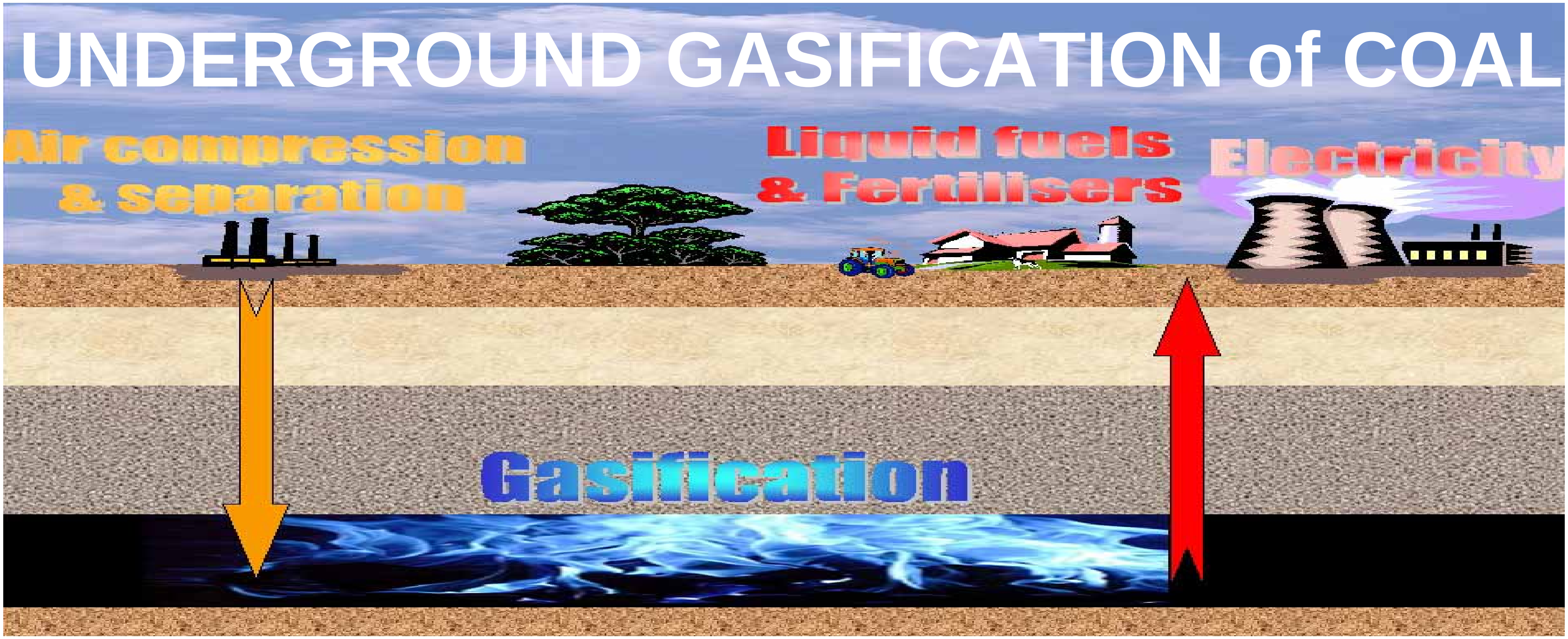

Managing Ground Deformation in UCG

Cliff Mallett

CarbonEnergy
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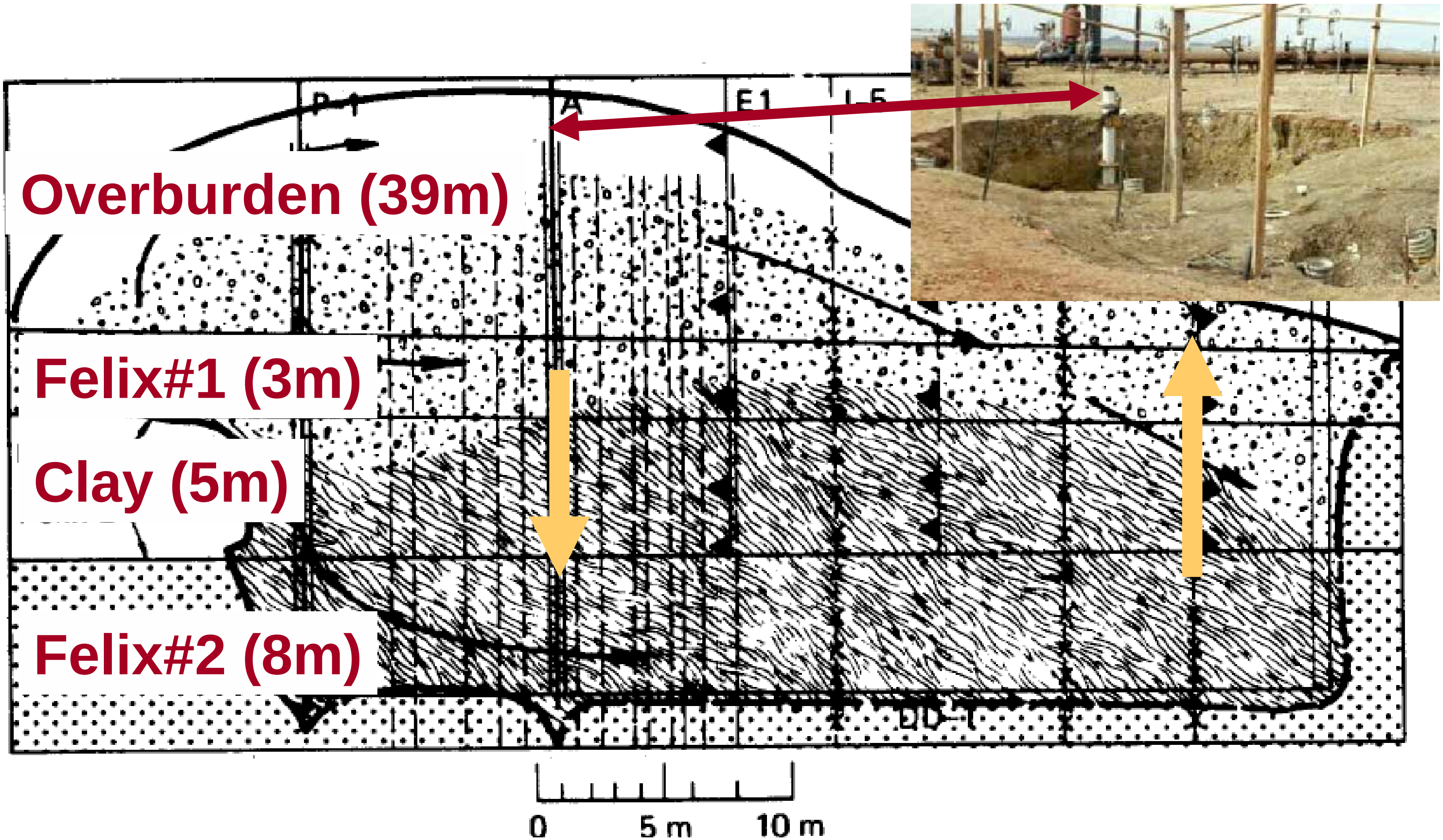
Why is Deformation an Issue?

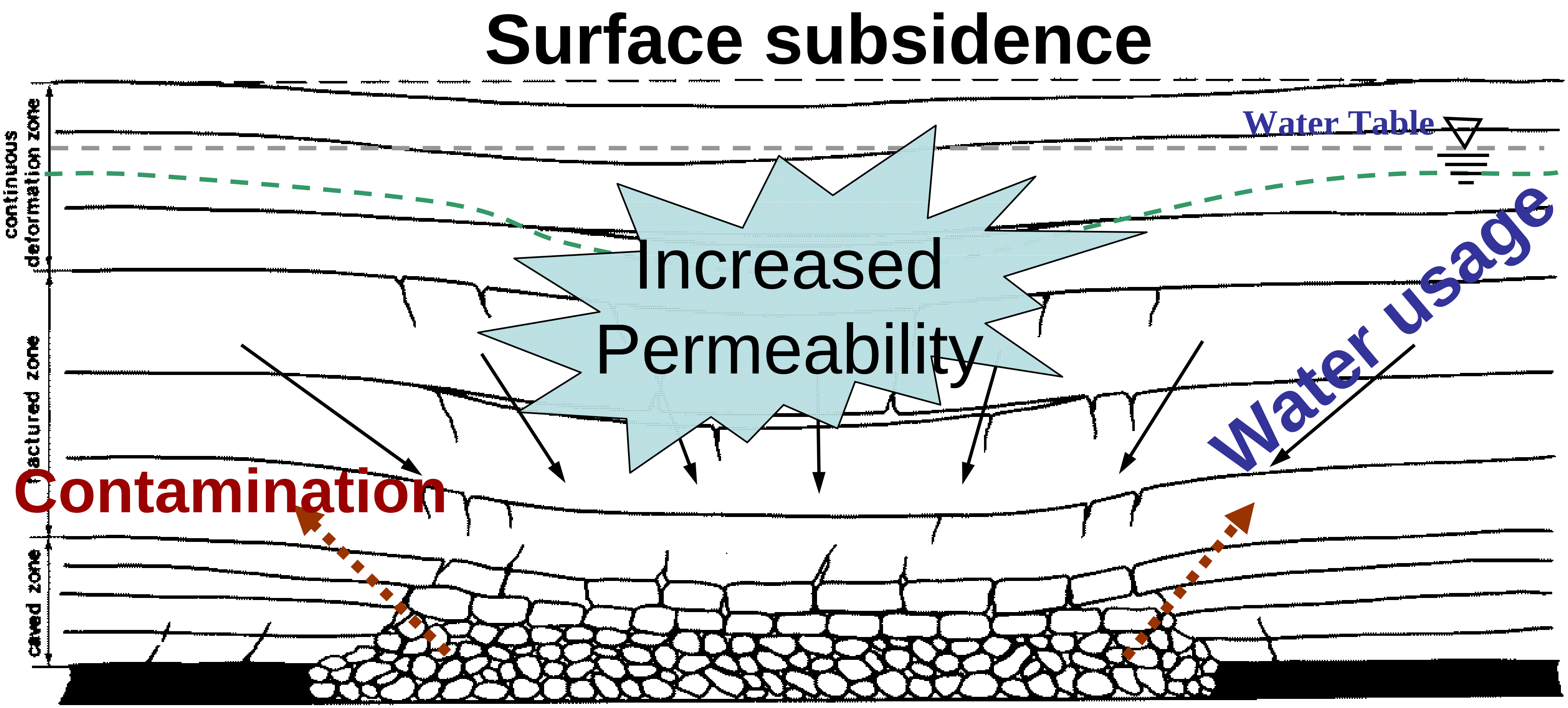
- Commercial scale UCG removes similar coal volumes to a large longwall mine
- UCG Designs must provide consistent high volume gas production, and be viable with large scale extraction
- Cavity collapse results in induced permeability and subsidence
  - Changes gasification conditions with water inflow
  - Cause mixing in overlying aquifers
  - Surface impacts

