Understanding caprock behavior during underground hydrogen storage in depleted gas fields

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Introduction and Background

- Global demand for hydrogen is expected to increase several folds, primarily driven by the transition to a sustainable energy-fueled future.
- Increased demands requires cost-effective storage solutions, especially as current bulk storage options require capital and maintenance intensive large surface metal containers.
- The geologic subsurface, especially depleted oil and gas reservoirs provide a unique opportunity for cost-effective underground hydrogen storage (UHS) at bulk scale.
- Effective UHS operations depends on the integrity of the caprocks which acts as a seal to hold the gas in place. The stored hydrogen can be prone to volumetric loss via. the pore-space in the caprock, quantifying which is the focus of this work.

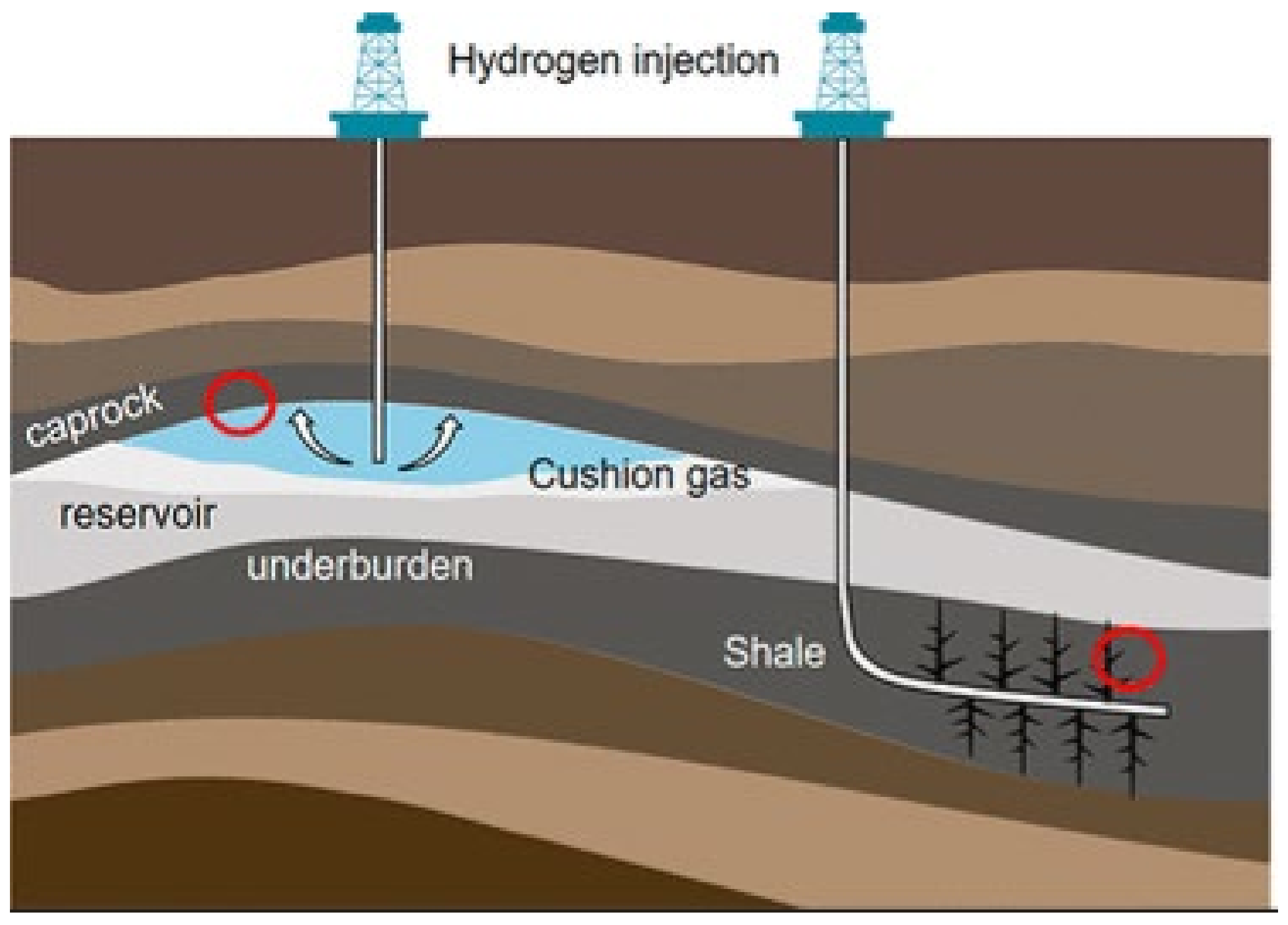

Fig 1: Schematic showing a depleted oil and gas field for UHS (Liu et al. 2022).

Research Aim

This work aims to evaluate changes in the porosity and permeability of the Marcellus and Wolfcamp shale caprocks during underground hydrogen storage in depleted gas fields.

Materials and Methods

- *Figure 2* presents the experimental procedure implemented to evaluate the effect of (dry and pure) hydrogen exposure to the petrophysical properties of the shale samples.

