



# **Geo-mechanical Assessment of UCG & CCS**

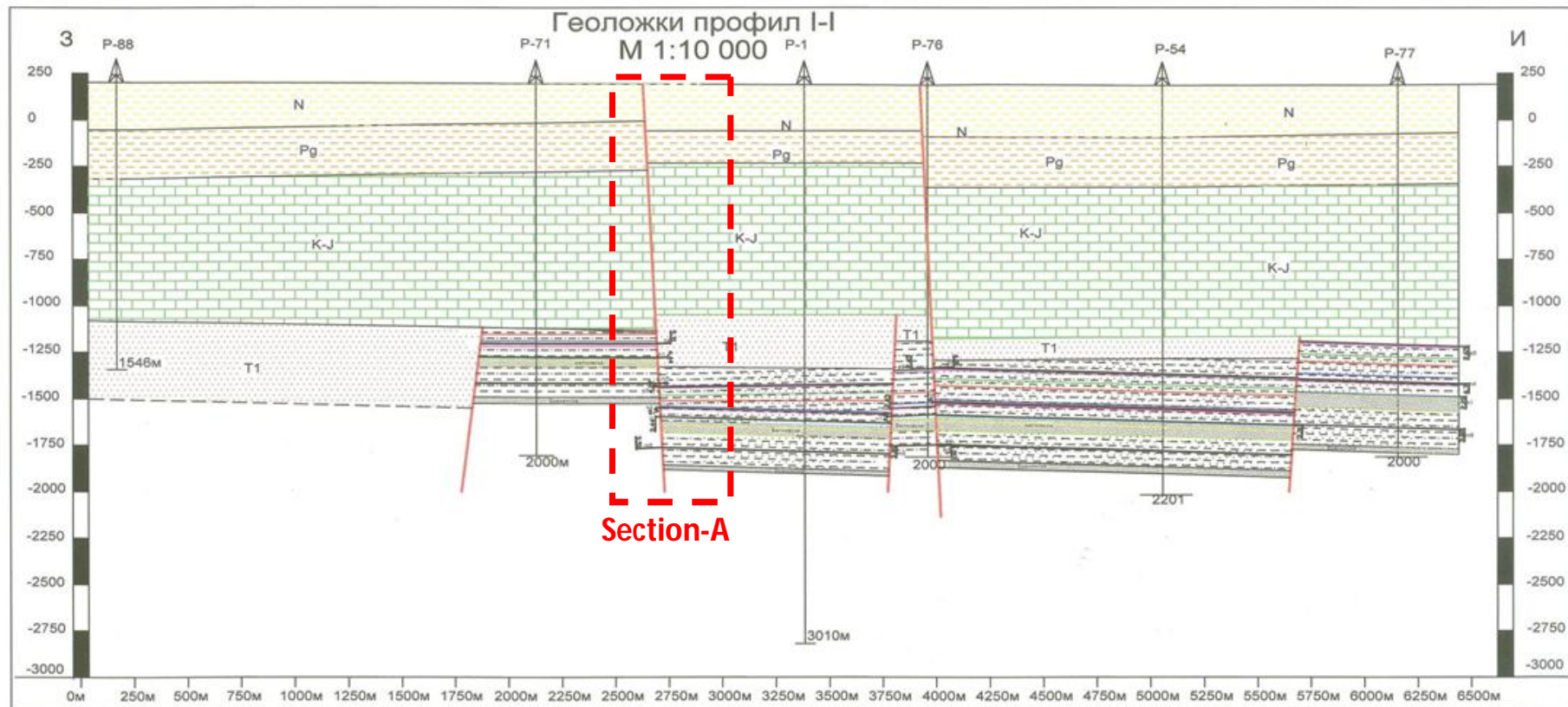
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# A Case Study in Bulgaria



Results presented here are adopted from a recently completed RFCS project: “Study of deep underground coal gasification and the permanent storage of CO<sub>2</sub> in the affected areas”



**Legend:**

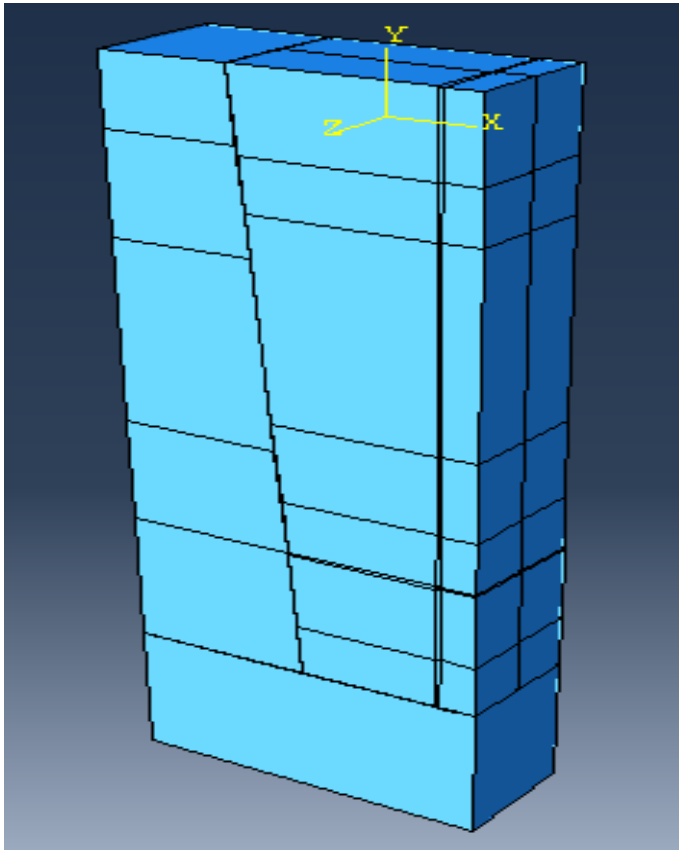
	Marker in the Upper Carboniferous		Velkovo Formation;
	Makedonka Formation with seam M5		Vranino Formation;

Geological West-East cross section

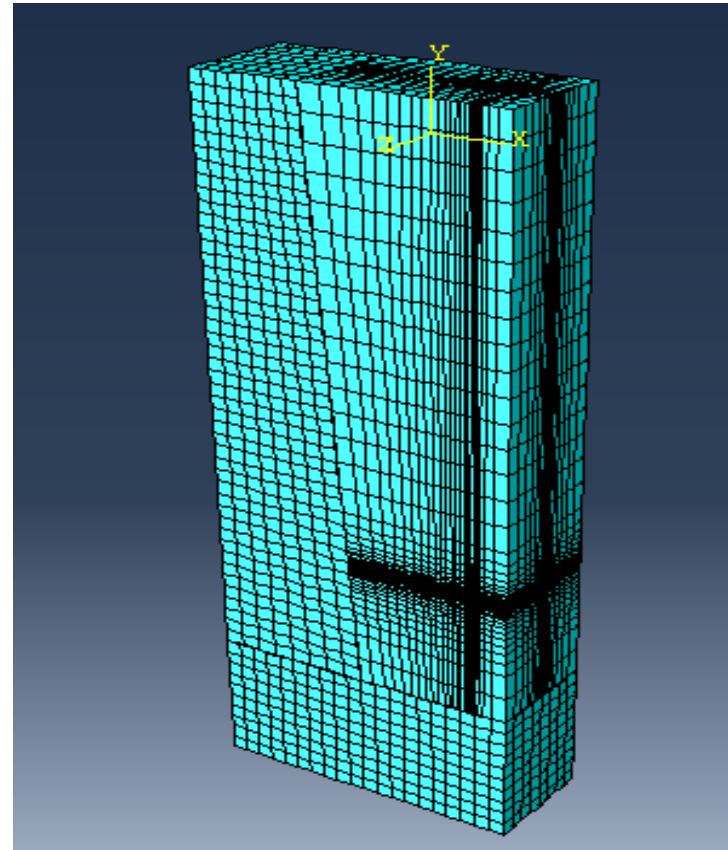
**Section A was selected because:**

- It includes all of the lithologic ages of the area;
- A fault is passing along the section of the geologic formation; and
- It consists of different layers of coal seams.

