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# Geomechanical Simulation of $CO_2$ Injection in Fractured Granite Formations at the St John's Dome (SJD): A Dual-Permeability Coupled Modeling Approach

**Jacqueline Adjimah[1,2], William Ampomah[1,2], Najmudeen Sibaweihi[2], and Abdul-Malik Alahassan[1,2]**

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[1]New Mexico Tech
[2]Petroleum Recovery Research Center

## Abstract

This study investigates the geomechanical response of fractured granite at the St. John's Dome (SJD) during long-term $CO_2$ injection using a dual-permeability coupled modeling framework. A fully coupled 3D finite-element model was developed to simulate fracture-controlled flow and mechanical deformation, with granite represented as an elasto-plastic medium governed by the Mohr–Coulomb failure criterion. $CO_2$ injection at 1 MMTPA for 30 years was followed by a 30-year monitoring period. Results show pressure buildup and volumetric strain localized near injection wells, while surface subsidence remained minimal and spatially uniform. Supercritical $CO_2$ dominated storage, with additional structural and solubility trapping. The results demonstrate that fractured crystalline reservoirs can provide mechanically stable and secure long-term $CO_2$ storage.

## Conclusion

- Pressure increase localized near injection wells.
- Fracture-dominated flow controls $CO_2$ plume migration.
- Volumetric strain concentrated in near-well regions.
- Surface subsidence minimal, confirming mechanical stability.
- Geomechanical coupling critical for accurate risk assessment.

## References

David, C., Nejati, M., & Geremia, D. (2020). On petrophysical and geomechanical properties of Bedretto Granite. ETH Zurich.

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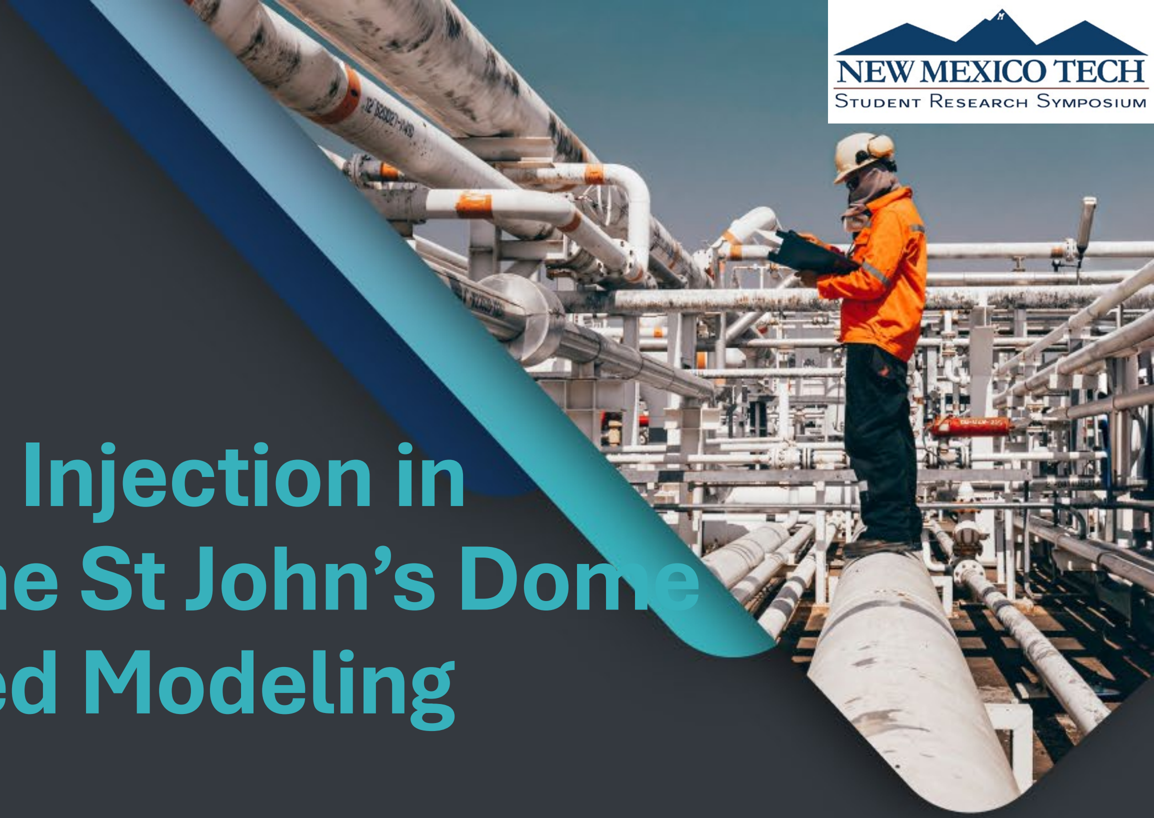

# Geomechanical Simulation of $CO_2$ Injection in Fractured Granite Formations at the St John's Dome (SJD): A Dual-Permeability Coupled Modeling Approach


By: Jacqueline Margaret Adjimah
Dr. William Ampomah
Dr. Najmudeen Sibaweihi
Abdul-Malik Alahassan

# Outline

- Context
- Objectives
- Methods
- Model Setup
- Results
- Implications
- Conclusion
- Backup

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# Context

- Crystalline basement like granite provides a mechanically competent but low-permeability storage medium.
- Fluid transport is dominated by discrete fracture networks.
- $CO_2$ injection perturbs pore pressure and alters the in-situ stress field.
- Coupled hydrodynamic–geomechanical analysis is required to evaluate containment integrity.
- St. John’s Dome offers a natural analog for $CO_2$-rich systems.

