The Münsterdorf sinkhole cluster: Void origin and mechanical failure

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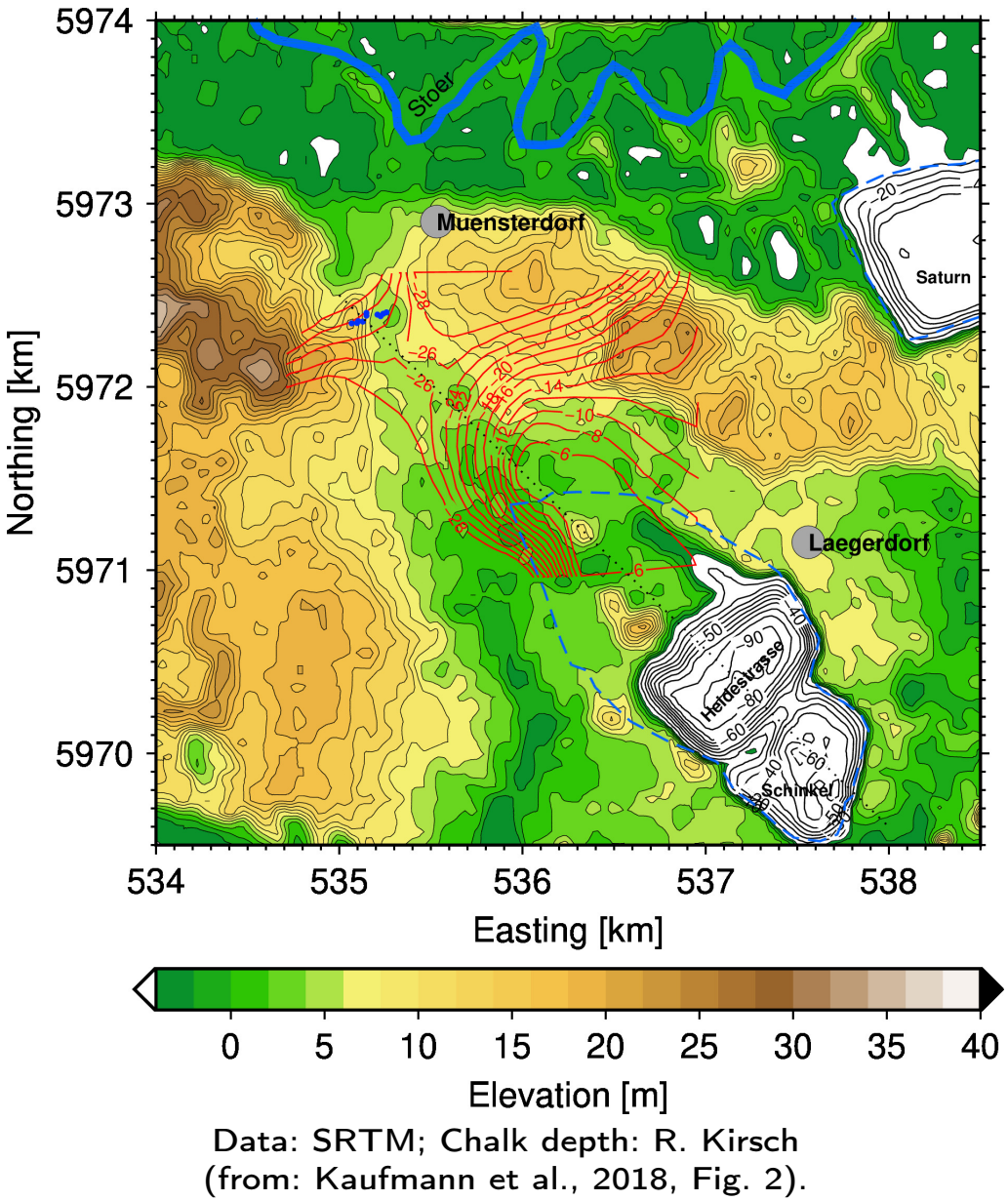
Location

- North of **Hamburg**.
- Village of **Münsterdorf** (grey dot).
- **Sports field** (blue dots).
- **Sinkholes** (blue dots).
- **Chalk** in 20 m depth (red contour lines).
- Large **open-pit mines** (white areas).