Hoe Creek #3 Trial (USA, 1979)

- Total of 11m of coal at 39-55m depth



Potential Environmental Impacts



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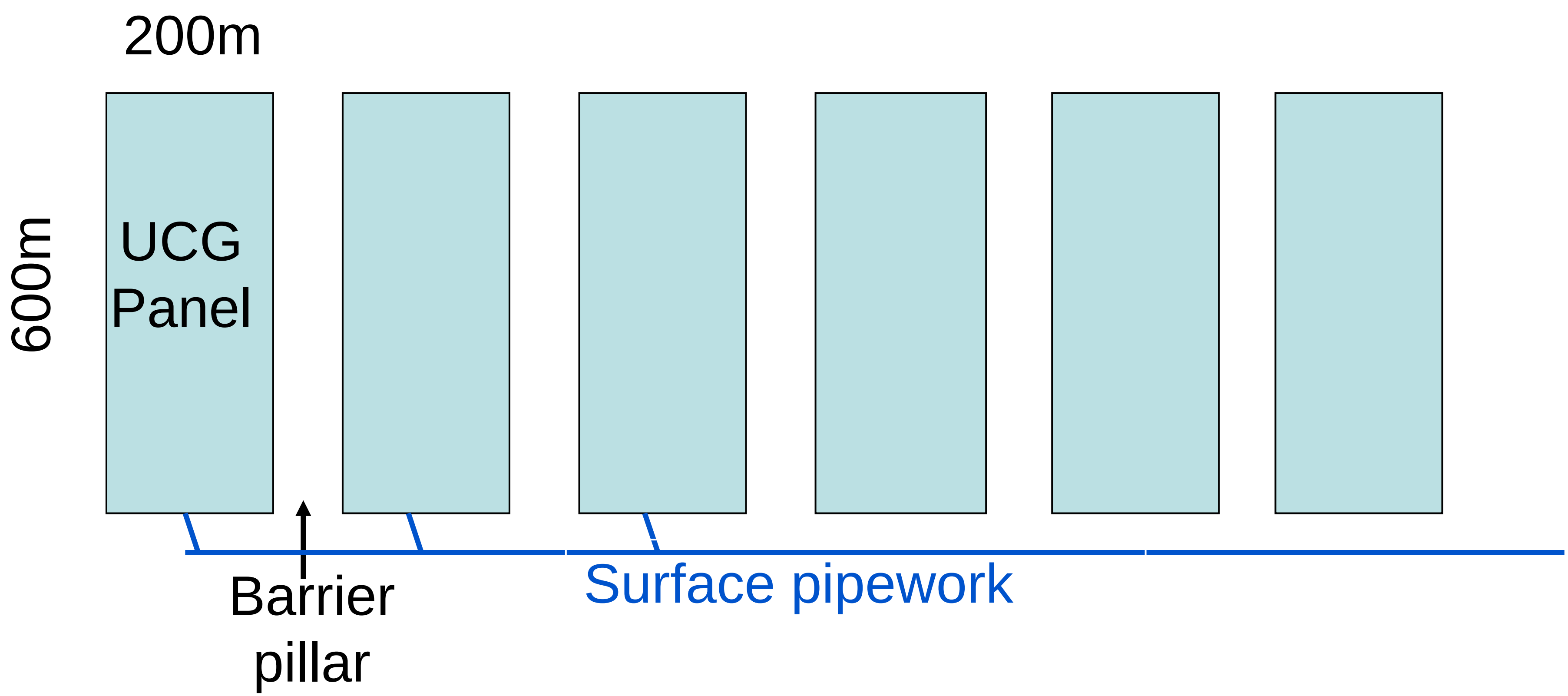
Typical UCG High Production Layout



Commercial scale may use 1 to 7 panels a year

What can be done about Deformation?

- **Predict ground and water behaviour from site characterisation data**
- **Incorporate whole-of-life water flow into UCG operational designs**
- **Assess environmental impact models & monitor**
  - Surface features
  - Groundwater systems

But we cannot stop deformation, and if impacts cannot be managed, we must abandon the site for UCG

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Understanding Deformation

- UCG is analogous to longwall mining
  - Comparable coal will be removed
  - Thickness of coal – ash left but more coal taken
- Learn from longwall mine behaviour
  - We know that deformation is severe immediately above a cavity, but decreases in impact at higher levels
- Apply verified longwall predictive models to UCG eg COSFLOW
  - Stress and Strata movement
  - Fracture and Induced permeability
  - Fluid flow

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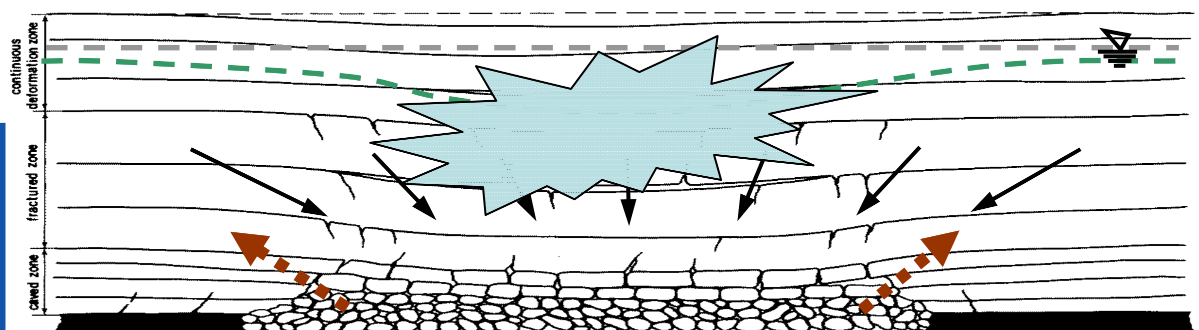
Critical Implications for UCG

- Large scale shallow UCG extraction will
  - – Open direct pathways from surface to gasification cavity
  - – Disrupt groundwater requirements for gasification
- Minimum depth for large scale extraction 300m
  - – Maintain 150m of undeformed buffer over disrupted strata
  - – At depth. in seam drill holes better than vertical holes
- Above 300m only partial extraction is safe
  - – This limits UCG gas production levels achievable



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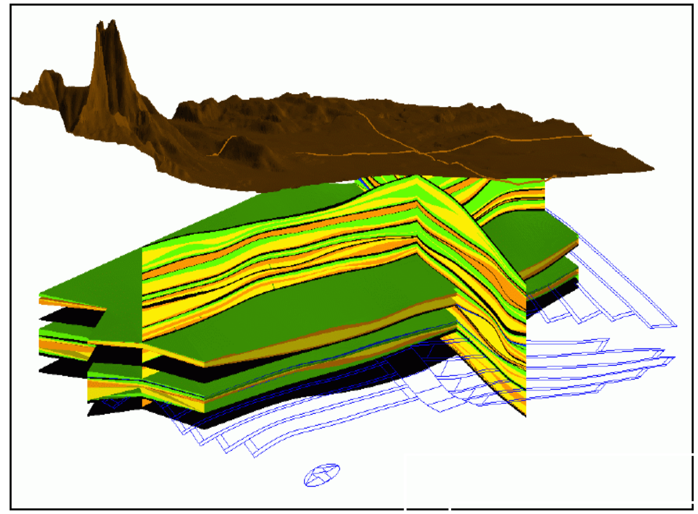
Managing Deformation

- **Integrated site characterisation**
- **Numerical modelling**
  - Mine Water
  - Mine subsidence
- **Field monitoring**
- **Subsidence control**

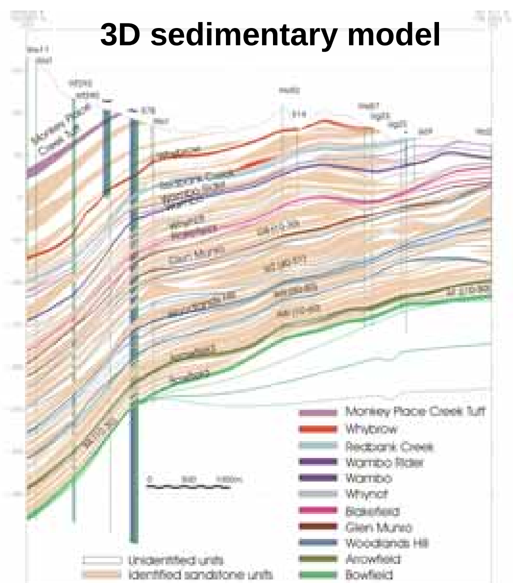
Site Characterisation

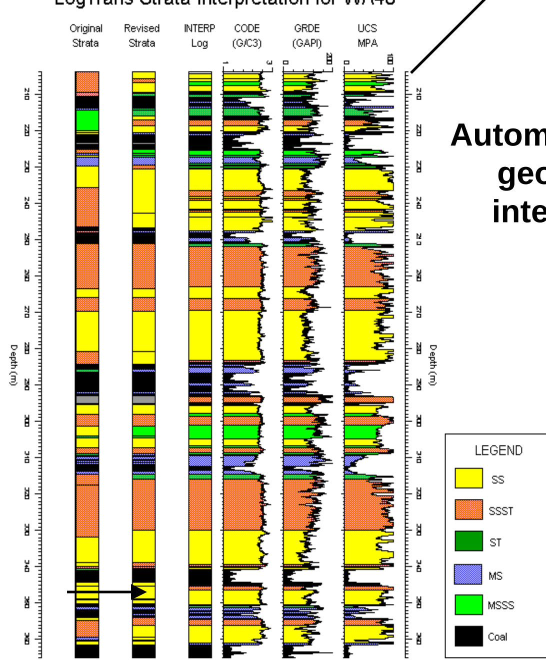
Drilling, in-situ stress and permeability measurements

