

GEOLOGIC CONTROLS ON COALBED OCCURENCE IN THE DONETS BASIN (UKRAINE)

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ABSTRACT

The Donets Basin contains one of the major coal fields in the world. About 95.4% of Ukraine's coal production is from the Donbas. The Carboniferous (post-Early Visean) succession hosts more than 300 coal seams and layers (among them 130 seams with a thickness over 0.45 m). The coal rank patterns are controlled mainly by temperatures attained during deep Early Permian burial. The resulting coalification pattern was distorted and overprinted in some areas by thermal events related to these Late Permian - Triassic magmatic pulses. Thermal maturation of concentrated in coal beds and dispersed in the Carboniferous host rocks organic matter has led to formation of an enormous methane resource with retention potential after Permian uplift and inversion and following tectonic phases in range of 12-27 trillion m³. Almost the all coal fields of the Donets Basin excluding most eastern anthracite regions are characterised by high coal bed methane content (from 8-10 to 35-35 m³/t). Most of methane in coal beds is sorbed onto microporous surfaces of coal beds and dispersed coaly matter in rock massive. The significant methane resource is expected as result of conventional trapping related with gas migration and permeability contrasts of tectonic and lithological origin. Variations of methane content in coal beds and country rock massive in the Donbas reflect a consequence of events from kerogen breakdown to gas generation, migration and formation of reservoirs and local entrapments. Hydrocarbon and, more specifically, methane generation is a function of primary maceral composition, burial and thermal history. However, the final balance of retention of gas is critically dependant on timing of hydrocarbon generation pulses and their relationships with inversion episodes, and following temporal and spatial distribution of tectonic stress regimes.

The Donets Basin (Donbas) is one of the major late Palaeozoic coal and methane provinces in the world. Geographically, it is a 150 km wide, elongate region extending ESE for approximately 500 km from Eastern Ukraine (mainly Donetsk and Lugansk regions) into Rostov region of Russia. Geologically, the Donbas is located between the Dnieper-Donets Depression Basin and the buried Karpinsky Ridge within the limits of continuous Devonian rift system (Fig 1, a). Among the set of palaeorift structures the Donets Basin is the most anomalous segment: it stands out by its up to 24 km

sedimentary column with prominent inversion. The Donbas Fold-and-Thrust belt is an inverted part of the Donets Basin characterised by WNW-ESE trending folds and faults. The significant tectonic element of intrabasinal architecture is WNW-ESE trending principal displacement zone (PDZ) consisting of a set of dextrally *en echelon* arranged deep basement faults with oversteps superimposed on depressions (pull-aparts) in the basement (Fig. 1, b). During post-rift stage strike-slip pulses within PDZ affected local depositional environments in the vicinity of pull-aparts and influenced on depositional trends across the entire basin. Major post-rift subsidence occurred during the Carboniferous. In contrast with adjacent rift sectors in the Donbas during the long interval 290-340 Ma, extensive coal-forming environments have been developed periodically being autocyclically triggered by interplay of PDZ strike-slip motions and shuttle sign-variable rotations of the Donbas megablock. This caused recurrence from swampy coastal-marine plains with huge peatbogs to shallow sea environments and resulted in accumulation of thick (up to 14 km) paralic coal-bearing Carboniferous (post-Early Viséan) formation containing more than 300 coal seams and layers. In the Middle Carboniferous marine limestone layers, which depth of sedimentation did not exceed first dozens of meters, reiterate at regular basis every 10-100m, and sometimes rest directly on tops of coal seams.

