Modelling and simulation of stress in the submerged mine

Geoscience for a sustainable Earth
brgm

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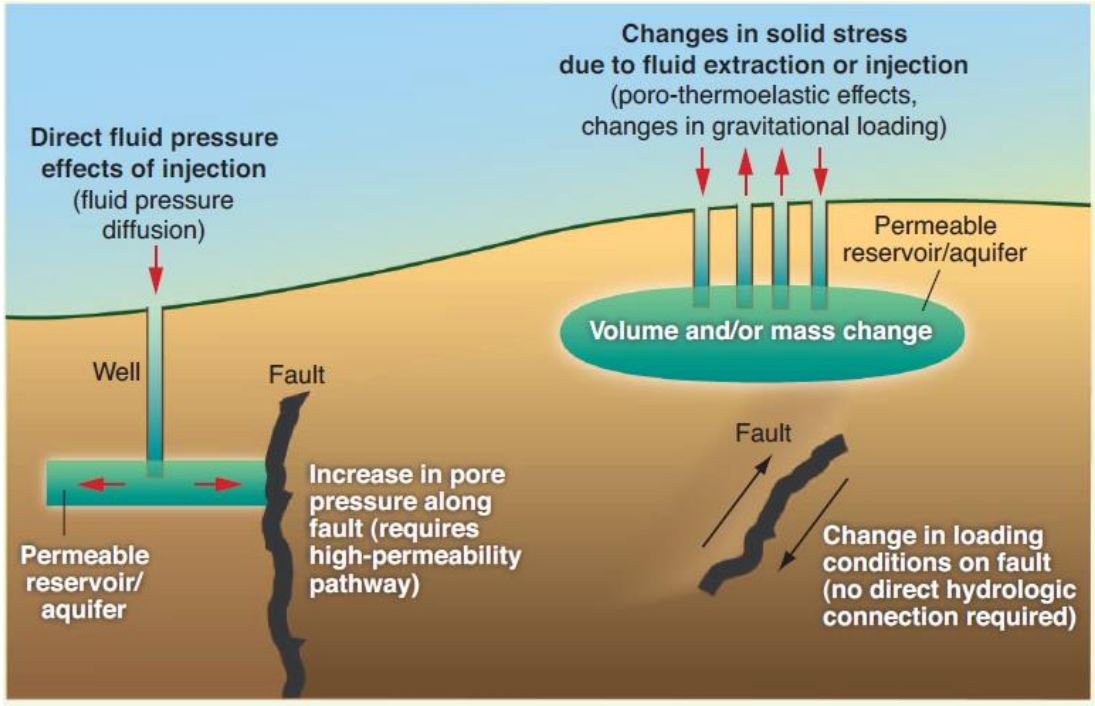
Introduction

Induced seismicity and mine closure

- Mine closure ➡ stop of water pumping ➡ flooding of the mine ➡ change in mechanical equilibrium of rock ➡ seismicity
- Two main mechanisms can lead to seismicity:
  - Due to ageing process accelerated by the water contact, the rock matrix can be weakened leading to a rupture of mine structures (such as pillars);
  - Due to change of pore pressure and volumetric changes, the existing geological discontinuities, such as faults and fractures, can be reactivated.

Introduction

Origin of induced seismicity related to hydromechanical perturbations



Ellsworth et al (2013)

Introduction

Importance of understanding the cause of seismicity

- If the origin of seismicity is known:
  - mitigation measure may be applied (water management);
  - better monitoring can be deployed: location of seismicity within the mine or on active faults.
- This work addresses only the scope of the second category of hazards, those linked to hydromechanical perturbations on faults/fractures because of fluid flows and water table variations within the geological vicinity of mines. Using numerical modelling, we investigate the possible sources of slip on faults.

