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TECTONIC FACTORS AFFECTING COAL BED METHANE DISTRIBUTION IN THE DONETS BASIN

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Донецький басейн є найбільшим вугледобувним регіоном України. Вугільні копальні Донбасу - серед найбільш небезпечних за газовим фактором у світі. Більшість шахт басейну працює у межах тектонічних блоків з широким розвитком зон малоамплітудної тектонічної порушеності зсувного генезису. Спеціальну увагу має бути приділено аналізу локальних структурно-тектонічних режимів, що впливають на розподіл метану і оцінку його ресурсів. Проникність вуглепородного масиву та варіації просторового розподілу метанових покладів зумовлені сучасним розподілом полів тектонічних напружень та насамперед локалізацією ділянок локального розтягу-стиску. Нашими дослідженнями встановлено, що так звані «солодкі ділянки» з видобутку метану просторово тяжіють до доменів з відносно великою проникністю, котрі розвиваються у межах секторів призсувного розтягу (дилатаційного розущільнення) в контурі зсувних зон.

Донецкий бассейн является наибольшим угледобывающим регионом Украины. Угольные шахты Донбасса - среди наиболее опасных по газовому фактору в мире. Большинство шахт бассейна работает в пределах тектонических блоков с широким развитием зон малоамплитудной тектонической нарушенности сдвигового генезис. Специальное внимание должно быть уделено анализу локальных структурно-тектонических режимов, кото-

рые влияют на распределение метана и оценку его ресурсов. Проницаемость углепородного массива и вариации пространственного распределения метановых залежей обусловлены современным распределением полей тектонических напряжений и в первую очередь локализацией участков локального растяжения-сжатия. Нашими исследованиями установлено, что так называемые «сладкие участки» по добыче метана пространственно тяготеют к доменам с относительно большой проницаемостью, которые развиваются в пределах секторов присдвигового растяжения (дилатационного разуплотнения) в контуре зон сдвиговых зон.

Fault of the Donets Basin (Ukraine/Russia) has a centuries-long history of coal exploration and mining. Very thick Carboniferous sedimentary deposits, that included significant organic material, were accumulated repeatedly throughout 14 km thick Late Viséan-Serpukhovian-Pennsylvanian succession. These formations subsequently were buried and uplifted in such a way that economically important hydrocarbon (especially coal) resources formed at economically exploitable depths in the Earth. The Donets Basin (Donbas) contains one of the major coal fields in the world. 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. 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. Most of the mines are operated within thrust-bounded domains with abundant occurrence of small-displacement strike-slip tectonic zones. 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 basin. In the course of mining in the Donets Basin, about two billion cubic meters of methane gas a year are vented into the atmosphere, which could otherwise be captured and used to produce heat and electricity.

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 Mariupol-Kursk (MK) and Lipetsk-Konstantinovsk (LK) lineaments [1] within the Sarmatian segment of the East European Craton and the Late Devonian PDDK rift (Fig. 1). Deep tectonic framework of the basin includes a set of NE striking basement transverse zones of lazy Z-shape geometry. The most prominent Donets-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.

Domal fault-breached structures along the northern marginal Donets Basin host conventional gas deposits in Bashkirian and Moscovian levels, whereas conventional gas occurs in Serpukovian levels in the southern Krasnoarmeisk and Southern Donbas regions.

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 with proven reserves in the order of 60 Gt. The most of coal seams 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. The thickness of coal seams currently mined is in the range of 0,6 to 2,5 m.