# Geological Framework of the SJD Natural $CO_2$ Reservoir

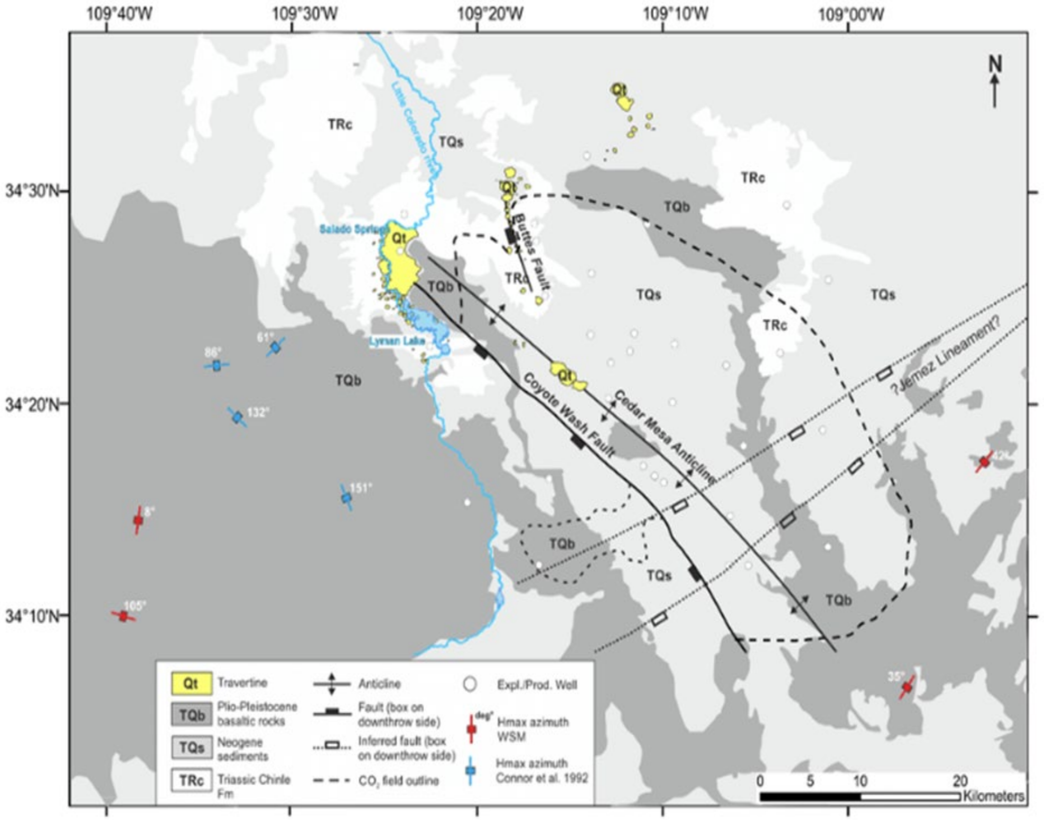


*Fig 1: Geological map of the St. Johns Dome natural CO2 reservoirs*

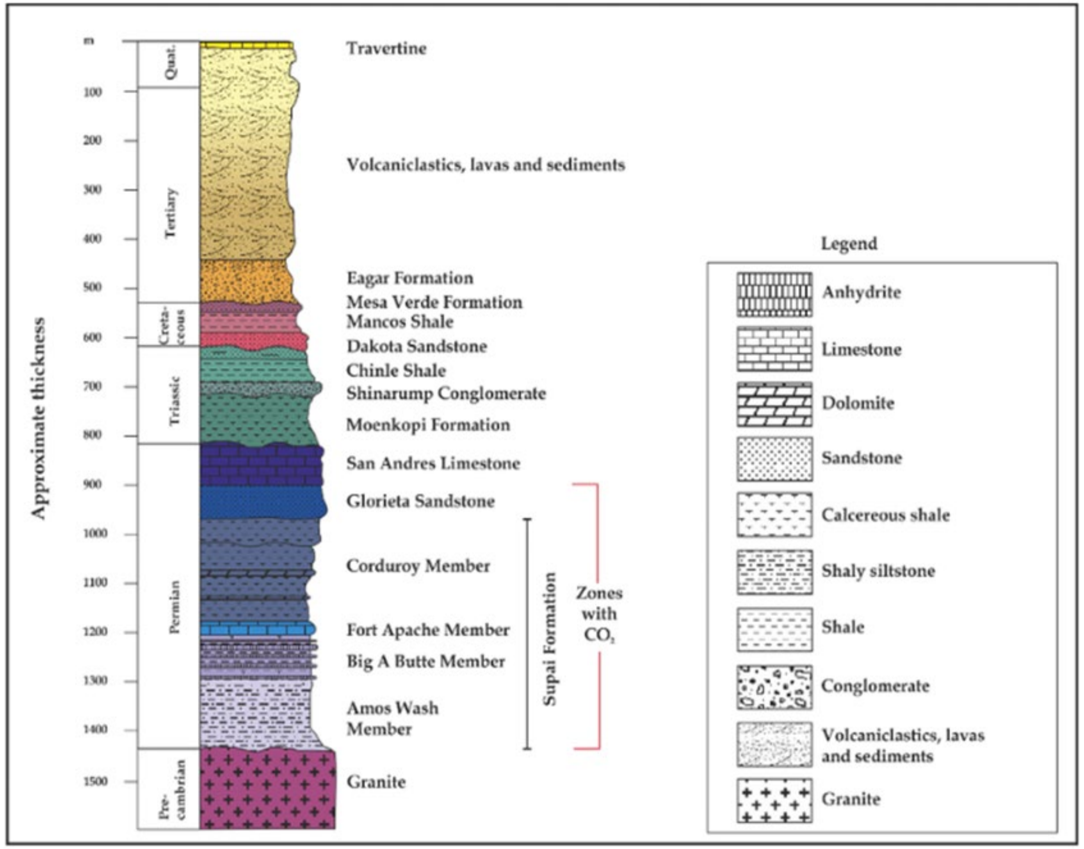


*Fig 2:General stratigraphic column of the St. Johns-Springerville area*

*Picture courtesy by research gate.net*

# Objectives

- Evaluate geomechanical response during $CO_2$ injection.
- Quantify pressure, strain, and deformation evolution.
- Assess fracture-controlled flow and containment integrity.
- Improve predictive capability using dual-permeability modeling.

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# Methods

- Fully coupled 3D hydrodynamic–geomechanical simulation.
- Dual-permeability representation of fracture and matrix.
- Mohr–Coulomb elasto-plastic failure model.
- Injection: 1 MMTPA for 30 years; monitoring for 30 years.