Introduction

Numerical predictive simulations approach :

1. Establishment of **structural model** of abandoned mining site: integration of different data like geology, seismotectonic, numerical field model, and mining archive;
2. **Hydro-mechanical simulations** for explaining the seismicity triggering phenomenon: The results of these models (based on structural model) give an estimation for the shearing of the faults under stress modification and its time evolution;
3. Identifying **phenomenon key-parameters**: parameters that influence the seismicity of the sites, test on the influence of an increase in water level or decrease and of what order this variation must be to change the seismicity parameters, site independent parameters influencing the seismic behavior?

Sites studied

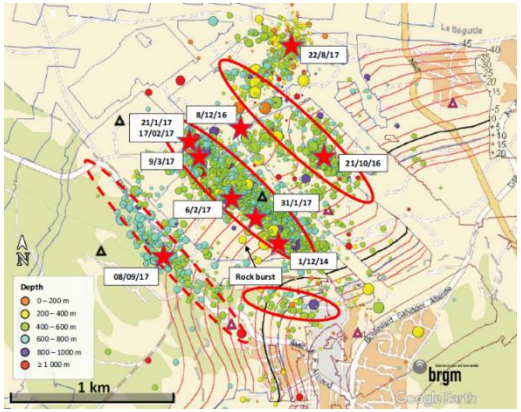
Gardanne (France), **Kazimierz-Juliusz** (Poland) & Petrvald (Czech Rep.)

