Modelling Migration and Trapping of Natural Hydrogen in Sedimentary Basins

Kinedyn Solutions, Bremen, Germany

Integrated Geochemical Interpretation - UK

Javier García-Pintado
jgarciapintado@marum.de

Marta Gussinyer-Pérez

Tiago Abreu Cunha
tiago@igiltd.com

Marianne Nuzzo

Dan Cornford

Mischa Gehlen

OBJECTIVES

- Use box models to understand the mechanisms that control migration and trapping of H_2; efficient and extensive testing of model setups and parameters
- Compile quality-controlled gas databases and build a property model to assist in the interpretation of the geochemical systems
- Build basin-scale models to assist in exploration and de-risk prospects

MOTIVATION

Hydrogen usage in the energy mix is predicted to increase 5-10 fold in the next 50 years, and natural H2 exploration involves low water and energy consumption

There is widespread evidence of natural hydrogen occurrences (generation), migration and seeps

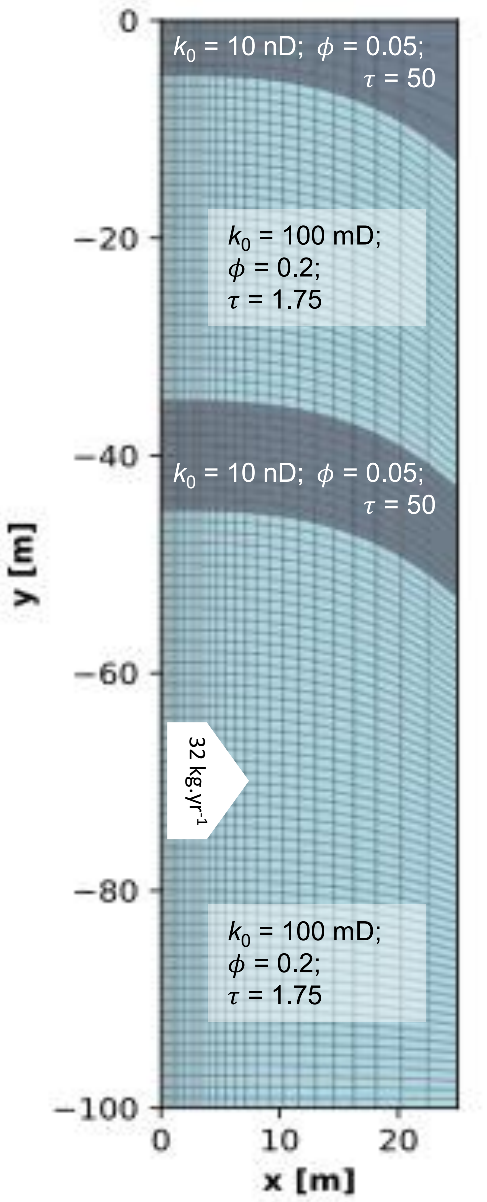
There are only sparse evidence of high H2 concentrations in sediments and crystalline rock underground

The development of fully-coupled, poroelasto-plastic models, is key to understand migration and trapping of H2 and associated gases in the subsurface.

Box-Size Numerical Experiments on H_2 Migration and Trapping: Model Setup

- 25 m * 100 m, high-resolution box model with two lower permeability zones
- Injection of 32 kg/yr of H_2 on the lower-left side for 40 yr
- P-T top boundary conditions at 1500 m,
- Linear geothermal gradient of 30°C/km with 10 °C surface temperature

