective hydrogen index HI for coal seams range from 200 to 300 mgHC/gTOC and it is quite enough to serve as effective gas and oil prone source rocks. Fig. 3 exhibits in-

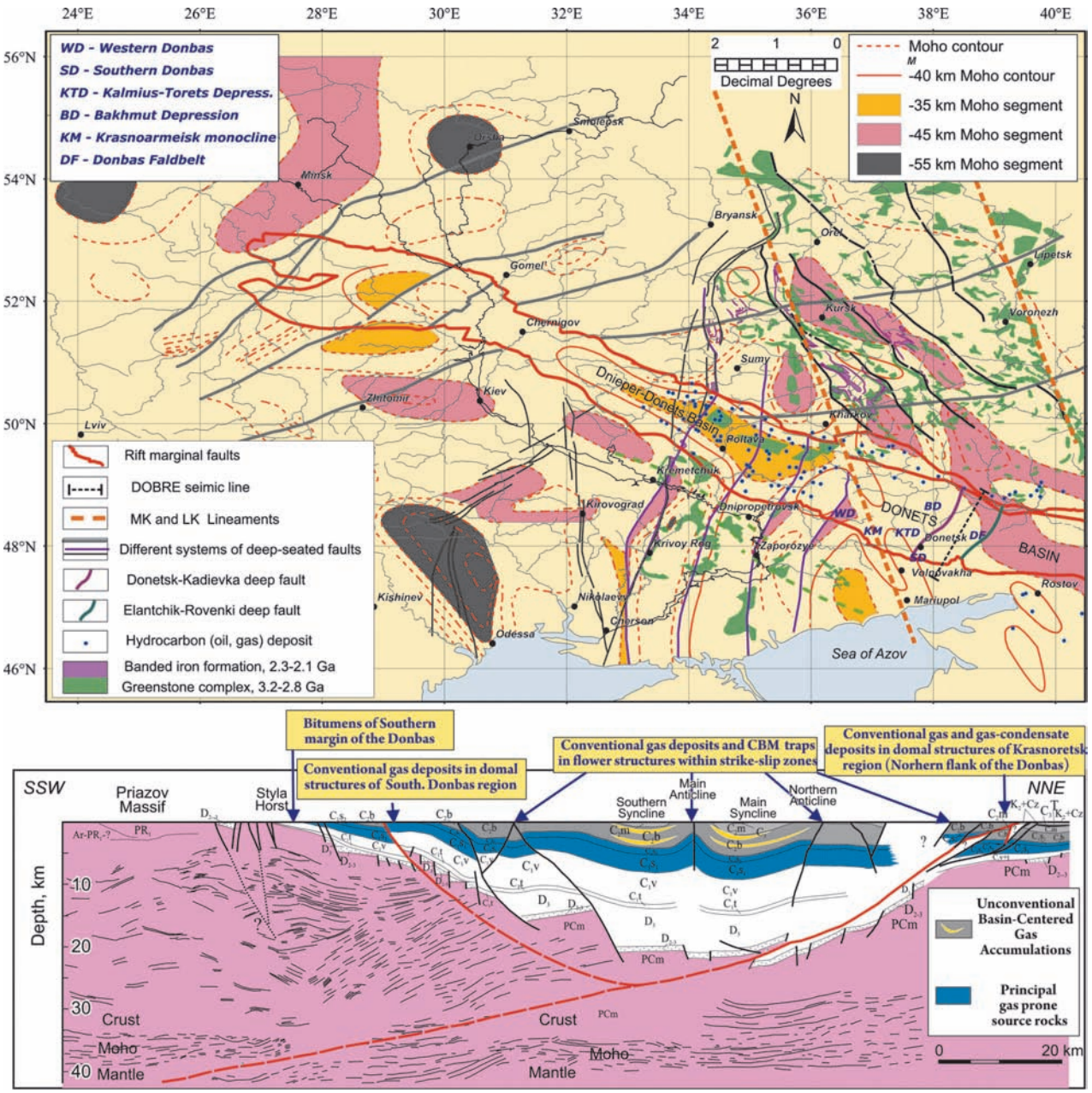

Fig. 1. Geostructural position of the Donets Basin within the Sarmatian segment of the East European Craton (Moho contours and deep-seated faults are shown; modified after de Boorder et al., 2006) and geological cross-section along DOBRE seismic profile (modified after Saintot et al., 2003) with indicated distribution of conventional and unconventional gas deposits

formation on the coal potential of the eastern part of the Dnieper-Donets Basin and the Donets Basin (Lazarenko et al., 1975), which is of a crucial importance for estimation of coalbed methane and conventional gas potential in the region.