Application example

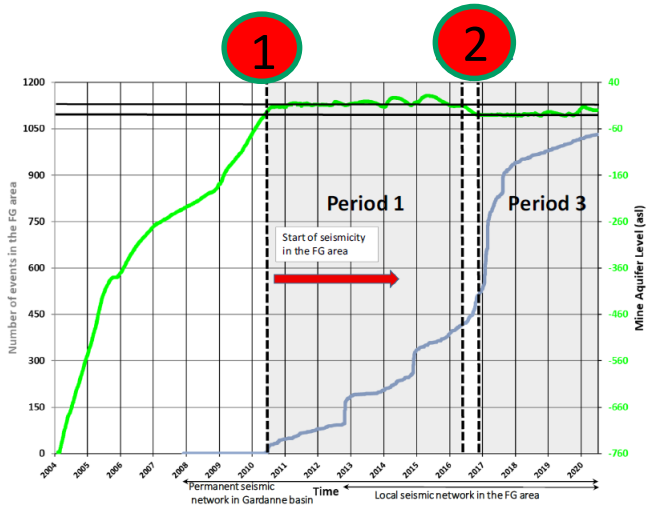
Gardanne

From structural model to numerical model at the scale of interest

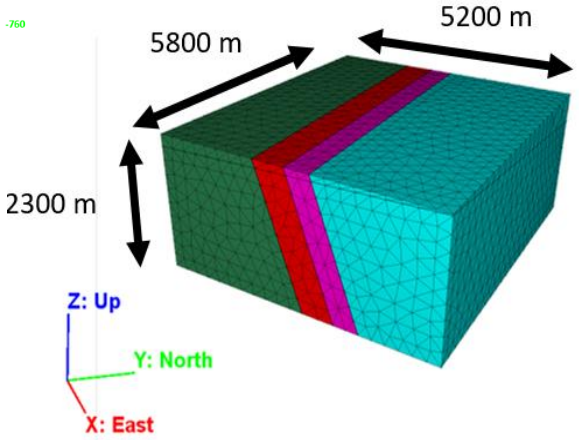
Dominique et al, 2022



Seismicity data



Flooding data

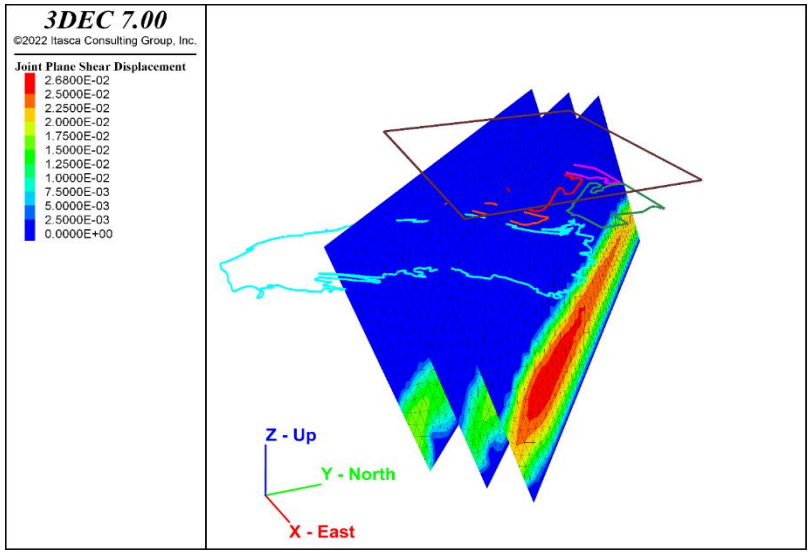


Scale of the 3D model
+
Seismic structures to take into account
+
Local tectonic stresses

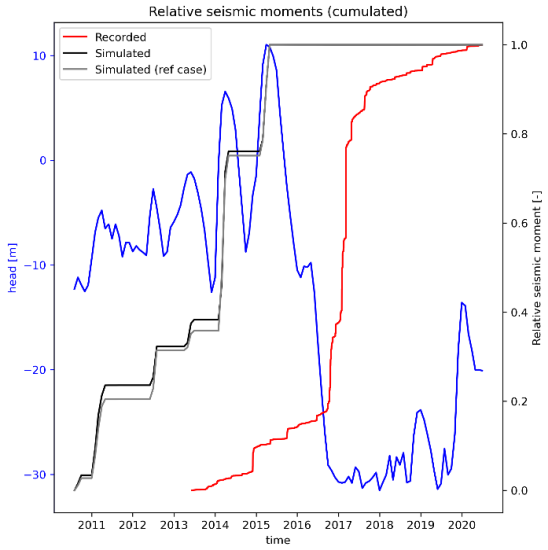
Application example

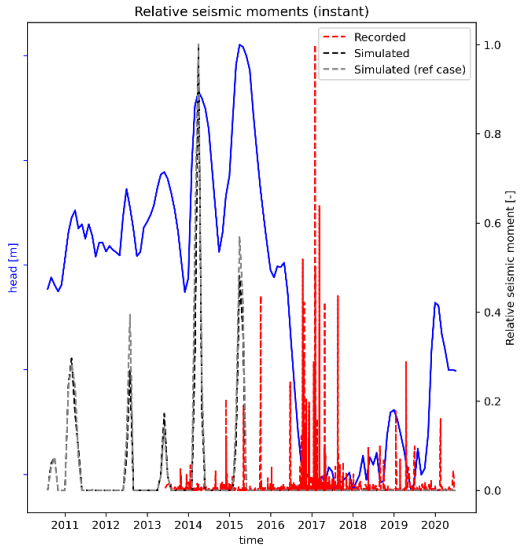
Gardanne: Effect of water table fluctuations

