RESEARCH FOCUS

Carbon sequestration and natural analogs

Julianna Fessenden
Decision Applications Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

Anthropogenic emission of carbon into the atmosphere has caused an imbalance of the global carbon cycle (Broecker et al. 1979; Sundquist, 1993). Ancient geologically stored carbon has been released primarily as CO_2 during fossil fuel combustion, and is building up in the atmosphere because the sinks of carbon (soils, plants, oceans) cannot keep up with the pace of emission (Raynaud et al., 1993). As a result, the atmospheric carbon burden has been overloaded, and is changing the Earth's surface through changes in global temperature, atmospheric and oceanic circulation, weather patterns, storm severity, global vegetation profiles, and atmospheric, land, and ocean chemistry (McClintock et al. 2009; Nema et al., 2012; Walsh et al., 2012).

A proposed solution to this problem is to pump anthropogenic CO_2 back into deep geologic formations—basically, to return this ancient carbon back to where it originated (Furnival, 2006; Jones, 2006). One proposed solution is to collect the CO_2 at the stacks of coal-fired power plants and cement plants, purify the CO_2, compress it to supercritical densities, then pump this CO_2 down deep wells into geologic formations (Engelenburg and Blok, 1993; Notz et al., 2011). The U.S. Department of Energy has invested billions of dollars over the past 8 yr to determine if this type of approach could help stop the atmospheric CO_2 increase (Litynski et al., 2009). Specific research has focused on separation and purification technologies to isolate CO_2 from coal-fired power plants, engineering optimization strategies of how best to move this CO_2 to a geologic storage site, understanding the storage capacity of different geologic reservoir types, optimizing well designs, monitoring the fate and transportation of CO_2 in storage reservoirs, and assessing the risk of storage failure at many different scales within a geologic reservoir (Eiken et al., 2011; Jensen et al., 2011; Koornneef et al., 2012).

Natural analogs, geologic formations where CO_2 naturally occurs as either stored (e.g., trapped under a seal) or escaping (e.g., geyser) gas, are good research opportunities to understand how CO_2 behaves in natural settings, or how CO_2 might behave in an engineered storage site over time. Research topics such as equilibrium CO_2–reservoir interactions, kinetic surface-chemistry changes, monitoring optimization, risk assessment, and groundwater impacts are examples of areas of research where natural analogs have been useful for carbon capture and storage (CCS) missions (Keating et al., 2010, Pearce et al., 2011).

One area of active research where natural analogs have been used is the tracking of CO_2-rich brine water movement through varying geologic settings, and understanding how this acidic water impacts the local mineralogy and chemistry (Pauwels et al., 2007; Lu et al., 2011). The CO_2-brine fluid has been shown to mobilize trace metals, change the major and minor ion chemistry, and change the isotopic composition of the solution and sediments that the fluid is moving through (Rempel et al., 2011). The chemical signatures of the CO_2-brine fluid as it is sampled through a reservoir can give information about the source of this fluid (depth, origin), the impact of the fluid on the regional sediments (metal leaching), and the lifetime of the channel openings (timing of fracture cementation) (Lowenstern et al., 1999; Nightingale et al., 2009; Eke et al., 2011).

Wigley et al. (2012, p. 555 in this issue of *Geology*) use chemistry signatures to interpret the origin and impact of CO_2-brine solutions in a natural CO_2 reservoir along the Green River anticline in Utah (United States). Their work highlights the chemical transformations that are occurring in the hematite-rich sandstones within the Green River anticline as the CO_2-rich brine moves through the sediments. The trace-metal leaching of the sediments is best observed at the reaction front. The stable isotope and elemental composition of the fluids and the mineralogical analysis of the sediments show that the Green River natural analog is distinct from other hydrocarbon-bleaching locations along the Colorado Plateau. Wigley et al. use their findings as an example of how chemical signatures of fluids and sediments can show the nature and origin of CO_2-brine movement, and geologic impacts. The significance of Wigley et al.'s findings is that carbonate re-precipitation and formation was observed in red sandstone. This shows that hematite-rich sandstones could effectively be used as engineered CO_2 storage sites, because fracture systems could cement over time due to this carbonate formation.

