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Numerical Modelling to Explain Flooding Induced Seismicity in the Ruhr Area Germany

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Introduction

The Ruhr region (Fig. 1) has a long history of intensive coal mining, with excavation depths exceeding 1000 meters. During mining operations, groundwater was continuously pumped to maintain low water levels within the mines. Seismic activity at the Heinrich Robert colliery was recorded by a local temporary seismic network, capturing data both during active mining and the subsequent flooding phase that began in 2019 (Rische et al., 2023). As part of the FloodRisk project, a relative earthquake localization approach was implemented to minimize location uncertainties (Niederhuber et al., subm., 2025).

Additionally, a 3D geomechanical model was developed to support stress arching mechanisms as explanation for the spatial distribution of seismic events.

Observations

- In total > 2500 microseismic events between -0.9 to 2.6 ML were observed in the flooding phase from 2019 to 2024 by a temporal network of 30 short-period seismometers (Fig. 2)
- Relocalization reduced the spatial uncertainty to less than 100 m for 630 events.
- Main activity occurs in the Southern part of Heinrich Robert in depths between 1200 and 1500 m (Fig.1)
- Clustering of events in pillars between the mined panels
- Mine water monitoring in open shafts by RAG

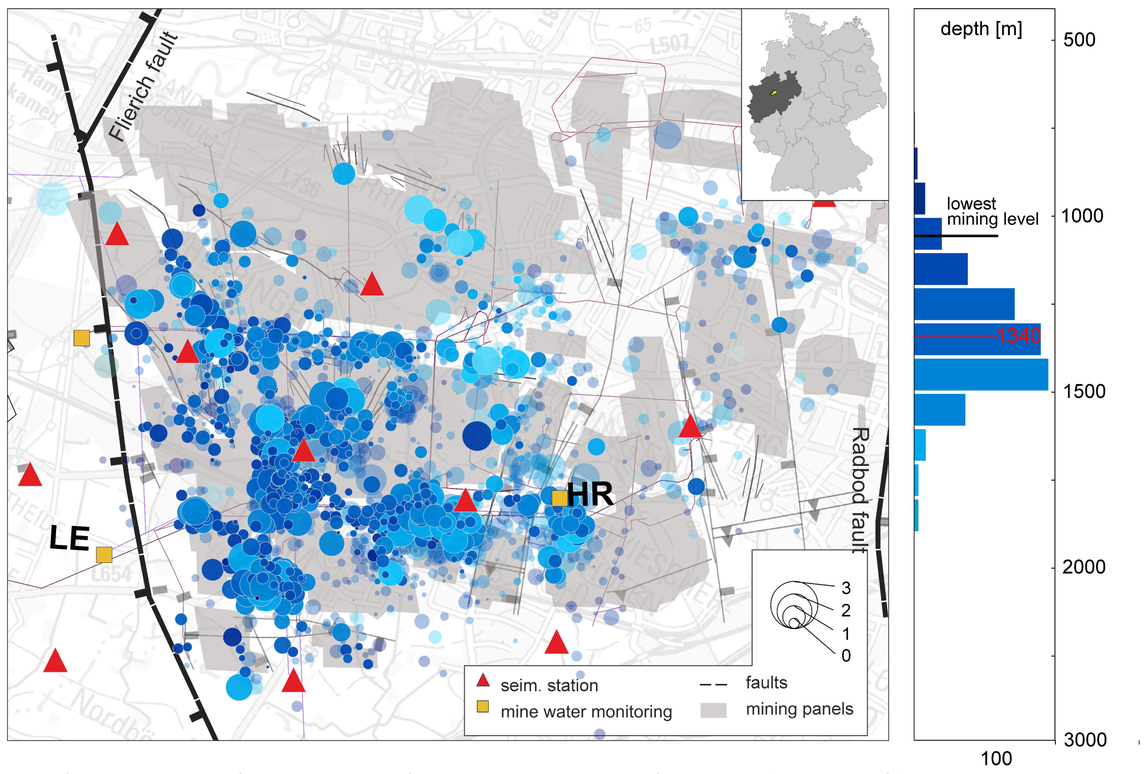

Fig. 1: Spatial distribution of microseismicity before relocalization. The inset figure shows the location of the water province Haus Aden of the Ruhr region in Germany. The study area is located in the NE of the water province. The histogram shows the depth distribution of the recorded events.