Shear displacement



Seismic moment



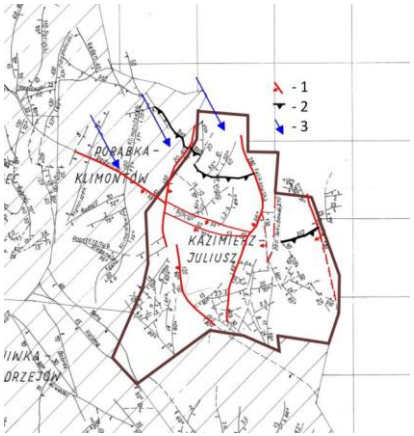


Application example

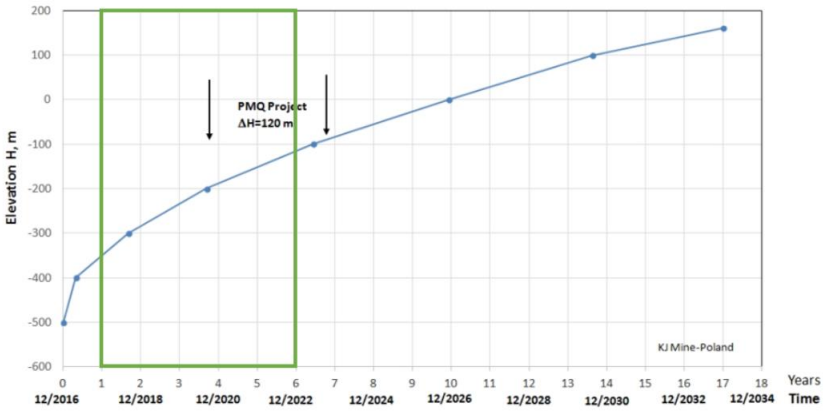
Kazimierz-Juliusz

From structural model to numerical model at the scale of interest

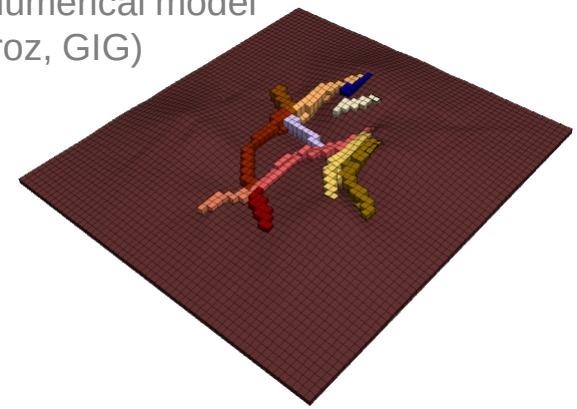
Structural data

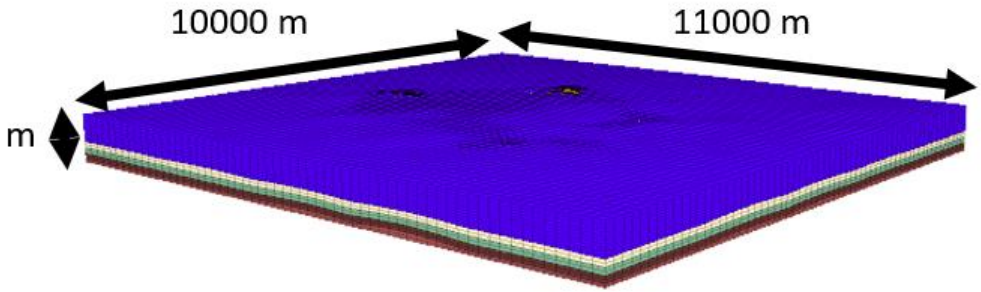


Predictive flooding data



Geometry of the numerical model (by Mateusz Jamroz, GIG)