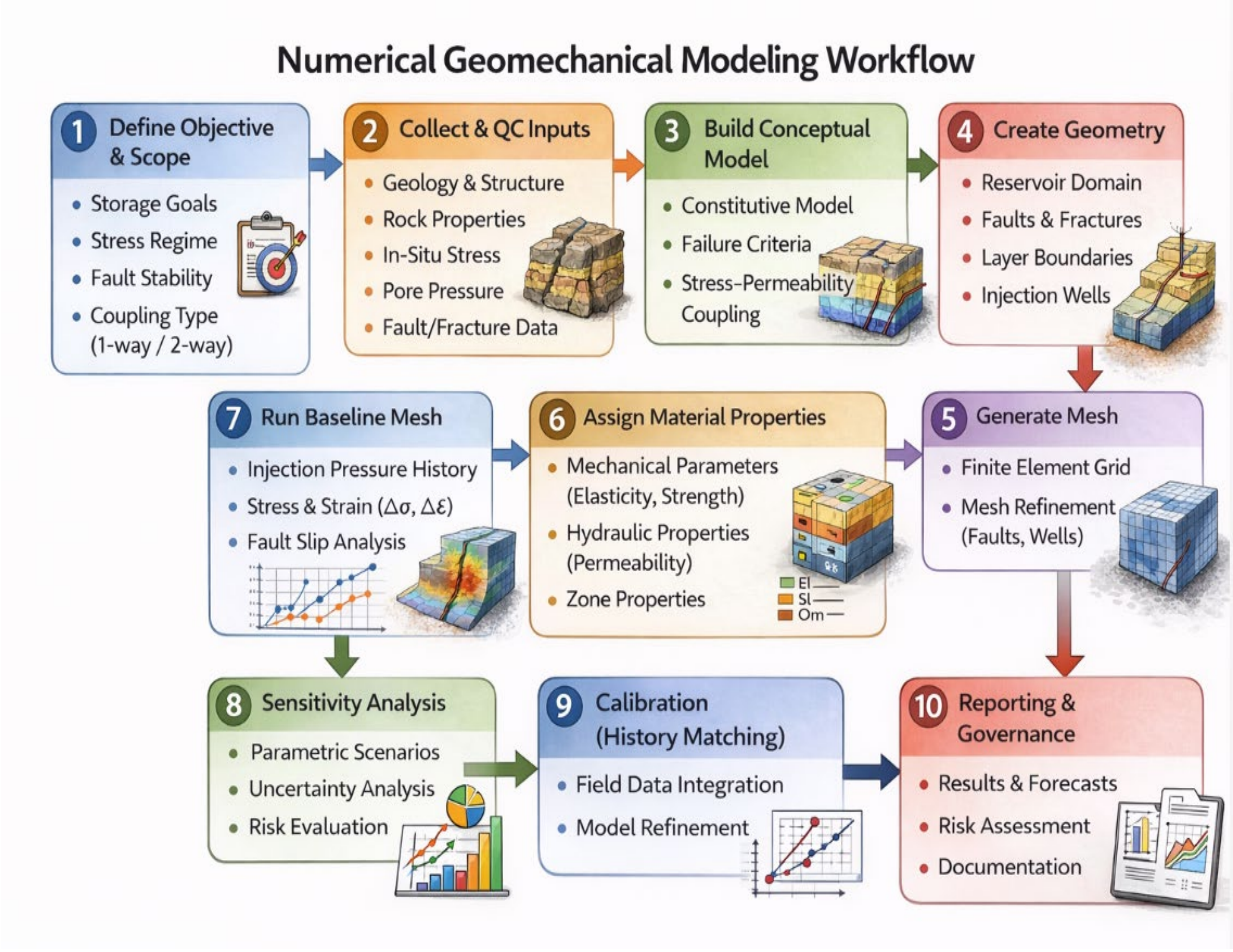


Fig 3:Integrated Modeling Workflow

# Model Setup & Simulation Domain

- Three injection wells in fractured granite basement.
- Boundary conditions include overburden and lateral stress.
- Hydrostatic pore pressure initialization.
- Mesh and timestep sensitivity verified.
- Outputs: pressure, strain, displacement.

