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Geodynamical Events (Coal-and-Gas Outbursts) in the Donets Basin, Ukraine

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SUMMARY

Optimization of production and effective management of mining hazards are in large part dependent on knowledge of geological, particularly structural properties of the mining medium. Over the past decade in the Donbas 1550 gas-geodynamic events, including 38 sudden instantaneous coal-and-gas outbursts, were recorded during underground mining. Coals of specific rank and mining depth with high initial desorption rates are traditionally considered prone to instantaneous outbursts. However, other factors such as in-situ stress, petrographical composition and structure of the coal, location and orientation of geological discontinuities, and elastic properties of the medium were also demonstrated to be important. It has also been observed that small-scale gas-geodynamic events, which tend to occur at the mining face, are typically unrelated to geological structure, whereas larger events are structurally controlled as they are preferably located along tectonic zones. The stress discharge at such localities is dangerous already in terms of levels of energy released, but additionally it also liberates gas from adjacent collectors, like fault gouge reservoirs or gas sorbed on microporous coal surface. While considerable effort was invested in developing prediction techniques, unexpected geodynamic incidents resulting in fatalities continue to be a major concern for underground coalmining.

Introduction

The energy policy of Ukraine is in large part dependent on domestic coal production. With rising uncertainties in the international oil and natural gas markets, and with recent climate changes, which hinder hydroelectric power production, the strategical importance of domestic coal mining is on the increase. On the other hand, today's market pressures demand economical, efficient and safe mining production. Optimization of production and effective management of mining hazards are in large part dependent on knowledge of geological, particularly structural properties of the mining medium.

Over the past decade in the Donbas 1550 gas-geodynamic events, including the most dangerous 38 sudden instantaneous coal-and-gas outbursts, were recorded during underground mining. The precise mechanisms of an instantaneous outburst are still not understood. Coals of specific rank and mining depth with high initial desorption rates are traditionally considered prone to instantaneous outbursts. However, other factors such as in-situ stress, petrographical composition and structure of the coal, location and orientation of geological discontinuities, and elastic properties of the medium were also demonstrated to be important. While considerable effort was invested in developing prediction techniques and protocols, unexpected outburst incidents resulting in fatalities continue to be a major concern for underground coal operations.

Regional tectonic picture and trends of geodynamic zones

About 95.4% of Ukraine's coal production is from the Donets Basin. Geologically, it forms a most anomalous segment of continuous Pripyat-Dnieper-Donets-Karpinsky (PDDK) aulacogen within Southern-Eastern margin of the East European Craton (EEC). The Donets Basin stands out by its up to 24 km sedimentary column with prominent inversion.

The PDDKA formed during Late Devonian break-up of the Sarmathian protoshield and sandwiched the Ukrainian Shield (UkS) and the Voronezh Massif (VM) as relicts of the protoshield. 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 et al., 1998). The corridor served as particularly weak zone within the Craton. It plunges beneath the Donbas segment of the PDDKA 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 (DF), which is the inverted part of the Donbas Basin, is dominated by WNW-ESE trending linear folds and faults in the central part of the basin (Figure 1). These tectonic elements bear the scars of repeated strike-slip deformations within the principal displacement zone (PDZ) of the basin. According our interpretation of seismic images of DOBRE profile we infer very typical for the restraining stepovers images of positive flower-palm tree structures (Figure 1, d) in the central part of the Basin.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. 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.

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.

