GŁÓWNY INSTYTUT GÓRNICTWA

Monitoring, Assessment, Prevention and Mitigation of Rock Burst and Gas Outburst Hazards in Coal Mines (based on MapROC project)

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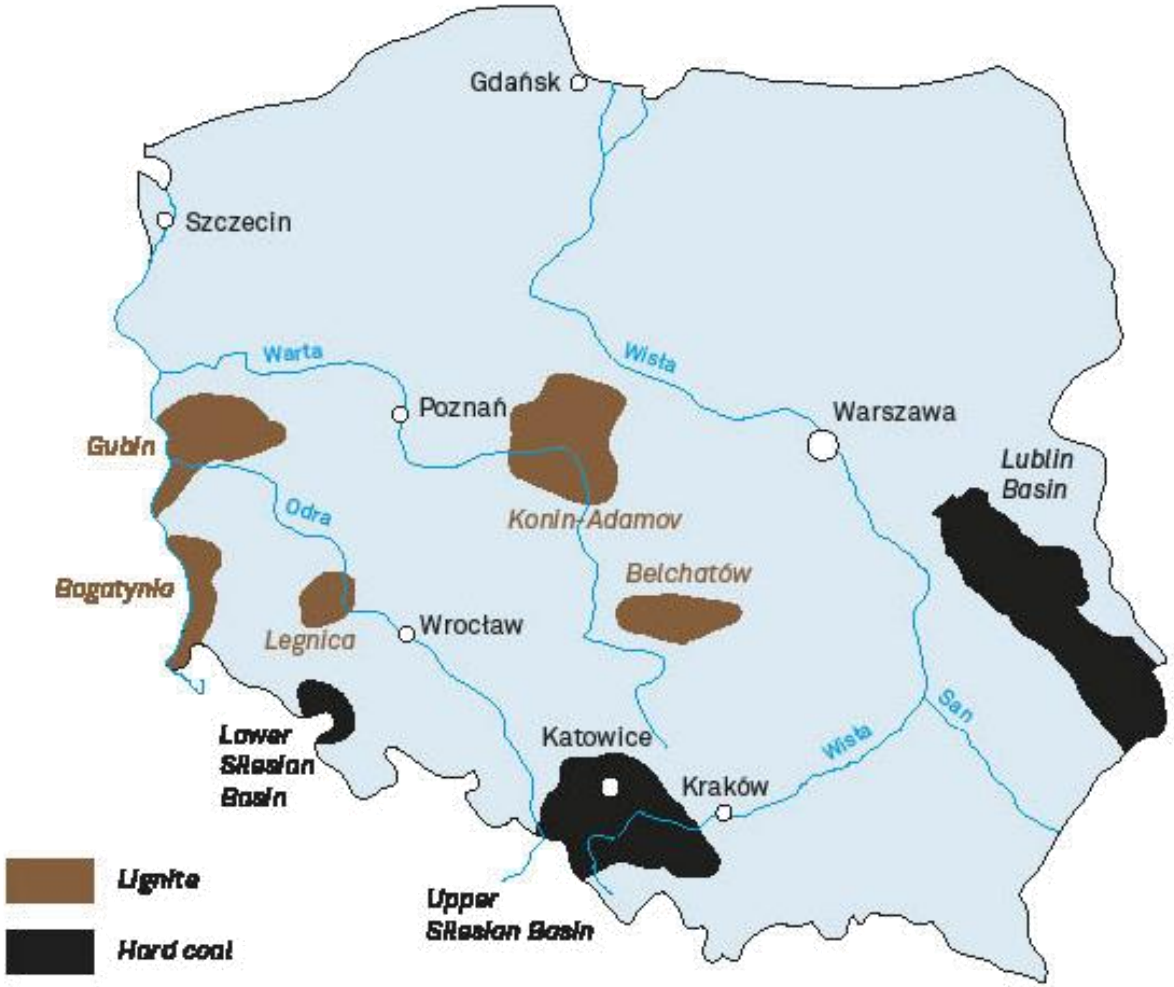
Ankara, June 10th, 2019

POLISH COAL BASINS



GIG

THE COAL SEAMS ARE MINED IN CONDITIONS OF NATURAL HAZARDS

- Gas hazards
- Fire hazard
- Dust hazard
- Seismic and rock burst hazard
- Water hazard
- Climatic hazard
- Radiation hazard

Such mining conditions negatively affect the costs of mining activity of Polish companies

GIG

Typical problems at gassy coal mines

- Ventilation and Gas Emissions Management in Coal Mines
- Development of Improved Methane Drainage Technologies by Stimulating Coal Seams for Major Risk Prevention and Increased Coal Output
- **Monitoring, Assessment, Prevention and Mitigation of Rock Burst and Gas Outburst Hazards in Coal Mines**
- Prediction and mitigation of methane explosion effects for improved protection of mine infrastructure and critical equipment

CMM related projects

- **AVENTO** (Ventilation and Gas Emissions Management in Coal Mines),
- **MAPROC (Monitoring, Assessment, Prevention and Mitigation of Rock Burst and Gas Outburst Hazards in Coal Mines),**
- **GASDRAIN** (Development of Improved Methane Drainage Technologies by Stimulating Coal Seams for Major Risk Prevention and Increased Coal Output),
- **EXPRO** (Prediction and mitigation of methane explosion effects for improved protection of mine infrastructure and critical equipment),

MAPROC (Monitoring, Assessment, Prevention and Mitigation of Rock Burst and Gas Outburst Hazards in Coal Mines),

The main objectives of **MapROC** are to:

- develop and field test rock burst/outburst prevention techniques based on the use of large diameter boreholes with alternative stress and gas pressure relief techniques;
- formulate a methodology to couple the near-real time processing of monitored microseismic data with Artificial Neural Networks and Fractal Dimension analysis to develop a short-term prediction method for rock bursts/outbursts;
- demonstrate the use of this prediction method as a tool for early risk assessment, prevention, and mitigation of these hazards;
- numerically model the application stress relief, stress control and protective mining options;
- develop and validate a generic risk assessment methodology for rock bursts/outbursts.

MapROC project partners:

*The participation of **seven** partners from **five** different countries with important coal mining industries, enable to cover a variety of mining conditions across Europe.*
The consortium includes a balanced participation of industry, research institutions and universities, thus allowing both laboratory and mine tests.

AITEMIN is a non-for-profit independent research organization based in Madrid, Spain;

