3D hydrogeological modeling of the Turaida castle mound under changing precipitation conditions

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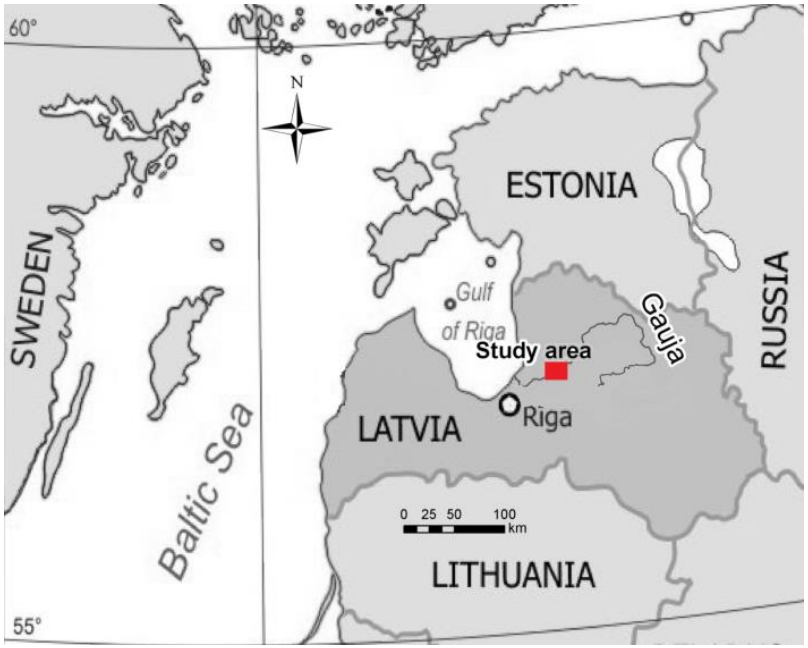
Introduction

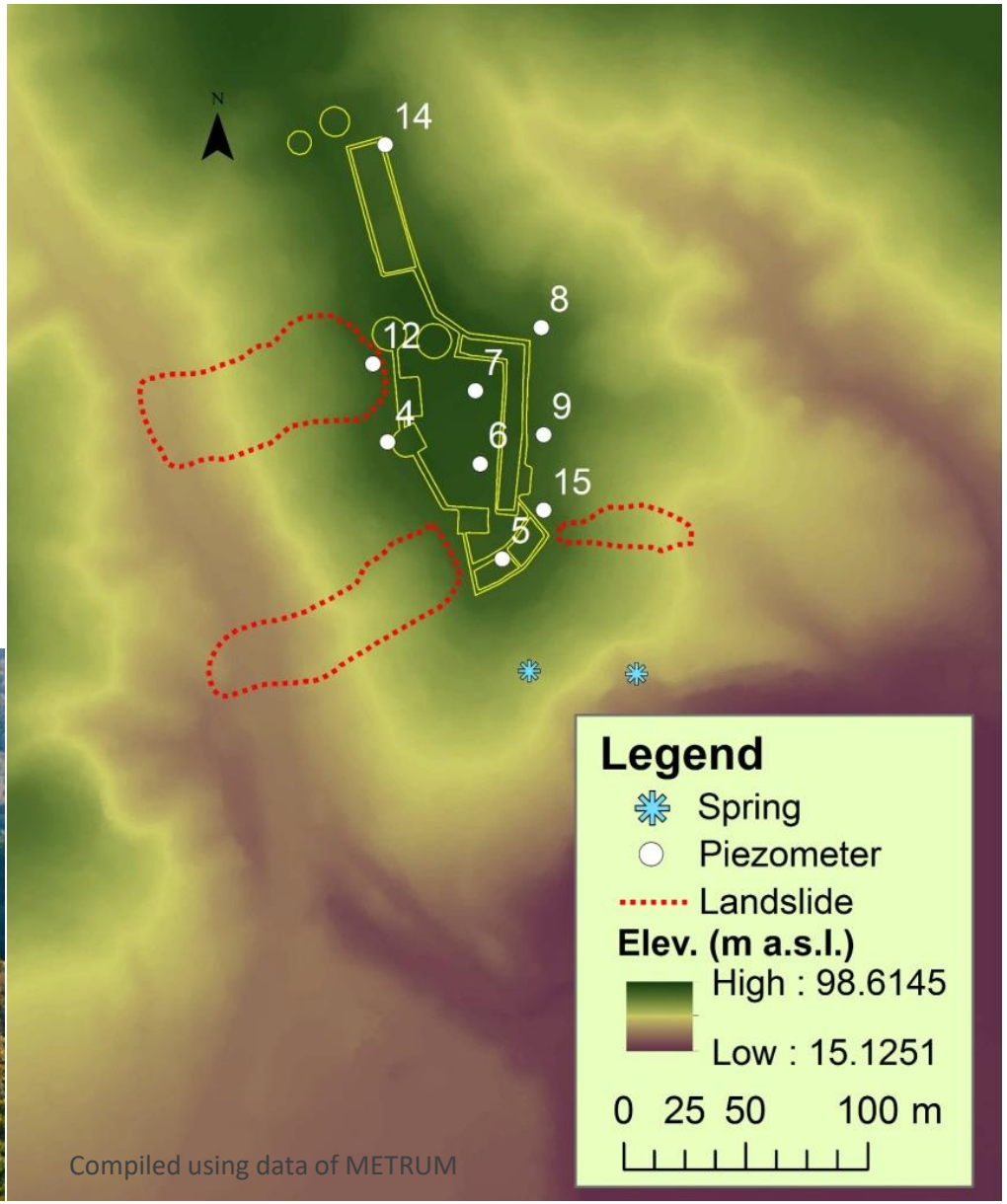
- February 2002: three landslide events at the Turaida castle Central Latvia
- Landslides at intervals of a few days in different locations after an intensive snow melting → indicates hydrogeological triggers

