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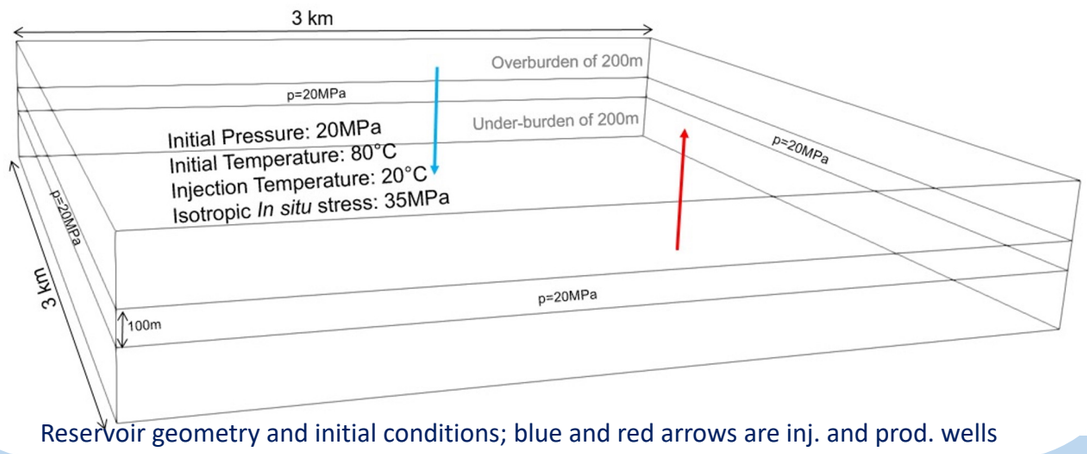
Fracture Spacing, Matrix Permeability, and Mechanical Feedbacks: Key Drivers of Heat Recovery in Geothermal Reservoirs

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INTRODUCTION

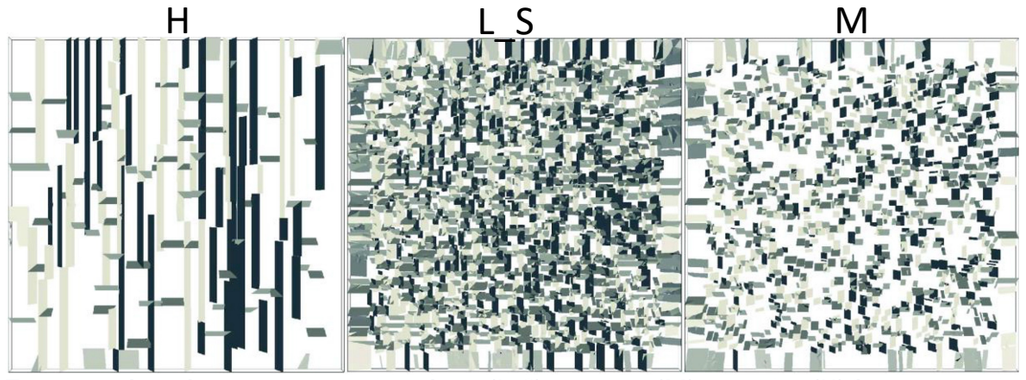
Enhanced Geothermal Systems (EGS) extract heat from deep subsurface rocks by circulating fluids through engineered fracture networks [1]. Efficiency and sustainability depend on fracture spacing [2], matrix permeability, and thermal–hydraulic–mechanical (THM) feedbacks [3, 4]. Recent advances in fully coupled THM modeling show that mechanical deformation, fracture connectivity, and fracture–matrix interactions significantly alter flow pathways and heat recovery, challenging earlier assumptions based on static fracture geometries. Understanding these dynamic processes is essential for optimizing EGS design and maximizing long-term energy extraction.



