

Investigation of the effectiveness of methane drainage in a multi-seam coal mine with the use of long-reach directional drilling - a case study from USCB, Poland

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Advanced methane drainage strategy employing underground directional drilling technology for major risk prevention and greenhouse gases emission mitigation

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DD-MET



POLSKA GRUPA
GÓRNICZA

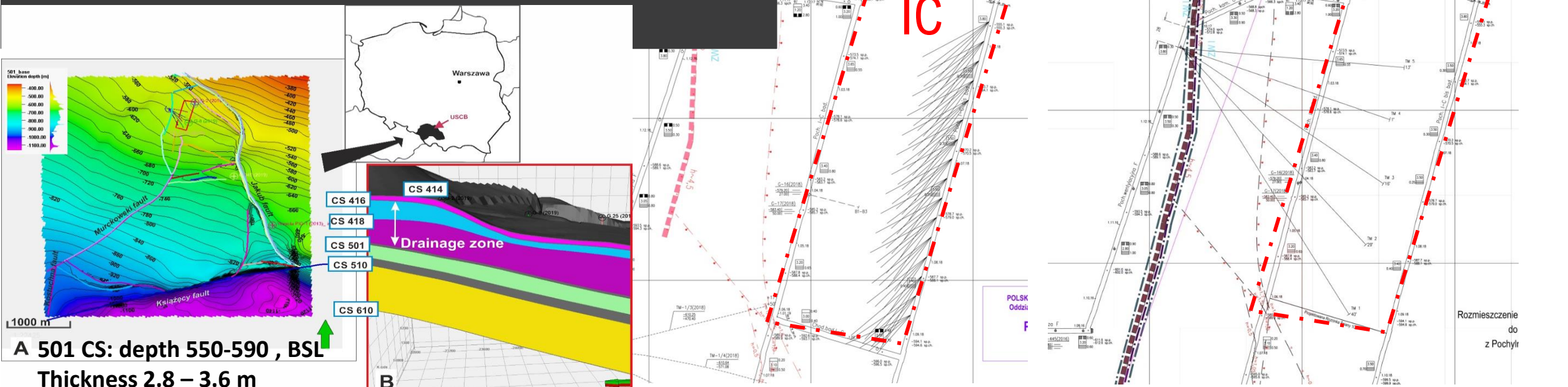
Imperial College
London

STUDY LOCATION AND OBJECTIVES

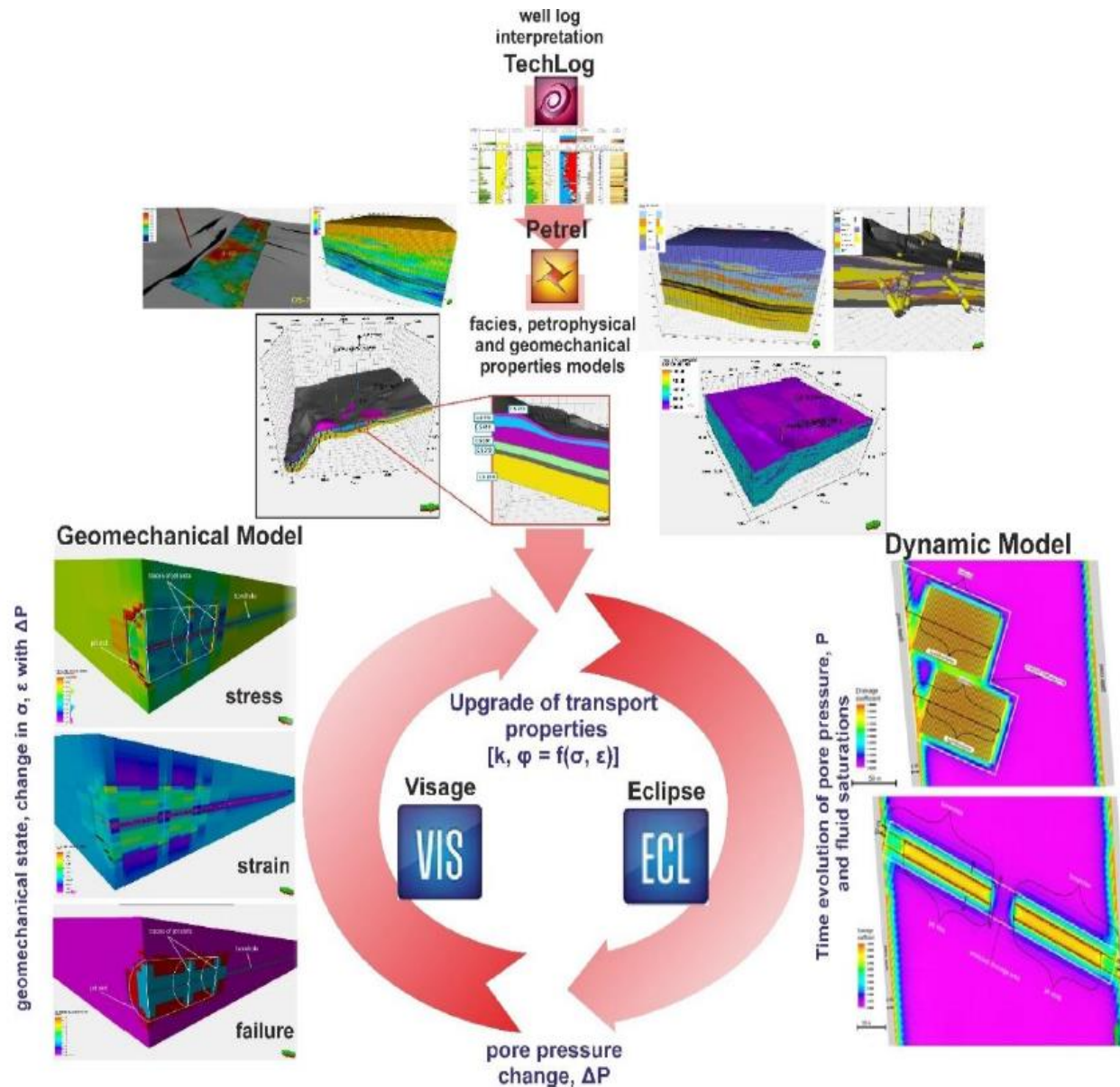
OBJECTIVES

aims to assess the effectiveness of the coal mine methane drainage in the multi-seam coal mine situated within the Upper Silesian Coal Basin (USCB) in Poland using the LRDB and cross measure boreholes.

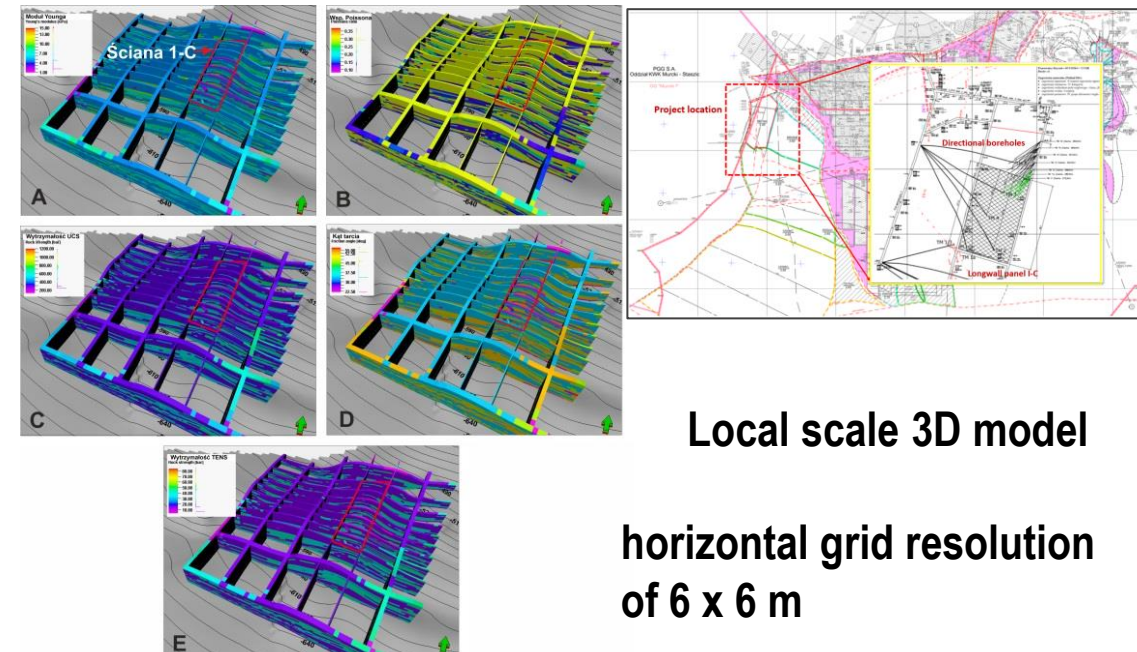
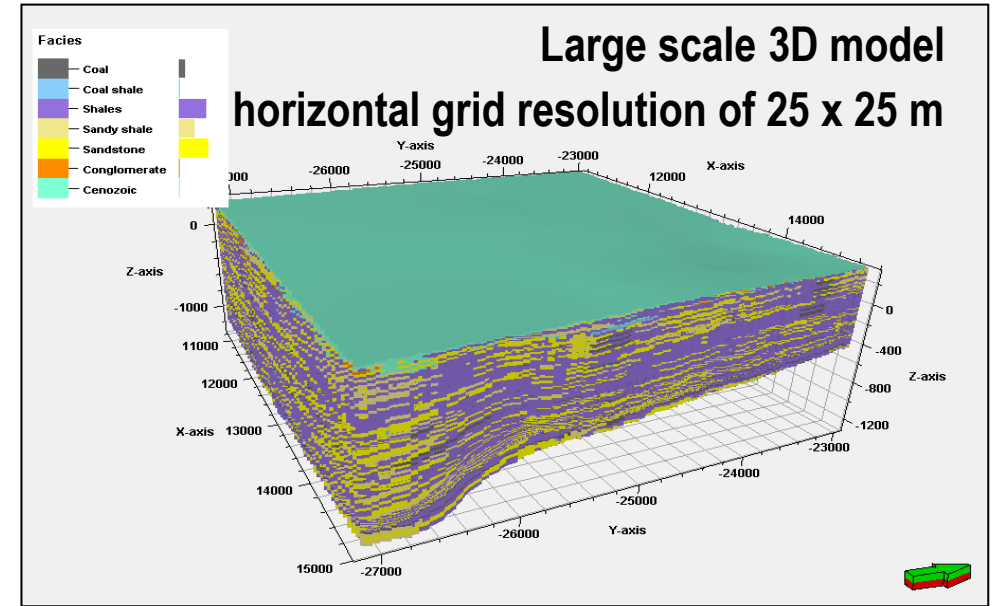
Determination of the effectiveness of the CMM drainage is carried out using numerical methods coupling geomechanics with the modeling of the reservoir fluid flow.



