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Structural Controls on the Formation of Coalbed Methande Accumulations in the Donets Basin

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SUMMARY

The Donets Basin (Ukraine/Russia) contains one of the major coalfields in the Europe. Thermal maturation of concentrated in coal seams and dispersed coaly mass has led to formation of an enormous methane resource. The hydrocarbon system of the study area has a strong structural component in relation with releasing jogs within the intrabasional principal displacement zone (PDZ). Results of 2-D numerical models were used to reconstruct gas migration routes and to localize deep-seated methane accumulation zones. We inferred that the higher amounts of trapped methane are located at 4 km depth with estimated maximum values of 38 Mt of methane within the junction of the Kalmius-Torets and Bakhmut Depressions with strong structural control by non-inverted pull-apart jogs. During multiple Cimmerian-Alpine dextral reactivations of PDZ these jogs had been served as dilatational domains and the most favorable places for localizing of abnormal heat flows and hot fluids transport responsible for thermogenic gas generation with further trapping in high-permeability and fractured secondary reservoirs.

Introduction

The Donets Basin or the Donbas (Ukraine/Russia) contains one of the major coalfields in the Europe. Coal seams and layers are present throughout the post-Early Visean Carboniferous succession, which maximum thickness is range of 14 km. 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 (10m thick, 10% porosity), coal seam (1-2m thick), marine limestone (1m thick) and claystone (10m thick) and deltaic siltstone (10m thick). 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. Total coal thickness in Carboniferous formations is about 60 m. The coal rank is controlled mainly by temperatures attained during deep Early Permian burial (Sachsenhofer et al., 2002). The resulting coalification pattern was overprinted in some areas by post-inversion thermal event. Modelling of the fission track data, combined with modelling of vitrinite reflectance data, revealed that some parts of the basin were affected by a Permo-Triassic (~250 Ma) heat flow event (Spiegel et al., 2003), which was related to post-inversion andesitic magmatism.

Thermal maturation of organic matter OM (~10^{12} t of coaly mass) has led to formation of an enormous methane resource ~$278*10^{12}$ m^3, which residual potential after Permian inversion and Cimmerian-Alpine tectonic events is estimated in range of $(12-27)*10^{12}$ m^3.

The primary focus of this contribution is to find possible structural controls on the formation of large methane accumulations with special emphasis on the results of 2-D models of hydrocarbon generation and delineating of migration gas routes.

Methods

The extensive database of mine-scale drilling combined data with results of deep seismic surveys) in the Donbas were used to establish deep tectonic framework of the basin. PetroMod software was used to reconstruct the burial and thermal history of the DF and to model hydrocarbon generation, migration, and trapping. Using stratigraphic, structural, petrophysical, and organic geochemical data, 2-D numerical models were developed along 6 section lines within the study area (Figure 1).