3D geotechnical model



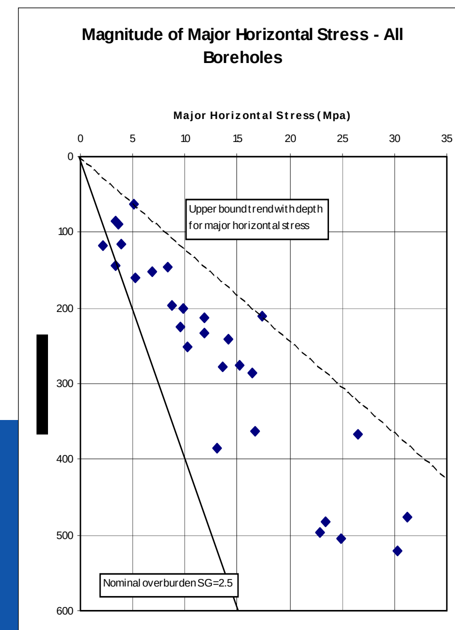
3D sedimentary model





Automatic drillhole geotechnical interpretation

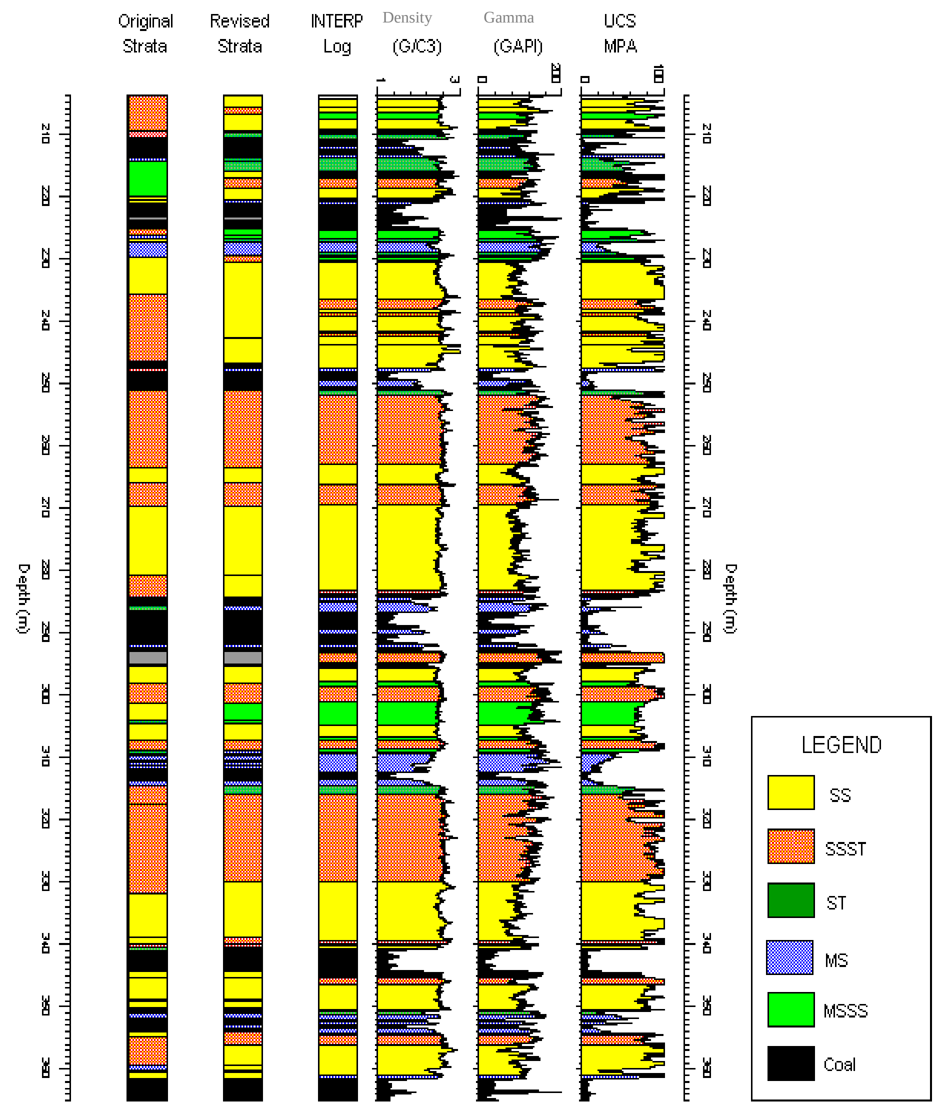
In-situ stress



Automated Log Transformation

The computer program LogTrans is used to identify Coal, Mudstone, Siltstone and Sandstone from their unique petro-physical signatures using the density, natural gamma and sonic velocity geophysical logs.

The figure shows the geological interpretation of a control hole. The first column is the geological classification from the geologist. The second column is the geophysical conciliated geological classes for LogTrans' training processing. The third column is the LogTrans interpretation from the geophysical logs presented in the other columns.



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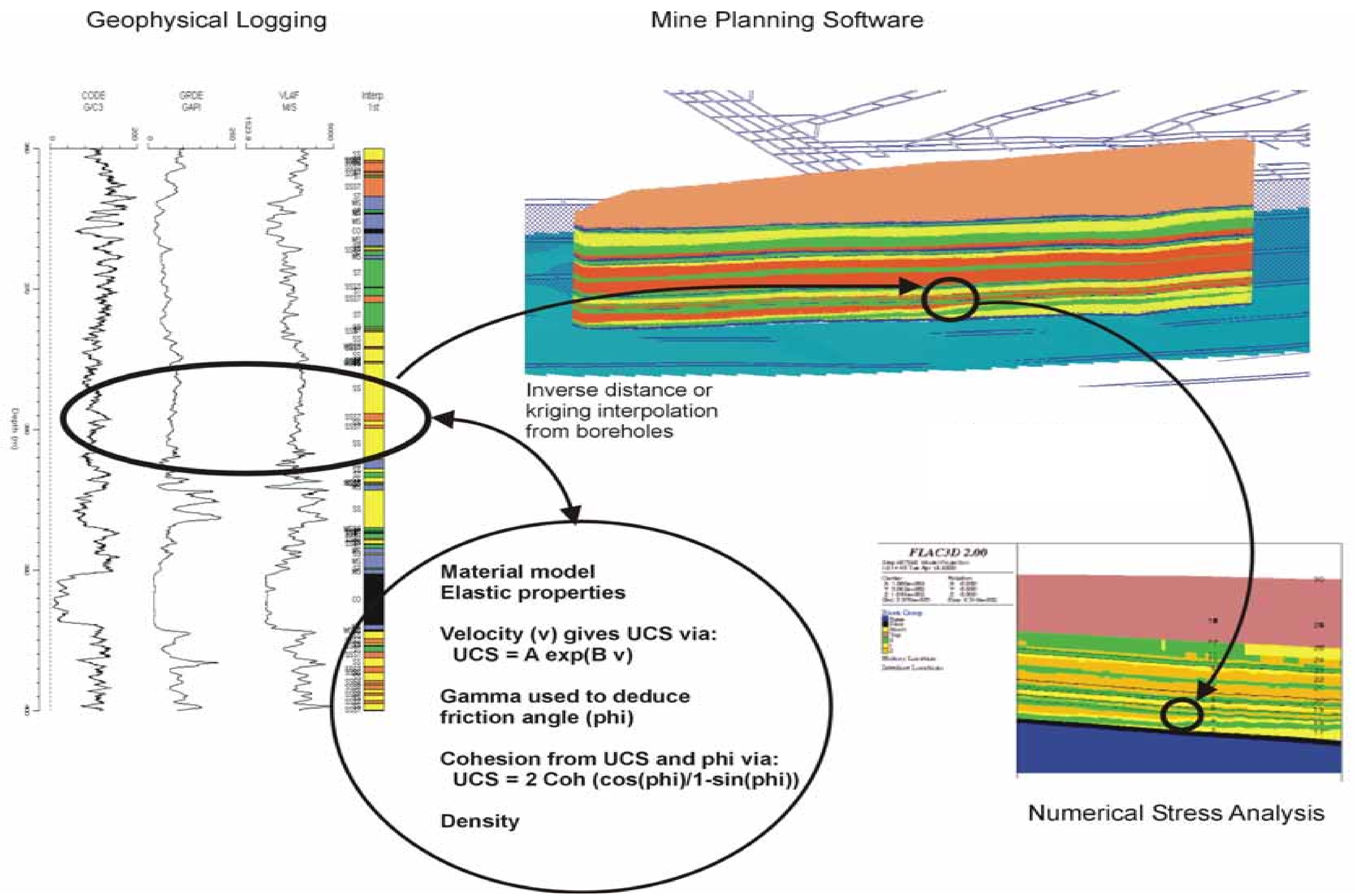
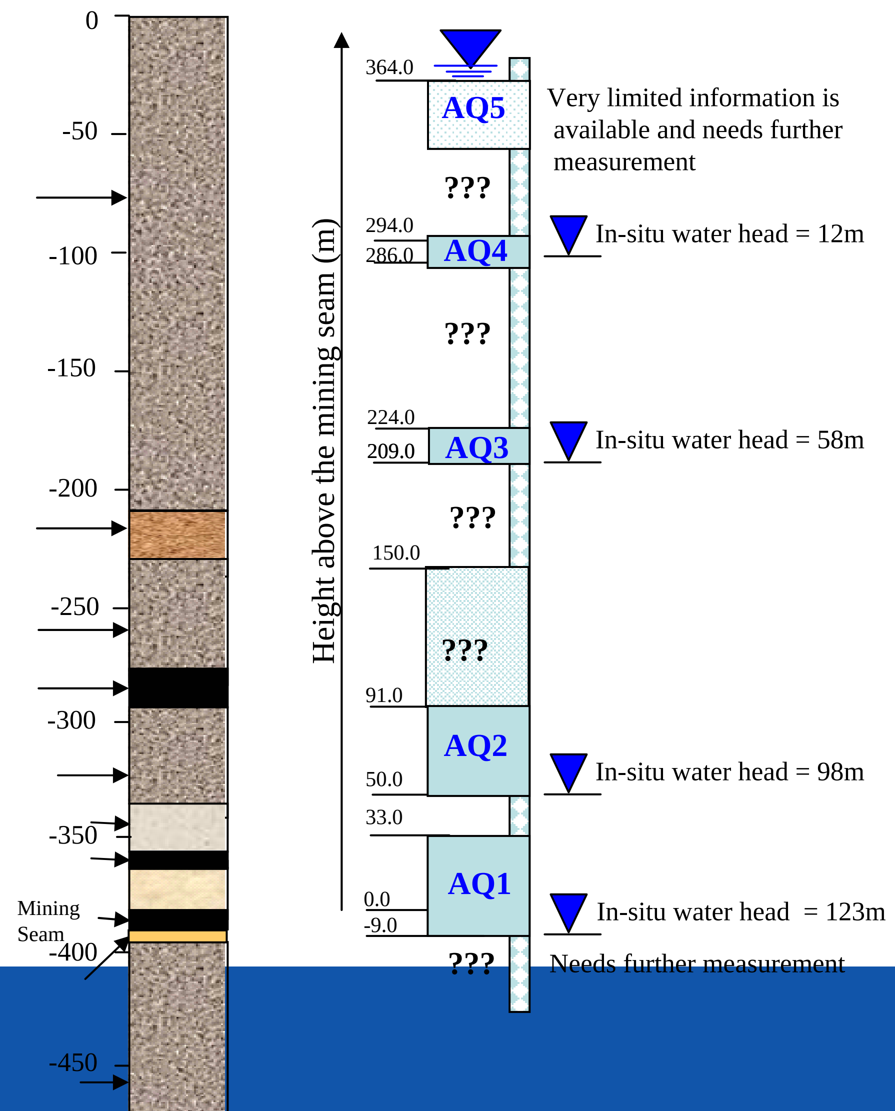
From Borehole to Numerical Model