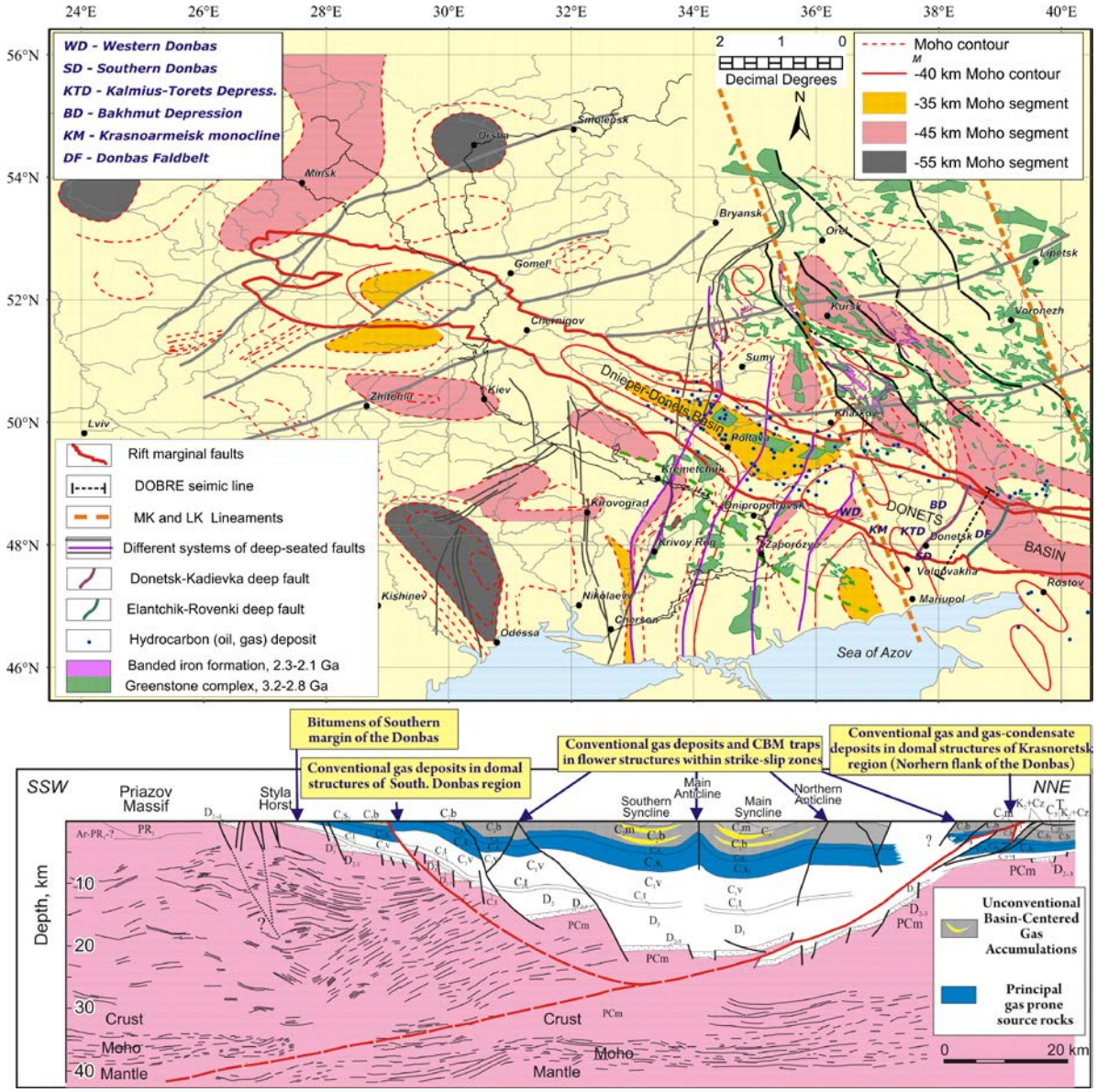

Fig. 1. Geostructural position of the Donets Basin within the Sarmatian segment of the East European Craton (Moho contours and deep-seated faults are shown; modified after [2]) and geological cross-section along DOBRE seismic profile (modified after [3]) with indicated distribution of conventional and unconventional gas deposits

The thermal maturation of coal deposits in the Donbas basin has led to generation of huge quantities of methane. CBM accumulations were formed in the Donets Basin during a number of phases including:

1) thermogenic hydrocarbons generation during pre-inversion Carboniferous-Early Permian burial and post-inversion thermal heating event caused Late Permian-Triassic andesitic magmatic intrusions (~250 Ma) of regional importance;

2) intensive gas migration, redistribution and even loss triggered by Permian and Mesozoic uplift/folding episodes;

3) multifold and multistage CBM trapping within fractured and sealed secondary reservoirs during Late Cimmerian and Alpine tectonic events.

Coaly clastics and coal seams could have sourced the gas also at deep levels of the basin [5, 6].

