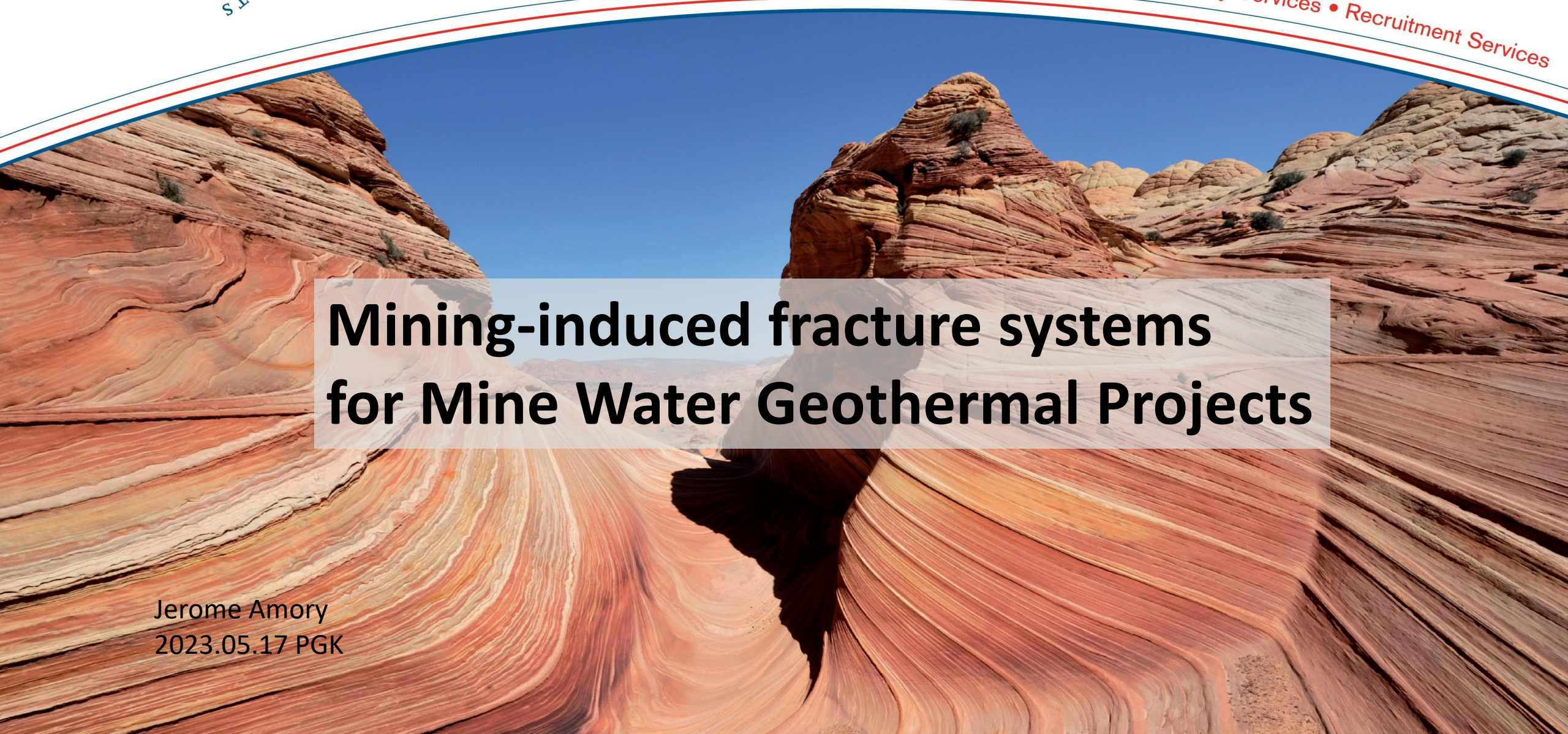
PANterra GEOCONSULTANTS

From data to solutions • Subsurface Evaluations • Laboratory Services • Recruitment Services



Mining-induced fracture systems for Mine Water Geothermal Projects

Jerome Amory

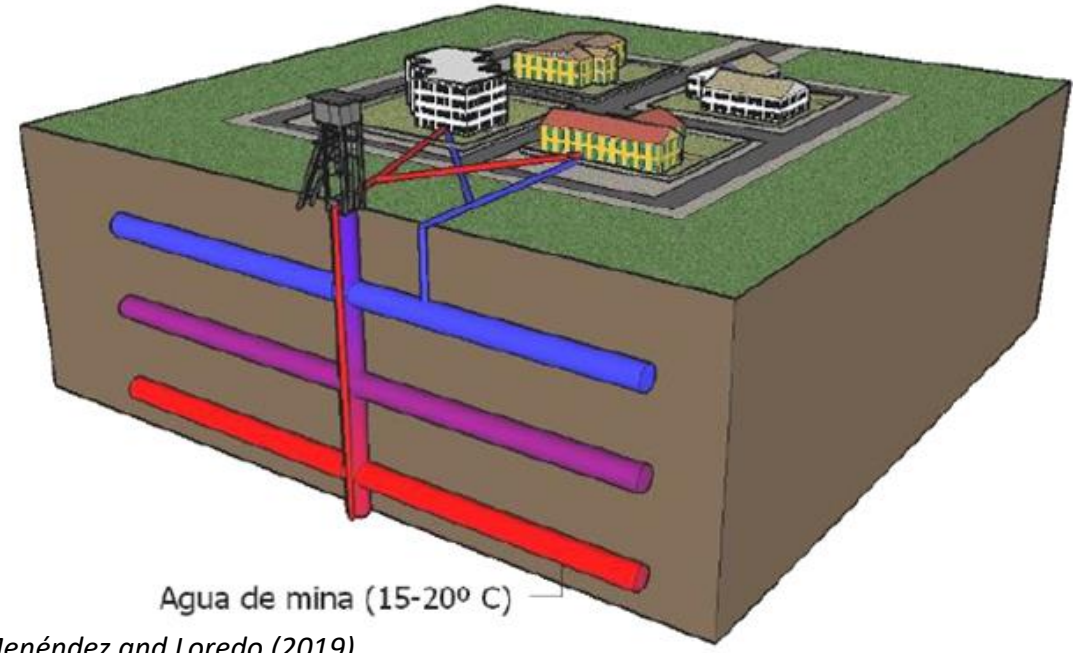
2023.05.17 PGK

Outline

- Introduction to Mine Water Geothermal Systems
- Mine Water Geothermal project examples
- Longwall mining principles
- Mining-induced fracture systems
- Conceptual enhanced heat drainage concepts
- Conclusions

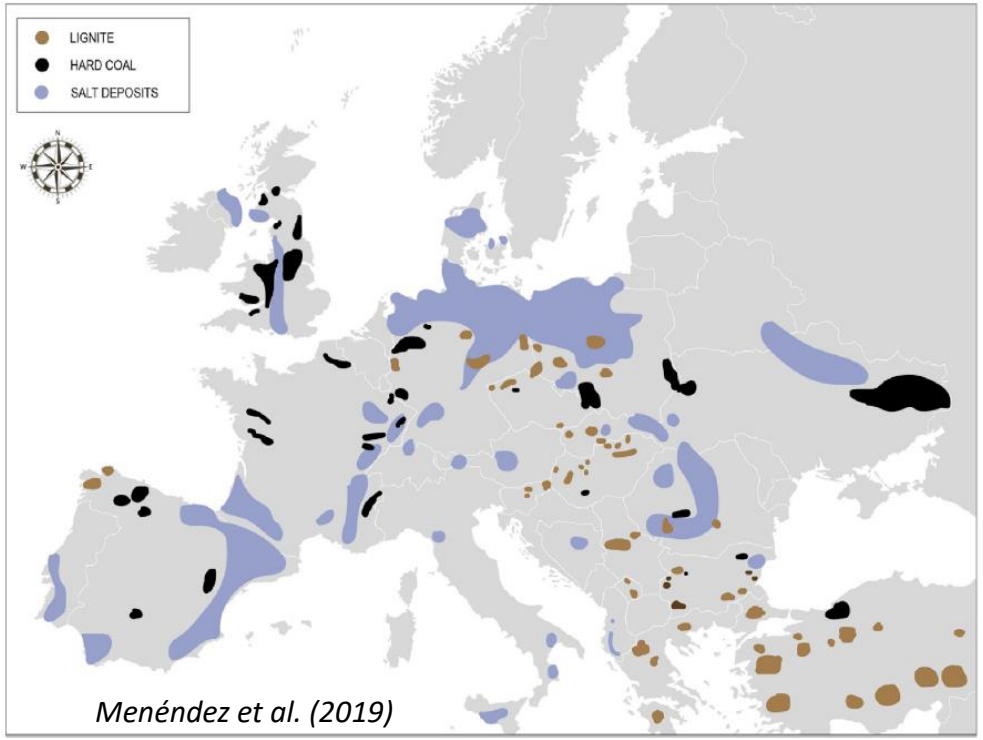
UNIVERSITÉ DE NEUCHÂTEL
Centre d'hydrogéologie et de géothermie (CHYN)
GEOCONSULTANTS PANterra

Mine Water Geothermal Systems: Introduction



Menéndez and Loredo (2019)

- Extensive enhanced porosity network
- Access to large aquifer volumes
- Very low enthalpy resource
- Can be used for Heating or Cooling



Menéndez et al. (2019)

- Core of historic industrial heartlands
- Close to dense population centers
- Opportunity for district heating

GEOCONSULTANTS
PANterra

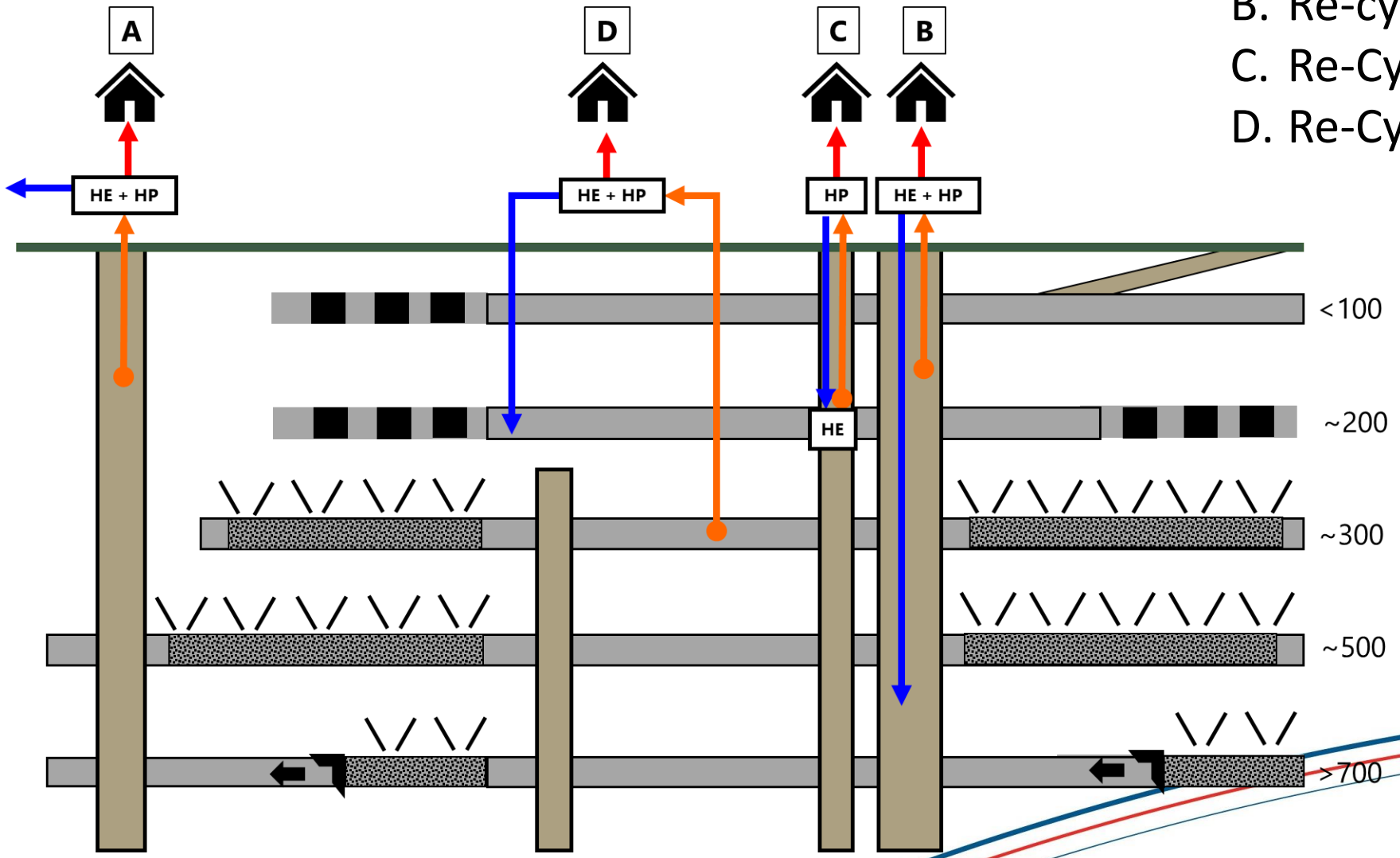
Mine Water Geothermal Projects: Top 8

- Portfolio of ~40 projects (20 based on abandoned coal mines)
- 2 large scale demonstrator projects: Hunosa and MijnWater

Type	Project Name	Location	Target	Used Water	Loop	Application	Customers	Capacity (kW_{th})	Project Phase
Pilot	Caphouse	UK	Shaft	Disposal	Open	Heating	Museum	10.5	Operate
Pilot	Markham	UK	Shaft	Re-inject	Open	Heating	Offices and operational building; pre-heat power plant gas turbines.	20	Operate
Pilot	Shettleton	Shettleton UK	Galleries	Re-inject	Open	Heating	Apartments (~1,600 m2)	65	Decommission
Flagship	**Hunosa**	**Hunosa Spain**	**Shaft**	**Disposal**	**Open**	**Heating Cooling**	**University housing Hospital**	**8,800**	**Operate**
Flagship	**Mijnwater**	**Heerlen Netherlands**	**Galleries**	**Re-inject**	**Open**	**Heating Cooling**	**Heating: Offices, housing complex, city administration. Cooling: data centre, supermarkets, offices.**	**5,000**	**Operate**
New	Seaham Garden Village	Seaham UK	Shaft	Disposal	Open	Heating	1,400 homes, primary school, shops, innovation centre.	6,000	Detailed Design
New	Pole Yvon Morandat,	Gardanne France	Shaft	Re-inject	Open	Heating Cooling	Commercial and industrial complex, innovation centre, offices (14 ha).	1,000 heating 1,700 cooling	Execute
New	Mark 51.7	Bochum Germany	Galleries	Re-inject	Open	Heating Cooling	Industrial complex		Execute