Reservoir geometry and initial conditions; blue and red arrows are inj. and prod. wells

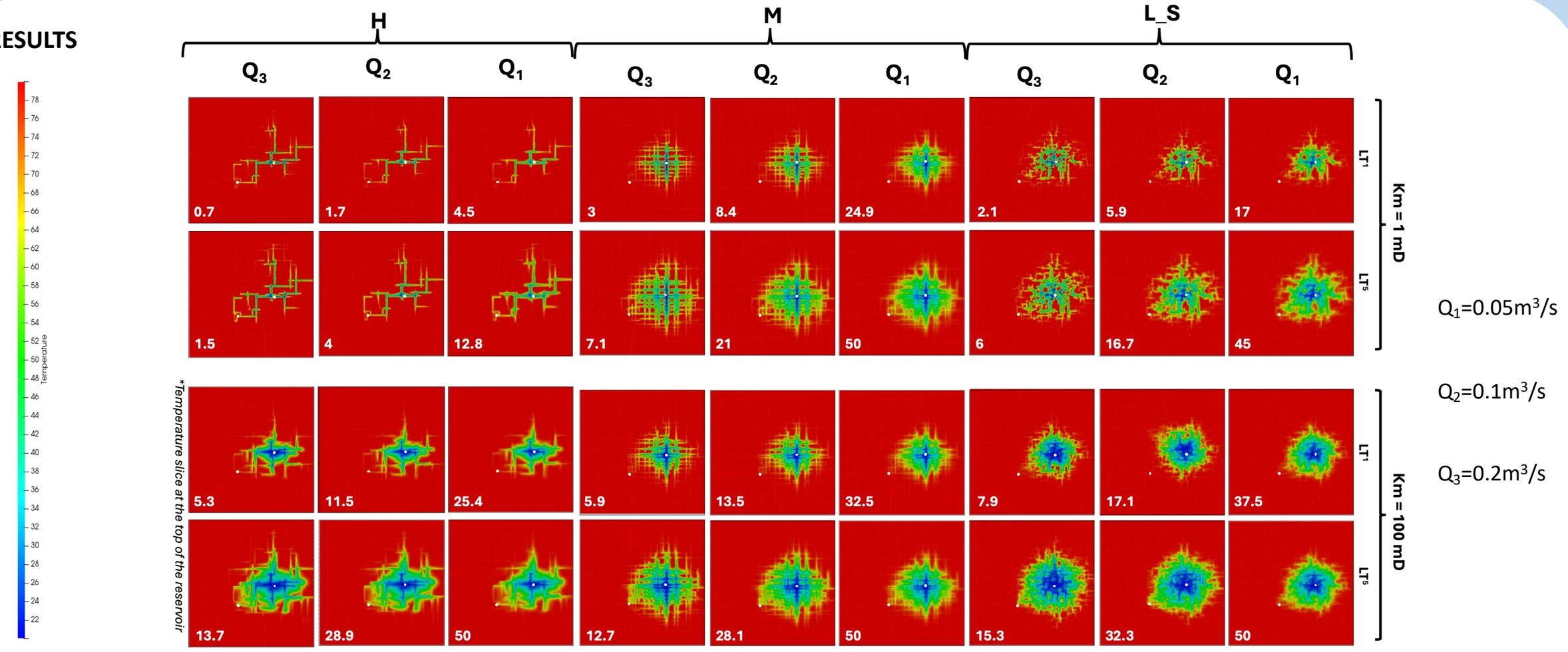
METHODS

A fully coupled finite element THM model was employed to simulate non-isothermal flow and mechanical deformation in fractured geothermal reservoirs [1]. Fractures were generated with different configurations [5] and represented as surface discontinuities within a 3D matrix, and their apertures evolved according to contact stress using the Barton–Bandis model [6,7]. Simulations considered a doublet system with cold-water injection and hot-water production under varying fracture spacing, matrix permeability, and injection rates. Boundary conditions allowed lateral flow, while top and bottom boundaries were sealed. Key performance indicators (KPIs) such as lifetime, net energy, and coefficient of performance were computed over a 50-year operational period.