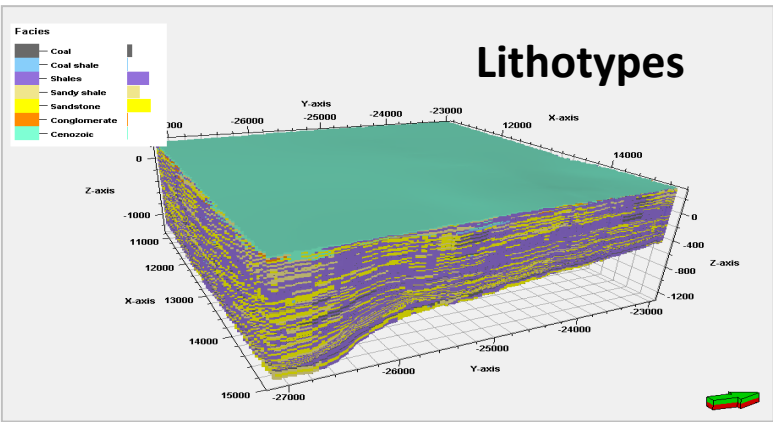
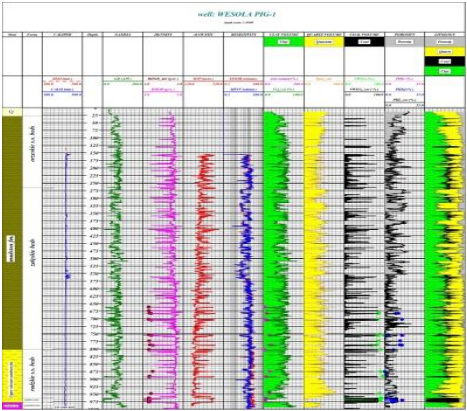
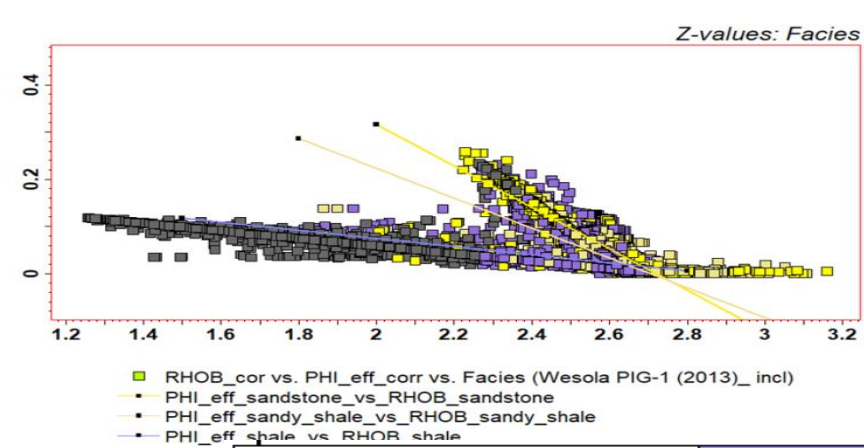
METHODOLOGY



Integrated geological geomechanical and fluid flow modelling and simulation workflow



3D PARAMETRIC MODEL – PETROPHYSICAL PROPERTIES



Lithotype	Shale	Sandy shale	Sandstone
Linear function	$\text{PHI_eff} = -0.0860927 * \text{RHOB} + 0.246791$	$\text{PHI_eff} = -0.316526 * \text{RHOB} + 0.855864$	$\text{PHI_eff} = -0.438728 * \text{RHOB} + 1.19334$
Correlation coefficient	-0.55	-0.76	-0.87

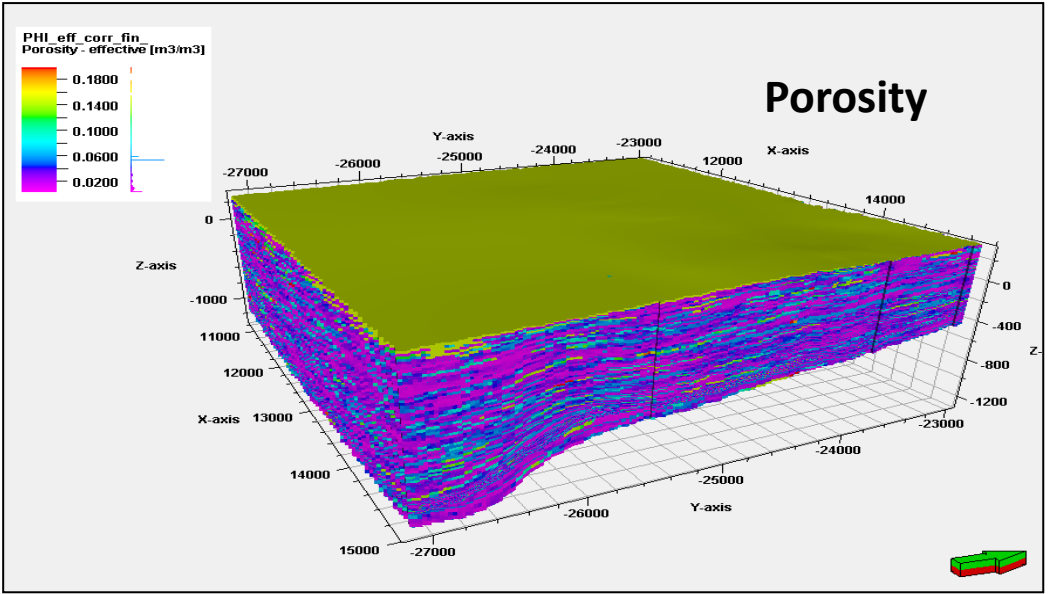
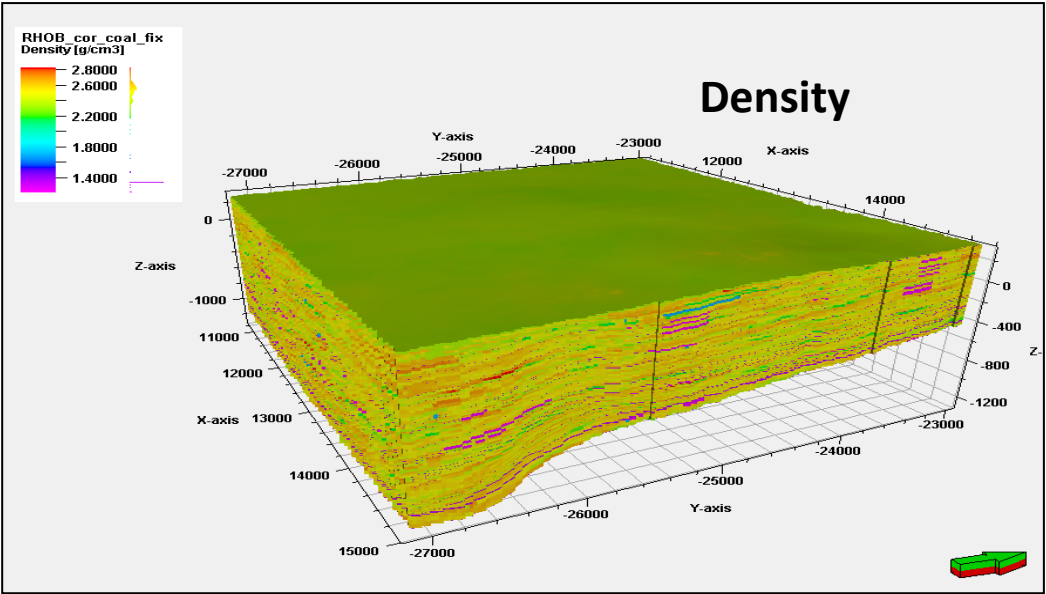


Fig. 4. Petrophysical large scale models of the C field strata between top surface and 610 CS in the Murcki-Staszic coal mine

3D PARAMETRIC MODEL – GEOMECHANICAL PROPERTIES

Lithotype/ parameter	Young modulus	Poisson ratio	UCS
Sandstone	$E_{stat}=1.1211 \cdot E_{dyn}-23.15$ (Xu et al, 2016)	$PR_{stat}=1.135 \cdot PR_{dyn}-0.063$ (Xu et al, 2016)	$UCS=3.3991 \cdot E_{stat}+63.69$ (Xu et al, 2016)
Sandy shale	$E_{stat}=1.170 \cdot E_{dyn}-24.36$ (Xu et al, 2016)	$PR_{stat}=1.435 \cdot PR_{dyn}-0.078$ (Xu et al, 2016)	$UCS=1.476 \cdot E_{stat}+70.479$ (Xu et al, 2016)
Shale	$E_{stat}=0.076 \cdot v_p^{3.23}$ (Horsud, 2001)	$PR_{stat}=1.108 \cdot PR_{dyn}-0.058$ (Slota-Valim, 2015)	$UCS=1.001 \varphi^{-1.143}$ (Chang, et al, 2006)

Based on well log data; KWK M-S archival data; WP2 data; Zhu et al., 2019; Ortiz, 1986; Jacobsen, 1942; Szott et al., 2018; Malkowski, 2008; Godula, 1984)