Mine Water systems- schematic diagram

A. Disposal / Shaft
B. Re-cycle / Galleries
C. Re-Cycle / Shaft HE
D. Re-Cycle / Shaft



GEOCONSULTANTS
PANterra

Mine Water Geothermal Projects: Mieres, Spain

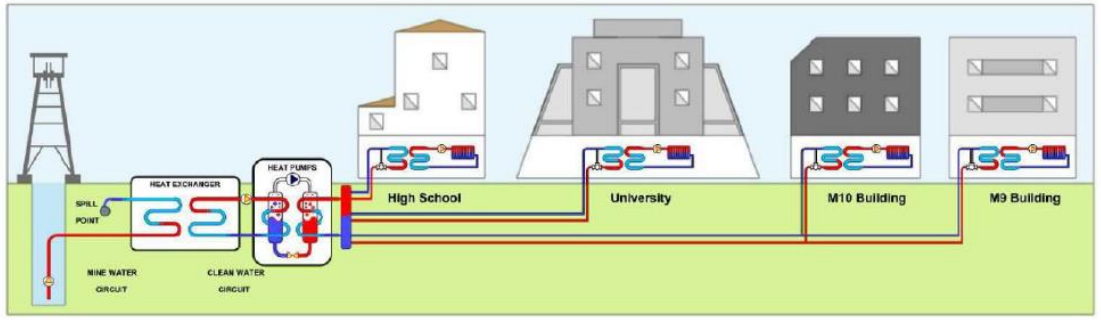


Figure 51: Mieres DH network scheme (source: Hunosa)

- **Pro-active dewatering** from ***main access shaft***
- Heating & cooling for University buildings, Hospital
- 6 MW_{th} installed capacity and growing

Galino Fernandez M. et al. (2021)

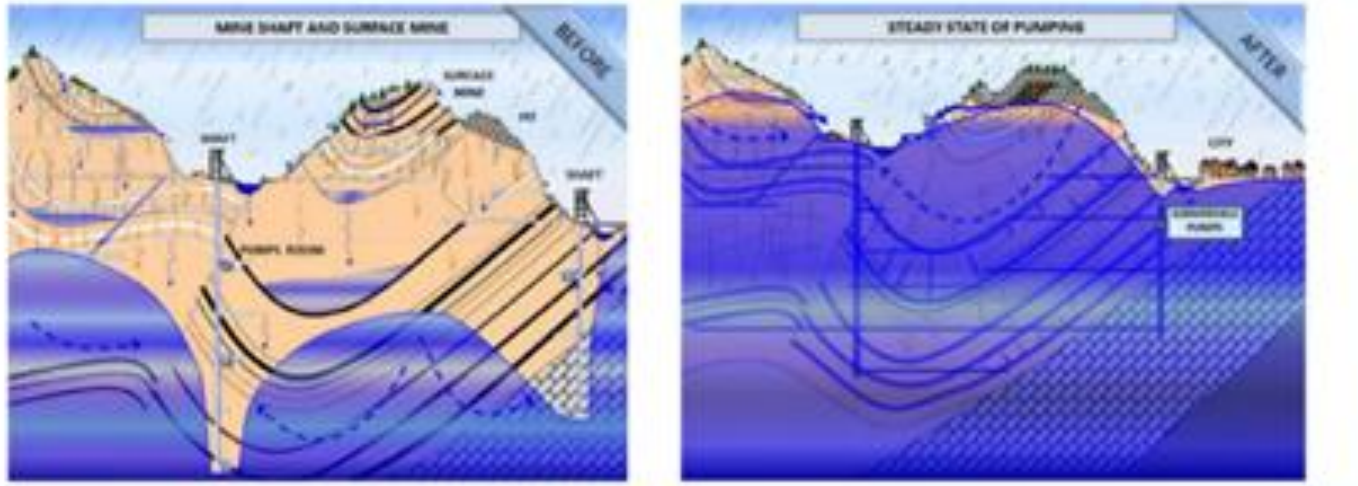


Figure 54: Mines flooding process and steady-state pumping obligation (source: Hunosa)

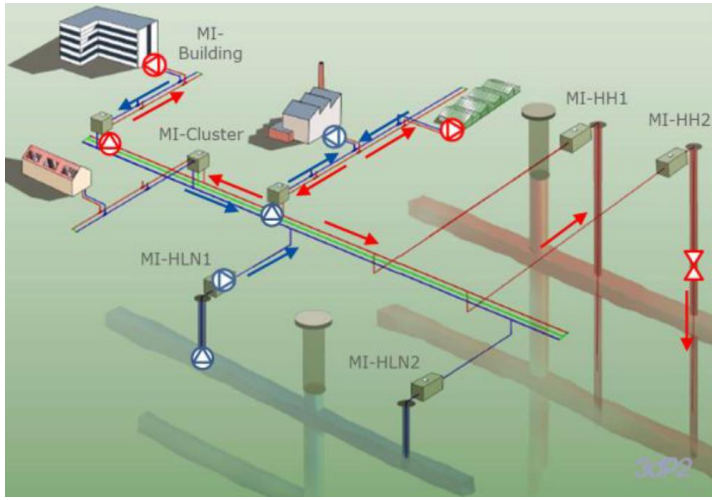
Galino Fernandez M. et al. (2021)

Figure 52: Map of Mieres geothermal facilities, including those of the DH system (in orange) (source: Hunosa)

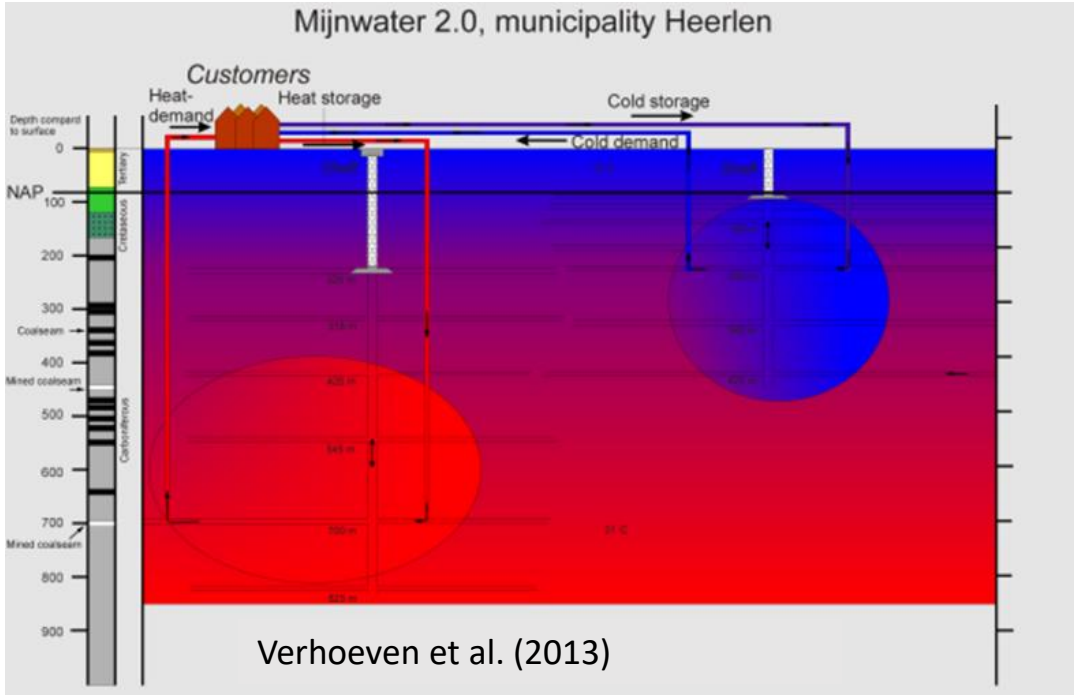
Galino Fernandez M. et al. (2021)

GEOCONSULTANTS
PANterra

Mine Water Geothermal Projects: Heerlen, NL



- **Drilled** into **shallow (Cold)** and **deep (Warm)** ***Galleries***
- Dual **District Heating & Cooling** Network:
  - Heating: offices, housing complex, administration
  - Cooling: data center, supermarkets, offices
- Very low enthalpy system (14 °/ 28°)
- Distributed « nodes » promote local heat/cold exchange
- Waste Cold / Heat recovered and returned to network
- Seasonal storage of Heat / Cold oversupply (deep / shallow)
- 5 MWth installed capacity



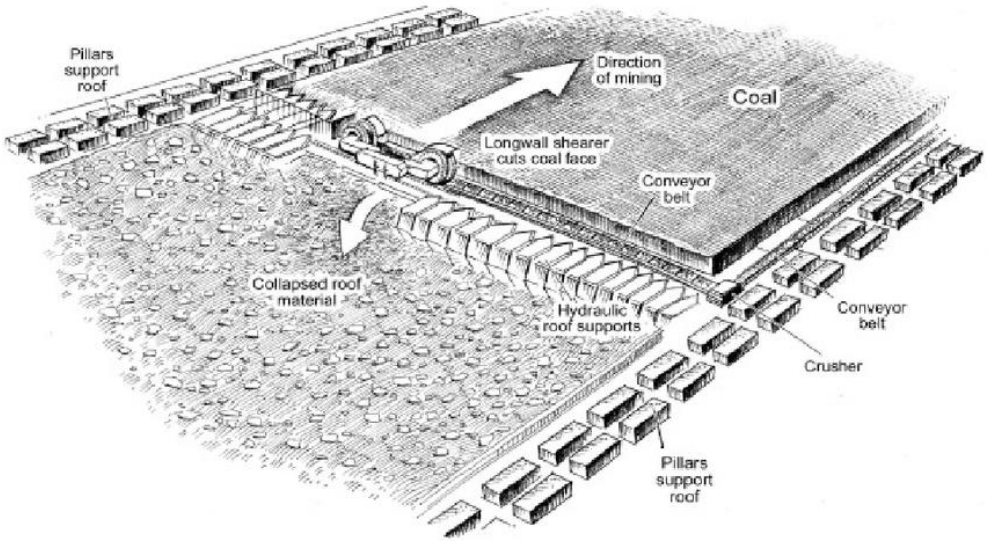
Verhoeven et al. (2013)

Figure 3b. Railway corridors in the Beringen coal mine.

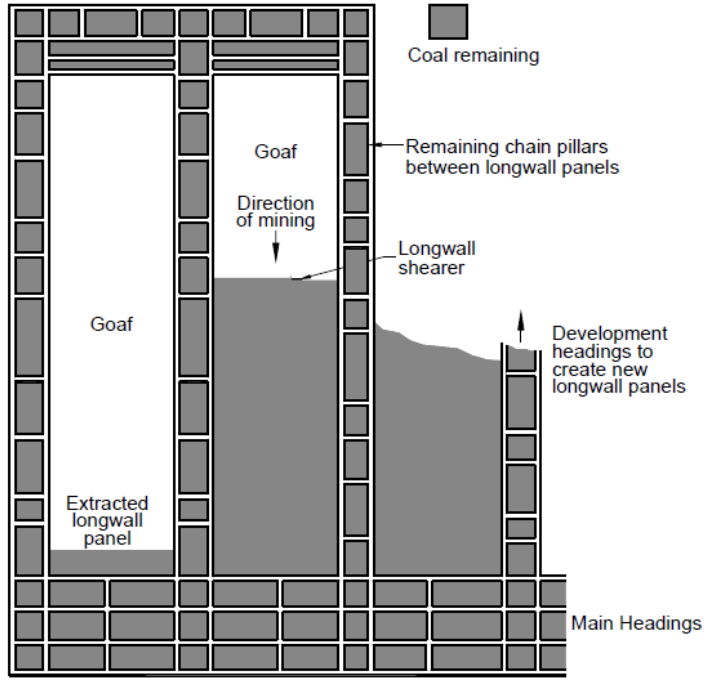
Van Tongeren and Dreesen (2004)

« Longwall » Extraction: Opportunity?

- Limitations of gallery – based geothermal systems:
  - Very high connectivity
  - Limited thermal exchange with country rock
  - Fast thermal breakthrough
- Potential solution: target the coal workings?
  - Indirect pathway from injector to producer
  - Improve heat exchange with host rock
- Longwall mining:
  - Large-scale geometrical workings
  - Induce significant disruption in host rock (goaf / gob)



US Securities and Exchange Commission



Mine Subsidence Engineering Consultants (2007)

Gob deformation zone

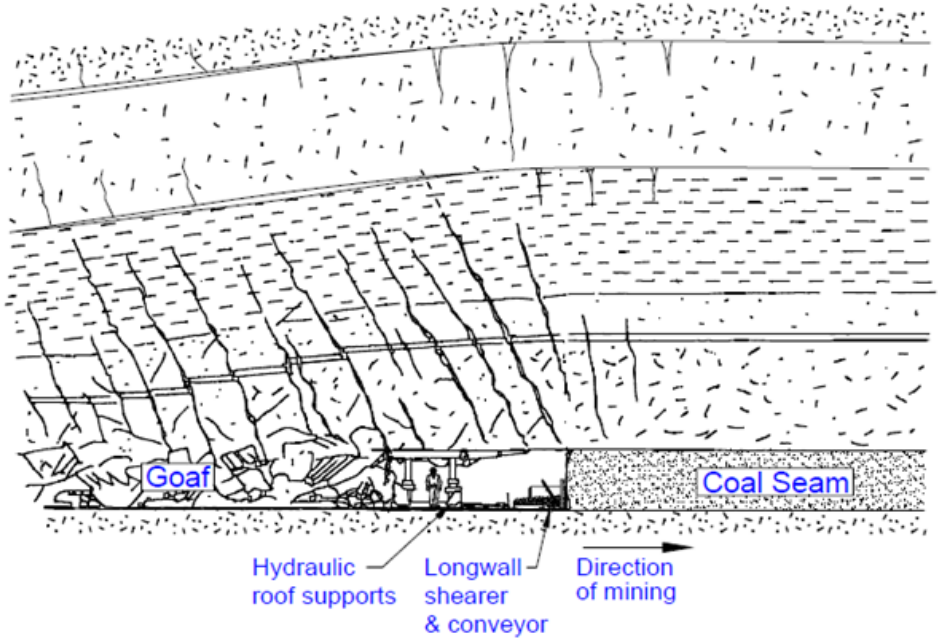
Predicable, geomechanically-constrained deformation zone:

- Structural bending
- Bedding plane partitioning
- Vertical fractures
- Collapsed blocks
- Chaotic caved zone