Hydrogeology-Delineation of Aquifers

Within a mine lease (10Km X 10 KM)

26 PIEZOMETERS INSTALLED IN 10 DRILL HOLES



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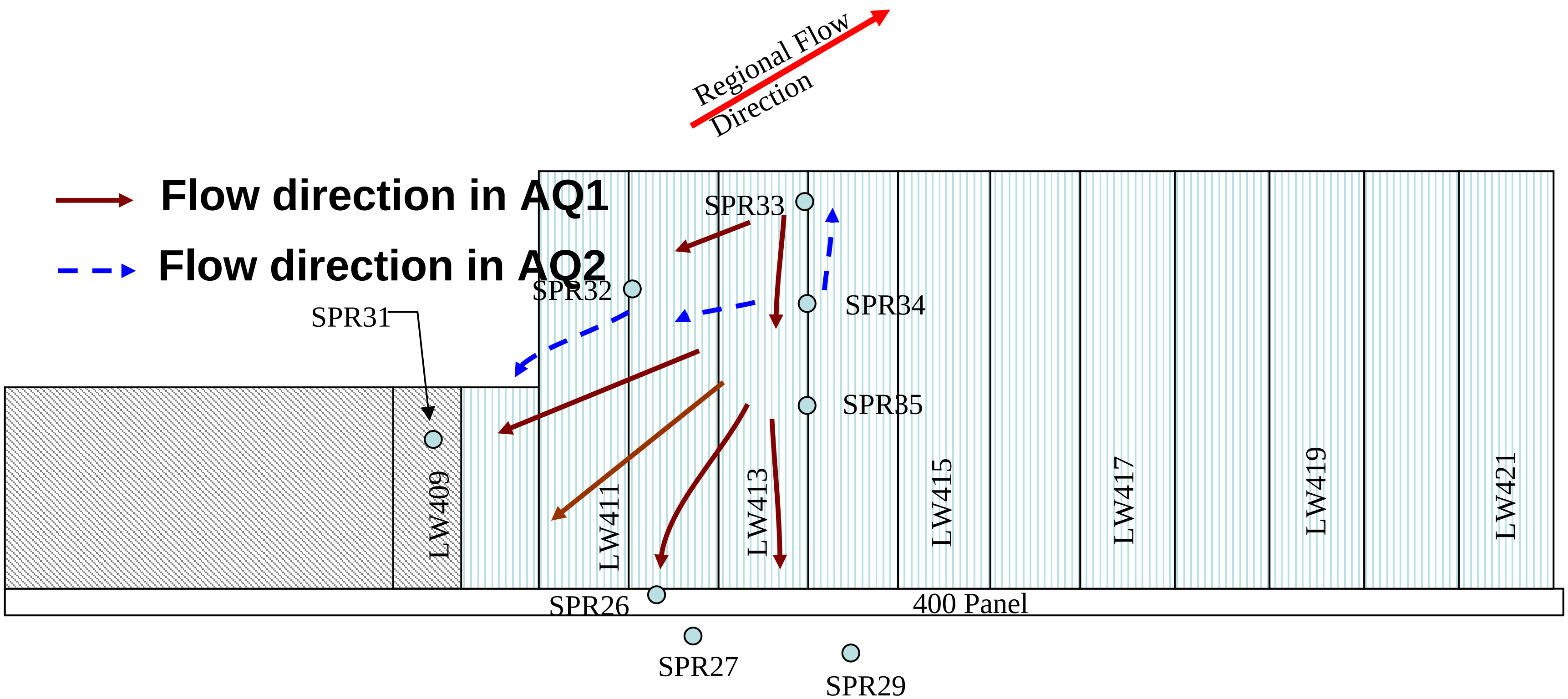
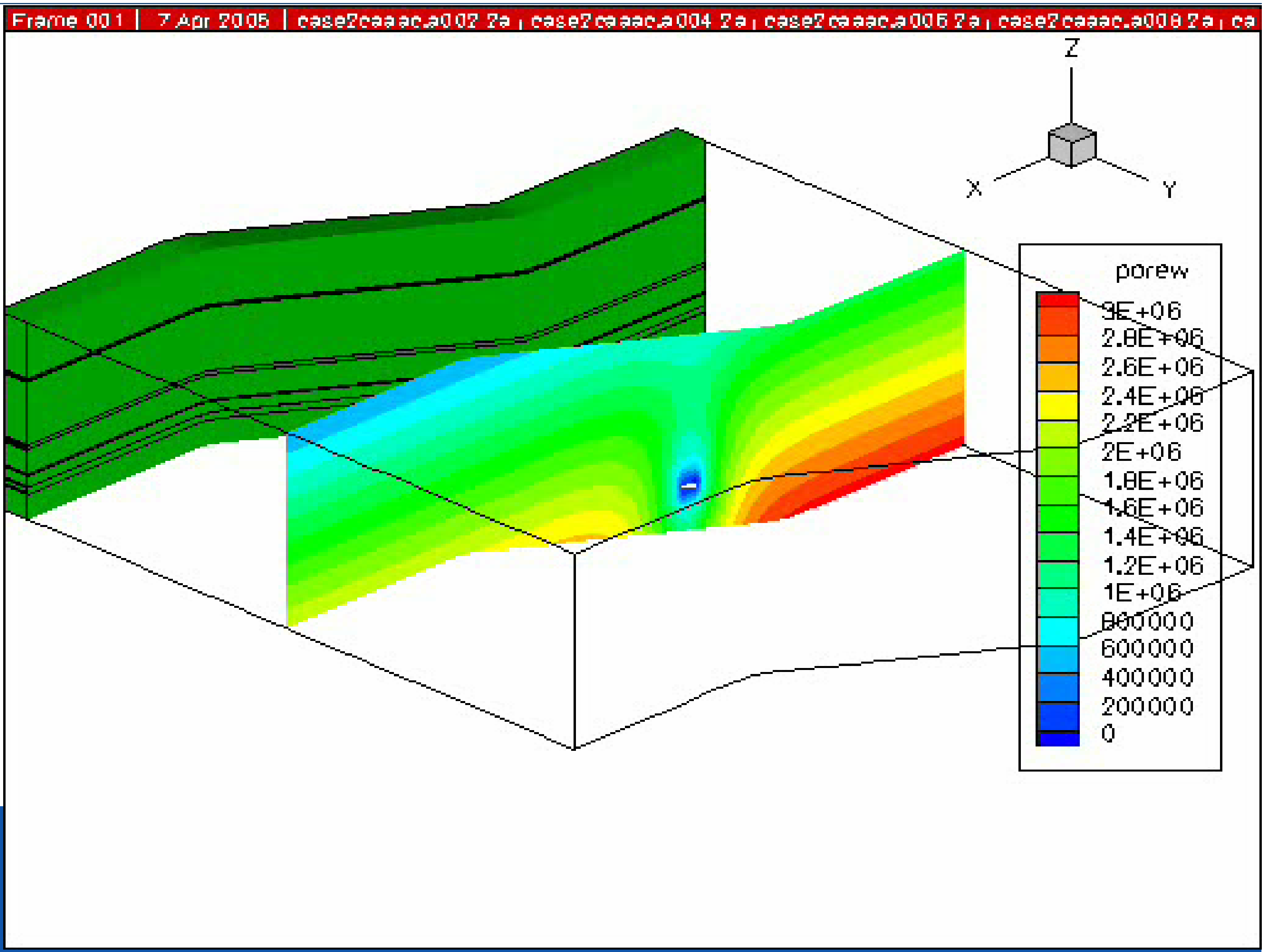
Local Flow Direction



Pore pressure over panel



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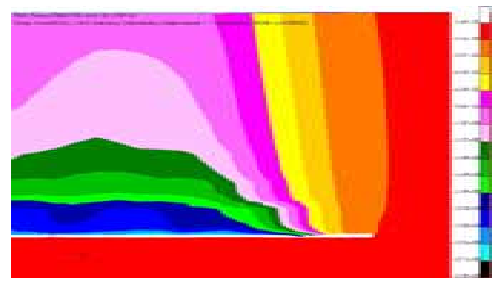
Numerical Modelling

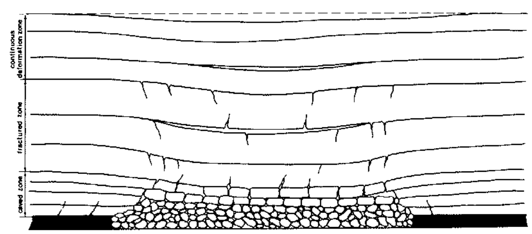
INTERACTION

Mining induced strata fracture/deformation



Vertical Displacement

Change in permeability and reservoir pressure



Change in effective stress

Caved, fractured and deformed zones

Ground Water Flow

Change in reservoir pressure and relative permeability

Gas diffusion and flow

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COSFLOW

COSFLOW is a coupled dual porosity two phase flow model developed with a specific objective of addressing the mine issues, such as ground deformation, water flow and gas emission

- Couples rock mechanics of layered strata with one or two phase compressible fluid flow
- Cosserat Continuum => efficient simulation of the deformation behaviour of stratified rock
- Estimates rock fracture induced changes in hydraulic properties (e.g. permeability and porosity)
- Simulates water and gas flow through fractured rock