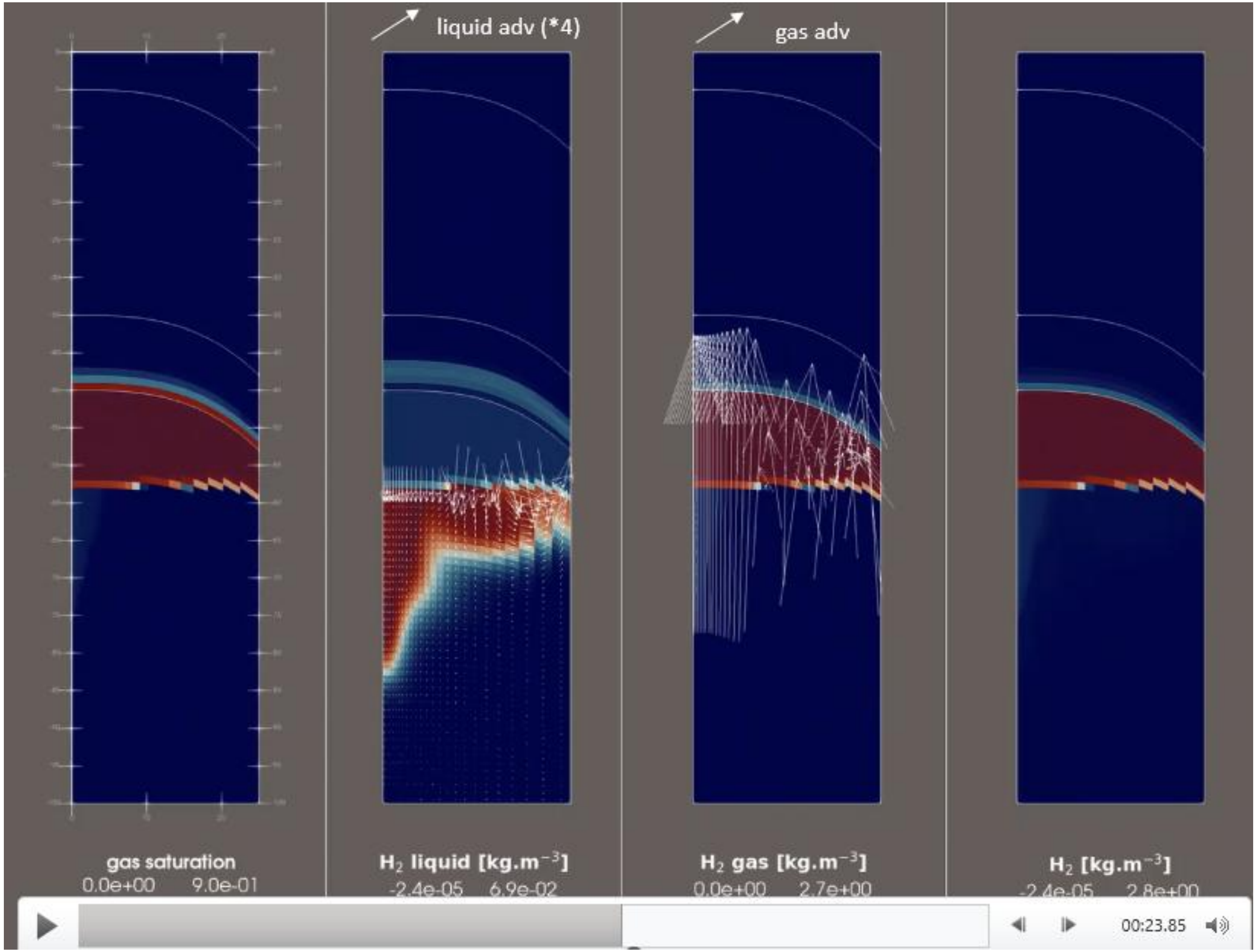
- Fully-coupled, poroelastic-plastic models, with feeds-backs between pore-pressure and mechanical deformation
- Two-phase flow with pure water and Hydrogen components
- Equations of state for density, viscosity & specific enthalpy
- Migration by diffusion and advection in gas & liquid phase
- Henry coefficient (temperature-dependent) controlling the equilibrium between the gas and dissolved mass fractions
- Corey (1954) effective-saturation dependent relative permeability; residual saturations are 0.15 for liquid and 0.05 for gas
- Van Genuchten (1980) capillary pressure-saturation