Data: SRTM; Chalk depth: R. Kirsch
(from: Kaufmann et al., 2018, Fig. 2).

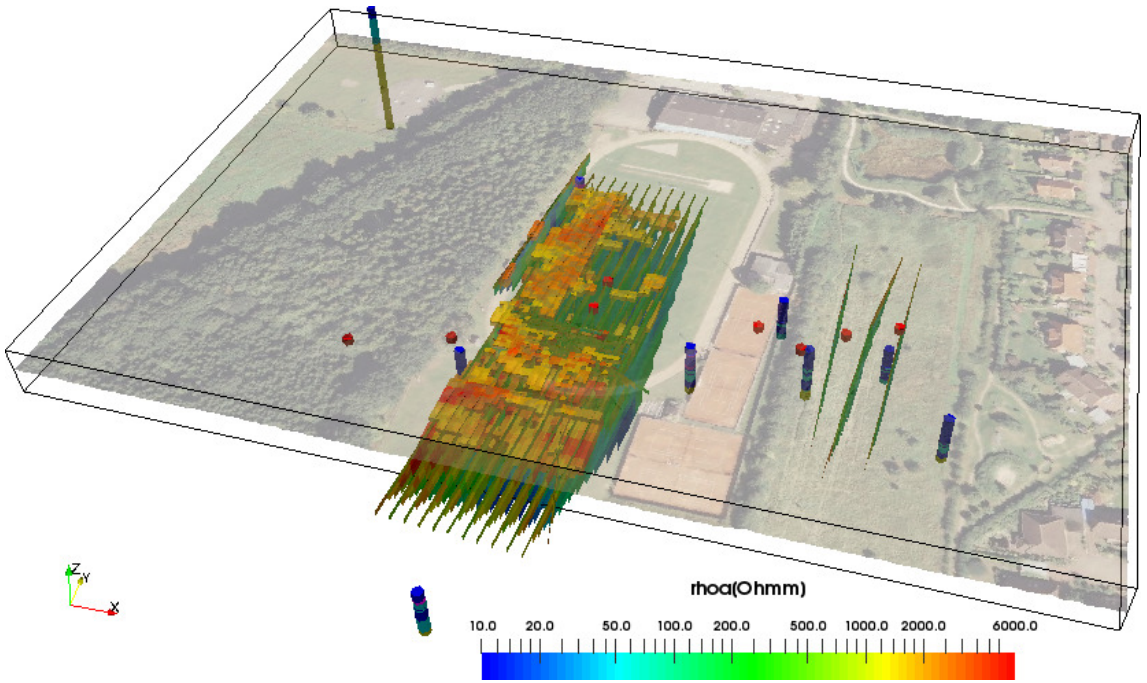
Sinkholes

- **Sinkhole cluster**
- Roughly **one every year**.
- **Size** around 2-3 m in diameter and 2-5 m deep.
- Expose **unconsolidated material**:
  - **Peri-glacial sand**
  - **Glacial till**
- Chalk in 20 m depth.

Photo: G. Kaufmann
(from: Kaufmann et al., 2018, Fig. 3).