# 3D coupled thermal-mechanical modelling of cavity growth and surface subsidence

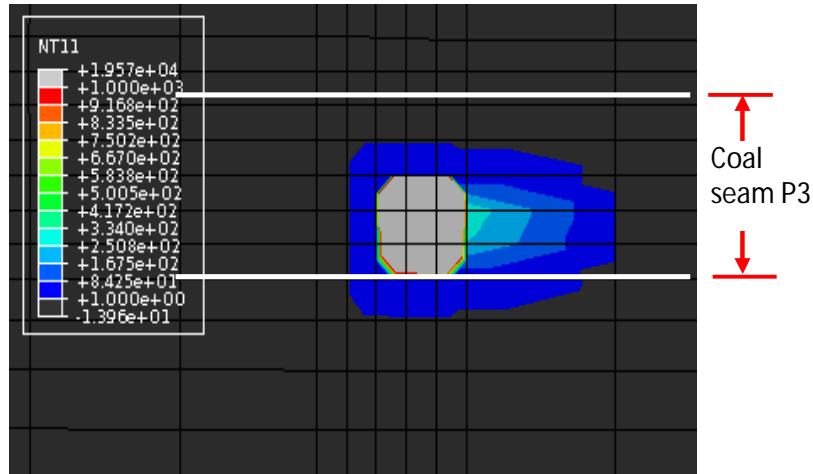


Partitioned 3D ABAQUS geometric model

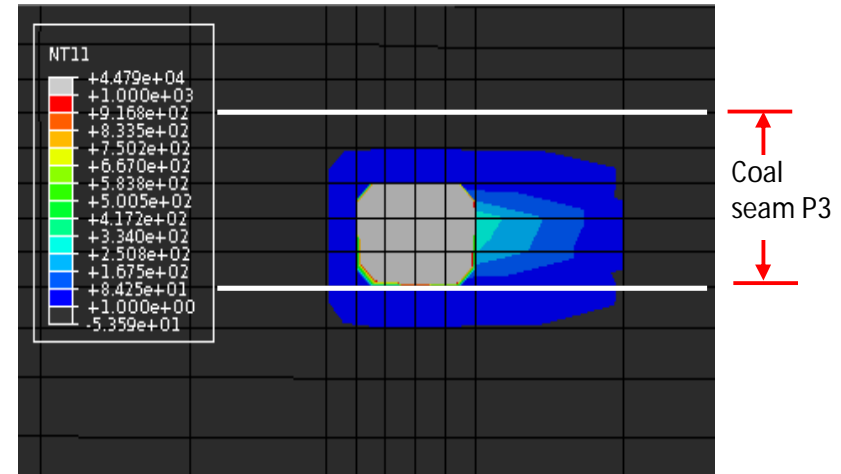


Meshed 3D ABAQUS model

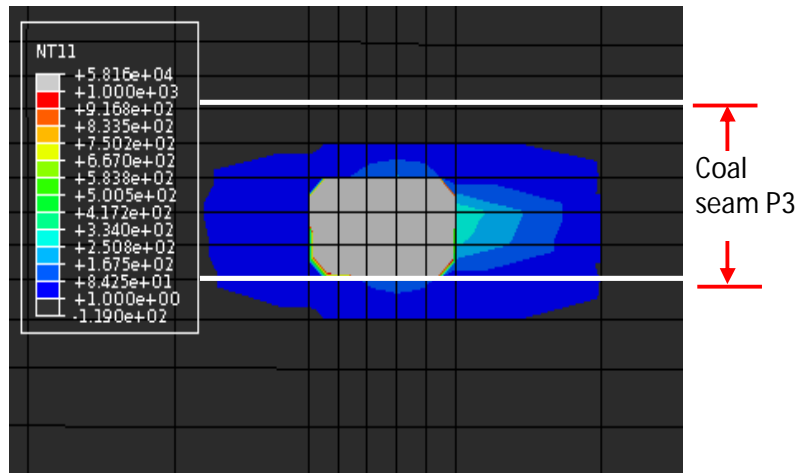
# Cavity growth in three days under ignition



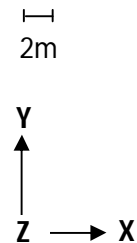
a) Day one



b) Day two

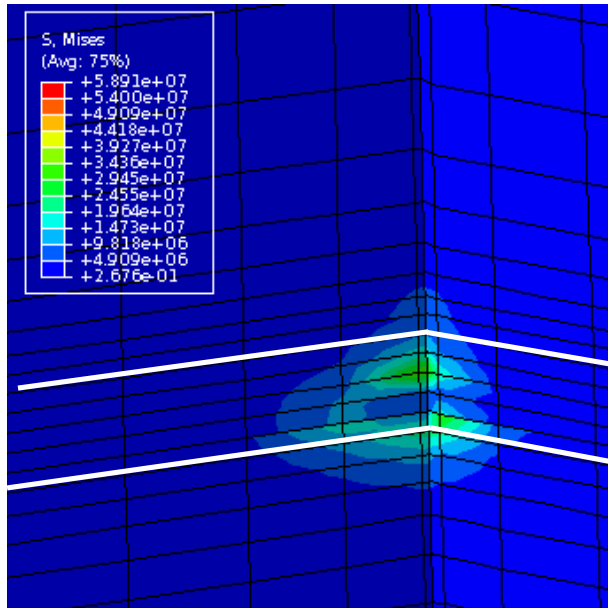


c) Day three

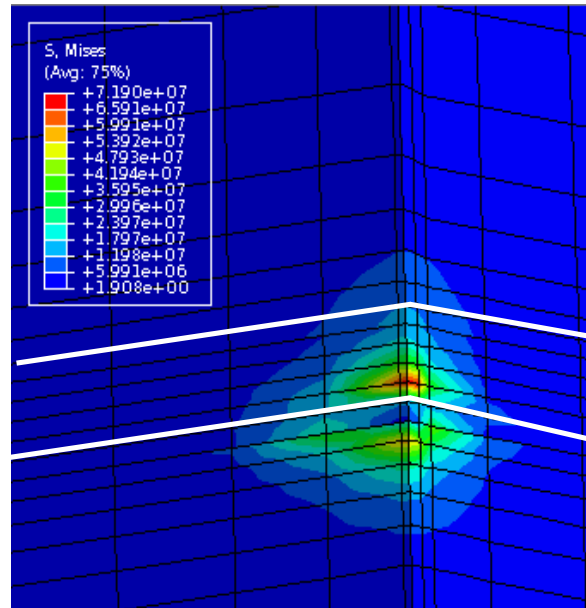




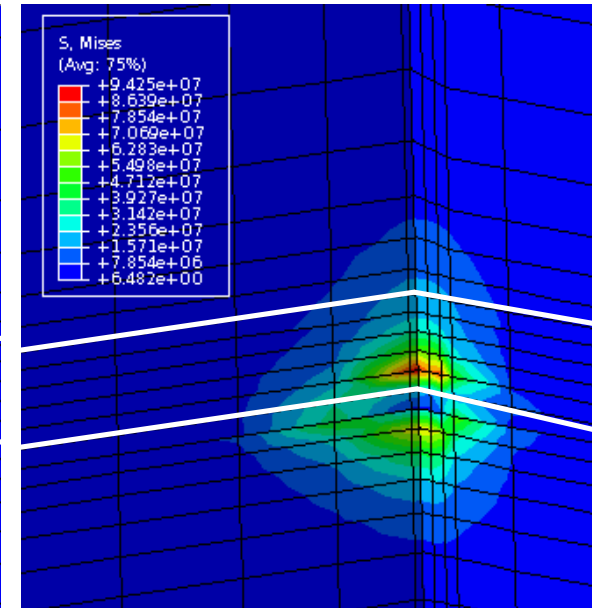
# Stress distributions in three days under ignition



a) After 1<sup>st</sup> day

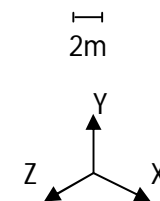


b) After 2<sup>nd</sup> day

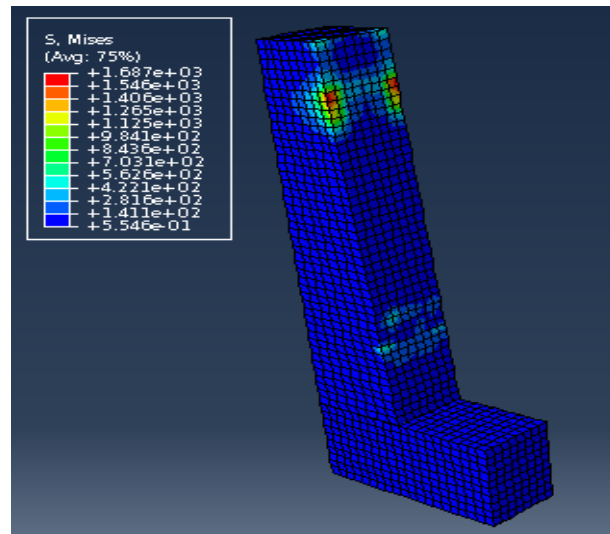


c) After 3<sup>rd</sup> day

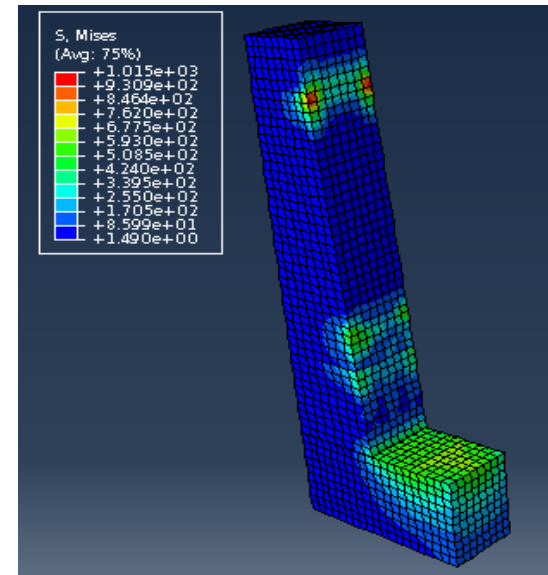
- Stress concentrated at the ignition centre.
- Both overburden and bottom rocks take more and more stresses as the gasification process continues.