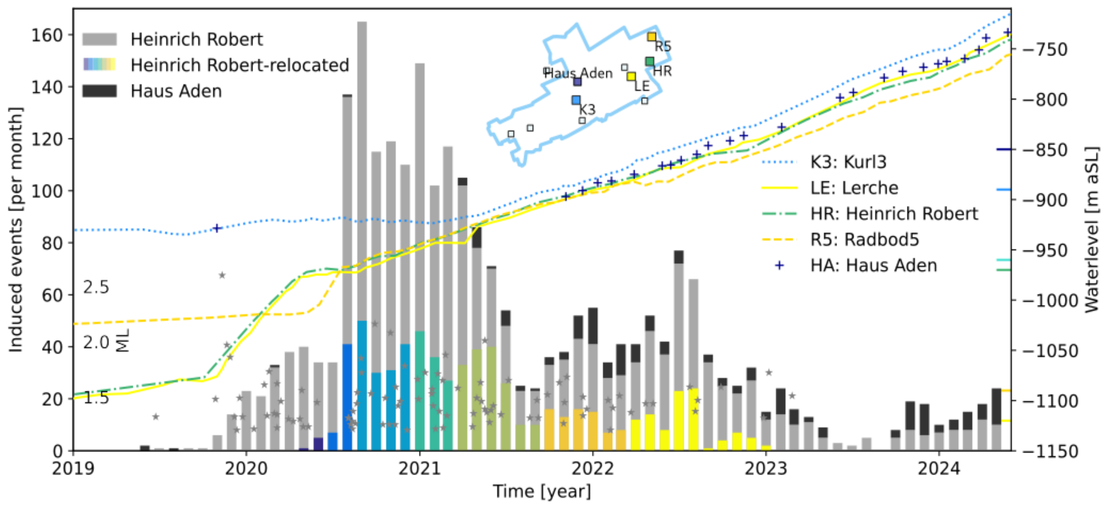

Fig. 2: Temporal distribution of microseismicity in comparison with water levels for different collieries in the Haus Aden water province. Colored bars stand for relocalized events per month. Grey and black bars show the total set. Colored lines show the rise in the mine water level in various shafts of the mine. Stars mark the events with $M_L > 1.2$

References:

Rische, M., Fischer, K. D., & Friederich, W. (2022). FloodRisk–Induced seismicity by mine flooding–Observation, characterisation and relation to mine water rise in the eastern Ruhr area (Germany). Journal of Applied & Regional Geology/Zeitschrift der Deutschen Gesellschaft für Geowissenschaften (ZDGG), 173(4).

Niederhuber, T., Rische, M., Müller, B., Röckel, T., Allgaier, F., Fischer, K., Schilling, F., Friederich, W. Geomechanics of Flooding-Induced Microseismicity – A Case Study from the Ruhr Coal Mining District in Germany (in review)

Stress Concentrations and Reactivation Potential

Numerical geomechanical models were developed including the distribution and thickness of the mined panels. For the final flooding level of -600 m the likelihood of fault reactivation has been calculated as DMF (distance Mohr Circle to Failure envelope) based on the modelled stresses.

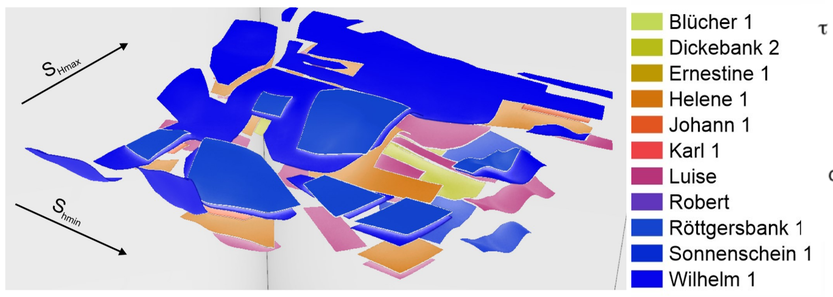

Fig. 3 : Numerical mine model with the dimension: 5 km x 5 km x 2 km. The model aligns with Shmax / Shmin and includes mined out panels (average height ca. 2 m).

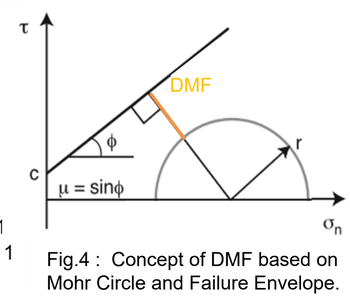

Fig.4 : Concept of DMF based on Mohr Circle and Failure Envelope.