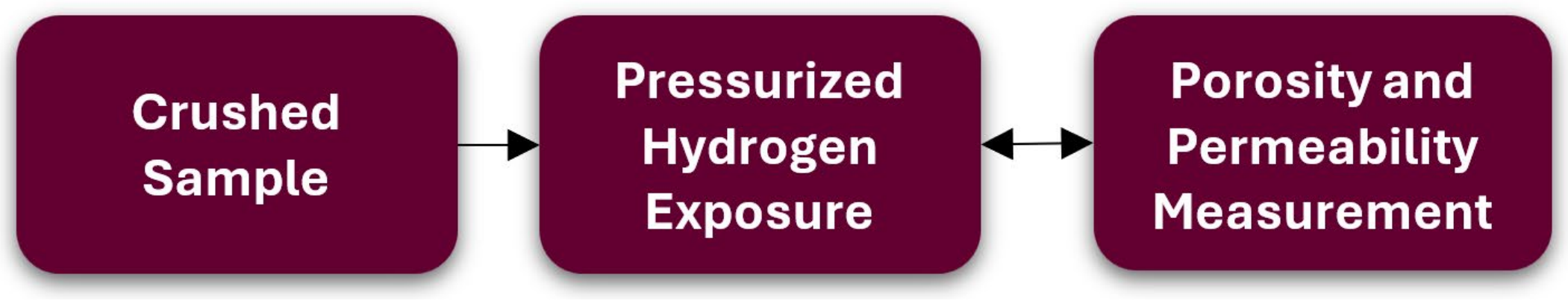

Fig 2: Schematic of the experimental procedure.

- The pressure reactor used for hydrogen-shale exposure experiment is shown in *Figure 3*. The shale samples were exposed to hydrogen at 1000 psia and 32°C.
- *Figure 4* presents the pycnometer setup used for porosity (Φ) and permeability (k) measurements.

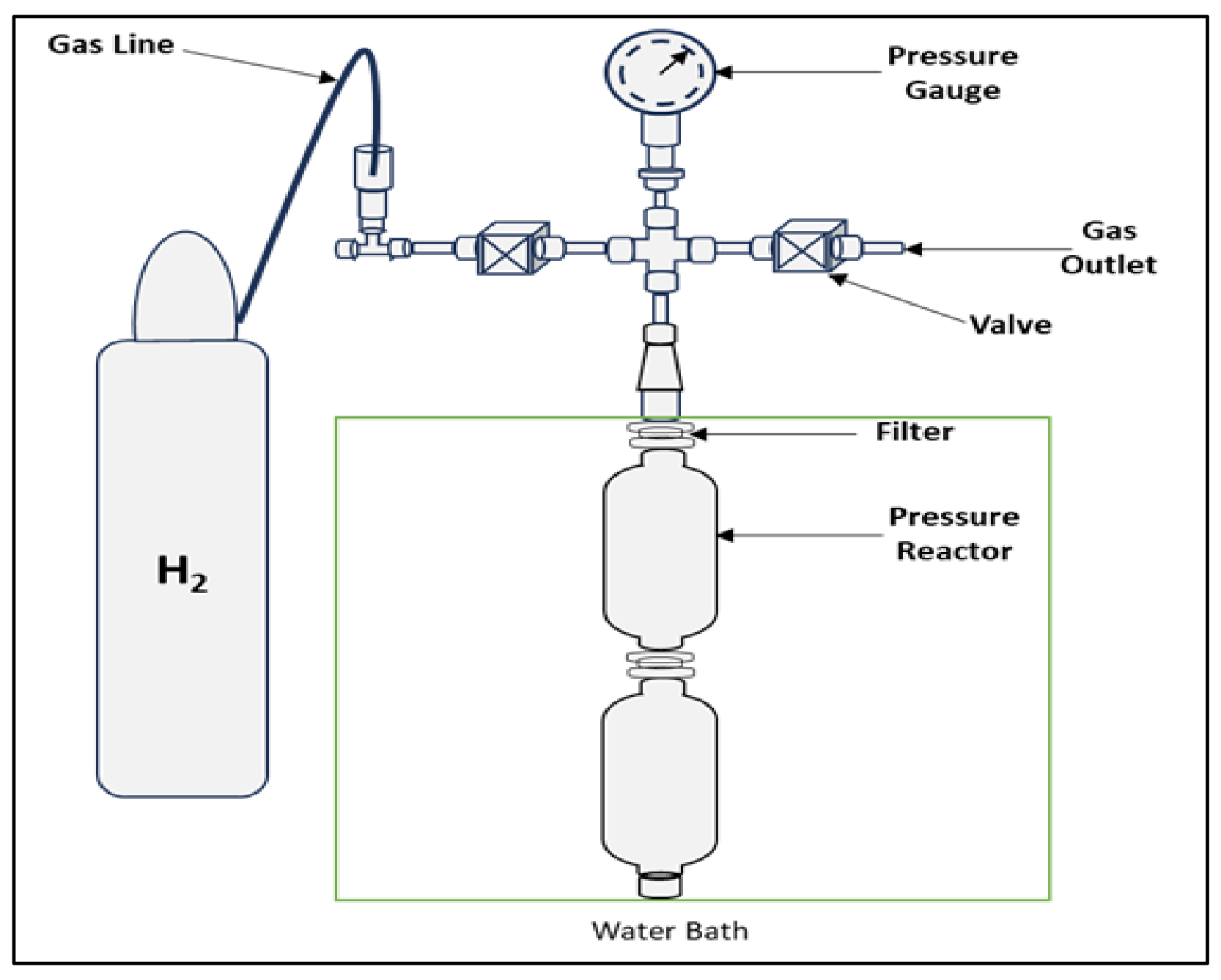

Fig 3: Setup for shale-hydrogen exposure.