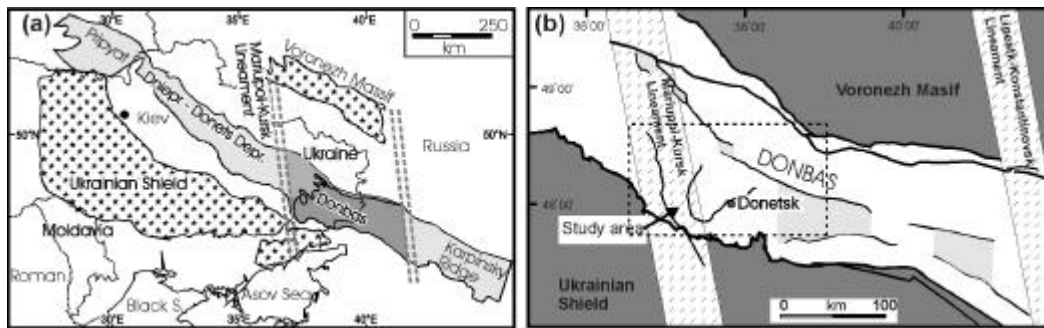


Fig. 1 - Location map. (a) Geostructural position of the Donbas. (b) Principal displacement zone (PDZ) of the Donbas.

The basin hosts significant economic accumulations of coal, methane and metals, and is, in fact, one of the most intensively explored in the Europe. About 95.4% of Ukraine's coal production is from the Donbas. The Carboniferous succession in the Donets Basin hosts about 130 seams with a thickness over 0.45 m. In the Ukrainian part of the Donbas occupying the area of 50,000 km², proven reserves of coal in the depth interval up to 1600 -1800 m are estimated at 52 Gt and additional resource base is considered to be 48 Gt. Mines are operating at depth ranging between 220 and 1380 m. The average coal mining depth is 620 m. Approximately 53% of the coal mined from the Donets Basin is from depth less than 600 m, 28% - from interval of 600 - 900 m, 16% - from interval 900-1,200 m. Ten mines are more than 1,000 m deep; their percentage in basin coal production is about 3%. In the most of regions the Carboniferous sequence contains from 10 - 14 to 30 - 40 workable seams. Major coal reserves are accumulated in coal seams with thickness

varying between 0.6 and 1.0 m, however, about 36% of coal reserves were identified in seams more than 1.0 m thick.

Coal seams and layers are present throughout the Carboniferous succession. However, lower Serpukhovian and Moscovian successions are especially rich in coal. Economic coal seams of suite C are mainly found in a narrow NW-SE trending zone along the south-western basin margin. Several NE trending rivers dissected the area with peat formation and discharged into a nearby shallow sea in the central Donets Basin. Moscovian seams have a significantly wider extent with some seams covering the entire Donets Basin.

The Donbas coals are mostly humic with sporadically located lenses and thin layers of sapropelic-humic origin. Serpukhovian and Moscovian seams differ considerably in terms of maceral composition: Serpukhovian coals contain higher amounts of liptinites and inertinites than Moscovian coals. High inertinite contents are interpreted to reflect relatively dry and cool conditions (Sachsenhofer et al., 2003). Moscovian coal is generally rich in vitrinite and accumulated in a tropical moist climate. The effective hydrogen index of Donbas' coal samples ranges from 200 to 300 mgHC/gTOC. This suggests that some seams can be considered gas- and oil-prone (Sachsenhofer et al., 2003).

Coal seams usually have high ash yields (12-18%) and high sulphur content (2.5-3.5%). However, in some regions (Donetsk-Makeevka, Krasnoarmeisk, etc.) coal seams with lower sulphur content (1.4-2.5%) are often reported. Coal properties vary widely in response to different peat facies.

The coal rank patterns are controlled mainly by temperatures attained during deep Early Permian burial. Using numeric models, Sachsenhofer et al. (2002) estimated Permian erosion to be in the order of 2 to 3 km in the Krasnoarmeisk Monocline and the Kalmius-Torets Depression, but 4 to 6 km east of the Donetsk-Kadievka fault zone. These results (Fig. 2) agree with estimates by Nagorny and Nagorny (1976), who assume erosion of up to 11 km thick rocks along the central part of the Donets Basin.

