3D Modeling of Water Inrush in Coal Mines: Understanding the Causes to Enhance Safety in Mining Operations

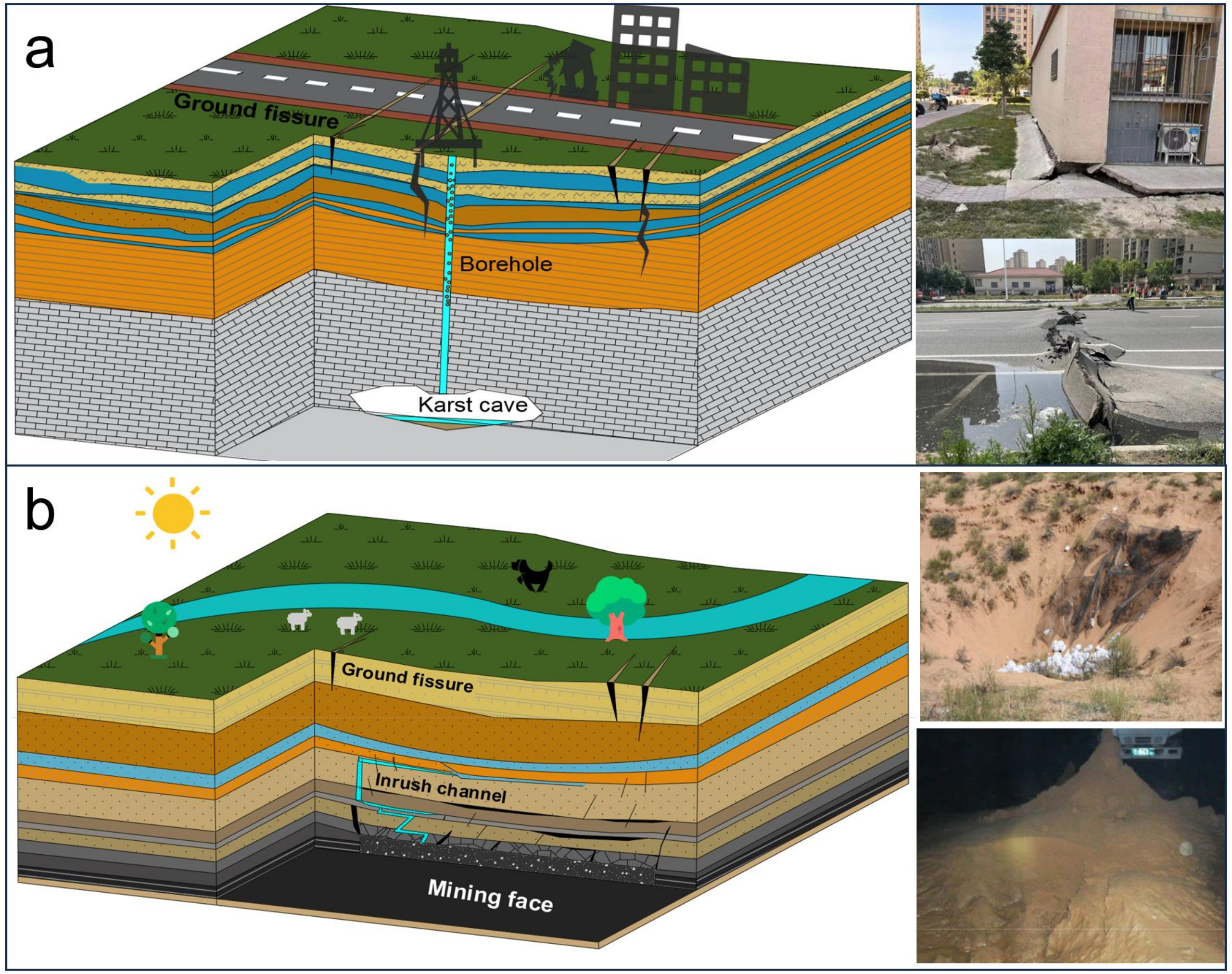
Jinxi Liang, Sara Kasmaeeyazdi, Xiaoning Liu, Francesco Tinti

China University of Mining and Technology

2025.02

Water-sand mixture flows (WSMFs) pose significant hazards to underground operations, threatening workplace safety, infrastructure stability, and nearby human settlements.