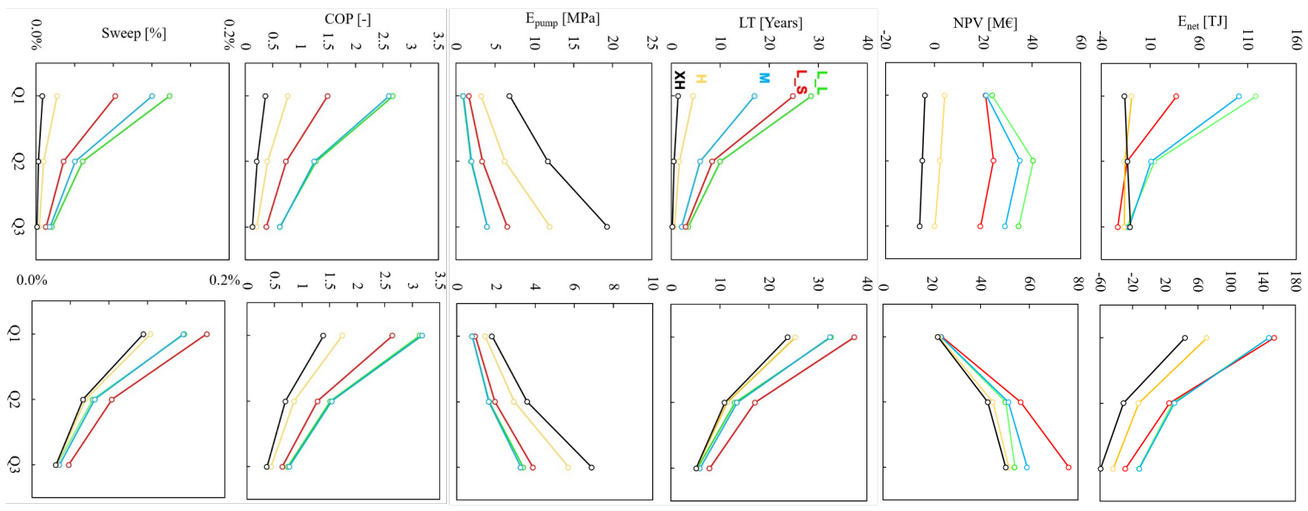


Top view of the fracture geometries of low (L_S), medium (M), and high (H) fracture spacing.

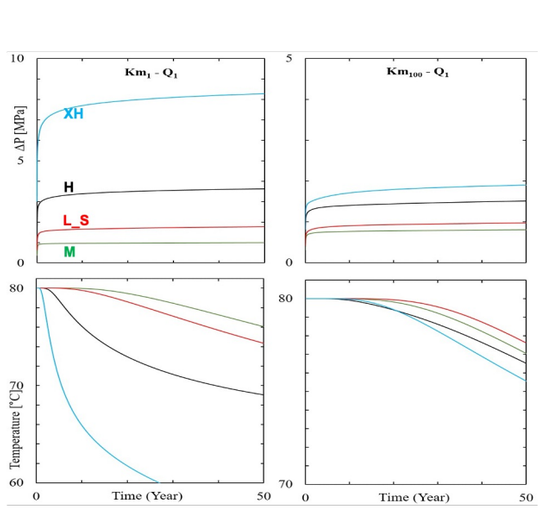
RESULTS

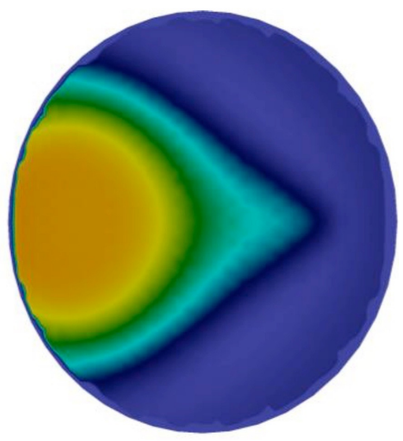


Temperature field for different matrix permeability and injection rates. The location of the wells and four laterals are shown with white points. Lifetime is depicted with bold white font for both 1 & 5^{oC} temp. decline.



KPIs (heat sweep, coefficient of performance, required pump energy, lifetime, NPV, and net energy production) calculated for all the scenarios.





Spatial distribution of aperture induced by cold injection [1, 4]

DISCUSSION

The findings underscore the critical role of fracture geometry [7], aperture [8] and matrix properties in geothermal system design. Mechanical deformation amplifies flow channeling, particularly in reservoirs with low matrix permeability, where fracture–matrix heat transfer is essential. While higher injection rates may temporarily boost energy output, they accelerate thermal breakthrough and shorten system lifetime. Neglecting THM interactions can lead to optimistic forecasts, risking premature cooling and economic underperformance. Design strategies should therefore integrate THM coupling and optimize fracture spacing and injection rates to balance energy recovery and sustainability.

CONCLUSION

Heat recovery in fractured geothermal reservoirs is fundamentally controlled by fracture spacing, fracture aperture matrix permeability, and mechanical feedbacks. Fully coupled THM models are indispensable for reliable performance prediction and system optimization. Future EGS development should prioritize fracture network design and operational strategies that enhance long-term energy extraction while minimizing environmental and operational risks

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