Consequences of the 2002 landslide events

The study analyzes the dynamics of groundwater heads using numerical models

Location of the landslide events





Study area

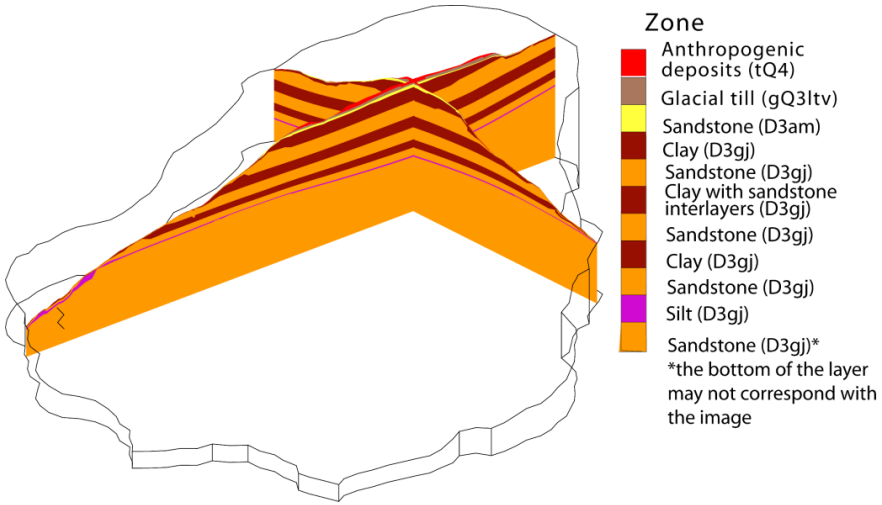
- Geological settings:
  - alternating Devonian sandstone, siltstone and clay sediments overlaid by quaternary glacial till and anthropogenic deposits (Āboltiņš, 1995)
- Climatic conditions:
  - temperate, humid semicontinental climate with average annual precipitation of 700-800 mm (Kalniņa 1995)
  - cold season: snowfall, can reach over 50 cm (LEGMC, 2014)
  - a recent extreme precipitation event on 29th July 2014 → 122.8 mm in 6 hours (LEGMC, 2014)