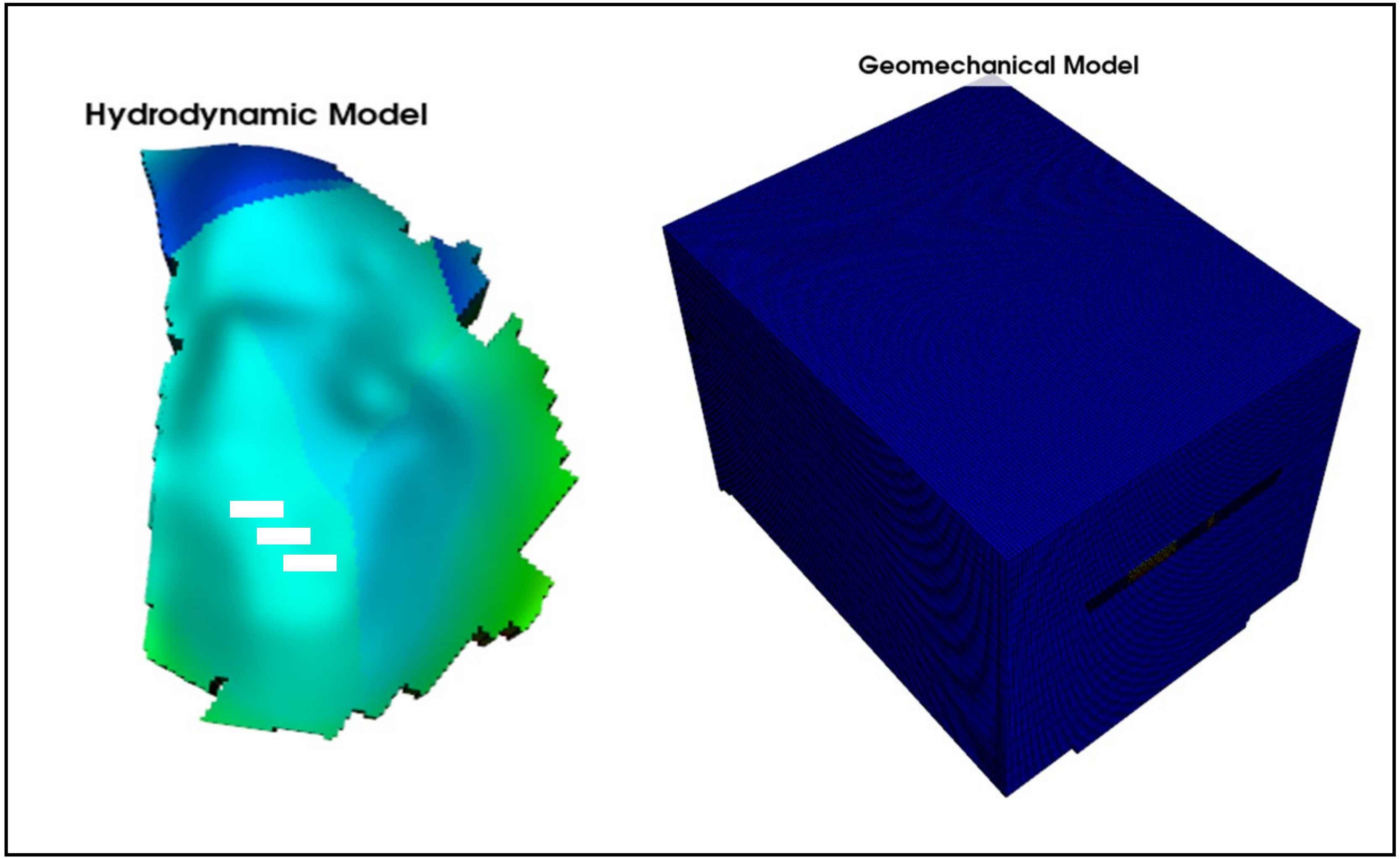


Fig 4: Coupled simulation domains for flow and geomechanics

# Results

## Pressure & $CO_2$ Migration

- $CO_2$ migration controlled primarily by fracture network.
- Pressure buildup localized near injection wells.
- Preferential flow was along high-permeability fracture corridors.
- Limited pressure propagation into intact matrix.

