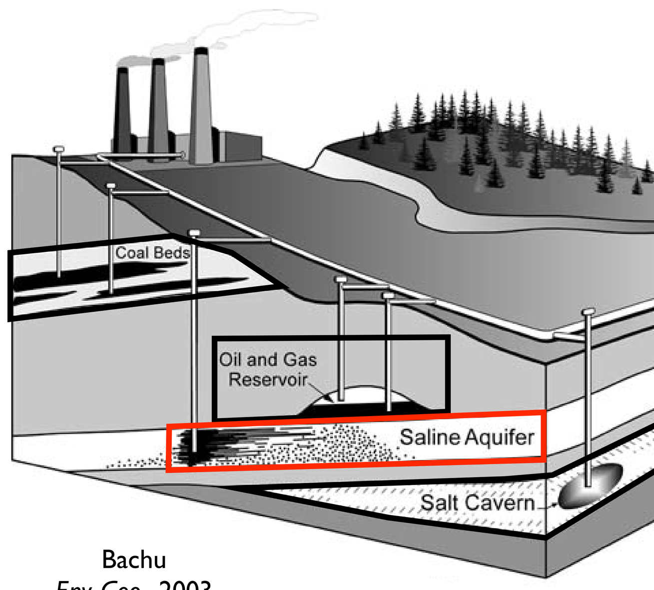
Geological CO_2 Storage: Model for Capacity Estimation

Christopher MacMinn
Michael Szulczewski
Ruben Juanes *
Massachusetts Institute of Technology



Bachu
Env. Geo., 2003
(adapted)

Deep Saline Aquifers

- Deep: ~2 km below surface
- Saline: full of salty groundwater
- Aquifers: weakly permeable layers of limestone or cemented sand
- Capped by impermeable layers
- Horizontal or weakly sloped

CO_2 Injection

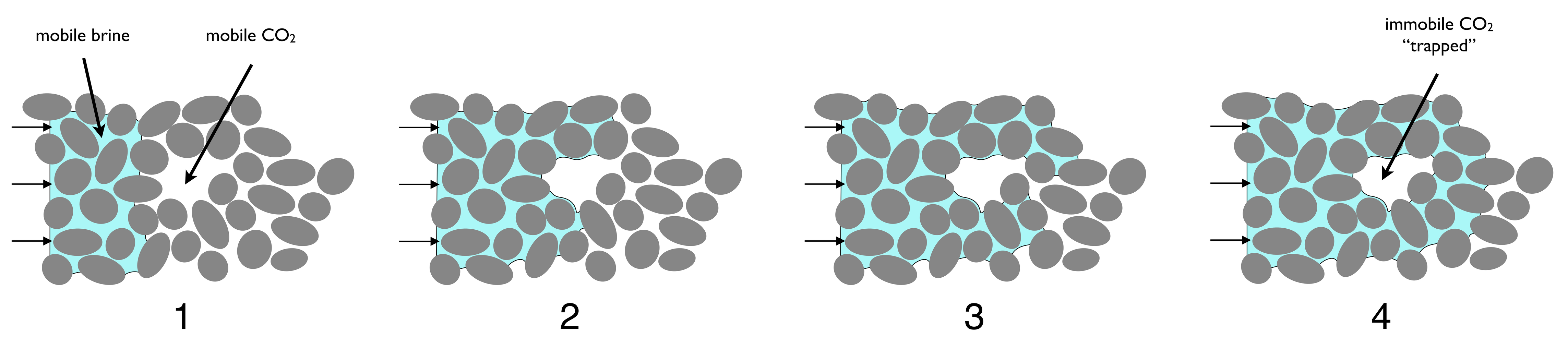
- Rate: ~ 0.2 Gton per year
- Duration: ~ 30 years
- Properties (at depth):
  - less viscous than groundwater
  - less dense than groundwater

★ CO_2 plume is large, mobile, buoyant

Ennis-King and Paterson
SPE, 2002

Storage Mechanisms

- Short-term (10's – 1,000's of years)
  - capillary trapping
  - structural trapping
- Long-term (1,000's – 100,000's of years)
  - dissolution into brine
  - mineral deposition



Capillary Trapping

1. As CO_2 migrates, brine is drawn into pore space behind it
2. Capillary forces draw brine preferentially into small spaces
3. As migration continues, regions of CO_2 are cut off from the bulk
4. Isolated blobs of CO_2 are trapped, immobile