According results of artificial maturation of Donbas coal samples [6] (Fig. 2):

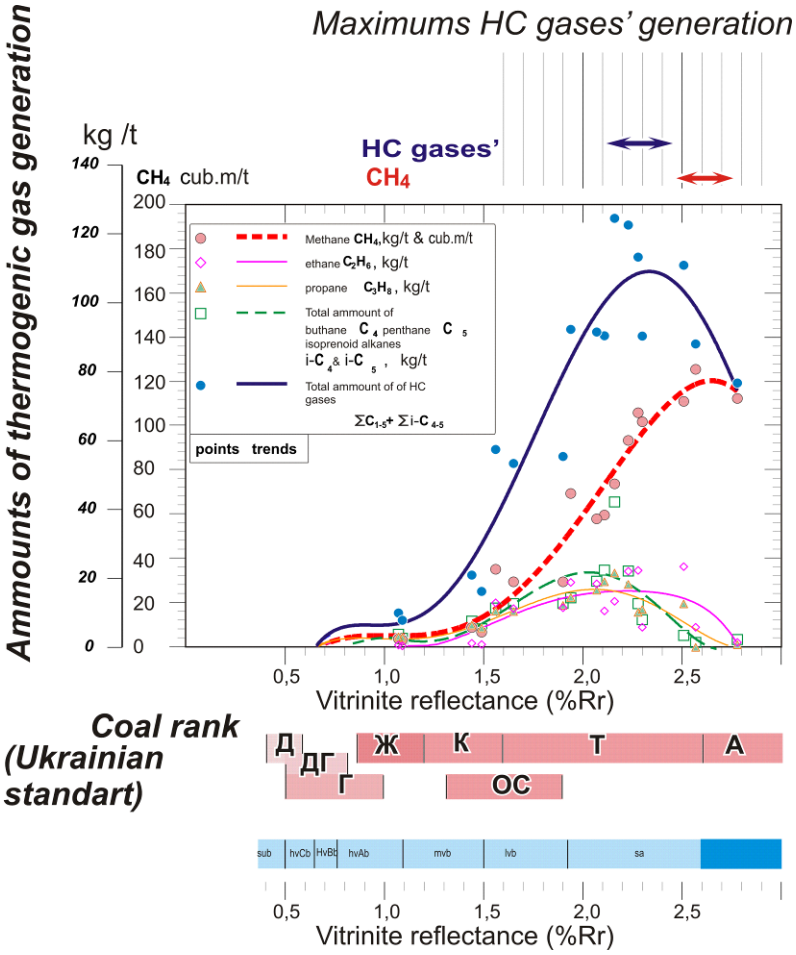

Fig. 2. Hydrocabon gases generation vs. coal rank after results of artificial maturation of Donbas coal samples

1) thermal generation of gas from humic coal beds begins at 0,7 % R_o;

2) large amounts of methane were formed at high temperatures by cracking of previously formed heavier hydrocarbons;

3) peak hydrocarbon gases'/ methane generation may occur at levels of thermal maturity between in 1,9 – 2,8 % R_o.

In terms of coal rank, the coal in the Donets Basin ranges from lignite to bituminous and anthracite (Fig. 3).

Much attention has been recently given to exploration using coal rank analysis and burial history reconstruction *(e.g.* [8]). Much more attention needs to be given to analysis of local tectonic-and-structural regimes affecting CBM producibility and resource assessments. Permeability patterns and, more specifically, lateral variations of methane content in coal beds are critically dependant upon present stress-state state and spatial distribution of local extension-compression domains. It has been observed that CBM production sweet spots, which tend to occur at relatively high permeability compartments, are typically structurally controlled by releasing bends or dilation traps located along strike-slip tectonic zones (Fig. 4).