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# Pressure Evolution Due to Geomechanical Coupling

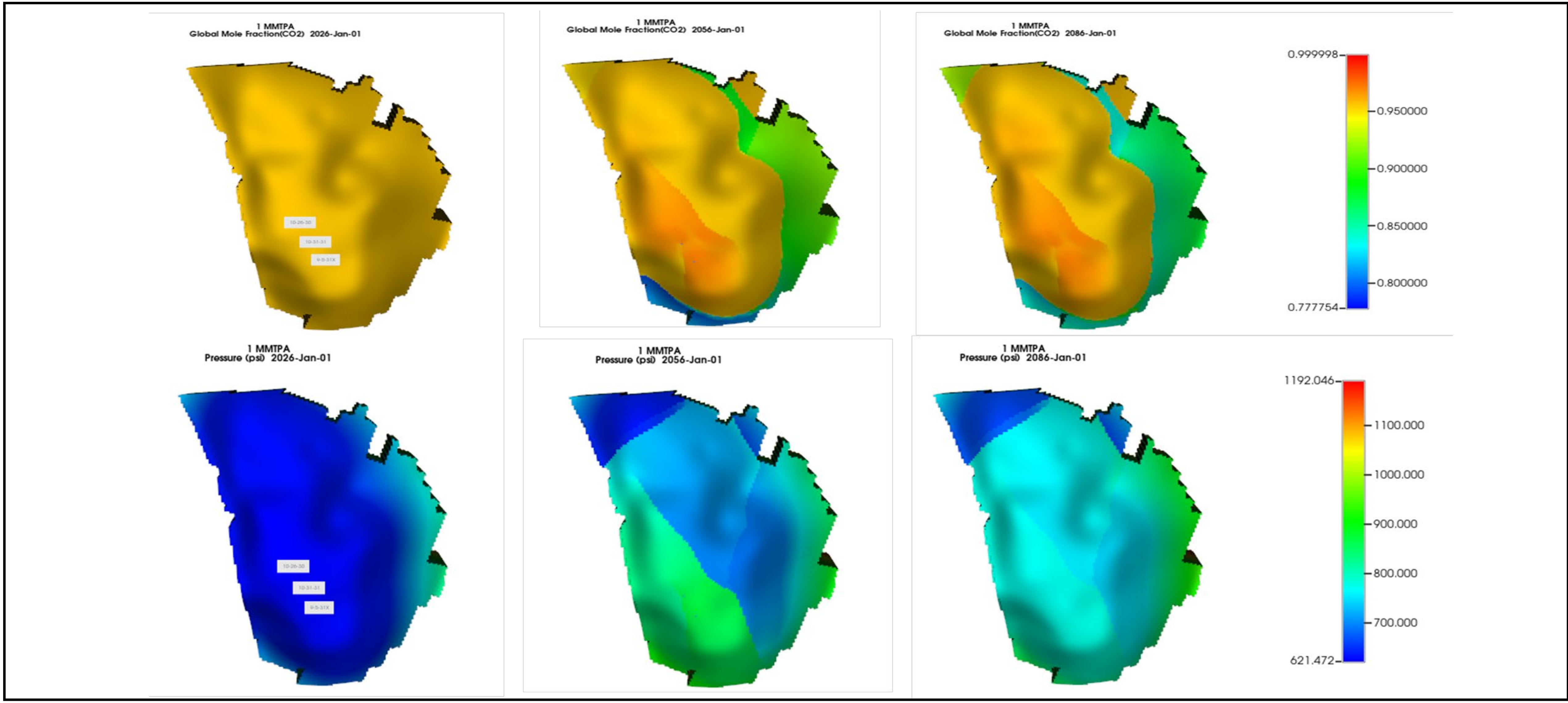


Fig 5: Pressure evolution at different injection times.