The concentration of dispersed organic matter is varying in different lithologies (0.5 to 6% for mudstones; 0.5 to 16% for siltstones), however, for deltaic siltstones, lacustrine and marine mudstones HI values are in range of 50–200 mgHC/gTOC (Privalov et al., 2005). This suggests that some facial intervals from low-permeable clastic host rocks have significant gas generation potential.

There is a clear depth dependency trend of the gas composition and the gas pressure. Within the uppermost few hundred meters methane is often missing and N_2 and CO_2 are prevailing (gas weathering or "carbon dioxide-nitrogen" zone). Below this hypergenic zone a "methane" zone follows with methane contents increasing downwards in normally pressured rocks containing both gas and water. This zone is accompanying by coalbed methane entrapments and convenient reservoirs within sealed fault-breached anticline structures. From depth of 700–1000 m rocks are almost dry and gas volumes increase; some evidences of moderately abnormal pressure are recorded.

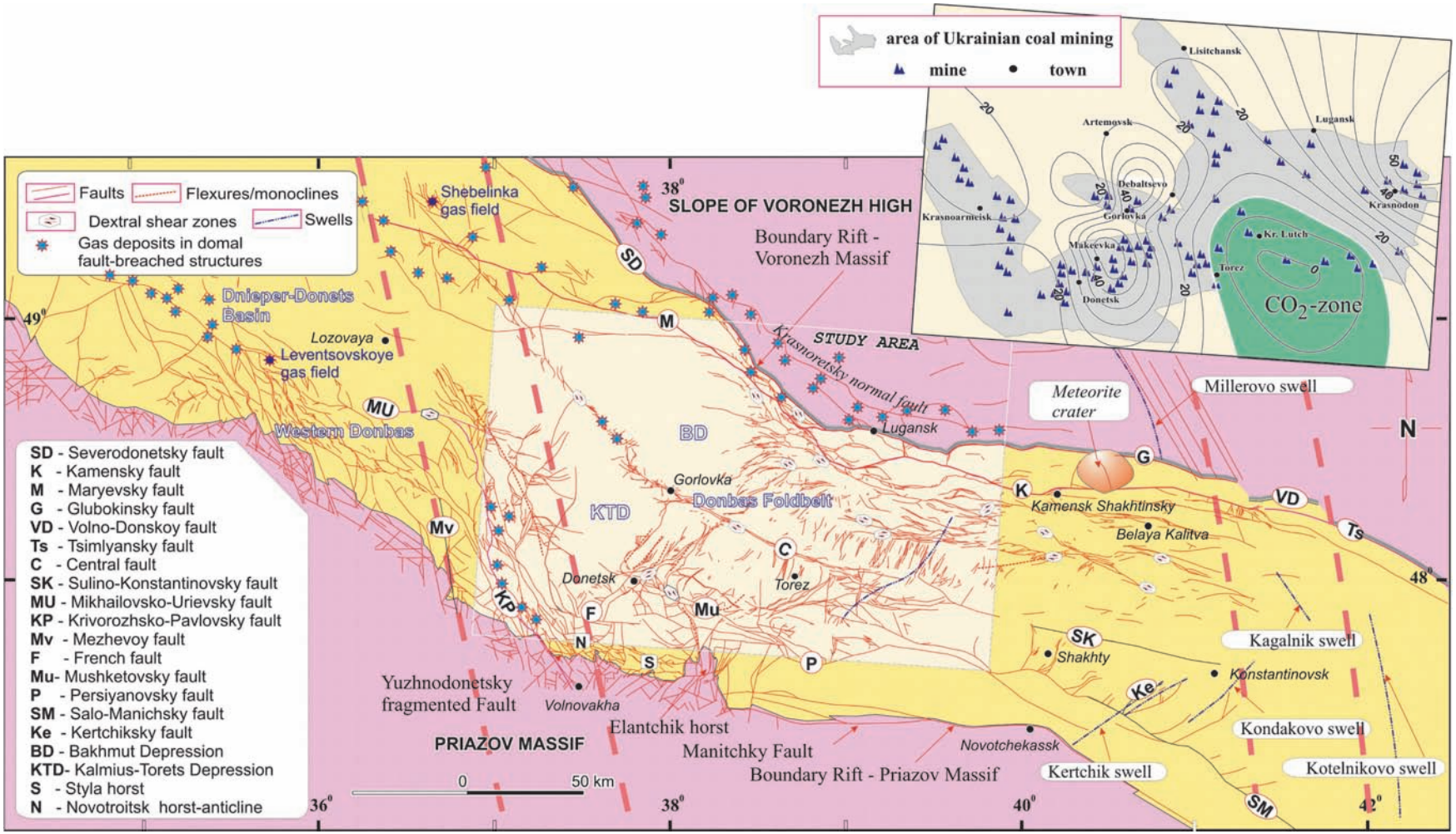

Fig. 2. Tectonic map of the Donets Basin. On the inset map of real observed methane content in coal mines (m^3/t of mined coal) at 1000m depth is shown