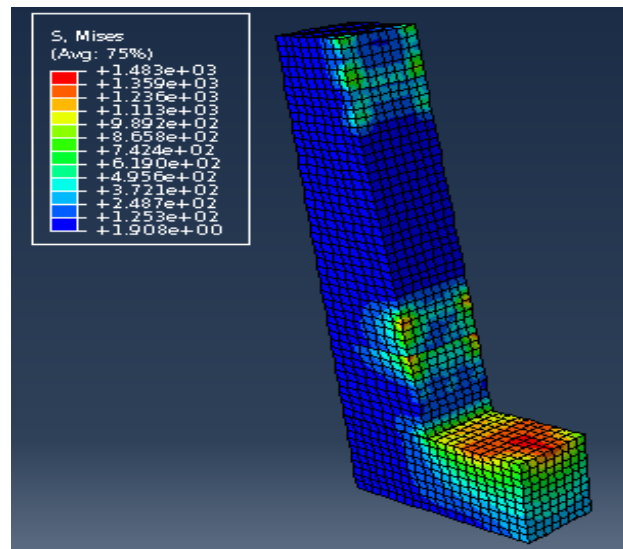
# Stress distribution at the fault and bed of the coal seam



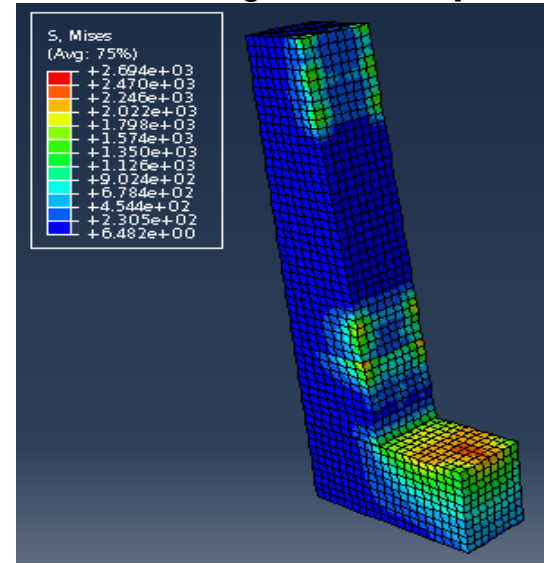
a) Under gravity



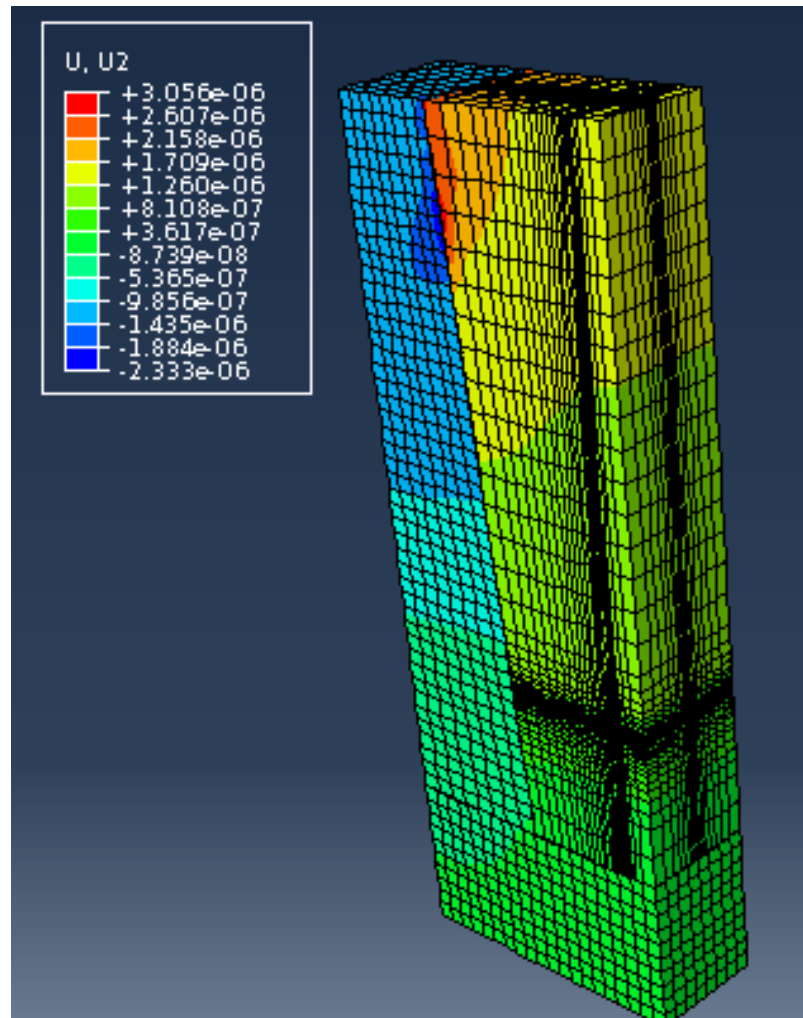
b) Under 1<sup>st</sup> gasification point



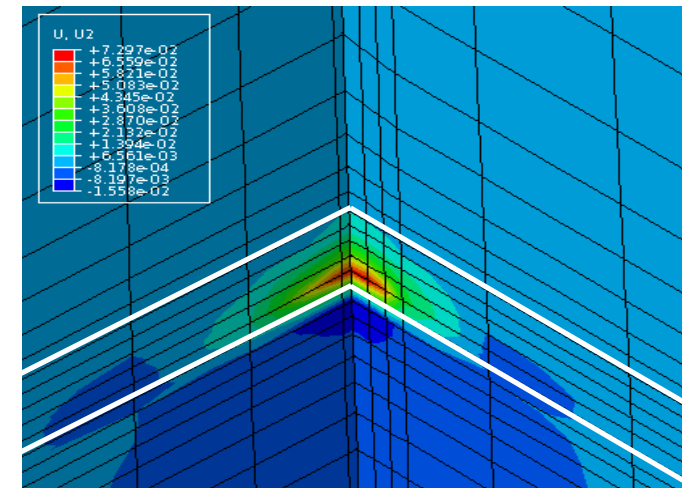
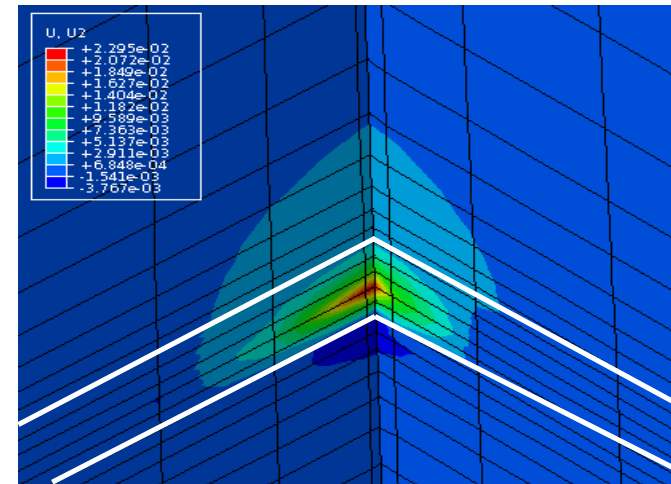
c) Under 2<sup>nd</sup> gasification



