CO_2-rich springs in Iceland: natural analogues for geologic CO_2 sequestration

Dana Thomas[1], Kate Maher[1], Dennis K. Bird[1], Stefan Arnórsson[2], Gordon E. Brown, Jr. [1,3,4]

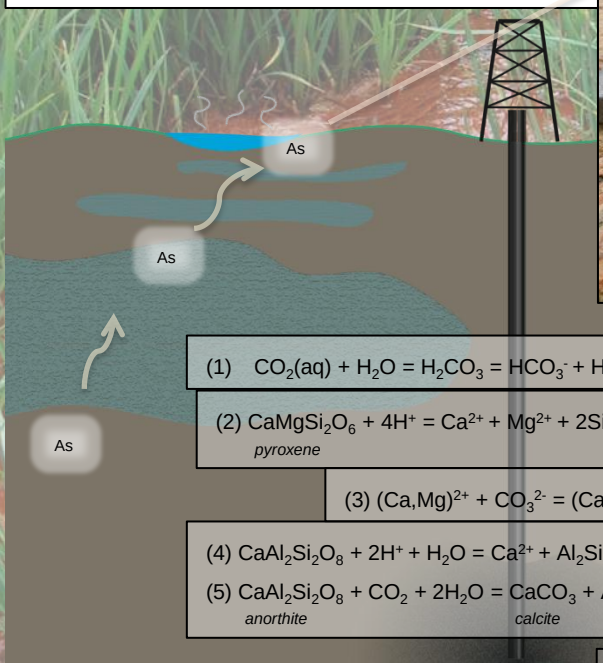
[1] Department of Geological and Environmenal Sciences, Stanford University, Stanford, CA.
[2] Institute of Earth Sciences, University of Iceland, Reykjavik, Icleand
[3] Department of Photon Science and Stanford Synchrotron Radiation Lightsource, SLAC, Menlo Park, CA.
[4] Department of Chemical Engineering, Stanford University, Stanford, CA.

MOTIVATION

- Geologic sequestration of CO_2 via mineral carbonation may be a way to store billions of tons of CO_2 for the long-term.
- In this process, CO_2 is injected into the subsurface either as a separate supercritical fluid or as a single phase fluid mixed with water.
- The CO_2-H_2O dissociates, releasing H^+ ions and decreasing pH (equation 1). The silicate minerals in basalts are destabilized at lower pH and release their divalent cations, which form carbonate minerals such as calcite ($CaCO_3$) and magnesite ($MgCO_3$) with the carbonate ions (equations 2-3). In addition, plagioclase dissolution can consume H^+ ions, or form carbonates (equations 4-5).
- Basalt carbonation experiments have yielded varied mineralogical results, making predictions difficult.
- Potential environmental harm from CO_2 leakage requires investigation.

OBJECTIVE

- CO_2-rich fluids in Iceland and the basalts through which they circulate serve as natural analogues of the **fluid-rock interactions and geochemical reactions that occur upon injection of CO_2-charged water into basalts**.
- Fluids at the surface and in the shallow subsurface represent the result of contamination from **potential CO_2 leakage**.
- Drill cuttings of altered basalt from wells HE-07, KH-11, ÖL-05 and ÖL-10 are used to identify the expected petrologic suite, while fluid analyses help to characterize trace element mobilization and saturation state of the fluids.s



(1) $CO_2(aq) + H_2O = H_2CO_3 = HCO_3^- + H^+ = CO_3^{2-} + 2H^+$

(2) $CaMgSi_2O_6 + 4H^+ = Ca^{2+} + Mg^{2+} + 2SiO_{2(aq)} + 2H_2O$
pyroxene

(3) $(Ca,Mg)^{2+} + CO_3^{2-} = (Ca,Mg)CO_3$

(4) $CaAl_2Si_2O_8 + 2H^+ + H_2O = Ca^{2+} + Al_2Si_2O_5(OH)_4$

(5) $CaAl_2Si_2O_8 + CO_2 + 2H_2O = CaCO_3 + Al_2Si_2O_5(OH)_4$
anorthite *calcite* *kaolinite*

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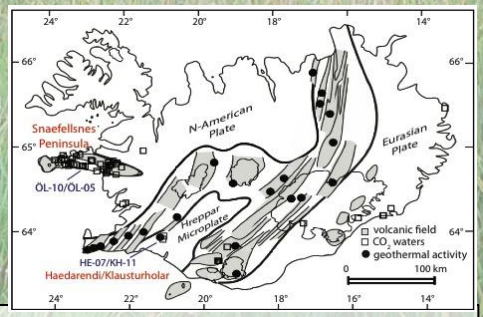
REFERENCES

