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Strike-slip Faulting and Block Rotations in the Donets Basin

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SUMMARY

Although abnormal tectonic evolution of the Donbas segment within the Pripyat-Dnieper-Donets-Karpinsky (PDDK) palaerift has been long time recognized and studied, the driving mechanisms and mechanics of the basin uplift and inversion remain poorly understood. In 3-D view, the Donbas is a deformed prismatoidal block located on the intersection of the NNW striking Early Proterozoic weak corridor zone within the Sarmatian segment of the East European Craton and the Late Devonian PDDK rift. In our approach we consider the role of strike-slip and rotational deformations in controlling the distribution of releasing-restraining jogs and generating of re-active compression stresses responsible for formation of the Donets Foldbelt pop-up structure. Our constraints are based on the analysis of an extensive database of subsurface and underground geological information in combination with existing geophysical information.

Introduction

In the course of two past centuries, the Donets Basin (Donbas) has been in the focus of geological interest mainly of the enormously high potential of its coal Carboniferous deposits. The Basin hosts also one of the largest mercury-antimony districts of Europe. The interest in the deeper levels of the Donbas has arisen from multiple showings of led-zinc-gold mineralization in the coal measures and speculations about the Basin's oil and gas potential. In gross structural terms, the Donets basin is the most anomalous segment of the Pripyat-Dnieper-Donets-Karpinsky (PDDK) Late Devonian rift located on the south-eastern part of the East-European Craton (EEC). On the different maps of geological and geophysical profile the Donbas is shown as the contrast anomaly. The prominent axial Moho high of the Dnieper-Donets Basin is not observed in the Donbas segment, which stands out from all segments of PDDK rift by its up to 20-24 km cyclically-formed sedimentary column and its prominent, kilometer-scale, uplift and well-pronounced inversion at the area of the Donets fold-and-thrust belt (DF). There are still no consensus in tectonic scenarios and driving mechanisms responsible for the abnormal geological behaviour of the Donbas segment within the continuous rift system. The primary focus of this presentation is to present new constraints of the basin geometry and kinematics on the basis of the model of interplay between localised domains of extension-subsidence and contraction-uplift caused by strike-slip and rotational deformations within the Donbas megablock. Our constraints are based on the analysis of an extensive database of subsurface and underground geological information in combination with existing geophysical information.

Structural setting and tectonic patterns of the Donets Basin

The PDDK aulacogen formed during Late Devonian break-up of the Sarmatian protoshield and sandwiched the Ukrainian Shield (UkS) and the Voronezh Massif (VM) as relicts of the protoshield. The structural patterns of the Precambrian in the UkS the VM are generally agreed to be very similar. Continuity of Precambrian structures in the limits of the Sarmatian crustal segment beneath PDDK rift has been demonstrated in a study by *Schipansky and Bogdanova (1996)*. At the area of the Donets Basin part, Late Archean terrains within the Voronezh High of the VM and the Priazovian Block of the UkM were reworked in the Early Proterozoic orogenesis. This has been resulted in formation of a number of subsequently inverted and eroded trough-type elongated basins with predominant NNW striking grain. In fact, these are not randomly distributed. Many of them cluster along a discrete NNW-trending corridor bracketed by two transcrustal Mariupol-Kursk (MK) and Lipetsk- Konstantinovsk (LK) lineaments *(Privalov, 1998)*. Northward to the Donbas these patterns stand out very clear through prominent bends of major rivers where they enter and leave the rift zone. Across the MK lineament and within the rift the Moho is vertically displaced by about 5 km, from ca. -35 km in the Dnieper-Donets Depression segment in the west to -40…-45 km in the Donbas to the east *(de Boorder et al., 2006)*. The LK lineament expressed at the VM in the Losev-Mamonov fault zone *(Uskov, 1971)* and can be traced to a depth up to 20 km as the tectonic bound between blocks of different crustal composition *(Kashubin et al., 1996)*. Within the rift this lineament coincides with termination of the Carboniferous paralic coal-bearing typical for the Donbas formation and its transition into the Carboniferous mostly marine succession in the Karpinsky swell. The corridor initiated as a boundary between contrasting crustal blocks represents a particularly weak zone within the Craton. It plunges beneath the Donbas segment of the PDDK rift and appears to propagate beyond the southern margin of the EEC into orogenic terranes of the Trans-Caucasian transverse uplift, possibly because it acted repeatedly as a stress concentrator during collisional tectonic events.