Model for Plume Migration

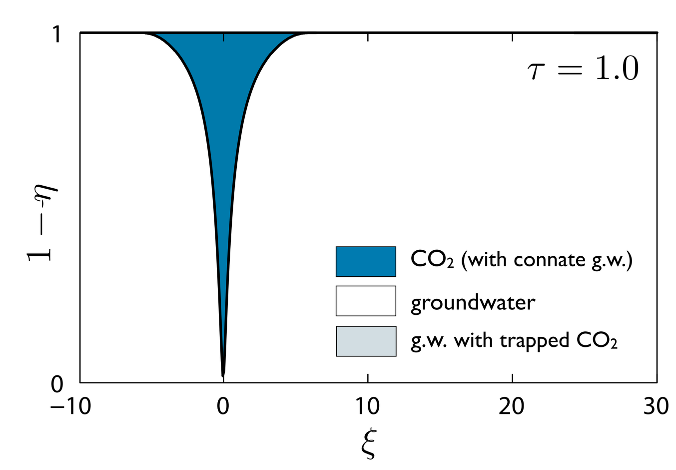
- Physical Mechanisms
  - flow: plume is "pushed" by natural g.w. flow
  - slope: plume migrates up-slope
  - gravity: plume spreads upward due to buoyancy
  - trapping: plume shrinks due to capillary trapping
- Approximations
  - sharp interfaces
  - vertical equilibrium ("Dupuit Approximation")
  - negligible capillary forces
  - negligible solubility effects
  - negligible compressibility effects

Huppert *JFM*, 1982	Nordbotten et al. *TPM*, 2005	Hesse et al. *JFM*, 2007
Kochina et al. *Int. J. Eng. Sci*, 1983	Hesse et al. *SPE*, 2006	Juanes and MacMinn *SPE*, 2008
Kochina et al. *Int. J. Eng. Sci*, 1982	Nordbotten & Celia *JFM*, 2006	Hesse et al. *JFM*, 2008

Injection Period

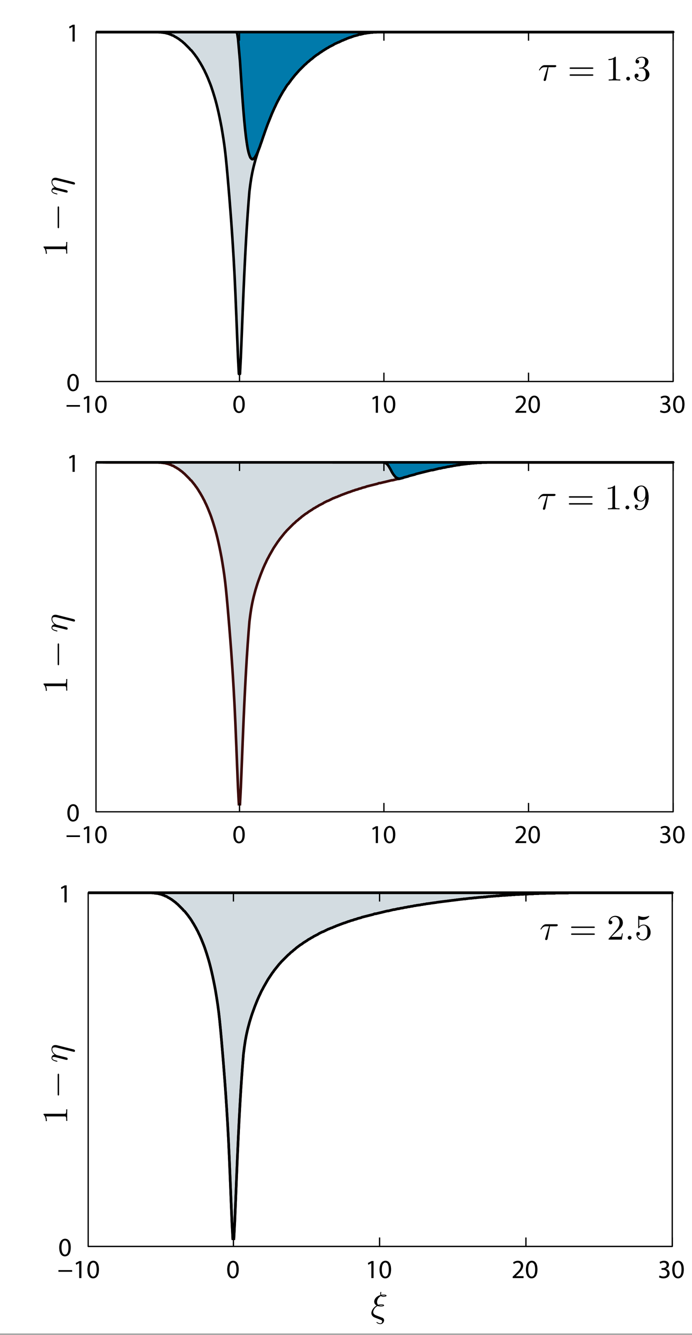
- plume spreads symmetrically about the injection well
- flow term dominates shape

$N_f \gg N_s\,,\ N_g$



Post-Injection Migration

- plume moves to the right, pushed by flow and slope
- plume spreads against the caprock
- plume leaves gas trapped in its wake