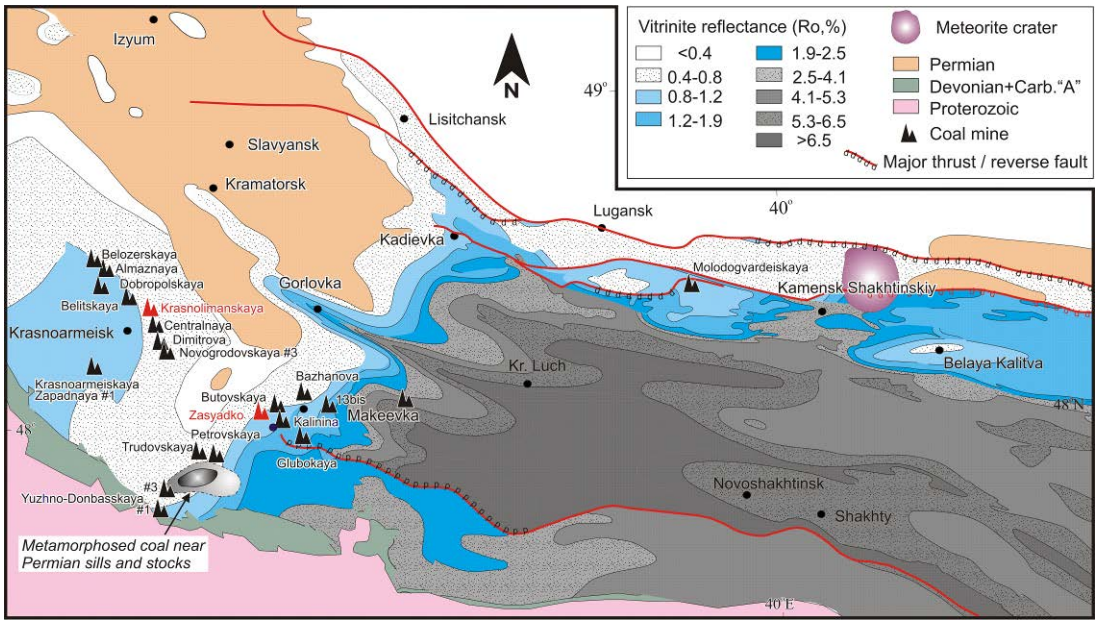

Fig. 3. Coalification map of the Donets Basin at the top of the Carboniferous (modified after [7]). Regions with coal ranks responsible for maximal HC gases' / methane content are shown in blue

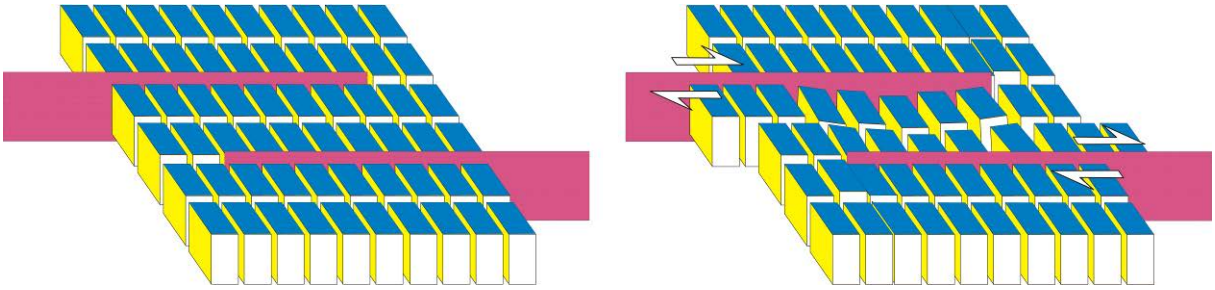

Fig. 4. Progressive increase of fracture/cleat apertures during formation of fractured reservoir of pull-apart morphology in sandstones related with dextral strike-slip Cimmerian-Alpine reactivation in the Krasnoarmeisk region

The flow of fluids (liquid and gaseous hydrocarbons, water) through coal-bearing strata is governed by permeability. Coal bed and sandstone permeability is a result of the natural fracture systems and consists of cleats of mostly tectonic origin. Strike-slip deformations are recognised across the entire basin in wide-scale range of structures. Most of the mines are operated within thrust-bounded domains with abundant occurrence of small-displacement strike-slip tectonic zones. It has been concluded that small displacement faults are concentrated within strike-slip zones with clear patterns of Riedel (R_1 and R_2), Y and P shears [9]. Such deformation bands as Riedel shears are barriers to fluid flow, however development of local releasing environments, e.g. of pull-apart morphology, enhance permeability due to progressive increase of cleat apertures.

Fig. 5, *b* demonstrates results of fractal treatment of gravimetric data [10] based on transformation of *Saxov and Nygaard* [11] in the area of the Ukrainian Donbas.

The depicted basement fault pattern (Fig. 5, *c*) advocates:

1) prominent structural control of distribution of conventional gas deposits in dome-type and fault-breached structures within Donbas margins;

2) presence to north from Lugansk a set of dextral shear belts, that can facilitate gas migration;

3) presence in the Krasnormeisk monocline area of dextral strike-slip zone containing row of CBM production sweet spots (rela-

tively high permeability compartments) within severe domains of local extension.