The structure of the Donbas Foldbelt, which is the inverted part of the Donbas Basin, is dominated by WNW-ESE trending linear folds in the central part of the basin (Fig. 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. According to *Privalov et al. (2002)*, 90 to 98% of the 1.5 – 2.9 km displacement on reactivated thrusts along the northern basin margin, between Lugansk and Kamensk Shakhtinsky (sector *A3*), occurred during Permian time. Late Triassic to early Jurassic and late Cretaceous compressional activities locally affected the northwestern sector *B4* (Izyum – Lugansk), northeastern (NNE Belaya Kalitva; *Popov, 1963, Nagorny, 1971; Privalov et al., 1998*), and SE margins of the Donbas Foldbelt (sector *B2*; *Belokon, 1975*), and the SW rim of the Kalmius-Torets Depression *(Popov, 1963)*. The Southern margin of the basin in sector *A1* 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 *(Privalov, 1990)* occur between zones of marginal deep faults and central zones of linear folds.

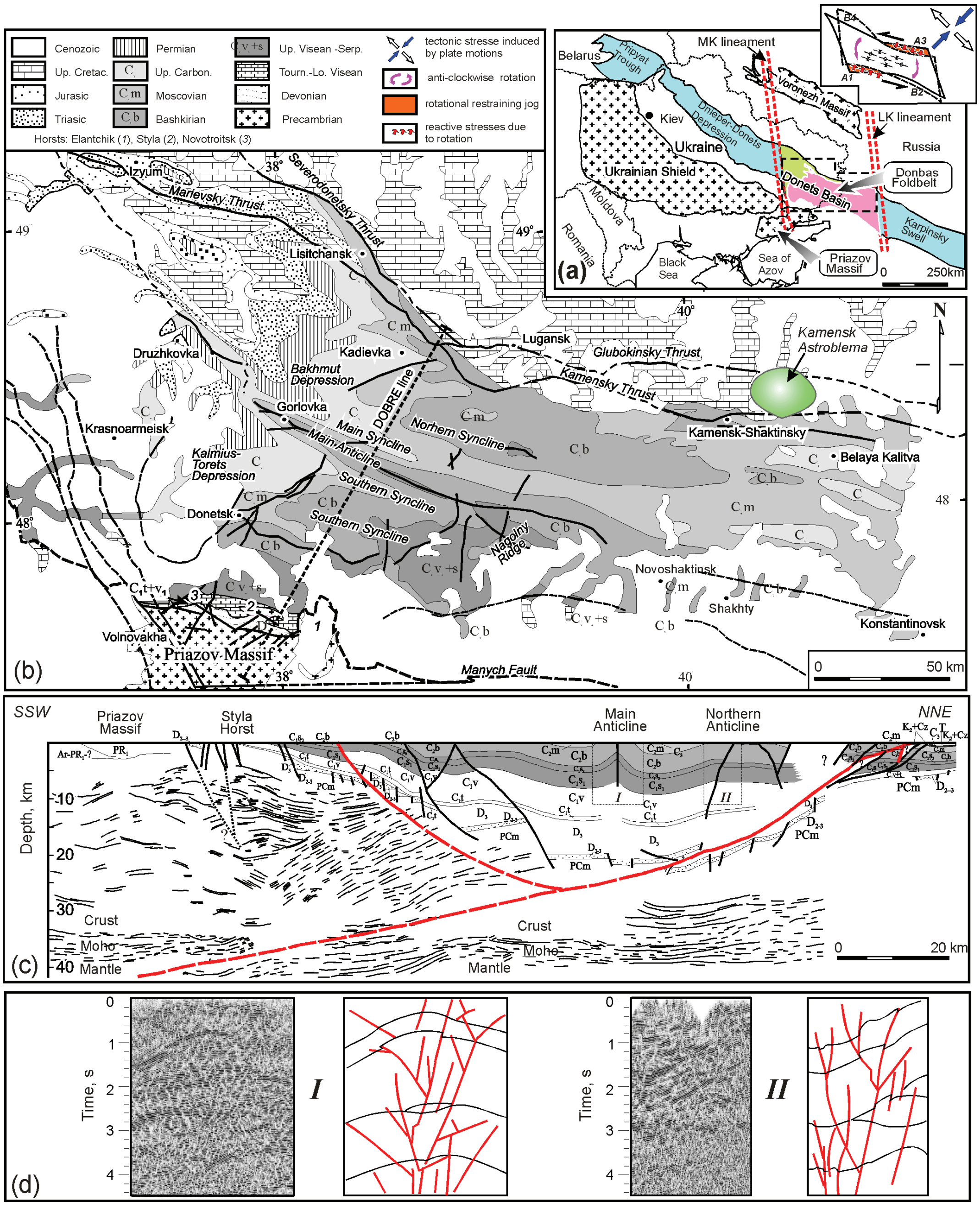

Fig. 1. Location of the study area (a); geological sketch map of the Donets Basin (b); geological cross-section along DOBRE seismic profile after *Maystrenko et al., 2003; Saitot et al., 2003* (c); flower type structures depicted from fragment of DOBRE reflection records (d). The inset demonstrates the mechanism of rotationally induced reactive forces responsible for the formation of principal folds in the DF.