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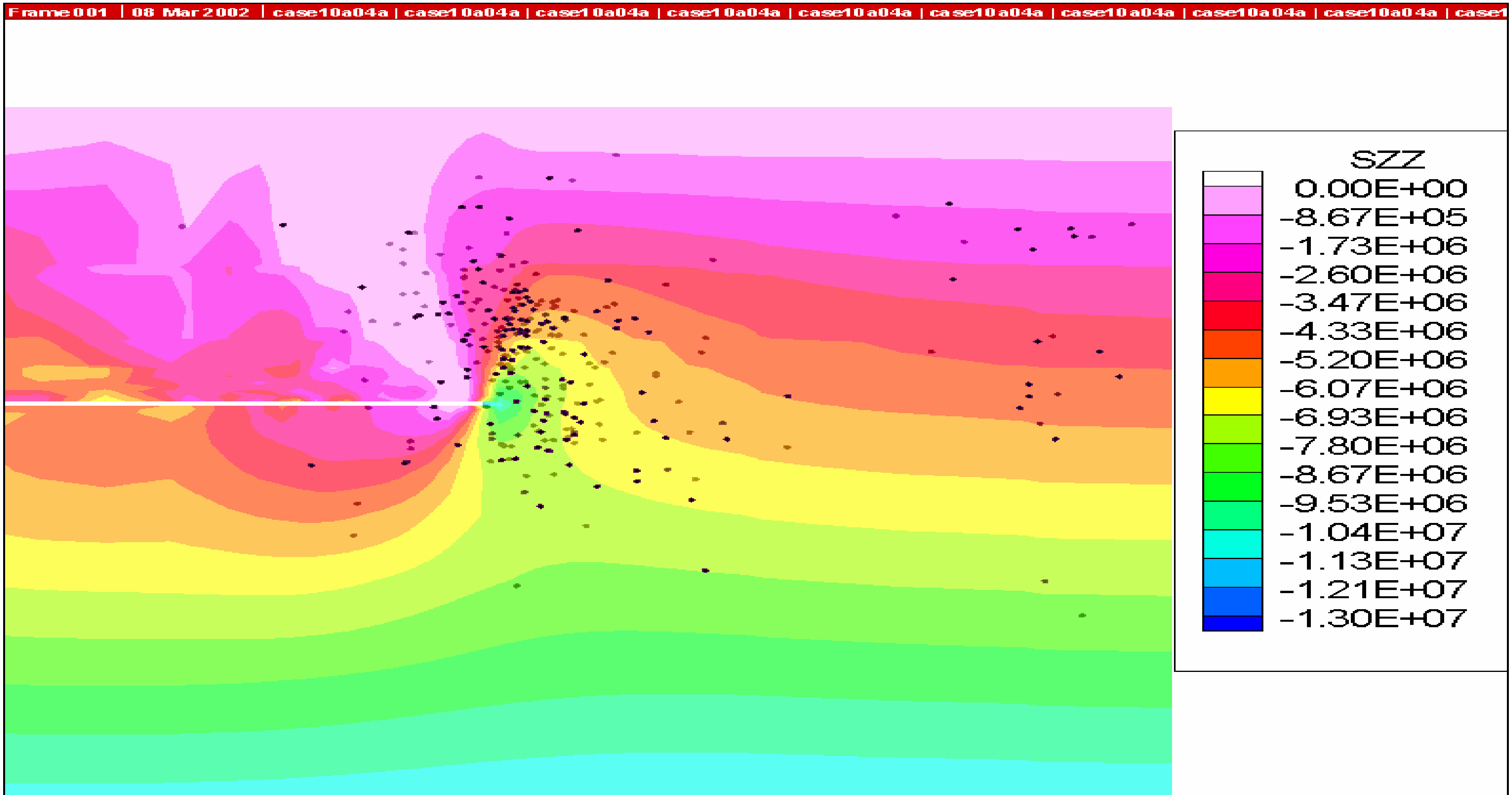
COSFLOW is a program developed
By CSIRO and JCOAL & NEDO

COSFLOW Application



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Modelled Vertical Stress & Microseismic data

COSFLOW Application

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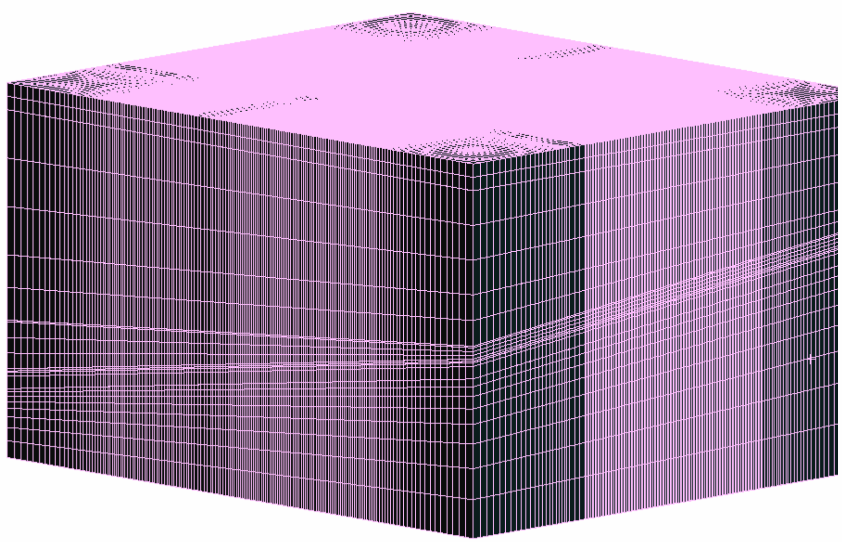
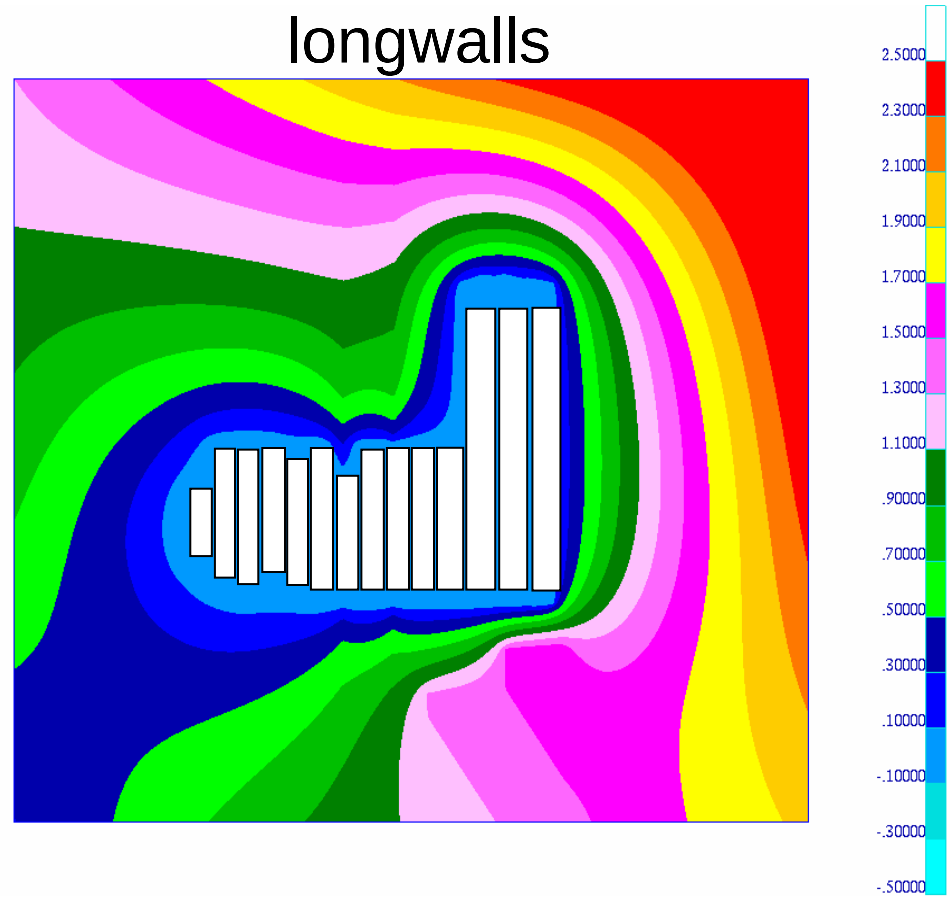
Vertical stress in a coal seam