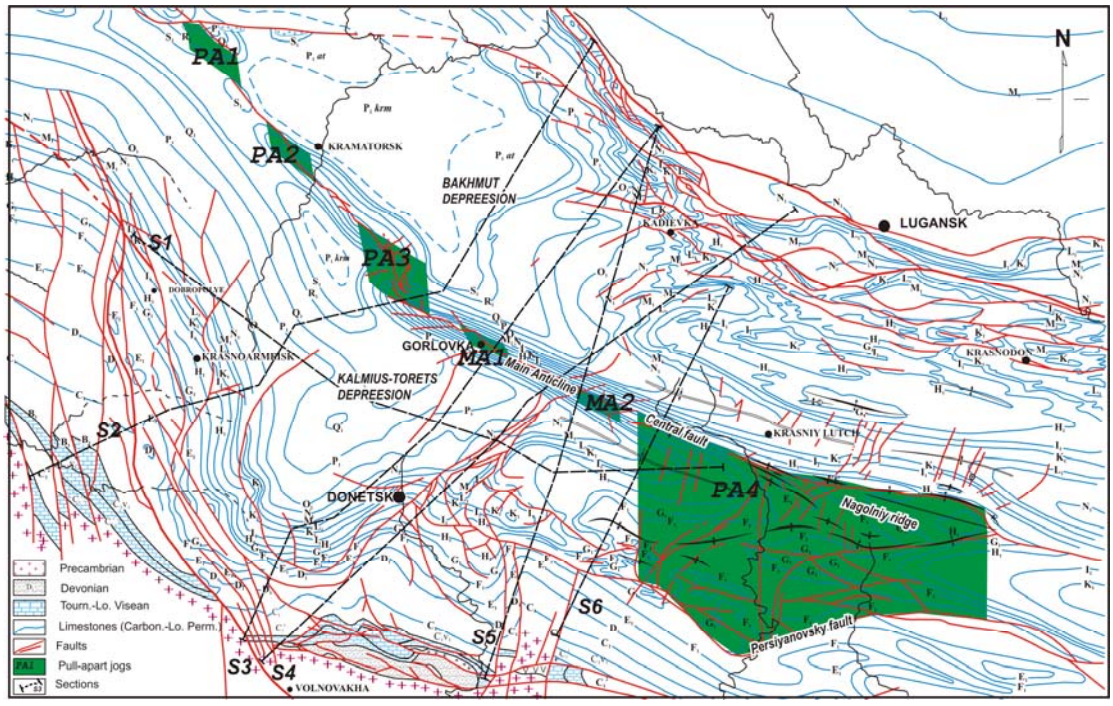

***Figure 1**: Geologic map of the study area - the Donets Basin in the southeastern Ukraine (modified after Popov, 1961; Privalov, 2001).*

Geological setting and deep tectonic framework

The structure of the Donbas Fold-and-Thrust Belt (DF), which is the inverted part of the Donbas Basin, is dominated by WNW-ESE trending linear folds in the central part of the basin (Figure 1). Major thrusts occur along the northern margin of the basin in the limits of a zone of the Northern SSW-dipping deep fault, which is rooted in the Moho. The Southern margin of the basin is represented by a set of adjoining horst - graben structures within a zone of the Southern NNE-dipping deep fault. Minor folds, reversed faults with significant and even dominating strike-slip displacement components, rotated fault blocks occur between zones of marginal deep faults and central zones of linear folds.

The important tectonic element of intrabasional architecture is the WNW-ESE trending principal displacement zone (PDZ) (Privalov, 2001) consisting of a set of dextrally *en echelon* arranged deep basement faults with overstepping jogs of a different scale or pull-aparts of megascale *PA* and mezoscale *MA* (Figure1). Some of them, jogs of megascale (excluding the most inverted Nagolniy Ridge jog *PA4*) coincide with depicted after seismic records depressions in the crystalline basement with depth in range of -20... -24 km. The jog *PA4* is located within restraining stepover structure of the Nagolniy Ridge on the junction of Central and Persiyanovsky faults, where the crystalline basement lies at a depth of -14…-16 km (Belokon, 1975).

However, taking into account the fact that here the oldest in axial part of the Main Anticline Upper Serpukhovian sediments are outcropped (i. e. in the present-day plan this jog *PA4* is uplifted in relation with the jog *PA3* at least on 6.3 km), we have to suggest the existence there in the pre-inversion stage the depression of comparable depth and mechanism of formation (Figure 2).

The most prominent deep fault within PDZ is expressed in Palaeozoic strata as the Main Anticline, which is the largest and most pervasive fold with steeply dipping limbs, complicated by faults developed at its hinge, in which strike-slip movements have been recognised. The documentation of kinematic indicators within faults under deep structure of the PDZ attests to an existence of sign-variable dextral and sinistral strike-slip displacements as in pre-folding (before tilting) and following stages of the structure development. We recorded the principal dominating of dextral reactivations in stage before folding; sinistral reactivations in the inversion moment and following forming of the main fold trends of the Basin; dextral reactivations in the moment of forming of shears and oblique horst-anticline compressional slices hosting mercury-antimony deposits on the west ending of the Main Anticline and dilational jogs (pull-aparts of mezoscale) and releasing bends with gold-polymetallic mineralization at the Nagolniy Ridge; the latest dextral reactivations during the time of forming linear sub-concentric strike-slip zones in the basement and sedimentary carapace due clock-wise torsion.