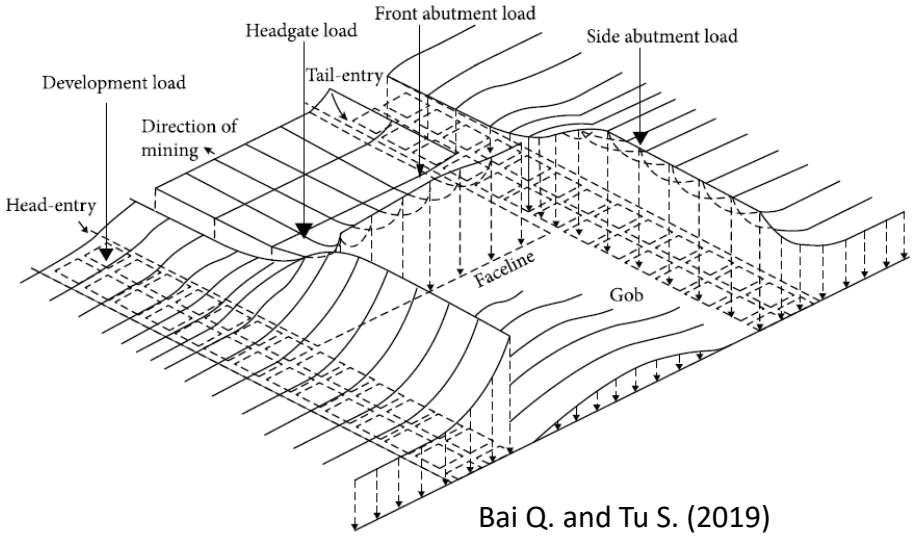
Surface

Coal face

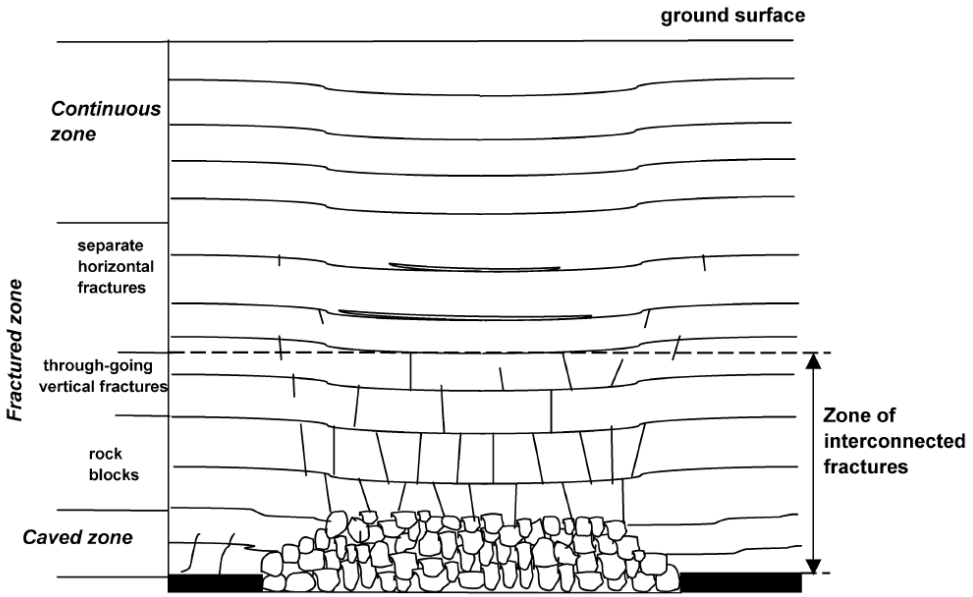
Mine Subsidence Engineering Consultants (2007)



High differential stress loads around panel edges



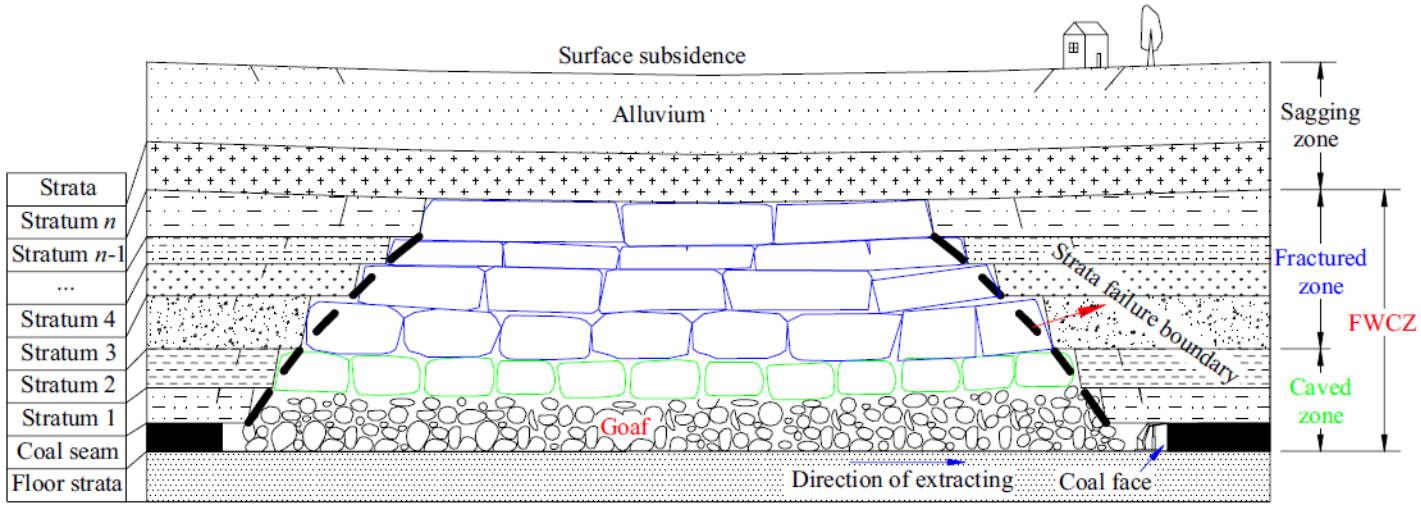
Bai Q. and Tu S. (2019)



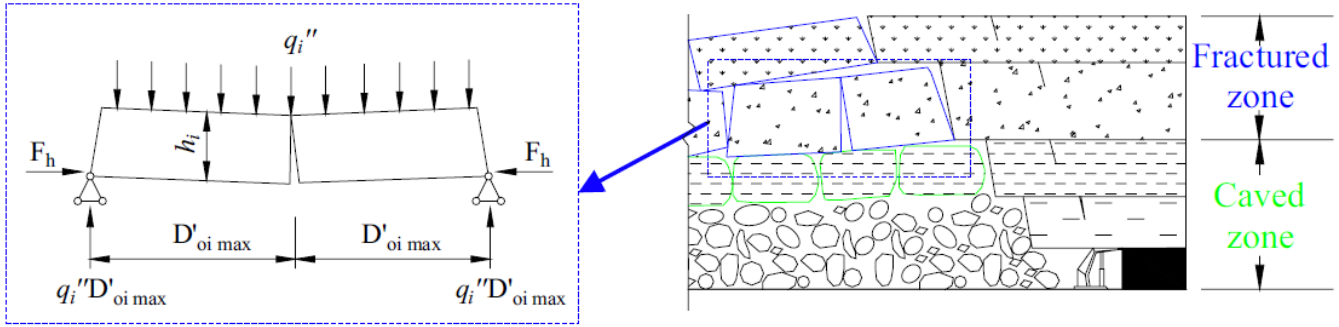
Palchik (2003)

Goaf collapse structure: Conceptual models

Schematic cross-section: transversal



FWCZ
Fractured Water-Conducting Zone



Fractured Zone

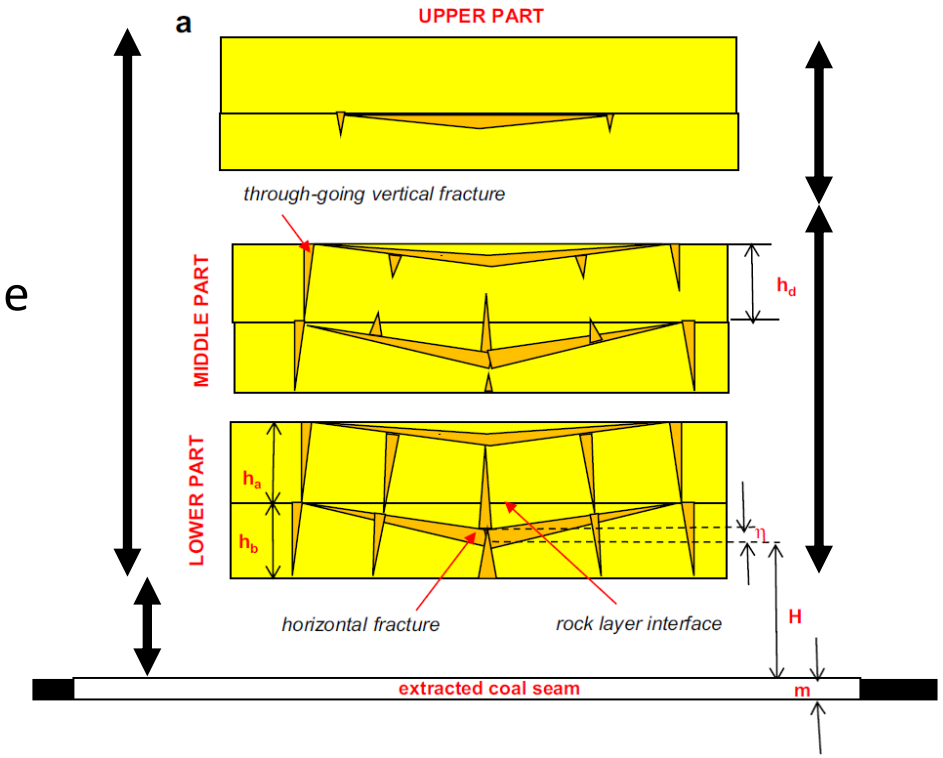
Caved Zone

Fig. 6 Three-hinged arch model of adjacent blocks

Source: **Guo W. et al. (2019)** A New Method of Predicting the Height of the Fractured Water-Conducting Zone Due to High-Intensity Longwall Coal Mining in China

Goaf collapse structure: conceptual models

Schematic cross-section: transversal



Fractured Zone

Caved Zone

Separate Horizontal Fractures

Interconnected fractures

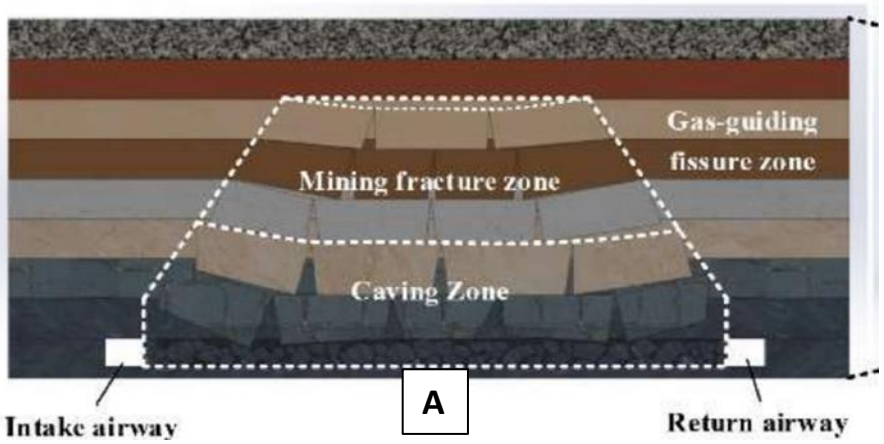
Palchik V. (2020) Analysis of Main Factors Influencing the Apertures of Mining-unduced horizontal fractures at longwall coal mining

Goaf collapse structure: *Height of gob fractured zone*

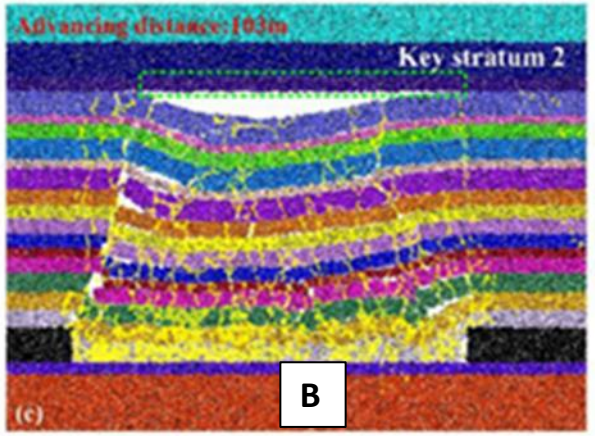
Width **200 m**
Length **800 m**
Thickness2 m

Author	Approach	Details	Application: Gob Fracture Zone Height (m) for a 2 m coal seam
Palchik (2003)	Experimental	30 x t	60
Younger and Adams (1999)	Rule of thumb	0.4 * W	80
Guo et al. (2018)	Empirical	$Hf = (100\ h / c_3 h + c_4) +/- c$ For strong and hard rocks: $C_3 = 1.2$; $c_4 = 2.0$; $c = 8.9$	45 (+/- 9)

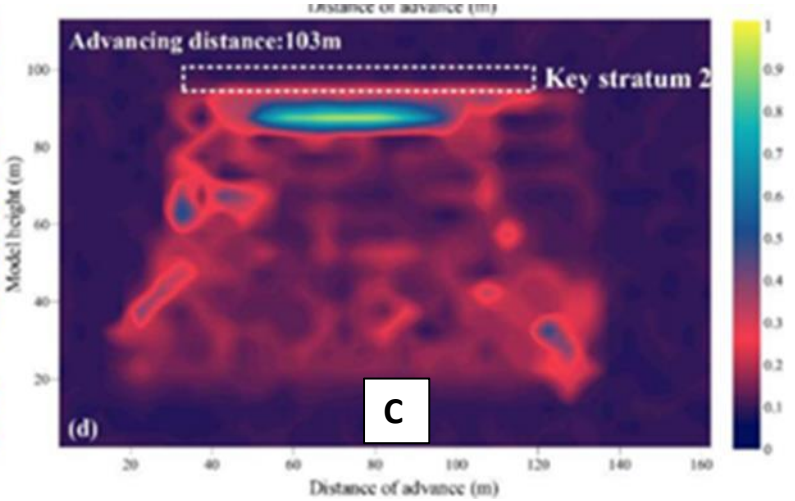
Goaf collapse structure: *geometrical modelling and flow characteristics*