d) Under 3<sup>rd</sup> gasification



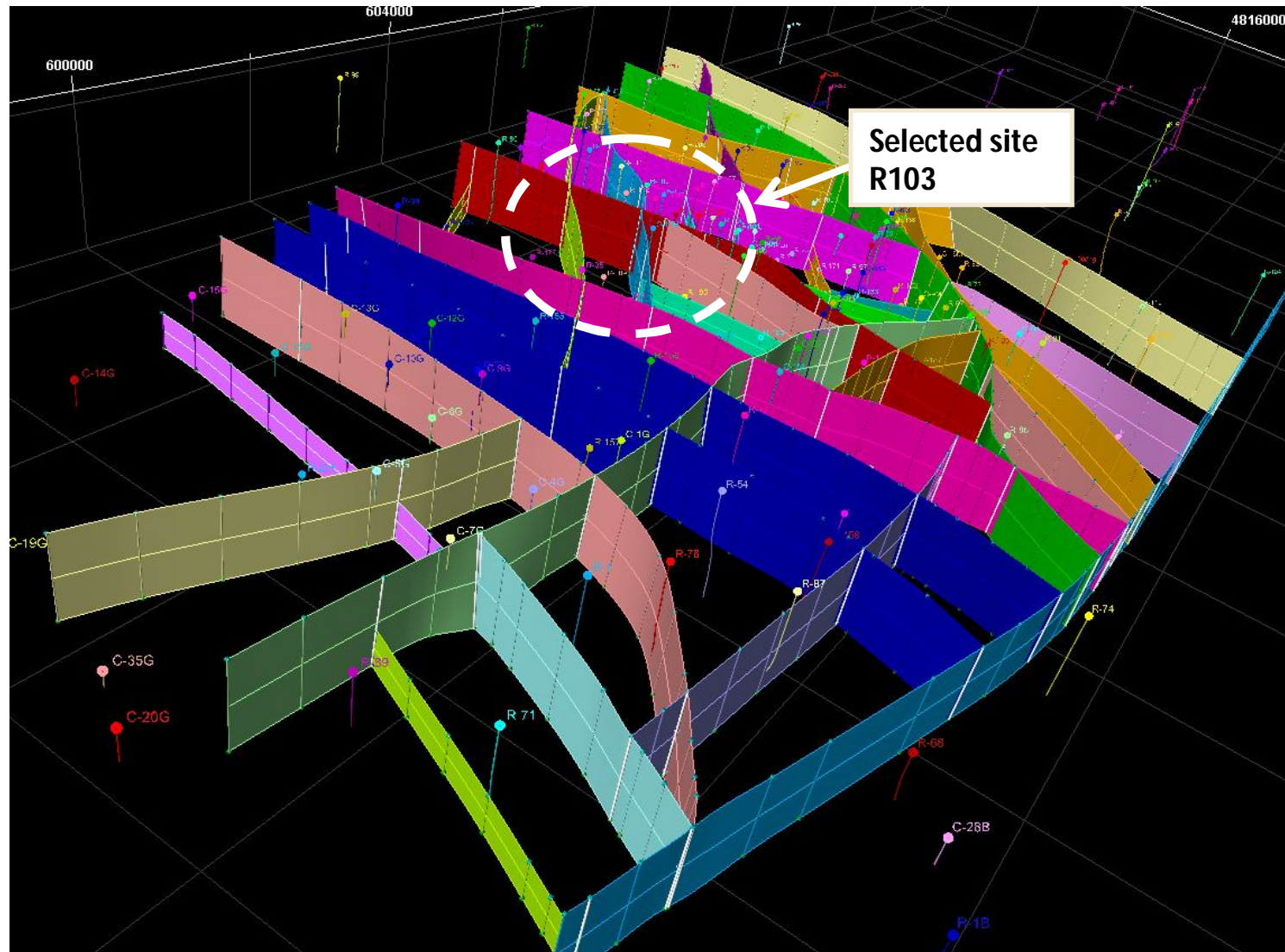
**Vertical displacement** distributions over the entire model



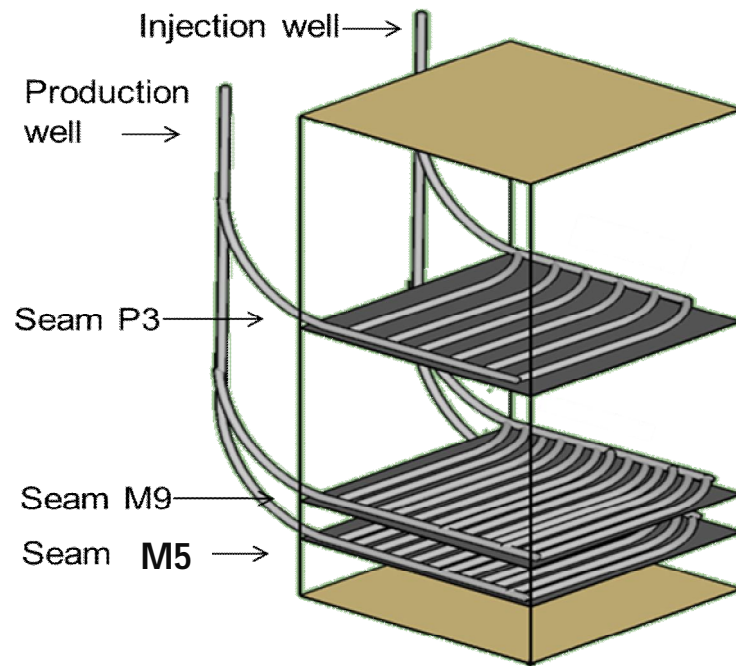
**Vertical displacement** distributions at the gasification point for the First ignition (Day 1 and 3)



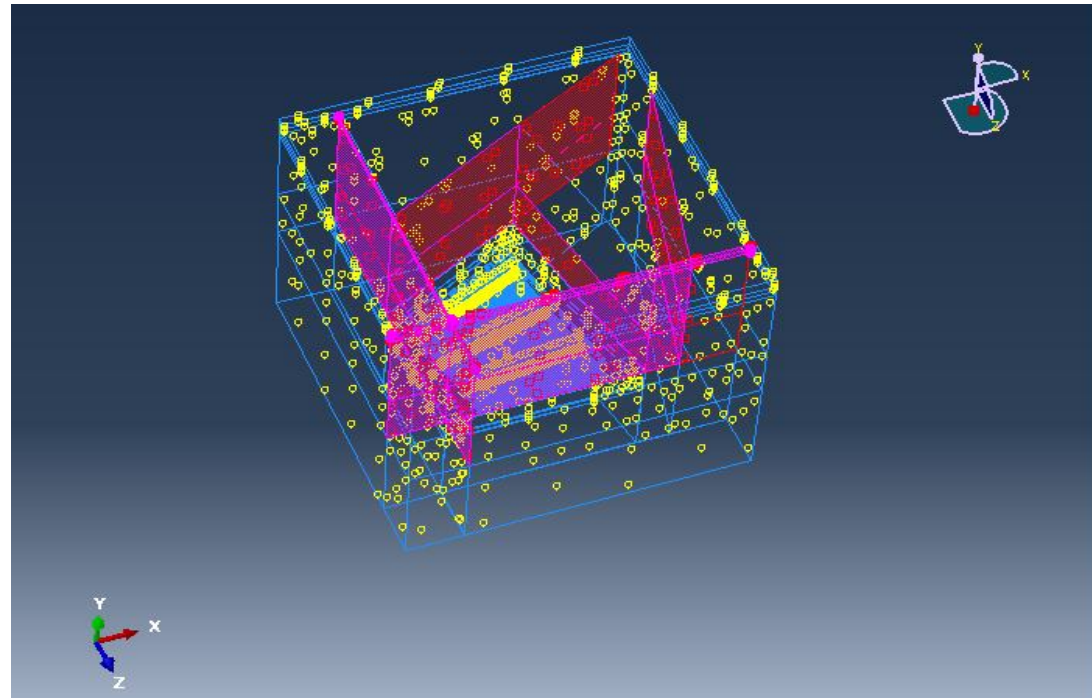
# Geological faults at the area



# Development of the geometry of the model



Well area R186 (ratio 1:10), not to scale



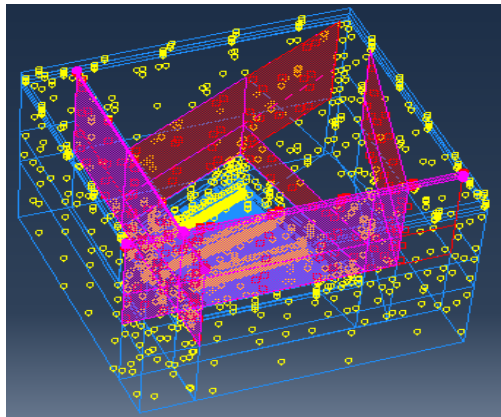
ABAQUS/CAE geometric model of the proposed site