Results and discussion

CBM accumulations were formed in the Donets Basin during a number of different phases (Privalov, 2002; Privalov et al., 2004 (a); Privalov et al., 2004 (b); Alsaab et al., 2008 (a); Alsaab et al., 2008 (b)):

i) the first phase of formation of primary pre-inversion methane deposits took place in the Carboniferous - Early Permian. This occurred before the Permian uplift and resulted from an intensive gas-generating process due to suitable thermic conditions and to the richness in the OM of Carboniferous formations, and that was combined with sedimentation;
ii) the second phase occurred in the Carboniferous formations during the Late Permian inversion, when a major part of the DF has been uplifted and deformed dramatically during the latest phases of Hercynian orogeny. This contributed to intensive redistribution of gases in the sedimentary rocks and to the escape of the major part of gas deposits;
iii) the third phase of post-inversion methane generation related with thermal affects of post-inversion Late Permian-Triassic magmatic intrusions;
iv) the forth phase of new coalbed methane short-track migration pulses and enhanced a role

of multifold and multistage trapping within fractured and sealed secondary reservoirs during Cimmerian and Alpine tectonic events resulted in multiple fault reactivations, deplanation of already deformed strata surfaces, formation of linear and subconcentric shallow dextral shear belts in the sedimentary cover.

The actual methane accumulation zones suspected in the DF were simulated by basin modeling. The present-day methane amounts accumulated in Carboniferous coal-bearing strata were evaluated for the cross-sections S1, S2 and S6 (Figure 2).

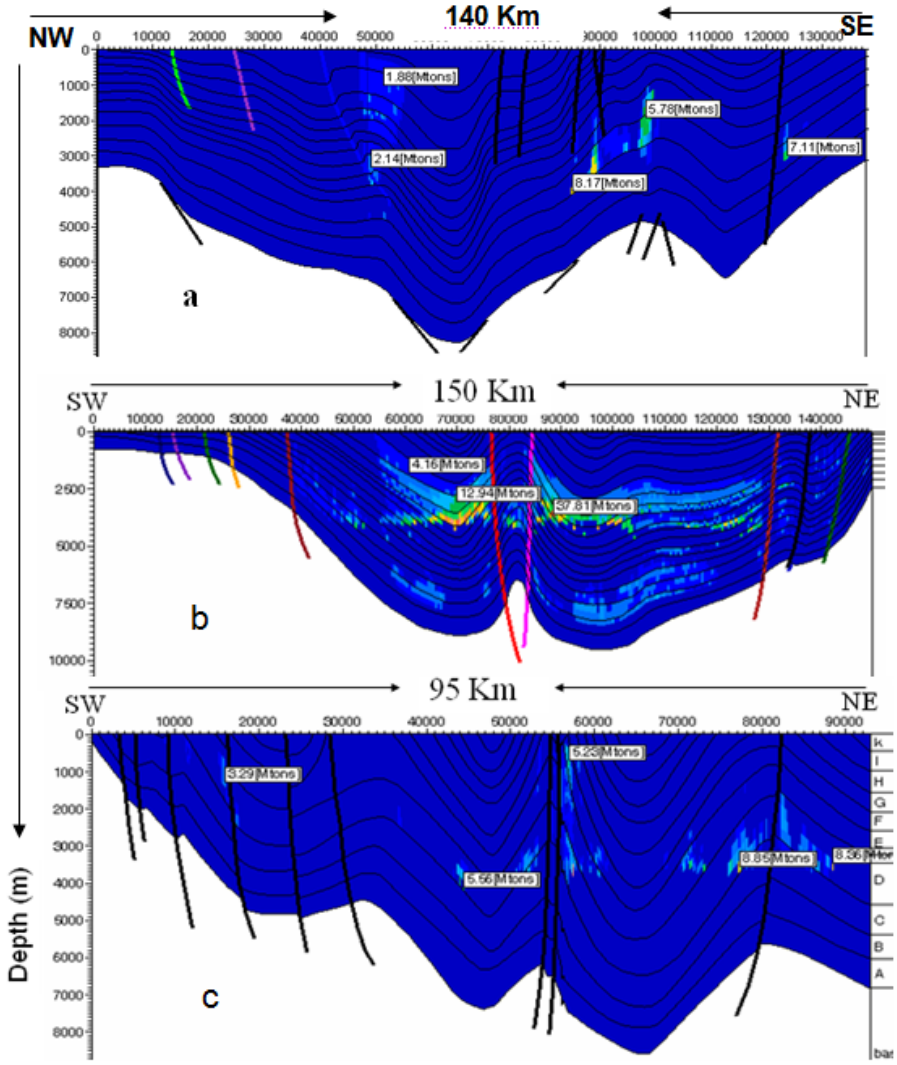

***Figure 2**: Models of gas saturation in potential reservoirs in cross-sections (a) S1, (b) S2, and (c) S6. Data are in Mt.*