To summarise, in 3-D view, the Donbas is a deformed prismatoidal block located on the intersection of the NNW striking Early Proterozoic weak zone within the Sarmatian segment of the EEC and the Late Devonian PDDK rift.

Principal displacement zone and distribution releasing and restraining jogs

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 (Fig.2, a). Some of them, jogs of megascale *PA1, PA2, PA3, PA5* coincide with depicted after seismic records depressions in the crystalline basement with depth in range of -20... -24 km (Fig. 2, b). 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 km), we have to suggest the existence there in the pre-inversion stage the depression of comparable depth and mechanism of formation. During post-rift stage strike-slip pulses within PDZ affected local depositional environments in the vicinity of pull-aparts, which have been served as local dilational (dextral reactivation) or contractional (sinistral reactivation) domains bearing marks of syntectonic sedimentation. Major post-rift subsidence occurred during the Carboniferous and was under a control of interplay of prevailing subsidence during local extension and short-time uplift pulses during local compression within stepover jogs. This conclusion allows to give a logical explanation to the phenomenon of lateral translation of the main depocentral axis of the Carboniferous stratigraphic units to south from the Main Anticline *(Shirokov, 1963)*, i. e. along line connecting centres of jogs *PA3, PA4 and PA5.*

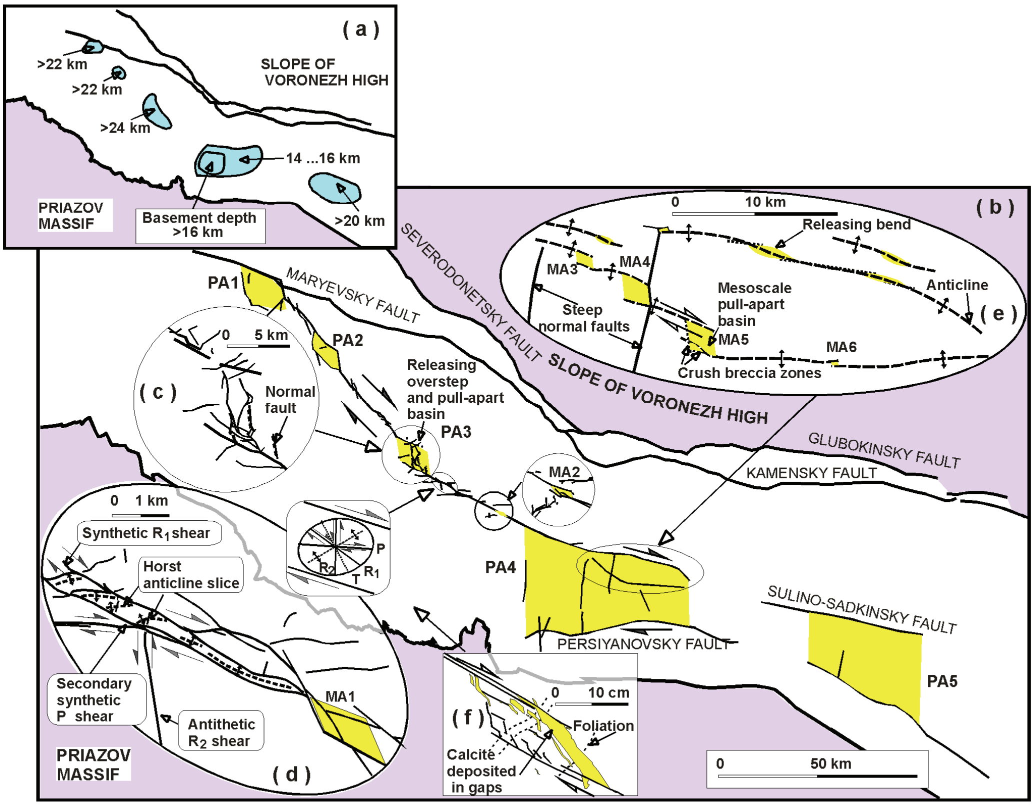

Fig. 2. Scheme of the PDZ of the Donbas (a); local depressions in the crystalline basement after *Belokon, 1975* (b); details within jog *PA3* (c), details within Nikitovka Hg-Sb ore field (d), wherein R_1 and R_2 - conjugated Riedel shears, P - secondary synthetic shears, T - tension fractures; details within Nagolniy Ridge (e), wherein mezoscale pull-aparts coincide with Au-Pb-Zn showings and deposits; nanoscale pull-apart in Styla horst (f).