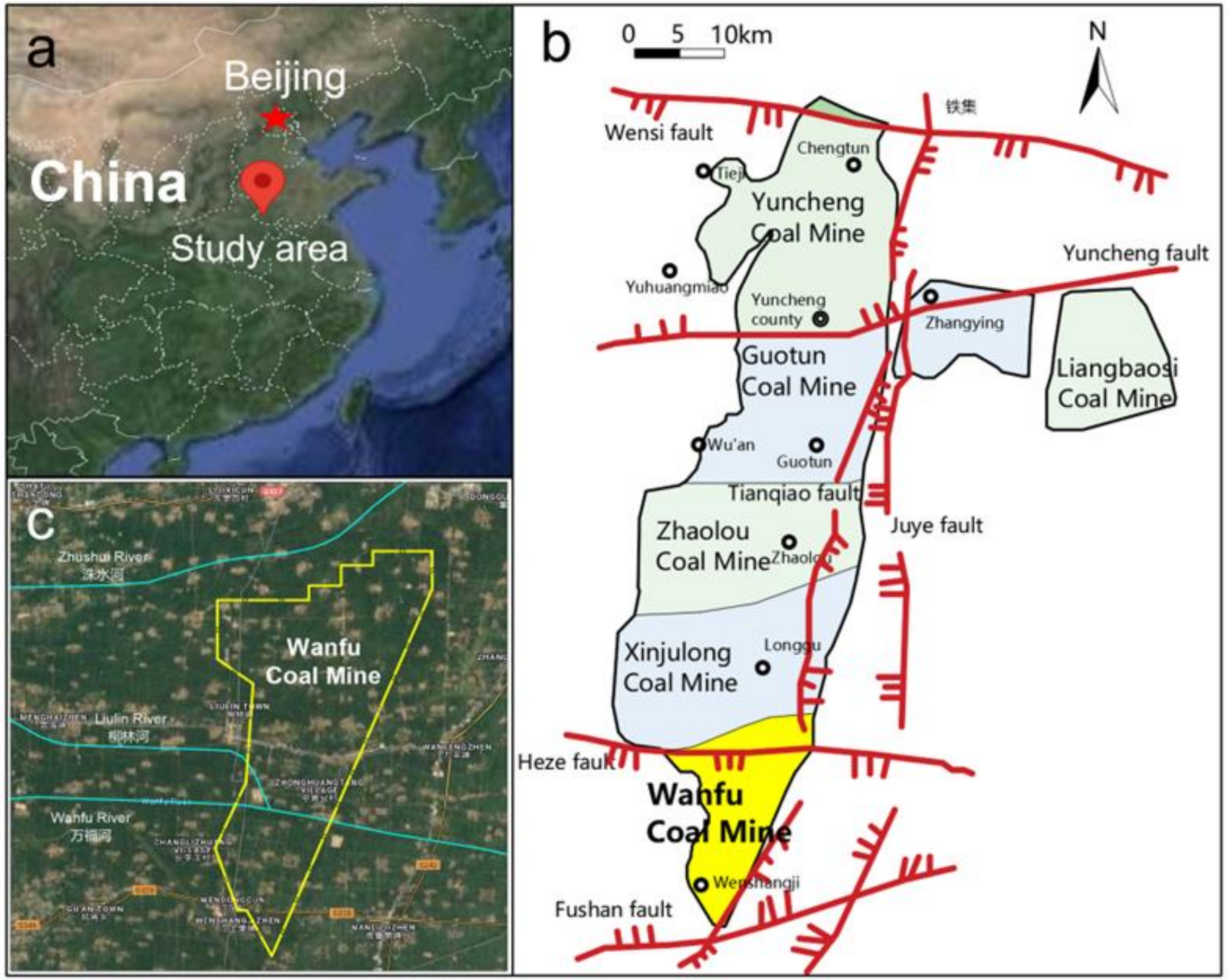
- In May 2023, a borehole penetrating a collapse column in Tianjin, China, triggered WSMF migration, resulting in uneven **ground settlement, building tilting**, and **road cracking**, which displaced approximately **4,000** resident.
- **Mining operations**, especially during resource extraction, represent **high-frequency scenarios** for such disaster.
- In the past decade, more than **13** similar accidents have been recorded in China, **resulting in over 50 fatalities and direct economic losses exceeding 18 million euros**.



