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Fault Lines to Frontlines: Geomechanical Challenges of Sustainable Energy Transition

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The transition to sustainable energy systems introduces a complex landscape, wherein geothermal energy and carbon dioxide storage (CCS) play critical roles. These activities target geological formations that are always faulted and fractured. As the focus intensifies on alternative energy systems for decarbonisation, understanding these faulted rocks in the subsurface gains great importance. Fault and fracture systems can act not only as conduits for fluid flow but they can also be zones of mechanical weakness that may respond dynamically to fluid pressure changes due to natural geological processes or anthropogenic activities, such as CCS or geothermal extraction. This dual role of fault and fracture systems as pathways for fluid flow and as potential triggers for mechanical failure makes their study a cornerstone of sustainable subsurface resource management. The challenge lies in accurately characterising the permeability of these systems and estimating their mechanical behaviour under changing stress conditions. This is vital for ensuring the integrity and efficacy of operations like CCS and geothermal energy extraction, where even slight variations in fluid pressure can have significant implications. For instance, experiences from the fluid injection experiment for an enhanced geothermal system in Basel, Switzerland, and the In Salah CCS pilot site in Algeria highlight how minor changes in pore fluid pressures (as little as 10 MPa) can induce leakage and/or seismic activities. We highlight selected case studies from both active and prospective CCS and geothermal sites (in Svalbard and Mid-Ethiopian Ridge, respectively). These examples illustrate methodologies in fault stability analysis and geomechanical characterization, shedding light on the relationship between fluid flow, stress alterations, and rock mechanics in faulted and fractured formations. By coupling empirical data with modelling techniques, we present strategies to mitigate risks and enhance the efficiency of subsurface decarbonisation efforts.