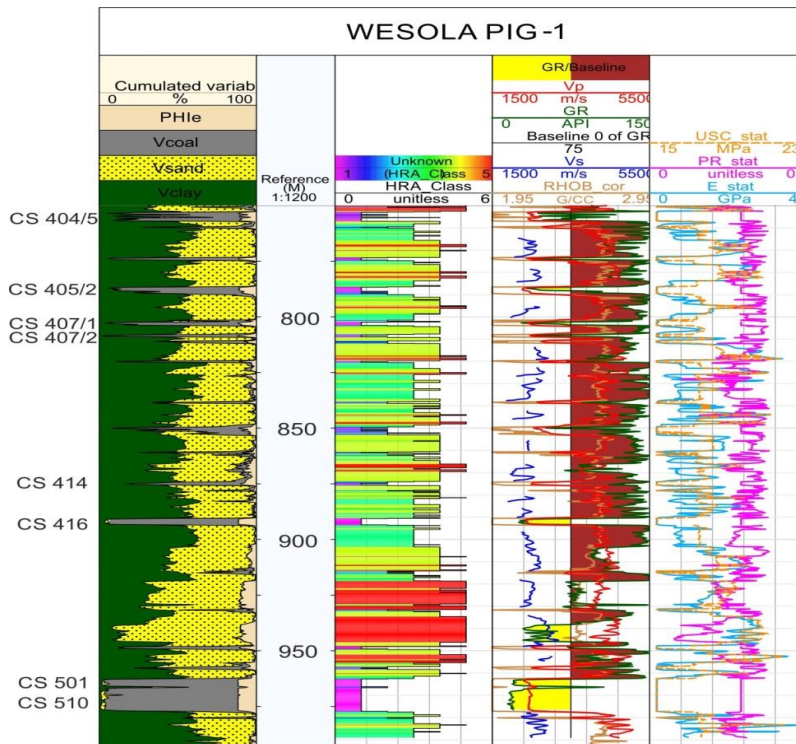
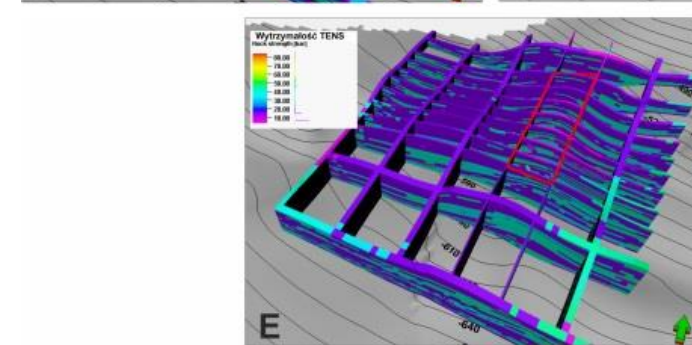
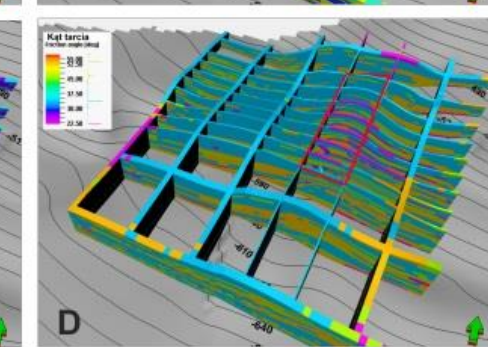
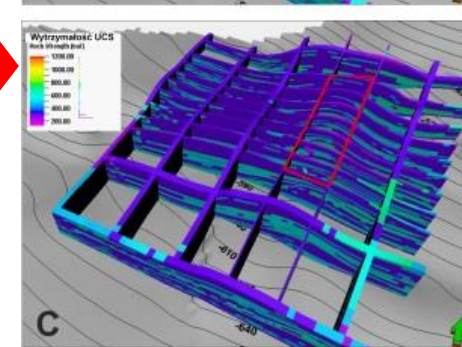
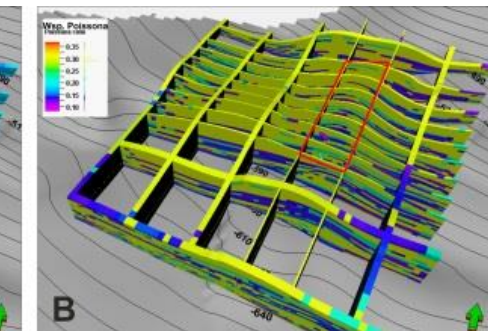
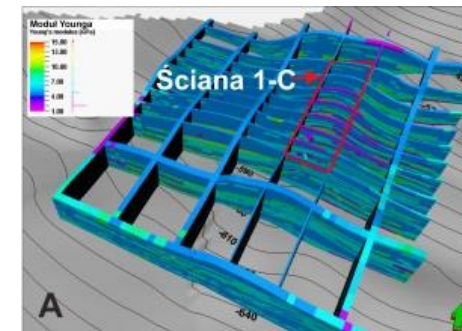
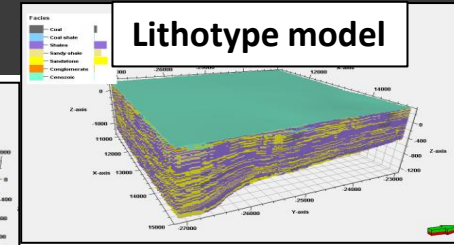
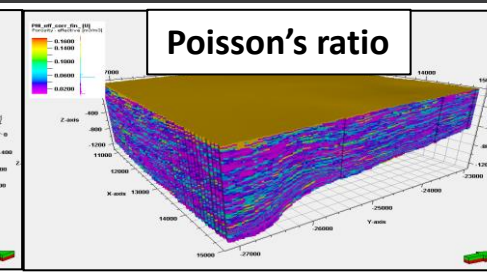
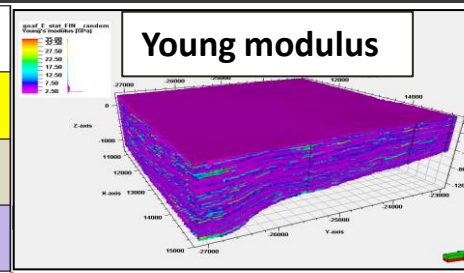
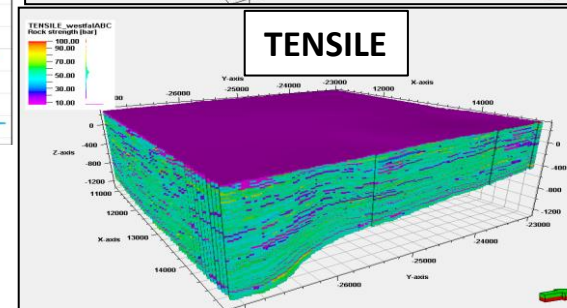
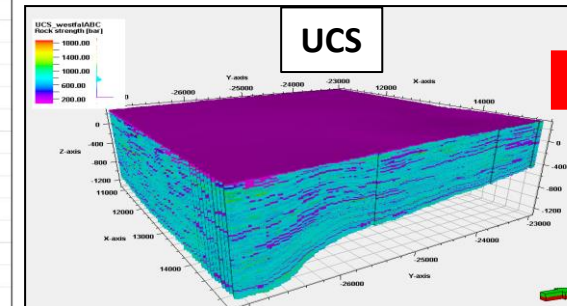
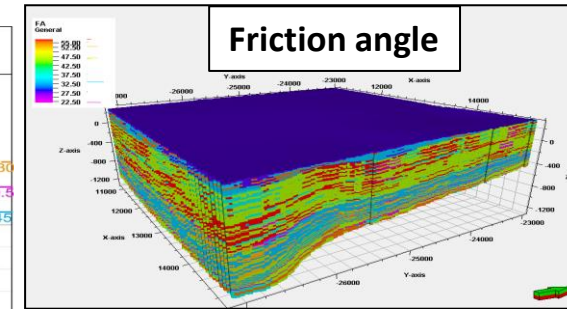


Diagram presenting the lithological model (track 1), HRA based lithotypes (coal – marked in pink, sandstones in red, shales in green sandy shales in green-yellow (track 3), input data (GR - Gamma Ray, vp - compressional velocity, vs - shear wave velocity, ρ - density) (track 4) and calculated static mechanical parameters (UCS –marked with orange dashed line, Young modulus – marked with blue line and Poisson ratio – marked with pink continuous line).



Local scale parametric 3D models of petrophysical and geomechanical properties

INITIAL STRESS AND STRAIN IN REGIONAL MODEL

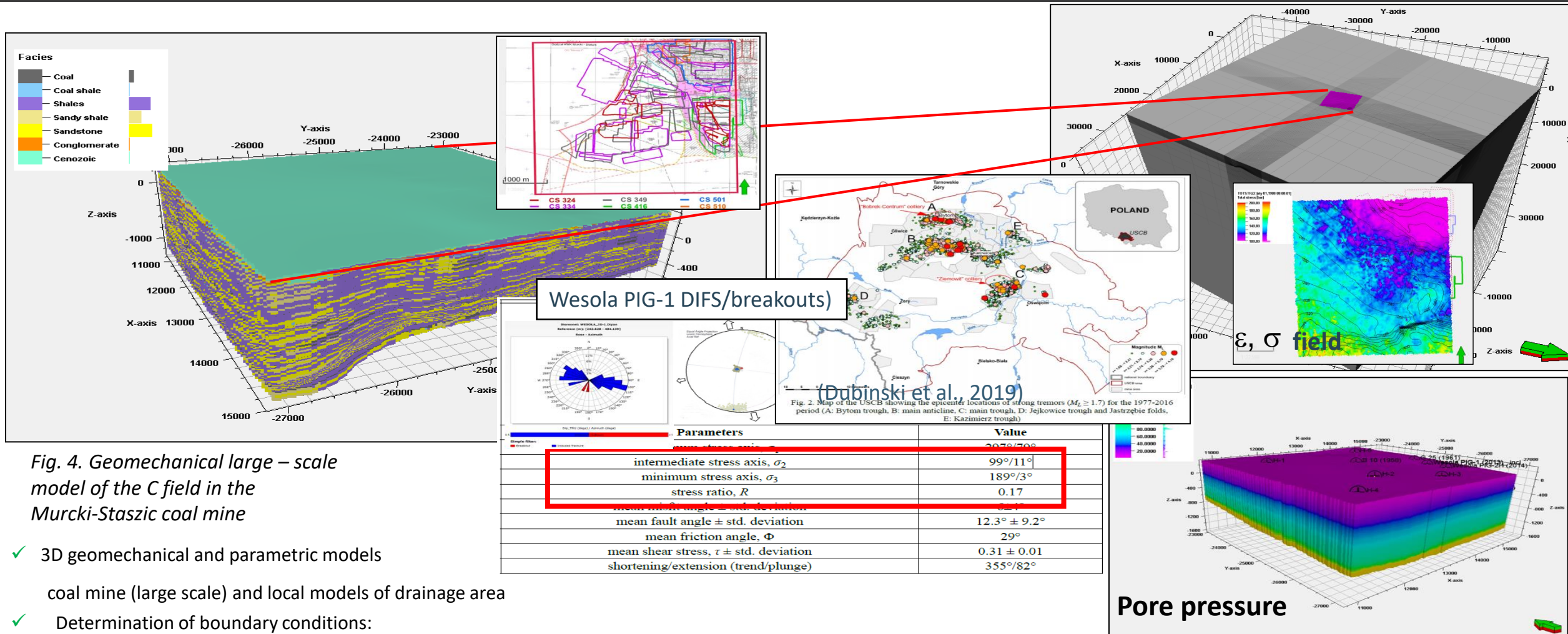


Fig. 4. Geomechanical large – scale model of the C field in the Murcki-Staszic coal mine

3D geomechanical and parametric models

coal mine (large scale) and local models of drainage area

Determination of boundary conditions:

Stress regime: normal faulting, $\sigma_v > \sigma_H > \sigma_h$ (Zuberek et al., 1997), $\sigma_H/\sigma_h = 1.25$ (Jarosinski, 2005), σ_H azimuth = 99 deg (Dubinski et al., 2019; analysis of damage zones in Wesola PIG-1 borehole)

Calculation of stress and strain field in initial geological conditions prior and due to the mining activity in the large scale model

Calculation of stress and strain field in mining conditions affected by the mining activity (large scale model)

Tab 2. Content of solids dissolved in underground water in Carboniferous productive intervals changing with depth (based on Rózkowski et al., 1990).