Study Area

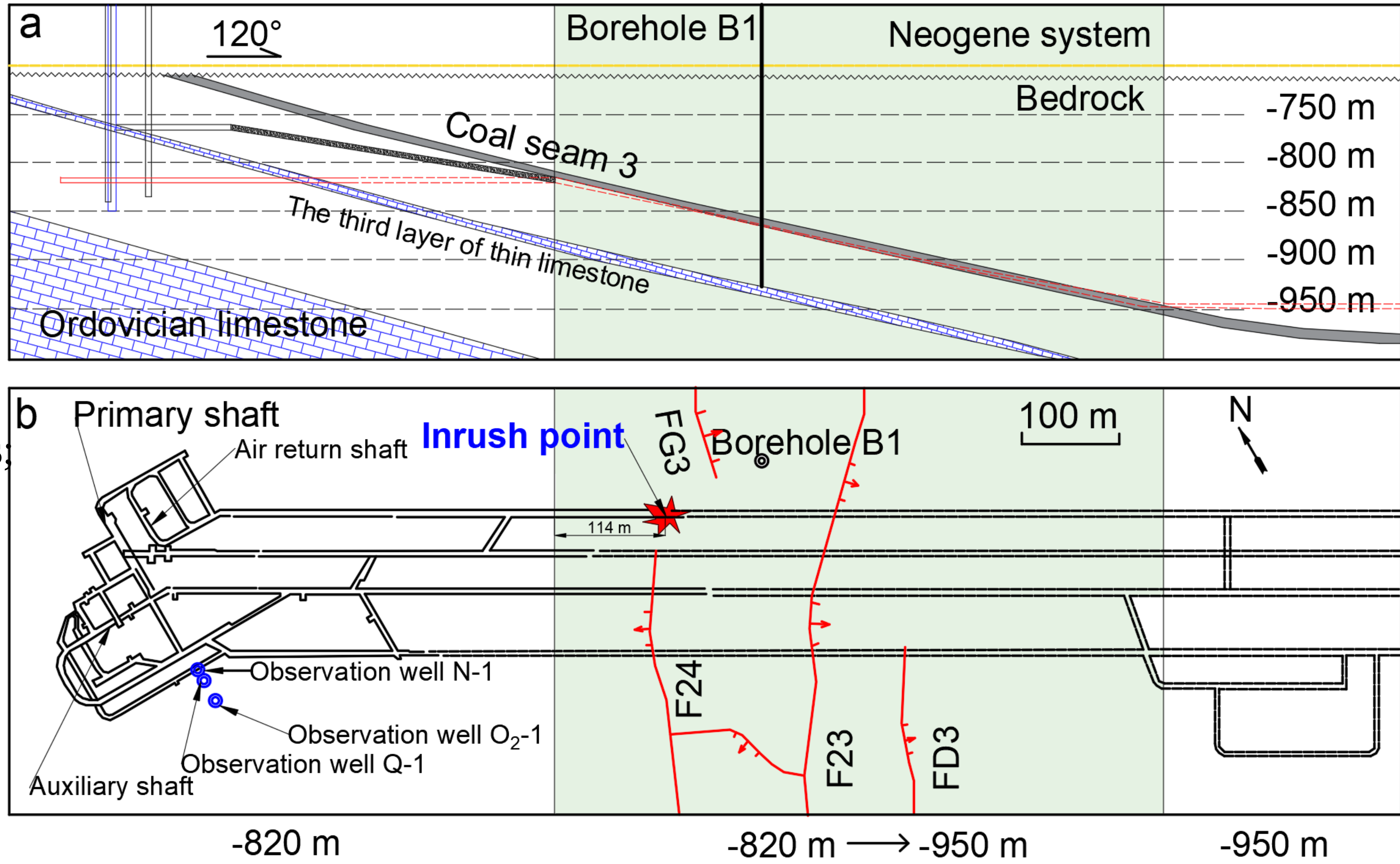
The Wanfu Coal Mine, **located in** the Juye Coalfield on the Yellow River alluvial plain in Shandong Province.

- Overburden: Up to 750 m of unconsolidated clay and sand.
- Bedrock: Thin layer beneath the sediments.
- Geological characteristics:
  - High water pressure (up to 8.2 MPa)
  - Significant ground stress (>30 MPa)
  - Well-developed normal fault systems



On November 2, 2018, a WSMF disaster occurred in the ventilation inclined tunnel of Wanfu Coal Mine. It **took place at a depth of approximately 830.0 m** with a **bedrock thickness of 113.5 m,** led to **the loss of one worker and direct economic damages estimated at 1.05 million Euros**.

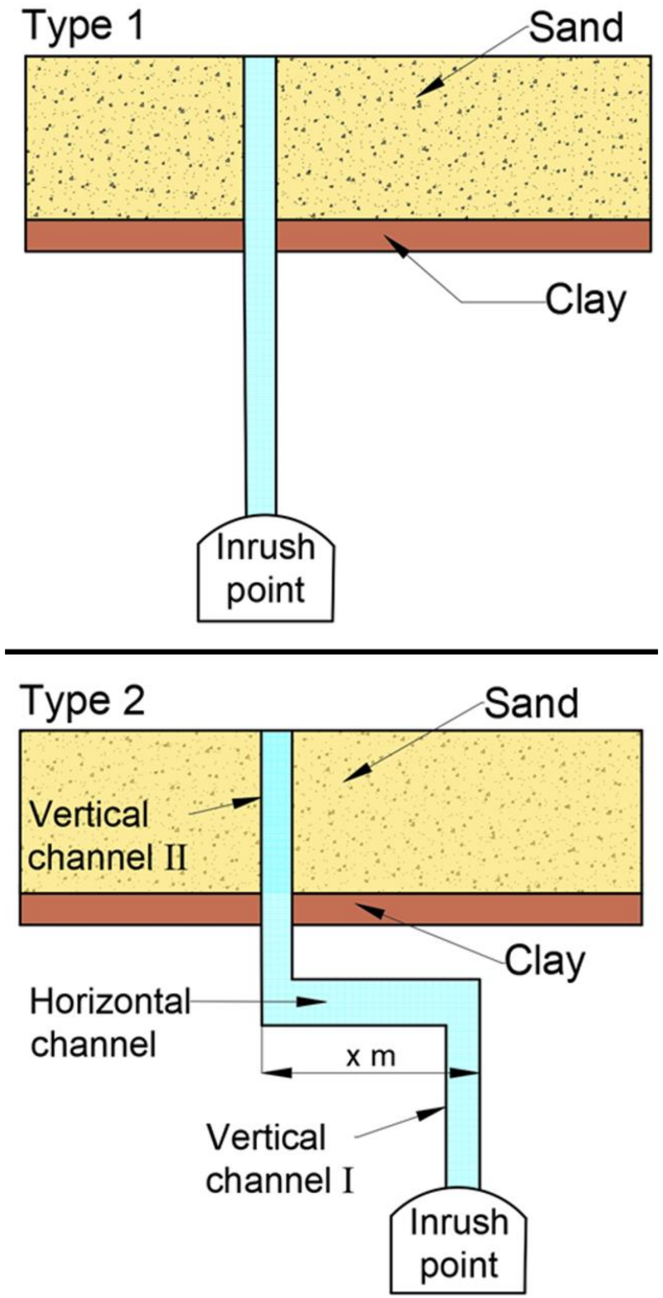
- The WSMF reached an instantaneous rate of **14,580 m³/h**;
- Post-disaster recovery operations were completed by December 30, 2018;
- Involving the clearance **2,413 m of tunnels**;
- The removal of **337,000 m³** of water;
- The extraction of **22,000 m³** of sand and sediment



- The occurrence of such disasters must meet four conditions: **material source**, **pathway**, **driving power** and **space**.
- The key to the control and prevention of such disasters is to determine the **type and location of the pathway**.