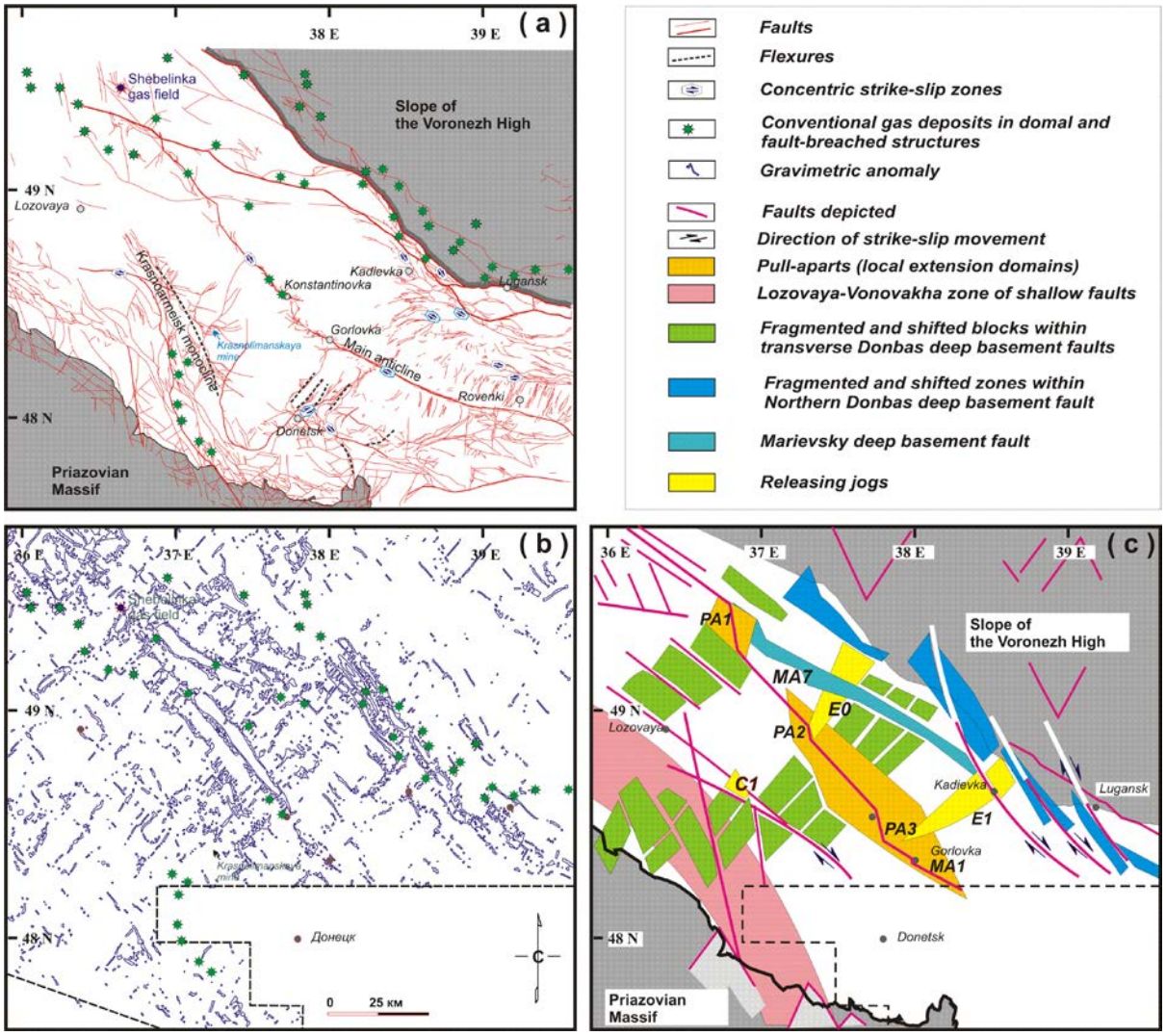

Fig. 5. *a*- tectonic map of the western part of the Donbas; *b*- results of fractal treatment of gravimetric data*; c* - depicted deep basement patterns. The location of *C1* sector with releasing environment due to block rotation and tectonic escape is shown

The presence of fractured reservoir of pull-apart morphology in sandstones here can be proved by results of 3D seismic exploration techniques. Fig. 6 exhibits location of faults and horizontal slice of 3D seismic cube within Krasnolimanskaya mine with characteristic ge-

ometry of released jog between junction of two regional "normal faults" (in fact, these are dextral shears).