(Rozkowski et al., 1990)

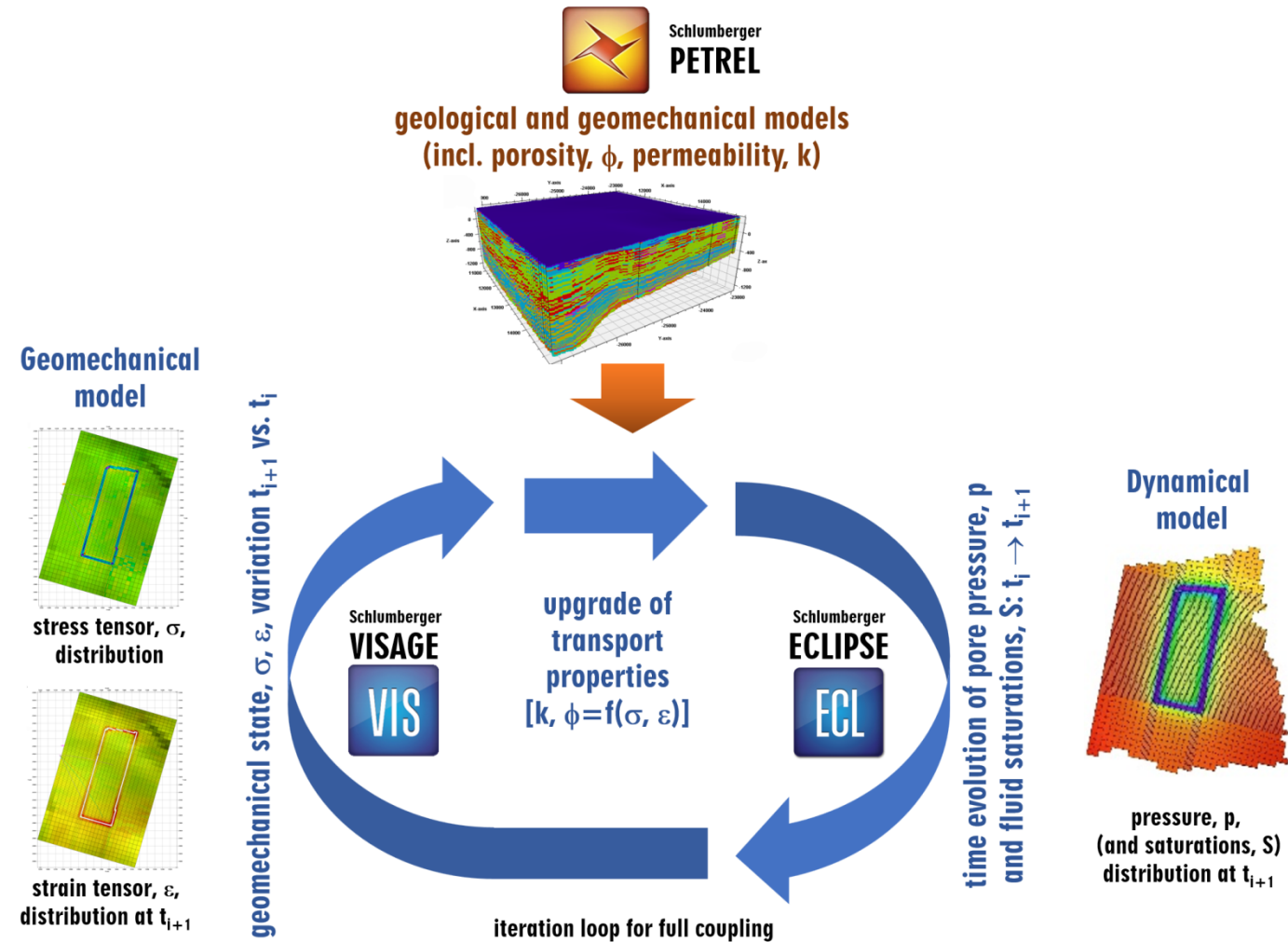
Detph	Average value (mg/dm3)	Pressure gradient
0-200	3349,45	0,100018008
200-400	13941,45	0,101077029
400-600	51836,07	0,104865849
600-800	76887,38	0,107370556
800-1000	117377,12	0,111418844

EFFECTIVE COUPLING OF FLOW AND GEOMECHANICAL SIMULATIONS

PROBLEM: Simultaneous flow and geomechanical simulations – **complex** simulation modelling of very high computational costs

CONVENTIONAL APPROACH: External coupling between separate simulations of fluid flow evolution (pressure and saturation distributions) and static geomechanical state (strain and stress tensor distributions) by best available flow and geomechanical simulators, respectively – **iterative method** supplemented with **correlations** between rocks transport properties and their geomechanical state – until appropriate consistency achieved

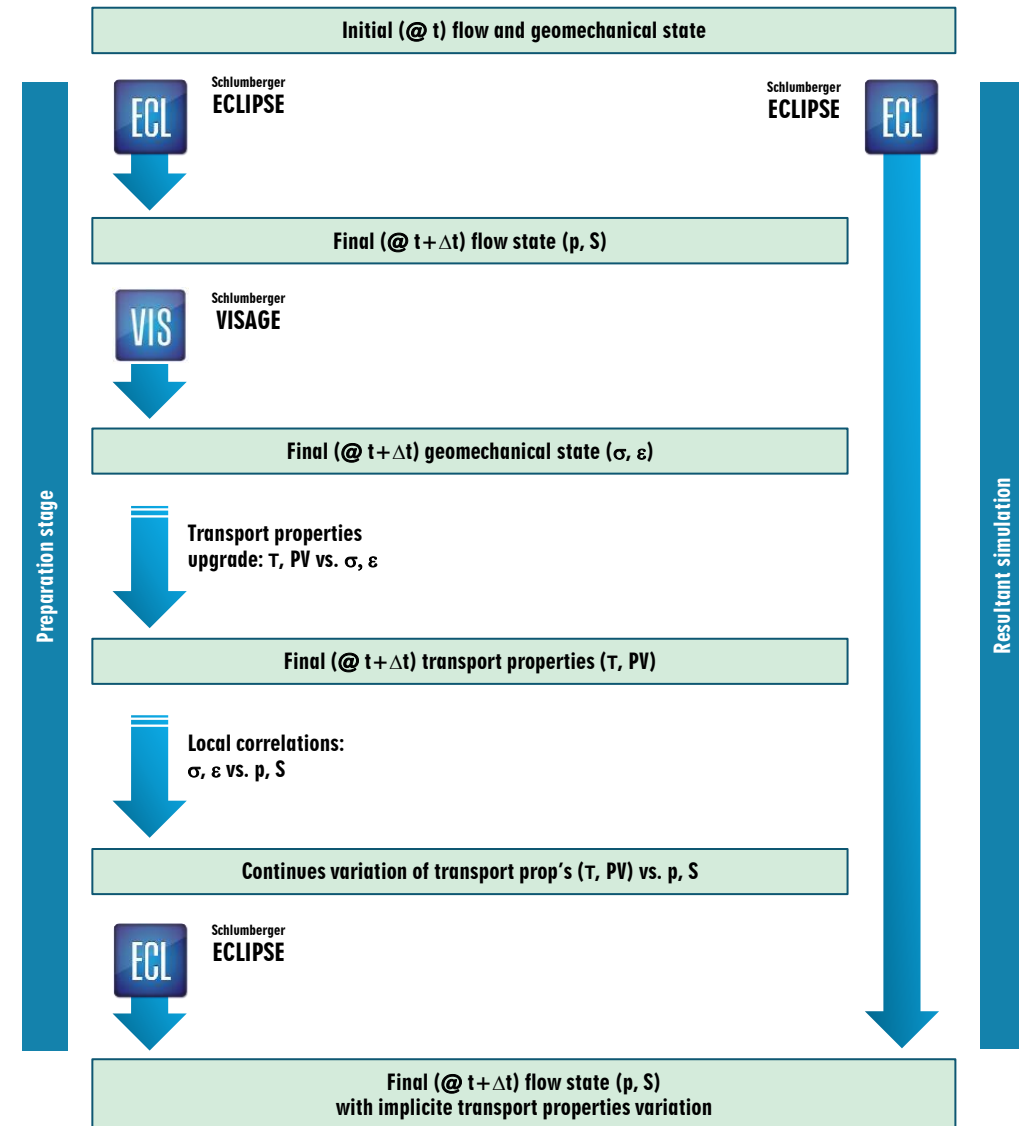
Effectiveness of the approach, depending on the rates of geomechanical and transport properties variations, may result in **work– and time– consuming runs**



Flow diagram of conventional simulation coupling

EFFECTIVE COUPLING OF FLOW AND GEOMECHANICAL SIMULATIONS

ALTERNATIVE SOLUTION: Effective coupling by **local correlations** between reservoir **pressure variations (ΔP)** and modifications of rock transport properties from **geomechanical effects ($\Delta \epsilon, \Delta \sigma$)** and their **correlations with transport properties ($\Delta T, \Delta PV$)** at **specific time intervals** including continuous flow and geomechanical variations: $\Delta P \rightarrow \Delta \epsilon, \Delta \sigma \rightarrow \Delta PV, \Delta T$ – **maximum implicate approach**



Flow diagram of simulation effective coupling

GEOMECHANICAL EFFECTS UPON ROCK PROPERTIES

Geomechanical state variations during coal mining:

- elastic deformations due to pressure reduction – continuous variations – global (model) range – implicit simulations
- plastic deformations due to excavation activities – (model) discrete variations – local range – explicit simulations
- rock (coal) failure – (model) discrete variations – local range – explicit simulations

Effects of geomechanical state variations upon transport properties of rocks:

- porosity, ϕ (pore volume, PV) modifications due to elastic and plastic deformations
- permeability, k (transmissibility, T) modifications due to elastic and plastic deformations
- diffusion rate increase due to rock (coal) failure

EFFECTS OF CONTINUOUS DEFORMATIONS

Effective correlations between reservoir pressure variations (ΔP) and rock transport properties (ΔT , ΔPV) implicitly applied in simulation process and combined from:

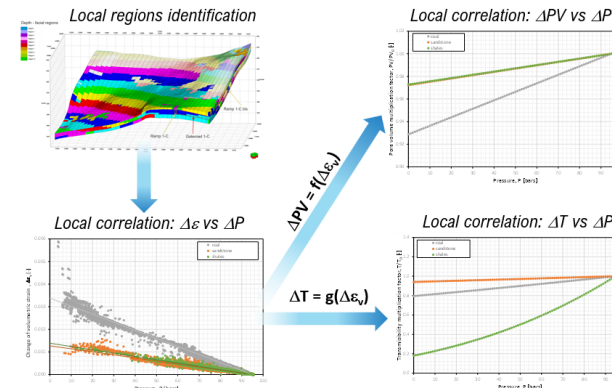
- local correlations between reservoir pressure variations (ΔP) and modifications of rock transport properties from geomechanical effects ($\Delta \epsilon$, $\Delta \sigma$)
- correlations between geomechanical state variations ($\Delta \epsilon$, $\Delta \sigma$) and rock transport properties (ΔT , ΔPV), e.g.

Kozeny-Carman isotropic model

$$T_i = T_{0i} \frac{\phi^3 / (1 - \phi)^2}{\phi_0^3 / (1 - \phi_0)^2}$$

where:

T_i = modified transmissibility in i -th main direction,
 T_{0i} = initial transmissibility in i -th main direction
 ϕ = modified porosity,
 ϕ_0 = initial porosity,
 $\Delta \phi$ = change in porosity,
 $\Delta \epsilon_v$ = change in volumetric strain,
 α = Biot's coefficient



EFFECTS OF DISCRETE DEFORMATIONS

Step-like modifications of rock transport properties (ΔT , ΔPV) explicitly introduced into simulation process and determined from correlations between the properties and geomechanical state modifications ($\Delta \epsilon$, $\Delta \sigma$), e.g.

Durucan and Shi anisotropic model

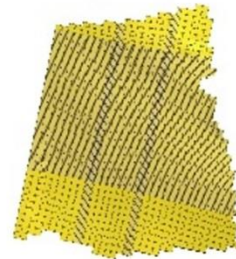
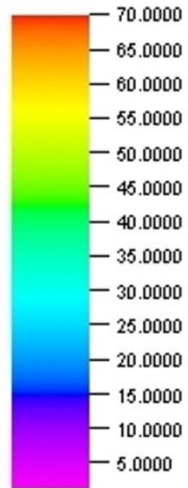
$$T_i = T_{0i} e^{-c \sum_{j=1}^3 \Delta \sigma_j (1 - \delta_{ij})}$$

where:

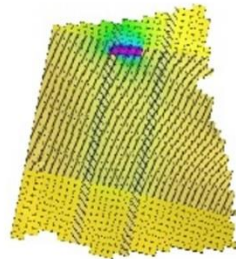
T_i = modified permeability in i -th main direction,
 T_{0i} = initial permeability in i -th main direction,
 c = permeability compressibility,
 $\Delta \sigma_j$ = change in effective stress in j -th main direction,
 δ_{ij} = Kronecker delta

DISCRETIZATION OF THE SIMULATION PROCESS

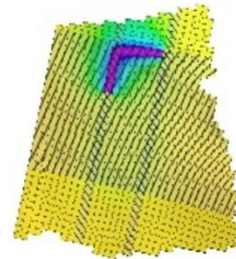
Pressure (PRESSURE) - fracture
Pressure [bar]



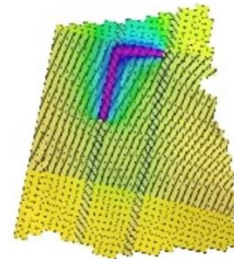
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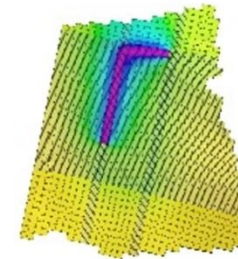
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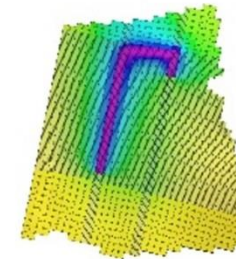
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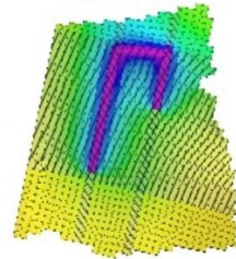
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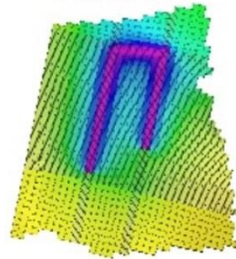
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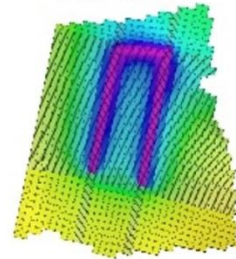
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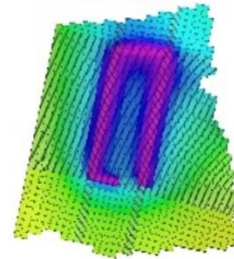
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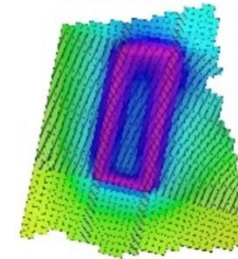
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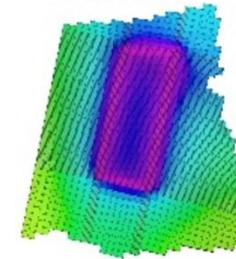
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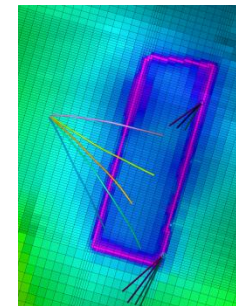
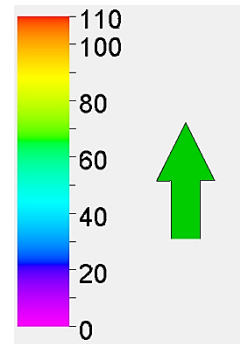
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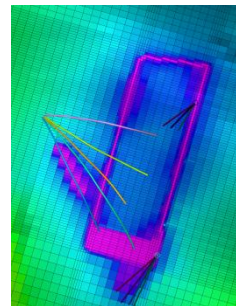
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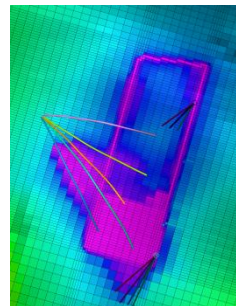
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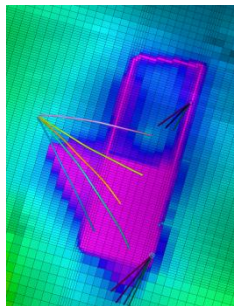
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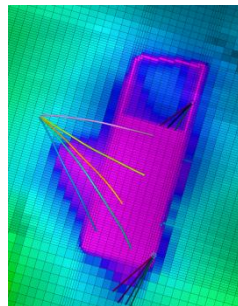
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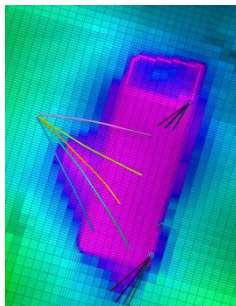
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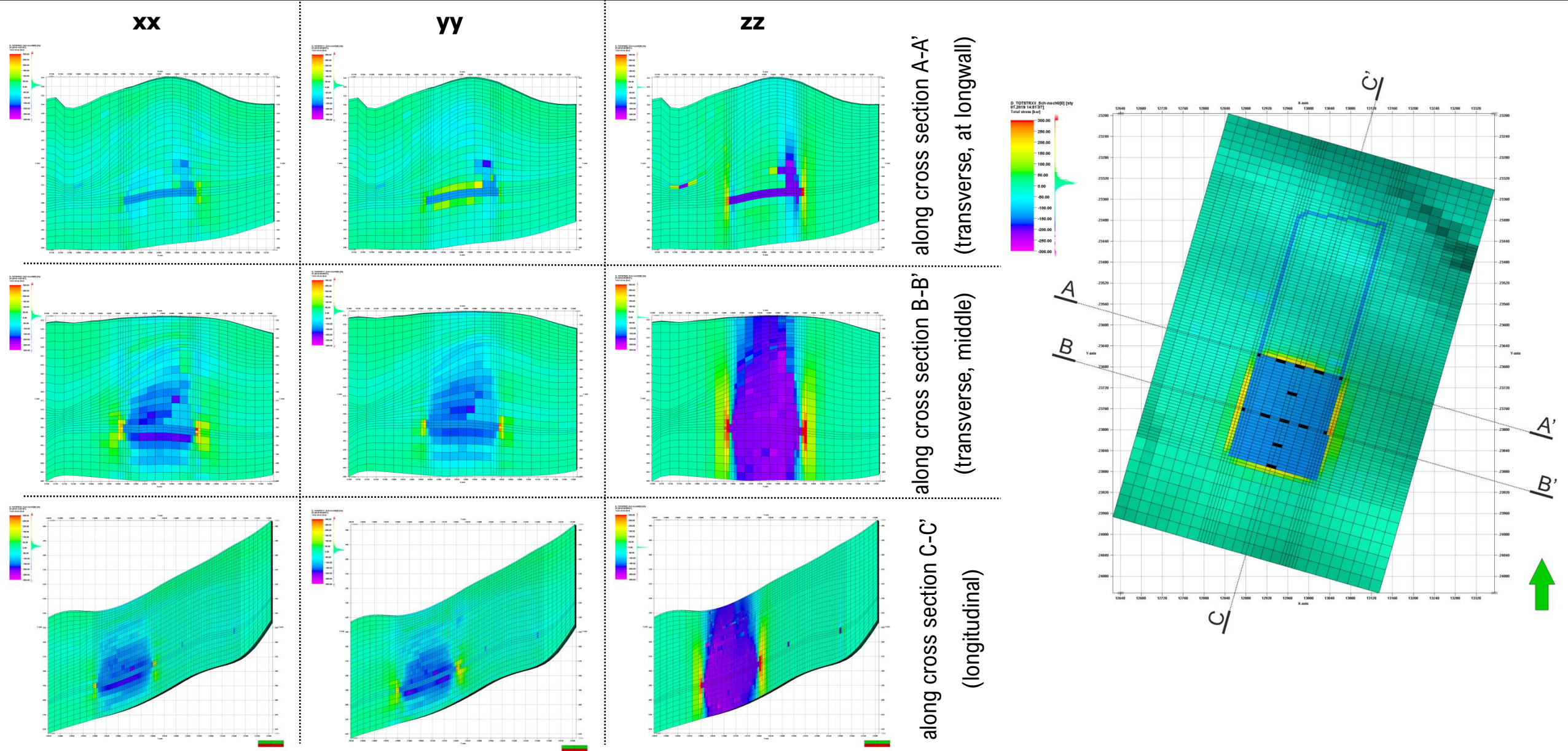


