John Fox Annual Lecture
4th February 2026

Hydrogen storage in salt caverns: how can geo-mechanical data inform fluid dynamics models to optimize capacity and operational efficiency?

Katerina Kyrkou, Charlotte Botter, Adam Mc Arthur, David Healy
School of Earth, Environment & Sustainability, University of Leeds, LS2 9JT Leeds, United Kingdom
E-mail: K.Kyrkou@leeds.ac.uk; C.D.Botter@leeds.ac.uk; A.McArthur@leeds.ac.uk; D.Healy@leeds.ac.uk

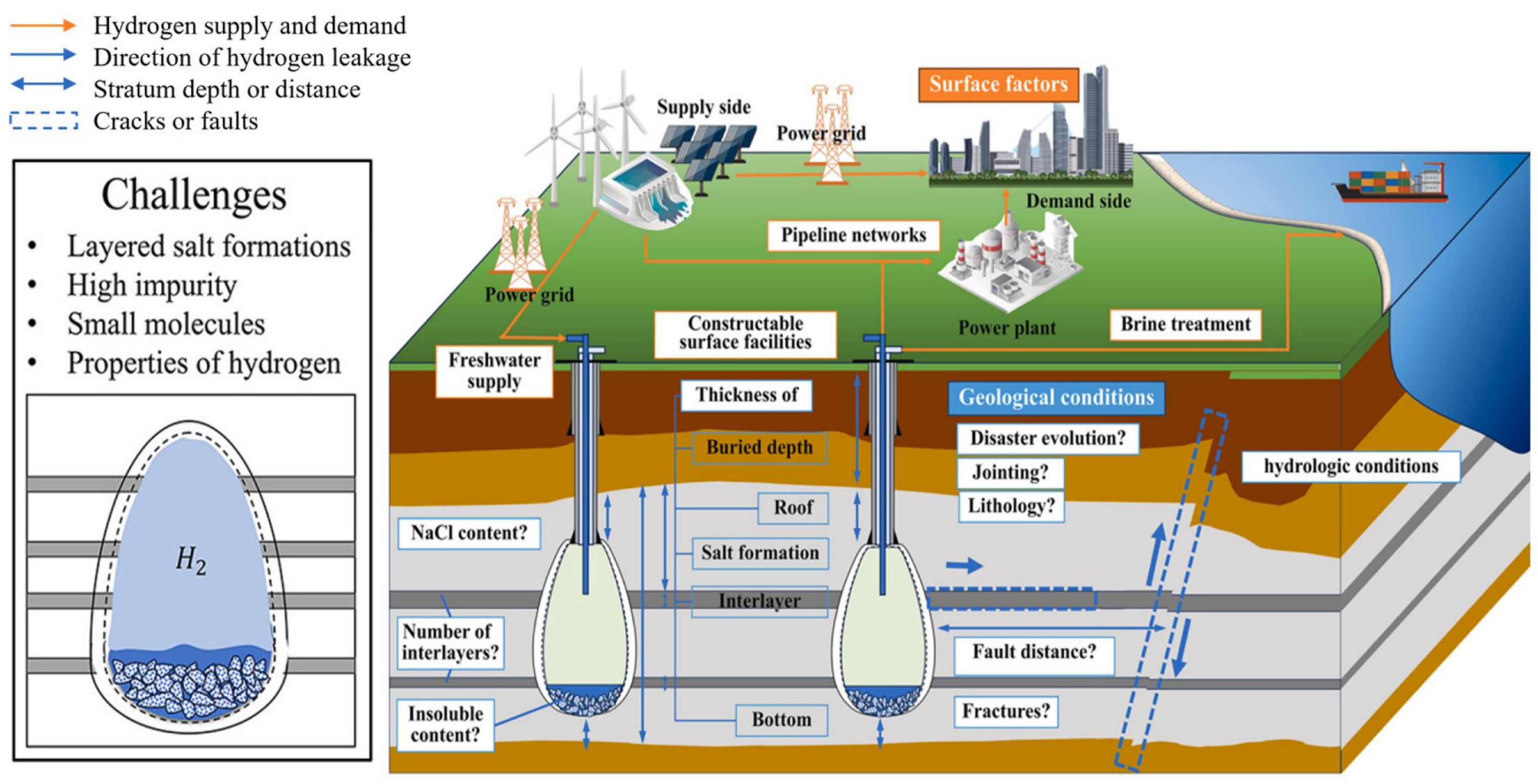
The challenge

Coupled effects of high temperature and pore pressure have become a central concern in the development of deep salt caverns [1].