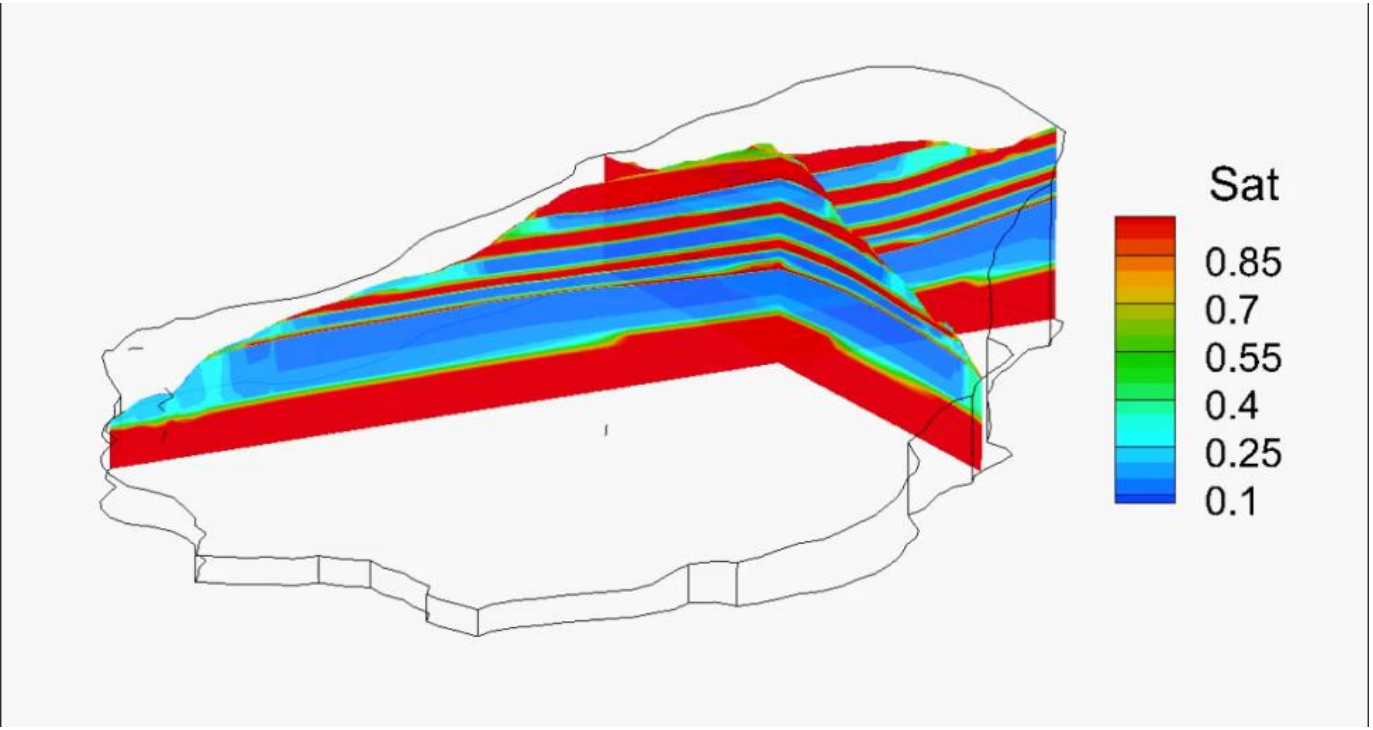
Numerical modeling

- 3D geological model (GeoModeller) using geological cores, soundings and geophysical surveys
- A high resolution 3D hydrogeological model (HydroGeoSphere code) considering:
  - saturated
  - unsaturated
  - fractured media
  - changing rain and snowmelt conditions (Aquanty Inc., 2013)
- PEST code (Doherty, 2015) applied to calibrate the hydraulic conductivities of the sediments according to the piezometer measurements
- Different scale modeling including models of the entire castle mound and more detailed simulations of separate slope sections for modeling of the fracture flow