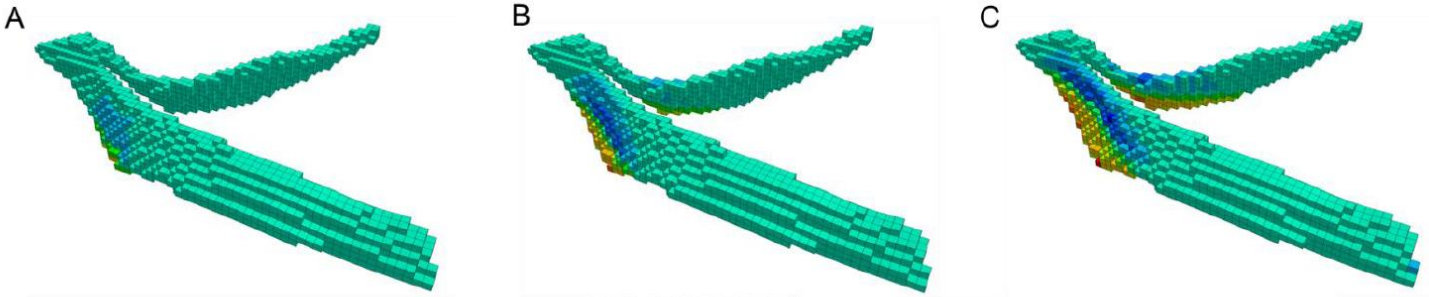


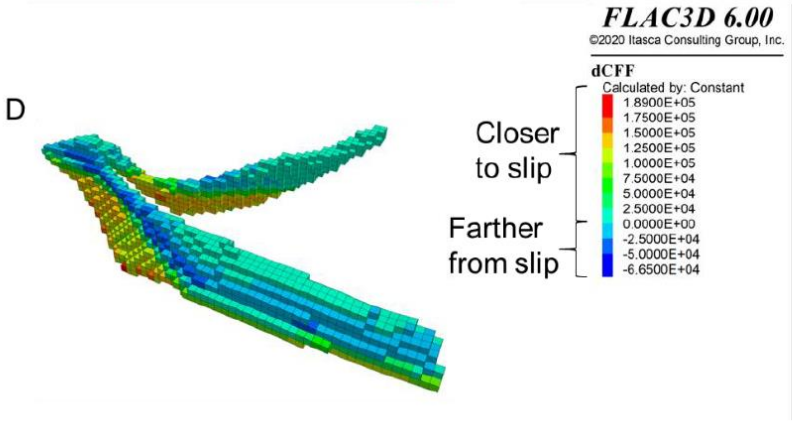
Application example

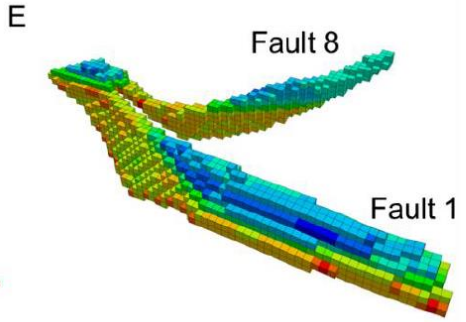
Kazimierz-Juliusz

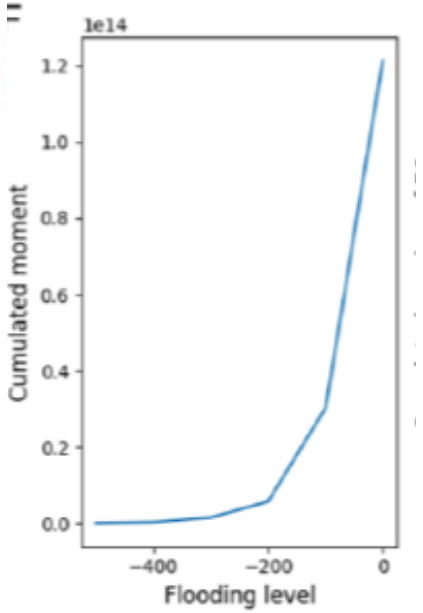
A B C D E

increase in flooding (flooding scenario)







