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Potential for Unconventional Deep Gas Accumulation in the Donets Basin, Ukraine

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SUMMARY

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. Single total gaseous hydrocarbon system encompassing the entire sedimentary succession is identified in the Donbas. 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 thermogenic gaseous hydrocarbons in deep-seated reservoirs. 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. Taking into account the unique concentration of coal reserves, tremendous mass of coaly dispersed in clastic rocks material, we can conclude that there is a great opportunity of targeting here one of the biggest unconventional deep basin gas deposits.

Introduction

The Donets coal Basin (Donbas) covers an area of 60.000 km² 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. The total amount of economically recoverable coalbed gaseous hydrocarbons in the Ukrainian Donbas is estimated by Antsiferov et al. (2004) as 800 Gm³. 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.

Methods

Interpretations and conclusions presented in this paper are based on comprehensive information from published sources and reports provided by the coal-mining industry and several research entities. The extensive database of deep parametric exploratory drilling combined data with results of deep seismic surveys in the Donbas were used to establish deep tectonic framework of the basin. Log data, structural mine-scale maps and sections, results of Rock Eval and confined pyrolysis experiments for quantification of gaseous hydrocarbons potential of coals and clastic rocks, geological and basin modeling information were available for this analysis.

Assessment for Non-Conventional Basin-Centered Gas Accumulations

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 (Figure 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. Being essentially a "solitary" block within continuous rift system, the Donbas responded much more sensitively to plate motion stresses accommodating them in strike-slip and reversed fault reactivations, block rotations within marginal master faults and the principal displacement zone in the centre of the Basin. Summary of stratigraphic records and important aspects of the basin evolution are shown in Figure 2. 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. 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.

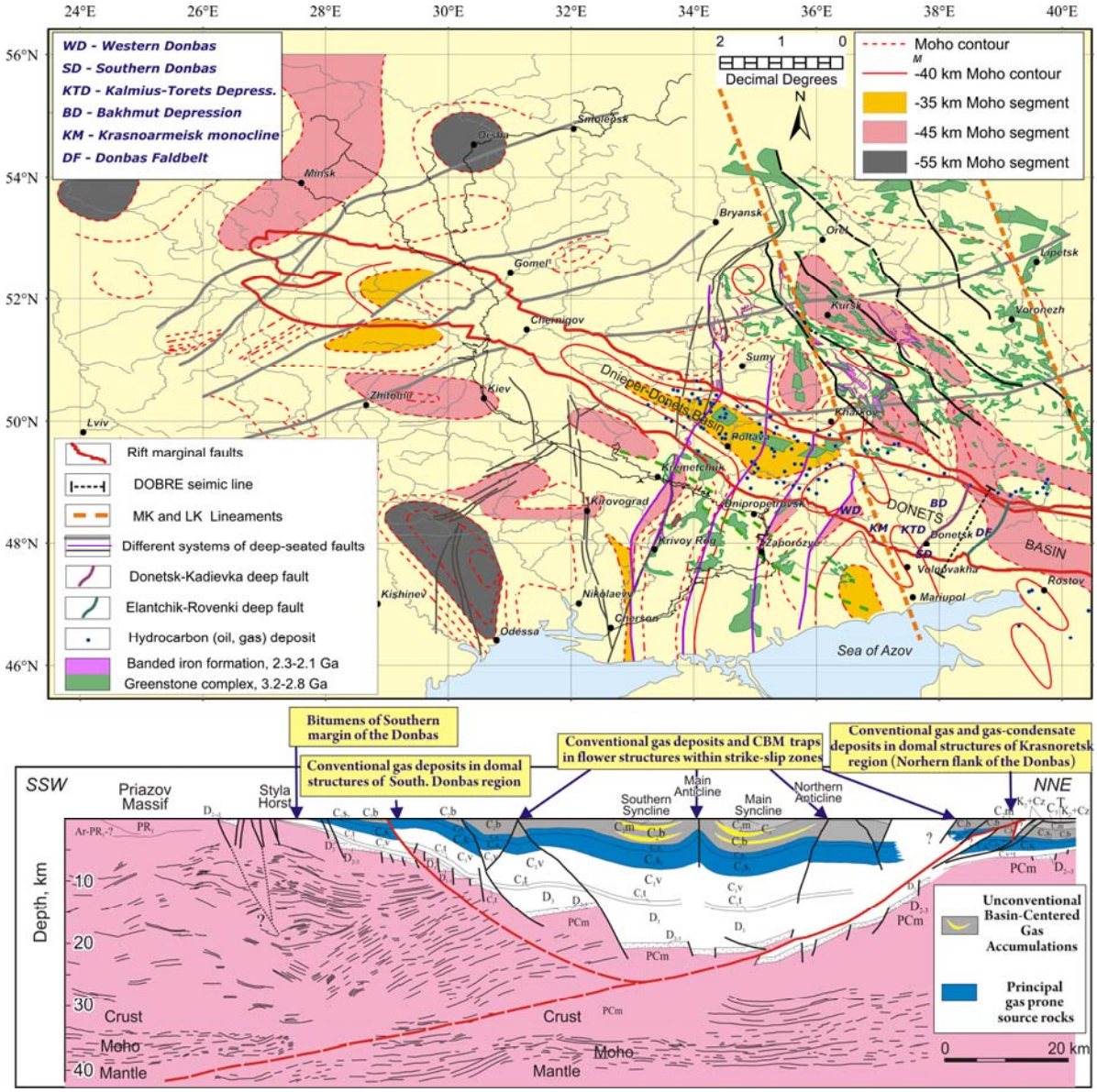

***Figure 1**: Geostructural position of the Donets Basin within the Sarmatian segment of the East European Craton (Moho contours and deep-seated faults are shown; modified after de Boorder et al., 2006) and geological cross-section along DOBRE seismic profile (modified after Saintot et al., 2003) with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

