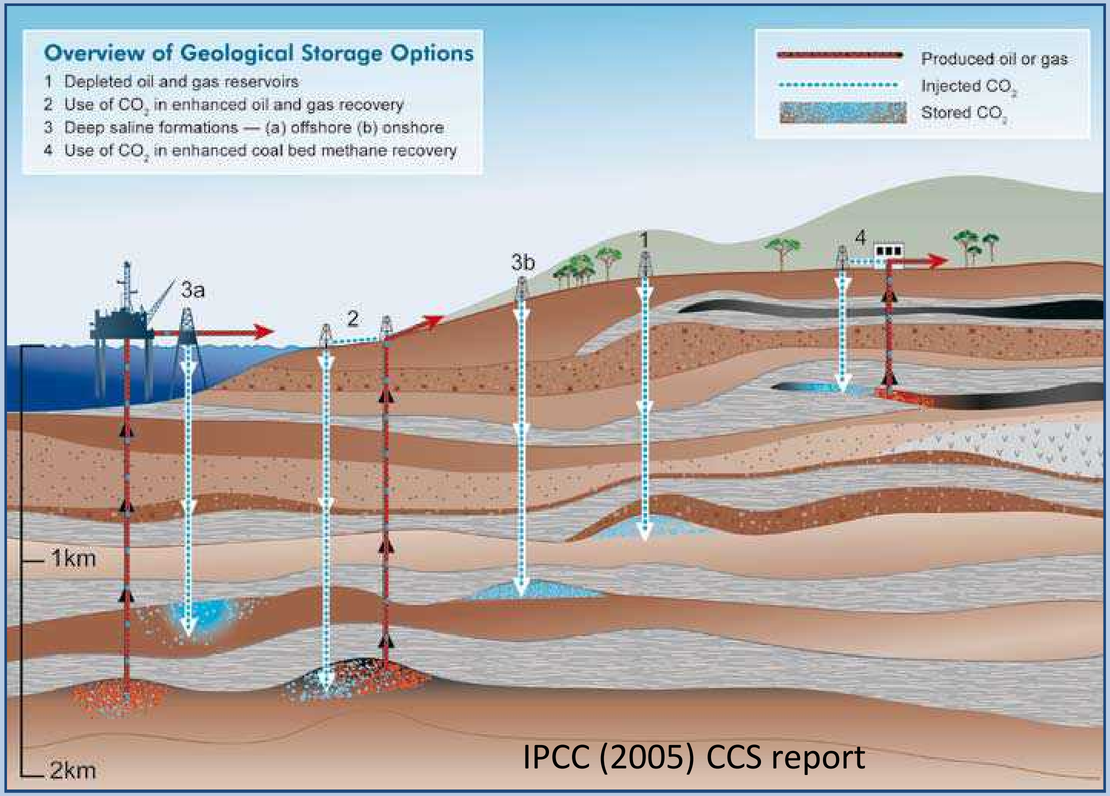
SAND2011-6157C

Variation in energy available to populations of subsurface anaerobes in response to geological carbon storage