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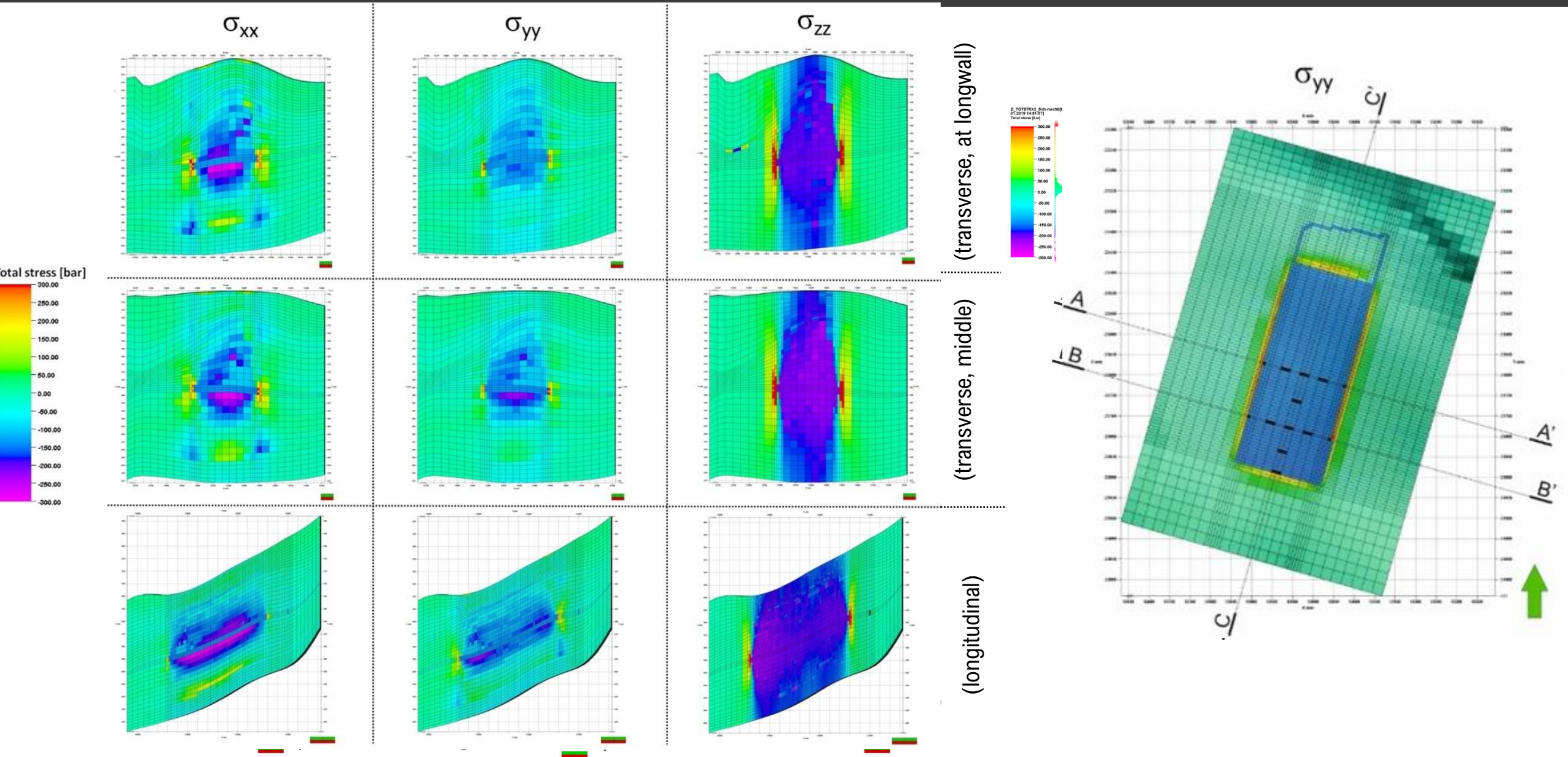


01.02.2020

DISTRIBUTION OF STRESS TENSOR VARIATIONS ($\Delta\sigma_{ii}$, $ii = xx, yy, zz$) ALONG VERTICAL CROSS SECTIONS AT HALF TIME



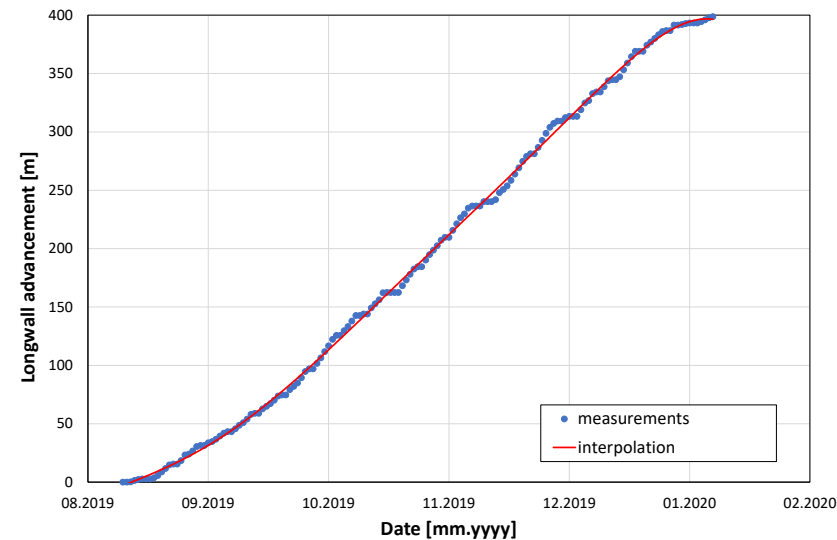
DISTRIBUTION OF STRESS TENSOR VARIATIONS ($\Delta\sigma_{ii}$, $ii = xx, yy, zz$) ALONG VERTICAL CROSS SECTIONS AT COMPLETED EXCAVATION



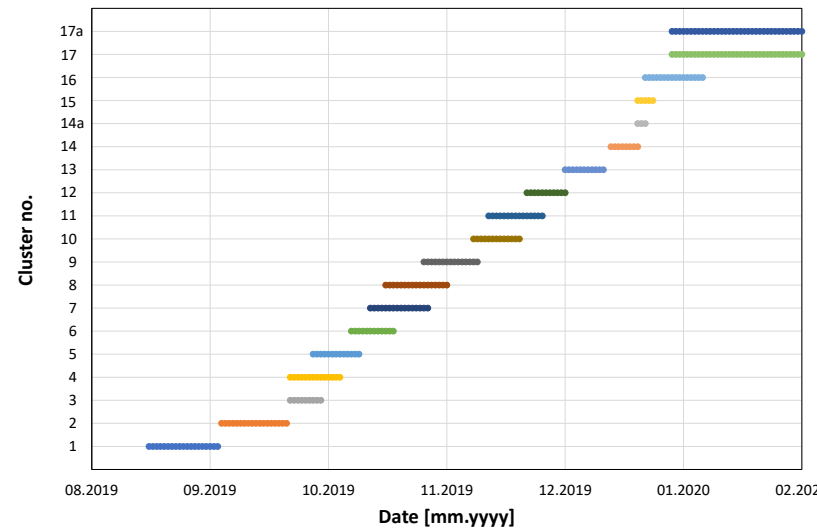
Model calibration – history matching

Calibration data: historical data of the coal production from the C lot of the 501 coal seam:

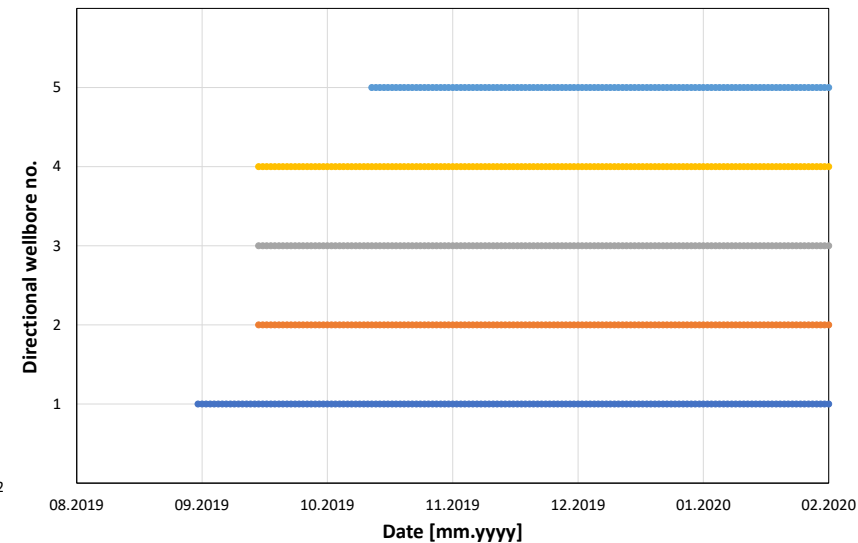
- Schedule and measurement data from the excavation and ventilation of the gate roads before the coal excavation – air injection, total gas and methane production of the ventilation system – vs time (29.01.2018 through 31.08.2019)
- Schedule and measurement data from the C lot coal production: air injection, total gas and methane production by:
 - (1) ventilation system,
 - (2) standard methane drainage boreholes grouped into 19 clusters,
 - (3) directional methane drainage boreholes – vs time (01.09.2019 through 28.02.2020)
- Pressure conditions of the ventilation system and the methane drainage boreholes