A/ Conceptual model



B/ Lithology and fracture model



C/ Porosity model

Theoretical **gob height calculations:**
H caving zone = 31 m
H Fracture zone = 17 m
Total = 48 m

Depth 900 m
Thickness 9 m
Panel 820 x 120 m

Wang G. et al. (2018) Determination of Long Horizontal Borehole Height in Roofs and its aplication to Gob Gas Drainage

Goaf fracture zone: *experimental production tests w. Gob Gas Vent wells*

- Methane released by
  - depressurisation
  - stress release
  - bedding plane separation

- fracturing
- faulting
- gob collapse

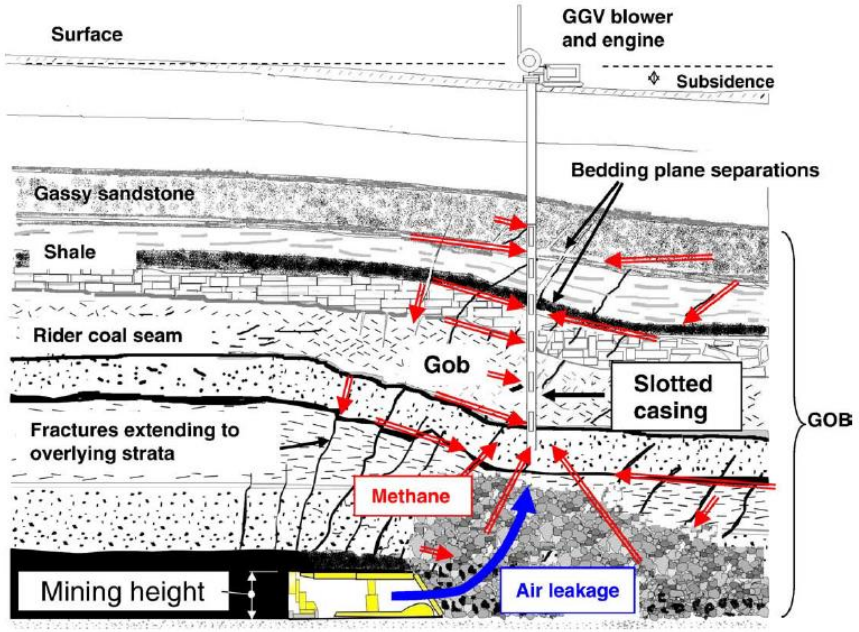


Fig. 1. A schematic representation of longwall mining with a shearer. The figure shows the fractures extending the overlying strata, bedding plane separation, subsidence and possible methane flow paths (red arrows) and air leakage from the face (blue arrow). A schematic of a GGV producing this gas is also shown.

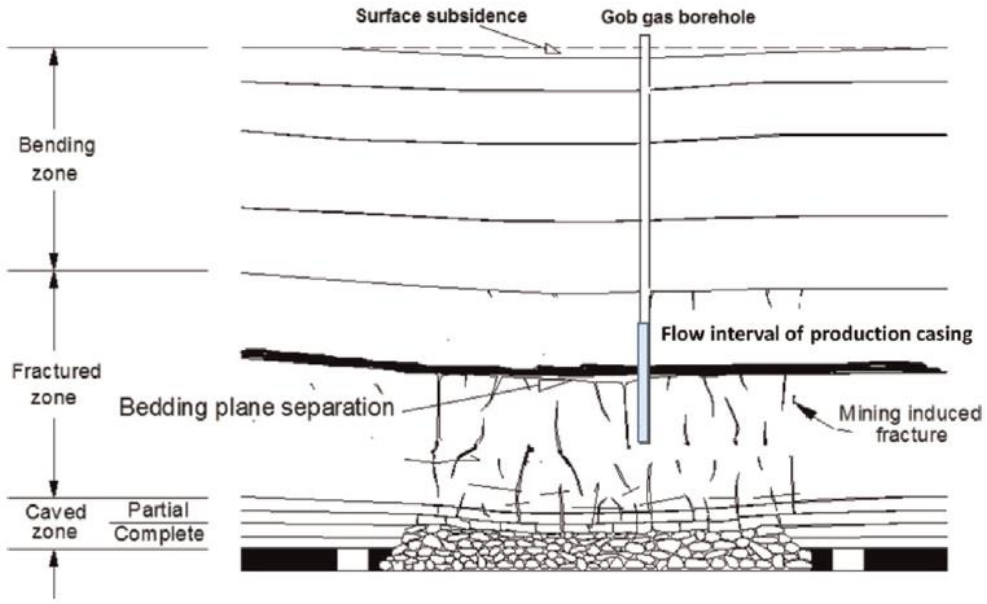


Fig. 1. A schematic representation of deformed overburden as a response to longwall mining, and location of GGV to control strata gas.

Karacan C.O. (2015)

Karacan C.O. (2009) Reconciling longwall gob gas reservoirs and venthole production performances using multiple rate drawdown well test analysis

Goaf fracture zone: *experimental production tests*

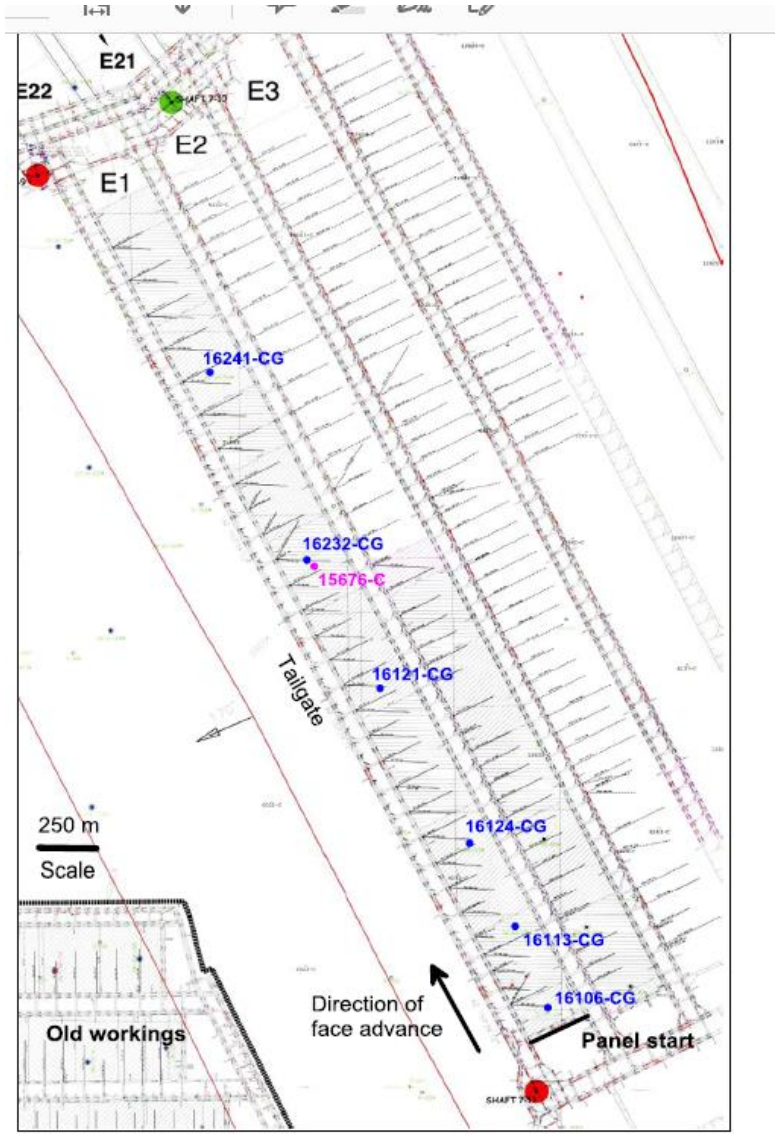


Fig. 5. Detailed map of the mine, the E-1 panel layout, and locations of the GGVs.

- GGV well above center of longwall cut face
- Most gas production from shallower coal seam
- Main seam drained by in-situ horizontal wells
- GGV well performance track longwall progress

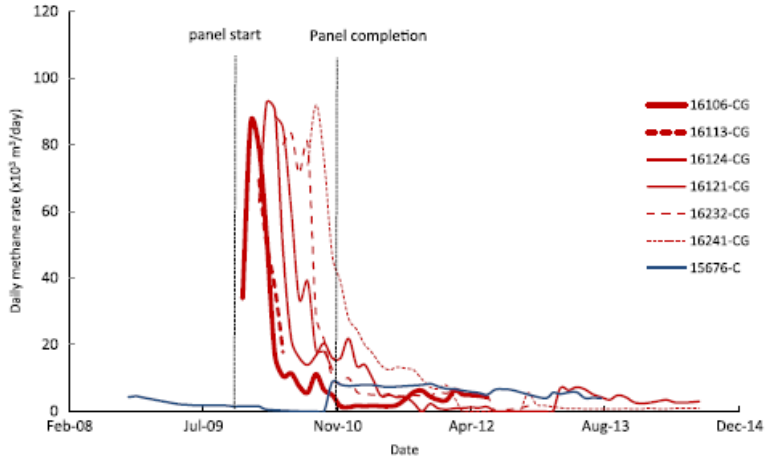


Fig. 7. Methane production profiles of GGVs during and after mining of the E-1 panel.

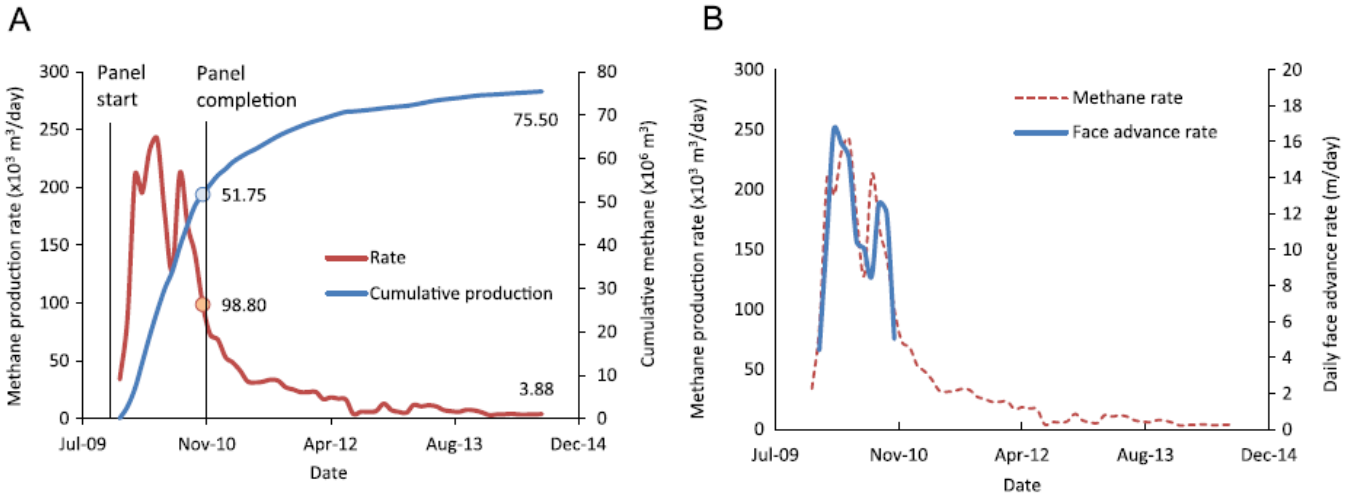
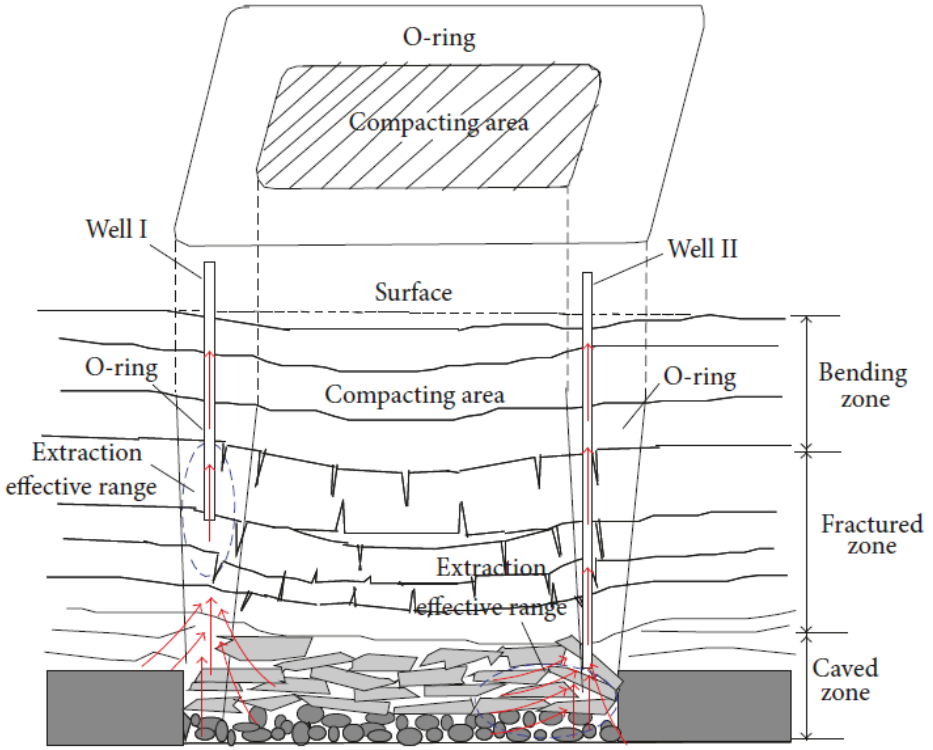


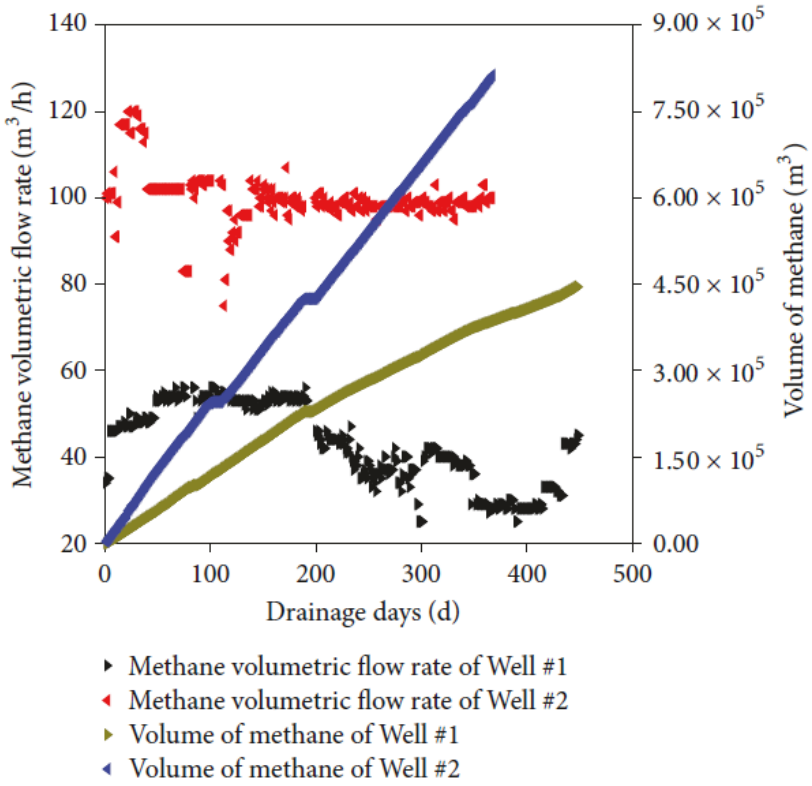
Fig. 8. Rate and cumulative methane production from all GGVs (a) and the correlation of mining advance rate to methane production rate (B).