CM-Velenje - Premogovnik Velenje D.D., Slovenja

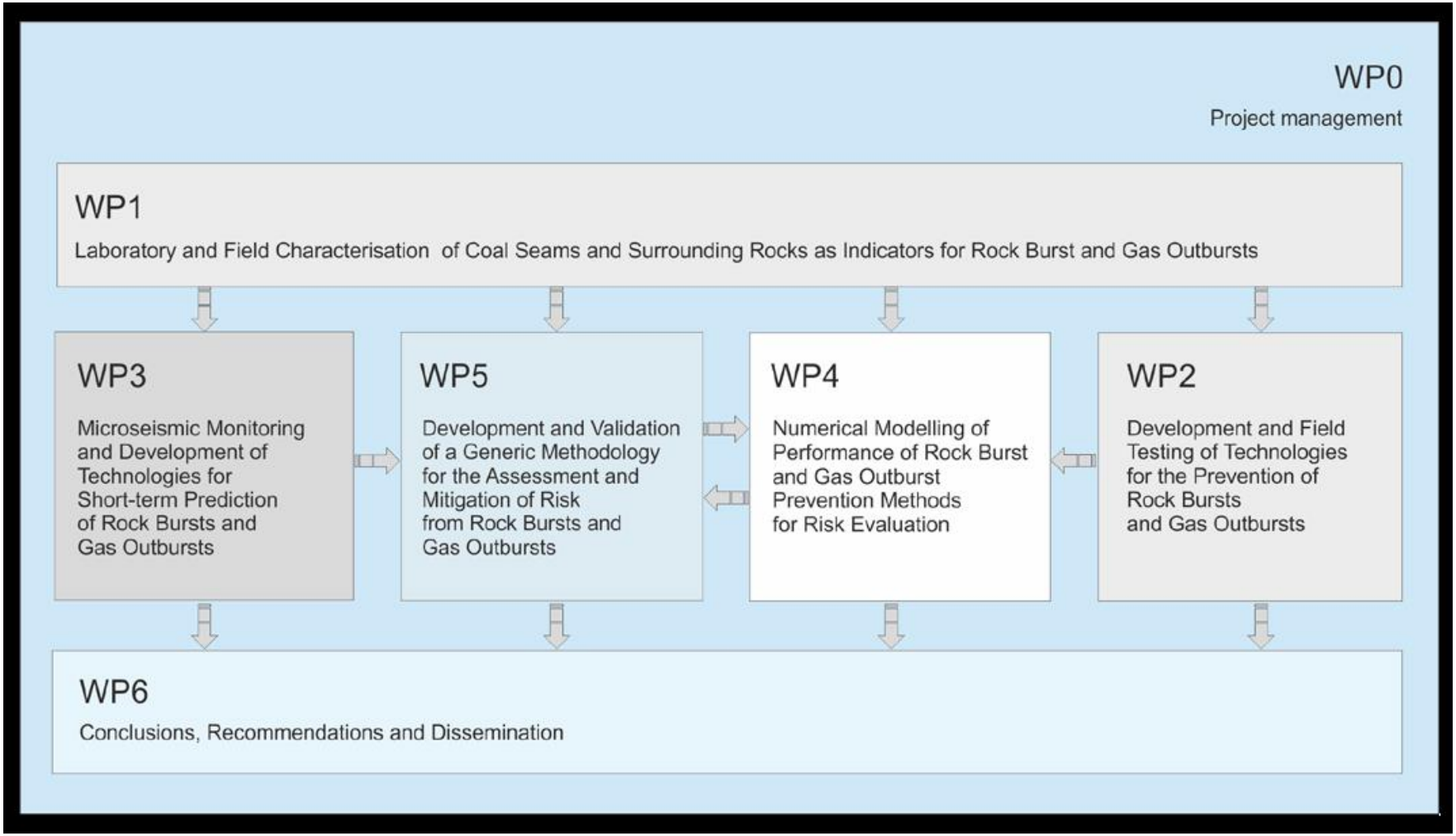
GIG - **C**entral **M**ining **I**nstitute of Katowice, Poland

HVL - **H**ullera **V**asco-**L**eonesa, Spain

IMPERIAL - Imperial College of Science Technology and Medicine (U.K.)

JSW SA - Jastrzebska Spolka Weglowa SA, Poland

RWTH Aachen University, Germany


WP0
Project management
WP1
Laboratory and Field Characterisation of Coal Seams and Surrounding Rocks as Indicators for Rock Burst and Gas Outbursts
WP3
Microseismic Monitoring and Development of Technologies for Short-term Prediction of Rock Bursts and Gas Outbursts
WP5
Development and Validation of a Generic Methodology for the Assessment and Mitigation of Risk from Rock Bursts and Gas Outbursts
WP4
Numerical Modelling of Performance of Rock Burst and Gas Outburst Prevention Methods for Risk Evaluation
WP2
Development and Field Testing of Technologies for the Prevention of Rock Bursts and Gas Outbursts
WP6
Conclusions, Recommendations and Dissemination

Work Package 1 aimed at carrying out a limited number of laboratory experiments to characterise some partner mine and other European coals for their gas release dynamics to fill in missing data which may not have been collected in previous projects. Additional laboratory research involved upgrading of the large diameter triaxial cell to enable acoustic measurements under stress and gas flow conditions. The prevailing in situ stress state and strain conditions around working Longwall and Longwall Top Coal Caving and Sub-Level caving coal faces at JSW, CM-VELENJE and HVL were assessed through empirical and numerical methods.

MapROC WP1 Laboratory and Field Characterization

Imperial College London

RWTH RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

Supported by:

GIG

PREMOGOVNIK VELENJE

JSW

In the MapROC project laboratory experiments have been performed to characterize coals from partner mines with respect to

- **gas storage capacity**
- **gas uptake and release kinetics**
- **permeability under different effective stress conditions**

Together with data from other European coals a comprehensive database was established.

RWTH/EMR Petrophysics Laboratory

Experimental investigation of gas storage and transport processes

- **Coals**
- Carbonaceous shales
- Tight sandstones

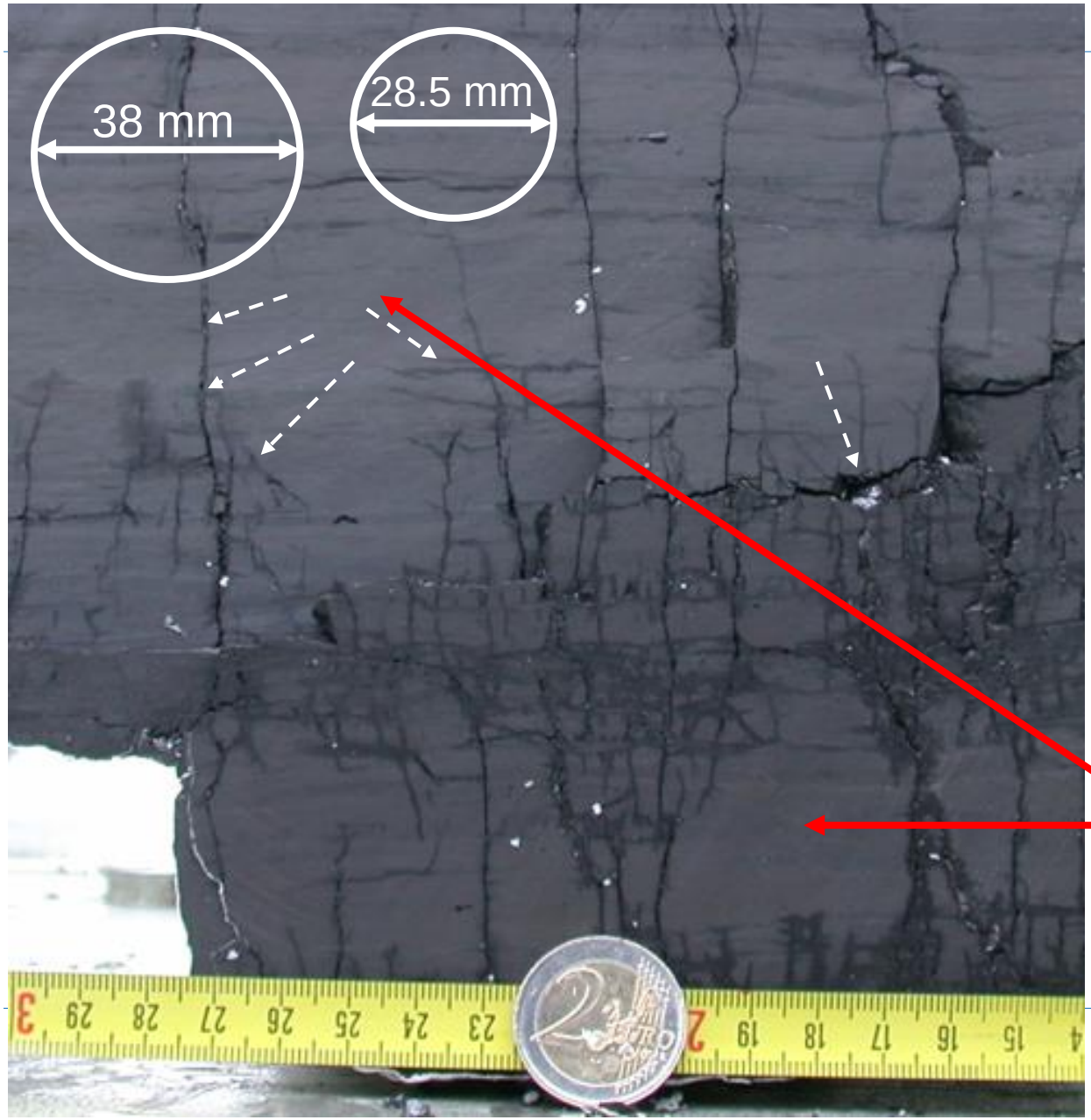
High-pressure adsorption of CH_4, CO_2, N_2 ... ✔