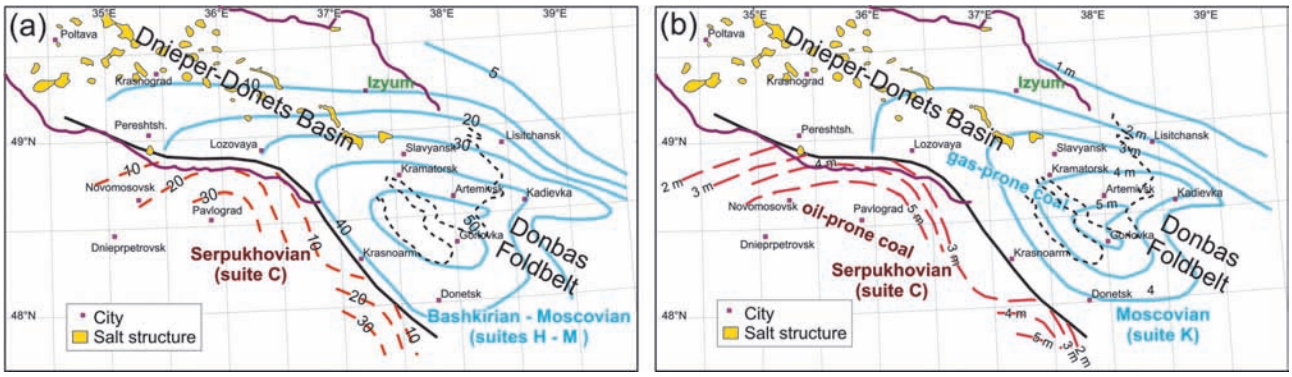

Fig. 3. Information on the coal potential of the eastern part of the Dnieper-Donets Basin and the Donets Basin: a) number of coal seams with a thickness >0.45 m. Blue lines represent Middle Carboniferous seams (suites H to M). Red (dashed) lines represent Lower Serpukhovian suite C; b) total thickness of coal seams with a thickness >0.45 m in the Middle Carboniferous suite K (blue lines) and in Lower Serpukhovian suite C (red dashed lines) (modified after Lazarenko et al., 1975)

Drilling data indicate that the Carboniferous section with low matrix permeability lithologies may be overpressured at depths below 1.7–2.0 km. The numerical basin modeling of the Ukrainian part of the Donbas indicates that Carboniferous coals and dispersed organic matter in coal-bearing measures are thermally mature in the deep basin and have generated large volumes of gaseous hydrocarbons in the South and the Main synclines, where Lower Permian seal rocks are preserved (Alsaab et al., 2008). These reservoirs contain primarily thermogenic gas. Gas from deep overpressured compartment and low-permeability levels may have escaped via several major fault and fracture zones or through outcrops along the margins of the basin (see Fig. 1).

The total amount of economically recoverable coalbed gaseous hydrocarbons in the Ukrainian Donbas is estimated by Antsiferov et al. (2004) as 800 Gm . High methane contents also provide a high potential for coal mine methane (CMM) and coalbed methane (CBM) projects. Highly charged gas tight sandstones occur throughout the basin.

Thus it is not surprising that many companies expressed an interest in developing CBM projects in the Donets Basin. To define sweet spots for CBM projects as well as to understand the distribution of gas in clastic sediments, it will be important to understand gas generation, adsorption, desorption and distribution in dependency of the basin tectonic and thermal history. Most of the Donbas coals exhibit some directional permeability, controlled by cleat systems and small displacement faults. Small displacement faults which caused dramatic obstacles for safe and efficient underground coal-mining have been traditionally interpreted in the Donbas as normal and/or reversed faults. However, most of them are concentrated within strike-slip zones with clear patterns of Riedel (R_1 and R_2), Y and P shears. These shears and related tectonically induced cleat systems usually align with directional stresses, more specifically, of strike-slip-compressional regime governed by NW-SE or NNW-SSE trending maximum stress axis.