COSFLOW Application

Hydrogeology



Pore pressure plots around longwalls



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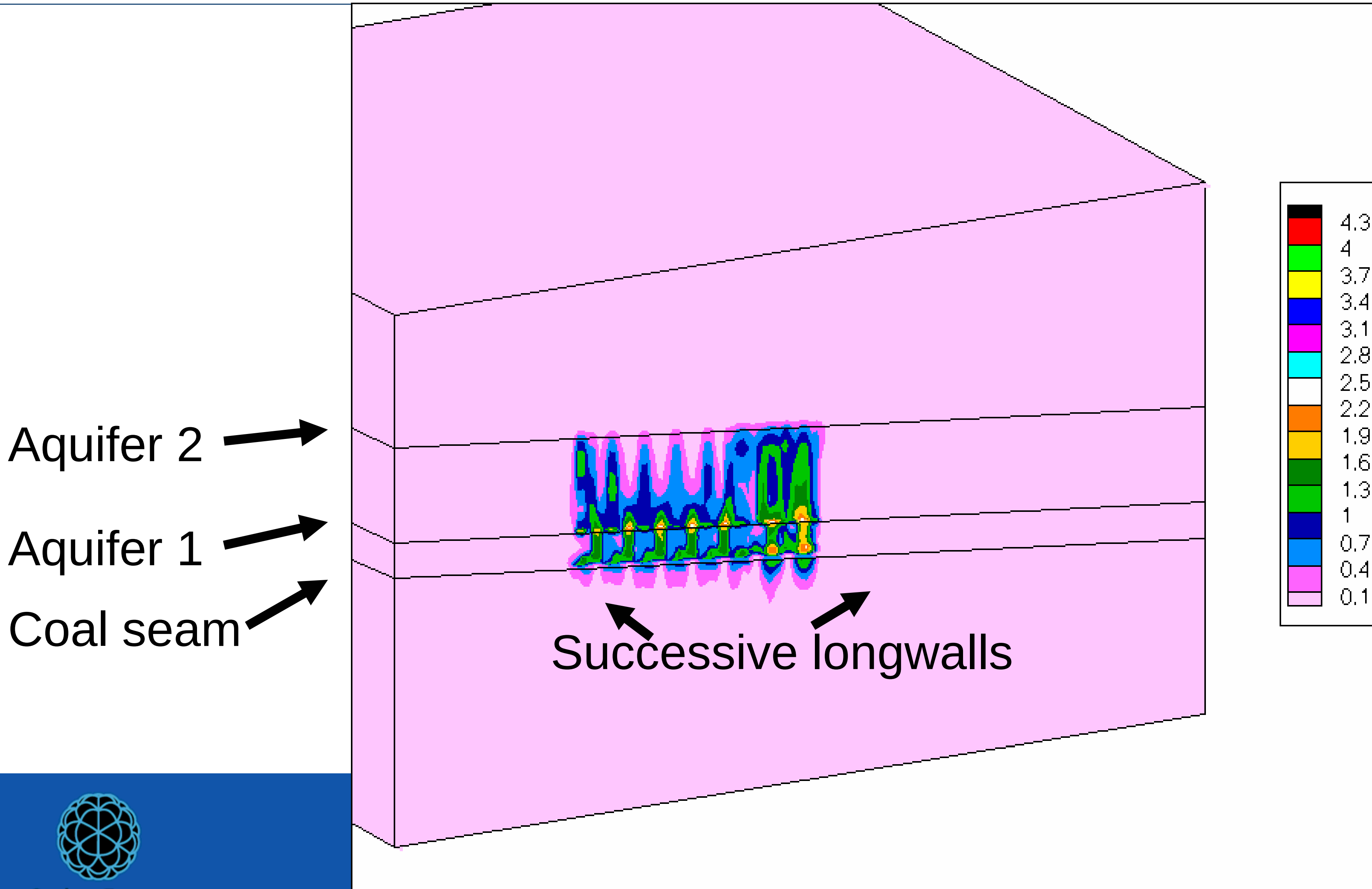
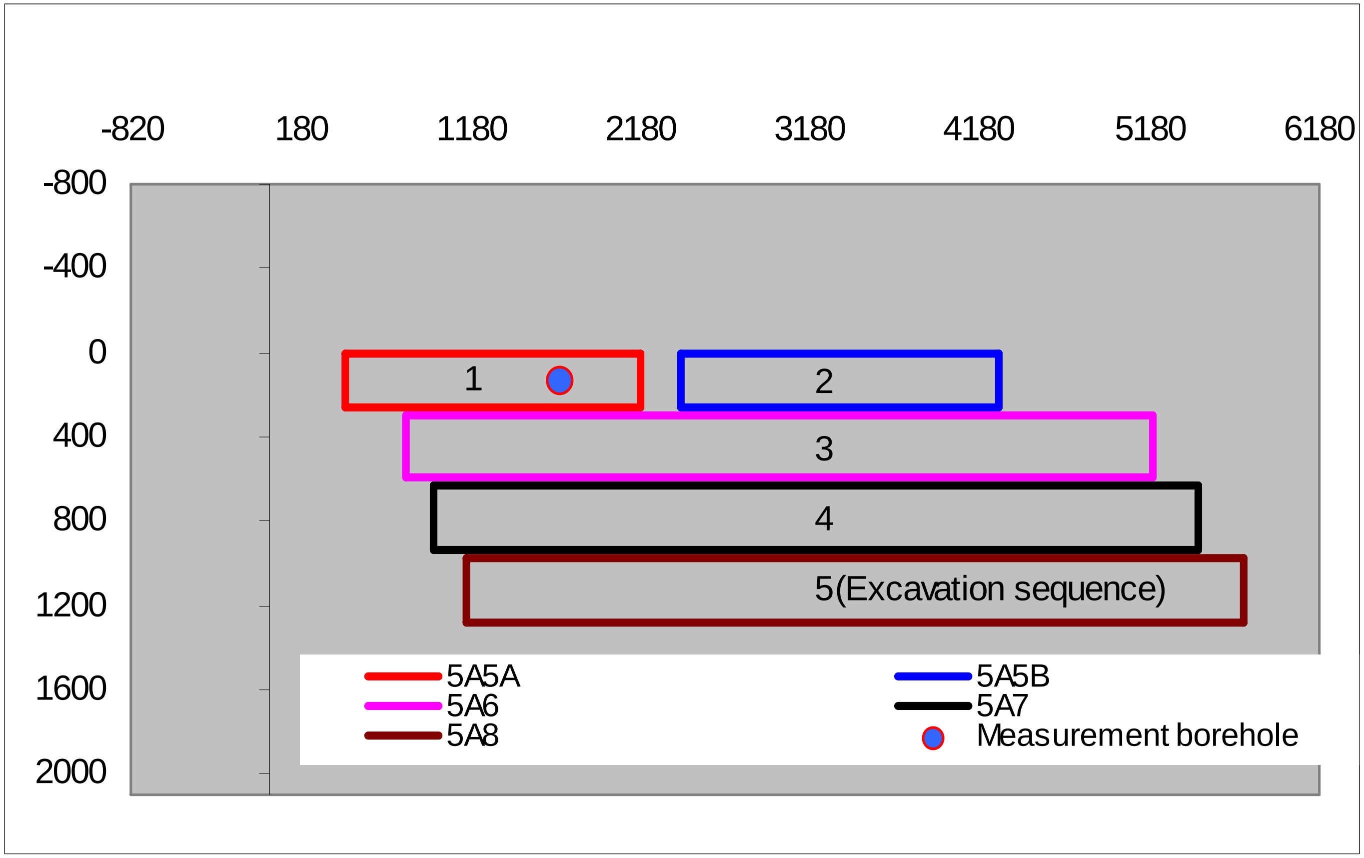
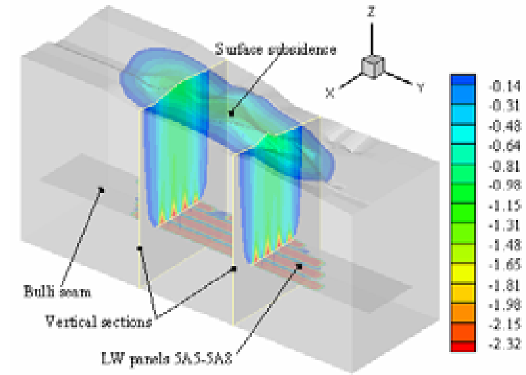
Predictions of mine water inflow made 2 years ago are are within 10% of actual inflow