## Technical well layout for selected site in Bulgaria

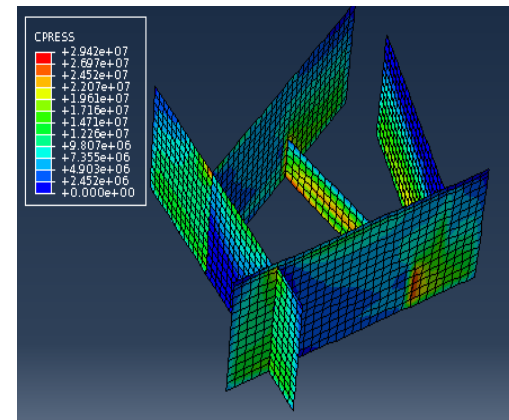
Coal seam	Depth	Thickness	Distance between two channels	Width/height ratio of the channels
P3	1322m	10m	20	2
M9	1734m	2m	4	2
M5	1800m	4m	8	2

# Geo-mechanical assessment of UCG processes

- The geomechanical model with the detailed geologic structure of the site including the positions and depths of the faults as well as the thickness of and depth of the coal seams
- Risk assessment of the product gas migrating through geologic faults and openings (fractures) in rock strata to the upper water aquifer



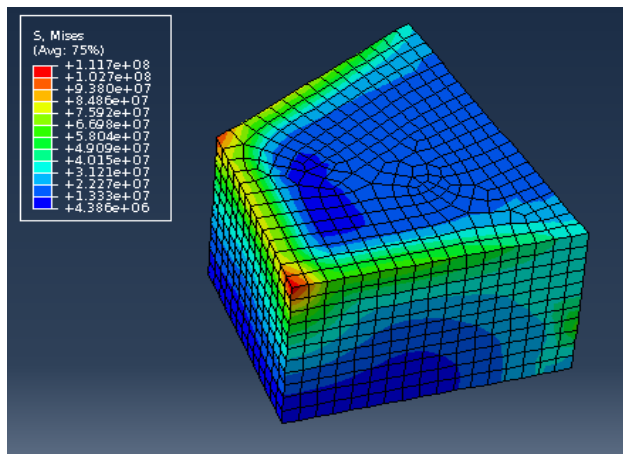
faults structure



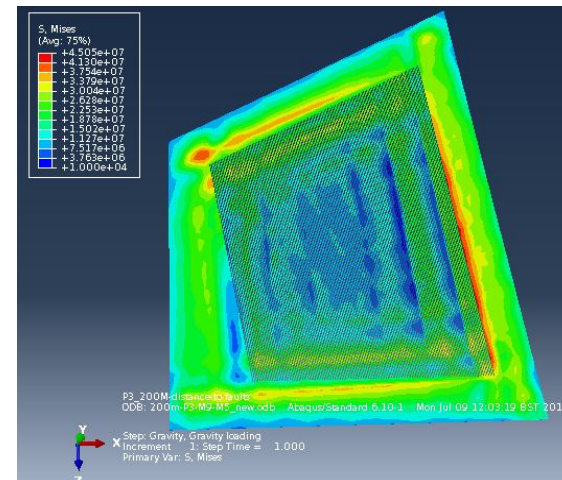
Contact pressure distributions on the faults

## Stress analysis of the rock strata and remaining coal

Spalling of overburden strata and unbalanced hydrostatic pressure surrounding the UCG cavities could create paths for the aquifer water into the cavities

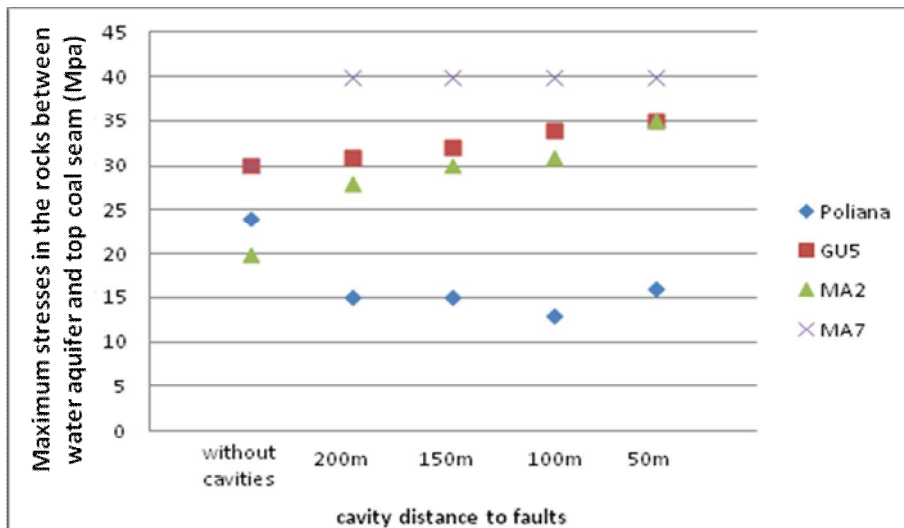
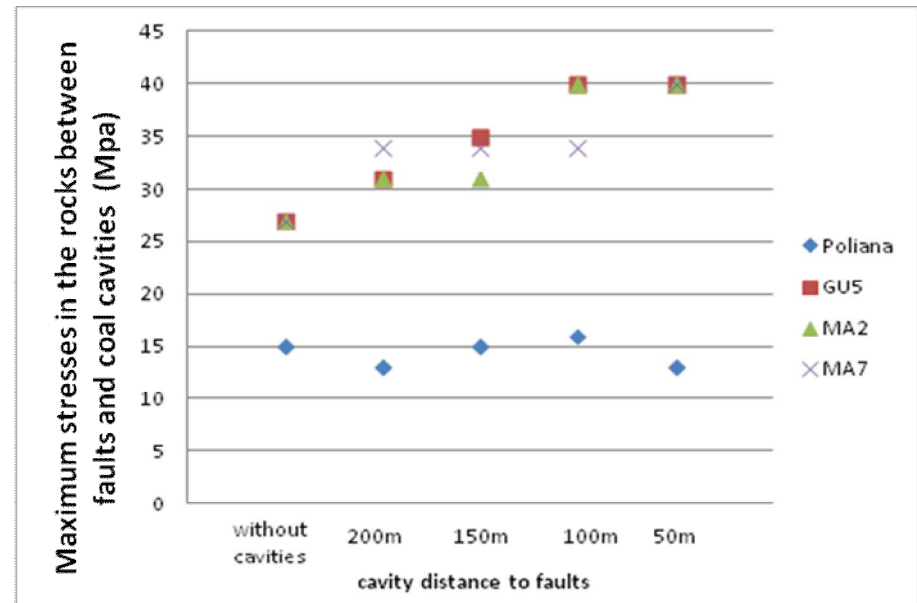
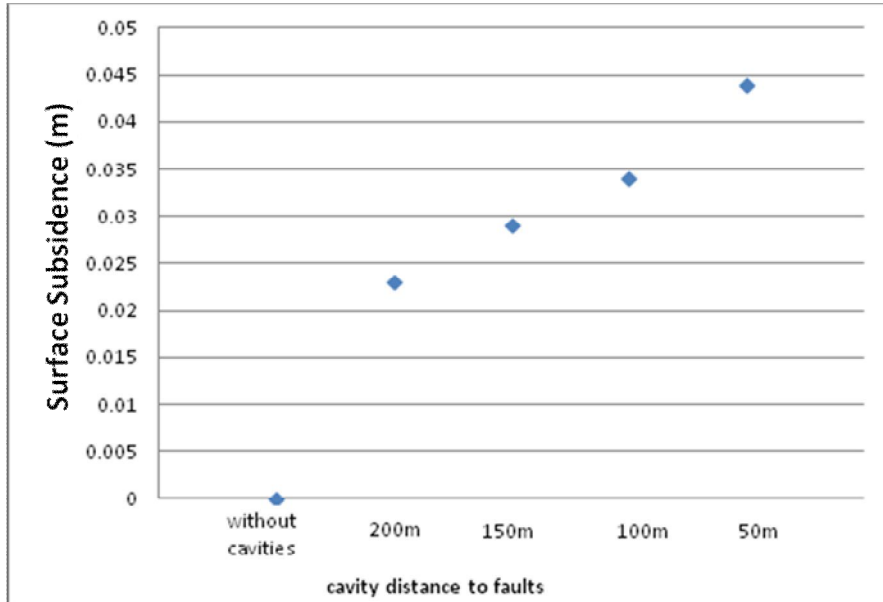