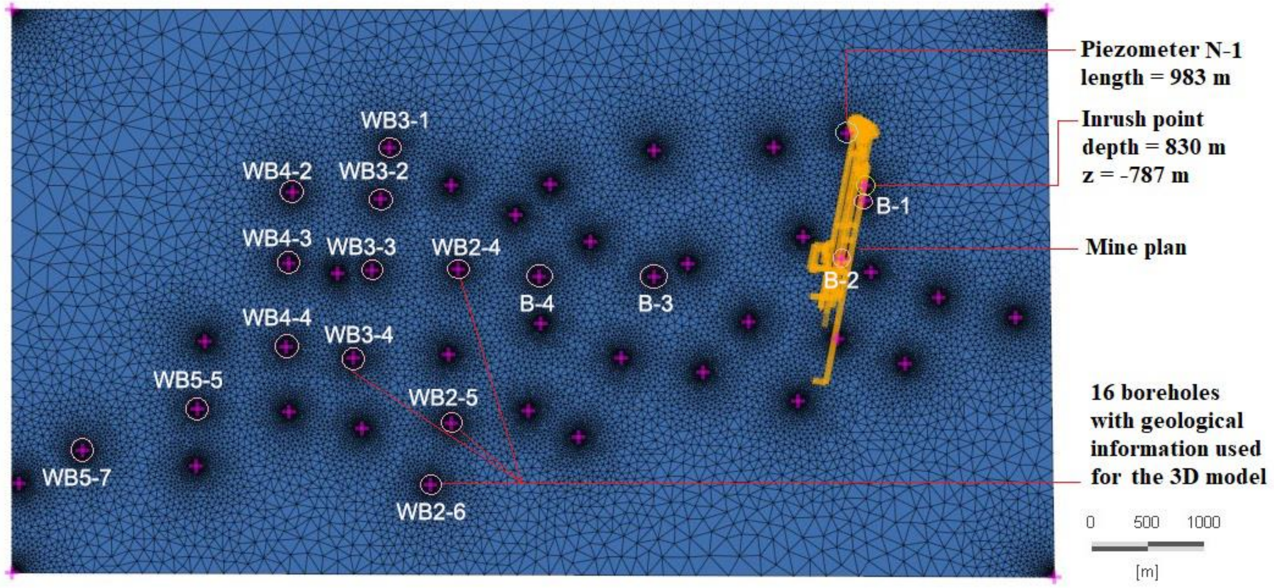
According to situation of study area, the presence of these two channel types in the study area is plausible and schematic diagrams of the two types of pathways:

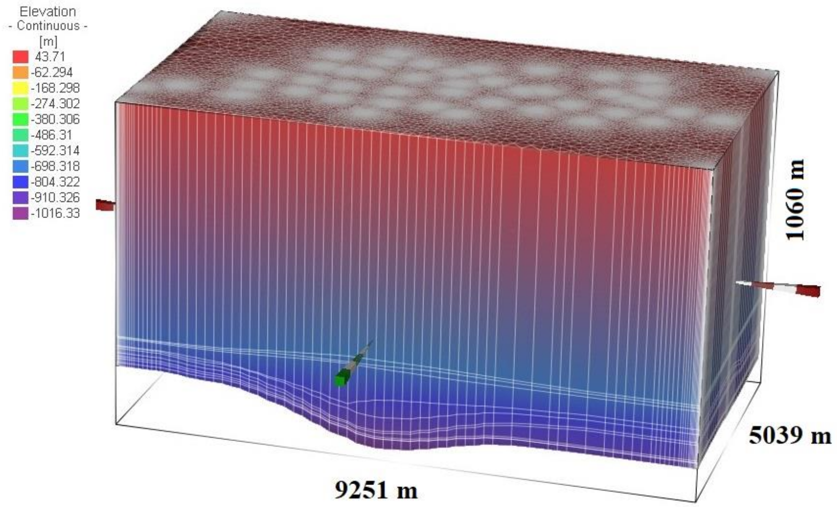
- The first type of channel may have formed during the mining of the return air incline tunnel, where nearly **vertical normal faults and caving zones** were exposed, **directly connecting the water-sand source and triggering the disaster**.
- The second type of channel may be associated with **small faults** developed on-site. Drilling data indicate that these fractured rock layers could act as a medium through which **multiple vertical pathways connect the water-sand source**, leading to the disaster.