Cross-section *S1* displays two methane accumulation zones that are closed to the transverse Donetsk-Kadievka deep basement fault with amounts in the range 5–8 Mt of methane (Figure 2, a). Cross-section *S2* is the richest cross-section in methane reservoirs, especially in the Kalmius-Torets and Bakhmut Depressions with amounts from 4 to 38 Mt of methane (Figure 2, b). Cross-section *S6* is located in the anthracite zone of the Donbas Foldbelt (Figure 2, c). Three main methane accumulation zones are predicted in the southern part close to faults, in the zone of Main Anticline and in the northern part close to fault and anticline with amounts of 3-9 Mt of methane. The methane reservoirs were simulated for all other cross-sections to construct iso-methane accumulation maps at 4 km of depth.

Figure 3 shows that the higher amounts of trapped methane are located at 4 km depth with estimated maximum values of 38 Mt of methane within the junction of the Kalmius-Torets and Bakhmut Depressions with strong structural control by non-inverted pull-apart jogs *PA3*,

MA1 and *MA2*. During multiple dextral Cimmerian-Alpine tectonic reactivations of PDZ these jogs had been served as dilatational domains and the most favorable places for localizing of abnormal heat flows and hot fluids transport responsible for thermogenic gas generation with further methane trapping in high-permeability and fractured secondary reservoirs.

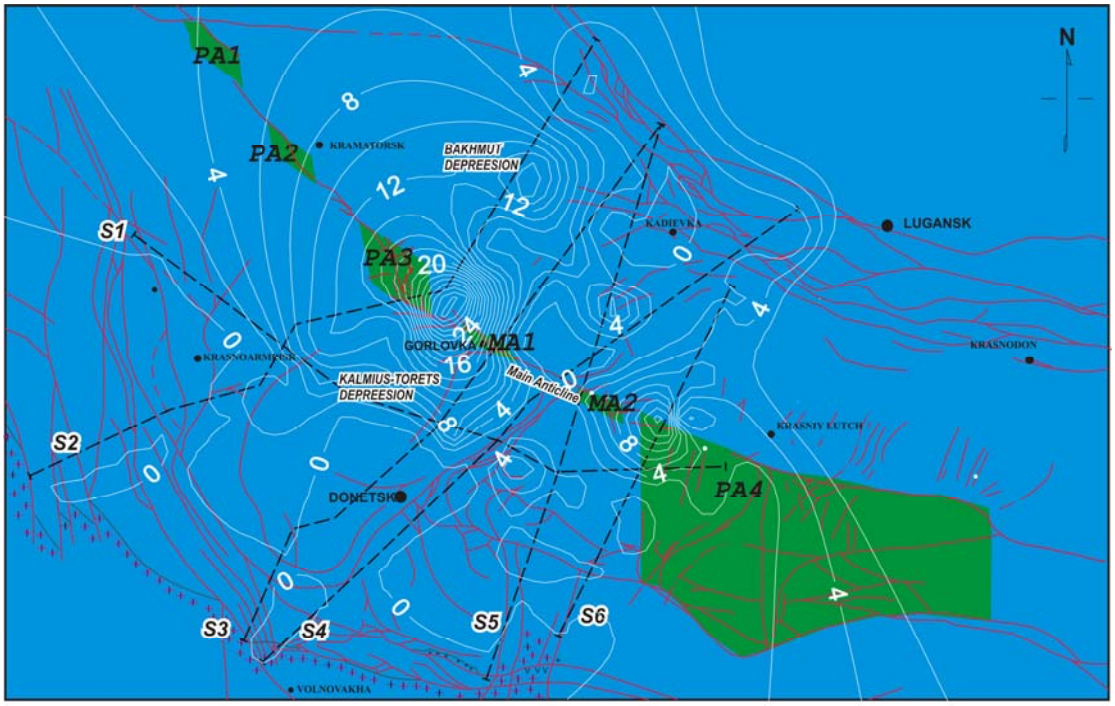

***Figure 3**: Predictive model of natural gas trapped in the Donbas Foldbelt at a depth of 4 km. Data are in Mt.*

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