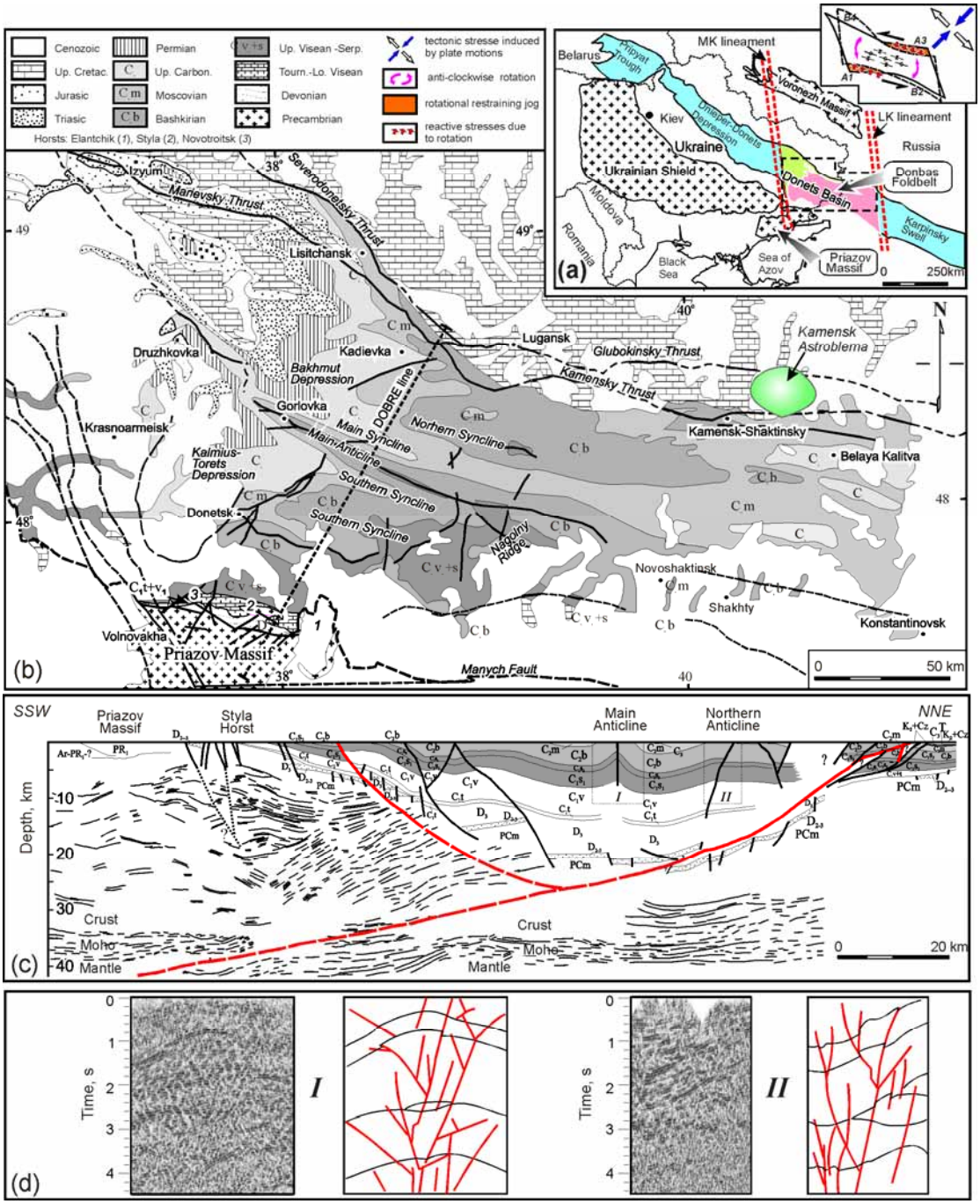

Figure 1 *Location of the study area (a); geological sketch map of the Donets Basin (b); geological cross-section along DOBRE seismic profile after Maystrenko et al., 2003; Saitot et al., 2003 (c); flower type structures depicted from fragment of DOBRE reflection records (d). The inset demonstrates the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

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 structure. This process triggered mechanism of shuttle clockwise and anti-clockwise rotations of the Donbas megablock and its local blocks.

On 200 coal mines in Donbas, 75% present high risk of outbursts and 35% explosion. The figure 2 depicts the latest Alpine dextral subconcentric strike-slip fault zones reactivations within the Donbas associated with regime of clock-wised torsion of the Donbas megablock. The regional spatial location of geodynamic (rock-gas and coal outbursts) zones of can be explained by: i) developing of subconcentrric dextral shear zones 2) by recent NW-SE compression vector oriented perpendicular to trend of these zones.

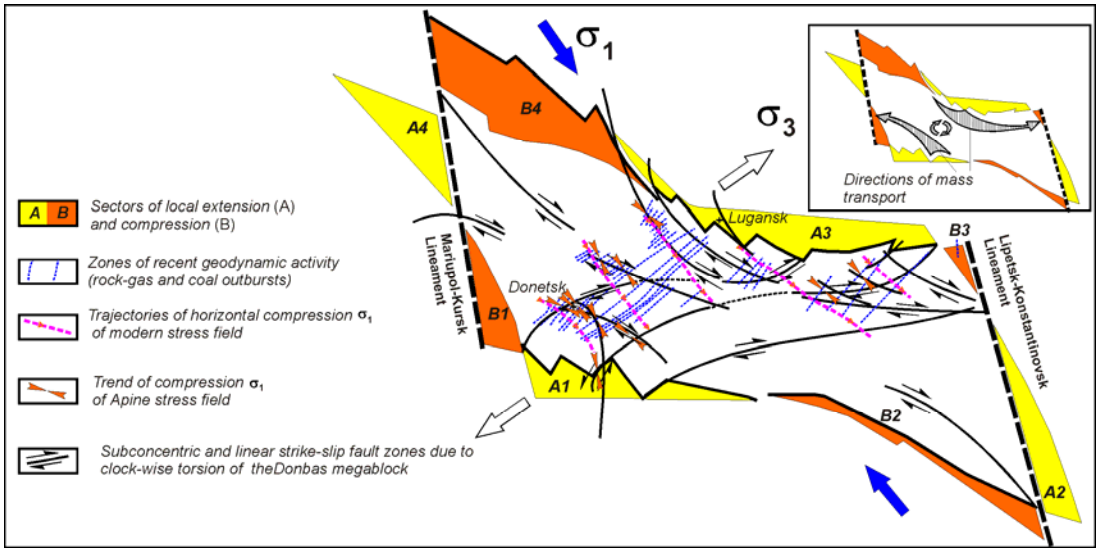

Figure 2 *Mechanism of forming linear and subconcentric strike-slip zones and induced zones of geodynamic activity in coal mines in sedimentary cover of the Donbas.*