Figure 2, right, shows the detailed stratigraphic column of Moscovian rocks together with a number code for limestone layers (capital letters) and coal seams (small letters). For example, limestones of suite C_2^5 have indexes K_1, K_2, K_3, etc, coal seams – k_1, k_2, k_2^2, $k_3^{b+н}$, k_3^1, etc. 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). Total coal thickness in Carboniferous formations is about 60 m. 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).
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.

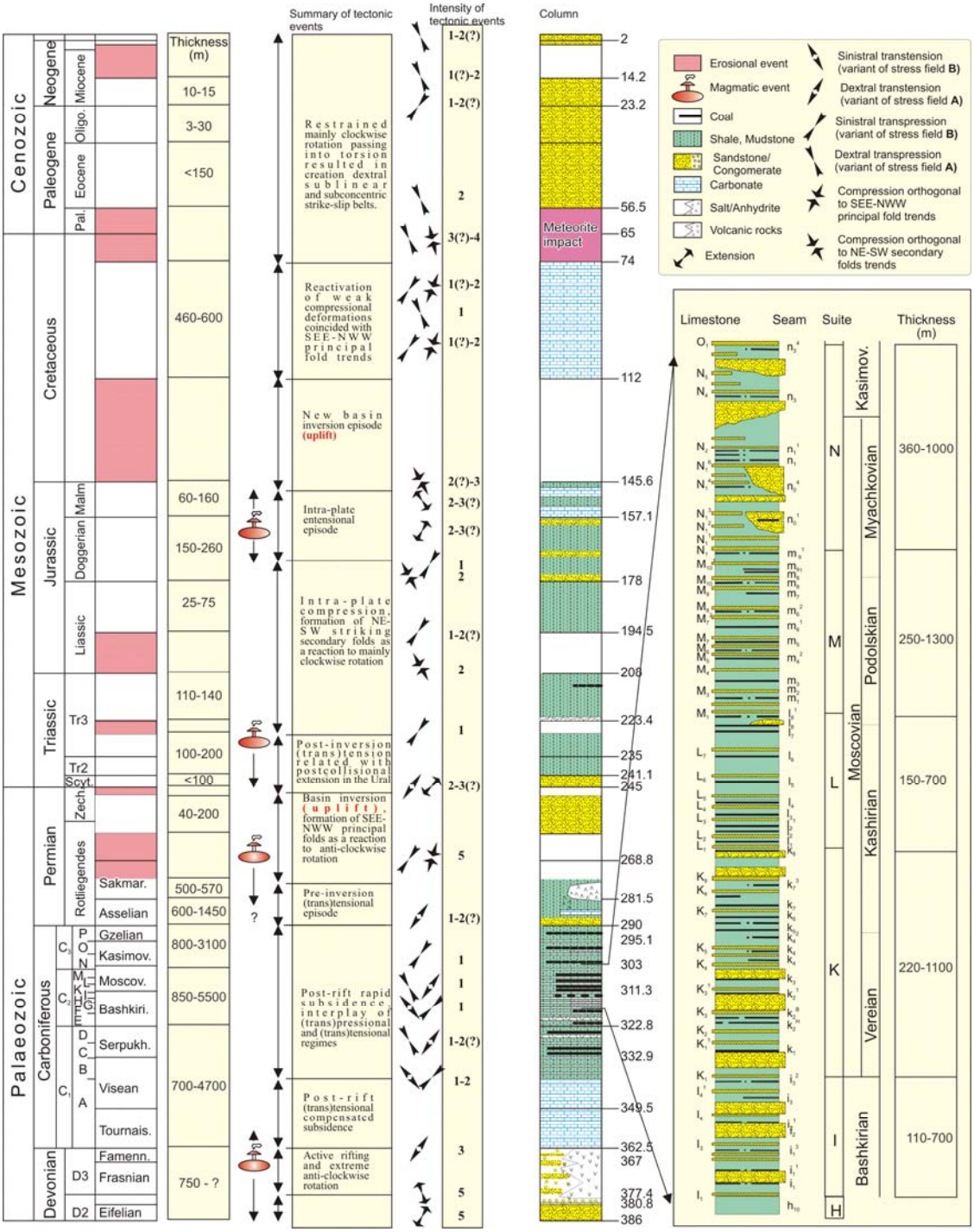

***Figure 2**: Summary of stratigraphic records, important aspects of the basin evolution and magmatic pulses in the Donbas.*

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.

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. 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 Figure 1). It has been concluded (Privalov et al., 2005) that two inversion events (see Figure 2) have impacted negatively to methane preservation potential in brittle coal seams. On the contrary, intervals of deep-seated plastic gas-rich argillaceous and tight sandy-aleurolitic rocks 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 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 Tt), 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.

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