CCUS: 4186575

CO2 storage risk assessment in large-scale industrial projects: In Salah case study

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This paper was prepared for presentation at the Carbon Capture, Utilization, and Storage conference held in Houston, TX, 03-05 March.

Abstract

In large-scale CO2 injection projects, risk evaluation and management are critical, particularly with pre-existing faults. This study delves into the In Salah project, which has been a focal point of research due to the distinct double-lobed surface deformation observed following CO2 injection. InSAR data has indicated that this deformation may result from the reactivation of a fault near the KB-502 injector well, coupled with fluid migration. Through a fully coupled simulation of CO2 injection, incorporating fault mechanics via the GEOS simulator, we explored this phenomenon. Our model constructed using comprehensive geological, petrophysical, geomechanical, and operational data, supports the hypothesis of progressive fault opening driven by increased injection pressure. The findings underscore the necessity of considering the interplay between injection well pressure and fault pressure variations to accurately replicate observed data. This work enhances our understanding of subsurface fracture geometry and highlights the critical role of mechanical property contrasts and vertical fracture extent.

Introduction

In the context of large-scale CO2 injection initiatives, managing and evaluating risks is of upmost importance, especially when dealing with pre-existing geological faults. The In Salah project, located in Algeria, has been extensively analyzed over the past decade due to the notable double-lobed surface deformation linked to CO2 injection activities. This deformation, as revealed by InSAR data, suggests that fault reactivation near the KB-502 injector well and subsequent fluid migration are key factors contributing to the observed surface changes.

The In Salah project serves as a critical case study for understanding the complexities involved in CO2 storage and the associated risks of fault reactivation. Previous studies highlighted the importance of accurately modeling these interactions to predict and mitigate potential risks. This study aims to investigate the risk of fault reactivation through a fully coupled CO2 injection simulation that incorporates fault mechanics using the GEOS simulator. By leveraging this tool, we seek to provide a detailed understanding of the mechanisms behind fault reactivation and the associated risks.

The objectives of this study are to:

- Develop a 3D model that accurately represents the geological, petrophysical, geomechanical, and operational conditions of the In Salah project.
- Simulate the CO2 injection process and its impact on fault reactivation via fully coupling approach (in this case, using GEOS simulator).
- Compare the model results against InSAR data
- Analyze the results to understand the conditions under which fault reactivation occurs and the subsequent impact on surface deformation.
- Provide insights into the subsurface fracture geometry and the significance of mechanical property contrasts and vertical fracture extent.

Theoretical Background and Methods

Our approach involves constructing a structurally simple but representative model based on available geological, petrophysical, geomechanical, and operational data available the literature. The model is isotropic and spans 12 km by 12 km horizontally and 4 km vertically, comprising six distinct layers: a shallow aquifer, a primary caprock, a secondary caprock, a tight sandstone layer, a reservoir, and a basement layer. The fault, situated within the reservoir and adjacent layers, aligns with the maximum horizontal stress direction. Additionally, the fault presents contact mechanical elements to better capture the double lobe shape at the surface. Fully coupled poromechanics simulations were performed. It should be noted that fully coupled modeling allows to account for complex interactions in the flow and mechanical parameters which is important during the fault reactivation. In particular, the leak-off to the host formations from the fault and volume changes following fluid injection can be estimated.
The history match of the model was achieved by comparing simulation results with InSAR data, adjusting critical parameters such as fault pressure, Young's modulus, reservoir permeability, and fault height. The initial simulations revealed discrepancies when compared to the observed historical data, a challenge also noted in previous works. To address this, monosensitivity analysis was conducted on key model parameters influencing the model's behavior at the surface. By adjusting Young's modulus, reservoir permeability, pressure in the fault and fault contact length, we observed their impact on fault reactivation and displacements caused by CO2 injection. This analysis is important for refining our understanding of the phenomena and adjusting the model to better reflect actual data, while identifying the most influential properties on the system's behavior.

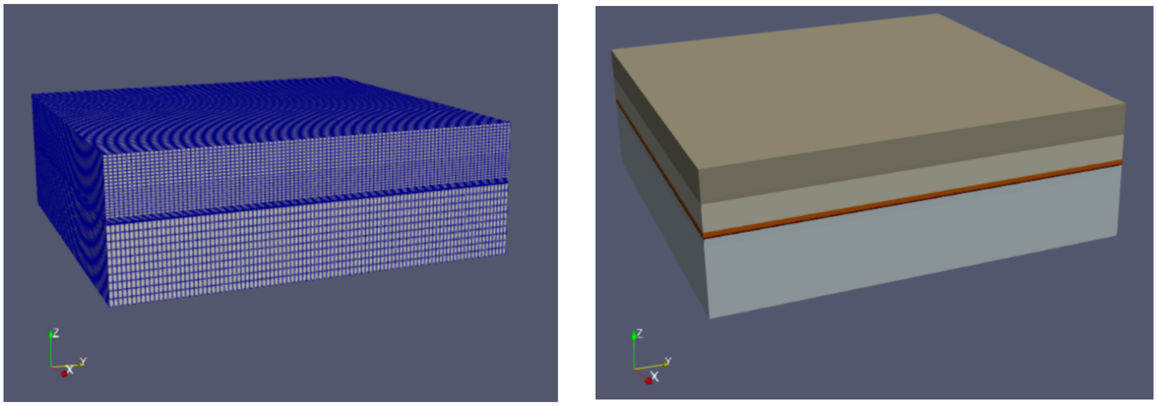

Figure 1: In Salah simulation grid (left) and model layering (right)