Modeling of the entire castle mound

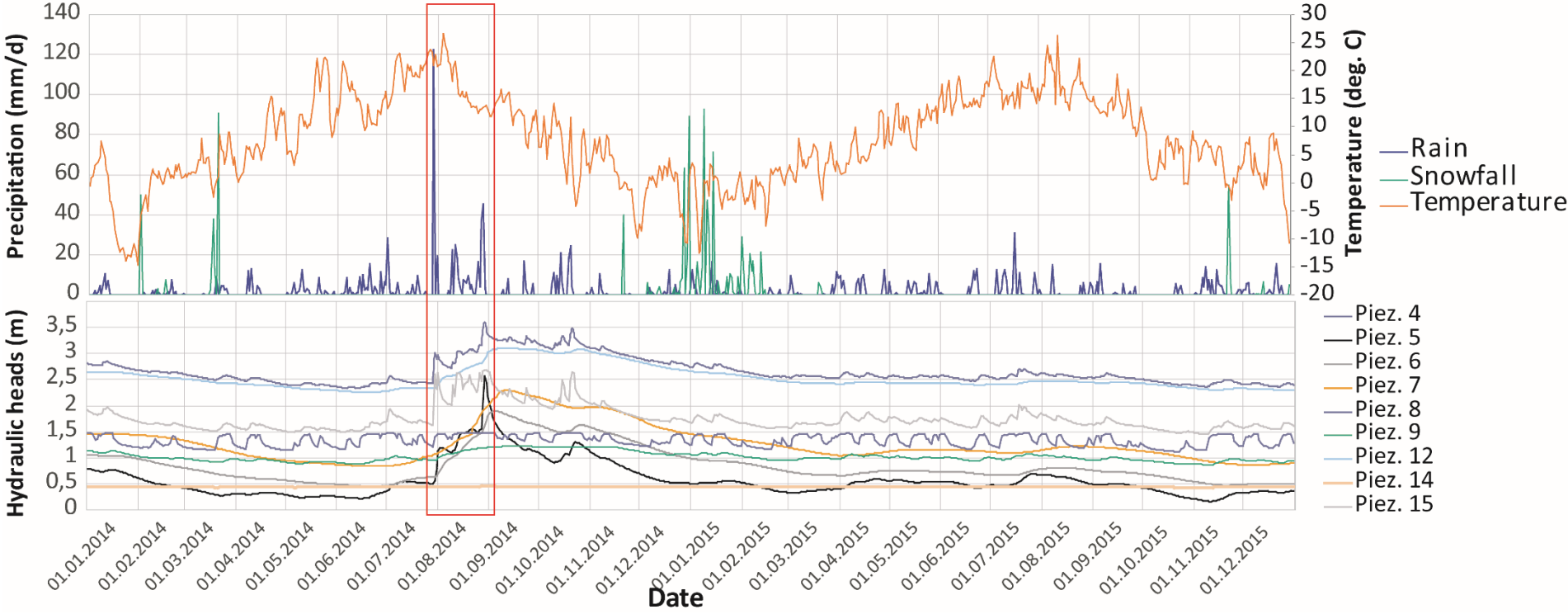
3D geological model of the study site





3D hydrogeological model showing saturation of the model's domain

Results of hydrogeological modeling

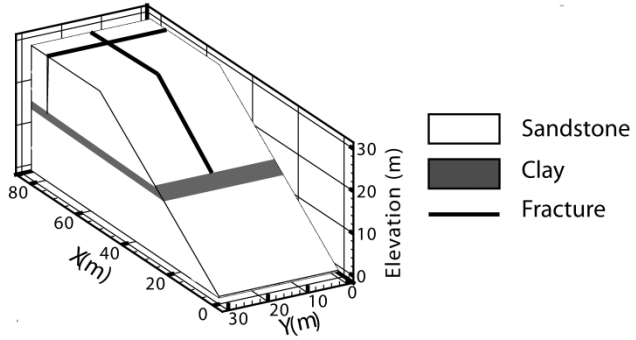


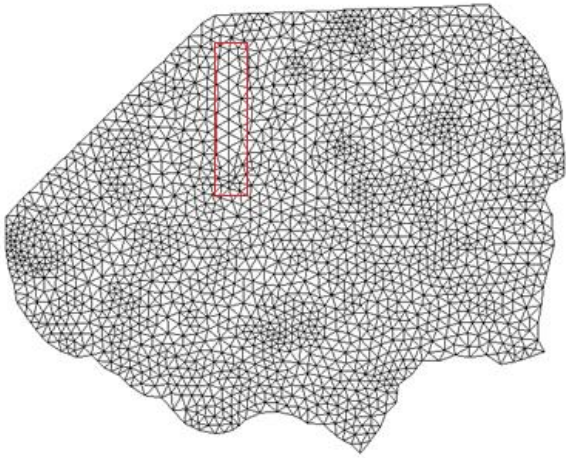
Correlation between precipitation and simulated groundwater heads in the piezometer wells