The Krasnolimanskaya mine is one of the most dangerous coal mines in the basin due to naturally high levels of methane, relatively high permeability of coal-bearing strata and significant risk of coal dust explosion hazards.

Here within the Krasnolimanskaya mine gas accumulations are coincided with sandstones horizons l_7Sl_6, l_6Sl_5, l_5Sl_4, l_4Sl_3, l_2Sk_7, k_7Sk_5: open porosity of these is varying from 10,58 to 4,68 %, permeability is in range 0,06 –0,69 mD. Free bitumen showings are recorded within horizons m_8Sm_9, M_5Sm_5, $m_4^1Sm_3$, $l_8Sl_8^1$, $l_4^1 Sl_5$, L_7Sl_7, k_8Sl_1, $k_9Sk_7^5$, $k_7^2Sk_9$, $k_7^1Sl_7^2$ (mainly in region of Glubokoyarsky fault). Maximal gas content is documented as 14,0, 14,0, 20,1, 27,8, 24,3, 26,6, 24,1, 25,4 m^3/t^{daf} within seams m_6^2, m_4^2, l_7, l_5, l_4, l_3, k_7, k_5 at following depths 338, 429, 406, 467, 538, 632, 634, 980 m.

It has been observed here that the most intensive methane emissions during underground mining coal seams are typically related with zones of active recent migration of hydrocarbons from deeply seated dilatational traps.

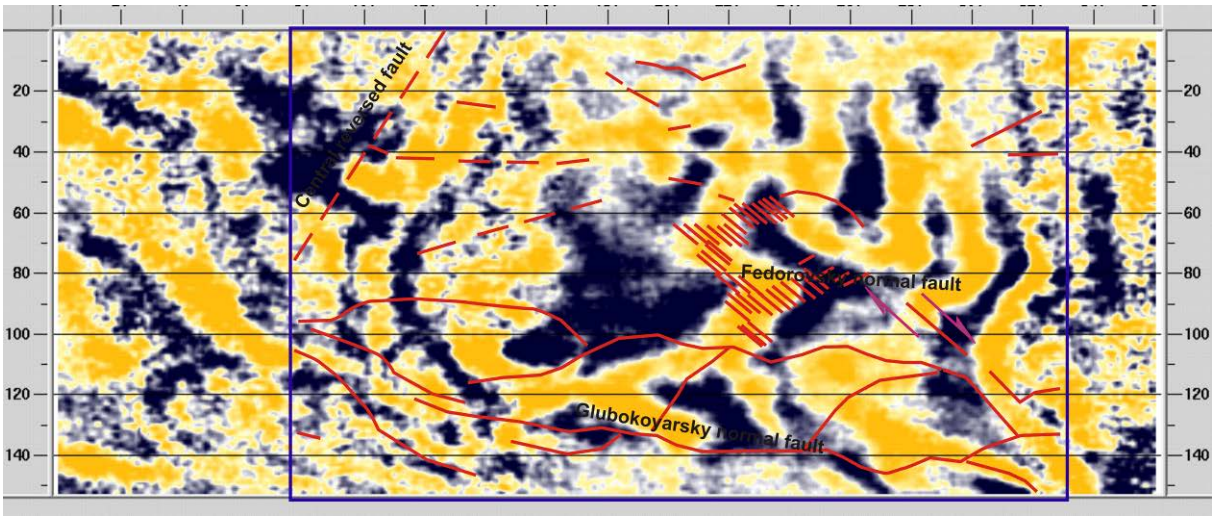

Fig. 6. Horizontal section of 3D seismic cube within Krasnolimanskaya mine in Krasnoarmeisk monocline region

Methane occurs here within coal seams, but also within sandstone reservoirs. Sandstone formation is characterised by significant variation within the section. Maximal total thickness of sandstones

within interval $l_1 - l_5$ is recorded on Krasnolimanskaya mine and Severo-Rodinsky site. Gas content in sandstones increases with total thickness of sandstones.

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