Results

The simulations results support the scenario of progressive fault opening due to rising injection pressure, with fault reactivation occurring when the minimum horizontal stress threshold was exceeded. In the absence of fault reactivation, the surface uplift pattern exhibited a circular shape rather than the observed double-lobed configuration. Note that both pressure increase due to mechanical activation and pressure increase due to leak-off in the reservoir and overburden can only be put into evidence with fully coupled simulations. Our analysis also provided a detailed assessment of the depth and extent of fault reactivation, utilizing realistic geological parameters without introducing additional complexities in the constitutive laws. A good match of the observed data was achieved (figure 2). The double lobe shape on the surface deformation is well captured (3D contours) as well as magnitude of the deformation (extraction along the cross-section AA').

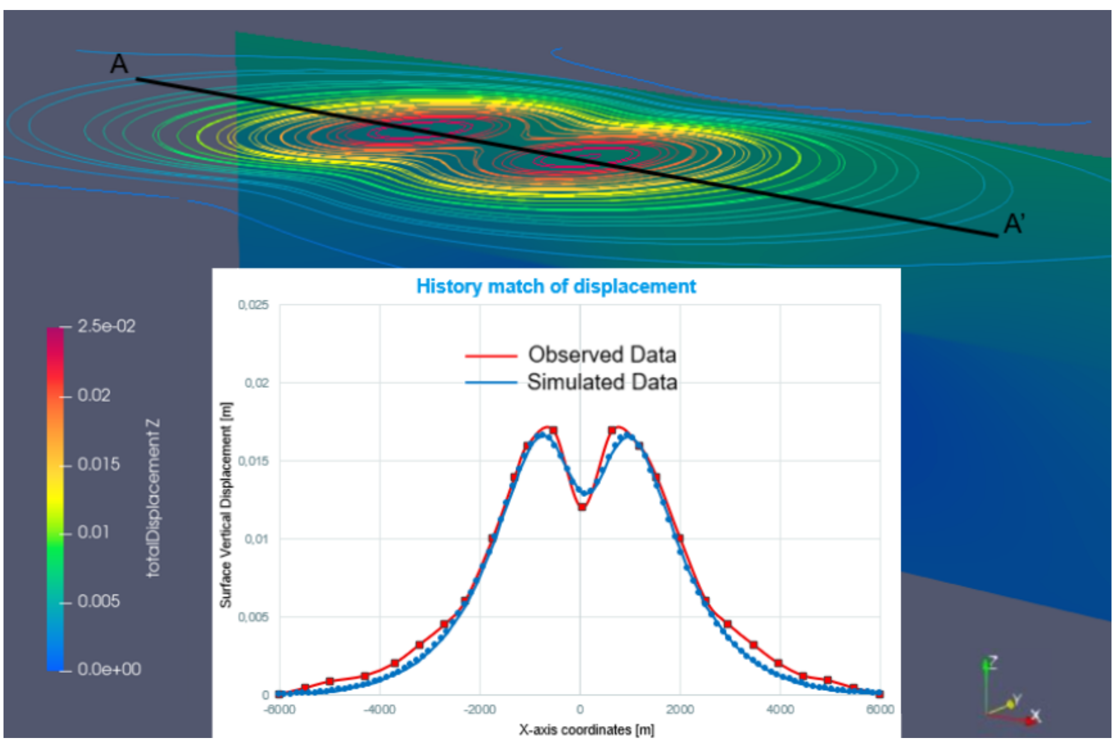

Figure 2: History match of vertical displacement at the end of injection

Discussion

Achieving calibration is challenging due to the interdependence of physical processes during CO2 injection. This interdependence highlights the complexity of the system and underscores the importance of a multiphysics approach to history match.

While the base case simulation helps to understand the complex interactions of physical processes, the uncertainty analysis is necessary to capture the possible ranges of the responses based on the uncertainty in the input parameters. By integrating geomechanical uncertainties, an enhanced multiphysics uncertainty workflow was built. Using native Multiphysics GEOS capabilities (which performs flow and mechanical simulation in the sme tool), an ensemble of realizations was created, capturing uncertainty in the flow parameters, geomechanics properties as well as model structural framework and the interactions between these parameters. Detailed analysis of this ensemble and exploration of the other possible combinations will be addressed in the next steps of this work.

Conclusions

In conclusion, this study highlights the importance of coupled flow and geomechanics simulations for managing uncertainties in geological CO2 storage, emphasizing the need for accounting on the interactions between reservoir properties and mechanical parameters like Young's modulus, reservoir permeability, and fault height to better reflect field data. It underscores the impact of higher permeability on pressure diffusion within the reservoir and the uplift of the model. Additionally, variations and contrasts in Young's modulus affect rigidity and displacement patterns. The shape and magnitude of the double lobe are controlled by the height of the fault. A fully coupled simulations approach put in place in this study allows for a more precise evaluation of subsurface fracture geometry accounting the interactions between mechanical properties and vertical fracture extent.

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