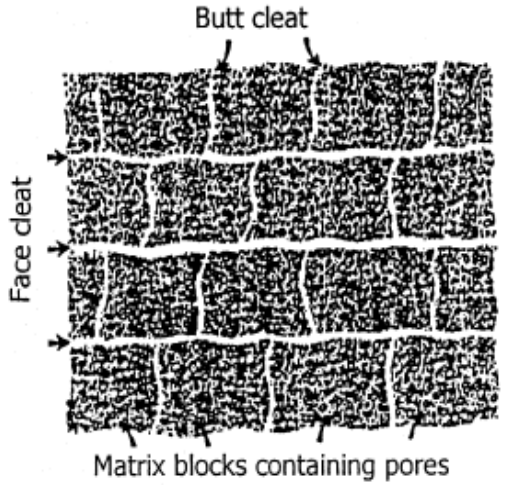
- Temperature range (room temp. ➔ 150° C) ✔
- Pressure range (➔ 35 MPa) ✔
- Effect of water on CH_4 and CO_2 sorption ✔
- Gas mixtures (CH_4/CO_2; $C_1 – C_3$) ✔
- Stress-dependence ✔

Transport processes (stress-dependence) ✔

- Darcy flow (liquids and gases) ✔
- Slip flow, Knudsen flow, transitional flow (gases) ✔
- Diffusion ✔

GAS SORPTION AND TRANSPORT IN COALS





cleat system
(transport avenues)

matrix volume
(storage capacity)

Project coals:

Pniówek (404/1)

Zofiówka (411, 412, 413)

Velenje

Laboratory experiments at RWTH Aachen and Imperial College London

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Database

Germany:
- Osnabrück-Bielefeld-Münster Area
- Saar Area

Belgium:
- Campine Basin
- Borinage Basin
- Liège Basin

The Netherlands:
- Limburg coal mines

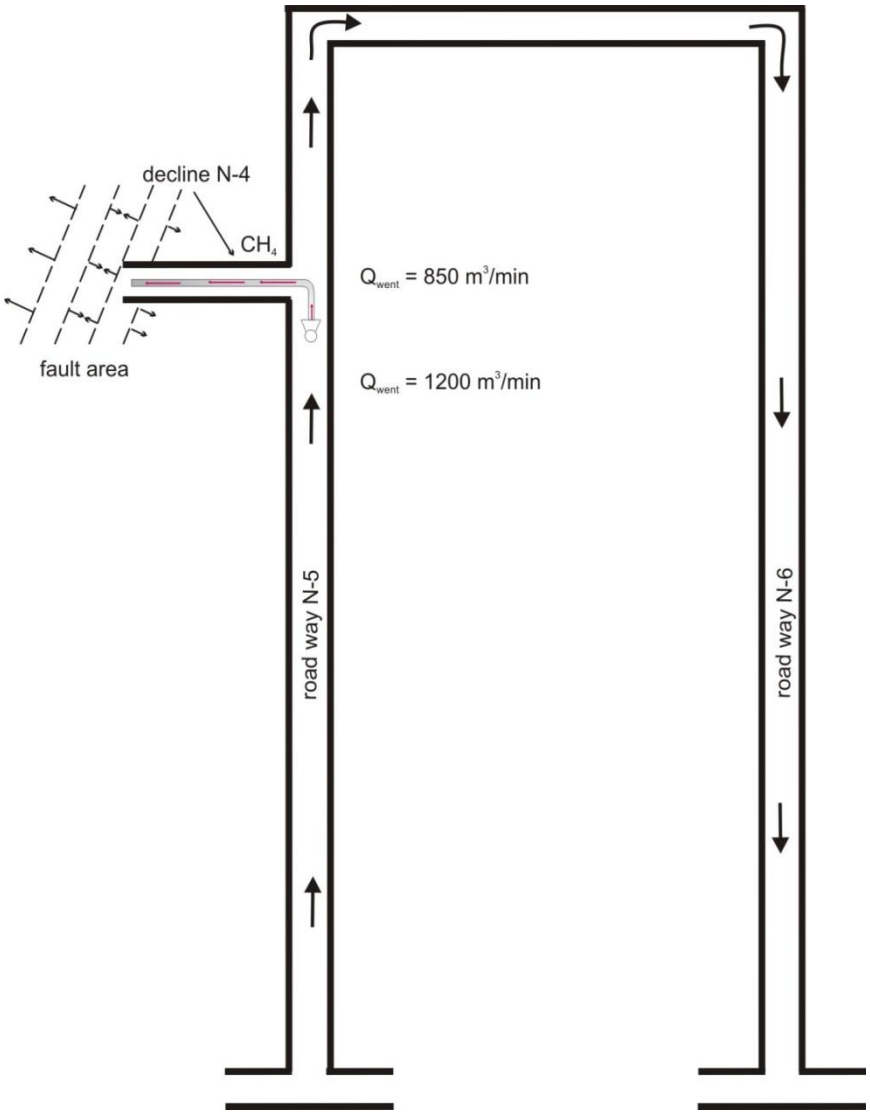
Czech Republic:
- SW Upper Silesian Coal Basin

Spain:
- Competidora
- Sueros

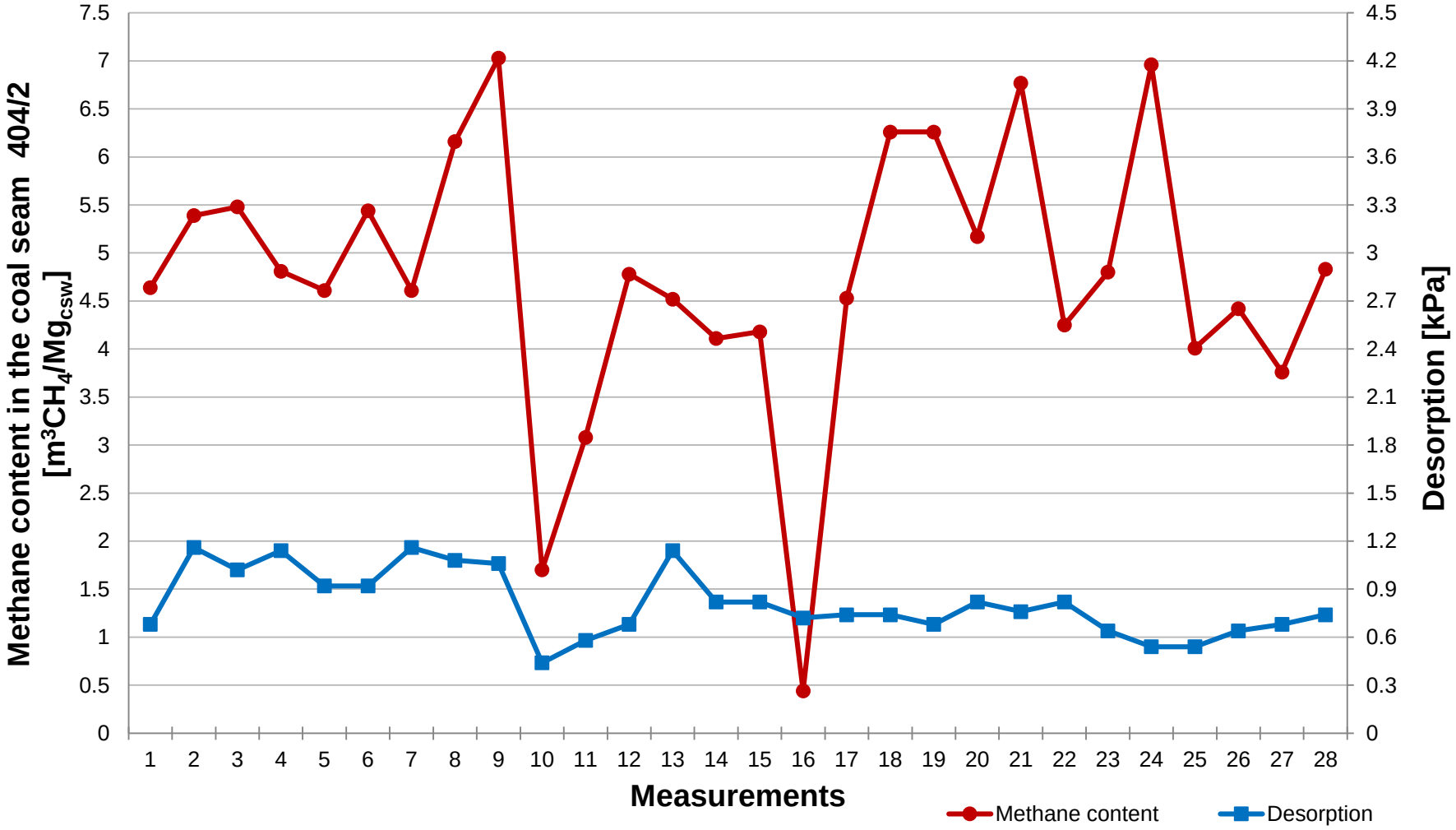
The United Kingdom:
- Point of Ayr
- Odd House
- Watson Head
- Carrington Farm
- Sellar
- Tower