Von Mises stress distribution in overburden rock strata when nearest gasification channels have a distance of 200m to the geologic faults



Von Mises stress distribution in remaining coal when nearest gasification channels have a distance of 200m to the geologic faults

# Pathways for contamination - Risk Assessment



**A distance of 150m away from the fault is adequate**



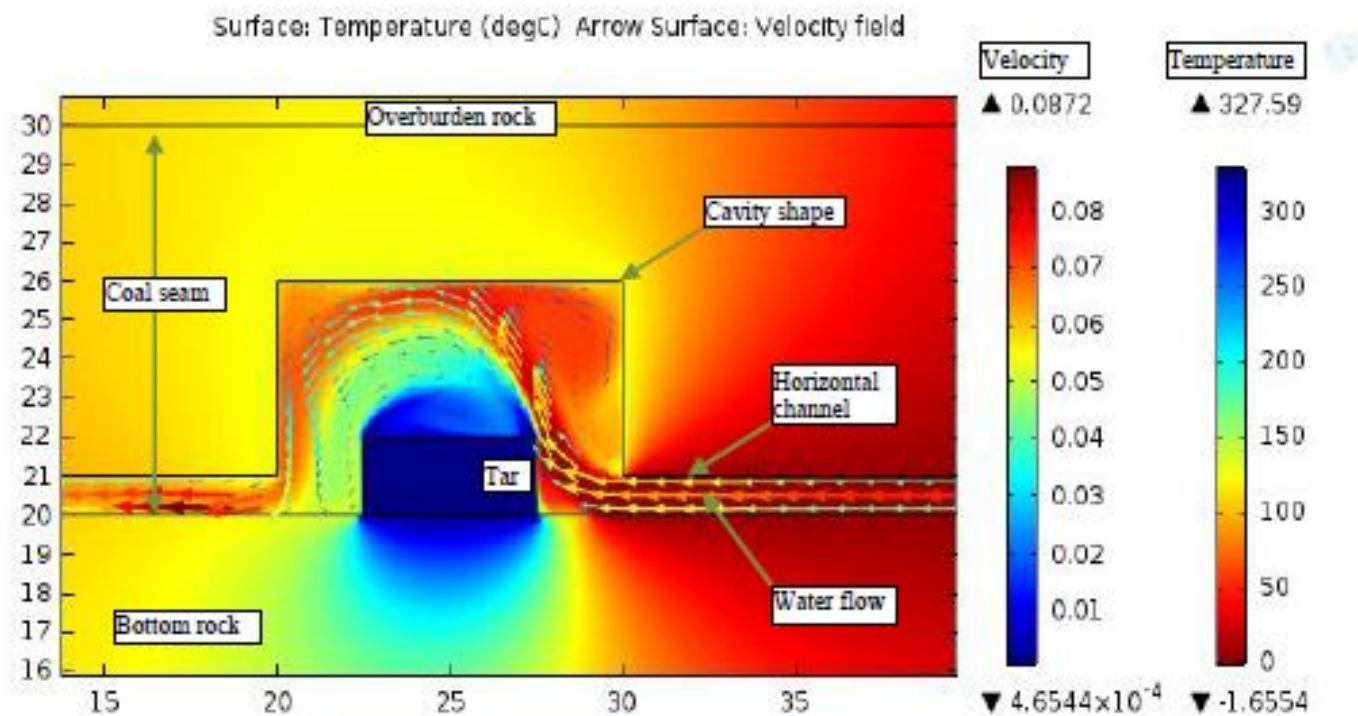
# Site selection criteria

- Based on the calculation results, a series of site selection criteria have been developed that can be used for the implementation of the works.

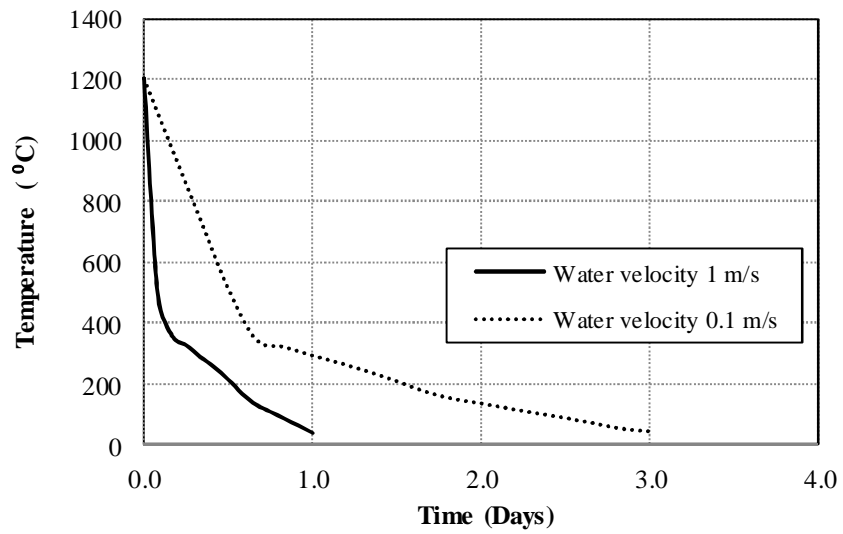
Category	Desired Value	Comments
Coal thickness	$30\text{m} < t < 2\text{m}$	Ideally 5 – 10m
Distance to nearest overlying water bearing unit	100m	
Coal aquifer characteristics	Confined	
Proximity to faults	>150m depending on site conditions	<i>If many major faults then site specific calculation required to be carried out for the accurate estimation of the distance.</i>
Geotechnical strata properties	Rock strength: UCS: >50MPa. Density: >2000kgr/m <sup>3</sup>	<i>Avoid excessively fractured, faulted and broken rocks as they may cause water inrush or product gas and contaminant leakage</i>
Available coal resources (10 <sup>6</sup> m <sup>3</sup> )	>3.5Mt	<i>&gt;20 years long operation. Depend upon gas utilization and profitability.</i>
Number of seams to be gasified	<i>Avoid seams with overlying coal within 15m.</i>	
Gross calorific value of coal	>12MK kg <sup>-1</sup>	