# Pressure Representation on the Mohr Circle

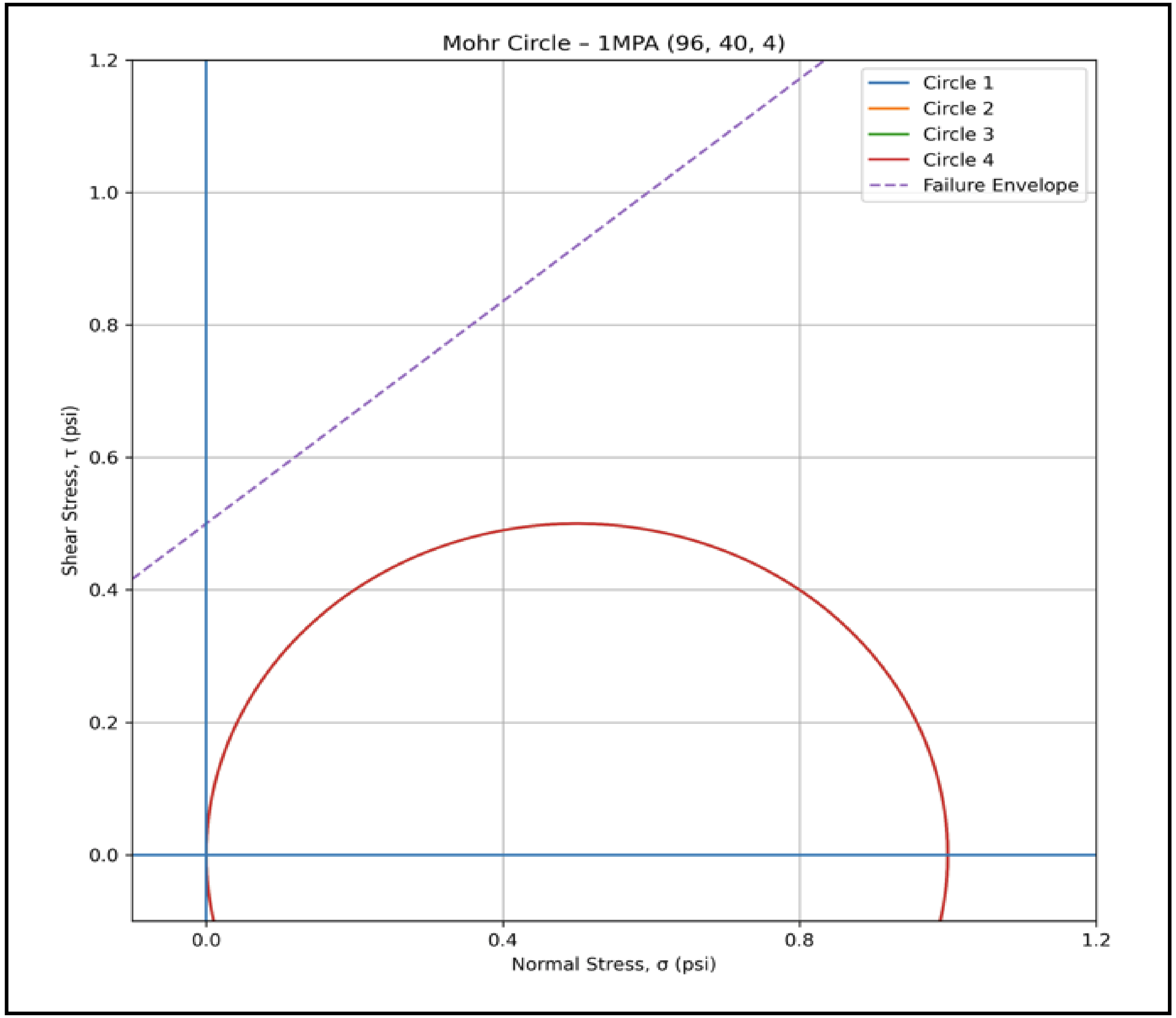


Fig 6: Pressure representation on the Mohr Circle.

# Results

## Geomechanical Response

Volumetric strain concentrated near injection zones.

Compaction-driven deformation observed.

Minimal far-field mechanical disturbance.

# Volumetric Strain Response During $CO_2$ Injection

Measures how much a rock volume changes (expands or contracts) due to stress changes like pressure drop or fluid injection. Negative volumetric strain = compaction (rock volume shrinks). Positive volumetric strain = dilation (rock volume increases).
Important for understanding reservoir deformation, fracture behavior, and storage capacity changes during $CO_2$ injection.