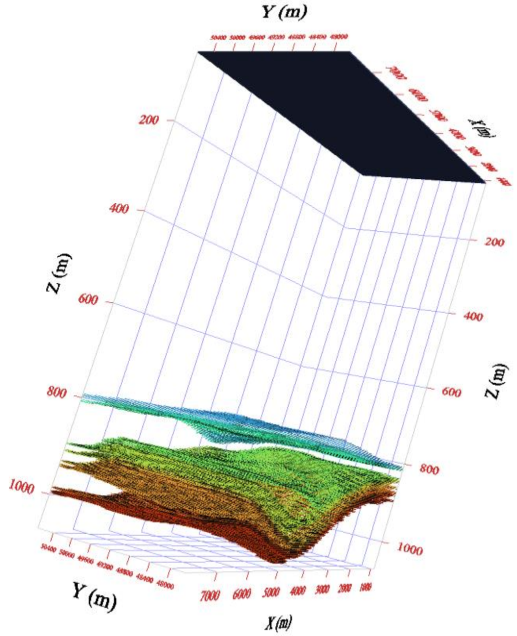


3D Modeling

- Using data from **16 boreholes**, a three-dimensional model of the study area was constructed.
- The geological information includes **11 layers** including quaternary sediments, clay and then three sequences of sandstones and mudstones, then the coal layer and at the bottom of the coal layer, again one sequence of mudstone and sandstone.
- **CoKriging** used to estimate layer thickness
- **Co-regionalization models** applied to direct & cross variograms
- **Post-processing** ensures proper layer stacking.

