SUBSURFACE ALLIANCE

DATA DRIVEN | SCIENCE BASED | FIT-FOR-PURPOSE

We are a network of subsurface specialists using a team-of-teams approach to efficiently solve problems that have a direct business impact in today's fast-paced and evolving energy industry.

We provide high quality subsurface solutions by bridging the gap between geoscience and engineering.

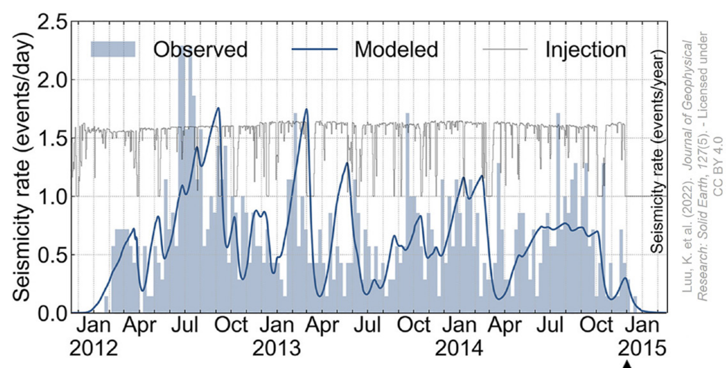
Make sure to check these boxes for your CCS project:

- ☑ Induced seismicity
- ☑ Formation integrity
- ☑ Fault reactivation
- ☑ *In situ* stress

Underground storage of CO_2 in depleted oil and gas reservoirs or saline aquifers will become increasingly important as a pathway to reduce CO_2 industrial emissions into the atmosphere. To fulfill government regulations and to secure public acceptance, planning and operation of storage sites must consider all potential risks. We help you understand and mitigate key geomechanical risks: induced seismicity, fault reactivation and formation integrity by constraining the in situ stress.

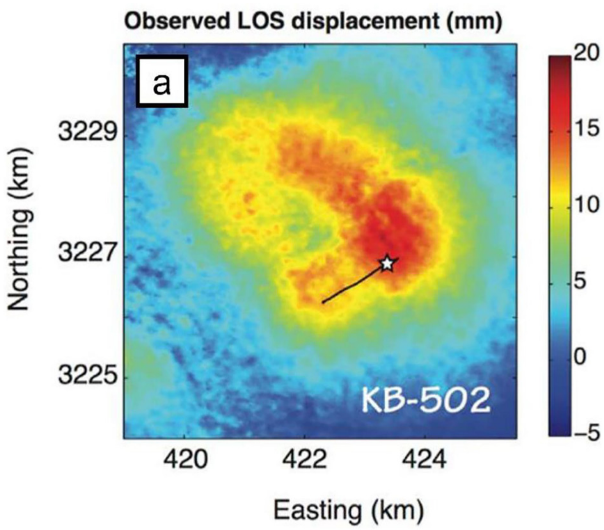
MAIN GEOMECHANICS RISKS

Induced seismicity. Large scale injection of fluids in the subsurface has the potential to change pore pressure and stress distribution in the rock mass. It is documented that this has induced seismicity, mostly of limited magnitude, in wastewater injection, geothermal and CO_2 injection projects. **Field evidence:** Since 2020 several large magnitude (>4.5) earthquakes, related to re-injection of produced-water, have hit west Texas (USGS Earthquake Hazards Program).



Recorded seismicity rate (events/per day) during Phase 1 of the Decatur CCS project (Luu et al., 2022)

Reactivation of faults. Changes in subsurface stresses can lead to slip along pre-existing faults and as a consequence to the creation of flow pathways for CO_2 to escape the intended containment zone. Leaked fluids may contaminate shallow water aquifers or even reach the surface. **Field evidence:** In 2011, drilling operations led to the reactivation of a fault offshore Brazil with subsequent leakage of oil to the sea floor. Watch footage of the leak, recorded by an ROV, here.



Formation Integrity. Injecting CO_2 increases the formation pressure, while the temperature contrast between the formation and the CO_2 lowers the least principal stress. As a result, hydraulic fractures can be initiated in both the target injection zone and the top seal, compromising seal integrity and injection operations. **Field evidence:** In June 2011, CO_2 injection operations at the In-Salah project in Algeria were suspended after seismic and InSAR data revealed possible hydraulic fractures developing in the storage unit and extending into the caprock.

Figure on the left shows InSAR observed line of sight (LOS) surface vertical uplift (in mm) near the KB-502 horizonal CO_2 injection well at the In-Salah project. Illustration from Song et al. (2023), licensed under CC BY 4.0 DEED.

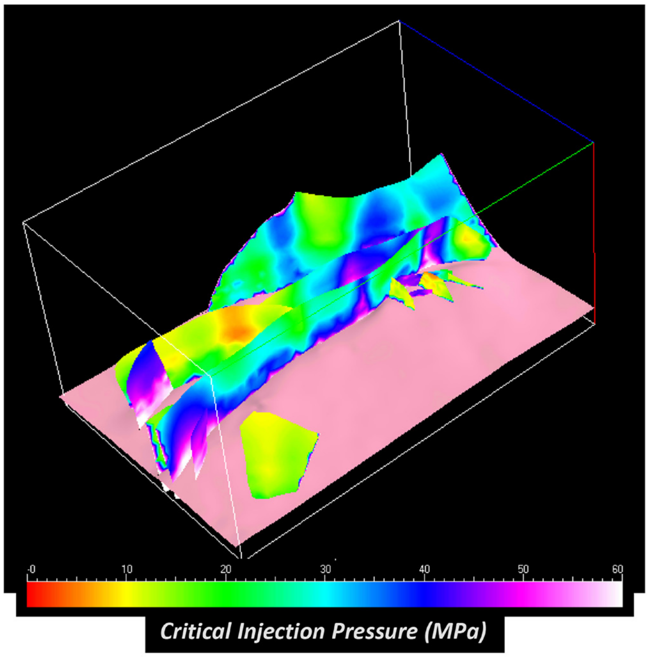
RISK MITIGATION

Constrain in-situ stress. This is the first and foremost task that any CCS project must conduct to ensure safe and successful operations. Using standard data collected while drilling, our experts can constrain the stress magnitudes following the guidelines outlined by the different government agencies. This is at the core of our business, as our technical advisors themselves developed the methods now indicated by the goverment agencies to characterize the in-situ stress (e.g., EPA, Site Characterization Guidance, pp. 26-27). The geomechanical model forms the base for ensuring wellbore stability during drilling and injection, as well as for understanding and mitigating the key risks of fault stability, reactivation of fractures and induced seismicity.

Fault stability assessment. We can conduct studies in the planning and development phase to assess the maximum allowable pressures to prevent fault reactivation and associated leakage.

Baseline definition. Determining the natural levels of seismicity and ground movement is fundamental before starting injection operations. Continued monitoring and comparison to the baseline can be used to understand location and movement of the injected CO_2. Our workflows integrate monitoring data and the understanding of the in-situ stress state to assess the risk for induced seismicity or severe ground deformation.

Natural fractures. Our experts can assess the impact of fracture-driven permeability anisotropy on injections rates and plume geometry. For the caprock, we can evaluate the likelihood of natural fractures compromising the integrity of the seal.



Fault stability assesment results. Figure shows critical injection pressure calculated for multiple fault surfaces. Hot colors correspond to fault regions more prone to reactivation due to injection (Fernandez-Ibanez et al., 2010)