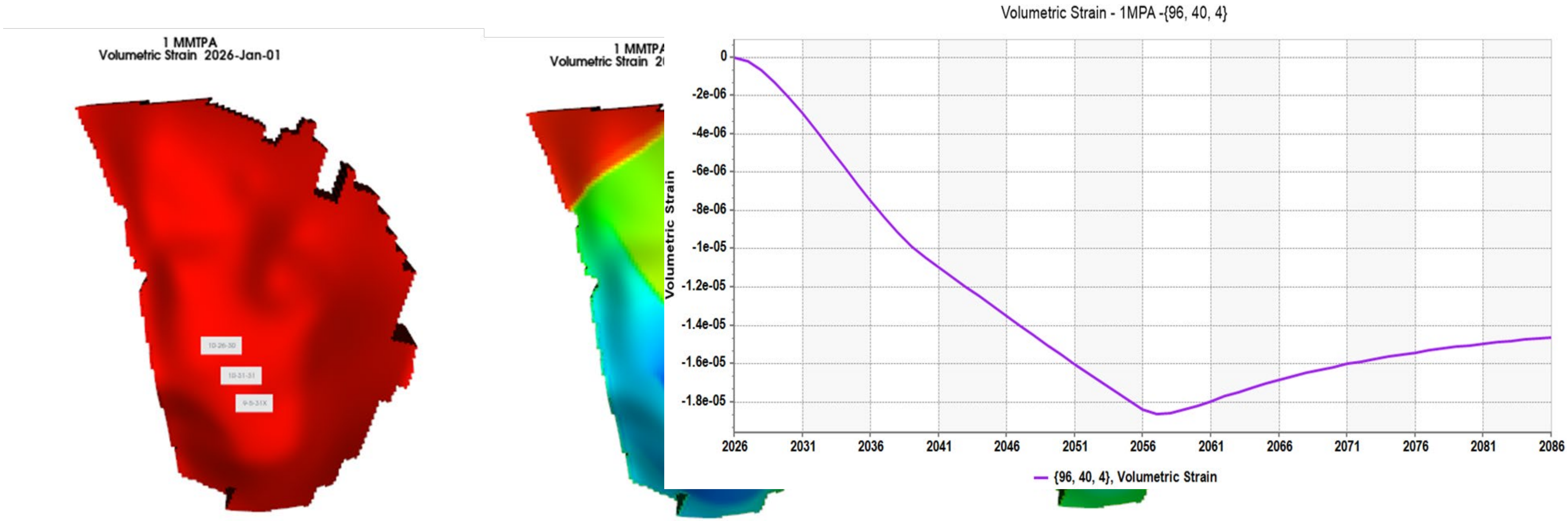


Fig 7: Localized compaction near injection wells.

# Results

## Surface Subsidence

- Surface subsidence small and spatially uniform.
- Indicates stable long-term mechanical behavior.

# Surface Subsidence Due to $CO_2$ Injection

Refers to the sinking or downward movement of the ground surface caused by compaction of subsurface formations. Often occurs when fluids are withdrawn or pressures change in a reservoir.
Negative subsidence signifies sinking and positive subsidence signifies upward movement. Excessive subsidence can damage surface infrastructure, wells, and cause environmental concerns.

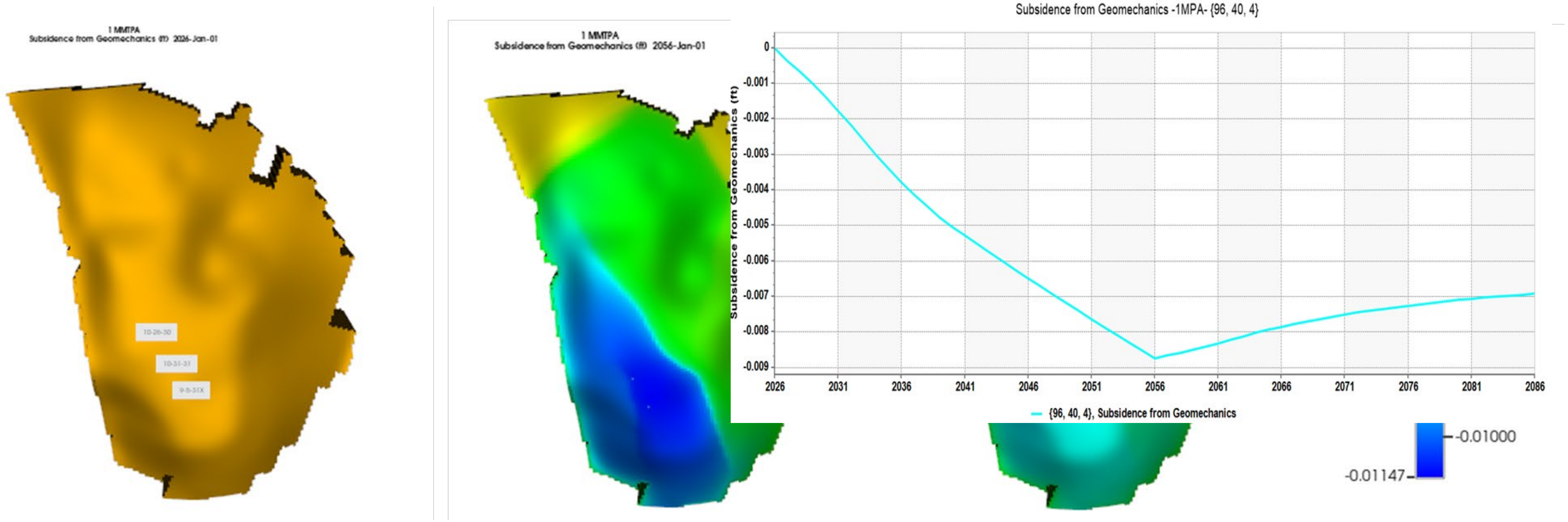


Fig 8: Minimal surface deformation during and after injection

# Results

## Storage Security & Trapping

- Gaseous $CO_2$ is the dominant storage mechanism.
- Structural and solubility trapping provide secondary contributions.
- Geomechanical feedback influences stress redistribution.
- Dual-permeability model improves prediction reliability.