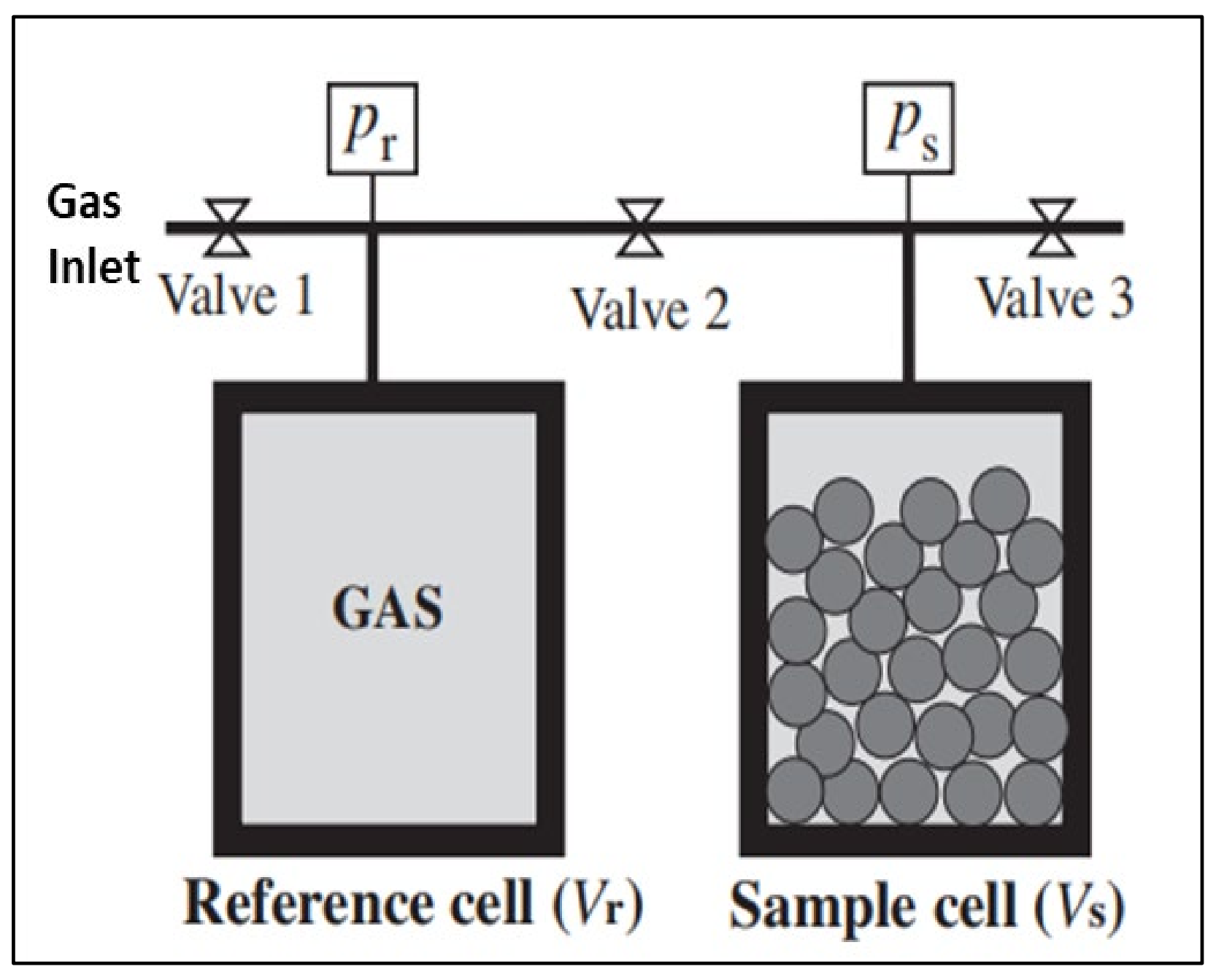

Fig 4: Pycnometer setup (Cui et al., 2009).

- The stepwise procedure along with a simplified pressure decay curve for the gas research institute (GRI) unsteady state permeability measurement is displayed in *Figure 5* below.
- Helium at ~200 psi is injected into the reference cell and allowed to reach equilibrium, following which gas from the reference cell is allowed to expand into the sample cell by opening valve 2.
- As gas starts to permeate through the sample, the headspace pressure continues to decrease until equilibrium is reached. The Φ and k is then calculated using Cui et al.'s (2009) late time method.