While extensive syn-rift magmatism occurred in most of the Dnieper-Donets Depression Basin, post-rift magmatic rocks have been described only in the Donets Basin. They include Permian (~280-270 Ma) alkaline rocks southwest of Donetsk, which intruded during early basin uplift.

The post-rift phase was characterised by relatively thin unconformity-bounded sedimentary sequences. Magmatic events occurred during tensional to trans-tensional stages and produced Triassic (~230-200 Ma) trachyandesites and Jurassic (~155 Ma) lamprophyres (Lazarenko et al., 1975). Using magnetic data, deep seismic sounding data and field observations, Aleksandrov et al. (1996) mapped large hidden intrusions and their hydrothermal haloes in the western Donets Basin. The authors advocate for a late Permian- Triassic age of the intrusion. The resulting coalification pattern was distorted and overprinted in some areas by thermal events related to these Late Permian - Triassic magmatic pulses (Privalov et al., 2001; Sachsenhofer et al., 2002).

Thermal maturation of concentrated in coal beds and dispersed in the Carboniferous country rocks organic matter has led to formation of an enormous methane resource about 278 trillion m³ (Uziyuk et al., 2001), which retention potential after Permian inversion and Cimmerian-Alpine tectonic

of which is believed to be fully recoverable, because these have been estimated for coal seams with gas content above 10 m³/t.

In spite of serious diminishing of annual coal production coal mines in the Ukrainian Donbas are still venting more than 2 billion m³ per year of methane into atmosphere. Methane emissions also occur from closed mines. In the global warming sense the significance of methane emissions, liberating during or after coal mining, has focussed attention on how to minimise or utilise such emissions.

The formation of gas hydrocarbons took place during geological evolution of Donets Basin due to multifold processes, including: i) thermal decomposition of organic matter in peatification and coalification stages; ii) bacteriogenesis related with favourable environments for fermentation processes within reasonably heated and moistured fractured zones; iii) polymerisation reactions in dispersed organic matter "attacked" by deep hydrogen and Carboniferous dioxide vents triggered by tectonic pulses in Latest Hercynian and Cimmerian stages.

Variations of methane content in coal beds and country rock massive in the Donbas reflect a consequence of events from kerogen breakdown to gas generation, migration and formation of reservoirs and local entrapments.

It has been concluded (Privalov, 2002), that hydrocarbon and, more specifically, methane generation is a function of primary maceral composition, burial and thermal history. However, the final balance of retention of gas is critically dependant on timing of hydrocarbon generation pulses and their relationships with inversion episodes, and following temporal and spatial distribution of tectonic stress regimes.

First and principal pulse of gas generation in the Donbas occurred mainly during the Carboniferous and Early Permian deep burial on the background of heat flow in range of 40-75 mW/m² (fig. 2).

A major part of the Donets Basin (so-called Donbas Fold-and-Thrust belt) has been uplifted dramatically and deformed with prominent NNE-SSW shortening grain during the latest phases of Hercynian orogeny. This was in response to stresses generated by convergence of plates in the Ural orogenic belt, transmitted to the Donbas region and re-actively amplified here because of sinistral shearing and following anti-clockwise rotation of the Donbas megablock. The basin uplift and compressive deformations caused intensive gas migration and even partial loss. However, the significant volumes of gas were retained in dilatational domains and bends. Second gas generation phase postdates maximal burial time and Permian inversion and is an inevitable result of Late Permian-Triassic thermal event, which epicentres at level of 125-200 mW/m² appear to be associated with releasing sectors along the PDZ and rotational jogs on the boundaries of transversal deep faults.

The secondary Early Cretaceous uplift episode affected mainly the south-eastern margin of the basin. During this event the full de-methanisation of anthracites adjoining Rostov block (Russia) took a place, and sorption niche in this region was re-occupied by carbon dioxide. However, on the rest of the Donbas region (mostly the Ukrainian part), Cimmerian and Alpine tectonic events resulted in sectorial syn- or transpressional reactivations of reversed, normal and lateral slip movements on fault planes, deplanation of already deformed strata surfaces, formation of linear and subconcentric shallow dextral shear belts superimposing onto principal Hercynian structural trends in

the sedimentary cover. These processes provoked new coal-bed methane short-track migration pulses and enhanced a role of multifold and multistage trapping within fractured and sealed secondary reservoirs.