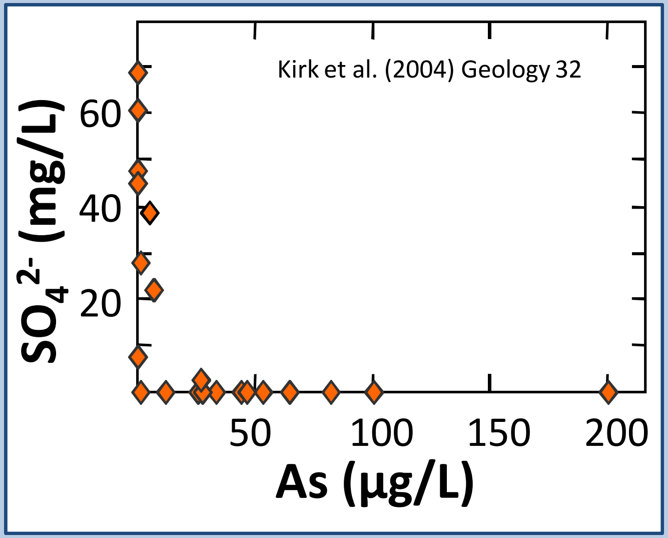
Matthew F. Kirk and Susan J. Altman

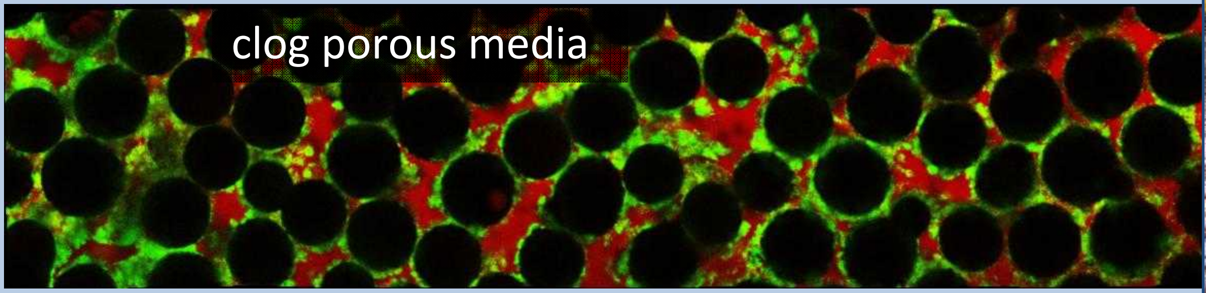
Sandia National Laboratories

Microbiology and geological CO_2 storage



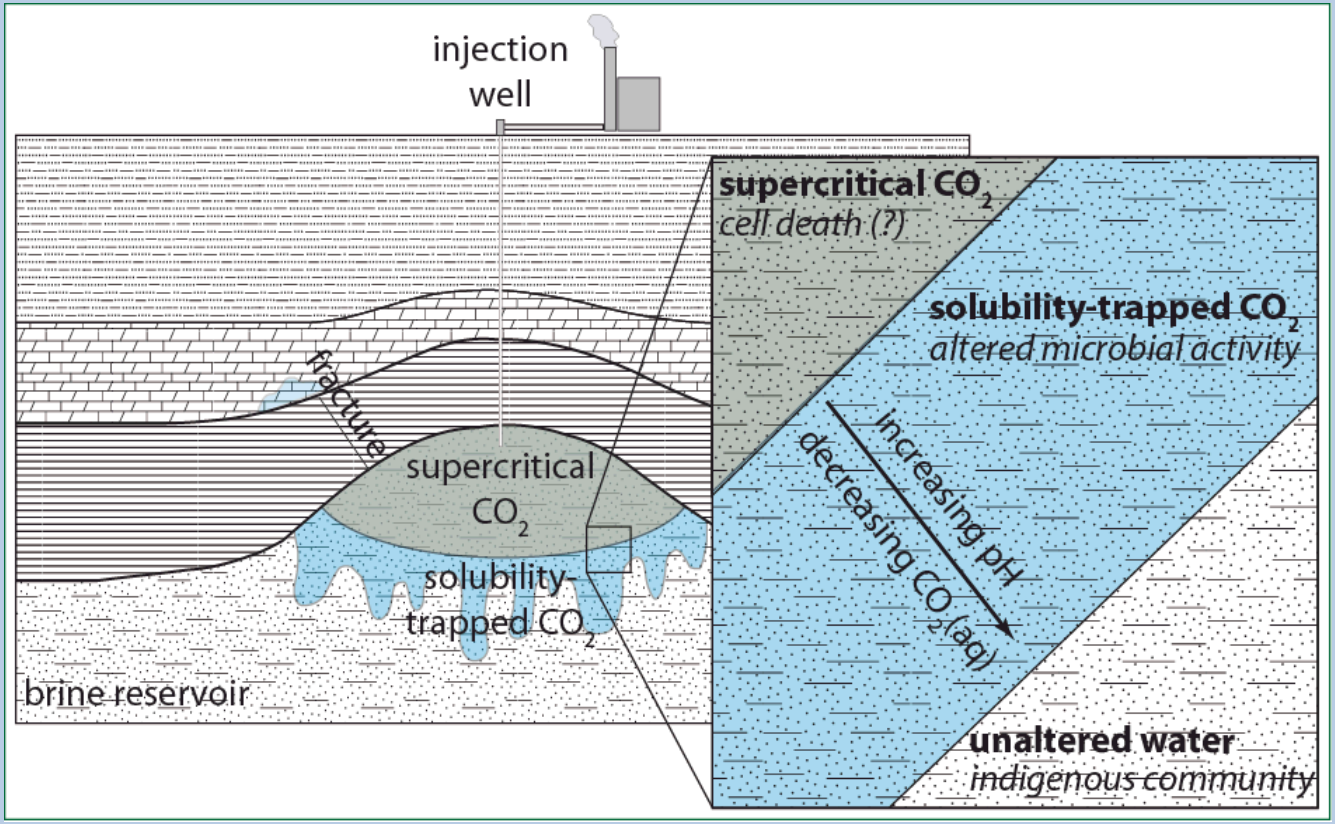
control contaminant mobility





bacteria water glass beads

Conceptual model



Unknowns:

$scCO_2$ tolerance?