Source: Karacan C.O. (2015)

Goaf fracture zone: *experimental production tests*

- Recently abandoned coal mine
- GGV well on panel edge
- One well TD in fracture zone, one well in caved zone
- Best rate and cumulative production from caved zone
  - Highest connectivity

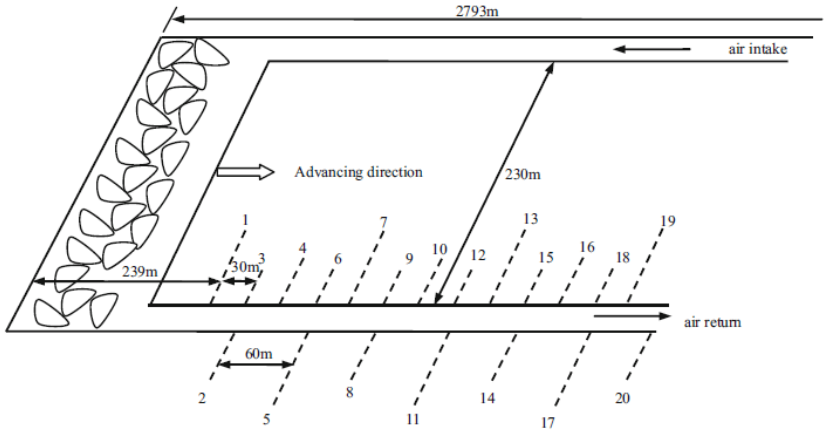




Hu S. et al. (2018)

Goaf fracture zone: microseismic monitoring

- Monitor microseismic events ahead of the mining face
- Highest density of events
  - at level of caved zone
  - In bottom ¼ of fractured zone
- Less dense in upper ¾ of fractured zone
- Few events at more than 145 m above
- Lot of events *under* the coal seam!



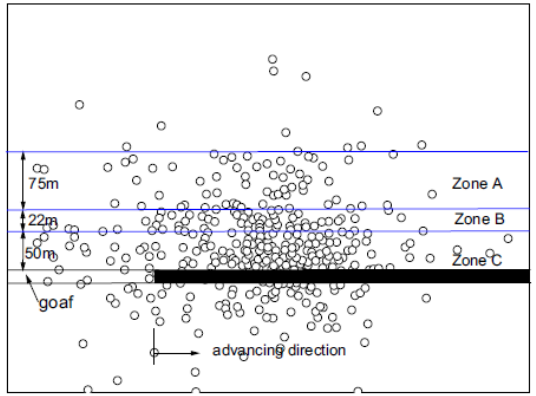


Fig. 5 Distribution of the microseismic events in a vertical plane along the strike direction

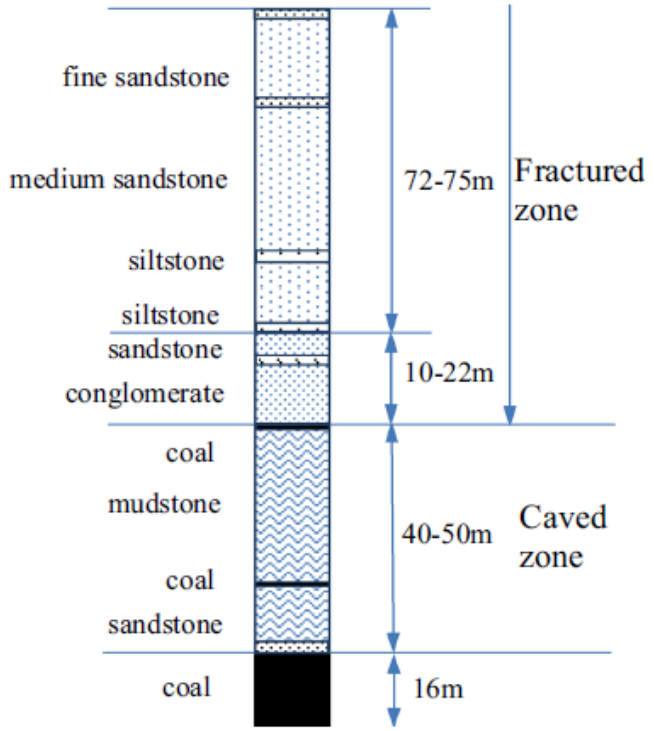
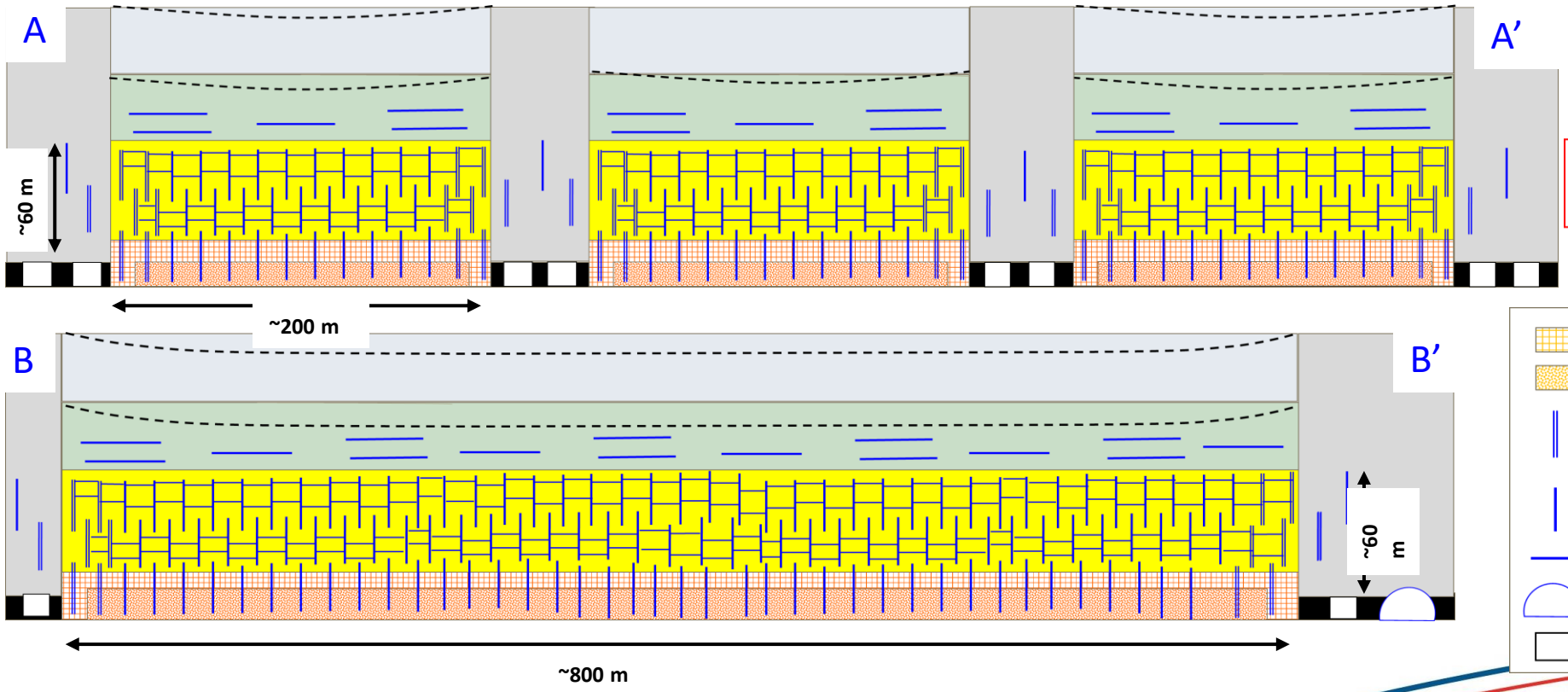


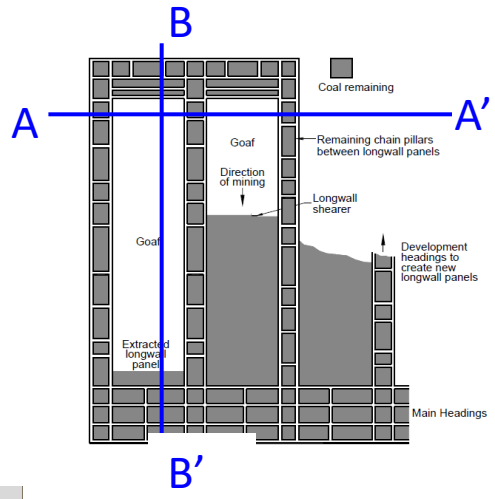
Fig. 2 Stratigraphy and lithological description of overburden and the location of fractured and caved zones above the extracted coal seam

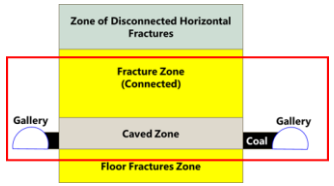
Yu B. et al. (2017) Case Study on Overburden Fracturing during Longwall Top Coal Caving Using Microseismic Monitoring

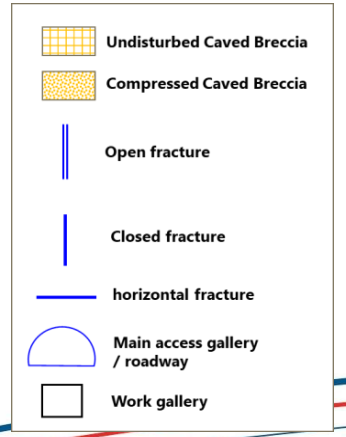
Gob Fracture Zone: Target Definition

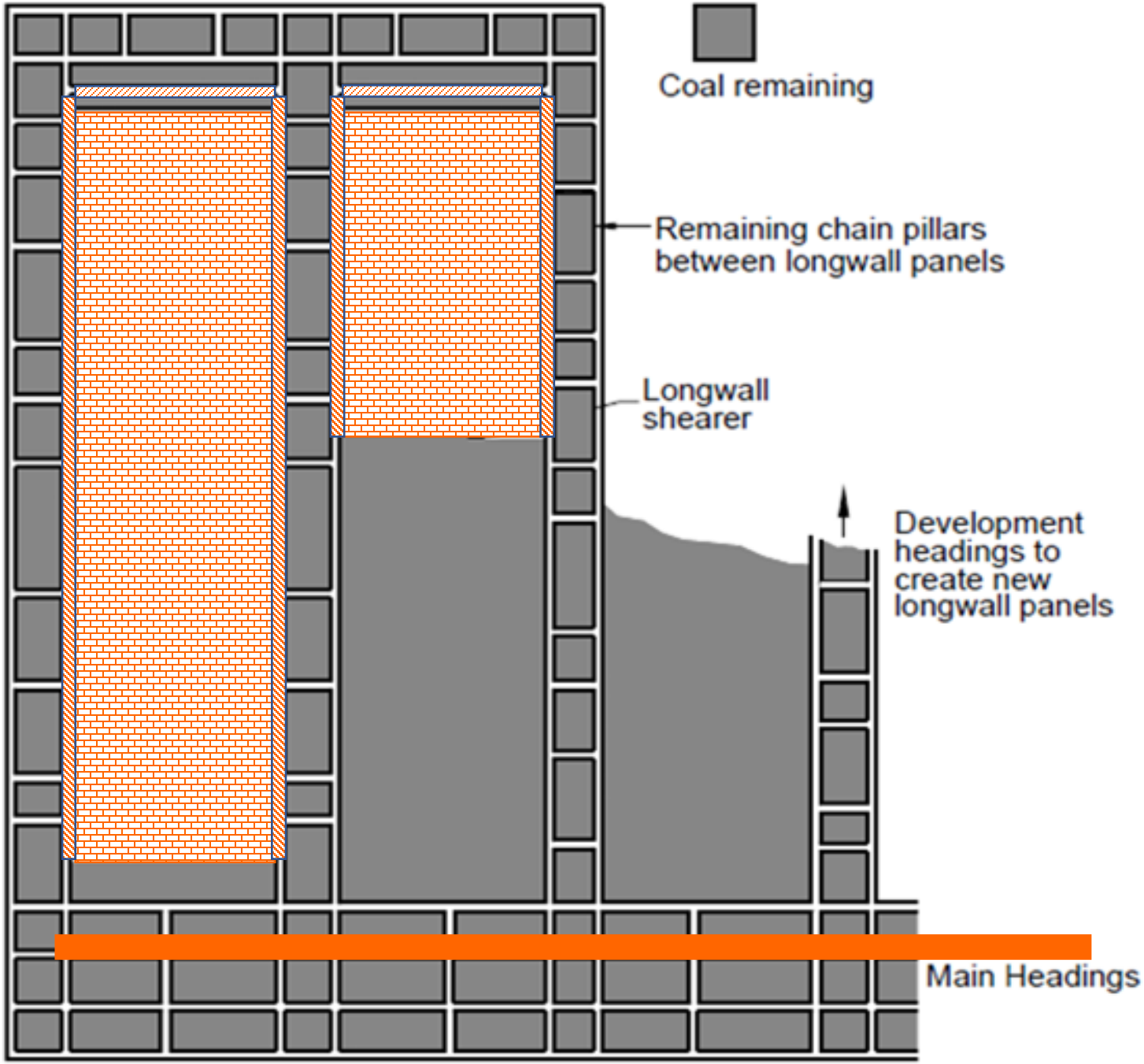
- Target enhanced permeability
- Increase flow pathway through country rock
- Avoid risk of flow bypass