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 (the Carboniferous – early Permian); 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 (Fig. 2, d) and dilational jogs (pull-aparts of mezoscale) and releasing bends with gold-polymetallic mineralization at the Nagolniy Ridge (Fig. 2, e); the latest dextral reactivations during the time of forming linear sub-concentric strike-slip zones in the basement and sedimentary carapace due to the Alpine clock-wise torsion (Fig. 3). According our interpretation of seismic images of DOBRE profile we infer very typical for the restraining stepovers images of positive flower-palm tree structures (Fig. 1, d) in the central part of the Basin. Strike-slip deformations are recognised across the entire basin. 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 *(Privalov, 1990)*.

Shuttle rotations of Donbas megablock

Being essentially a “solitary” block within continuous rift system, the Donbas responded much more sensitively to plate motion stresses accommodating them in dextral and sinistral strike-slip reactivations within marginal master faults and PDZ. This process triggered mechanism of shuttle clockwise and anti-clockwise rotations of the Donbas megablock and its local blocks *(Privalov, 1998; Privalov et al., 1998)* .

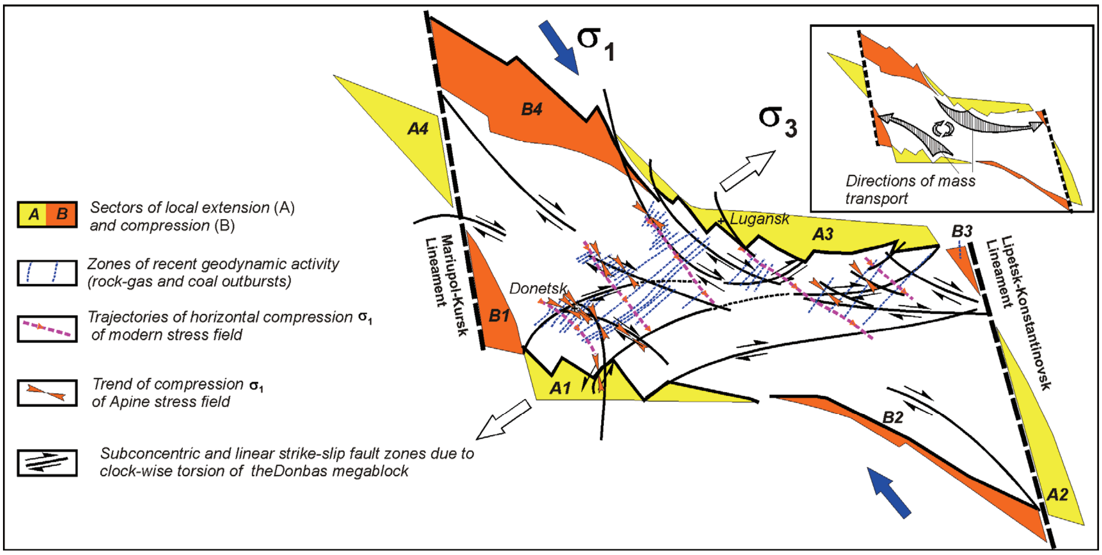

Fig. 3. Mechanism of forming linear and subconcentric strike-slip zones and induced zones of deodynamic activity in sedimentary cover of the Donbas due to the Alpine clockwise torsion.

A number of tectonic phases may have undergone strike-slip and following rotational deformations affected the Donbas. The most prominent rotation immediately follows after strike-slip reactivation in (trans)tension regime. This provokes the appearance of re-active compression forces generated in contractional jogs due to rotation closely followed by folding/thrusting event because of shortening of the sedimentary carapace. According to results of numeric modelling, we estimate that the formation of the pop-up structure and main fold patterns in the Donbas with 87% NNE-SSW shortening is consistent with angle of counter-clockwise rotation in range of 5-6°. The analysis of relationships and interplay of phases associated with rotations of the Donets megablock suggests the formulation a thesis on amplification of tectonic stresses in the Donbas governed by variant of stress field **B** (sinistral reactivation→anti-clockwise rotation), meanwhile for stages governed by variant of stress field **A** (dextral reactivation→clockwise rotation) the damping of tectonic stresses is occurred.

Because of specific "parallelogram" geometry of the Donets megablock we have to conclude that in terms of energy consumption the Donbas can much easily to be anti-clockwise rotated rather than to be clockwise rotated. This phenomenon is finally responsible for the local effects of amplification-damping of plate motion stresses and, more specifically, for the intensities of tectonic phases affected the Donbas. A major part of the Donbas has been uplifted dramatically and deformed with prominent NNE-SSW shortening grain during the latest phases of Hercynian orogeny in Permian. This was in response to stresses generated by convergence of plates in the Ural orogenic belt, transmitted to the Donbas and re-actively amplified here because of sinistral shearing and following anti-clockwise rotation of the Donbas megablock. The DF should be considered as mainly a Hercynian structure, which elements were affected by following Cimmerian and Alpine tectonic events. These locally reactivated already pre-existed fault structures and caused amplification of existed fold structures and formation new subordinate tectonic forms with further deplanation of deformed strata surfaces.

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