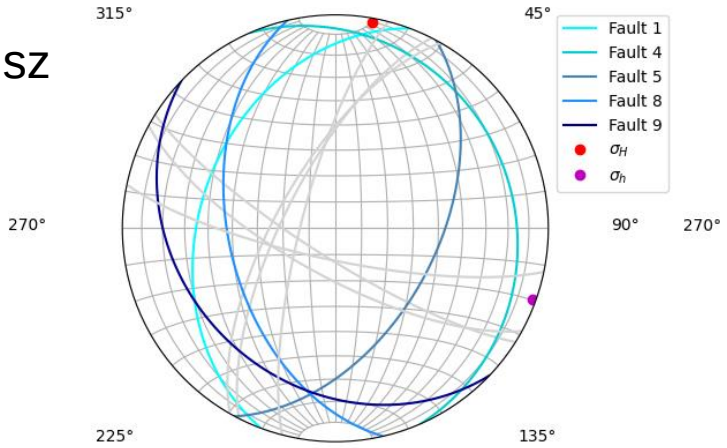


Application example

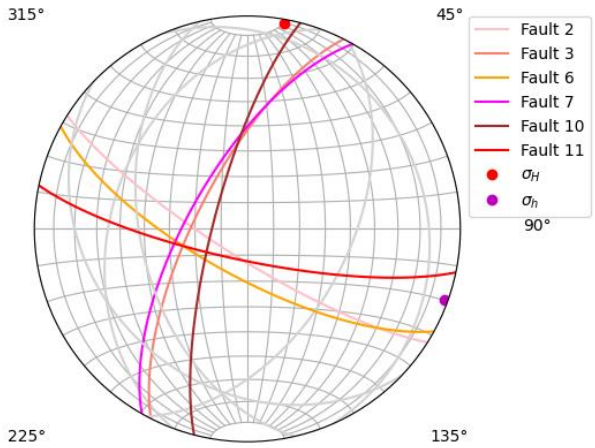
Key parameters

- From both sites studies, the simulations highlight major characteristics that can explain the triggering of seismicity during the flooding of abandoned mines (Kazimierz Juliusz) or during water table fluctuations in a flooded mine (Gardanne Fuveau). The key process**,** looks to be the increase of the pore pressure within the faults, these faults being in a specific mechanical loading state (with respect to their orientation and the local stress state).

Kazimierz-Juliusz



Slipping plane



Plane not slipping

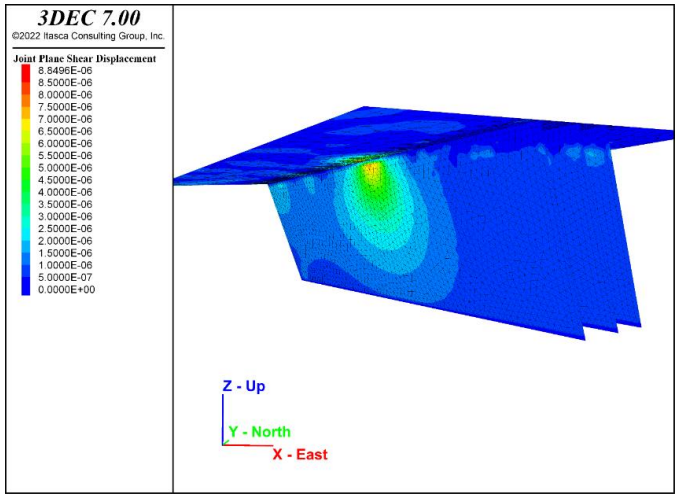
Application example

Key parameters

- In term of characterization : identify faults/fractures below and around mines and if or not they are hydraulically conductive.