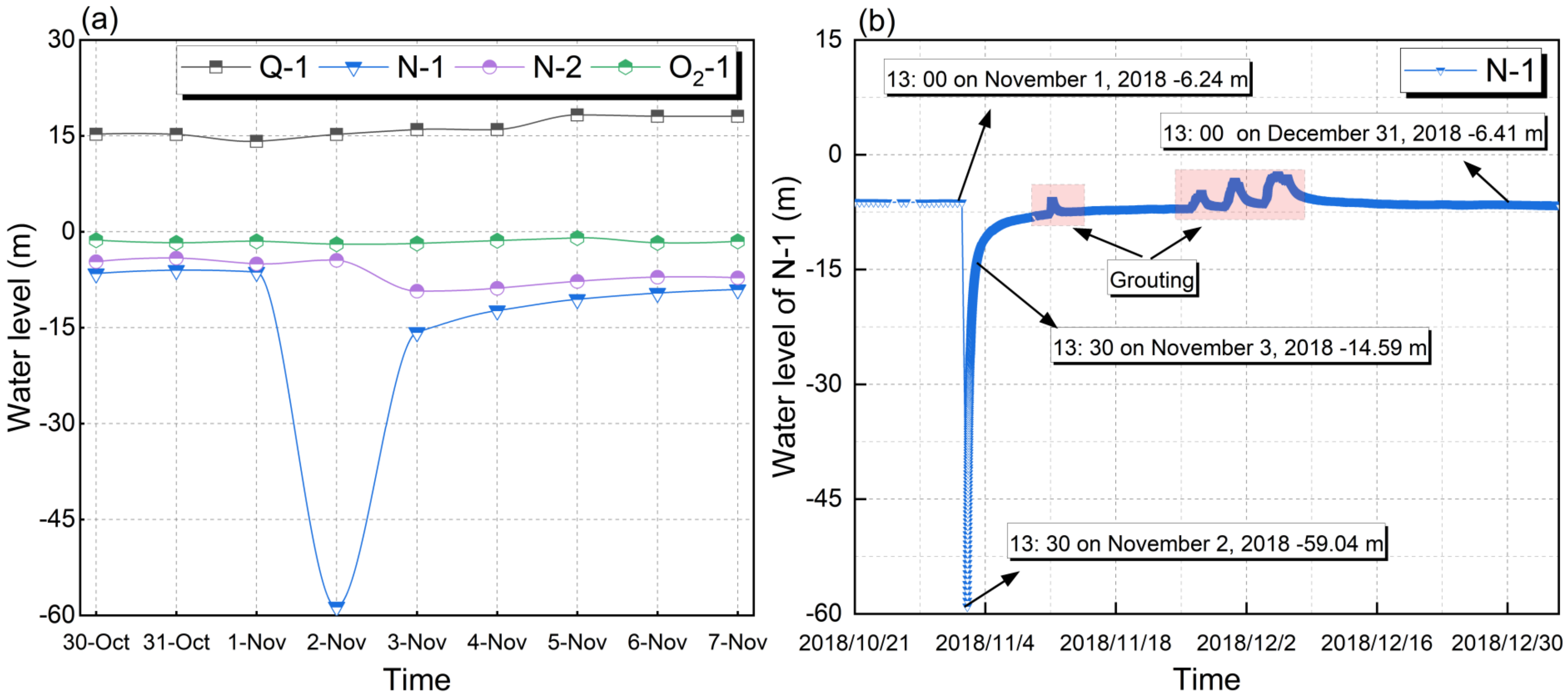




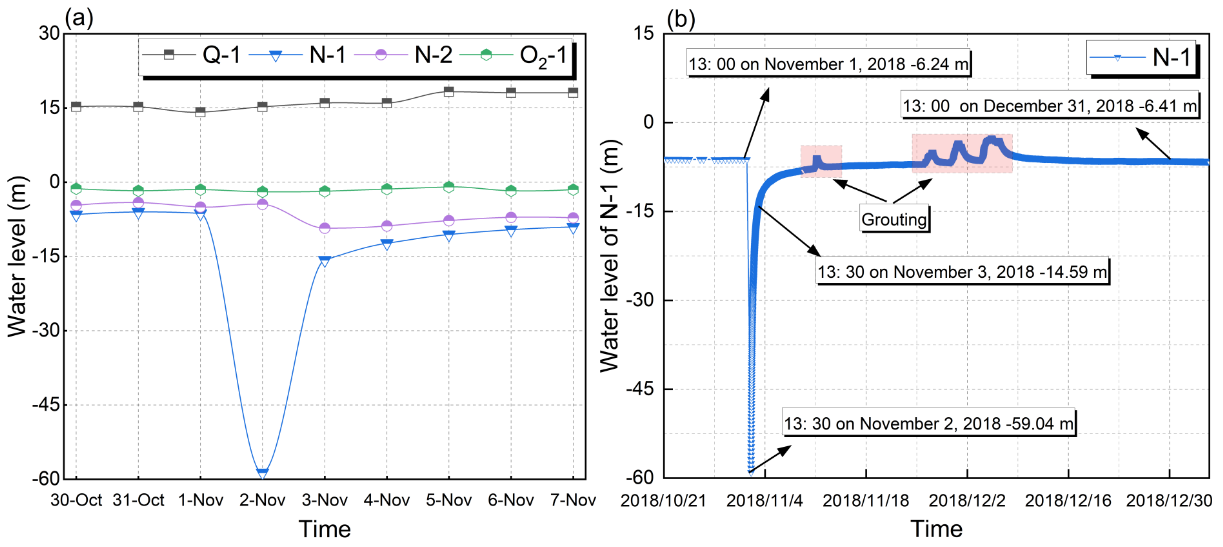


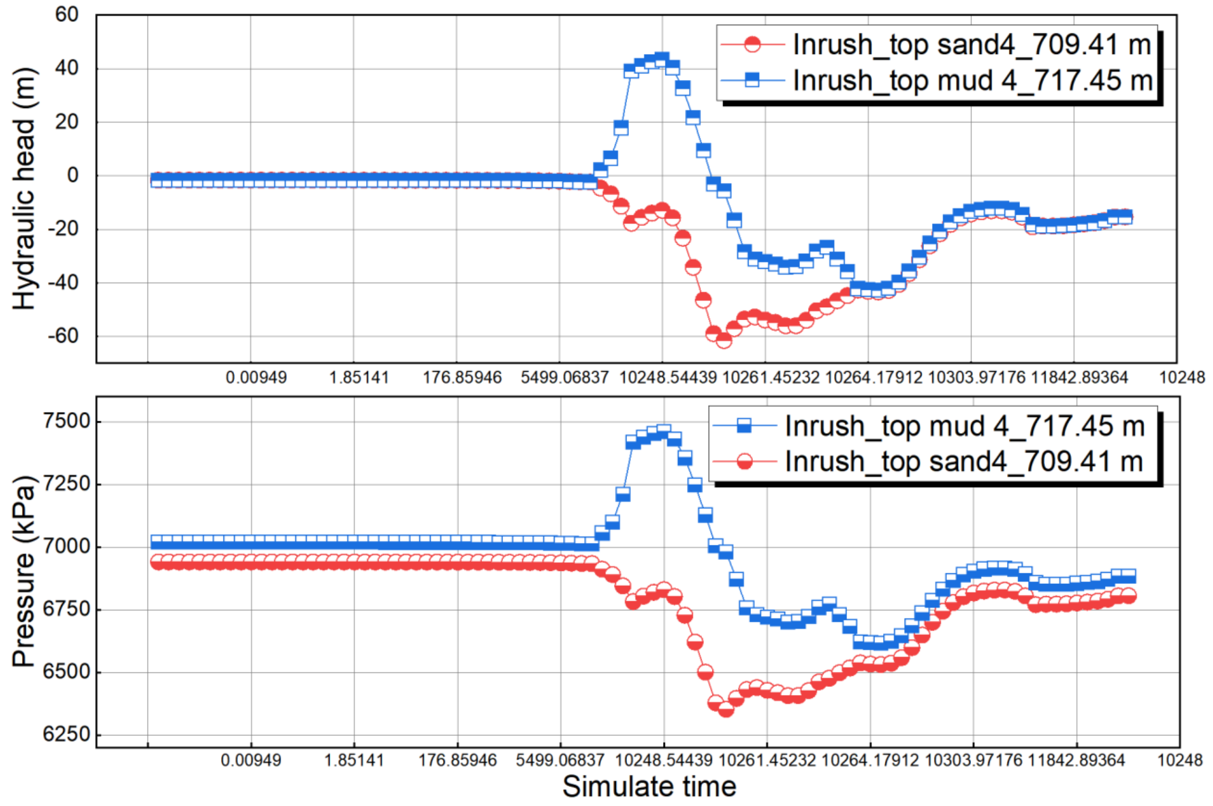
By constructing 3D models of geological layers and integrating them with water level data observed during the incident, it is possible to fit and simulate the flow dynamics.