Work Package 2 will carry out field experiments using large diameter boreholes for stress and gas pressure relief, implementing either blasting or slot cutting or high pressure water injection depending on the mine and type of coal that exists and aim at determining their effectiveness in developing the desired stress and gas pressure relief around the workings. As JSW will carry out similar experiments in small diameter gas drainage boreholes, most experiments will not be repeated there and the equipment and blasting methods developed in GasDRAIN will be available for use by the other two industrial partners who are not involved in GasDRAIN. JSW will help in the use of the equipment at CM-VELENJE and HVL as necessary. AITEMIN will investigate the potential use of Measurement While Drilling techniques in order to take advantage of routine drilling operations performed, either for pressure relief or for production (blasting), for acquiring data that is helpful to characterise the rock or coal mass from the point of view of outburst risk.

Under TASK 2.1, in the 1st quarter of 2017, in the coal seam 404/2 of JSW SA „Pniówek” mine, the tests covering degassing and stress releasing blasting were performed.


decline N-4
CH_4
fault area
Q_{went} = 850 m^3/min
Q_{went} = 1200 m^3/min
road way N-5
road way N-6

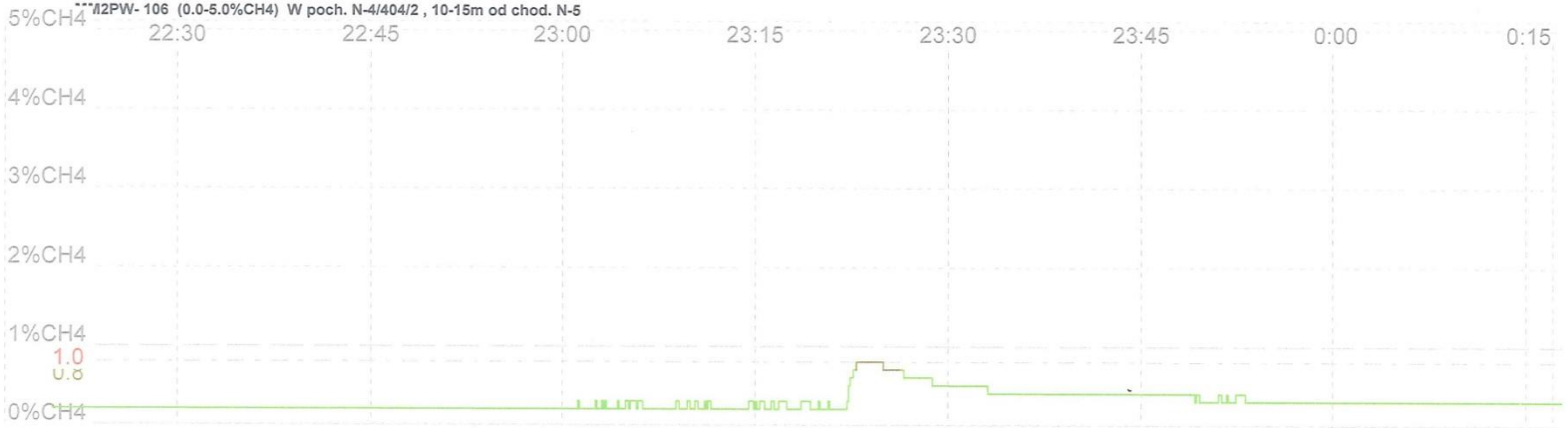
Roadway N-6 in the coal seam 404/2					
No of measurement	**Date of measurement**	**Methane content [m^3CH_4/Mg_{daf}]**	**Desorption [kPa]**	**Conciseness [-]**	**Coal cuttings [dm^3/1mb]**
1	17.12.15	2.6	0.20	0.4	2.0
2	27.01.16	3.81	0.78	0.44	2.3
3	10.02.16	2.54	0.52	0.44	2.5
4	17.02.16	2.97	0.48	0.45	2.5
5	25.06.16	2.48	0.48	0.46	2.2
6	3.03.16	4.33	0.42	0.45	2.3
7	11.03.16	3.36	0.4	0.44	4.2
8	21.03.16	3.24	0.54	0.46	2.1
9	30.03.16	4.39	0.4	0.45	2.2
10	6.04.16	4.06	0.62	0.44	2.3
11	14.04.16	4.13	0.48	0.42	2.3
12	21.04.16	3.73	0.58	0.45	2.4
13	27.04.16	7.08	1.16	0.44	2.4
14	11.05.16	7.11	0.88	0.42	2.4
15	20.05.16	5.01	1.02	0.42	2.5
16	27.05.16	5.05	0.86	0.43	2.3
17	07.06.16	7.53	1.12	0.44	2.3
18	15.06.16	5.89	0.96	0.44	2.5
19	22.06.16	5.51	0.92	0.44	2.5
20	29.06.16	5.31	0.94	0.43	2.4
21	8.07.16	4.52	0.92	0.4	2.6
22	15.07.16	6.13	0.84	0.42	2.4
23	28.07.16	1.82	0.54	0.35	2.4
24	3.08.16	3.65	1.02	0.42	2.5
25	11.08.16	6.18	0.82	0.39	2.6


Methane content in the coal seam 404/2
[m³CH₄/Mg_csw]
Desorption [kPa]
Measurements
Methane content
Desorption
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
4.5
4.2
3.9
3.6
3.3
3
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28