- Depth increase leads to both temperature and stress rise and hence increase salt creep behaviour and structural stability [2].
- High temperatures accelerate deformation, thereby increasing the risk of fracture and leakage in the surrounding rock. Additionally, high pore pressure may weaken gas containment and intensify salt damage [3].

Therefore, ensuring long-term integrity and stability in deep salt caverns remains a pressing technical challenge.

Despite global reports of storage failures, the fundamental mechanisms driving these events are not yet fully elucidated. Salt caverns are governed by intricate **thermo-hydro-mechanical (THM)** couplings—driven by high in-situ stresses, thermal shifts, and osmotic gradients—necessitating sophisticated numerical frameworks to assess long-term structural integrity. **Consequently, geo-mechanical laboratory characterization is vital to define the physical constants required to calibrate and refine these CFD models.**



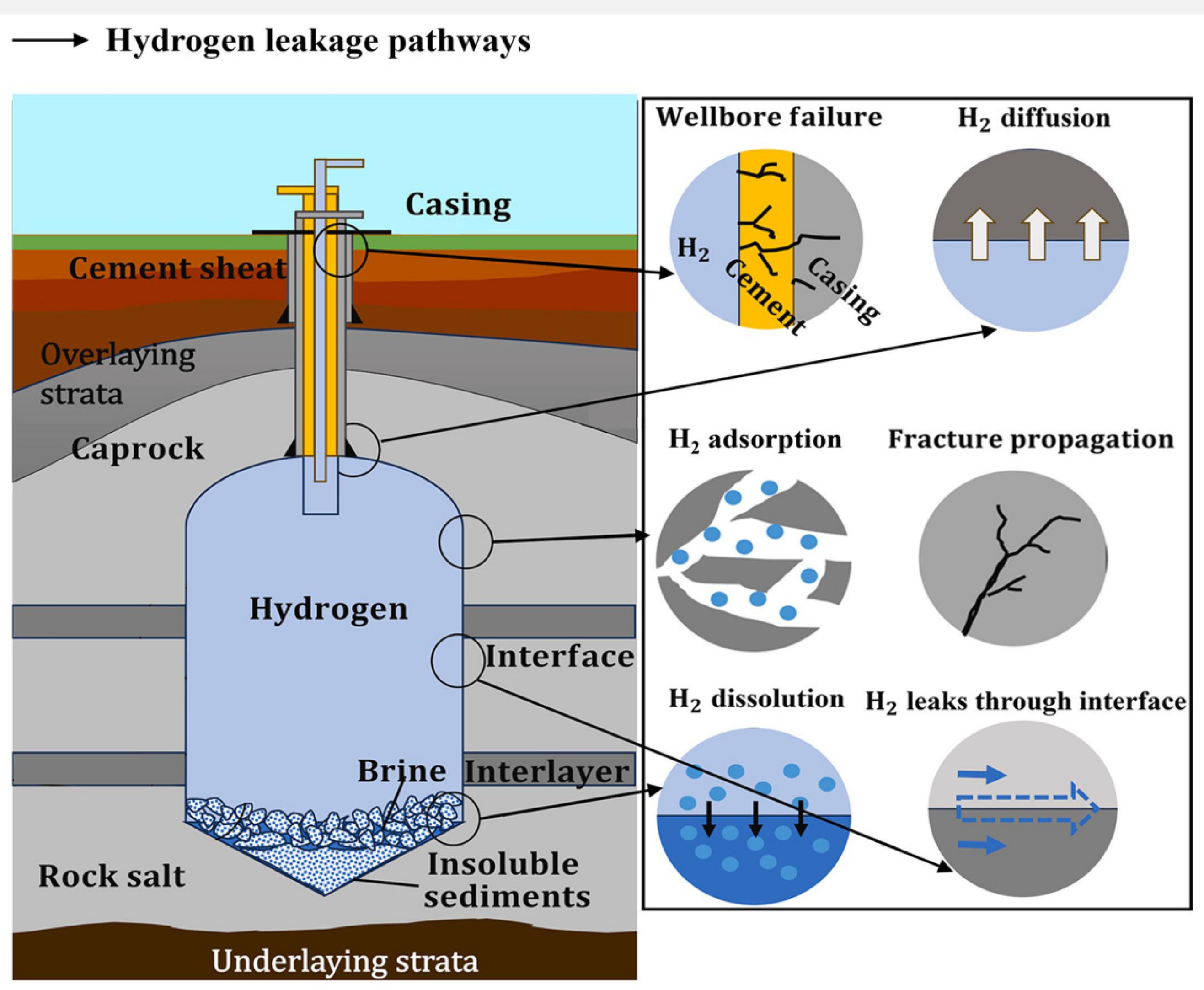
Technical challenges of hydrogen storage in layered evaporite rocks [4]