Advective Effects — Diffusive Effects

$$\tilde{\mathcal{R}}\frac{\partial \eta}{\partial \tau} + N_f\frac{\partial f}{\partial \xi} + N_s\frac{\partial}{\partial \xi}\Big((1-f)\eta\Big) - N_g\frac{\partial}{\partial \xi}\left((1-f)\eta\frac{\partial \eta}{\partial \xi}\right) = 0$$

g.w. flow — up-slope migration — buoyancy

$$\tilde{\mathcal{R}} = \begin{cases} 1 & \partial\eta/\partial\tau > 0 \\ 1-\Gamma & \partial\eta/\partial\tau < 0 \end{cases}$$

$$f = \frac{\mathcal{M}\eta}{(\mathcal{M}-1)\eta + 1} \qquad \mathcal{M} = \frac{\lambda_g}{\lambda_w}$$

Scaling $\left\{ \quad \eta = \frac{h}{H} \quad \tau = \frac{t}{T_c} \quad \xi = \frac{x}{L_c} \right.$

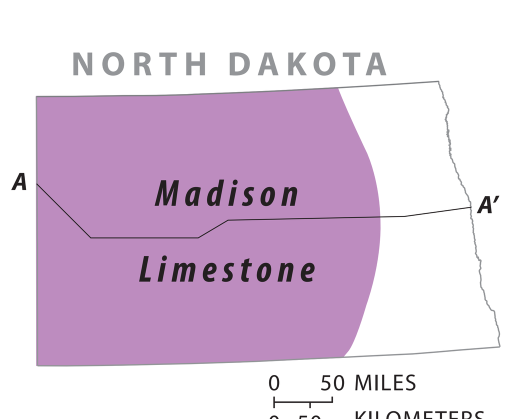
$$N_f = \frac{T_c}{T_i}\frac{U_n H}{Q_i} \qquad N_s = \frac{T_c}{L_c}\kappa\sin\vartheta$$

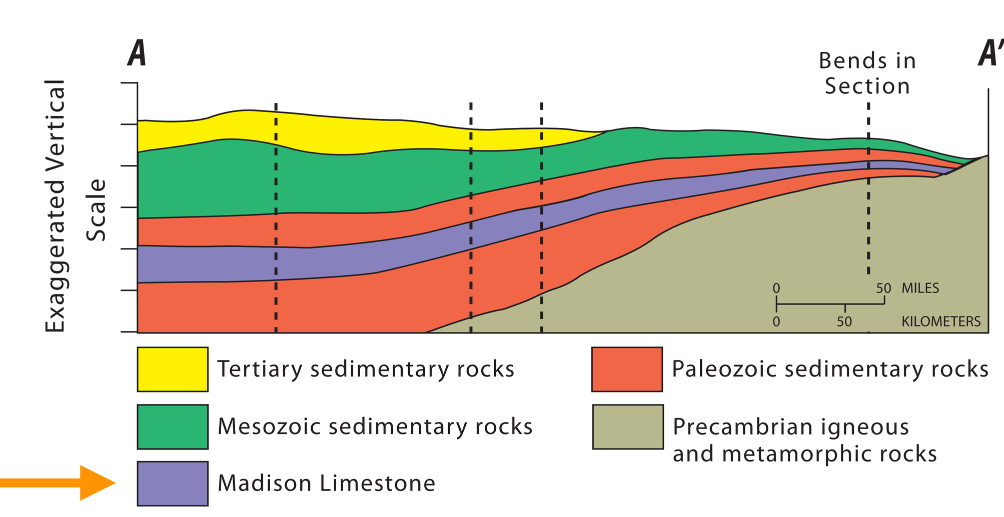
$$N_g = \frac{T_c H}{L_c^2}\kappa\cos\vartheta \qquad \kappa = \frac{(\rho_w - \rho_g) g k \lambda_g}{(1-S_{wc})\phi}$$

Estimating the Capacity of the Madison Limestone

- Principle:
  - inject the maximum amount of CO_2 that will fit in the basin
- Assumptions:
  - isotropic and homogenous basin properties
  - one-dimensional plume migration
- Method:
  1. Determine the boundaries of the storage area from the geological features of the basin
     - formation boundaries
     - faults
     - extent of caprock
  2. Choose the optimal location for a line-drive well array, and determine the largest allowable plume footprint
  3. Calculate the corresponding injection volume from the migration model (analytically or numerically) for the particular formation properties

Szulczewski & Juanes *GHGT-9*, 2008	Carbon Seq. Atlas US DOE NETL, 2007	Whitehead USGS HA 730-I, 1996