- Simulation time 01.01.2014. - 31.12.2015
- Impact of the extreme precipitation event of 29.07.2014
- The most critical groundwater heads for hillslope stability were reached approximately one month after the intense precipitation event

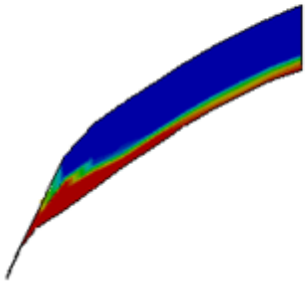
Detailed scale model with a discrete fracture

- Preliminary studies employing synthetic models
- For conceptualizing development of the saturated zone in perched aquifers

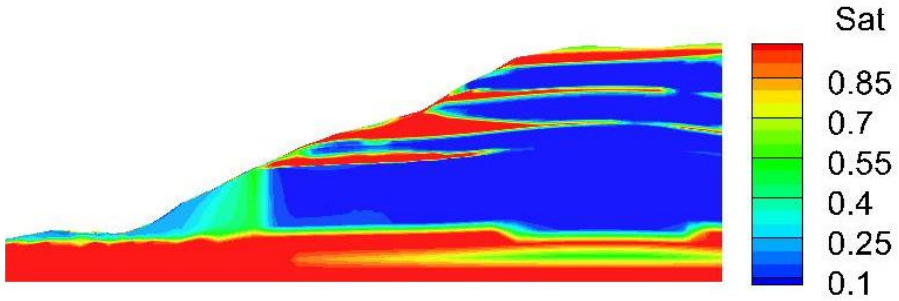




Discrete fracture integrated into the mesh



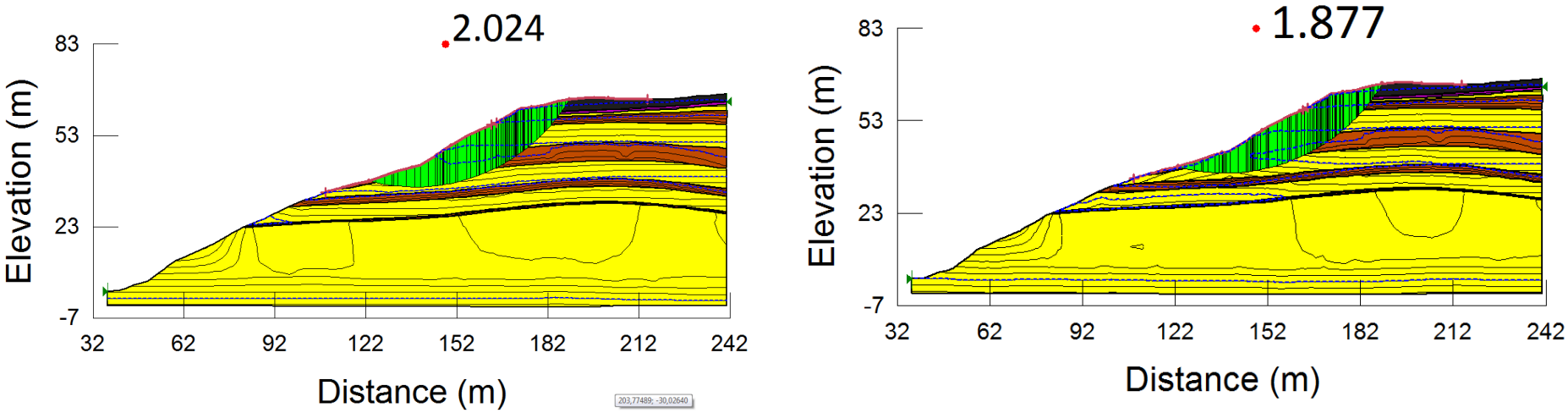
3D view of the discrete fracture plane



Intensive saturation caused by discrete fracture in the lower layers

- Discrete fracture set into the second sandstone layer
- Straight fracture geometry
- Fracture apparture 5 mm

Application of the hydrogeological scenarios



Slope stability simulation showing slope safety factor under dry climatic conditions (left) and after the long wet phase (right)

- Simulation shows significant decrease (from 2.024 to 1.877) of the slope stability after the long precipitation phase