The longwall advancement during the C lot coal production

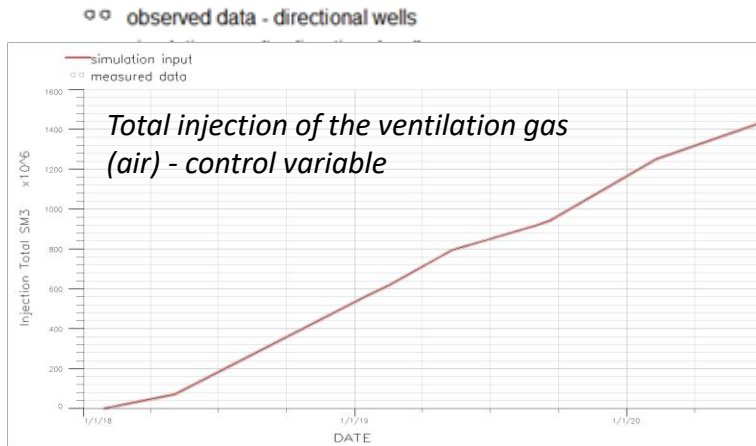


The production intervals of standard methane drainage borehole clusters

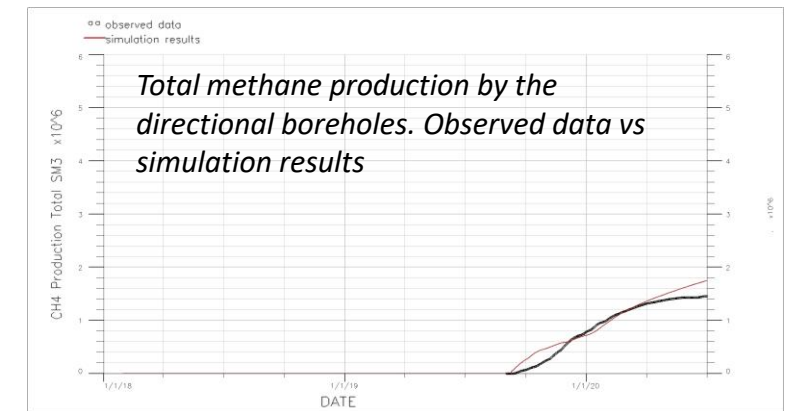
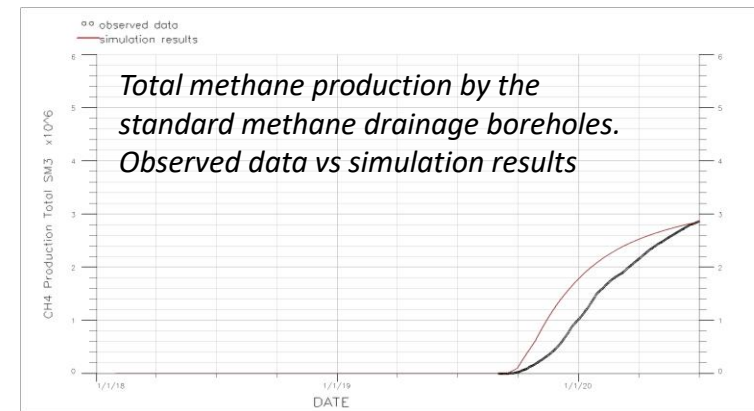
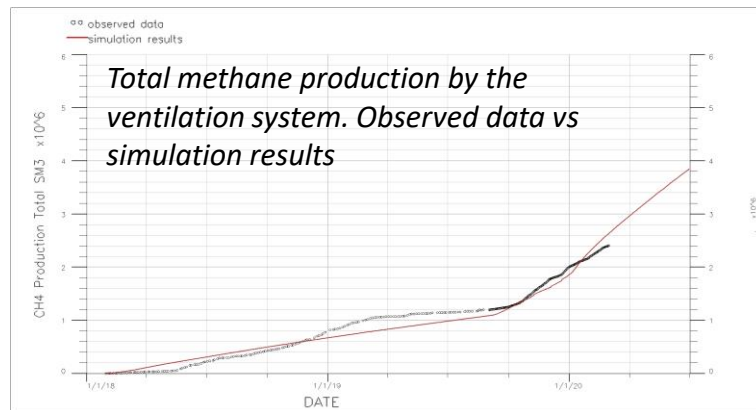
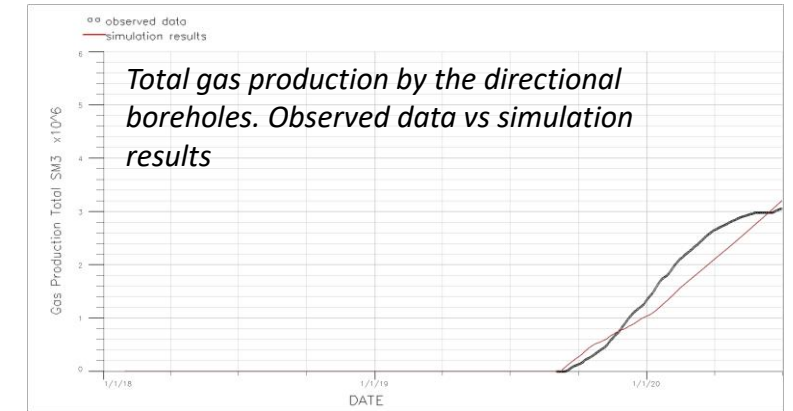
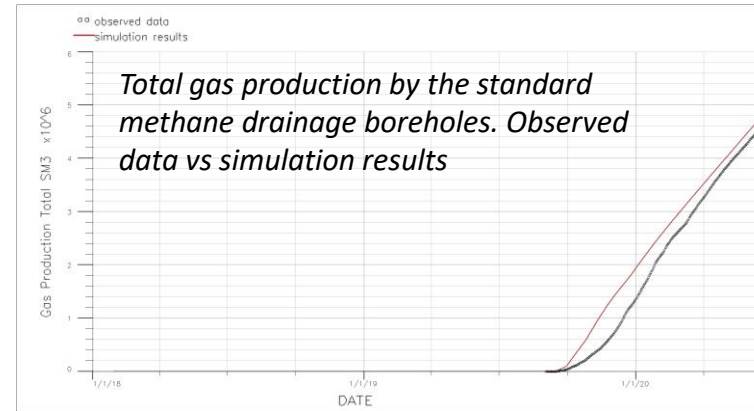
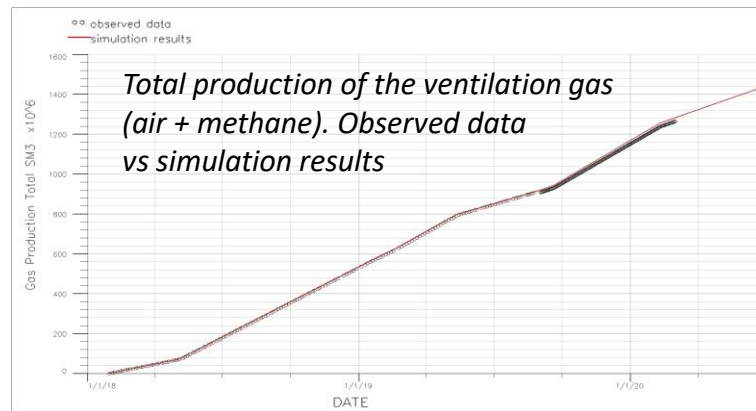


The production intervals of directional methane drainage boreholes

Model calibration – history matching results



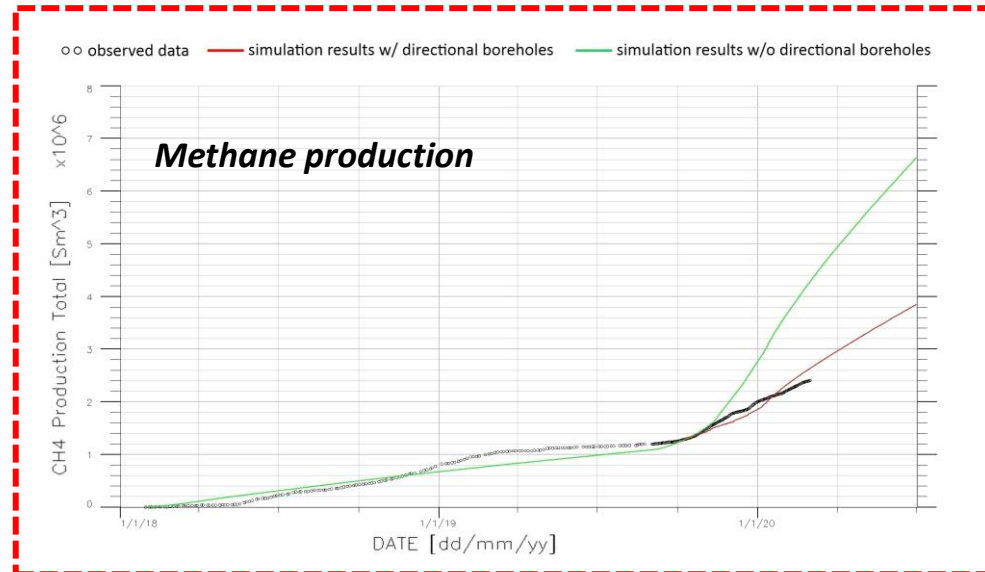
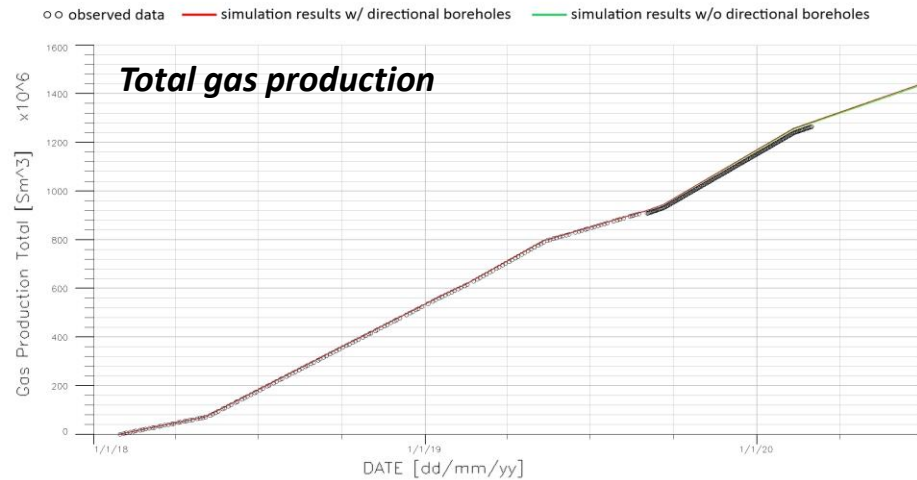
Satisfactory agreement between the measured data at the simulation results – good reliability of the model to correctly describe the methane drainage processes during the coal production from the C lot of the 501 coal seam