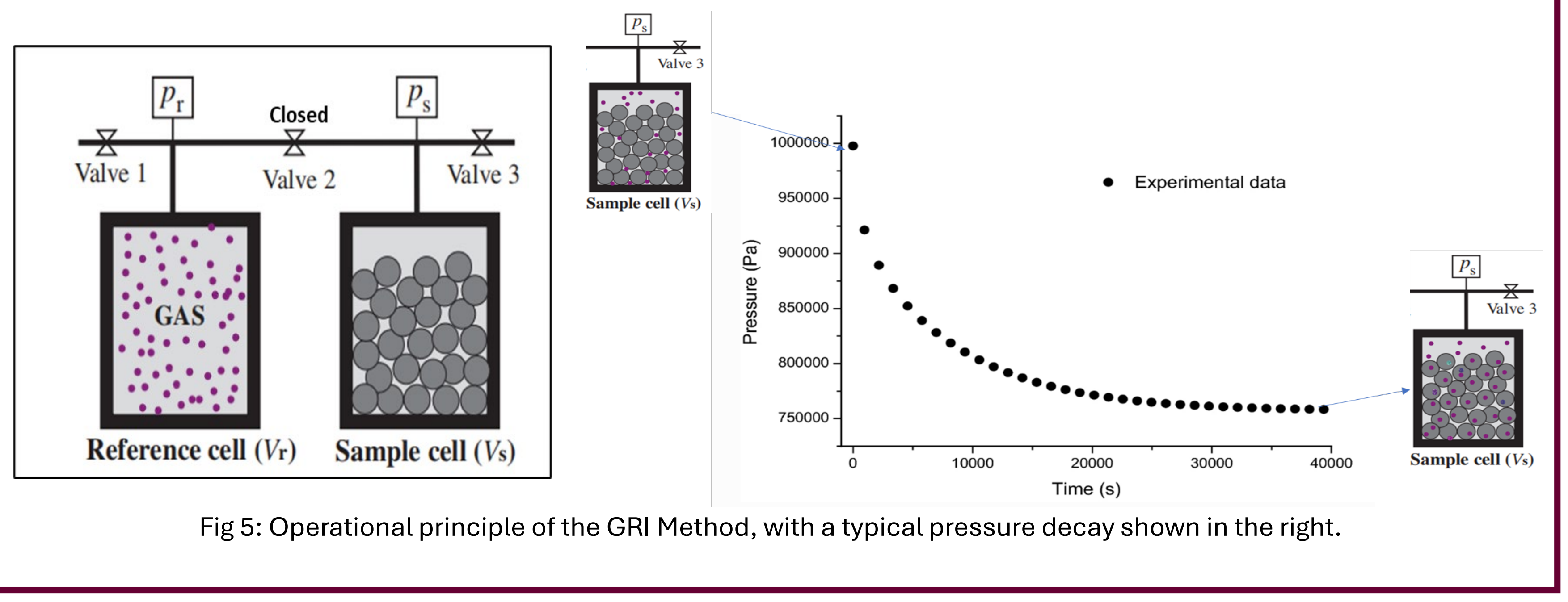

Fig 5: Operational principle of the GRI Method, with a typical pressure decay shown in the right.

Results

- *Figures 6* and *7* depicts the normalized pressure decay for the Marcellus and Wolfcamp shales respectively, whose responses to hydrogen exposure are very different:
  - Marcellus shale shows a *continued increase* in pressure-decay with increased exposure time.
  - Pressure decay for Wolfcamp shale remained *relatively similar* with continued exposure.
- The corresponding Φ and the k values, as shown in *Figure 8* reveals that at the end of 90 days:
  - Marcellus Φ and k *increased* by ~2.36 and 1.8 times its original value respectively.
  - Wolfcamp Φ and k remained *relatively constant* over 90 days of hydrogen exposure.
- *Figure 9* also shows that hydrogen exposure *decreased the tortuosity in Marcellus shale*. This is unlike in Wolfcamp, where flow paths stayed relatively unchanged.
- Additionally, the thermogravimetric analysis (TGA) of the shales, shown in *Figure 10* indicate:
  - No major H_2-induced chemical change (mineral dissolution, precipitation, etc.).
  - Implying any *changes in Φ and k are physical in nature*.
- XRD data in *Figure 11*, indicate a diverse mineral distribution, especially clays in Marcellus shale. This implies:
  - The mechanical effect of injection and depletion creates microfractures, likely along the multiple grain interfaces, especially in Marcellus shale.