Reconstructing the history of Donbas by thermal/subsidence history modeling in the Donbas, Sachsenhofer et al. (2002), Spiegel et al. (2003), Alsaab et al. (2008) suggested that the main phases of hydrocarbons generation occurred mainly during the Carboniferous and Early Permian subsidence phases. The figure 2 exhibits (1) a dextral shear belt consisting of NW–SE and NE–SW trending faults near Donetsk (DF in the SE part), and (2) a dextral shear belt consisting of W–E in the eastern part of Donets Basin. It is very important to note that both shear belts formed during the Cimmerian and Alpine deformational stages (Privalov et al., 1998), which post-dated gas generation. Therefore, it is likely that these faults played a significant role in gas redistribution and concentration in the Donets Basin by providing effective migration pathways. The results of numerical modeling of the Ukrainian part of the Donbas (Alsaab et al., 2008) showed the expulsion of thermogenic methane in these zones lasted long time and even in the Tertiary. Consequently, in the Donets Basin the area of coalbed methane exploitation and maximal risk of outbursts is not the area of anthracites that produced the highest volume of methane because of its expulsion, but the area of volatile bituminous coals where dextral shear belts facilitated its migration.

Applications on the forecast of coal-and-gas outbursts in coal mines of Donbas

Emissions of coal gas released by mining and related structurally induced underground hazards (coal-and-gas outbursts) are a major problem for safe and efficient coal exploitation in the Donbas. Most of the mines are operated within thrust-bounded domains with abundant occurrence of small-displacement strike-slip tectonic zones.

It has also been observed that small-scale gas-geodynamic events, which tend to occur at the mining face, are typically unrelated to geological structure, whereas larger events are structurally controlled, as they are preferably located along tectonic fault and fold zones. The stress discharge at such localities is dangerous already in terms of levels of energy released

(Panova and Privalov, 2003), but additionally it also liberates gas from adjacent collectors, like fault gouge reservoirs or gas sorbed on microporous coal surface.

The map of h_8 coal seam in the Donetsk-Makeevka region (Figure 3) exhibits that outbursts (circles) are located within small-displacement fault zones and flexures (knee-shaped folds) in connection with panels of exploitation. 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 with a vertical or stratigraphic displacement less than few decimeters or meters. 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 et al., 2004).

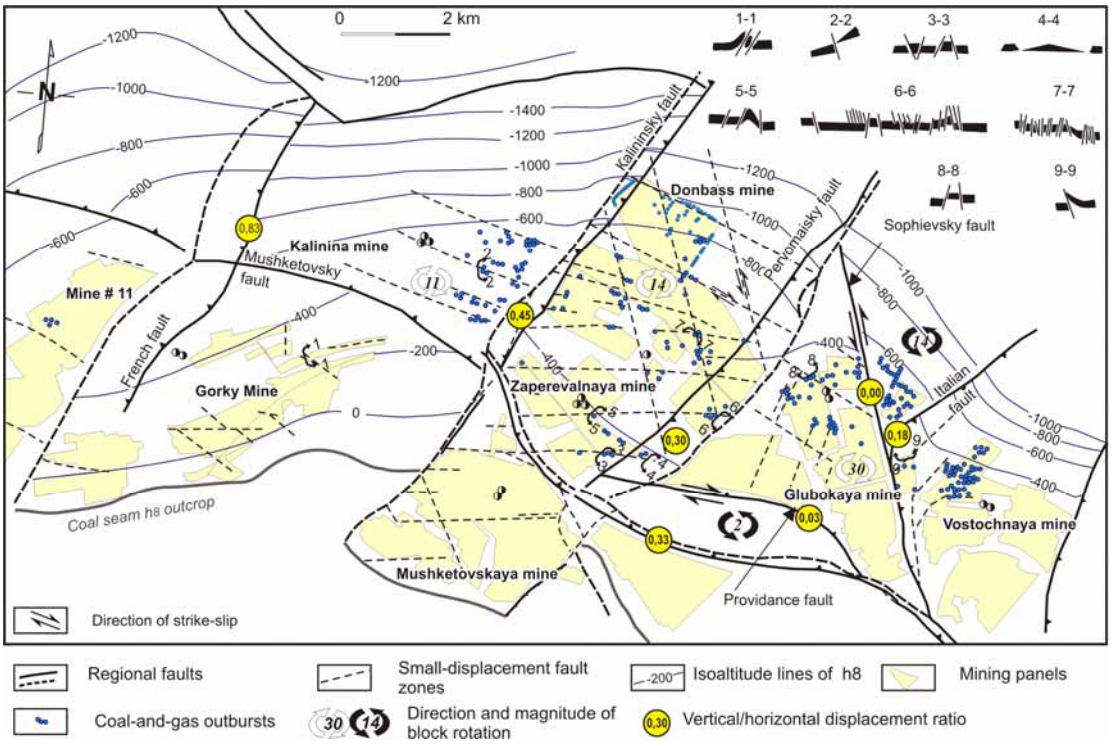

Figure 3 *Map of underground coalmining works for coal seam h_8 (Donetsk-Makeevka region).*

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