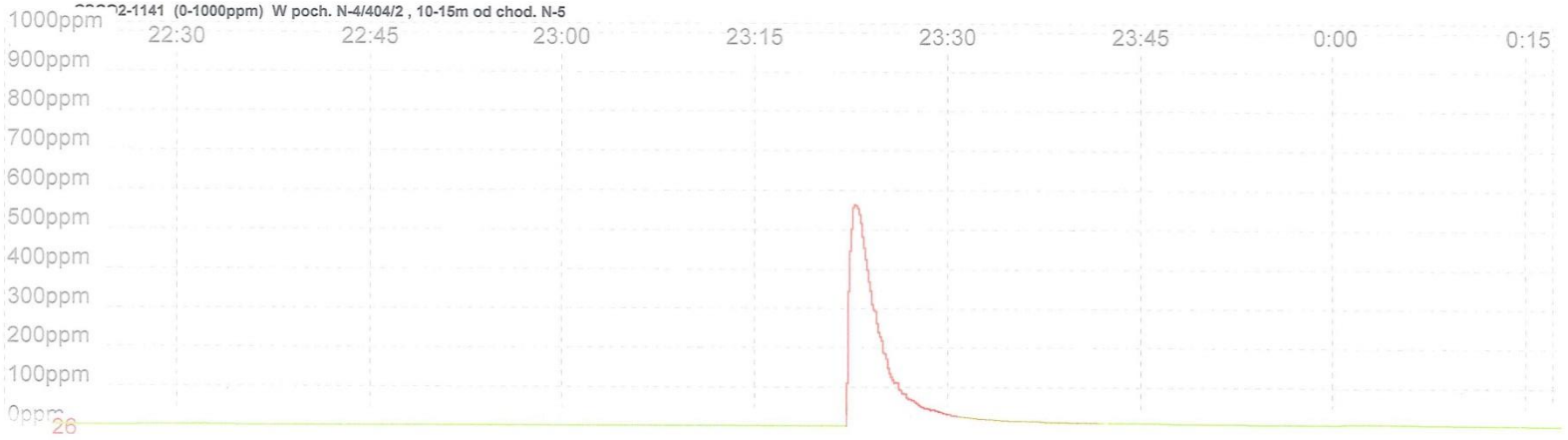
RAPORT GRAFICZNY

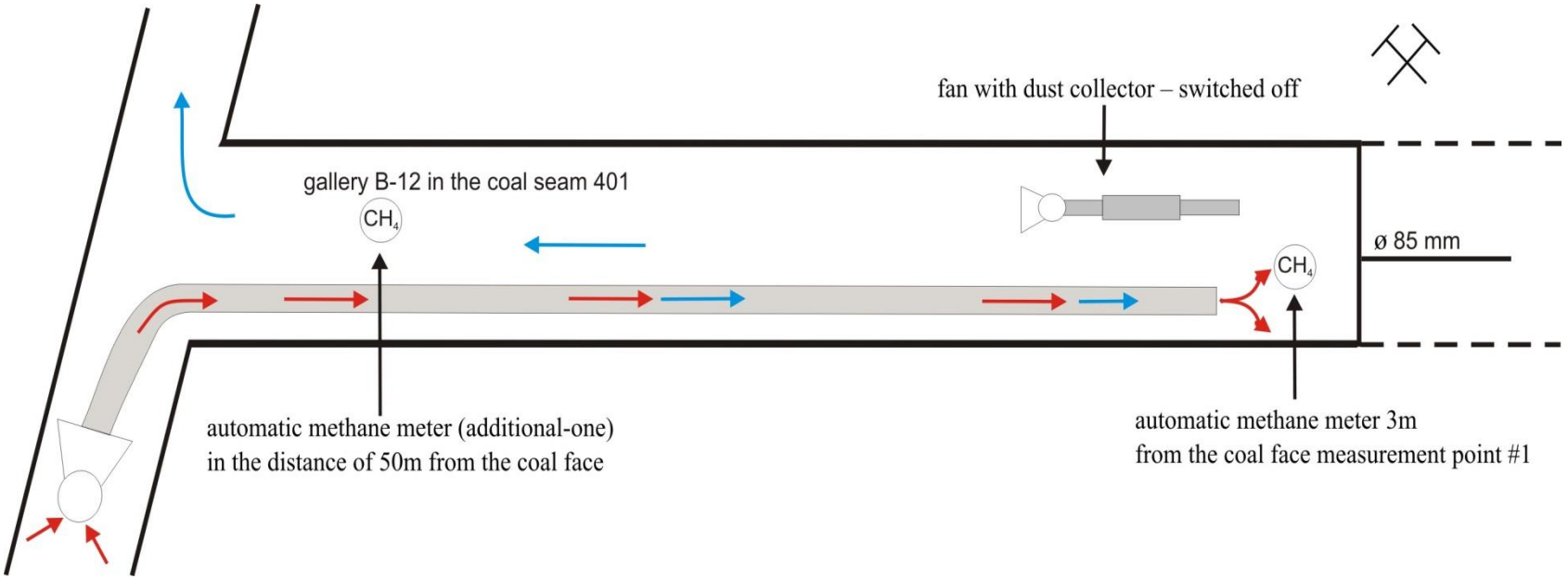
Kopalnia : KWK "Pniówek"
Data wydruku : 24.02.2017 17:43:51
Czujnik(i) : 106 1141

Okres wykresu : 1.02.2017 - 2.02.2017 (2g)
Statystyka : Max: 0.8%CH4 Min: 0.2%CH4 Średnia: 0.3%CH4

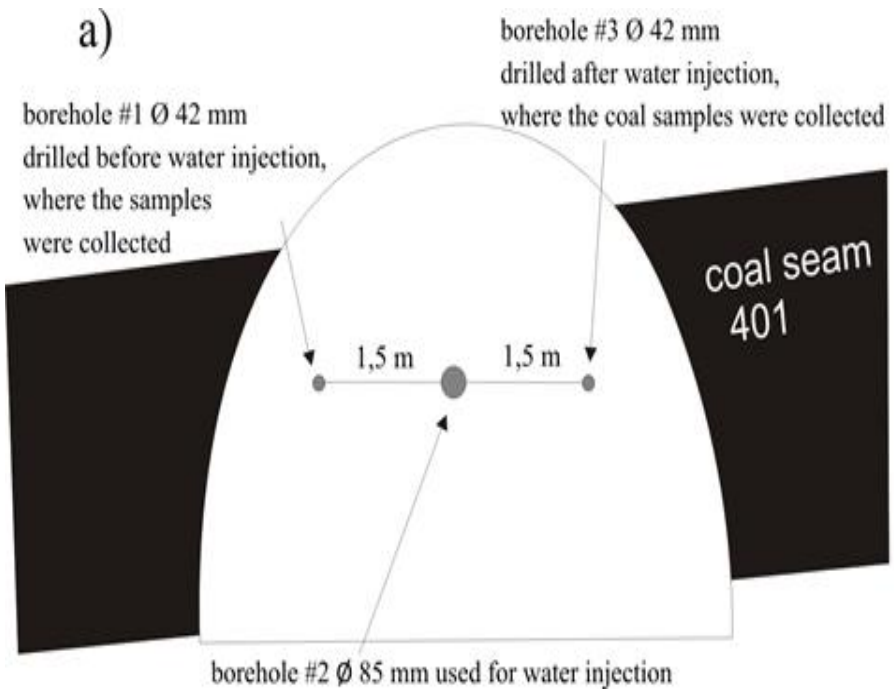


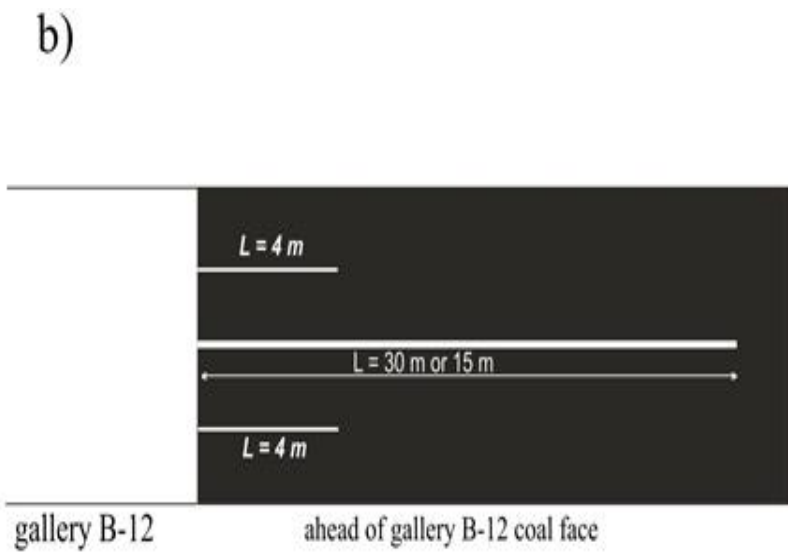
Okres wykresu : 1.02.2017 - 2.02.2017 (2g)
Statystyka : Max: 565ppm Min: 1ppm Średnia: 17ppm




fan with dust collector – switched off
gallery B-12 in the coal seam 401
CH4
ø 85 mm
CH4
automatic methane meter (additional-one)
in the distance of 50m from the coal face
automatic methane meter 3m
from the coal face measurement point #1

Location of the boreholes in the B-12 gallery coal face of 401 coal seam





Conclusions

- Conducted research in the coal seam 404/2 of JSW S.A. „Pniówek”mine in the first quarter of 2017 under Task 2.1 allowed to take clear position in the domain of fighting gas and rock outbursts' hazard by performance of degassing and stress releasing blastings

- Degasifying coal seam 404/2 by 24.7% comparing with its primary methane content not exceeding 6 $m^3CH_4Mg_{daf}$, allowed for keeping its gas parameters during drivage of N-4 incline at admissible level according to mining regulations.

- Conducting gas and rock outbursts hazard prophylactics based on performance of degassing and stress releasing blastings can be recognized as an effective method allowing to decrease level of outburst and bumping hazards.

- When comparing two applied methods of outburst hazard prophylactics i.e. degassing and stress releasing blasting and water injection into the coal bed the more effective is degassing and stress releasing blasting.