For example, during intra- Early Permian inversion (Uralian stage) northern part of *Krasnoarmeisk region and Tchystyakovo-Sneznyansky region* were under conditions of compression. Most pre- inversion thermogenic hydrocarbons was lost because of inversion. However, some gas was trapped in local dilatational domains (tension cracks on bottom parts of synclines, synform-deformed footwalls of thrusts). During Late Permian - Triassic (Pfalzian stage) these regions have been under local extension conditions. As result, the thermal event probably related with deep magmatic intrusions and new methane generation pulse took place. Most of the high methane content here (above 40 m³ per tonne of extracted coal mass) are because of post-inversion generation (Privalov, 2002).

In *Donetsk-Makeevka region* gas generation potential for Serpukhovichian deposits has been completely used during the Carboniferous burial, meanwhile in Bashkirian, Moscovian and Kasimovian gas generation occurred in the Early Permian too. During the Uralian stage this region has experienced local extension conditions and shallow listric normal faults were formed. Gas was migrating from depth along faults to the surface until this process was locked by on-going compressive deformations (Pfalzian phase) and reversed movements along fault planes. As result, most of retained gas accumulations are structurally focused onto crests of high hinges on monoclines, flexures and hangingwalls of reversed faults with strong respect on lithologically related permeability contrasts (Brizhanyev and Galazov, 1987). In course of the Cimmerian-Alpine tectonic epoch prevailing local (trans)pressive conditions and induced rotation of cleat-bounded clusters in the vicinity of strike-slip faults and thrusts have provided significant basis for good preservation potential of gas within coal seams and extreme danger of underground hazards, e.g. gas-and-coal outbursts (Panova and Privalov, 2001). Within *Yuzhno-Donbasky region* and southern part of *Krasnoarmeisk region* which had been developed in tectonic synchronism with Donetsk-Makeevka region there are many comparable features of methane distribution. Gas accumulations are gravitated to dome structures. High intensity methane fluxes are mapped under fault zones.

New geodynamic model (Privalov et al., 1998) explaining the origin and evolution of Donetsk basin sector within continuous Pripyat-Dnieper-Donetsk-Karpinsky palaeo-rift system in terms of strike-slip basin model and shuttle block rotations demonstrated and proved the significance of local extension domains along a set of dextrally *en echelon* arranged deep basement faults with oversteps superimposed on depressions in the basement. During dextral strike-slip reactivations these oversteps served as pull-apart basins and significantly influenced on permeability of deformed Carboniferous coal measures. These dextral reactivations can also modulate repeated fluid (Privalov, 1999) and heat flow pulses (Sachsenhofer et al., 2002) from a common deep magmatic source - large mantle (Lazarenko et al., 1975) beneath the Basin into weak released domains. In particular, very promising results of delineating areas suitable for commercial methane production were obtained for structural highs within Druzhkovka-Konstantinovka (DK) anticline to the west from pull-apart PA3.

In contrast, results of detailed prospecting works within the study area show an average low levels of porosity of Carboniferous sandstones (from 2 - 5 to 9 - 13 %) and permeability of coal seams and country rocks (0.05 - 0.1 mD) (Zhykalyak, 2002). Because of dynamic interplay of regional structural setting characteristics and local on-site tectonics and permeability contrasts, much more attention needs to be given to delineating and detailed 3-D mapping of specific areas in the basin that contain large strata gas resources. Additionally, these can provide a reasonable basis for: i) successful and efficient degasification of coal mine fields; ii) choice of technologies for mitigating fugitive methane emissions; iii) accessing the real potential of CBM commercial production.

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