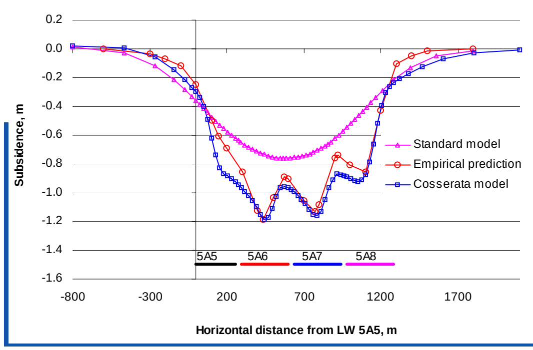
Permeability prediction



COSFLOW - Subsidence

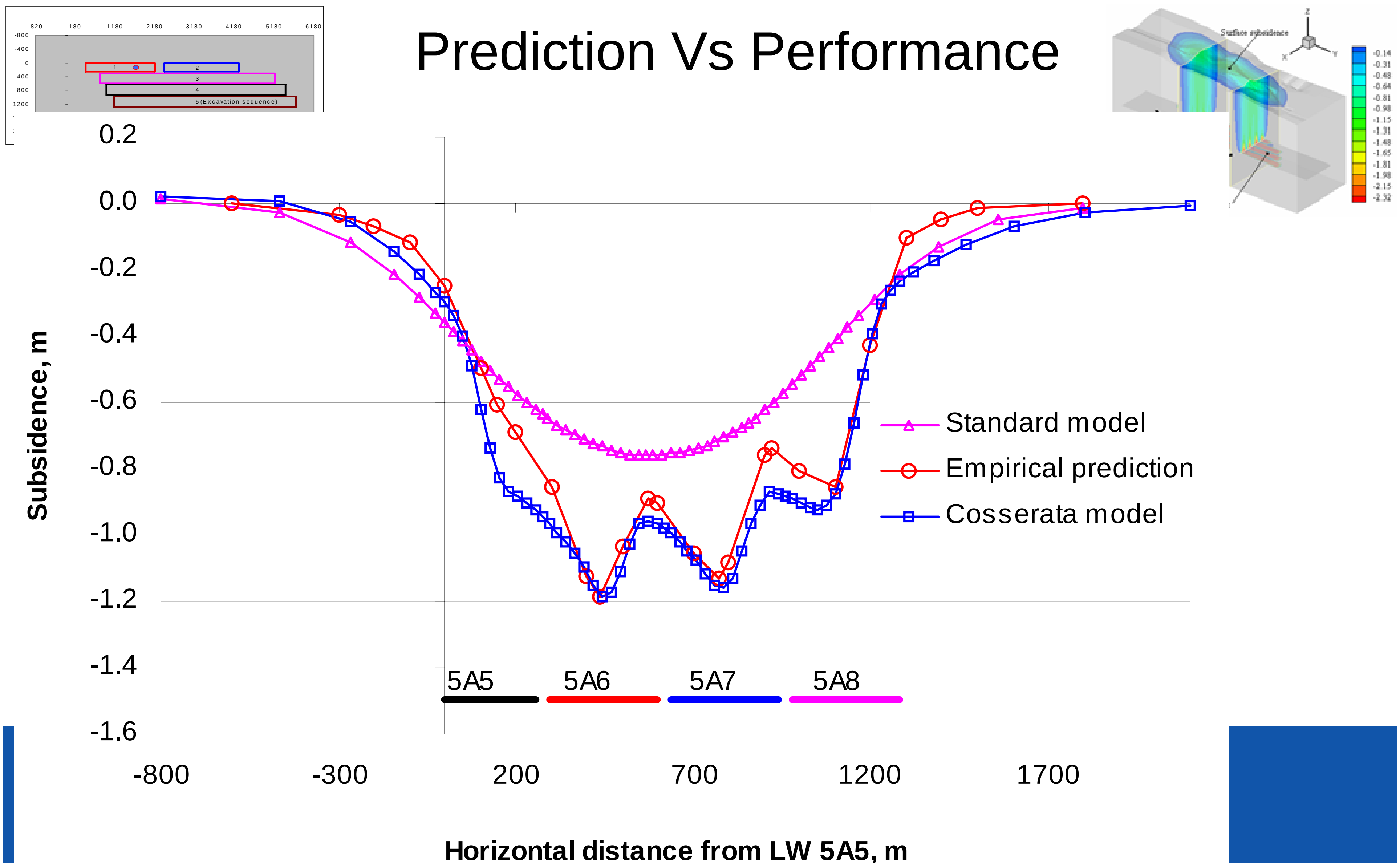




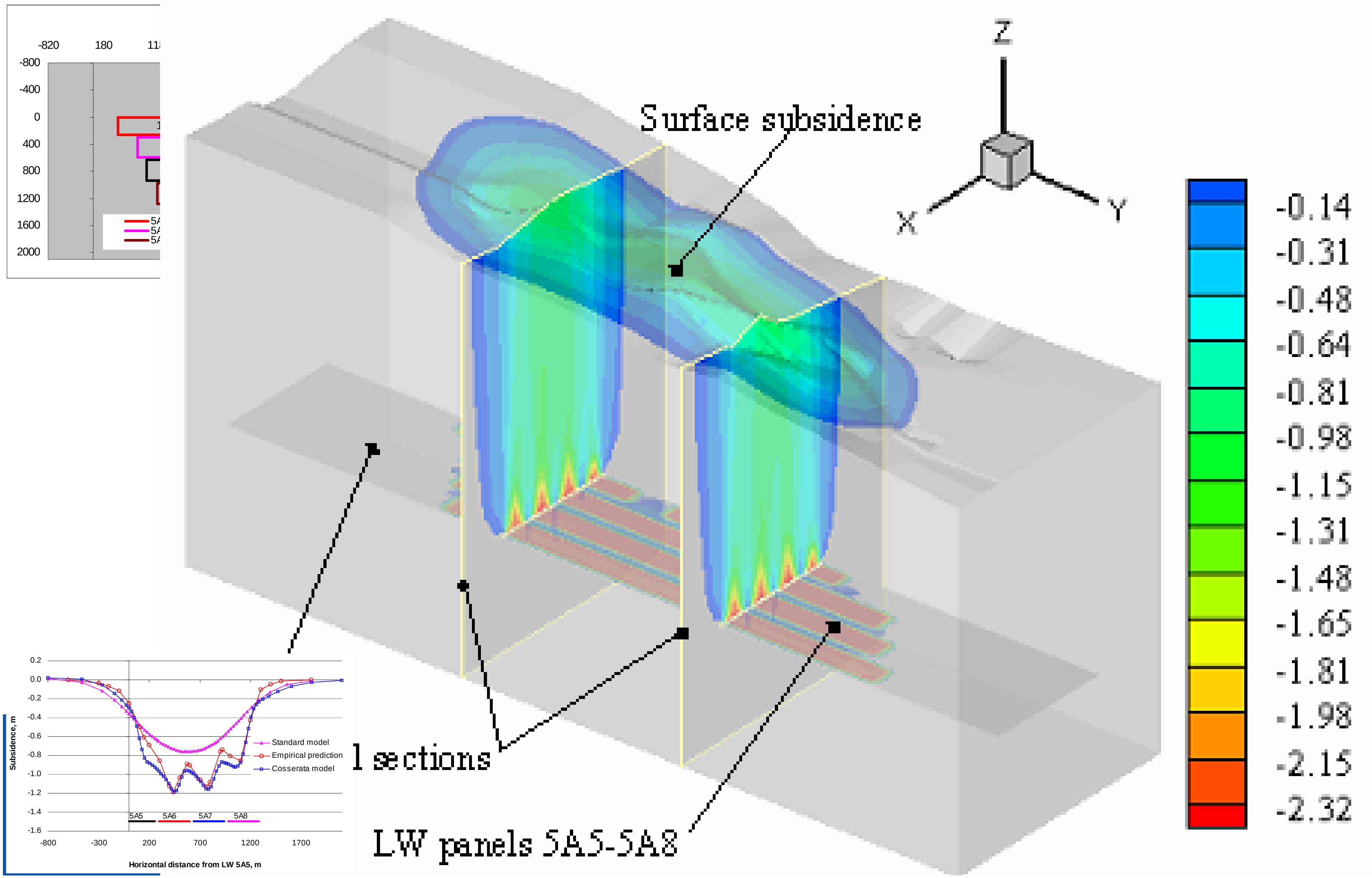


A sequence of longwall blocks

COSFLOW - Subsidence



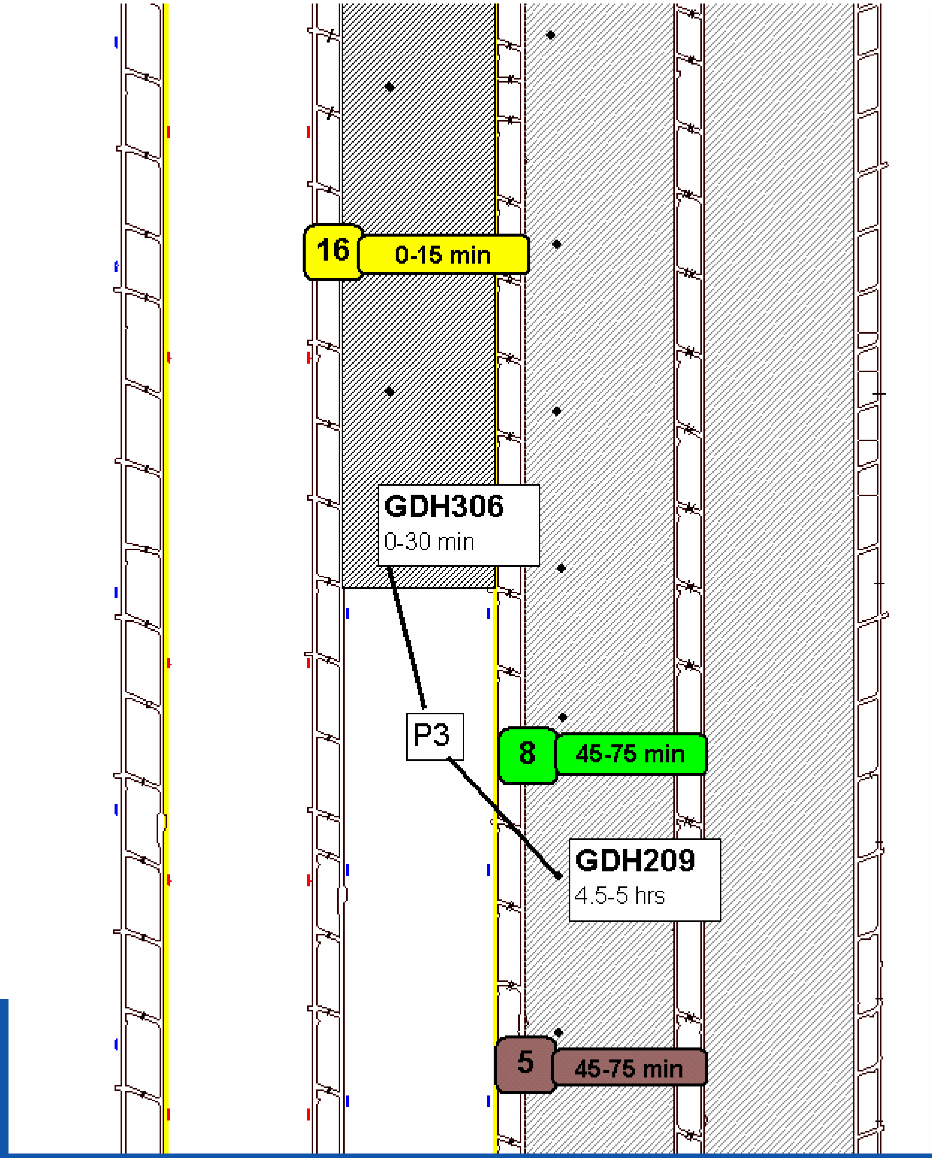
COSFLOW - Subsidence



Connectivity in Goafs

Tracer gas studies(1)

- Gas migration between adjacent longwall panels
- Longwall goaf – behaves as one system for gas
- Gas pressure and buoyancy effects – across all goafs



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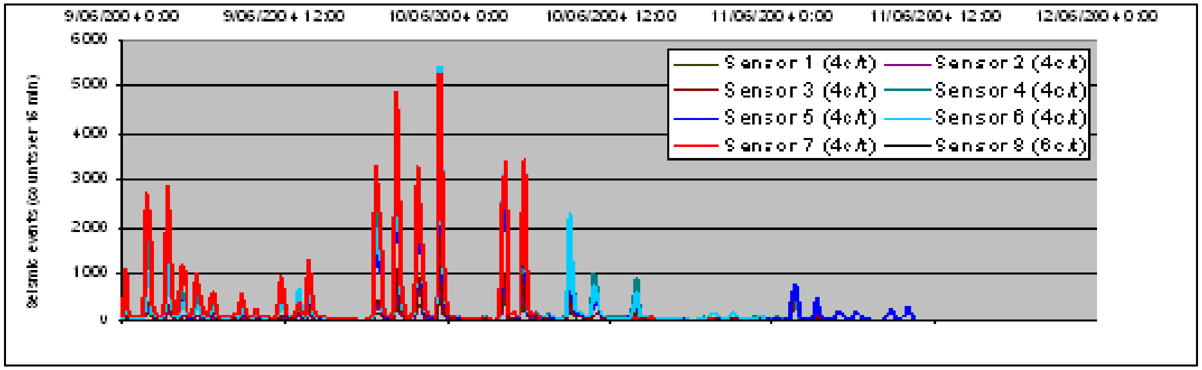
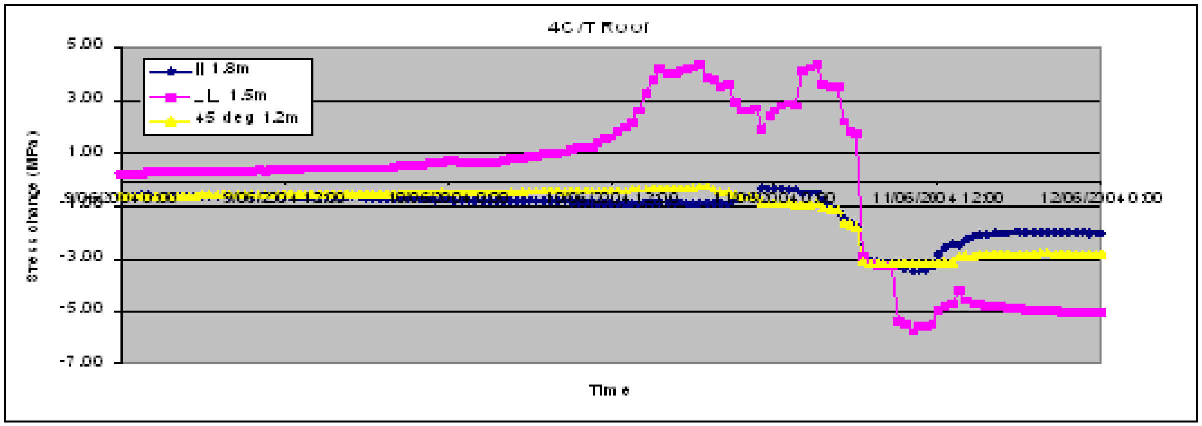
Managing Deformation Impacts