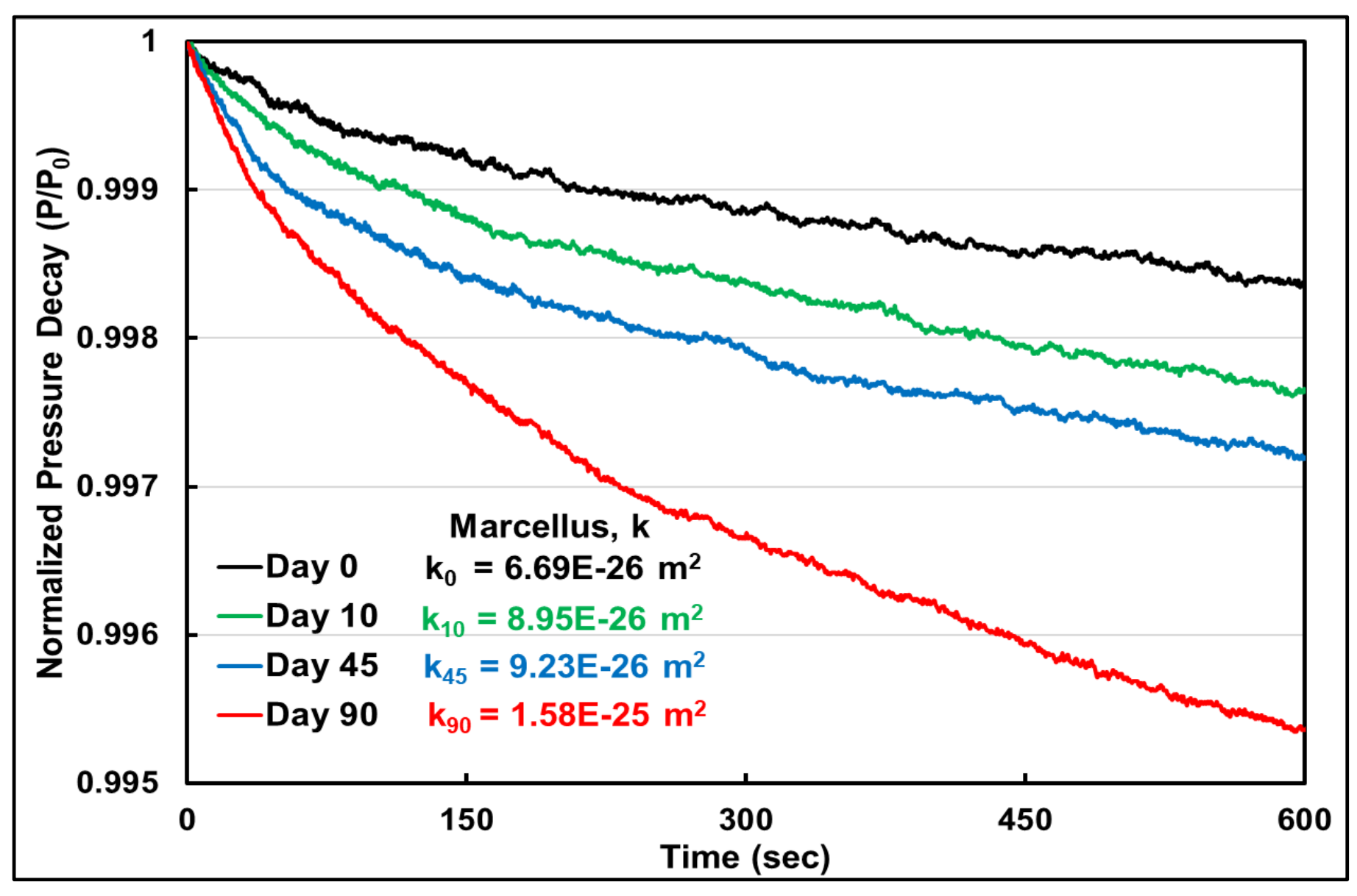

Fig 6: Normalized pressure decay curves with time for Marcellus.

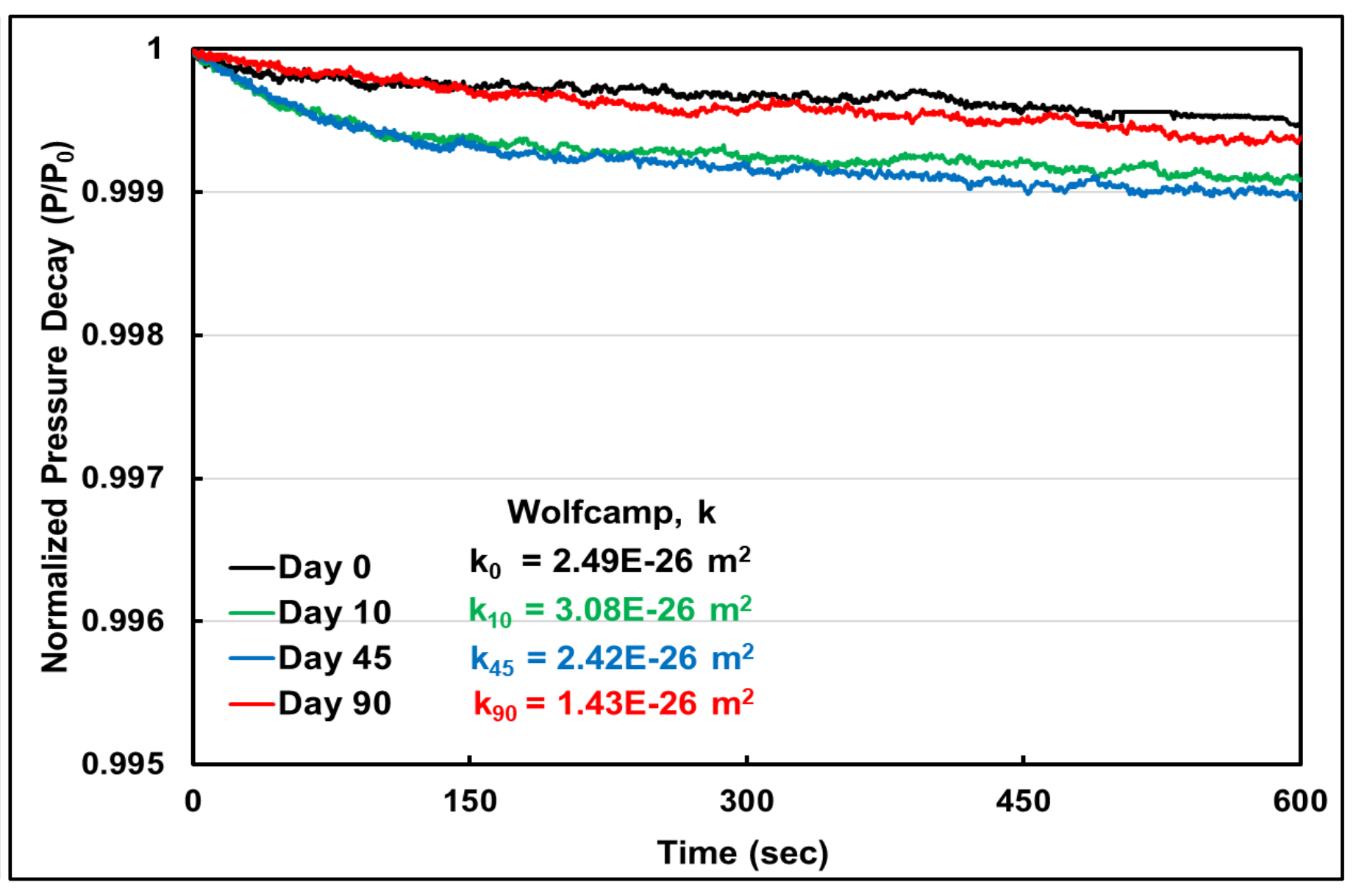

Fig 7: Normalized pressure decay curves with time for Wolfcamp.