Water Inflow and Spatio-Temporal Evolution of Seismicity

- Galleries and shafts govern the water inflow from neighboring collieries and from upper to lower mining levels (Fig.5)
- Seismic activity starts beneath the pillars of the lowest mining levels, corresponding to most negative DMF
- Fast seismic response where pore pressure propagates almost instantaneously through shafts and galleries to zones of stress concentration (**1**)
- Time delay in seismic response where water migrates through porous media (**2**, **3**, **4**)

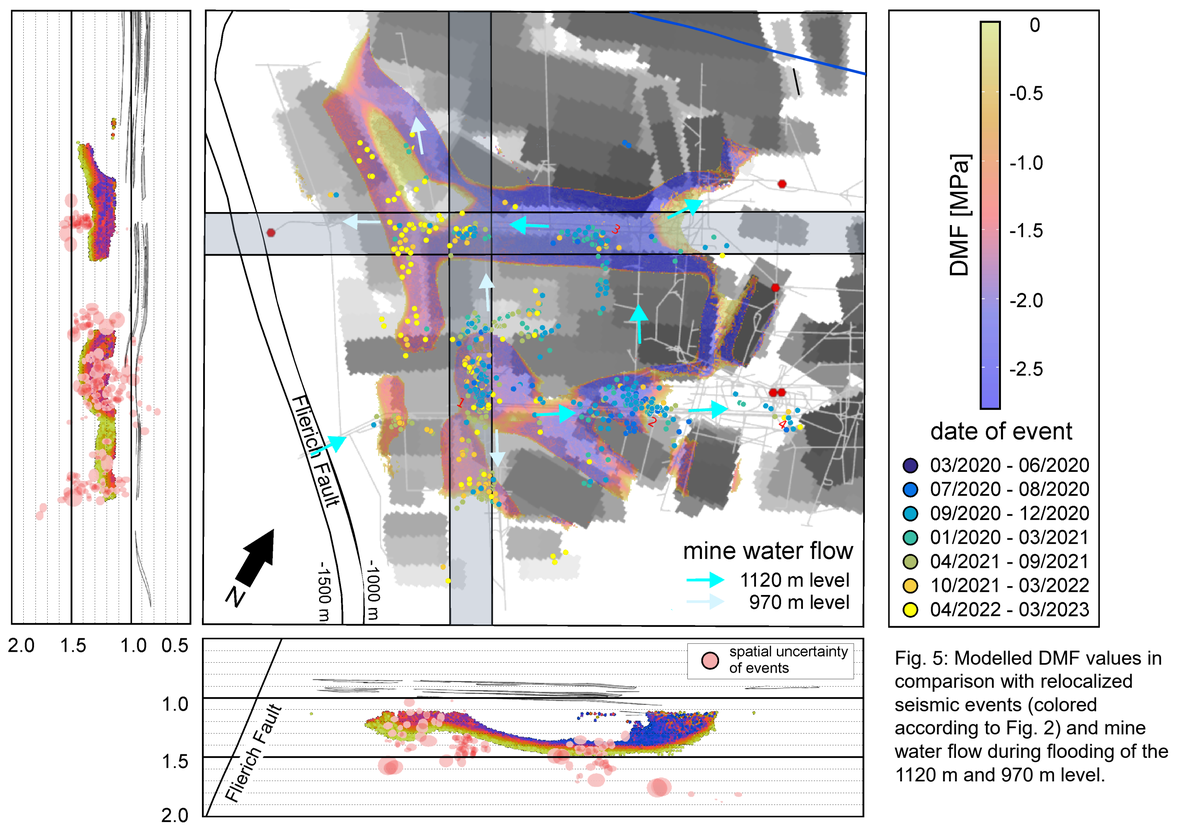

Fig. 5: Modelled DMF values in comparison with relocalized seismic events (colored according to Fig. 2) and mine water flow during flooding of the 1120 m and 970 m level.

Conclusion

- Flooding-induced seismicity is attributed to localized stress arching below the mining level and below the pillars and alterations in pore pressure
- By flooding the effective vertical stress remains unchanged. The effective horizontal stresses are reduced
  - under the mined panels, the tectonic regime is thrust faulting, and the differential stresses decrease → stability
  - under the pillar sections, the tectonic regime is normal faulting and the differential stresses increase → potential fault reactivation
- Flooding-induced seismicity is primarily controlled by the pillar and mine geometry as they define the locations and extent of stress concentration
- Events do not occur on larger natural faults nearby and are likely to remain limited in magnitude

Acknowledgement:

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