2-D Numerical Modeling of a Fault Zone Leaking Carbon Dioxide in East Central Utah: Implications for MMV Protocols

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Introduction

The Little Grand Wash fault zone in east-central Utah, USA, cuts a large section of sandstones, shales, and siltstones. Faults in these types of rocks typically generate fault seal. However, this **fault leaks CO_2-rich fluids to the surface** as evidenced by springs and geysers that lie in the fault zone. Abundant calcite precipitation located along the trace of the fault indicates a long history of fault-influenced fluid flow. **Study of this fault is ideal for understanding the processes that affect accumulation, migration, and leakage of CO_2 in and from the subsurface.**

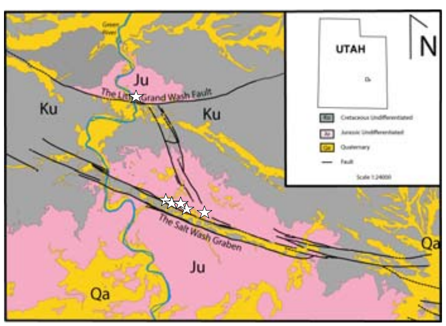
Study objectives

- ❑ Test and evaluate conceptual models of the water and gas flow system. Special emphasis is placed on understanding the role the fault plays in facilitating CO_2 leakage.
- ❑ Evaluate CO_2 migration rates (emphasis on fault) and effects of CO_2 on mineralogy, porosity, and permeability.
- ❑ Use model results to aid in MMV design

Methods

We have gathered information from our previous studies (Heath, submitted; Shipton et al., 2004, Williams, 2004) to further develop a conceptual model of the water and CO_2 flow system. We test the conceptual model with a 2-D mathematical model that includes coupled heat and multiphase fluid flow, and reactive transport.

Study area and geologic setting

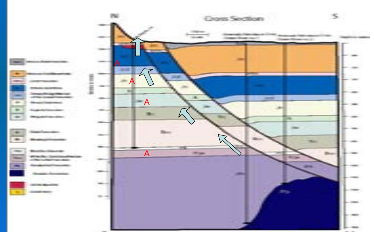


Geologic map of the study area showing the Little Grand Wash fault zone and surrounding area (Williams, 2004). The fault dips to the south and cuts a north plunging anticline. The stars indicate locations of springs, geysers, and abandoned wells that leak CO_2-rich waters to the surface.

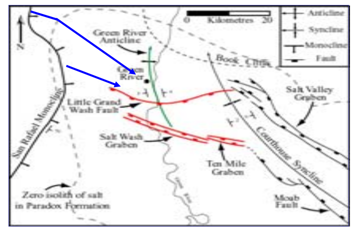
Current active leakage of CO_2 near the LGW fault.

Carbonate veins near the LGW fault. This deposit evinces ancient fluid flow and CO_2 leakage.

Conceptual Model

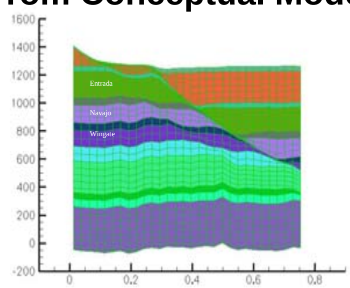


North-south cross section at the LGW fault (adapted from Williams (2004)). The blue arrows represent the flow paths of CO_2–laden groundwater. The letter "A" represents aquifers that have high bicarbonate levels (> 1 g/L), which indicates that they have been charged by CO_2.



Blue arrows represent groundwater flow paths determined from the potentiometric surface of the Navajo Sandstone (Hood and Patterson, 1984; map compiled by Z. Shipton). The water flows from the recharge area, gets impeded by the faults, and then is assumed to travel to the surface through the faults.

From Conceptual Model to Numerical Model



2-D models of the fault zone and surrounding area were developed for TOUGHREACT (Xu et al., 2004). The immediate goals are to evaluate CO_2 migration rates for a range of fault permeabilities, under artesian conditions. We are also using this model as a tool to evaluate potential mineralogic changes and thus porosity and permeability changes.

Boundary conditions:

Left, bottom, and right sides: Neumann, no flow, except for heat flow (set at background ~50 mW/m^2)
Top: Dirichlet
Surface fluxes of CO_2 will be used for calibration
Surrounding topography of ~1km is suggested as a mechanism for mild artesian conditions (e.g., ~10MPa above hydrostatic) at depth

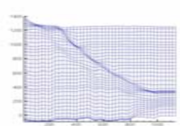
CO_2 input into the model:

Location of source: southern edge of subsurface fault zone; assumed constant source of CO_2, e.g., from recharge of CO_2-saturated groundwater or from supercritical CO_2 "bubble" some distance away

Model Parameterization

Limited selection kinetic parameters for sandstone units and fault gouge in the reactive transport model.