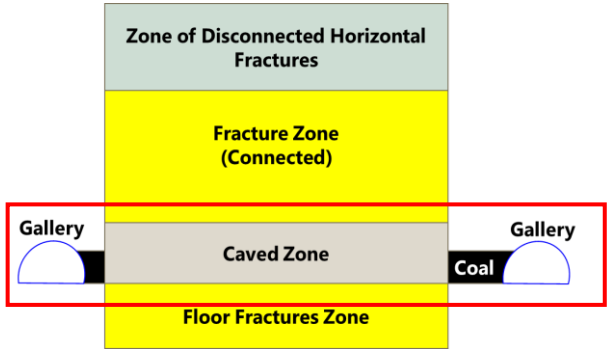












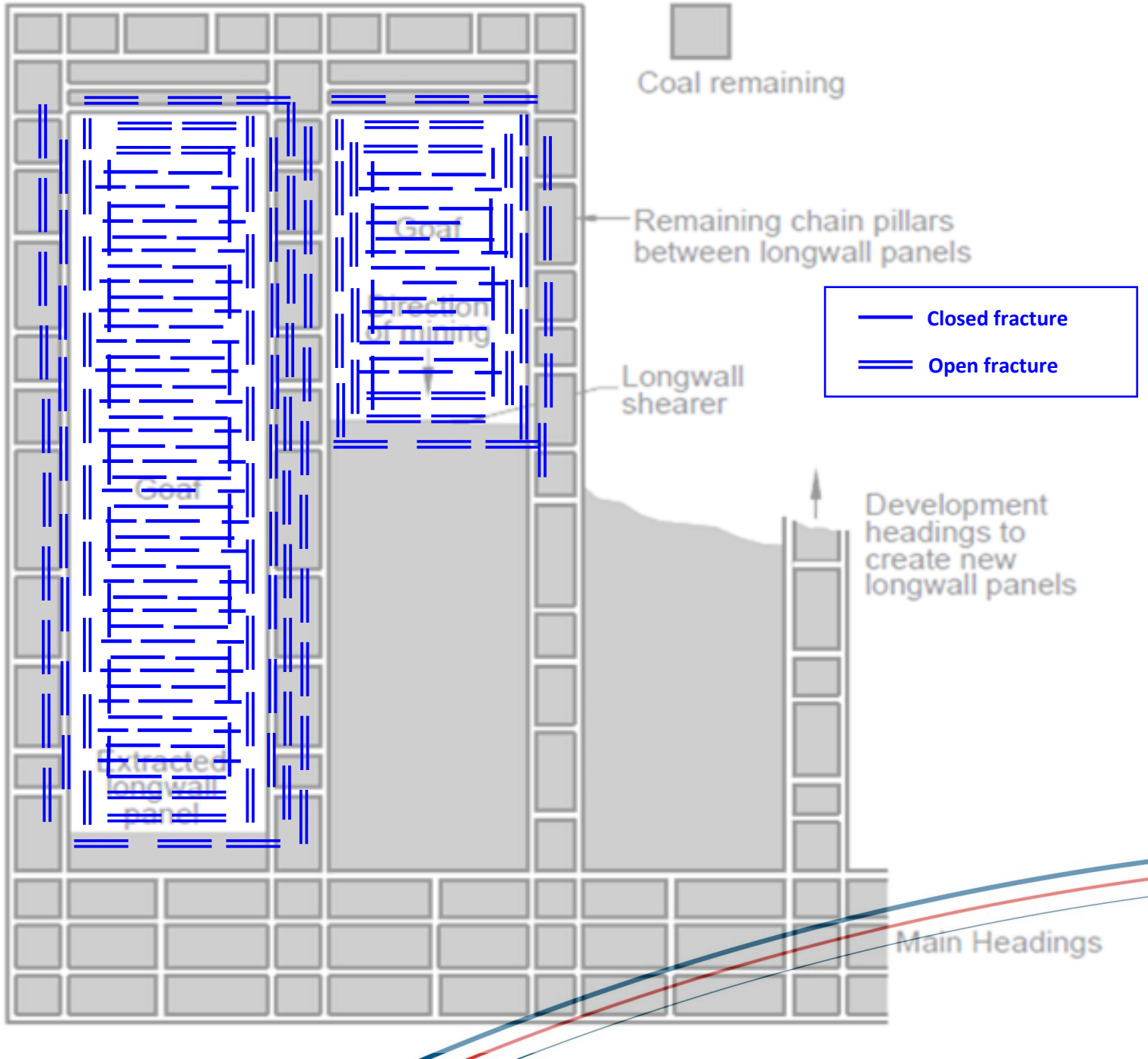
Chaotic goaf / gob collapse breccia

Working access gallery
Fully or partially collapsed
(X axis preferential flow)

Working access gallery
Collapsed or partially collapsed
(y axis preferential flow)

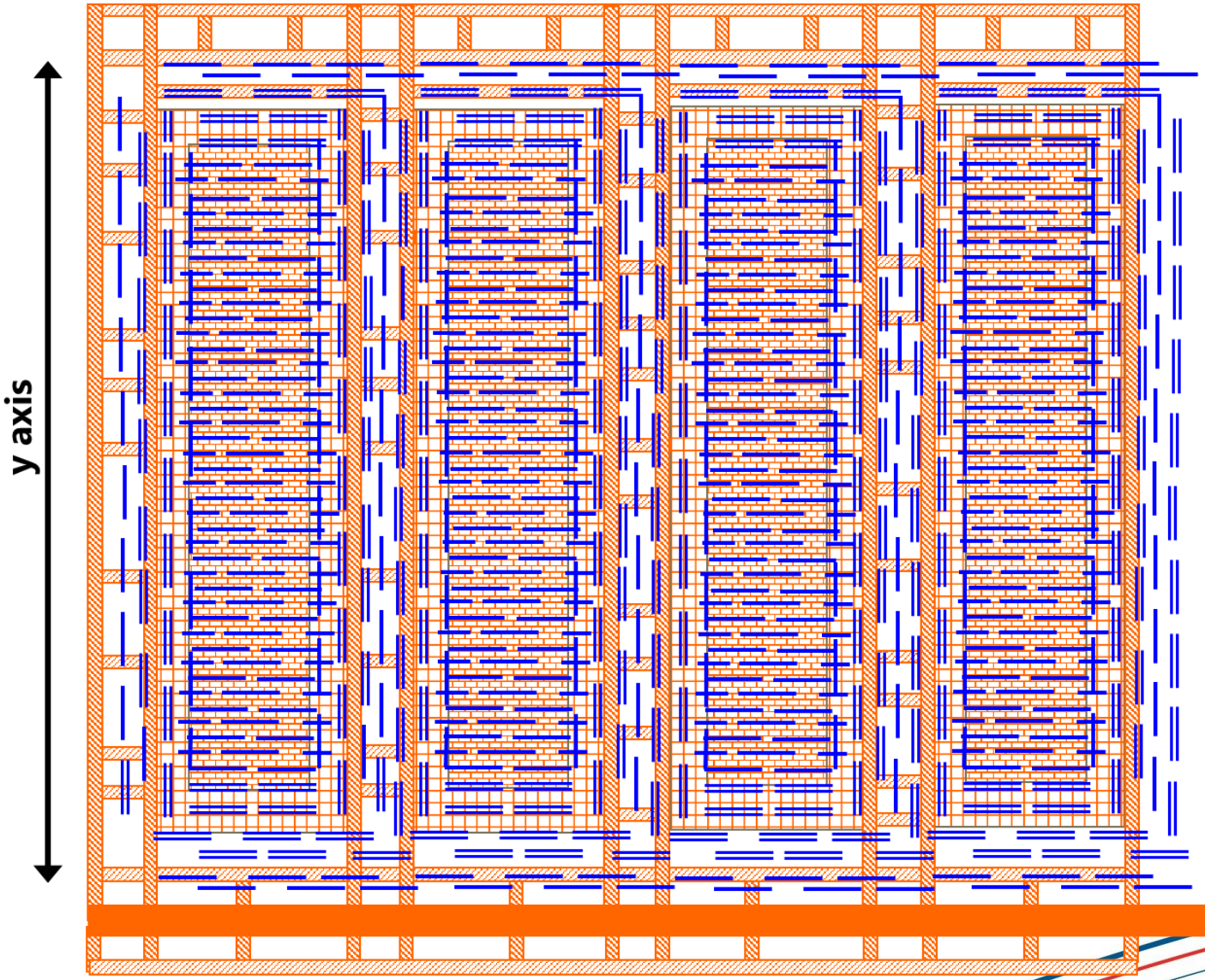
Main access gallery or roadwork
Mostly intact
X axis 'tunnel' flow

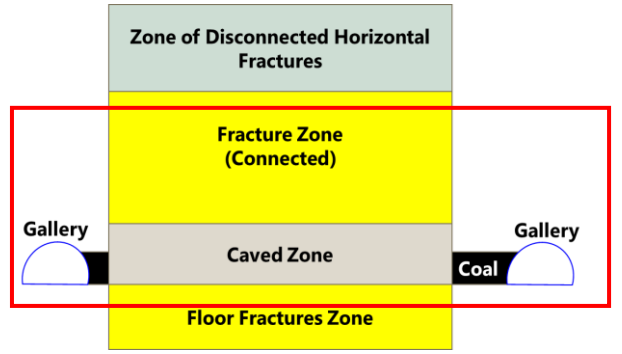
GEOCONSULTANTS
PANterra


Coal remaining
Remaining chain pillars between longwall panels
Goaf
Direction of mining
Longwall shearer
Closed fracture
Open fracture
Goaf
Development headings to create new longwall panels
Extracted longwall panel
Main Headings

Gob Conceptual Flow Characteristics (2/2)

Merged caved & fracture zone features





Closed fracture

Open fracture

High Permeability Caved Zone
Chaotic collapse breccia
Irregular / chaotic flow

Compressed caved zone with
Reduced permeability
Deformed chaotic collapse breccia
Irregular / chaotic flow

Working access gallery
Fully or partially collapsed
(X axis preferential flow)

Working access gallery
Collapsed or partially collapsed
(y axis preferential flow)

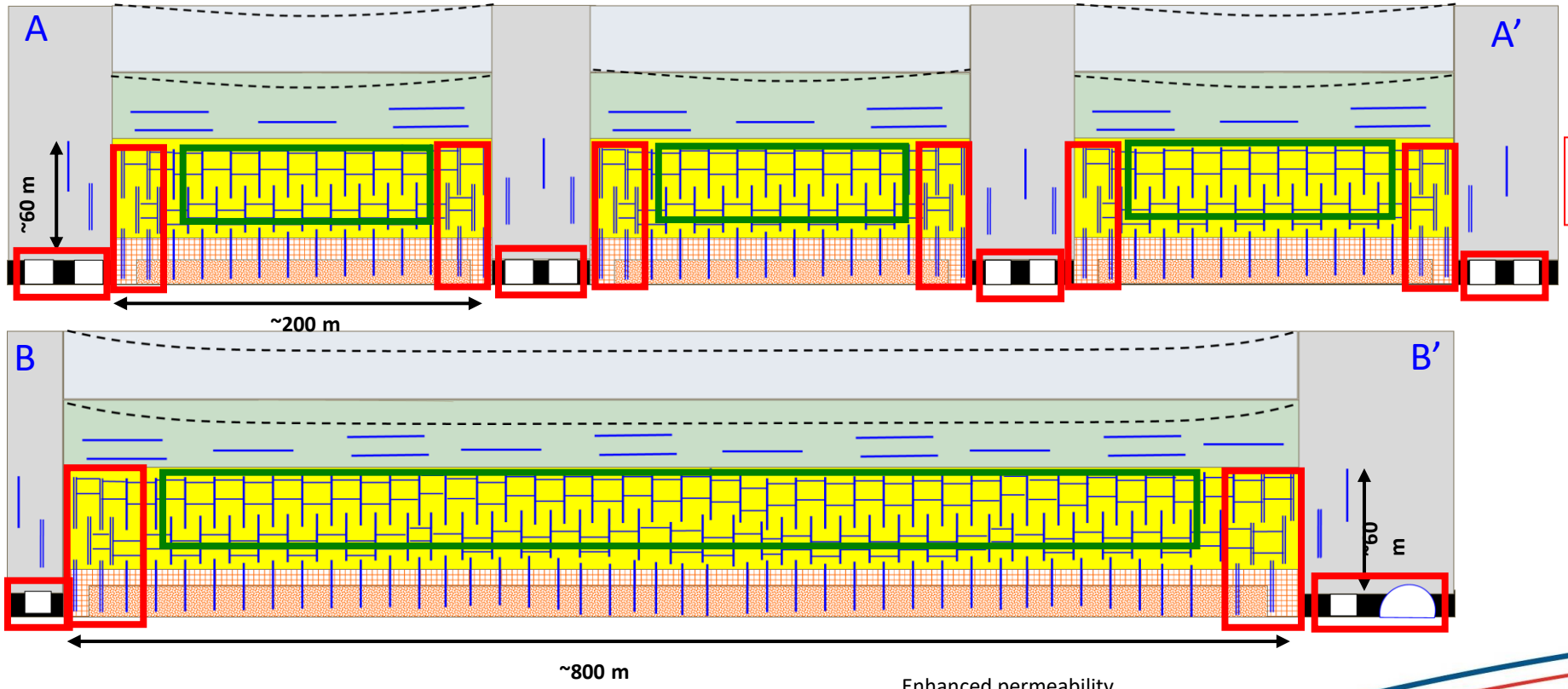
Main access gallery or roadwork
Mostly intact
X axis 'tunnel' flow

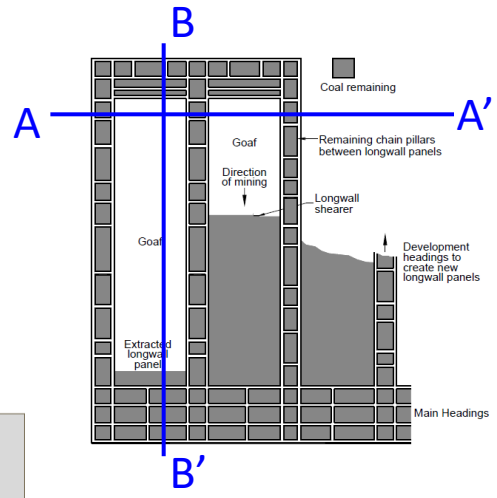
PANterra

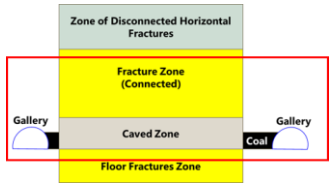
NSULTANTS

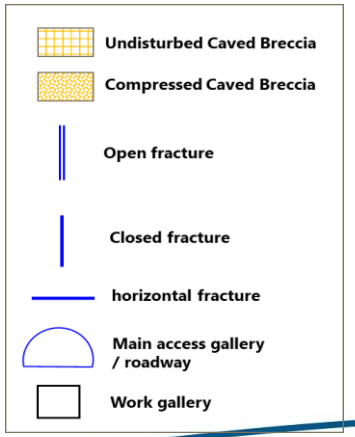
Gob Fracture Zone: Target Definition

- Target enhanced permeability
- Increase flow pathway through country rock
- Avoid risk of flow bypass