It has been concluded (Privalov et al., 2005) that two inversion events (Late Permian and Cretaceous) have impacted negatively to methane preservation potential in brittle coal seams. On the contrary, intervals of deep-seated plastic gas-rich argillaceous shales and tight sandstones with low matrix permeability and low open porosity could keep considerable volumes of methane, even after inversion events.

To summarize, a single total gaseous hydrocarbon system encompassing the entire Carboniferous sedimentary succession is identified in the Donets Basin. Taking into account the unique concentration of proven reserves in the order of 60 Gt for workable coal seams at exploitable depth (Privalov et al., 2004), and, more specifically, tremendous mass of mostly originated from terrestrial plants dispersed organic matter (in range of 1 to 6 trillion tons), appropriate gas-generation window thermodynamic conditions over most of the basin area, we can conclude that there is a great opportunity of targeting here one of the biggest unconventional basin-centered gas deposits.

REFERENCES

1. **Alsaab D., Elie M., Izart A., Sachsenhofer R.F. and Privalov V.A.** Predicting methane accumulations generated from humic Carboniferous coals in the Donbas fold belt (Ukraine) // AAPG Bull. – 2008. – 92. – № 8. – P. 1029–1053.

2. **Antsiferov A.V., Tirkel M.G., Khoklov M.T., Privalov V.A., Golubev A.A., Maiboroda A.A., Antsiferov V.A.** Gas occurrence in the Donbas coal deposits (in Russian). – K.: Naukova dumka, 2004. – 232 p.

3. **de Boorder H., Zeylmans van Emmichoven M., Privalov V.A.** Distribution of Precambrian iron and gold deposits on the southwestern East European Platform reflected in underlying transcrustal structure and current river systems // Ore Geology Reviews. – 2006. – 29. – P. 242–259.

4. **Izart A., Sachsenhofer R.F., Privalov V.A., Elie M., Panova E., Antsiferov A., Alsaab D., Rainer T., Sotirov A., Zdravkov A., Zhykalyak M.V.** Stratigraphic distribution of macerals and biomarkers in the Donets Basin: Implications for paleoecology, paleoclimatology and eustacy // Int. J. Coal Geology. – 2006. – 66. – P. 69–107.

5. **Lazarenko E.K., Panov B.S., Gruba V.I.** The mineralogy of the Donets basin, 1 (in Russian). – K.: Naukova dumka, 1975. – 255 p.

6. **Privalov V.A., Sachsenhofer R.F., Panova E.A., Antsiferov V.A.** Coal Geology of the Donets Basin (Ukraine/Russia): An overview. BHM. – 2004. – 6. – P. 212–222.

7. **Privalov V.A., Antsiferov V.A., Panova E.A., Izart A., Sachsenhofer R.F.** Parameterization of organic matter from gas source rocks of the Donets Basin (in Russian). – Sc. Trans. of Donetsk Nat. TU. – 2005. – 96. – P. 137–145.

8. **Sachsenhofer R.F., Privalov V.I., Izart A., Elie M., Kortensky J., Panova E.A., Sotirov A., Zhykalyak M.V.** Petrography and geochemistry of Carboniferous coal seams in the Donets Basin (Ukraine): implications for palaeoecology // Int. J. Coal. Geol. – 2003. – 55. – P. 225–259.

9. **Sachsenhofer R.F., Shymanovskyy V.A., Bechtel A., Gratzer R., Horsfield B., Reischenbacher D.** Palaeozoic source rocks in the Dniepr–Donets Basin, Ukraine, Marine and Petroleum Geol. – 2010. – 16. – № 4. – P. 377–399.

10. **Law B.E., Ulmishek G.F., Clayton J.L., Kabyshev B.P., Pashova N.T., Krivosheya V.A.** Basin-centered gas evaluated in Dnieper-Donets basin, Donbas Foldbelt, Ukraine // Oil and Gas J. – 1998. – 96. – № 47. – P. 74–78.

11. **Saintot A., Stephenson R., Brem A., Stovba S., Privalov V.** Paleostress field reconstruction and revised tectonic history of the Donbas fold and thrust belt (Ukraine and Russia). Tectonics. – 2003. – 22. – № 5. – 1059; doi:10.1029/2002TC001366, 2003.

12. **Ulmishek G.F.** Petroleum Geology and Resources of the Dnieper-Donets Basin, Ukraine and Russia // U.S. Geological Survey Bulletin 2201-E, U.S. Department of the Interior U.S. Geological Survey, 2001: http://geology.cr.usgs.gov/pub/bulletins/b2201-e/