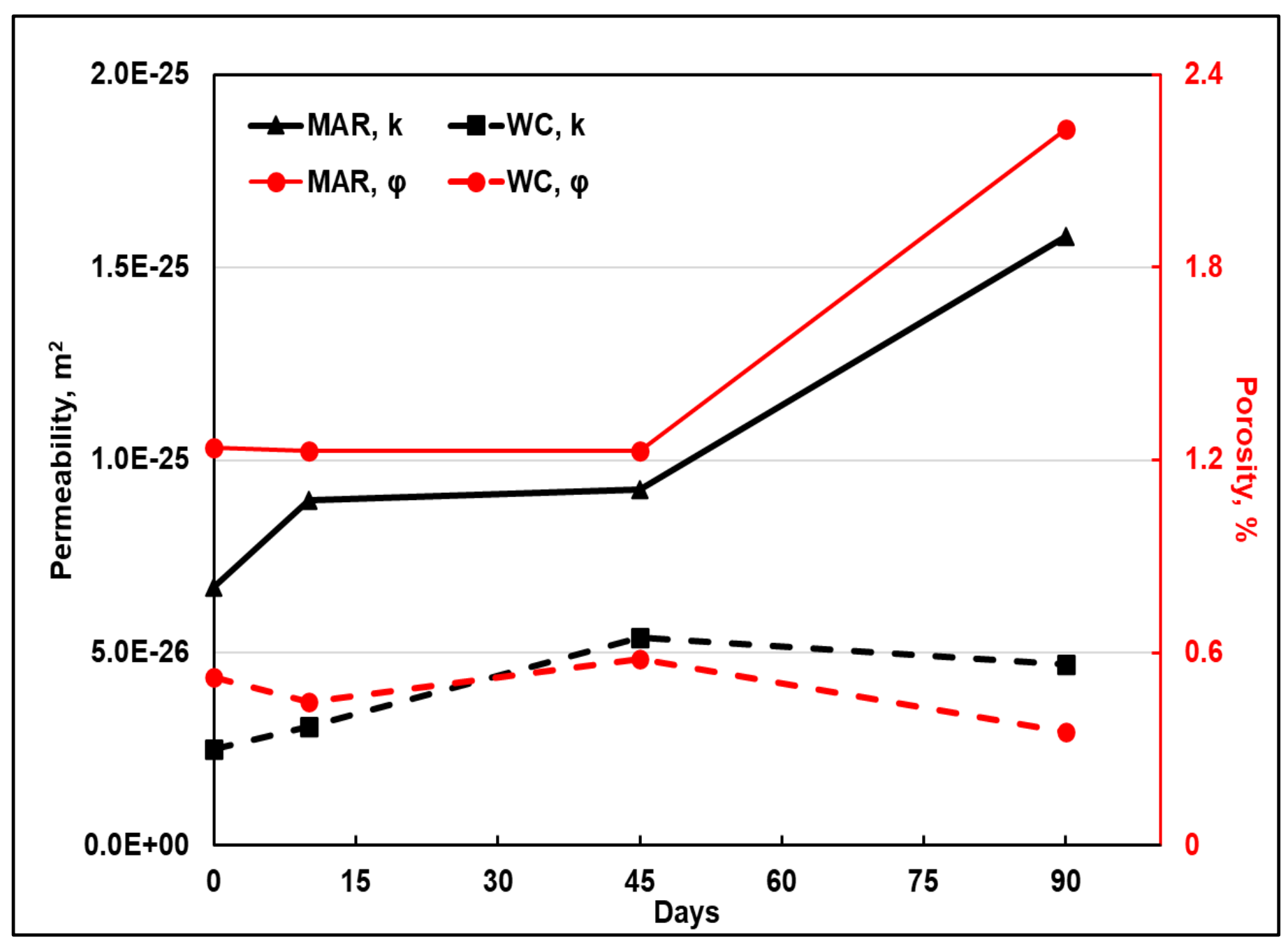

Fig 8: Marcellus and Wolfcamp shale **k** and **ϕ** evolution.