Garcia-Pintado *et al.* (H-NAT Summit, Paris 2025)

Box-Size Numerical Experiments on H_2 Migration and Trapping

- The injected H2 migrates upward until it reaches the firs seal barrier
- The dissolved H2 quickly reaches critical saturation, exsolves and develops a gas accumulation
- Accumulated gas beneath the seal displaces the liquid
  - Strong fluid dynamics at gas-liquid interface
- After ~10 yr, the reservoir reaches the spill point
- After 40yr injection model predicts 1200 kg H_2 gas column, 25 kg dissolved H_2 and 40 kg loss via spill
- Tests with CH_4 predict advection velocities approximately 3x lower.
- Some H_2 percolating the seal (advancing diffusion front?)



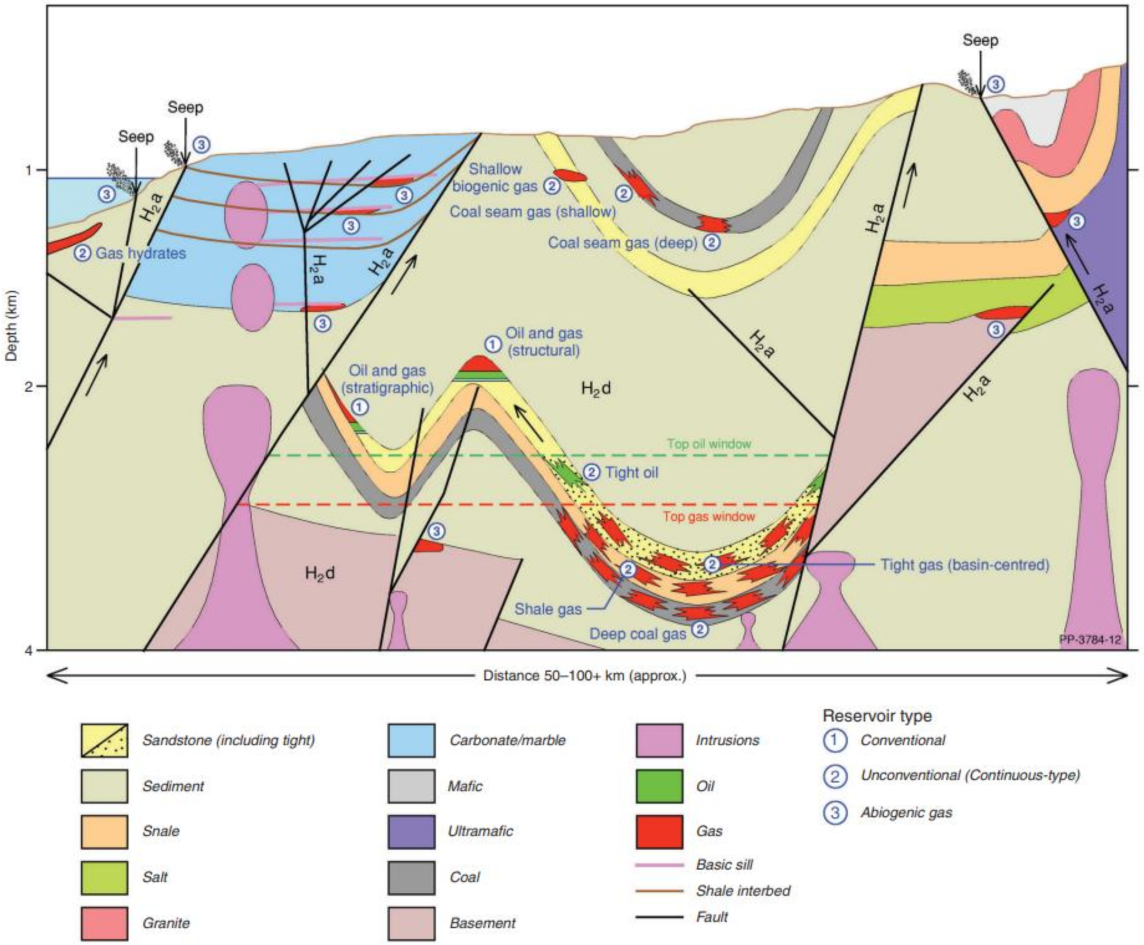
Next Steps with Box-Size Numerical Experiments and Going Natural