Gardanne

Case of impermeable faults

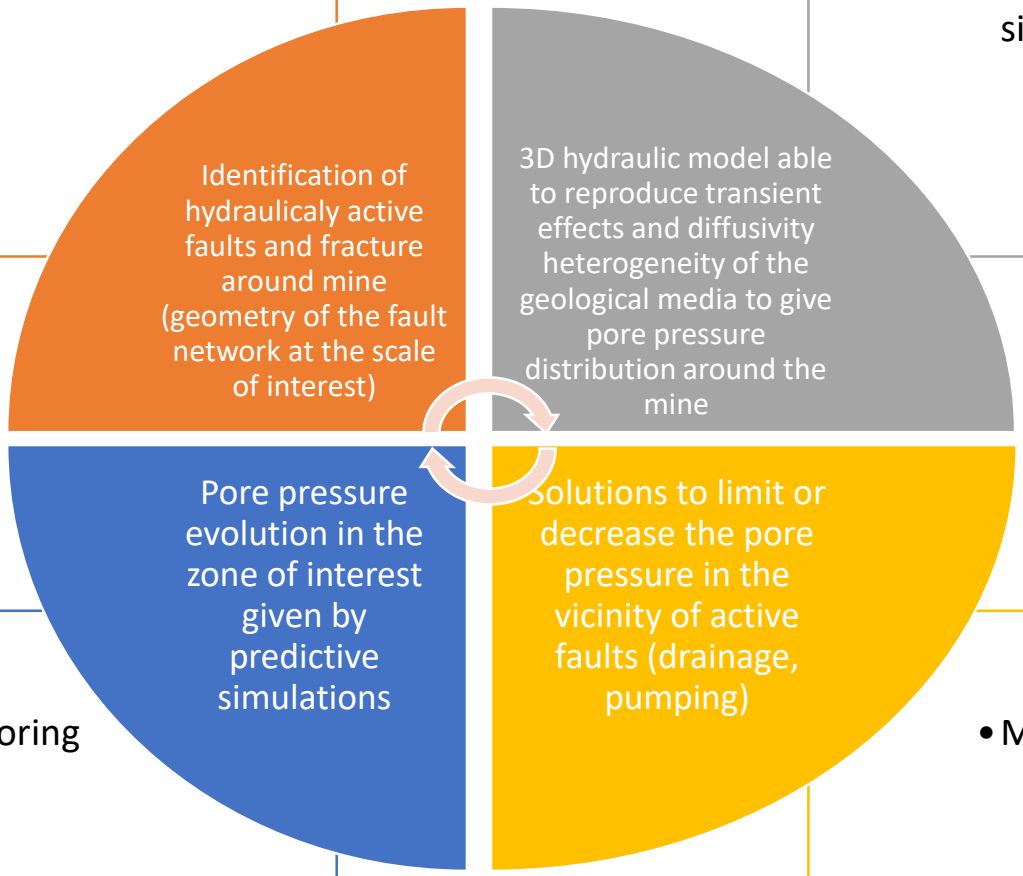


The Mohr Coulomb criterion is never reached during the whole hydraulic sequence.

- An important improvement of the models would be to impose heterogeneous distribution of pore pressure because of the heterogeneity of the rocks diffusivity and transient effects. This could be done by numerical simulations with a real 3d hydraulic model of the mining sites (such as Petrvald model).

Recommandations

- Characterization
- Predictive simulations



- Monitoring
- Mitigation

Recommandations

- The hydromechanical models should be updated if new information become available, related to the monitoring of seismicity for example.
- In practice, HM models should be realised before mine closure based on seismicity information acquired during the exploitation period.
- Key parameters must be extracted at this step and a monitoring protocol established, as well as recommendations on characterization and further modelling.

Conclusions

- Hydromechanical simulations have been made for two mining sites, Gardanne-Fuveau and Kazimierz Juliuz sites, to estimate the impact of flooding and water table fluctuations on the triggering of seismicity.
- For the Fuveau Gardanne site : we show the impact of the increase of the pore pressure variations because of water table fluctuations in the triggering of seismic events. Nevertheless, the model shows a limit in its ability to reproduce the recorded seismic events when the water table goes down.

Conclusions

- For the Kazimierz Juliuz site, simulations have been focused on the flooding phase of the mine. From these simulations, it appears that the major characteristics acting on the triggering of seismicity are the mechanical loading state of faults, the permeability of faults and the pore pressure impact due to water level increase.
- From these simulations, generic recommendations in terms of numerical models have been established to better predict seismicity related to loading state of existing/assumed faults near mines and its variation due to hydraulic changes because of flooding and water level fluctuations. These recommendations shall be considered in light of the hypotheses, limits and needed improvements of the numerical models (3D hydraulic model).

Thank you

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