Our VISION:

To undertake a multi-parametric analysis of host evaporites (salts), specifically regarding geo-mechanical integrity and hydrogen's unique fluid dynamics. This will be achieved through deriving laboratory data to be fitted into computational fluid dynamics (CFD) modelling, using evaporite formations from the Central North Sea as a primary case study.

The integrity of hydrogen storage in salt formations is primarily threatened by five phenomena:

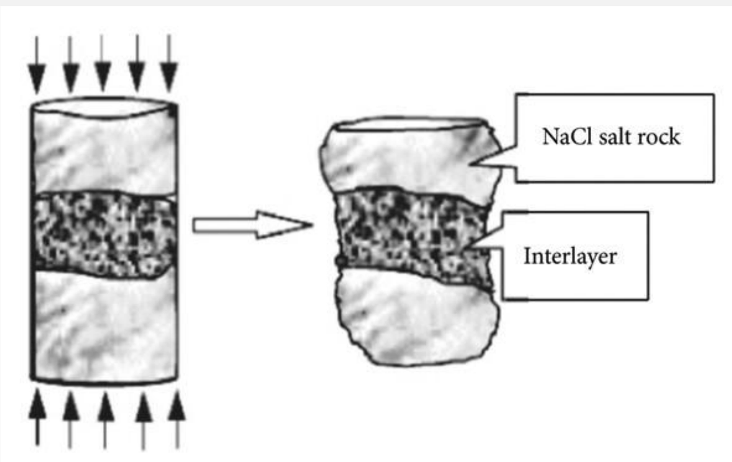
- mechanical wellbore compromise,
- molecular diffusion,
- chemical adsorption and dissolution,
- seepage through non-salt interlayers, and
- the development of fractures.



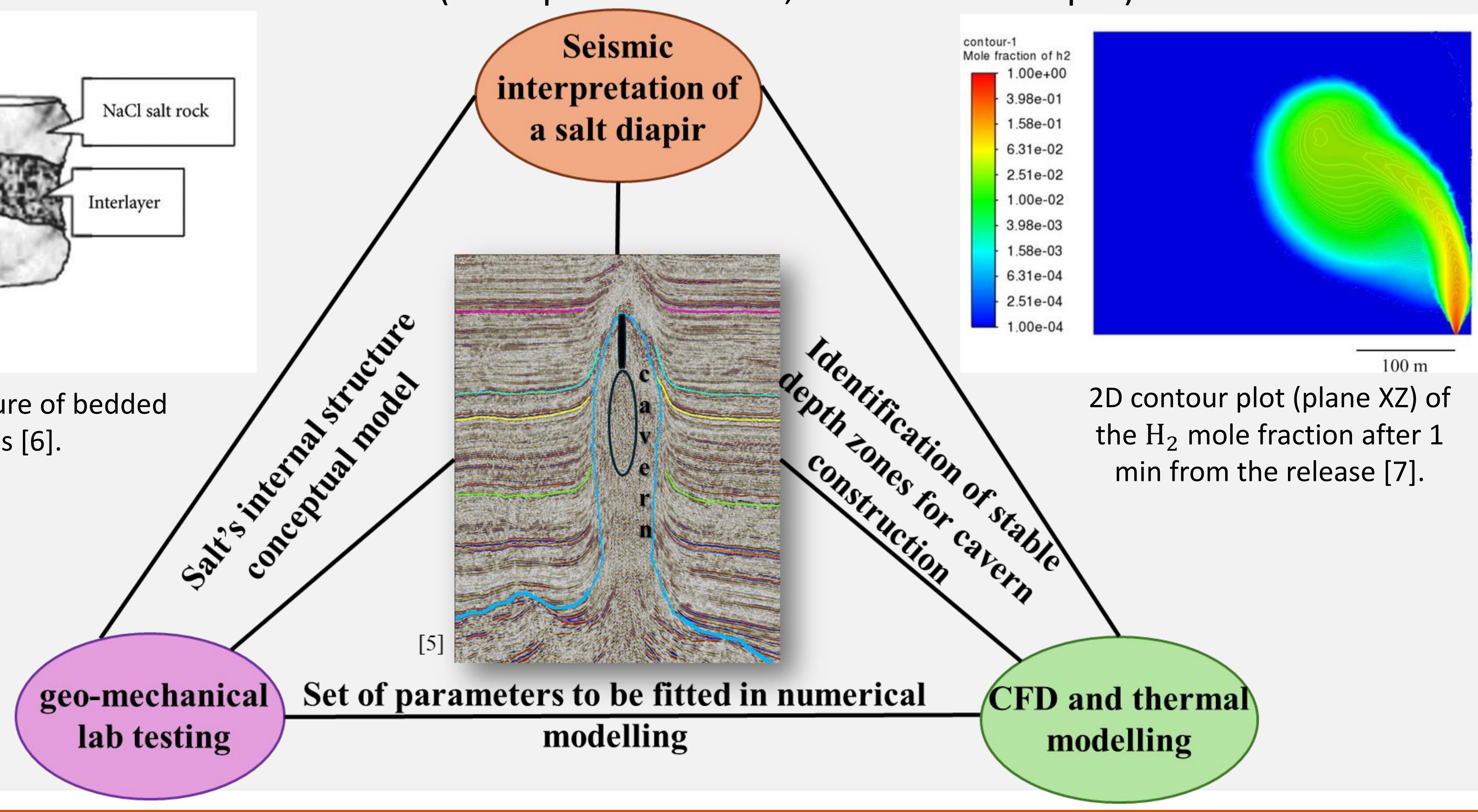
Hydrogen leakage pathways in salt caverns [4].