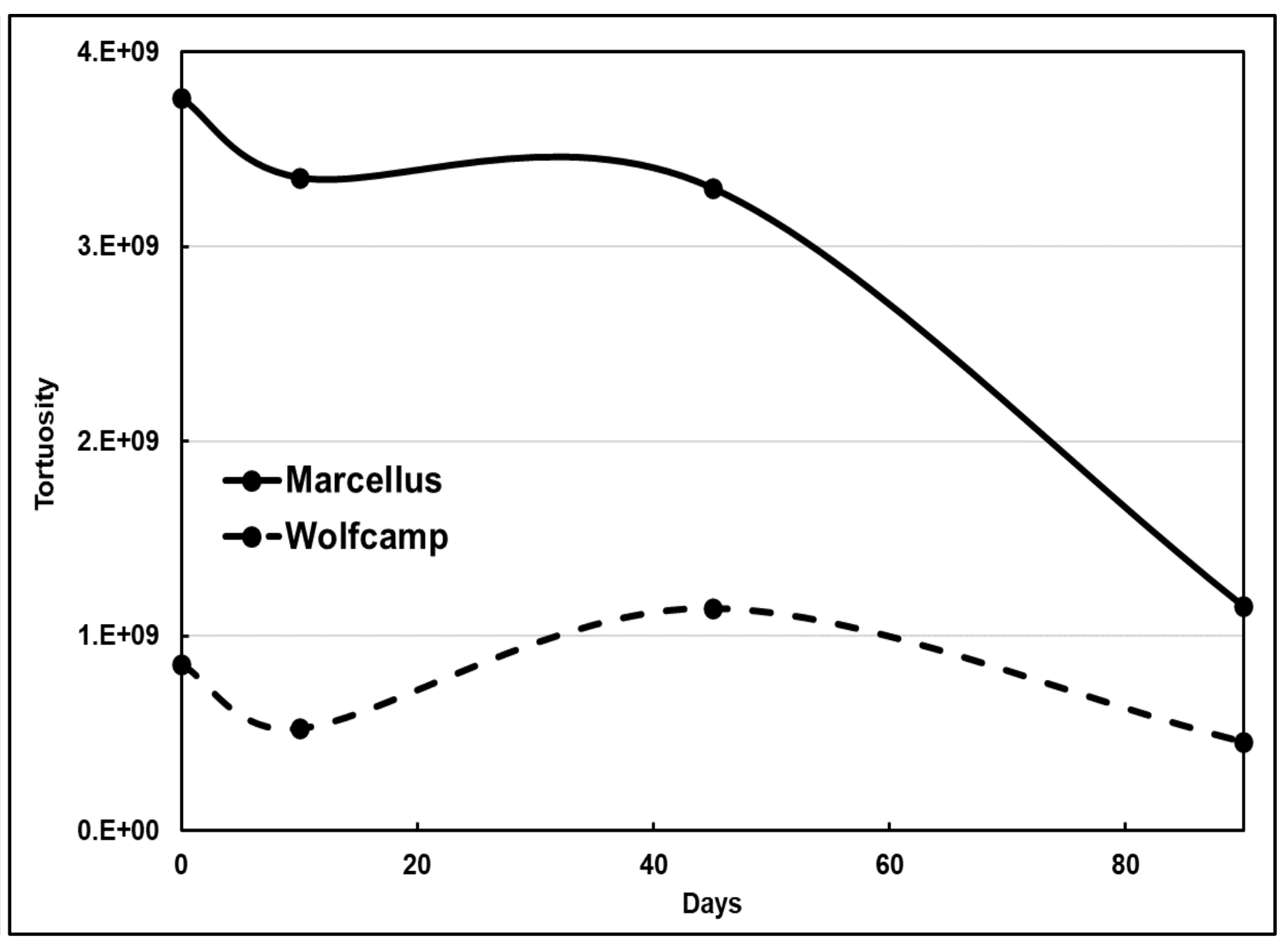

Fig 9: Marcellus and Wolfcamp shale tortuosity evolution.

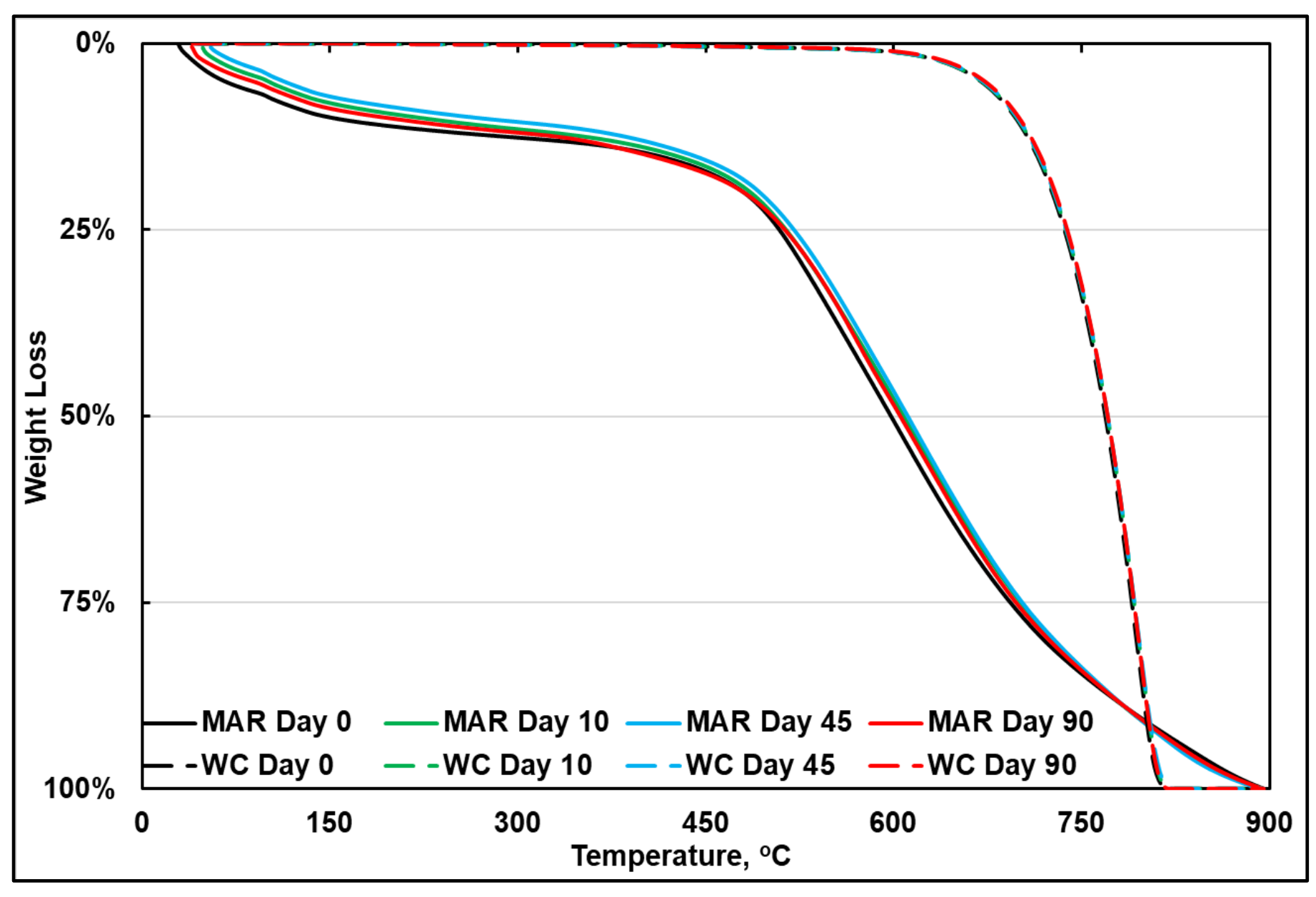

Fig 10: Marcellus and Wolfcamp shale TGA evolution.