Geophysical field work

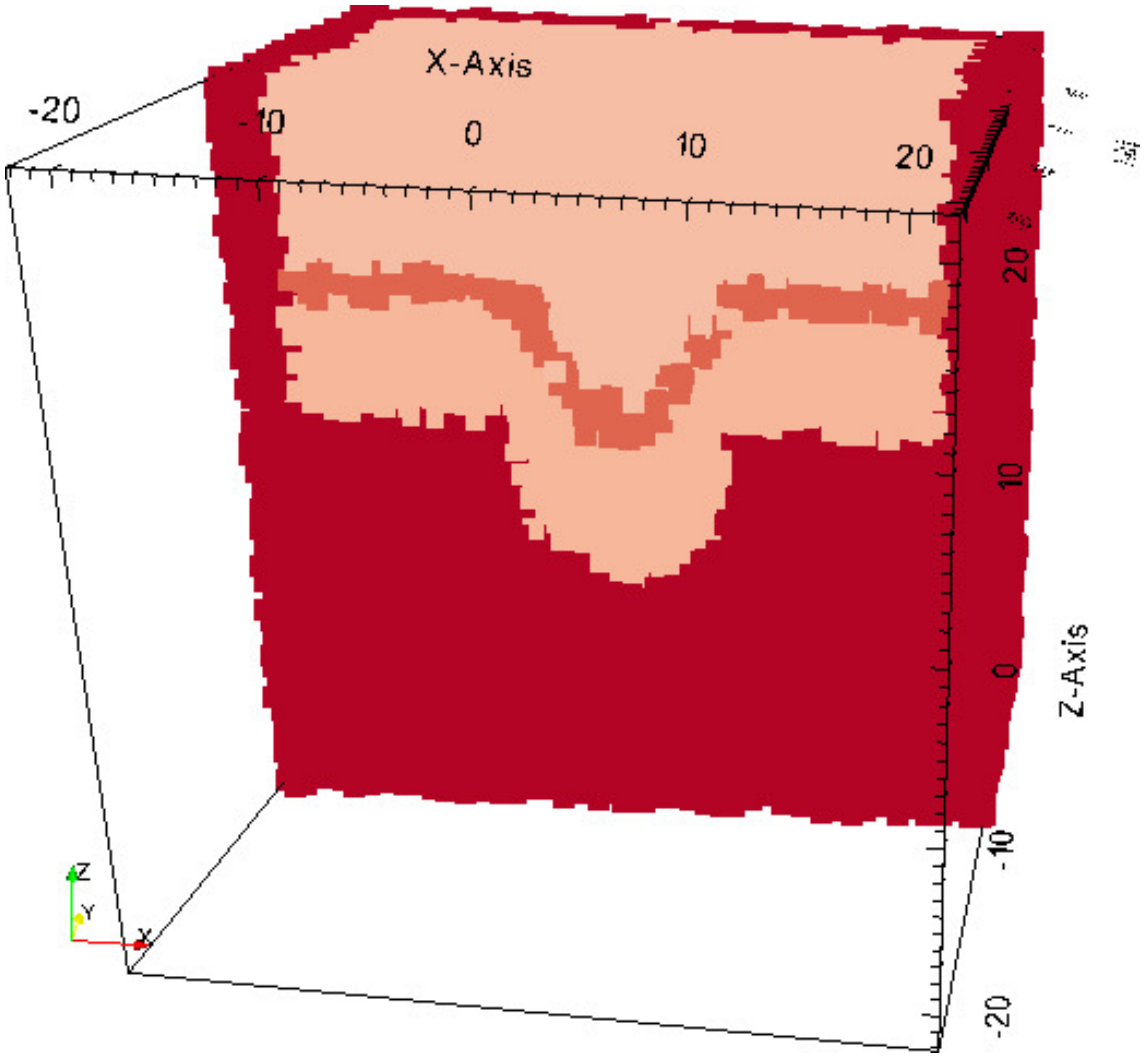
- **Methods**
  - **Gravity**
  - **Electrical resistivity tomography**
  - **Georadar**
  - **Direct-push measurements**
- Reveals change in sub-surface structure:
  - **North: Shallow glacial till**
  - **South: Deeper glacial till**



Data: Areal photo LLUR; borehole logs: R. Kirsch; ERT data color-coded.
(from: Kaufmann et al., 2018, Fig. 7).