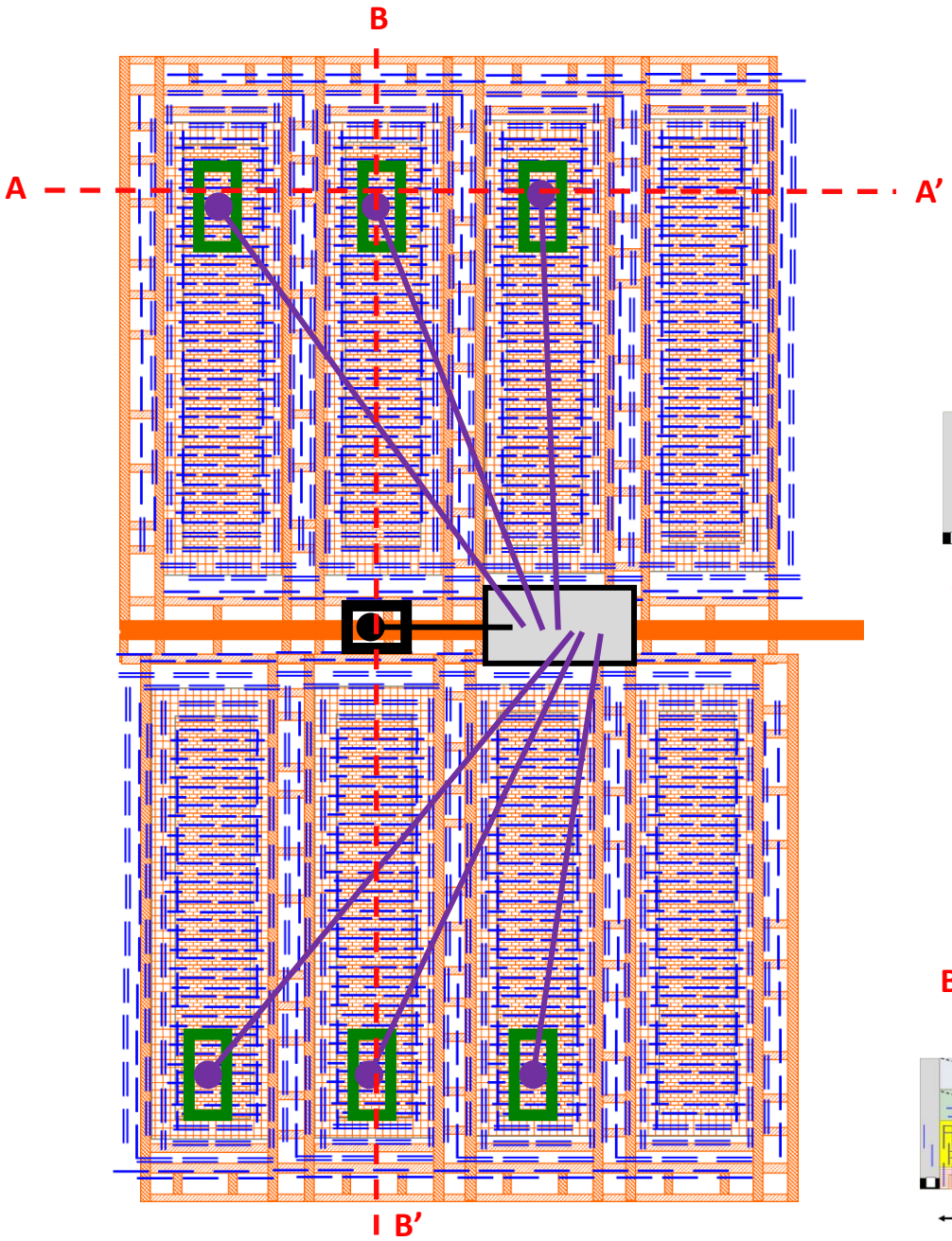


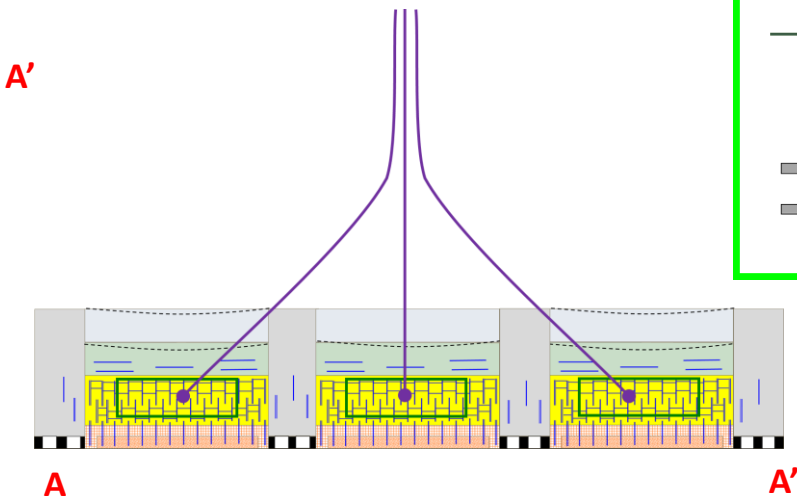


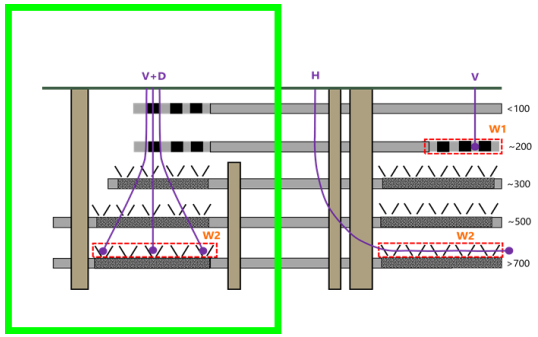
Extremely high permeability
High connectivity
Potential target OR possible Thief Zone

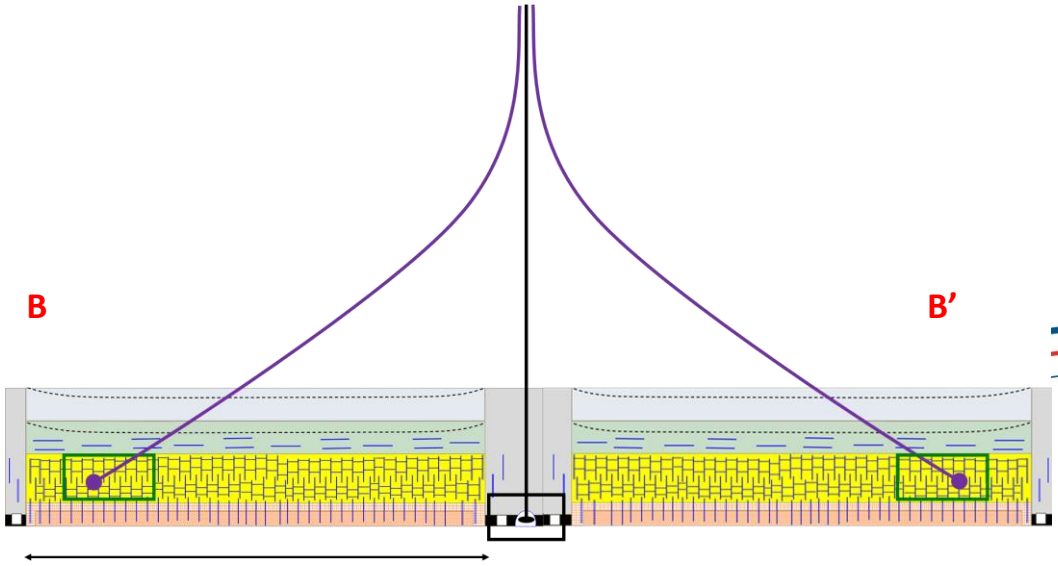
Enhanced permeability
Good but indirect connectivity
Potential Target