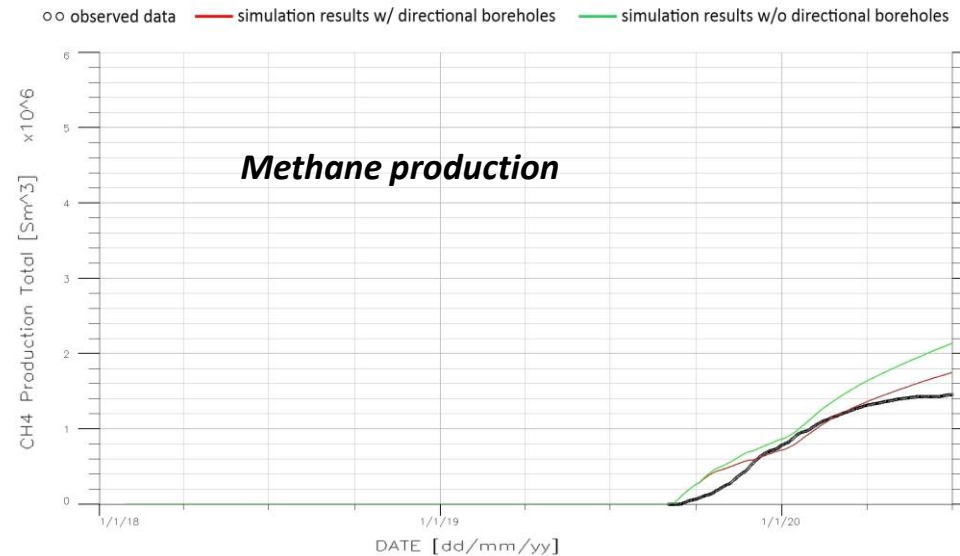
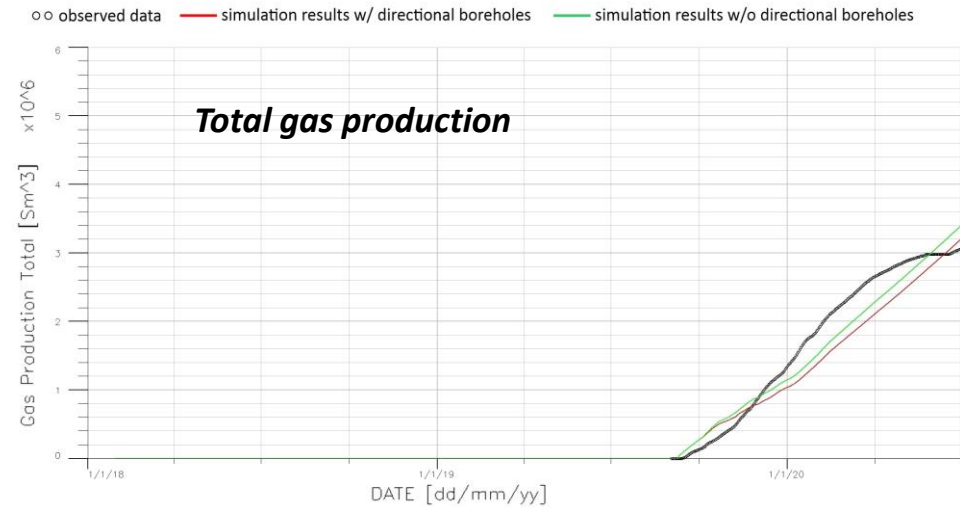
Effects of methane drainage by the directional boreholes

Comparison of simulation results for scenarios with the directional boreholes vs scenarios without the directional boreholes

Ventilation system

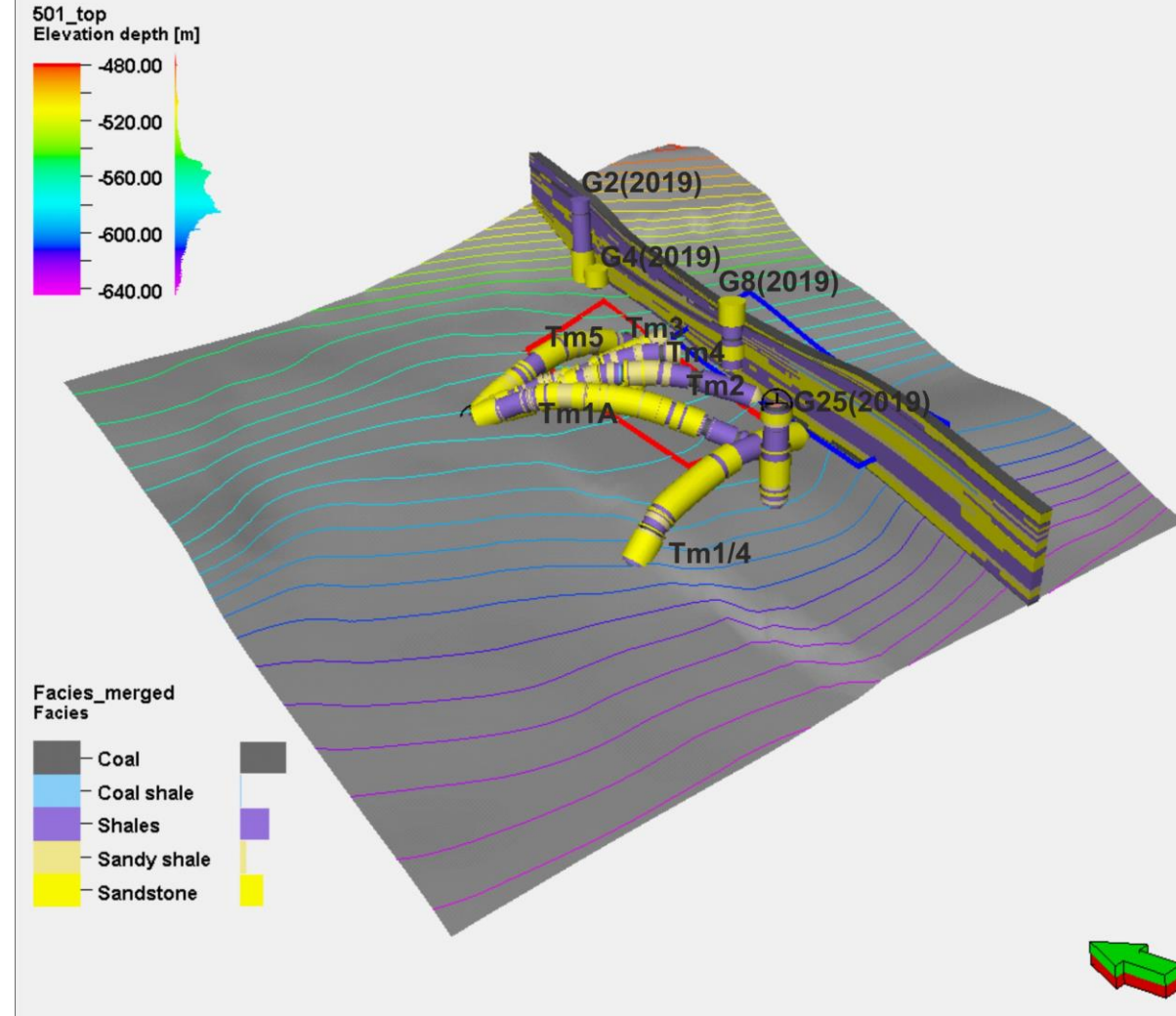


Standard boreholes

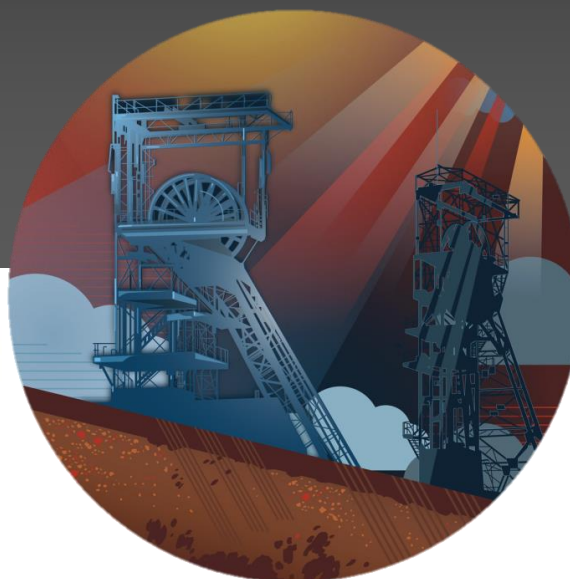


SUMMARY AND CONCLUSIONS

- To assess the effectiveness of the applied drainage technology a numerical methods coupling geomechanical and fluid flow models were used
- The method proposed in the studies and comprising effectively coupled geomechanical and dynamical simulations of reservoir region and its extension allows to take into account impact of geomechanical effects ($\Delta\varepsilon$, $\Delta\sigma$) upon transport properties of reservoir rock (ΔPV , ΔT) at various considered stages including gate road excavations, long wall movement or drilling conventional and LRDD including continuous flow and geomechanical variations: $\Delta P \rightarrow \Delta\varepsilon$, $\Delta\sigma \rightarrow \Delta PV$, ΔT
- the quantitative results of those geomechanical effects depend upon detailed properties of both geomechanical state evolution and geological characteristics of the coal seam and surrounding strata,
- the following 2 correlations are key factors when the effective transport properties of the rock are concern:
 - the correlation between geomechanical state (stress and strain field) and
 - and rock transport properties Kozeny – Carman (isotropic model) and Durucan and Shi (anisotropic model)
- The presented results prove the effectiveness of the proposed methane drainage with the use of the long-reach directional boreholes. In particular, the method significantly (by ca. 52%) decreases the methane content in the ventilation gas and notably reduces the methane content in the coal matrix of the excavated coal seam.



THANK YOU FOR YOUR ATTENTION



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