Across-fault pressure perturbation induced by CO_2 injection

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Kyung Won Chang
Timothy A. Meckel
Marc A. Hesse
Jean-Phillipe Nicot

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TITLE: Across-Fault Pressure Perturbation Induced by CO2 Injection

AUTHORS (FIRST NAME, LAST NAME): Kyung Won Chang[1, 2], Tip Meckel[1], Marc A. Hesse[2], Jean-Phillipe Nicot[1]

INSTITUTIONS (ALL): 1. Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, United States.

2. Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, Austin, TX, United States.

ABSTRACT BODY: Geological carbon sequestration aims at long-term storage of carbon dioxide in deep geological formations. To minimize the risk of leakage, the integrity of the geological seal has to be characterized carefully. The focus of this study is to simulate CO2 injection and observe the interaction of the CO2 and pressure evolution with a modeled fault intersecting the injection interval. Such features may be fairly common at a variety of scales in many sequestration reservoir targets, but their hydrologic and mechanical response to rapid pressure changes induced by CO2 injections requires investigation. We present numerical simulations from a commercial simulator (GEM from CMG). Preliminary numerical studies will determine the dependence of the CO2 and pressure evolution along and across the fault as a function of geological parameters. Additionally, the study is designed to complement and understand the field data being collected from the DOE-funded SECARB Phase 3 of the Cranfield CO2 injection project in the fall of 2009. A 12-level 3-component microseismic array has been deployed in a well approximately 1200 feet from a continuous CO2 injection well. A reservoir-scale fault intersects the reservoir between the injection and observation well. Available field data will be integrated with the flow model and analyzed to estimate the hydrologic properties of the adjacent fault. Pressure evolution predictions from the flow simulation will be critical for understanding the temporal distributions of any observed microseismic events detected. This project was funded thought the National Energy Technology Laboratory Regional Carbon Sequestration Partnership Program as part of the Southeast Regional Carbon Sequestration Partnership

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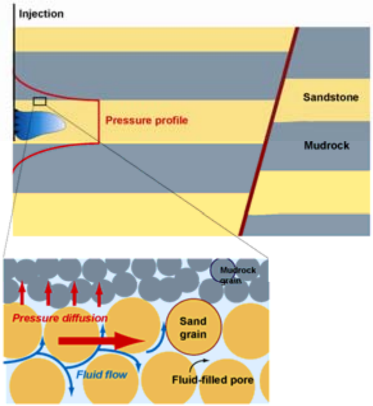
Kyung Won Chang [a,b], Tip Meckel [b], Marc A. Hesse [a], Jean-Philippe Nicot [b]

[a] Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin

[b] Bureau of Economic Geology, Jackson School of Geosciences, The University of Texas at Austin

1. Motivation

- Injection-induced pressure build-up
  : will maximum pressure fracture caprock?
- Lateral propagation (speed) of pressure-pulse
  : how large is the area of review?
- Role of over/under burden
  : do we need to work over/under burden?
- Communication with overlying aquifers
  : does pressure increase in overlying aquifers indicate fluid leakage?



2. Pressure diffusion into over/underlying mudrock

- Parameters

1. fraction of mudrock layers (f_m)

$$f_m = \frac{(\text{thickness of mudrock})}{(\text{thickness of sandstone})} = \frac{L_m}{L_s} = \frac{L_1 + L_3}{L_2}$$

2. diffusivity ratio (D_m/D_s)