- The 3D geological model, together with its hydraulic conductivity features, based on geological information was then imported in the software FEFLOW®

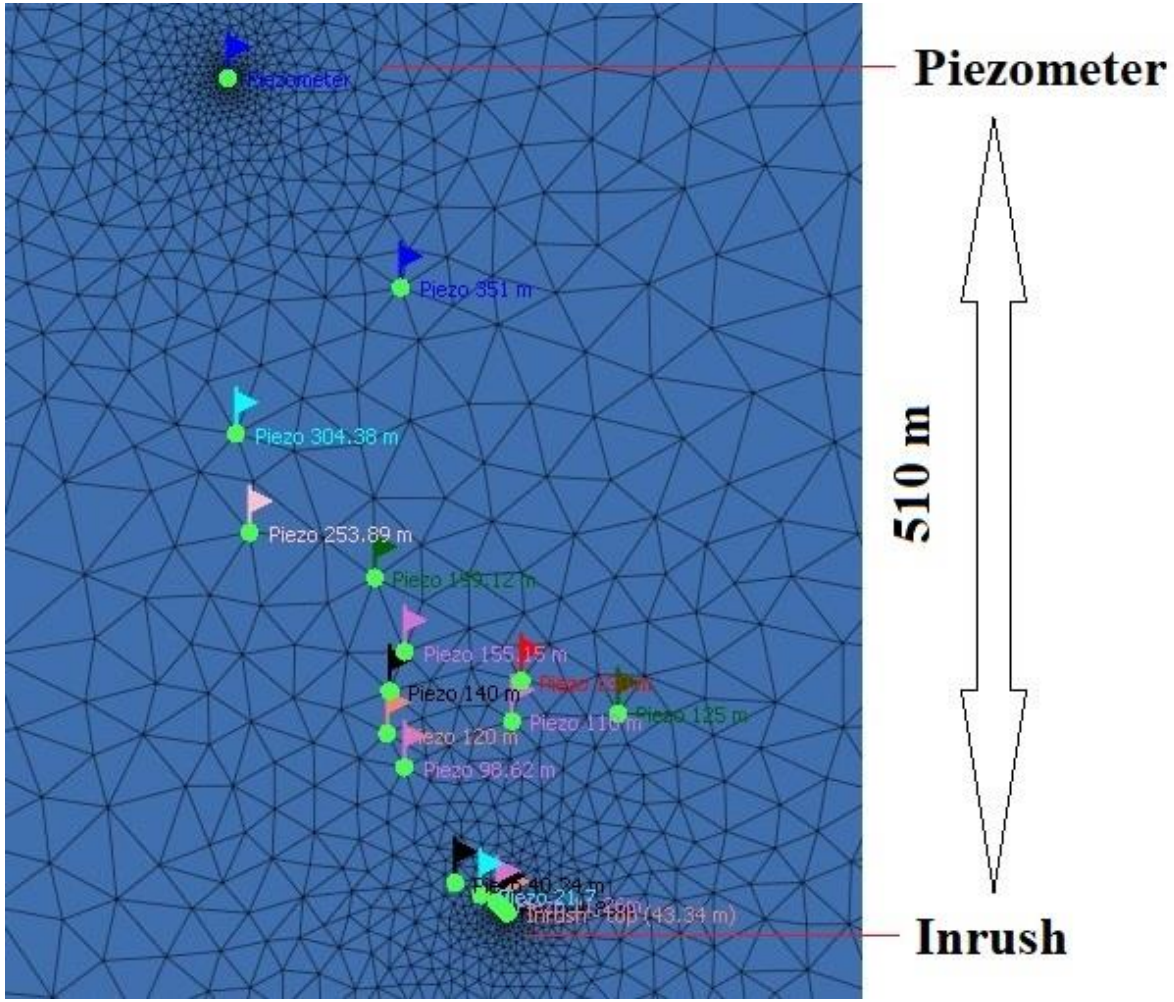


Based on the statistics of water inflow and water level at the accident site, the simulation is carried out. Simulation results revealed that **the water pressure and hydraulic head** at the top of the aquifer initially measured approximately **6940 kPa**. Following **the incident, it dropped rapidly to around 6350 kPa**, with **the hydraulic head decreasing by roughly 60 m**, **consistent with on-site monitoring data**.