- Predict ahead
  - Reject area for UCG if unsuitable
  - Manage the issues
- Management plan for risks
  - Monitor insitu – know what is happening and have a planned response for all identified risks
  - stop activity if it causes problems
- Active mitigation
  - Specific operational procedures
  - Innovative practices

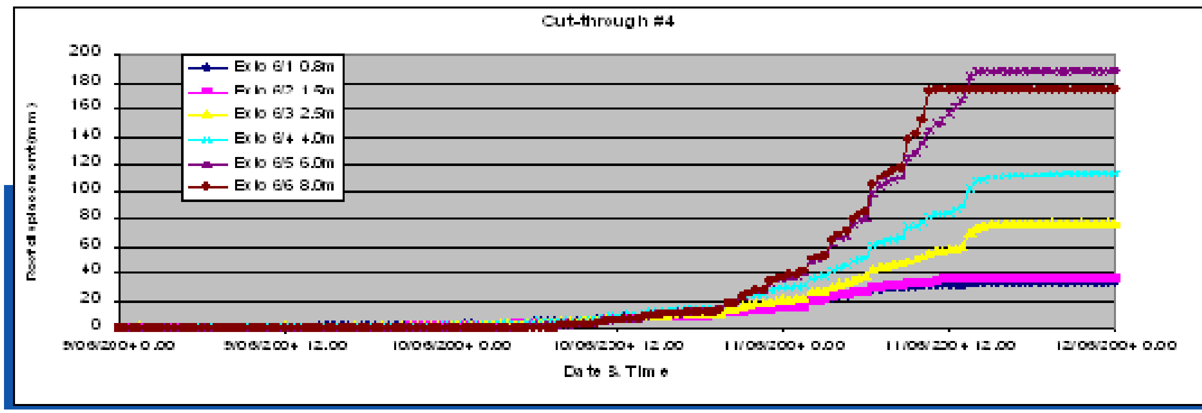
Geotechnical monitoring



Microseismic monitoring

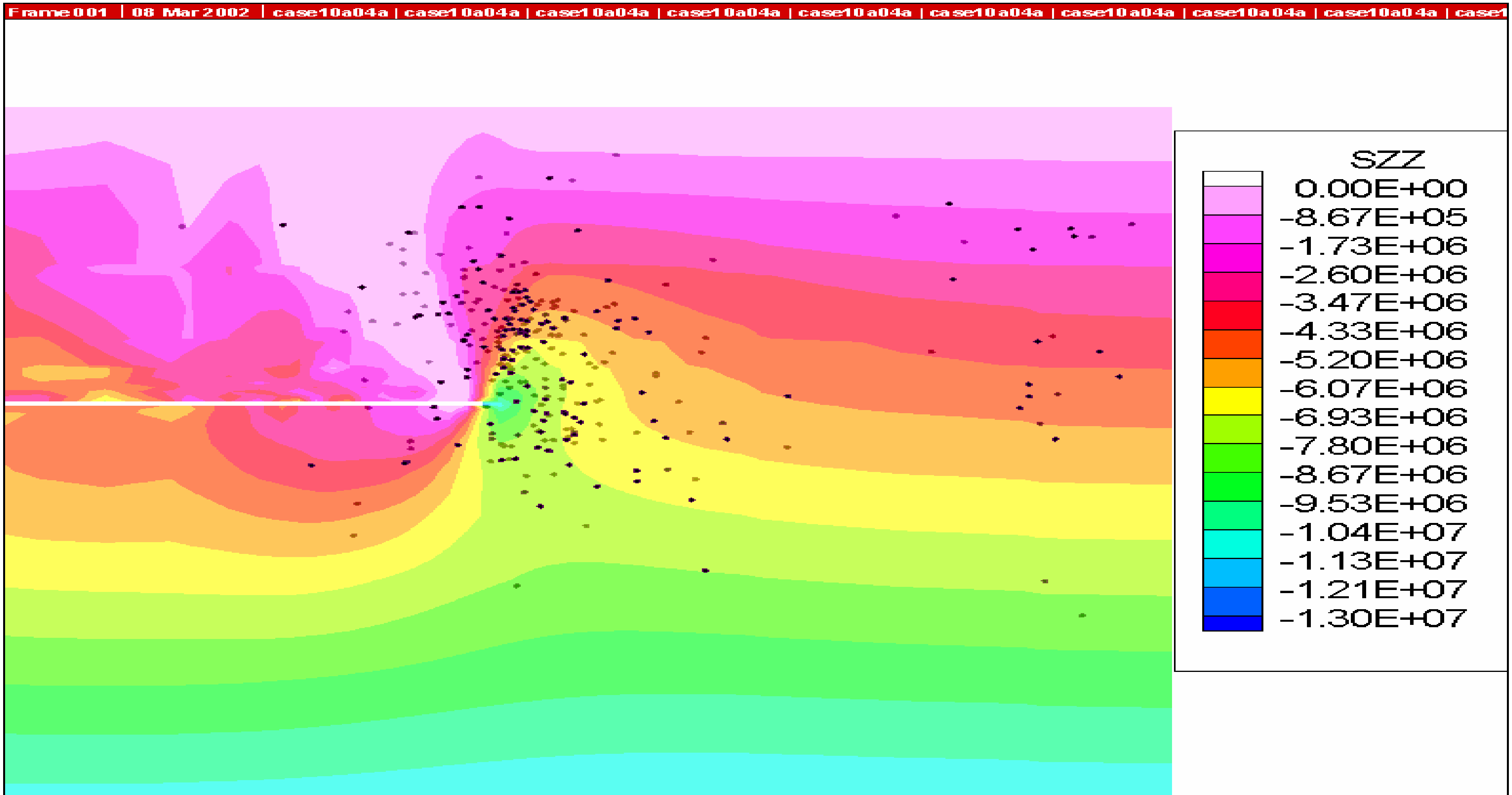


Stress monitoring



Displacement monitoring

Microseismic monitoring



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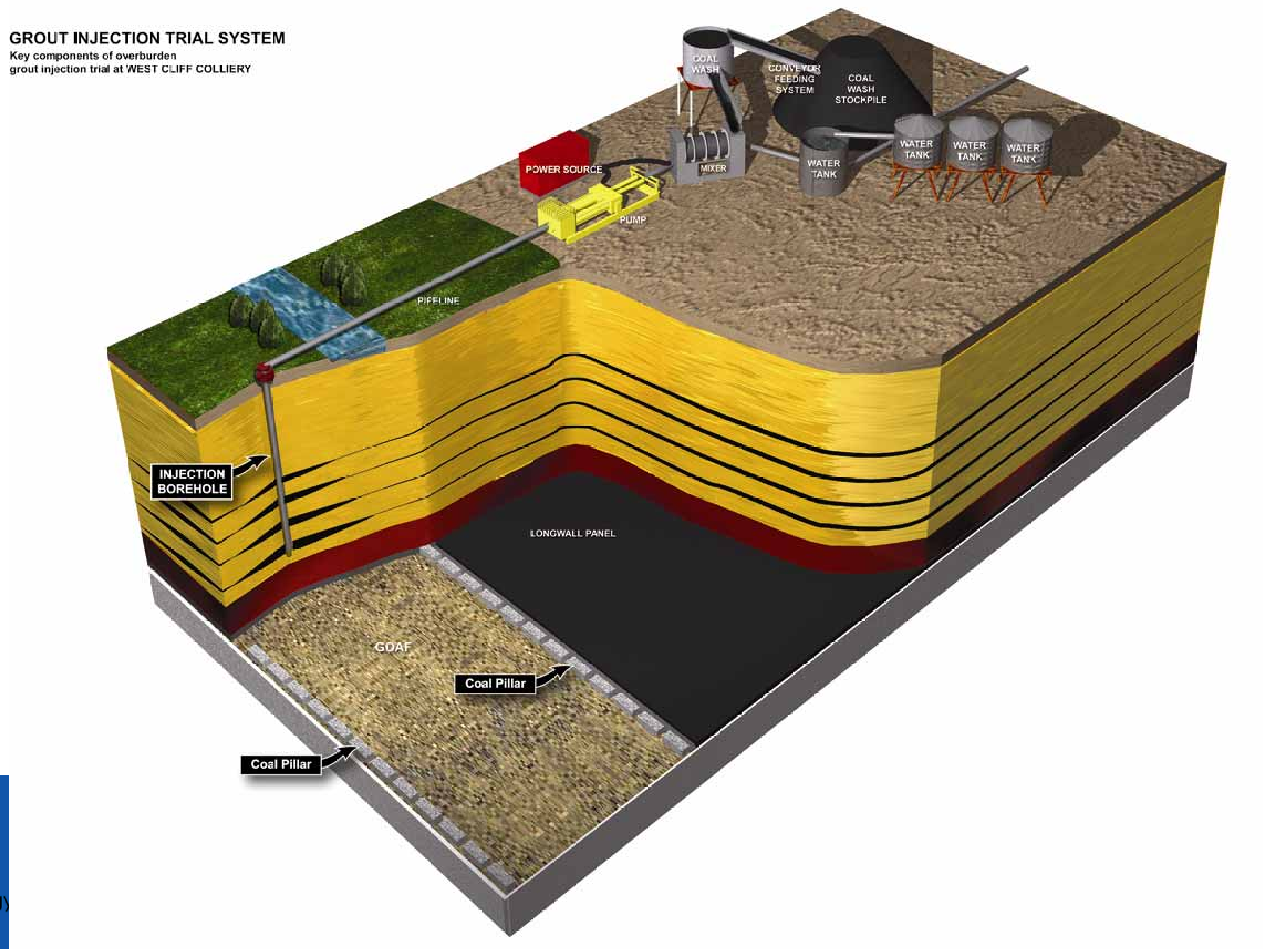
3D location of microseismic deformation events & burn front positioning

Subsidence mitigation



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