Variation in aqueous chemistry – electron donors, energy available, pH?

Biomass distribution?

Learning more about how CO_2 injection affects subsurface microbes is useful for developing biological strategies to enhance CO_2 storage.

Objective

Examine how variation in aqueous chemistry after CO_2 injection affects the balance between subsurface microbial reactions

- Calculated variation in energy available for microbial reactions during 2 CO_2 injection field experiments:
  - Frio Formation experiment
  - Zero Emission Research and Technology (ZERT) experiment
- Considered 3 groups of microorganisms:
  - Fe(III) reducers (goethite, hematite, magnetite)
  - SO_4^{2-} reducers
  - methanogens
- Two electron donors:
  - acetate
  - hydrogen

Energy available

- Energy available to a group of microorganisms is the free energy released by that groups metabolic reaction:

$$\Delta G_A = -\Delta G_r = -[\Delta G_T^{\circ} + RTlnQ_r]$$

$$Q_r = \prod_i (\gamma_i \times m_i)^{\nu_i}$$

stoichiometric coefficient

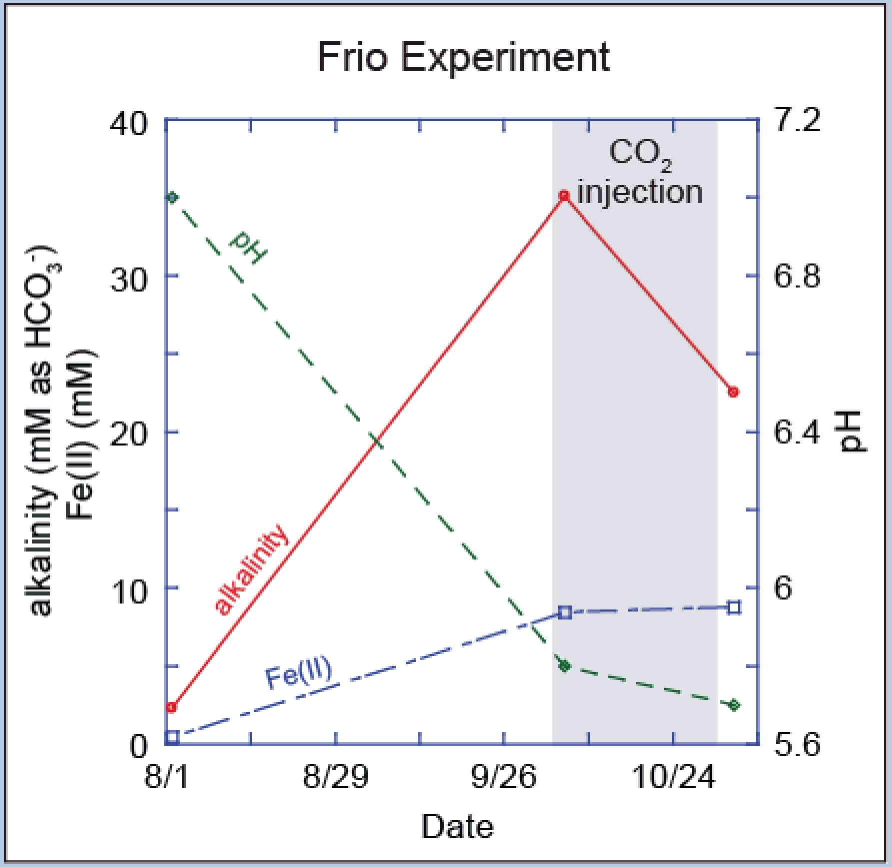
activity coefficient

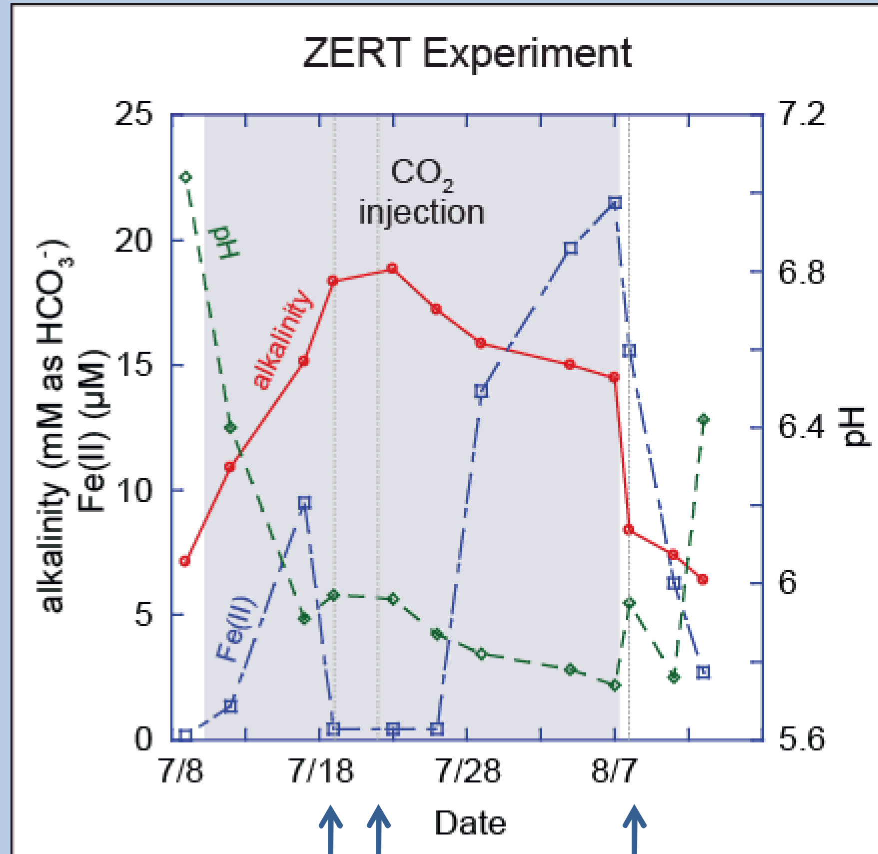
molality

- Speciation modeling - GWB using LLNL dataset and *B*-dot equation
- Result normalized to conditions prior to CO_2 injection:

$$\Delta G_A^{CO_2} - \Delta G_A^{initial} = \Delta G_A^n$$

Variation in aqueous chemistry

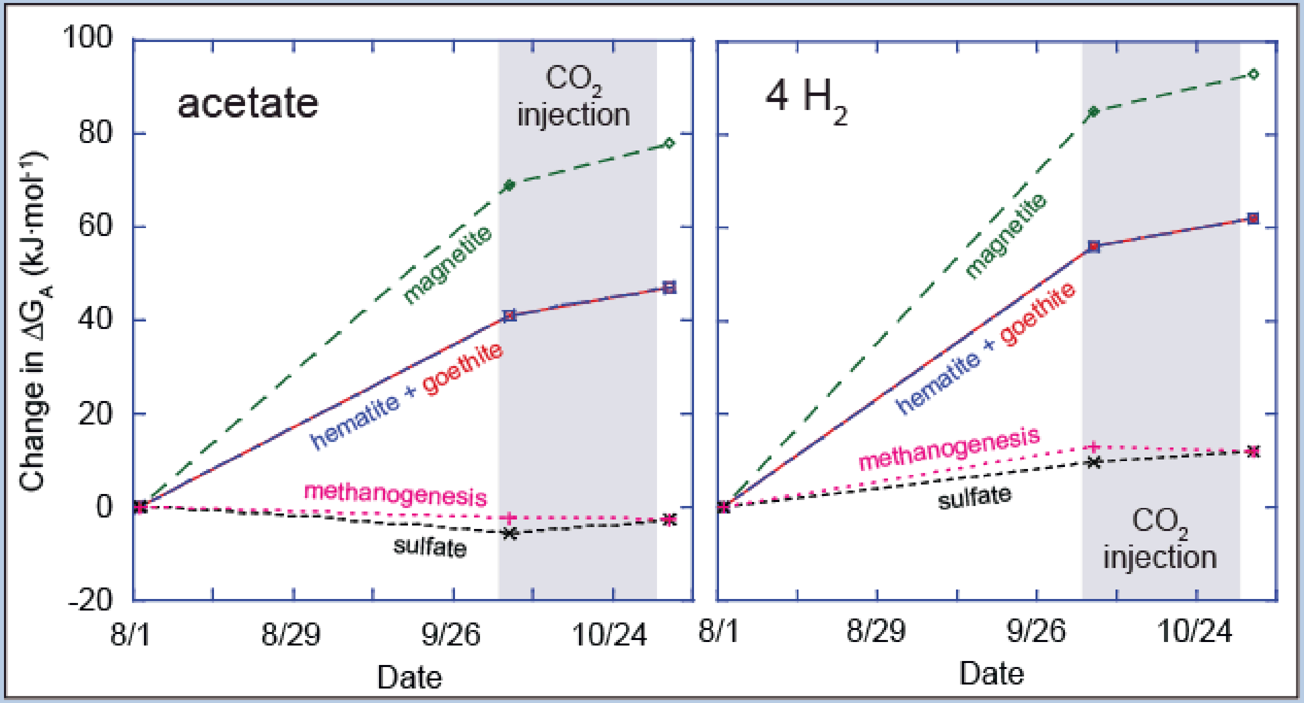




Precipitation events

Data sources – [Frio] Kharaka et al. (2006) Geology 34; Kharaka et al. (2007) J. Geochem. Expl. 89; [ZERT] Kharaka et al. (2010) Environ. Earth Sci. 60