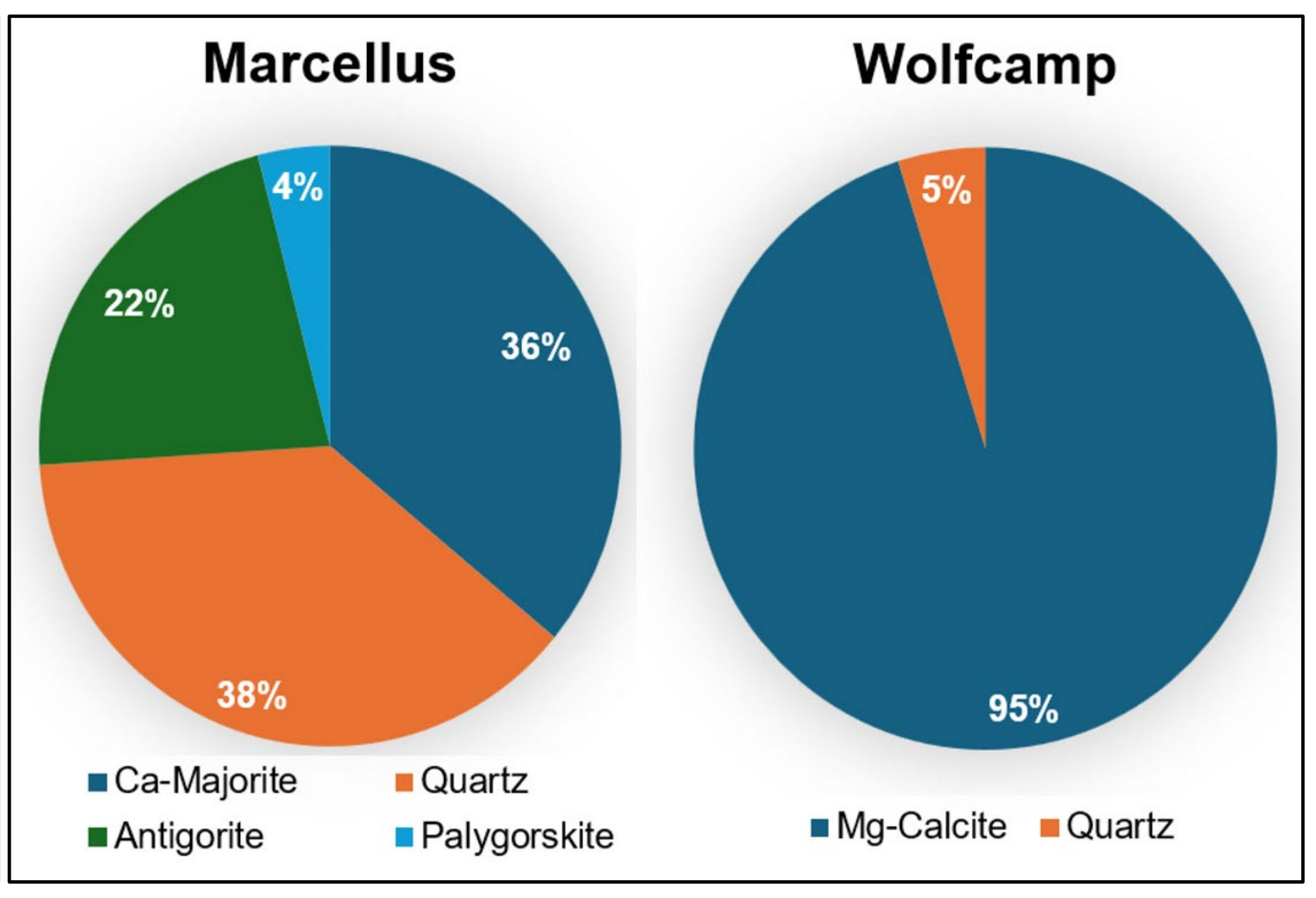

Fig 11: XRD mineralogy for Marcellus and Wolfcamp shales.

Conclusion

- For the first time, changes in matrix porosity and permeability was observed in shale caprocks due to continued hydrogen exposure.
- The observed changes in the pore-structure is primarily physical in nature.
- The impact of hydrogen exposure to the petrophysical properties also depends on the type of shale. Preliminary results indicate shales with limited mineral complexity are better suited for UHS.
- Failure to consider the increase in matrix permeability, as commonly practiced in reservoir simulations would underestimate hydrogen loss through the shale caprock.

References

- Liu, J., Wang, S., Javadpour, F., Feng, Q., & Cha, L. (2022). Hydrogen Diffusion in Clay Slit: Implications for the Geological Storage. Energy & Fuels, 36(14), 7651-7660. https://doi.org/10.1021/acs.energyfuels.2c01189
- Cui, X., Bustin, A. M. M., & Bustin, R. M. (2009). Measurements of gas permeability and diffusivity of tight reservoir rocks: different approaches and their applications. Geofluids, 9(3), 208-223. https://doi.org/https://doi.org/10.1111/j.1468-8123.2009.00244.x

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