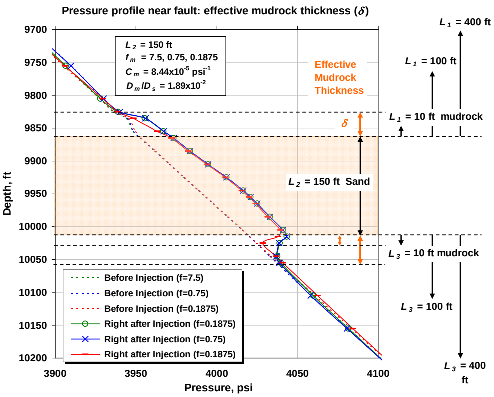
$$\frac{D_m}{D_s} = \frac{\left(\dfrac{k_m}{\mu c_{e,m} \phi_m}\right)}{\left(\dfrac{k_s}{\mu c_{e,s} \phi_s}\right)} = \frac{k_m c_{e,s} \phi_s}{k_s c_{e,m} \phi_m}$$

k_i = permeability

$c_{e,i}$ = effective compressibility

ϕ_i = porosity

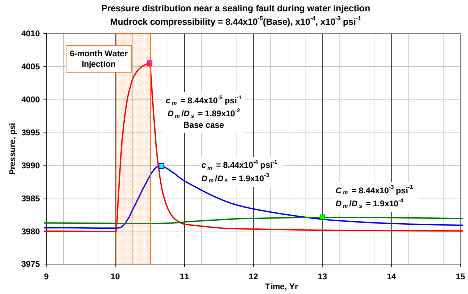
$i = m(\text{mudrock}), s(\text{sandstone})$

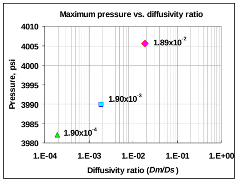


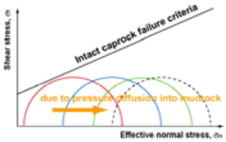
- Effective mudrock thickness
  : thin boundary layer (δ) where pressure diffuses vertically
  $\Rightarrow f_m$ will not be important
- D_m/D_s will be a key parameter
- Usually, $k_m \to 0$, $D_m/D_s \to 0$ $\Rightarrow$ neglect over/under burden in reservoir modeling

3. Maximum pressure & caprock integrity

- Pressure diffusion into over/under burden (mudrock layers) reduces maximum pressure in the target formation (sandstone layer)







- Intact rock failure equation

$$\sigma_t \geq \mu_i (S_n - p_p) + S_0$$

S_n = total normal stress $\quad \mu_i$ = friction coefficient

p_p = pore pressure $\quad S_0$ = cohesion

4. Propagation of pressure front

- Speed of pressure propagation in the target formation

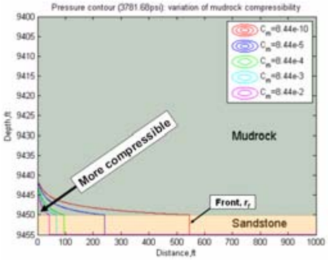
$$r_f \propto \sqrt{t} = t^{1/2}$$

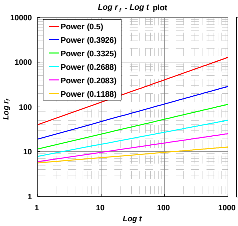
- Radius of review

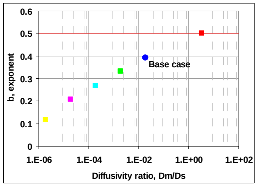
$$r_f \propto t^{\beta}$$

$\Rightarrow$ reduced by pressure diffusion into over/under burdens

$\Rightarrow$ increase time until a pre-existing fault is encountered







5. Do we need to model this?

- Effect of mudrock compressibility
  : area of elevated pressure due to injection
  $\Rightarrow$ *reduced area of review*
  : maximum pressure build-up
  $\Rightarrow$ *reduced failure probability*
  : lateral propagation speed
  $\Rightarrow$ *increased travel time to fault*
- Implications for modeling
  : strong pressure gradient just outside reservoir
  : high-resolution required
  $\Rightarrow$ *in terms of pressure, we need higher resolution just outside reservoir*
  : aim to develop a pressure boundary condition that accounts for pressure diffusion into mudrock
  $\Rightarrow$ *reduces numerical cost*

6. Future work

- How can we detect leakage through a overburden into overlying aquifer?
  : Does pressure increase in overlying aquifer indicate leakage?

Kyung Won Chang: k1chang@mail.utexas.edu

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