Mineral	Volume %	Reactive Surface Area A (cm^2/g)	Activation Energy E (KJ/mole)
Quartz	60%	9.8	87.7
Calcite	2%	equilibrium	equilibrium
Kaolinite	2%	151.6	22.2
Na-Smectite	4%	151.6	35
Illite	1%	151.6	35
K-feldspar	7%	9.8	38
Oligoclase	19%	9.8	69.8
Chlorite	4%	9.8	88
Hematite	1%	12.9	66.2



Physical dimensions:
- Length: 1440 meters
- Area: 1.47 km^2
- Number of cells: 1665

Initial conditions:
Pressure: hydrostatic
Temperature: conductive

Permeability/Porosity
Permeability and porosity values assigned appropriate to each lithology at depth. Fault assigned higher permeability (uniform 10^{-12} m^2)

CO_2 origin: the gas was generated by clay and carbonate diagenetic reactions during the burial of the Colorado Plateau, or the CO_2 has traveled to this location from areas of Tertiary igneous intrusions (McPherson et al., 2004) .

CO_2 migration: CO_2 in groundwater/brine migrates along the damage zone of the faults and charged several shallower aquifers (see results in right-side panel). Aquifers impacted by high levels of CO_2 are White Rim and Entrada/Navajo/Wingate.

CO_2 accumulation: the fault cuts a north-dipping anticline. The CO_2 accumulates in this structural high.

CO_2 leakage: the fault provides a leakage pathway from depths of > 1 km to the surface.

References

Heath, J.E., Lachmar, T.E., Evans, J.P., Kolesar, P.T., Hydrogeochemical characterization of leaking CO_2-charged fault zones in east-central Utah (in preparation for submission to a respectable journal).

Hood, J. W., and Patterson, D. J., 1984, Bedrock aquifers in the northern San Rafael Swell area, Utah, with special emphasis on the Navajo Sandstone. Utah Department of Natural Resources Technical Publication 78, 128 p.

Pruess, K., Oldenburg, C., Moridis, G., 1999, TOUGH2 User's Guide, Version 2.0. Lawrence Berkeley Laboratory Report LBL-43134, Berkeley, California.

Shipton, Z.K ., Evans, J.P., Kirchner, D., Kolesar, P.T., Williams, A. , Heath, J., 2004, Analysis of CO_2 leakage through "low-permeability" faults from natural reservoirs in the Colorado Plateau, southern Utah. In: S. Baines and R Worden (eds.) *Geological Storage of Carbon Dioxide*, Geology Society of London Special Publications 233, 43-58 (in press).

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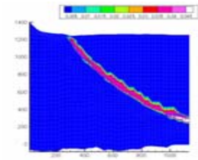
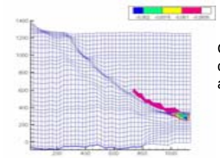
Selected Model Results

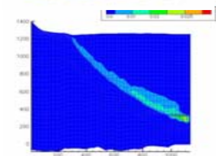


CO_2 concentration (dissolved) after 8.5 years

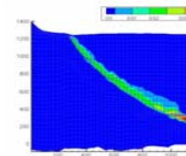
nder these artesian nildly overpressured) onditions, dissolved CO_2 avels ~1 km to the urface in < 10 years!



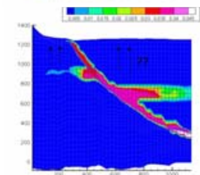
Change in calcite (%) after 8.5 years



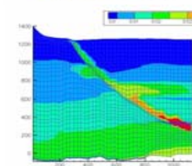
Change in porosity (%) after 8.5 years



Change in porosity (%) after 100 years



CO_2 concentration (dissolved) after 8.5 years; Navajo SS assigned uniformly higher (10^{-12} m^2) permeability.



Porosity change after 8.5 years; Navajo SS assigned uniformly higher (10^{-12} m^2) permeability

It's possible that more shallow units are continuously "recharged" with CO_2 from the fault and CO_2 leaks to the surface through local high-permeability flow conduits (e.g., non-visible fault splays, etc. – black arrows in panel immediately above and left) in addition to leakage at the fault scarp. Our field measurements (see Allis et al., 2005, this conference) show CO_2 flux measurements from the fault and also from areas close to but not in the fault zone. Models can be made to fit the observations, but the goal of modeling is to understand the system, not necessarily replicate it.

Conclusions and Implications for MMV

(1) We performed many different model permutations, and only a few are shown here. All model results for this natural system suggest that it is imperative to monitor bicarbonate levels in the groundwater following injection of CO_2, inasmuch as the migration rate of dissolved CO_2 can be relatively rapid under even mildly artesian conditions.

(2) Detailed, reliable knowledge of the subsurface structure, stratigraphy, and hydrodynamics are absolutely essential for developing a meaningful conceptual model of a subsurface CO_2 flow and chemistry system – MMV strategies depend on these data.

(3) Models are useful for estimating migration patterns and rates, and thus for predicting where to focus MMV efforts (direct/surface and indirect/subsurface) but resolution of results depends on extent and reliability of (2).

(4) Porosity, permeability, and mineralogic evolution are extremely difficult to predict, because of lack of resolution of mineralogy and heterogeneity.

(5) Models like this are critical for MMV design and development -- we suggest an "adaptive" MMV strategy: models are used to design MMV plans, then MMV data are used to refine models, then model results are used to update MMV plans, and so on.