Conclusions

- Integration of geological model in complex flow simulations provides a solid basis for stability assessment
- Modeling shows that short-time, high-magnitude precipitation events do not have an immediate effect on the groundwater table
- Identification of the most critical hydrogeological scenarios and their triggers is crucial for subsequent landslide risk mitigation in the Turaida castle mound

References

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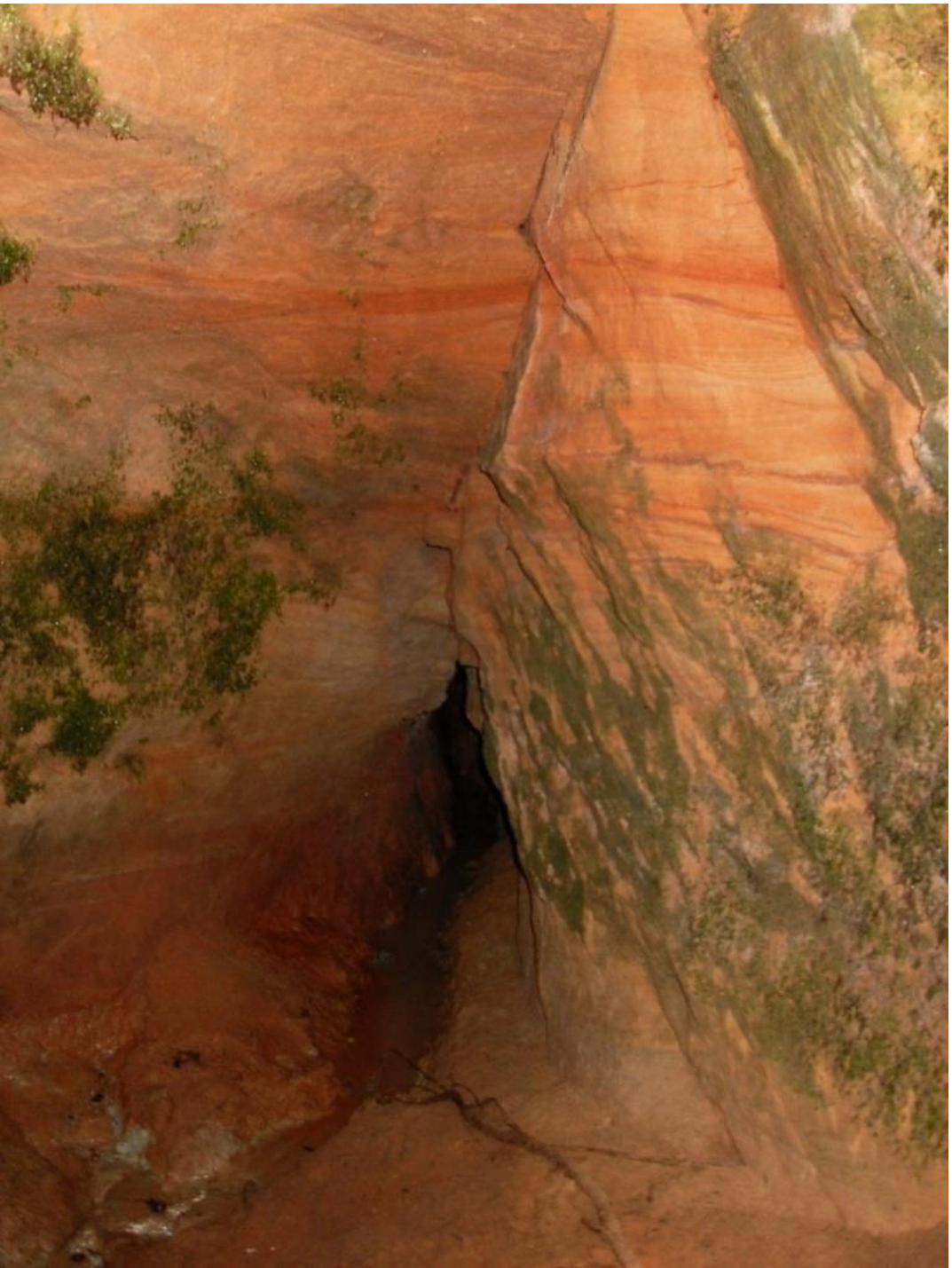

Discrete fracture in sandstone