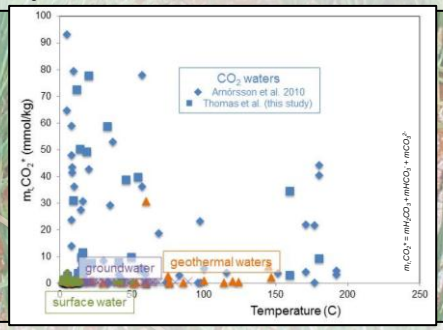
[1]Arnorsson, S., & Barnes, I. (1983). The Nature of Carbon-Dioxide Waters in Snaefellsnes, Western Iceland. *Geothermics*, *12*(2-3), 171-176.
[2]Arnorsson, S., Hurtig, N., Gysi, A. P., Bird, D. K., & O'Day, P. (2010). Carbon dioxide waters in Iceland: A natural analogue to CO2 sequestration in basaltic aquifers.
[3]Arnorsson, S. N., Gunnarsson, I., Stefansson, A., Andresdottir, A., & Sveinbjornsdottir, A. E. (2002). Major element chemistry of surface- and ground waters in basaltic terrain, N-Iceland. I. Primary mineral saturation. *Geochimica Et Cosmochimica Acta*, *66*(23), 4015–4046
[4]Arnórsson, S. (2003). Arsenic in surface- and up to 90°C ground waters in a basalt area, N-Iceland: processes controlling its mobility. *Applied Geochemistry*, *18*(9), 1297-1312.

GEOLOGIC SETTING

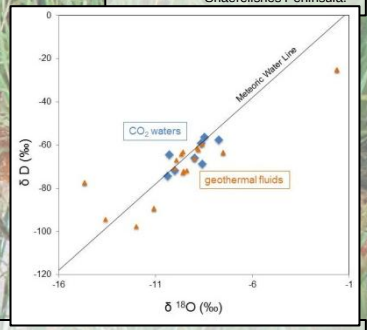


(a) CO_2-rich fluids are found in low-temperature geothermal systems in Iceland on the margin of the Mid-Atlantic Rift and in off-rift divergent volcanic zones such as on the Snaefellsnes Peninsula. Drill cuttings are from wells HE-07, KH-11, ÖL-05 and ÖL-10.

(b) CO_2 bubbles readily discharging from a shallow geothermal well on the Snaefellsnes Peninsula.

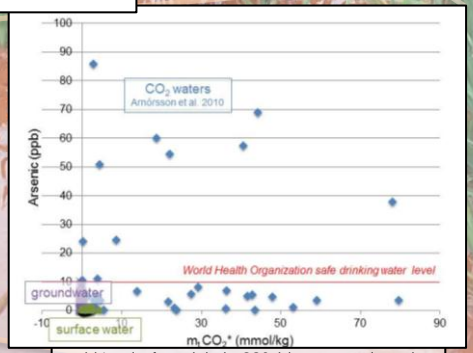


(c) Concentrations of CO_2 are orders of magnitude higher than ground, surface and geothermal waters.

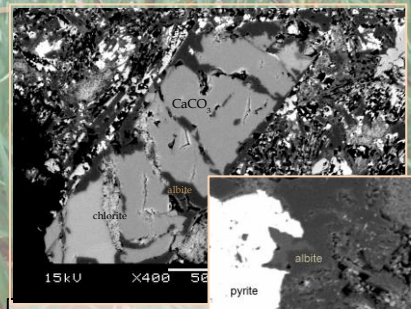


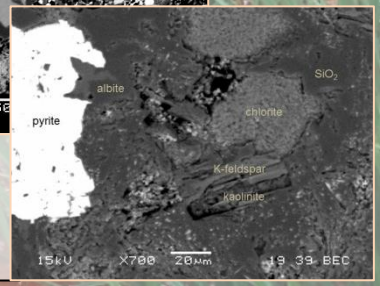
(d) Isotopic analyses indicate a magmatic CO_2 source.

RESULTS



(a) Levels of arsenic in the CO2-rich waters are elevated relative to surface and groundwaters.





(a) Initial scanning electron microscopy (SEM) and x-ray diffraction results indicate primary feldspars replaced by secondary carbonates; and the presence of Fe sulfides, Fe and Ti-oxides, chlorite and kaolinites.

FUTURE WORK

- Identify phases in which trace elements are hosted.
- Determine divalent cation uptake by secondary phyllosilicates vs. carbonates vs. oxides
- Use mineral phases to quantify conditions at depth.