A fully coupled THM multi-physics model should incorporate the maximum tensile stress criterion, the Mohr-Coulomb failure envelope, and a temperature-dependent evolution of the elastic modulus for the salt formation. These can be measured in the lab through:

- Cyclic creep tests, where applied loads and temperatures are changed, to map long term deformation;
- P- and S-waves tests for Poisson's ratio and Young's modulus, to accurately define the conceptual model from seismic data interpretation;
- Permeability tests to assess the chemical-mechanical interactions and correlate porosity evolution with sealing capacity;
- Triaxial compression tests with strain gauges to precisely measure stress-strain curve/ test under different temperatures based on available well data and different stress/confining pressure to evaluate the effect on mechanical stress response;
- Thermal conductivity tests to refine boundary conditions for thermal modelling (C-Therm kit to measure at ambient and elevated Pc (2000 psi = 13.7 MPa, about 500 m depth).



Sketch of creep failure of bedded salt samples [6].



2D contour plot (plane XZ) of the H_2 mole fraction after 1 min from the release [7].

Acknowledgements. Authors would like to acknowledge Geosolutions for funding this project and NDR for seismic data supply (contains information provided by the North Sea Transition Authority and/or other third parties).

References: [1] L. Cheng et al. (2025). A coupled thermo-hydro-mechanical-damage model for salt cavern gas storage under long-term injection-withdrawal operations, Energy, Volume 335.; [2] C. Lyu et al. (2021). Study on very long-term creep tests and nonlinear creep-damage constitutive model of salt rock, Int J Rock Mech Min Sci, 146.; [3] C. Lyu et al. (2022). Mechanical characteristics and permeability evolution of salt rock under thermal-hydro-mechanical (THM) coupling condition, Eng Geol, 302. ; [4] Qian, X et al. (2025). Underground Hydrogen Storage in Salt Cavern: A Review of Advantages, Challenges, and Prospects. Sustainability 2025, 17, 5900; [5] M. Alsaya (2025). Investigating Potential Sites for Hydrogen Storage in Selected Salt Diapirs in the Central North Sea, UK, MSc Thesis; [6] Zhang, Q. et al. (2021). Creep properties and constitutive model of salt rock. Advances in Civil Engineering, 2021(1), 8867673; [7] Portarapollo et al. (2025). CFD-based risk assessment of underground hydrogen storage in salt caverns. Energy Storage, 117192.