- Based on conducted tests of applied outburst hazard prophylactics degassing and stress releasing blastings can be recognized as prioritized-ones

In **Work Package 3,** GIG will aim at developing and validating a real time microseismic monitoring and data processing routines in order to provide near-real time (maximum one week intervals) seismic source energy, location and bent-ray tomograms to IMPERIAL for further analysis and development of Artificial Neural Network and Fractal Dimension based advance and near-real-time rock burst and gas outburst prediction models. The models will be trained and calibrated using the early period monitoring data from the mines, and will be validated by carrying out predictions during the second half of the project.

Work Package 4 will utilise the results of Work Packages 1, 2 and 3 and build numerical models to analyse the effectiveness of the large diameter borehole based stress and gas pressure relief methods for different mine layouts representative of those used at the partner mines and other European mines. Data generated through the field trials of different borehole techniques in WP 2 will be used to establish an understanding of the processes involved stress and gas pressure relief to prevent rock bursts and gas outbursts. Furthermore, WP4 will numerically assess two other preventative methods, namely stress relief mining and protective mining involving sacrificial drivages, pillars and under/over mining methods as could be applied in different coal mining methods (LW, LTCC, SLC).

Imperial College London

Development of Fractal Dimension and Artificial Neural Network (ANN) based Models for the Short-term Forecasting of Rock Bursts and Gas Outbursts

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Department of Earth Science and Engineering
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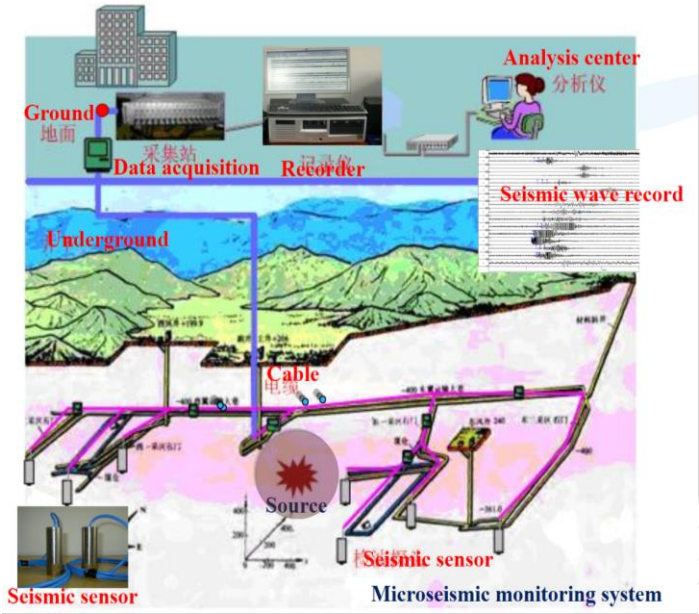
Outline

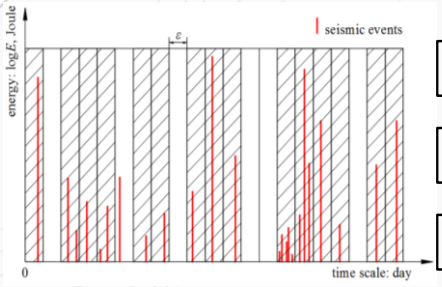
- Fractal Dimension based indicators
- Fractal-fuzzy evaluation methodology
- Artificial Neural Network model
- Applications at Coal Mine Velenje and Budryk Colliery

Modelling Framework

- Seismic phenomena
- Time-Space-Energy
- Clustering precursors
- Fractal dimensions

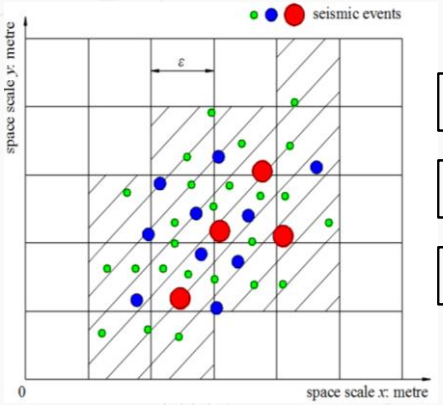


Microseismic monitoring system



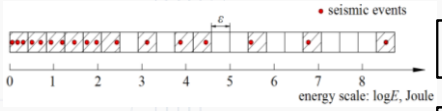
Time scaling indices D_T

- Capacity dimension D_{T0}
- Information dimension D_{T1} based number of events $D_{T1\text{-}N}$
- Information dimension D_{T1} based amount of energy $D_{T1\text{-}E}$



Space scaling indices D_s

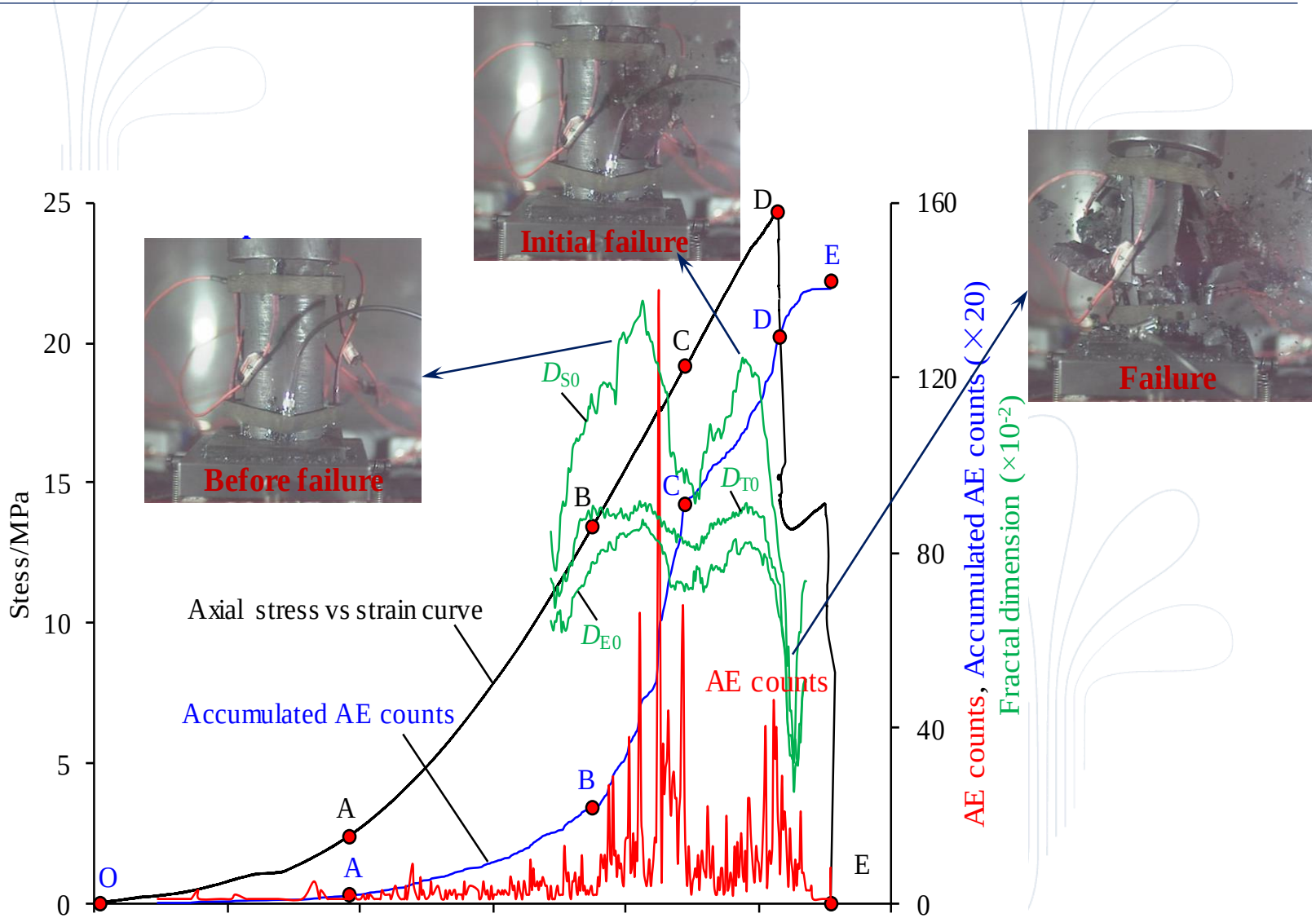
- Capacity dimension D_{S0}
- Information dimension D_{S1} based number of events $D_{S1\text{-}N}$
- Information dimension D_{S1} based amount of energy $D_{S1\text{-}E}$