# Trapping Mechanisms

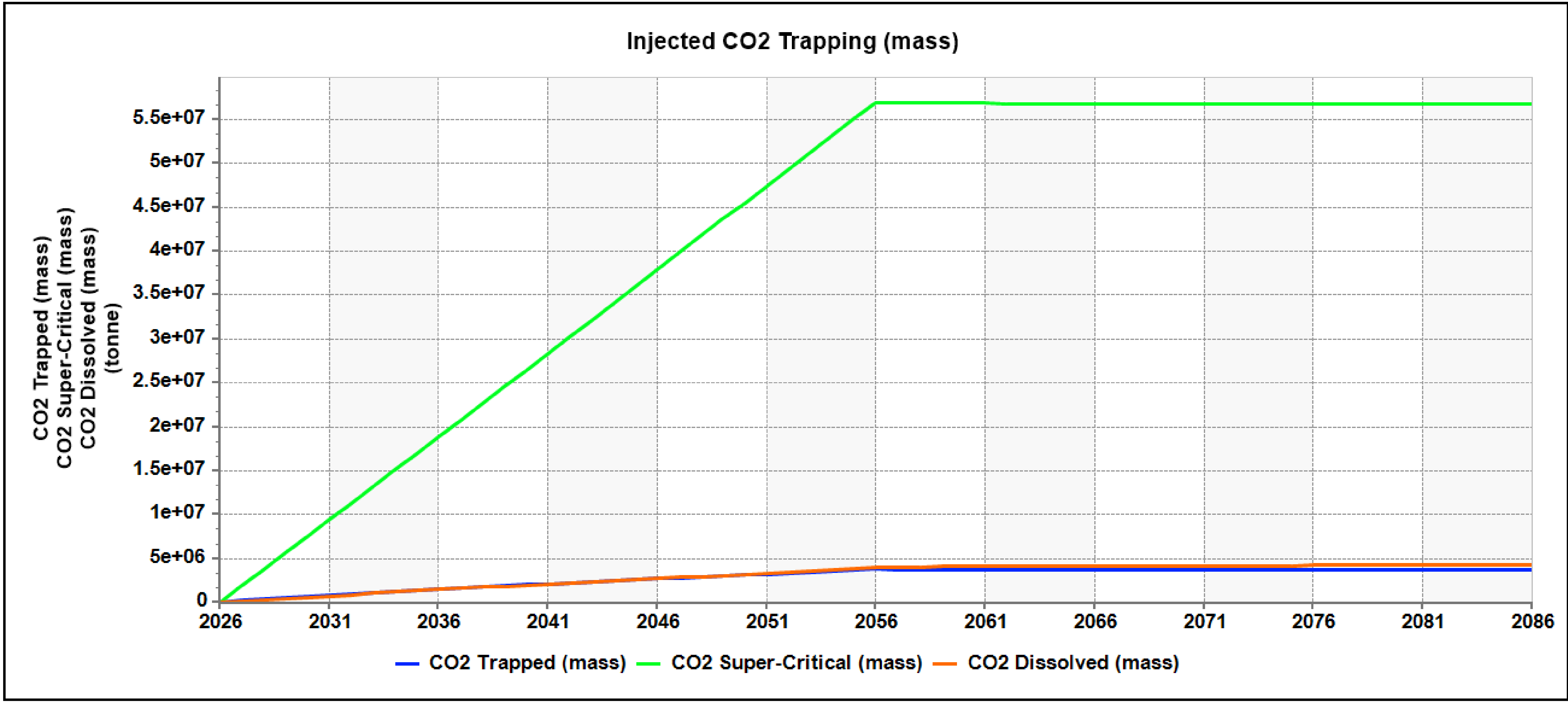


Fig 9: Trapping mechanisms observed

# Engineering Implications

- Geomechanical coupling essential for risk assessment.
- Supports suitability of crystalline basement reservoirs.
- Provides framework for optimizing injection strategies.
- Enhances monitoring and containment prediction.

# Conclusion

- Fractures dominate $CO_2$ migration pathways.
- Geomechanics significantly affects pressure and deformation.
- Storage remains mechanically stable over long term.
- Crystalline reservoirs are viable for secure $CO_2$ sequestration.

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- Research collaborators and advisors


Image courtesy of Pixabay.com

## Modeling Assumptions

- Dual-permeability fracture – matrix representation.
- Mohr–Coulomb failure criterion.
- Injection rate: 1 MMTPA for 30 years.
- Boundary conditions include in-situ stress and pore pressure.
- Fully coupled hydrodynamic – geomechanical simulation.

## Dual-Permeability Conceptual Model

- Matrix = low-permeability intact granite.

  Fractures = primary $CO_2$ pathways.
- Separate pressure/flow equations for each continuum.
- Coupling captures fracture–matrix interaction.
- Improves prediction of migration, pressure, deformation.

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# Backup

## Geomechanical Parameters

- Young's modulus → stiffness.
- Poisson's ratio → lateral deformation.
- Cohesion & friction → failure limits.
- Parameters calibrated from granite properties.

## Risk & Containment Assessment

- Failure evaluated using Mohr–Coulomb criterion.
- Safety margin maintained throughout simulation.
- No critical fault reactivation predicted.
- Storage integrity confirmed long-term.