Next steps in the box (test) models

- ❑ Run the models over geological timescales
- ❑ Parameterize other processes, such as adsorption, biological sinks and hydrodynamics
- ❑ Test multiple gases systems (ie. H_2O, H_2 and CH_4)
- ❑ Test sensitivities to a variety of realistic geological setting, such as lithologies, P-T conditions and H_2 generation rates

Going natural

- ❑ Build basin-scale models
- ❑ Compile gas (compositions, isotopes) datasets
- ❑ Calibrate the models to observations/data
- ❑ Test model scenarios to assist (de-risk) natural hydrogen exploration
- ❑ Test scenarios to assist induced hydrogen exploration



From Boreham *et al.* (2021)

Project Timeline

Time / Project elements	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Databasing of gas geochemistry	■	■						
Geochemical interpretation		■	■	■				
Sensitivity tests with box-size models	■	■	■					
Basin structural-thermal setup		■	■					
Basin-scale model: Analysis of model requirements			■	■				
Basin-scale model: Implementation of model components			■	■	■			
Basin-scale model: Integration and numerical testing				■	■	■		
Basin-scale model: Testing of model scenarios						■	■	■
Analysis of model results & reporting							■	■

Data and Inputs

- Available gas geochemistry and isotopic data. Where available we can also use the publicly available geochemistry data.
- A basin transect with interpreted stratigraphic horizons, lithologies and structural elements. Ideally, the model would be built along a depth converted seismic profile where we could define all elements of the play.
- Borehole data if available, including reports and logs, and temperature data for thermal calibration of the mode

Main Deliverables

- Gas geochemistry and isotopic database in pIGI format (also available in Excel and ASCII formats, as required)
- Geochemistry interpretation in PPT and PDF formats, providing an insight on the gas systems and their maturity, sources and sinks.
- All plots, videos and final report on the numerical model, with interpretation of results, insights on the tested modelling scenarios, and analysis of risk in the potential hydrogen prospects.
- Workshops with the Team every 3 months (or as requested) to discuss the work progress and the strategy moving forward.

Kinedyn software

- Any modification of Kinedyn software that may be required to achieve the project deliverables during the duration of this project will remain the sole intellectual property of Kinedyn Solutions

Project Cost

- The total cost of the study is USD 120,000 (exclusive of tax and any travelling expenses, billed at cost).

R&D Project Team

Dr. Tiago Cunha: Senior petroleum systems analyst, with 15+ years' experience in BPSM, integrating geology, geochemistry and geophysical data in sedimentary basins worldwide.

Dr Marianne Nuzzo : Senior organic- and bio-geochemist with over 20 years of experience in gas and petroleum with a specialism in hydrocarbon gas geochemistry. She has been working for the Oil & Gas (O&G) industry since 2013.

Dr. Dan Cornford: Experienced statistician with 30 years (20 academic, 10+ industrial) experience in machine learning, uncertainty quantification, model calibration and data assimilation. A firm believer in pragmatic Bayesian approaches to using data and models.

Dr. Javier Garcia-Pintado: Mining Engineer, with 20+ years of experience in code development and modelling of various components of the Earth system, including hydrogeology, flood-forecasting and geodynamic-hydrological interactions. Strong experience in model-data integration and data assimilation.

Prof. Marta Perez-Gussinye: Geophysicist with 25+ years of experience in seismic methods and geodynamical modelling. Published several seminal papers on the development of passive margins and the mechanics of lithospheric deformation. Recent research encompasses the implications of geodynamics for natural H2 production.