Gob drainage Concepts / Option #1: Vertical and inclined wells

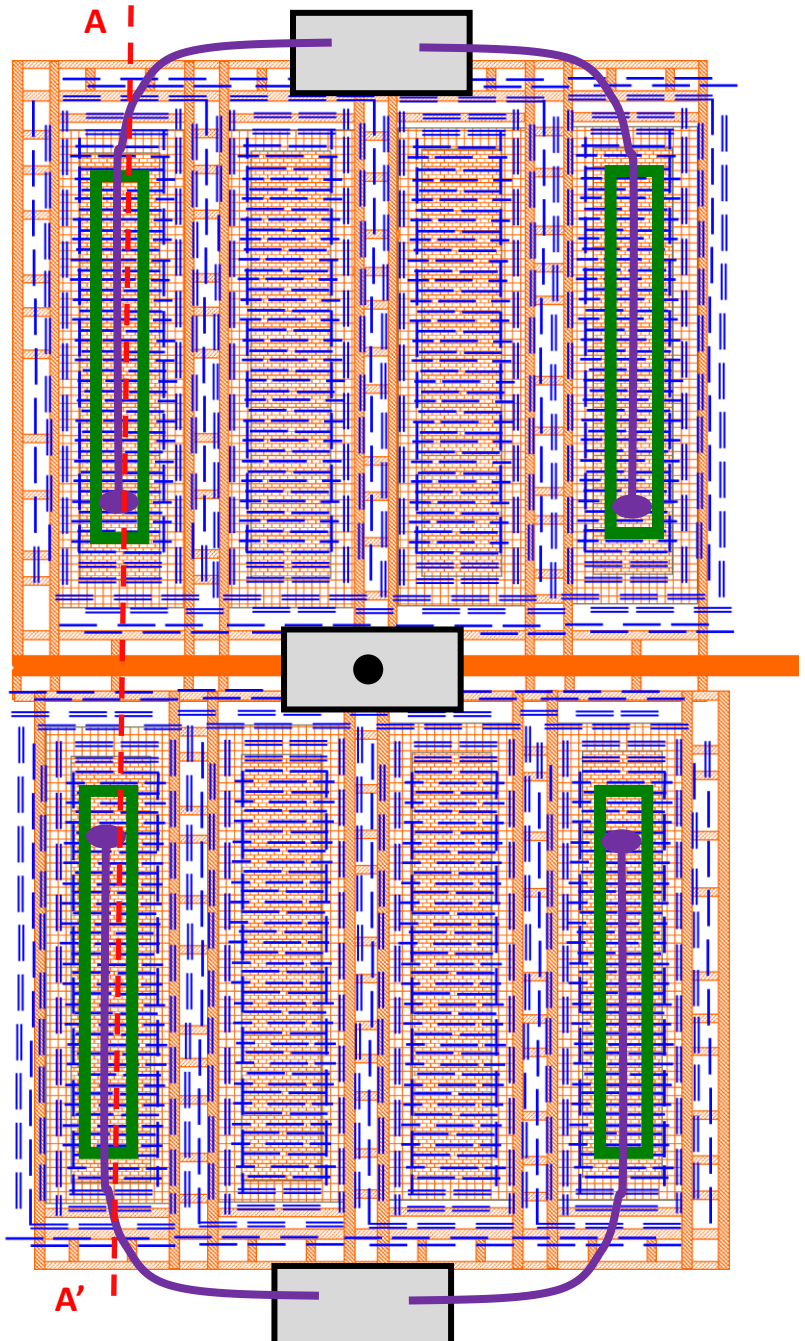


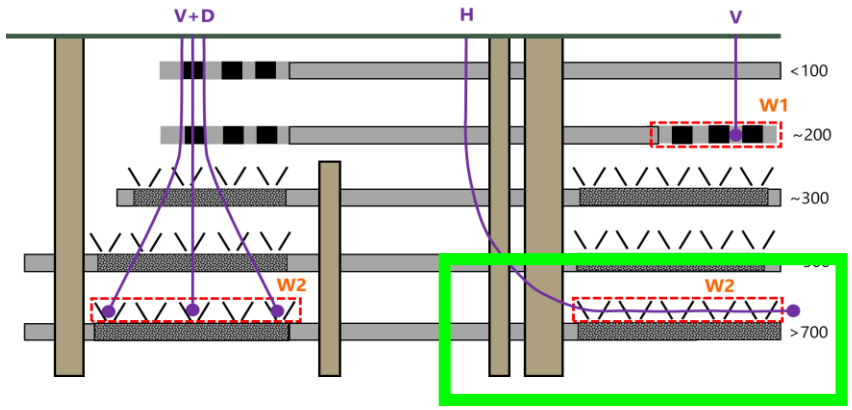


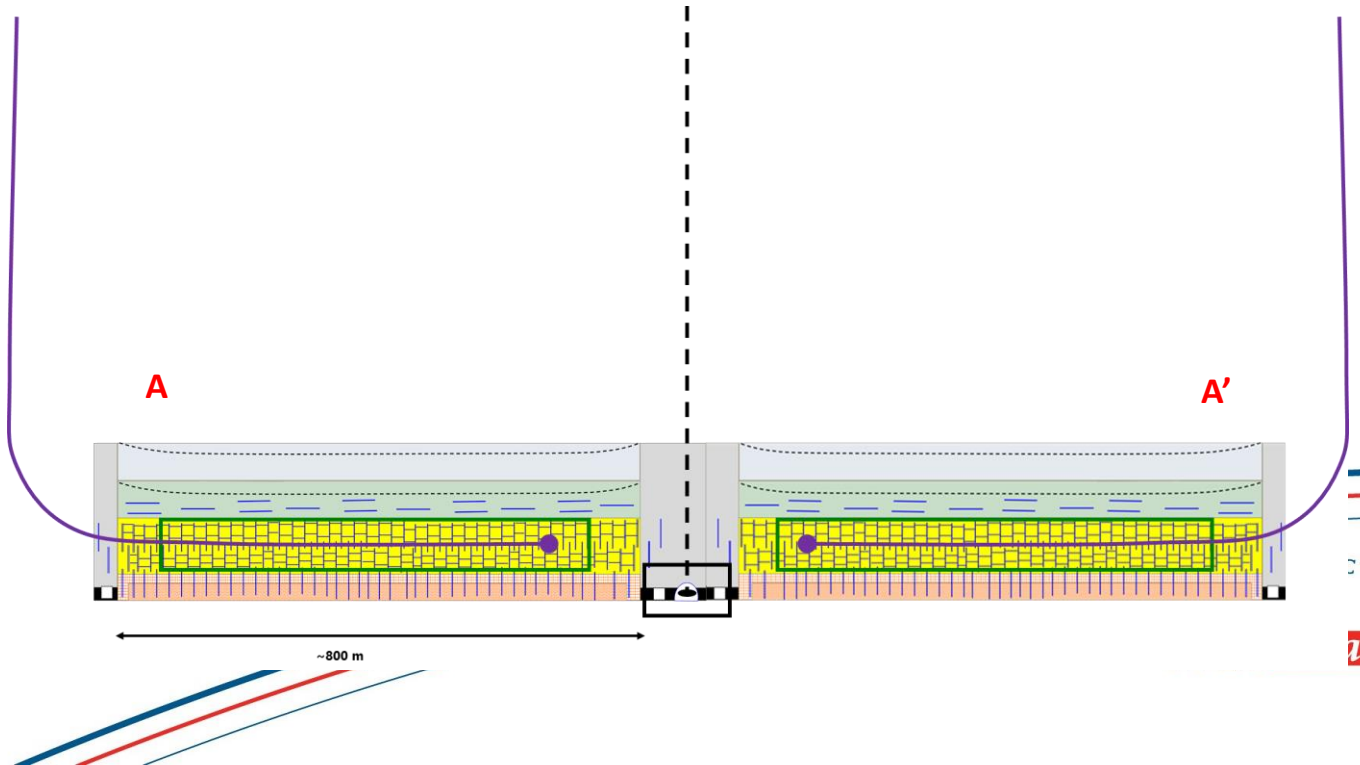




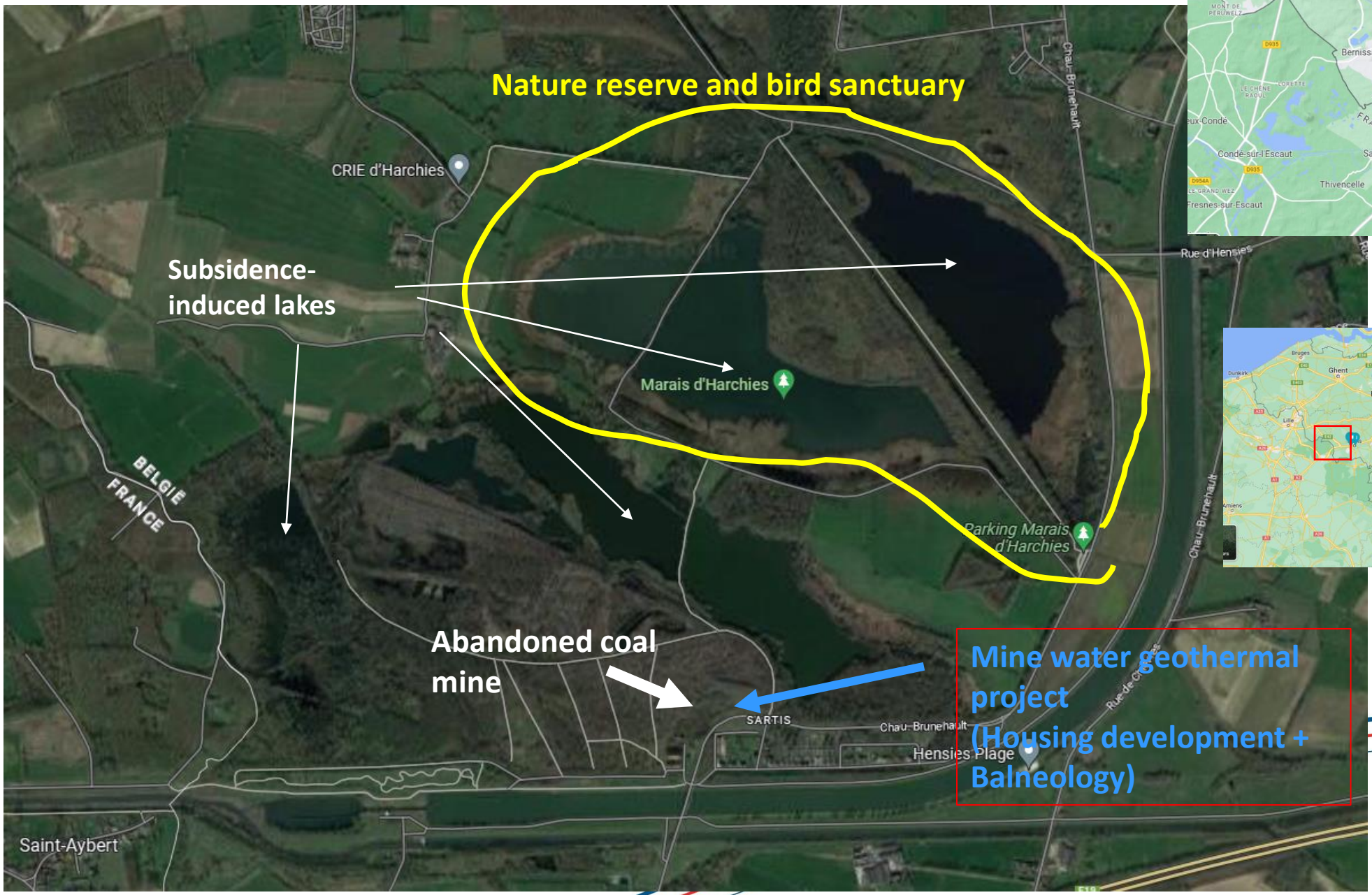
Gob drainage Concept Options #4B: Horizontal Single Zone injectors (toe close to producer)







Deployment: coal mines w. longwall operations



Mining-induced fracture systems for Mine Water Geothermal Projects: Conclusions

- Mine water geothermal projects:
  - Limited deployment so far
  - Large pilot schemes demonstrate signifiant potential
  - Usually limited heat exchange capacity with the country rock
- Longwall mining:
  - Predictable network of open and closed fractures
  - Potential drainage options to increase heat exchange with country rock
  - Challenges: drilling
- Advanced District Heating / Cooling Networks: enablers for Mine Water Geothermal
  - Integrated, parallel Heating / Cooling distribution
  - Modern buildings with optimized operational temperatures
  - Seasonal storage of excess heat / cold in subsurface mine system

GEOCONSULTANTS PANterra

Thank you!
Questions?

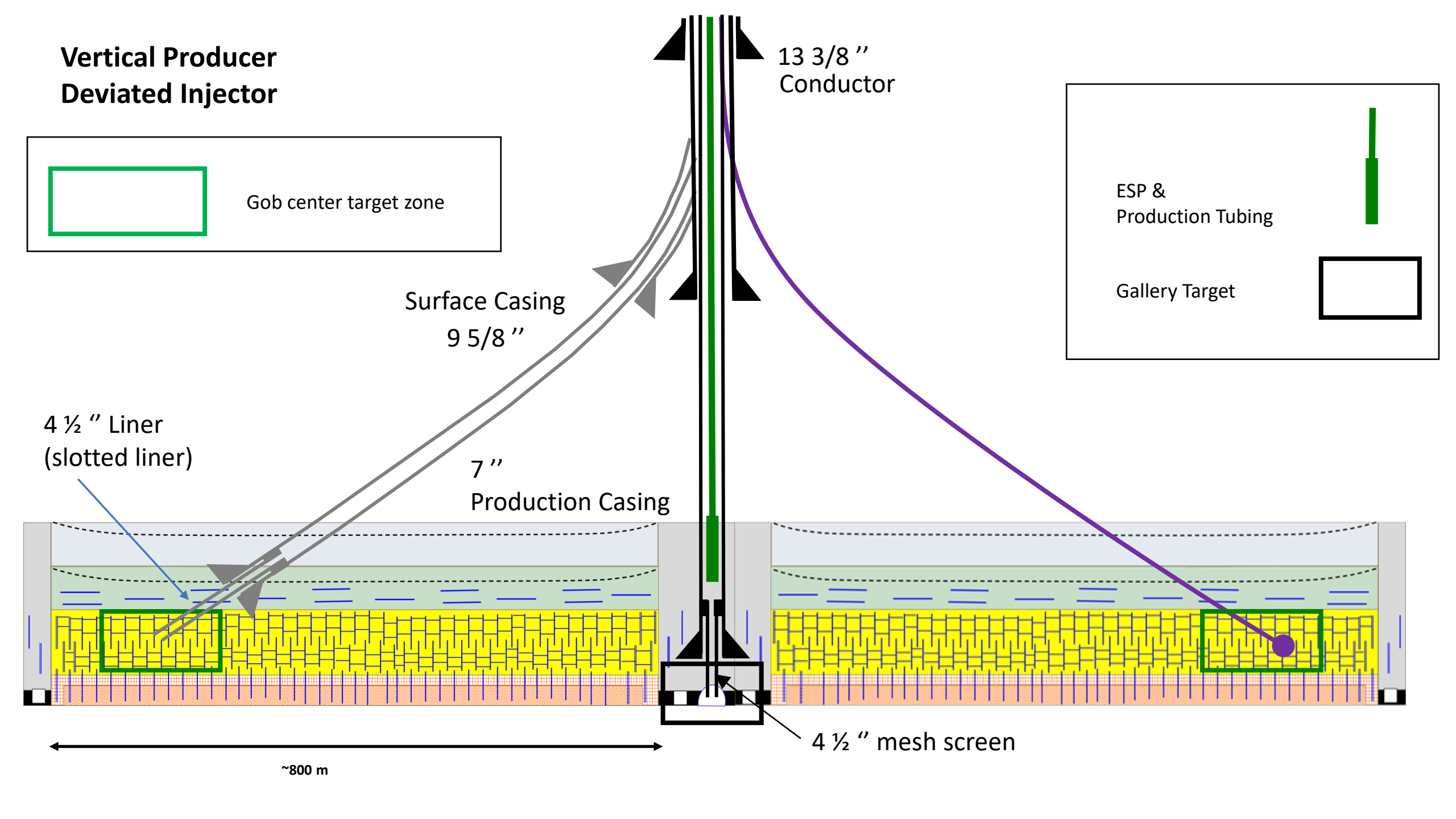
With special thanks to:

Benoît Valley

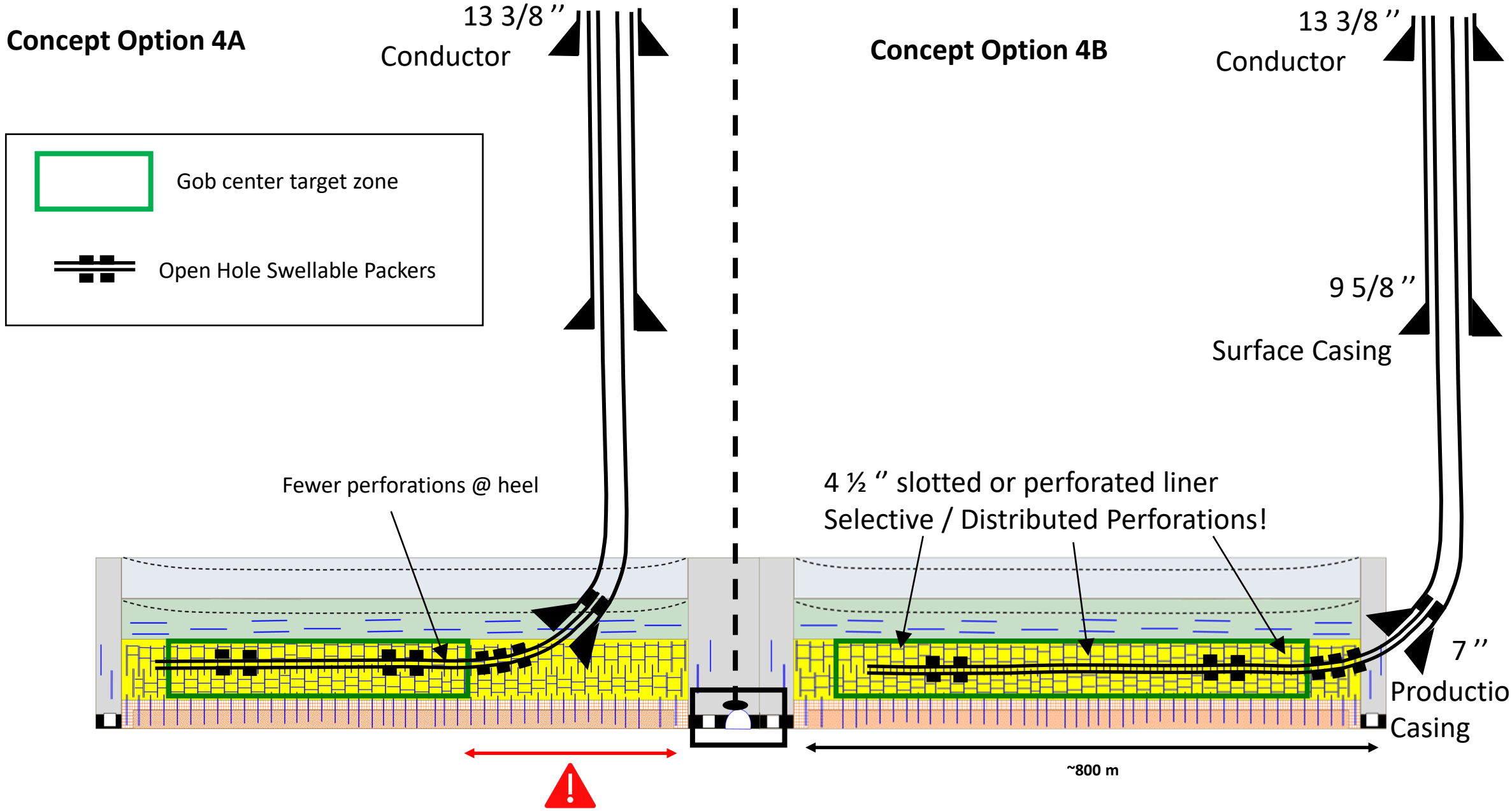
Miklos Antics

Nicolas Dupont
Olivier Kaufmann

Back-UP


Vertical Producer
Deviated Injector
Gob center target zone
13 3/8 ’’
Conductor
ESP &
Production Tubing
Gallery Target
Surface Casing
9 5/8 ’’
4 ½ ’’ Liner
(slotted liner)
7 ’’
Production Casing
4 ½ ’’ mesh screen
~800 m

Single-Zone Horizontal Injector



Conceptual geological drilling targets
3: Goaf / Gob