Failure model

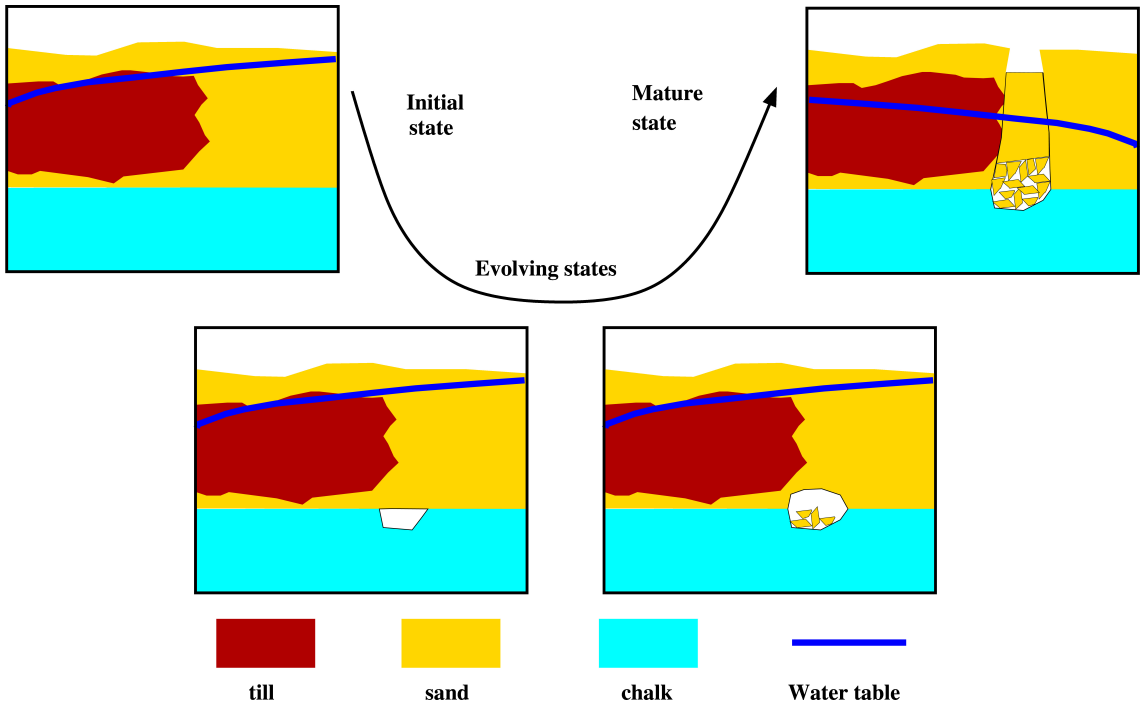
- **Yade** discrete-element model.
- Layers with **different** mechanical properties.
- Mechanical properties derived from **direct-push measurements**.
- Model indicates sinkhole collapse, when . . .
  - . . . **Void has formed in around 20 m depth.**
  - . . . **Buoyant support in void (partially) reduced.**



Lithology from Yade model.
(from: Kaufmann et al., 2020, prepared).

Hypothetical model

- Chalk in 20 m depth **karstified**.
- **Meter-size voids** in phreatic zone.
- **Groundwater level** originally in 2-3 m depth.
- Glacial till and peri-glacial sands (semi-)stable above voids.
- **Groundwater drop** due to pumping in large open-pit mines nearby triggers sinkholes!



From: Kaufmann et al. (2018), Fig. 11.

Conclusions

- Sinkholes on sports field start with abrupt onset around 2004.
- Sinkholes occur roughly once per year.
- Sinkholes are 2-3 m in diameter and 2-5 m deep.
- Initial void likely in chalk in around 20 m depth.
- Fall in groundwater level due to open-pit mining.
- Loss of buoyant support can induce instability of strong layers.

References:
• Kaufmann, G.; Romanov, D.; Tippelt, T.; Vienken, T.; Werban, U.; Dietrich, P.; Mai, F.; Börner, F. (2018). Mapping and modelling of collapse sinkholes in soluble rock: the Münsterdorf site, northern Germany. J. Appl. Geophys., 154, 64-80.
• Kaufmann, G.; Romanov, D.; Werban, U.; Vienken, T. (2020). The Münsterdorf sinkhole cluster: Void origin and mechanical failure, Solid Earth, prepared.