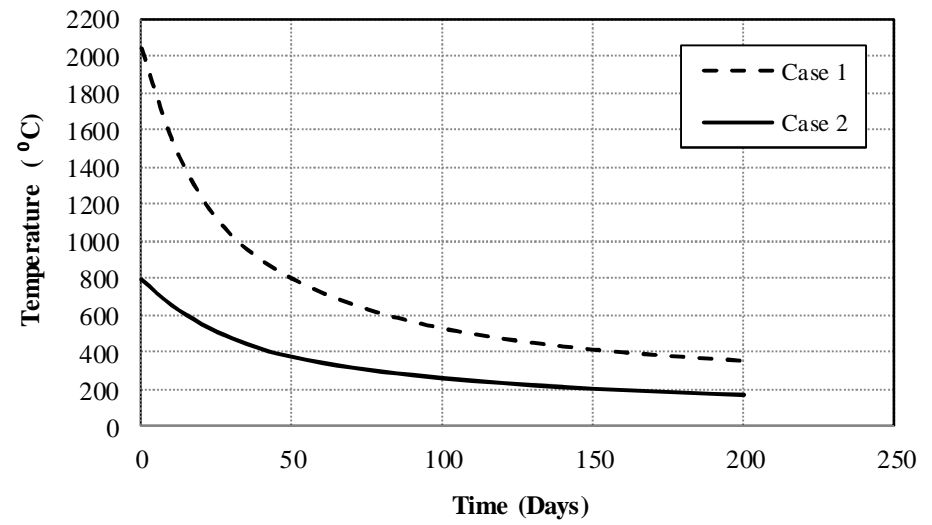
# UCG cavity washing and treatment



2D COMSOL modelling of cavity washing process with heat transfer and fluid flow



water flushing

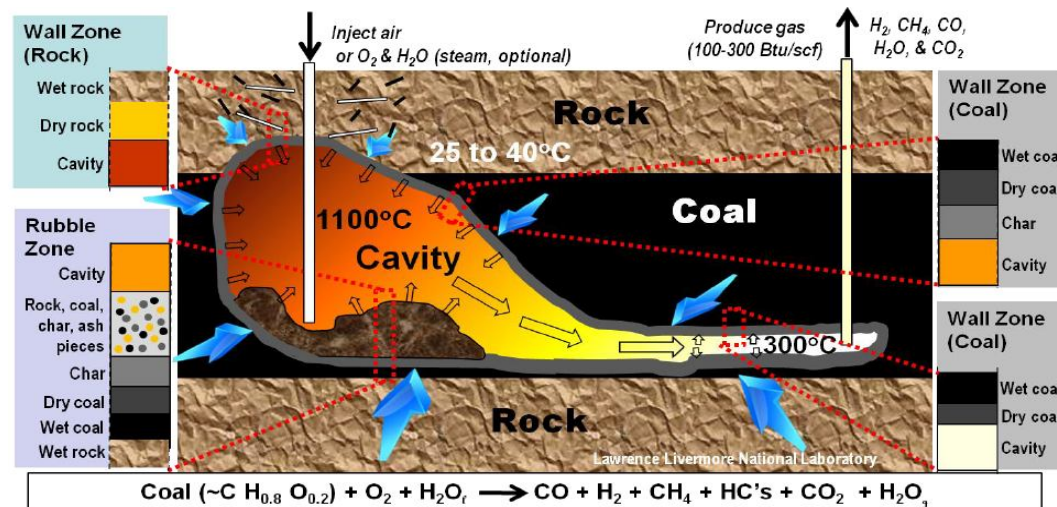


the natural cooling down process

# Geomechanical assessment of UCG processes

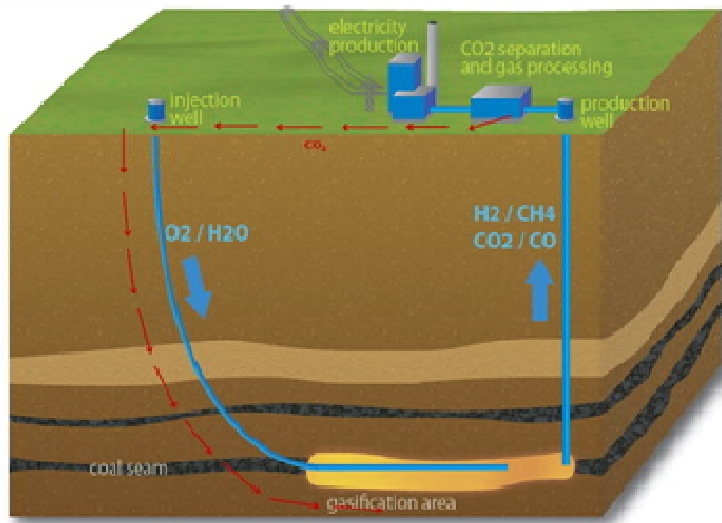
UCG involves interdependent multi-physical/chemical processes

- Integrated modelling
  - Cavity growth, geologic deformation and fracture, fluid permeation and environmental interaction
  - Integrate geomechanical model with thermal-hydrological model, cavity gas model and boundary evolution model



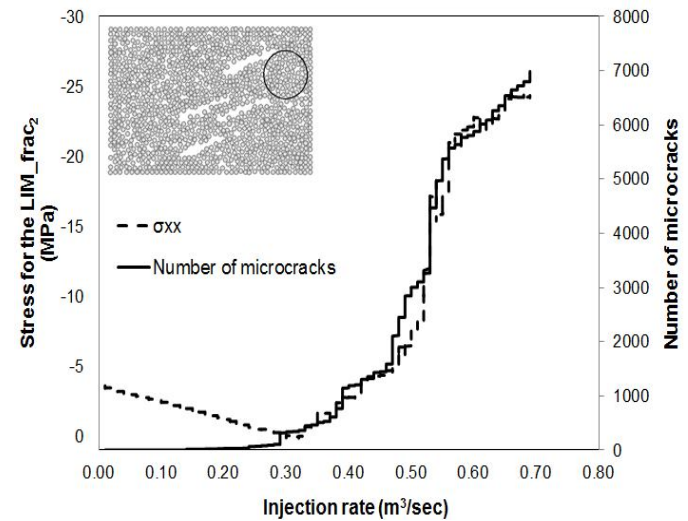
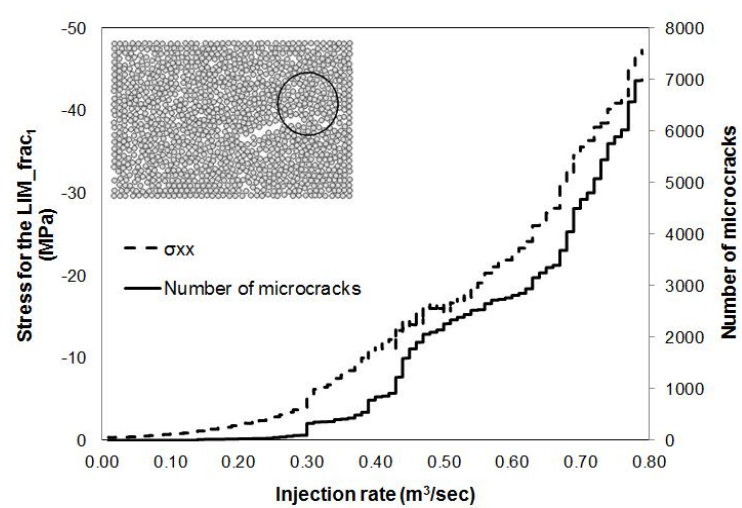
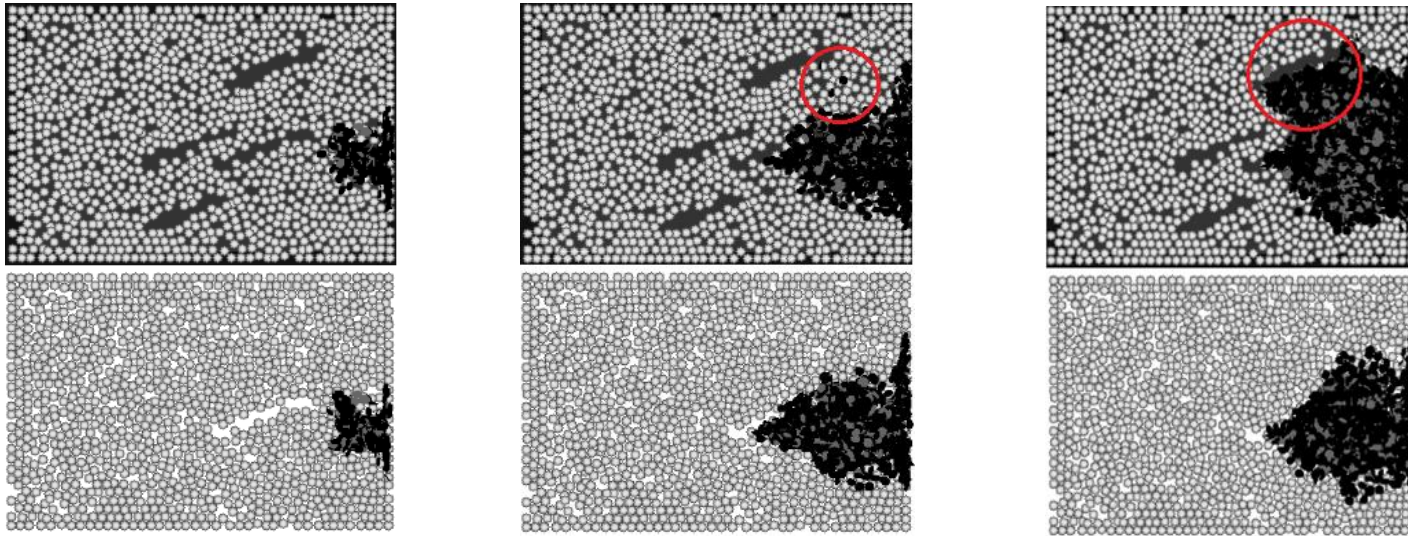
Source: Nitao, et al, 2011. Progress on a new integrated 3-D UCG simulator and its Initial Application

## UCG combined with CO<sub>2</sub> Storage-Geomechanical responses



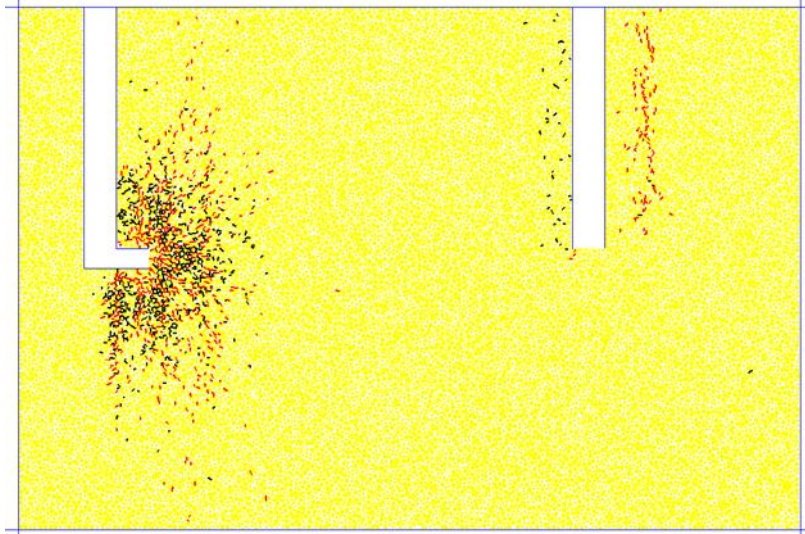
- The injection pressure must exceed hydrostatic pressures in order to displace cavity water. This will prompt a number of geomechanical responses, such as fracture dilation, crustal uplift, and potentially inducing fracture.
- This risk may be accentuated by the collapse of the cavity roof or walls.
- Valid geomechanical models for stress and rock deformation are required, as are coupled geomechanical/fluid-flow simulators