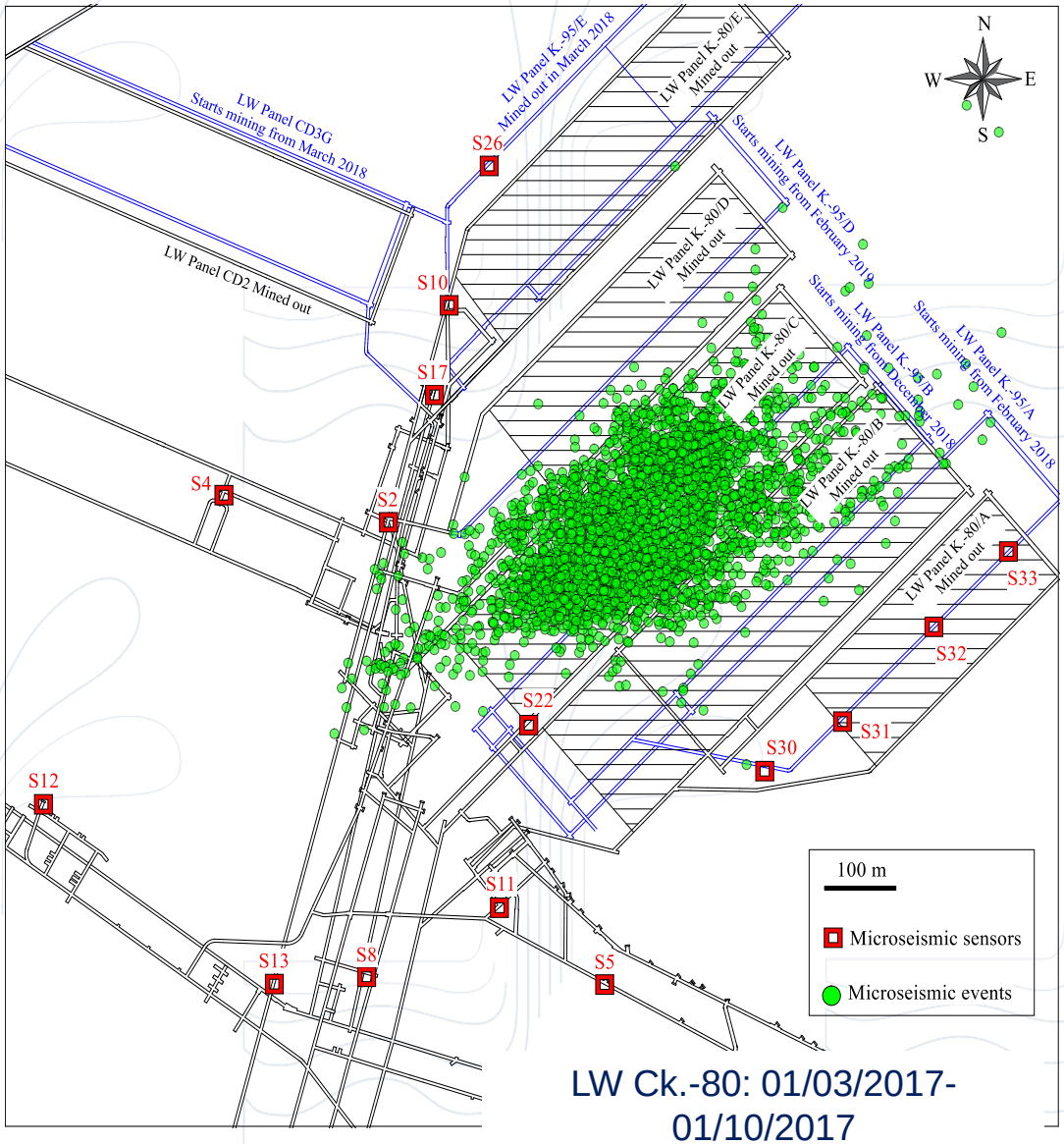
Energy scaling indices D_E

- Capacity dimension D_{E0}
- Information dimension D_{E1} based number of events $D_{E1\text{-}N}$
- Information dimension D_{E1} based amount of energy $D_{E1\text{-}E}$

Fractal Dimension: Physical meaning

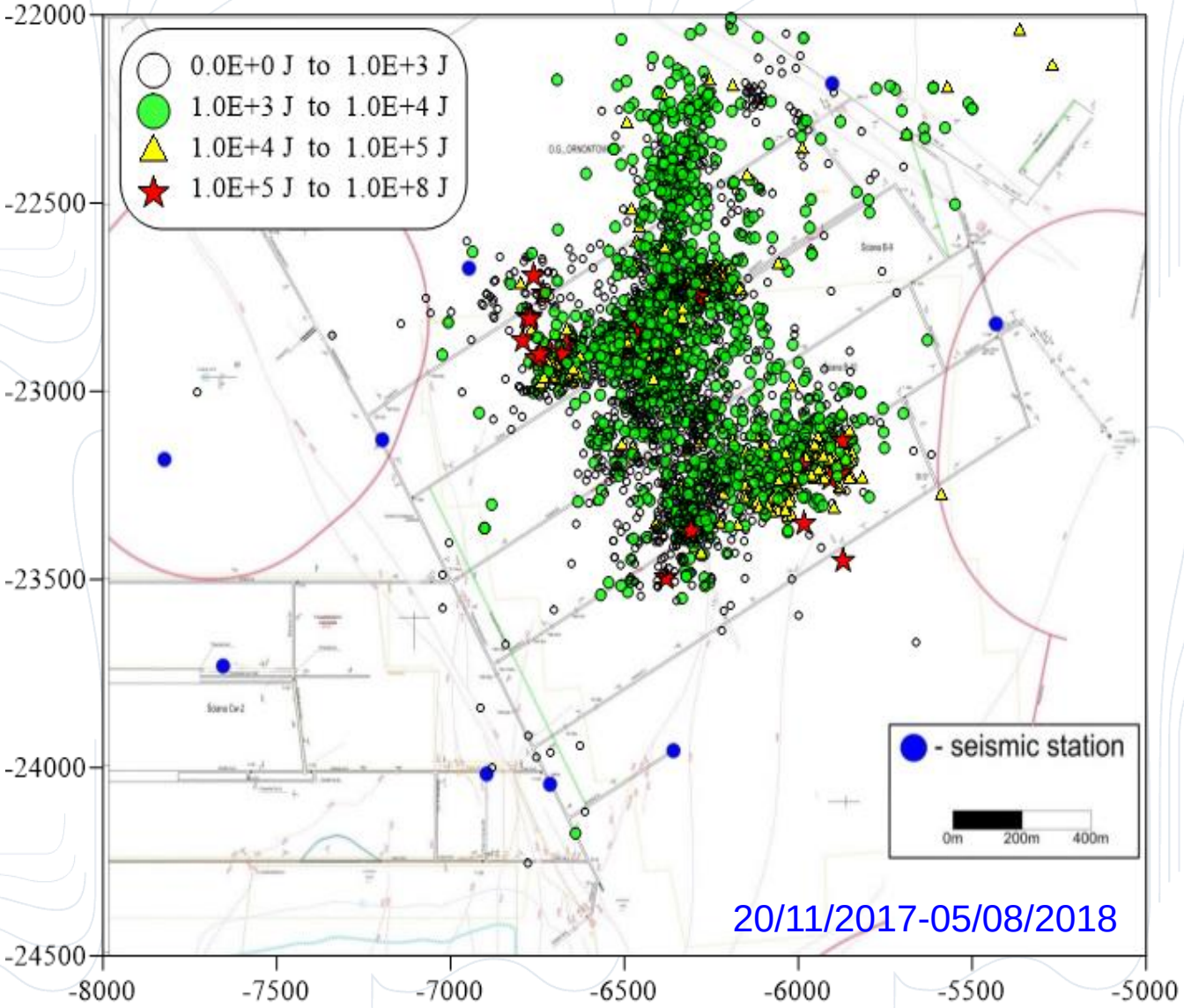


Application at Coal Mine Velenje: ANN example



LW Ck.-80: 01/03/2017-01/10/2017

Application at Budryk colliery: Fractal example



Summary

- Fractal-fuzzy evaluation methodology ultilising seismic sequences were developed for the short term forecasting of rock bursts and gas outbursts.
  - Dimension reduction in Fractal Dimension based indicators can be considered as the precursor of rock bursts and gas outbursts.
  - Fractal-fuzzy evaluation methodology allows for a better and quantitative assessment of the likelihood for rock bursts and gas outbursts on a daily basis.
- Feedforward neural networks were adopted to perform three kinds of neural net models: pattern recognition, fitting and time series, in an attempt to forecast rock bursts and gas outbursts ultilising seismic sequences.
  - Neural net pattern recognition model was carried out to forecast the probability of strong seismic event occurrence over the next time period, including two classifications of no risk and strong risk.
  - Neural net fitting model was carried out to forecast the magnitude of maximum seismic event which could happen over the next time period.
  - Neural net time series model was carried out to forecast total energy and number of seismic events which could happen over the next time period.