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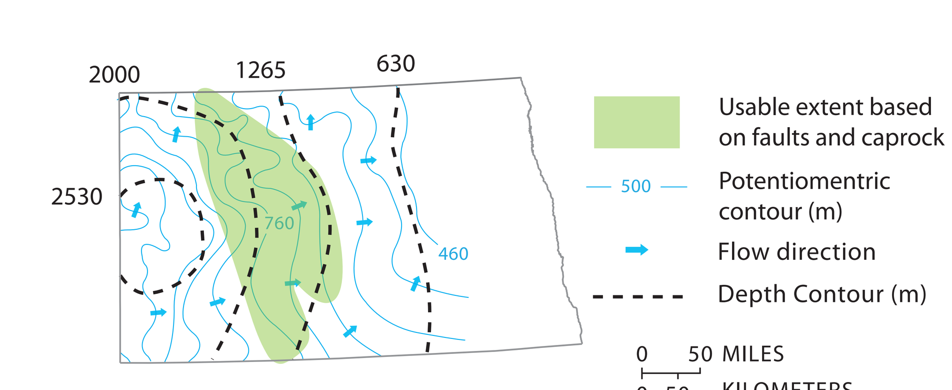

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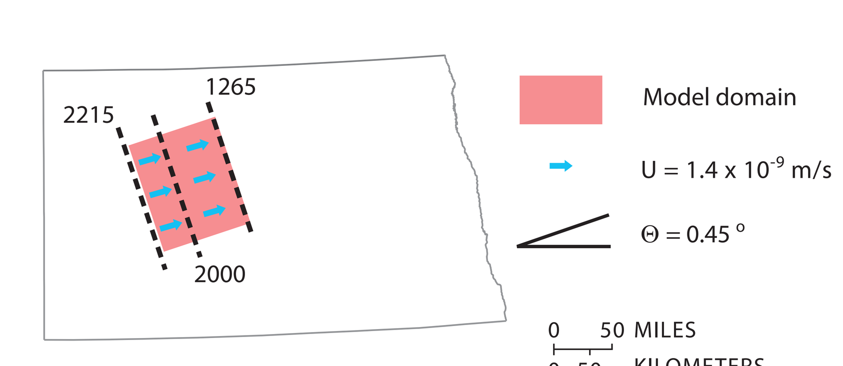

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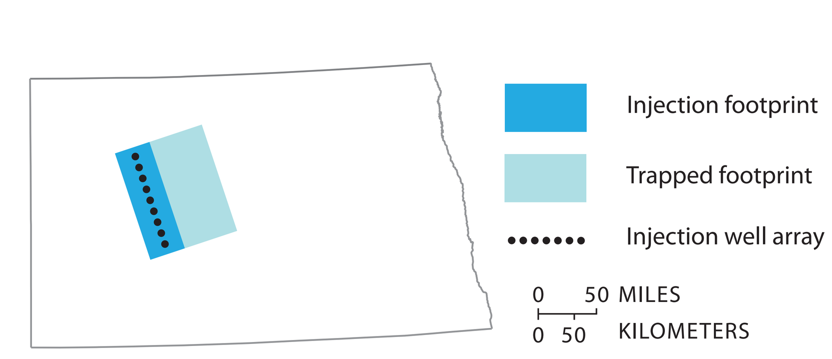

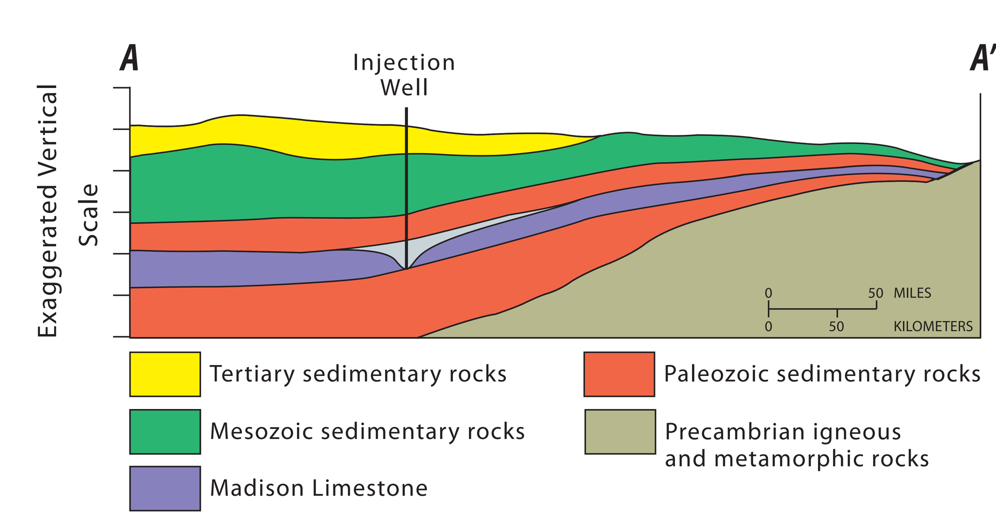

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