## Micro models for Hydraulic fracturing by CO<sub>2</sub> Injection

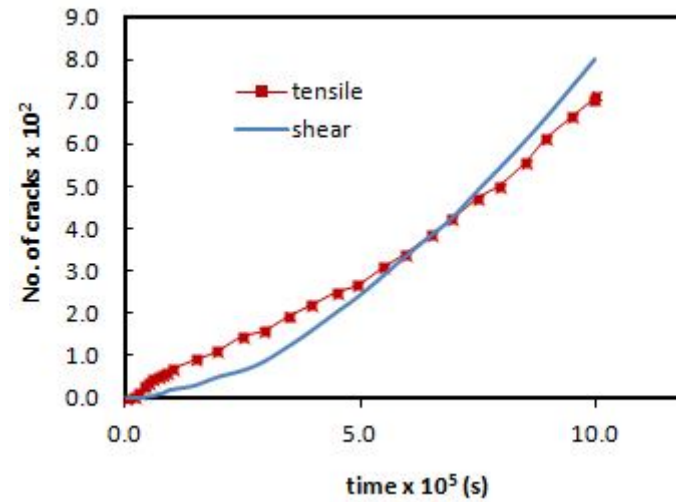




## Hydraulic Fracturing of Reservoir Formations during CO<sub>2</sub> Injection



Pattern of fracture propagation due to fluid injection  
(vel=0.75m/s)



Tensile and shear fracture development  
(vel=0.75m/s)



# Challenges in modelling UCG with CO<sub>2</sub> storage

CO<sub>2</sub> storage into UCG cavities (large scale and long term modelling, e.g. 50-100 years, challenging and substantial research required)

- Upscaling approaches (upscaling of permeability and multi-phase properties, and upscaling of geochemistry)

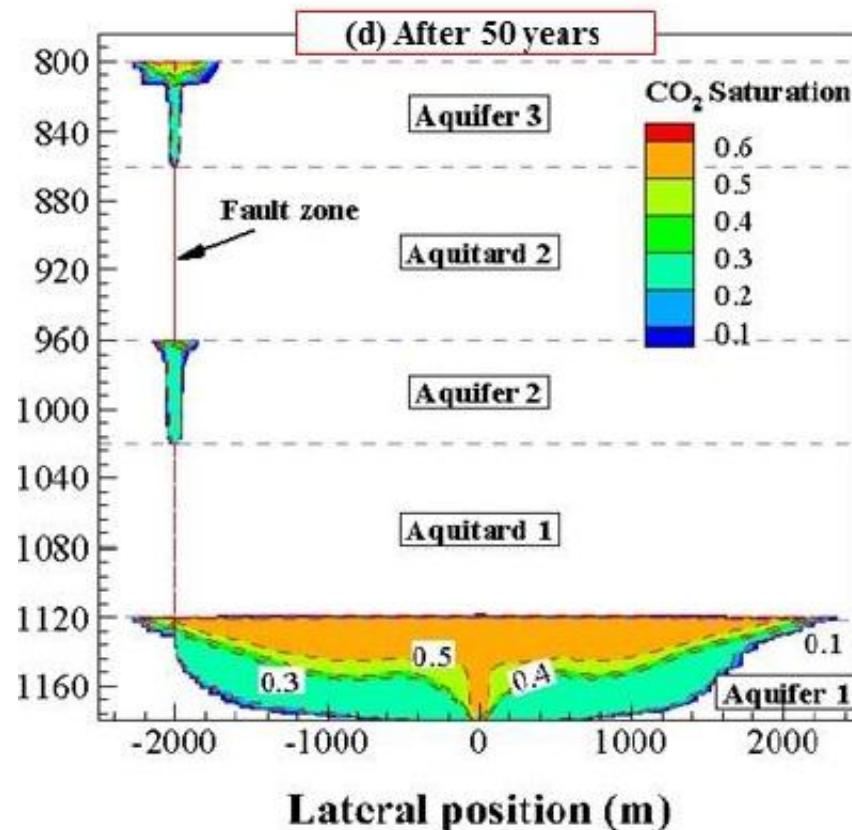
- Temporally adaptive time-stepping scheme, varying from few days at early times to few hours during transient periods;

- Spatially multiple grids, averaging in the coarse-grid and local fluctuating values in the fine grid;

- upscaling approach is case dependent; thus cross-validation between numerical simulations and experimental and/or monitoring data of long term CO<sub>2</sub> storage is required.

# Geomechanical assessment of UCG with CO<sub>2</sub> storage

Upscaling simulation of CO<sub>2</sub> storage in geologic aquifers (Wasim Hassen, 2014), this model could be coupled with geomechanical model to assess the long-term geologic structural stability during CO<sub>2</sub> storage.

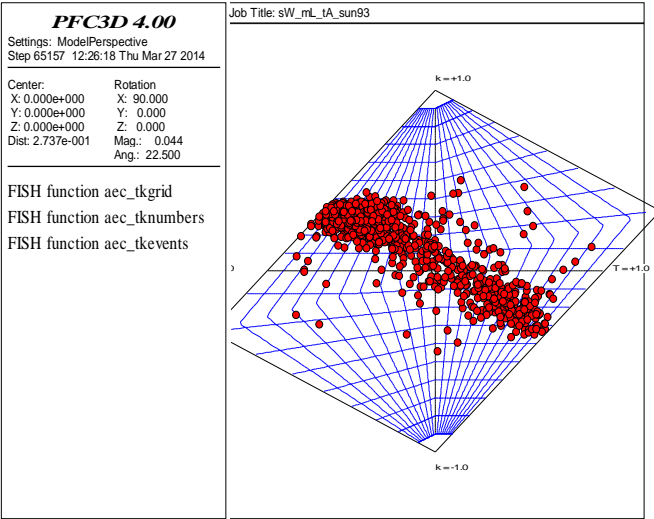
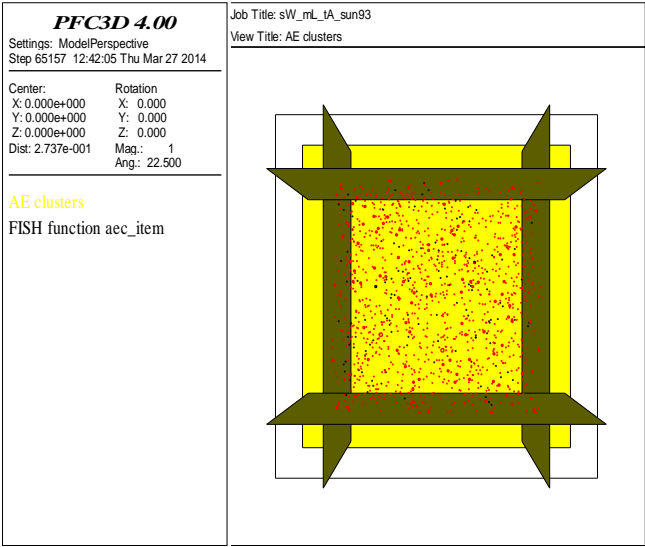


# Knowledge gaps

While there is much work still to be done to create and integrated simulation models for UCG, there is a larger gap to be filled with regard to the data needed to populate and test the model. These data gaps include:

- Quantification of changes in the hydraulic conductivity tensor and porosity reflecting rock crushing and possible of fracture/fissure propagation in the vicinity of the collapsed zone
- Model calibration to post-seam collapse hydraulic head and concentration measurements for pilot sites where historical data are available
- Assembly of the thermo-hydrological model and calibration to existing thermohydrological data such as temperature profiles
- Coupling the thermal effects on the density and viscosity to better mimic the pertinent physical processes and quantitative assessment of the effects of the thermally- and density-driven forces on the risk of contaminant migration

# Modelling of induced seismicity in a rock sample





Thank you