Frio – energy available

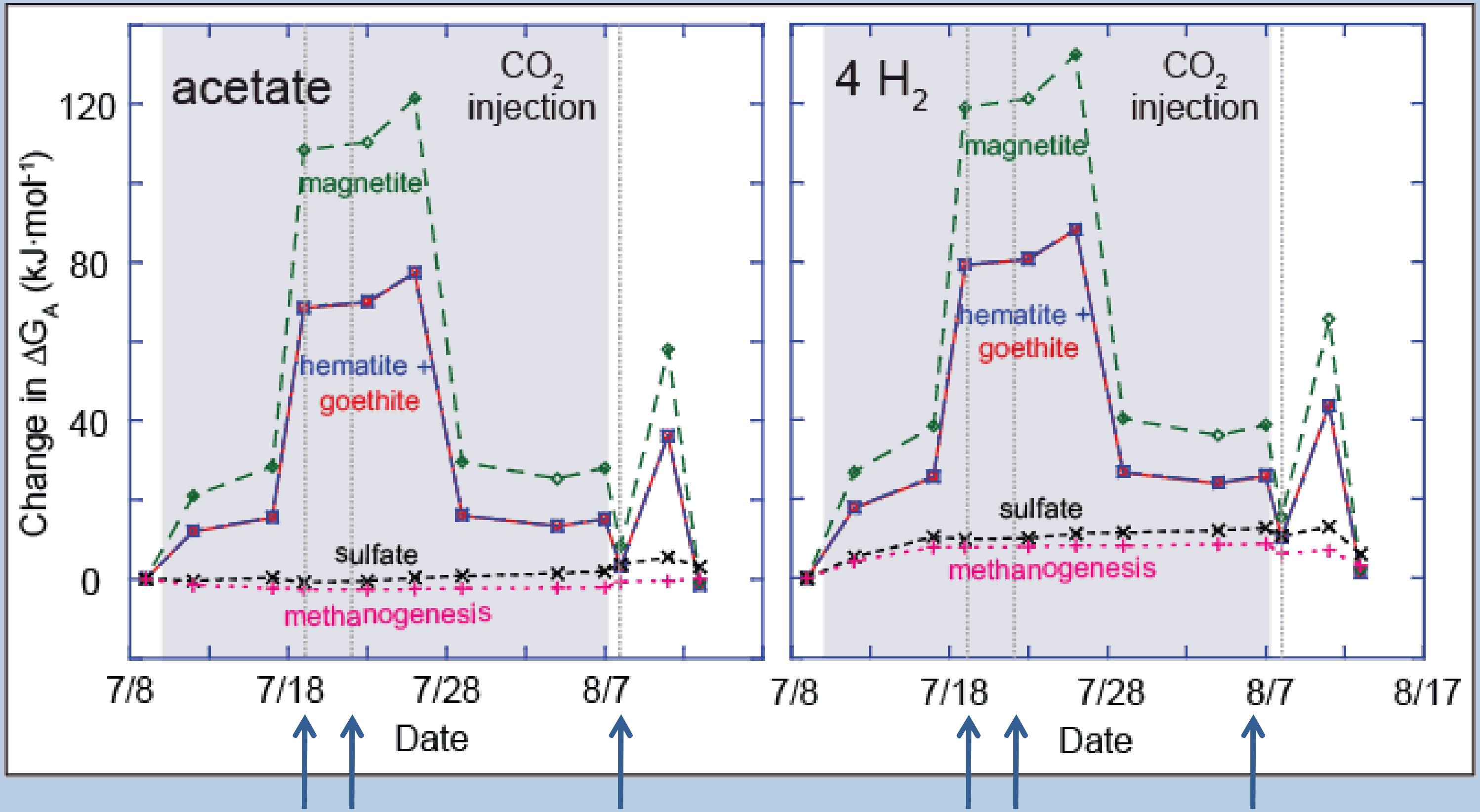


Fe(III) reduction
$8\ \text{Goethite} + CH_3COO^- + \underline{\mathbf{17\ H^+}} \rightarrow 2\ CO_2(aq) + 14\ H_2O + 8\ Fe^{2+}$
$8\ \text{Goethite} + 4\ H_2(aq) + \underline{\mathbf{16\ H^+}} \rightarrow 16\ H_2O + 8\ Fe^{2+}$

SO_4^{2-} reduction
$SO_4^{2-} + CH_3COO^- + \underline{\mathbf{3\ H^+}} \rightarrow 2\ CO_2(aq) + 2\ H_2O + H_2S(aq)$
$SO_4^{2-} + 4\ H_2(aq) + \underline{\mathbf{2\ H^+}} \rightarrow 4\ H_2O + H_2S(aq)$

methanogenesis
$CH_3COO^- + \underline{\mathbf{H^+}} \rightarrow CO_2(aq) + CH_4(aq)$
$CO_2(aq) + 4\ H_2(aq) \rightarrow 2\ H_2O + CH_4(aq)$

ZERT – energy available



Precipitation events

Precipitation events

Microbial reaction rates

Factors that control microbial reaction rates include the kinetics of electron donation and acceptance as well as energy available in the environment:

$$r = k_+[X]F_D F_A F_T$$

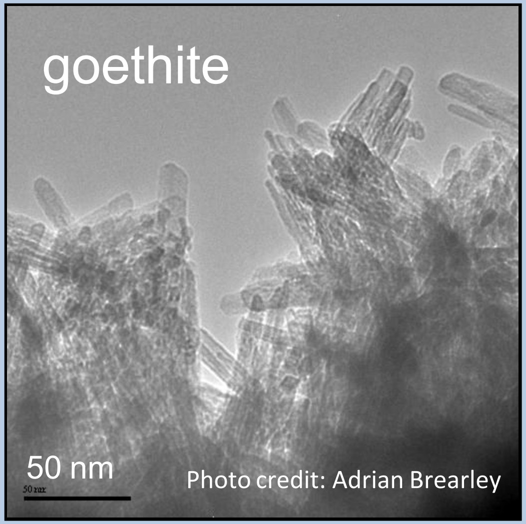
$$F_T = 1 - exp\left(-\frac{\Delta G_A - m\Delta G_P}{\chi R T_K}\right)$$

energy available

stored energy

rate limit step

The increase in ΔG_A for Fe(III) reducers resulting from CO_2 injection could allow the rate of Fe(III) reduction to increase.



Kinetic model – Jin and Bethke (2002) Biophys. J. 83; (2003) Appl. Environ. Microbiol. 69; (2005) Geochim. Cosmochim. Acta 69; (2007) Am. J. Sci. 307

Conclusions and implications

- Geological CO_2 storage can create conditions that are more favorable for microbial Fe(III) reduction

- The rate of Fe(III) reduction could increase as a result

- Result implies a biological pathway for enhanced trace element mobility

- Fe(III) reducers and other acid-consuming species may be ideal for biological strategies to enhance carbon storage

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Photo credit: Lucas McGrath

<u>**More details can be found in Kirk (2011) ES&T 45, 6676-6682**</u>

Acknowledgements

- We thank Randall Cygan, Qusheng Jin, Hongkyu Yoon, Jay Santillan, Yousif Kharaka, and Susan Hovorka for assisting with this work.

- This material is based upon work supported as part of the Center for Frontiers of Subsurface Energy Security, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Award Number DE-SC0001114.

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