Work Package 5 aims at developing and validating a generic risk assessment method for rock bursts and gas outburst. The site specific methodology developed by AITEMIN for HVL in CoGasOUT will be extended through collaboration with JSW and CM-VELENJE and utilise production and field measured data to generalise the methodology. The model will be validated through application to the conditions of the three industrial partners. This WP will also combine the numerical models of WP4 and the previously developed gas outburst models to carry out a probabilistic assessment of risk in different mining conditions and layouts, and analyse sensitivity to field parameters. Research will consider and evaluate the factors which may affect the performance of developed techniques in different coal fields and geological conditions and report these.

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Development of a Generic Methodology for the Assessment and Mitigation of Risk from Rock Bursts and Gas Outbursts: Application of the Methodology at Ddifferent Mining Scenarios

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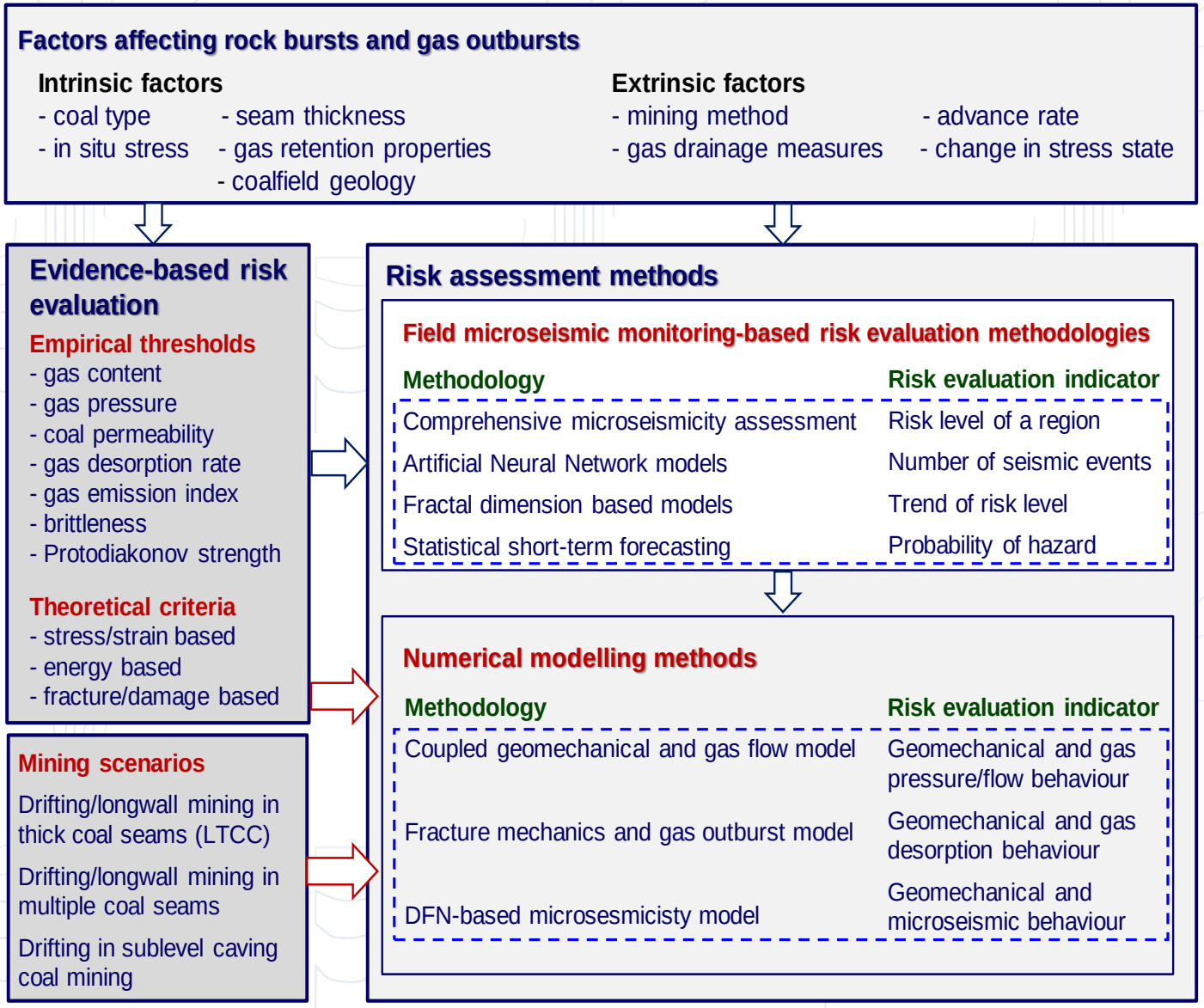
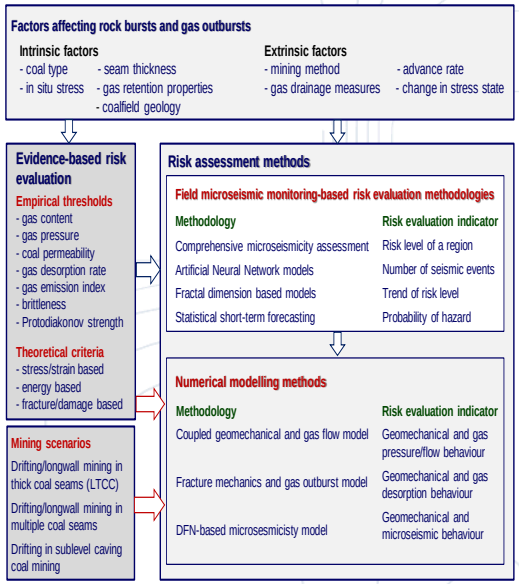
Risk Assessment Framework



Risk Assessment Framework



Generic risk assessment methodology driven by MapROCK project developments/findings

- **Methodology and examples of testing and validation**
  - **Artificial Neural Network models (at Coal Mine Velenje and Budryk Colliery)**
  - **Fractal dimension based models (at Coal Mine Velenje and Budryk Colliery)**
  - **Comprehensive microsesimicity assessment (at Coal Mine Velenje)**
  - **DFN-based microseismicity model (applied and validated at Coal Mine Velenje, applicable to both homogenous and heterogenous lithological settings)**
  - **Fracture mechanics and gas driven outburst model (generally applicable for in-seam roadway development, applied at Coal Mine Velenje and also applicable in longwall and sublevel caving mining conditions)**
  - **Coupled geomechanical and gas flow model (generally applicable for simulating *floor outburst conditions* and *protective mining* in multi-seam mining layouts such as JSW mines)**

Work Package 6 focuses on the conclusions and dissemination of research findings. Partners will compile the background state of the art knowledge in rock bursts and gas outbursts together with the MapROC field and numerical modelling practice and experience gained from the research outcomes. In particular, the short term prediction models developed will be documented and demonstrated to the industry. It is planned to organise a project Workshop to disseminate this knowledge to a wide audience within the European coal mining community. **As a second objective, and upon completion of all the project tasks, a project "lessons learnt and recommendations document" will also be compiled and issued to assist industrial stakeholders and the scientific community towards achieving the general objectives of predicting, preventing and mitigating rock bursts and gas outbursts in coal mines.**

THANK YOU FOR YOUR ATTENTION

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