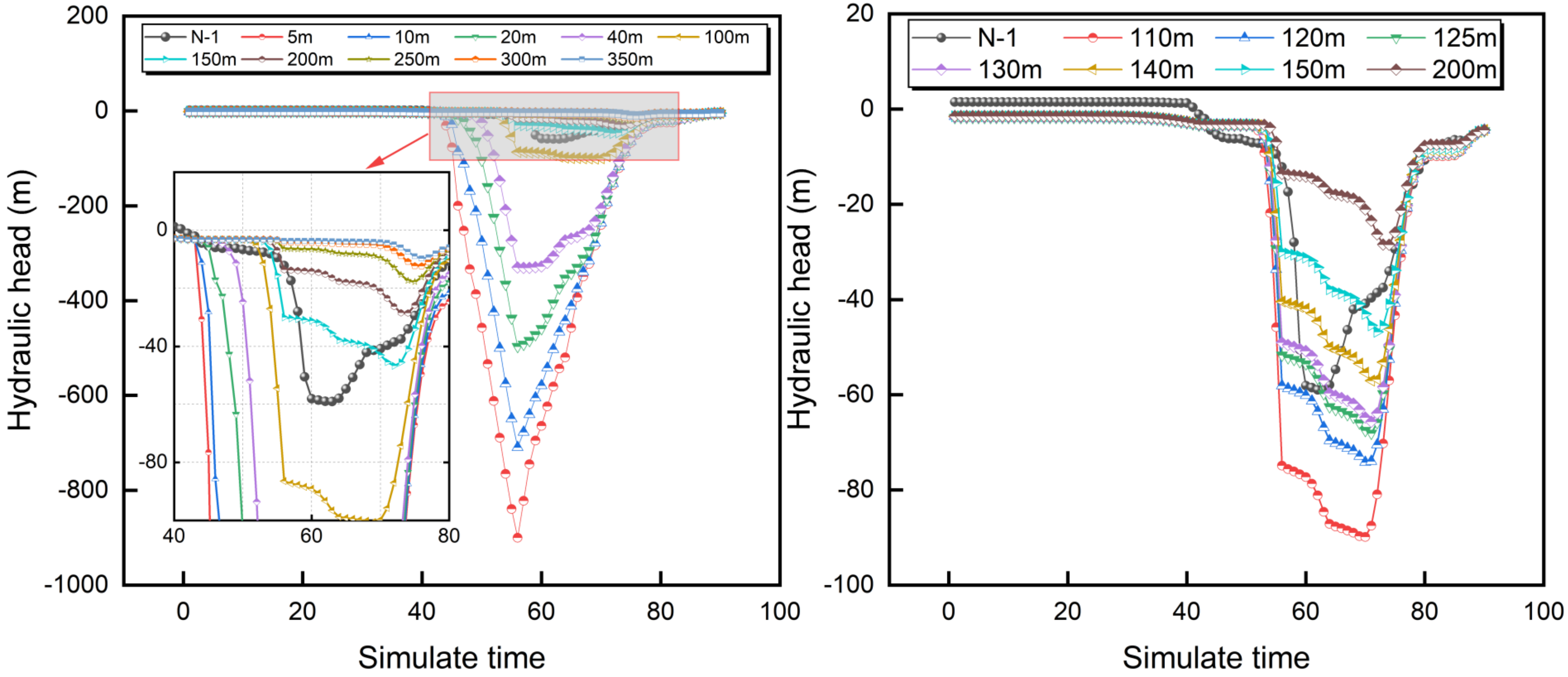




Based on the simulation results, the types of pathways can be further simulated. Starting from hydrological monitoring well N-1, multiple monitoring points were established at intervals of *i* m (*i* = 5, 10, 20, 40, 50, 100, 150 m...)

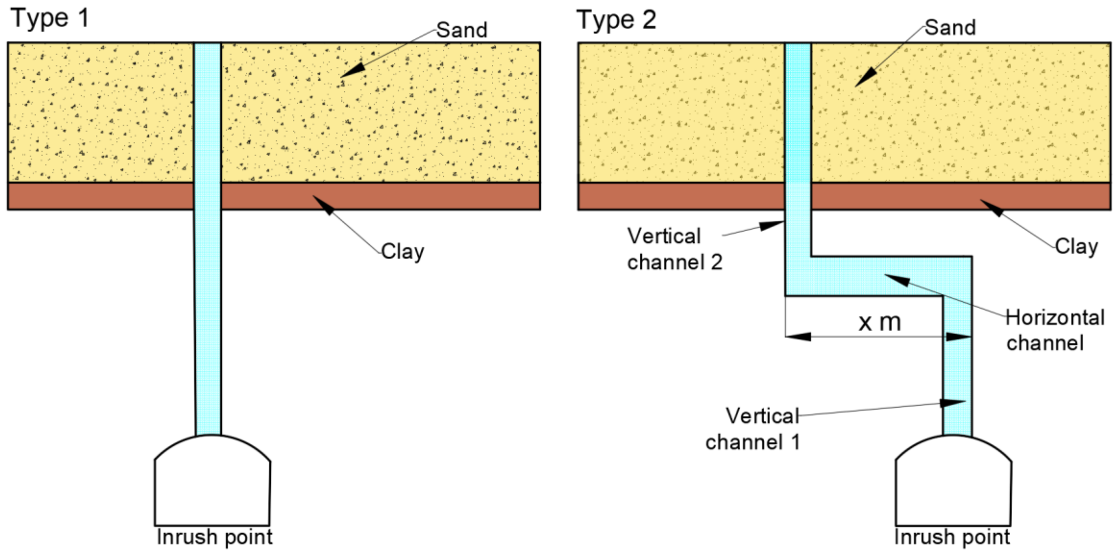


By simulating the water inrush during the disaster, the water level monitoring results of borehole N-1 fell within the range of *i* = 120 m to 200 m. Which means more than 350 m from disaster site.



Pathway:

- **Depth range:** -710-730 m~-835 m
- **Type:**
  - **Caving zone**
  - **Fault**
  - **Combination**
- **Horizontal range:** 350–400 m from the disaster site



Based on the numerical simulation results, the water-conducting channel is more inclined toward Type 2, with the main pathway located between the borehole and the disaster site, approximately 350–400 m from the disaster site.

中国矿业大学
CHINA UNIVERSITY OF MINING AND TECHNOLOGY

UNIVERSITY OF PETROSANI

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

THANK YOU

China University of Mining and Technology

2025.02