CO_2 injection and induced fault instability and seismicity in the sedimentary basin of the St. Lawrence lowlands (Quebec, Canada): insight from coupled reservoir-geomechanical modeling

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A coupled reservoir-geomechanical (TOUGH-FLAC) modeling is applied to evaluate the potential shear failure along pre-existing high-angle normal faults in the Early Paleozoic sedimentary units of the St. Lawrence Lowlands (Quebec, Canada) associated with CO_2 injection into the sandstone reservoir of the Covey Hill Formation. The spatial variations in fluid pressure, shear strain and vertical displacement are calculated for different injection rates using a simplified 2D geological model of the Becancour area between Montreal and Quebec City. The simulation results show that the likelihood of reactivating two reservoir-bounding faults (Yamaska and Champlain Faults) strongly depends on reservoir pressure at the faults, which in turn depends on injection rate, hydrological properties of aquifers and the distance between the faults and the injection well. The Yamaska Fault, which is located at a shorter distance (1.5 km) from the injection zone, is easier reactivated than the more distant (4.4 km) Champlain Fault. In addition, fault permeability affects the timing, localization, rate and length of fault shear slip. If the fault is sealing, shear slip occurs later in time and it is localized along the fault segment (230 m) below the caprock units. If the fault is permeable, the fault reactivation starts earlier and shear slip is nucleated along a 50-m-long fault segment in the caprock units and subsequently progressing up to the surface. Sealing fault behaviour causes asymmetric fluid pressure build-up and lateral migration of CO_2 plume away from the closer-to-injection Yamaska fault that reduces the overall risk of CO_2 leakage along faults. The fault permeability thus influences injection-related stress variations and the size of the rupture area and, consequently, the earthquake magnitude.