Geophysical Research Abstracts
Vol. 16, EGU2014-3164, 2014
EGU General Assembly 2014

Induced seismicity and CO_2 leakage through fault zones during large-scale underground injection in a multilayered sedimentary system

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Overpressure caused by the direct injection of CO_2 into a deep sedimentary system may produce changes in the state of stress, as well as, have an impact on the sealing capabilities of the targeted system. The importance of geomechanics including the potential for reactivating faults associated with large-scale geologic carbon sequestration operations has recently become more widely recognized. However, not withstanding the potential for triggering notable (felt) seismic events, the potential for buoyancy-driven CO_2 to reach potable groundwater and the ground surface is more important from safety and storage-efficiency perspectives.

In this context, this work extends previous studies on the geomechanical modeling of fault responses during underground carbon dioxide injection, focusing on both short- and long-term integrity of the sealing caprock, and hence of potential leakage of either brine or CO_2 to shallow groundwater aquifers during active injection.

The first part of this work aims to study the fault responses during underground carbon dioxide injection, focusing on the short-term (5 years) integrity of the CO_2 repository, and hence on the potential leakage of CO_2 to shallow groundwater aquifers. Increased pore pressure can alter the stress distribution on a fault/fracture zone, which may produce changes in the permeability related to the elastic and/or plastic strain (or stress) during single (or multiple) shear ruptures. We account for stress/strain-dependent permeability and study the leakage through the fault zone as its permeability changes along with strain and stress variations. We analyze several scenarios related to the injected amount of CO_2 (and hence related to potential overpressure) involving both involving minor and major faults, and analyze the profile risks of leakage for different stress/strain permeability coupling functions, as well as increasing the complexity of the system in terms of hydromechanical heterogeneities. We conclude that whereas it is very difficult to predict how much fault permeability could change upon reactivation, this process can have a significant impact on the leakage rate. Moreover, our analysis shows that induced seismicity associated with fault reactivation may not necessarily open up a new flow path for leakage. Results show a poor correlation between magnitude and amount of fluid leakage, meaning that a single event is generally not enough to substantially change the permeability along the entire fault length.

In the second part of this work we address the three following questions: (1) is there a link between fault-zone architecture and fault reactivation by CO_2 injection? (2) what is the impact of the fault architecture on the induced seismicity and on CO_2 leakage? and (3) how do caprock and reservoir thickness impact the results? We analyze the hydromechanical behavior of a fault zone represented either by: (i) a continuous damage zone, or by a discontinuous damage zone caused by (ii) variations in lithology of the different layers (shale caprock and limestone aquifers), and also by (iii) the initial properties of the sedimentary layers within the injection reservoir itself. We use the model to estimate the moment magnitude associated with a sudden fault slip event as well as the amount of CO_2 migrating from the injection aquifer and upwards across the primary caprock located just above the injection aquifer after a long-term post-injection period. We recognize that such migration out of the injection aquifer may not formally constitute CO_2 leakage up into potable shallow aquifers, if for example there is leak-off into intervening aquifers or multiple overlying low permeability formations that prevent further upward migration of the CO_2. Finally, results show that a thin caprock or aquifer allows smaller events, but a much higher percentage of leakage in the upper aquifer. The elevate amount of leakage reduces drastically by assuming a multi-caprock, multi-aquifer system.