Wigley et al.'s work is an excellent example of a current trend of research where natural analogs are more commonly being used as model systems to best understand how CCS reservoirs will behave over time. At the onset of CCS research efforts in the late 1990's and early 2000's, there was public concern about the stability of CO_2 sequestration, and how CO_2 may impact local resources and public health (Van Alphen et al., 2007; Miller et al., 2008; Stephens et al., 2009). During the mid to late 2000's, CO_2 storage pilot studies and larger demonstration studies showed safe permanent storage of CO_2 pumped into sequestration sites (Sohrabi et al., 2011; Whittaker et al., 2011). This, along with outreach efforts performed by the CCS community, allowed the public to become more at ease with CCS as a viable option to greenhouse-gas emission control (Daly et al., 2011). As a result, the study of natural analogs has come into favor as a model to explore CO_2 impacts to local geology, groundwater, infrastructure, and surface systems (Pearce, 2006). These natural analogue studies have provided decision makers with a model system of how best to decide upon risk assessment, monitoring, mitigation, and verification approaches for CCS sites.

In summary, the use of natural analogs for the understanding and assessment of CO_2 sequestration permanence is critical if engineered storage reservoirs will be accepted worldwide. The natural analogs provide an example of CO_2 storage over thousands of years. The interaction of the CO_2 with the natural environment (e.g., the storage reservoir, the groundwater) is typically in an equilibrium state, and monitoring the chemistry of the reservoir and intermediate liquid layers can provide insight into how engineered storage reservoirs will behave with time. The study presented by Wigley et al. shows such an example of a natural analog site, and how the site chemistry can be used to understand the origin of the CO_2, the reservoir-CO_2-brine interaction, and the reaction front behavior with time. This study provides a perfect example of how natural analogs can be used for CCS research on reservoir performance, monitoring optimization, risk assessment, and mitigation.

REFERENCES CITED

Broecker, W.S., Takahashi, T., Simpson, H.J., and Peng, T.H., 1979, Fate of fossil fuel carbon dioxide and the global carbon budget: Science, v. 206, p. 409–418, doi:10.1126/science.206.4417.409.

Daly, D., Bradbury, J., Garrett, G., Greenberg, S., and Myhre, R., 2011, Road-testing the outreach best practices manual: Applicability for implementation of the development phase projects by the regional carbon sequestration partnerships: Energy Procedia, v. 4, p. 6256–6262, doi:10.1016/j.egypro.2011.02.639.

Geology, June 2012; v. 40; no. 6; p. 575–576; doi: 10.1130/focus062012.1.

Eiken, O., Ringrose, P., Hermanrud, C., Nazarian, B., and Torp, T.A., 2011, Lessons learned from 14 years of CCS operations: Sleipner, In Salah and Snohvit: Energy Procedia, v. 4, p. 5541–5548, doi:10.1016/j.egypro.2011.02.541.

Eke, P.E., Naylor, M., Haszeldine, S., and Curtis, A., 2011, CO_2/brine surface dissolution and injection: CO_2 storage enhancement: Society of Petroleum Engineers Journal, v. 6, p. 41–53.

Engelenburg, B.C.W., and Blok, K., 1993, Disposal of CO_2 in permeable underground layers—A feasible option: Climatic Change, v. 23, p. 55–68, doi:10.1007/BF01092681.

Furnival, S., 2006, Burying climate change for good: Physics World, v. 19, p. 24–29.

Jensen, G., Nickel, E., Whittaker, S., and Rostron, B., 2011, Site assessment update at Weyburn-Midale CO_2 sequestration project, Saskatchewan, Canada: New results at an active CO_2 sequestration site: Energy Procedia, v. 4, p. 4777–4784, doi:10.1016/j.egypro.2011.02.442.

Jones, C., 2006, Back where it belongs: IET Power Engineer, v. 20, p. 14–17, doi:10.1049/pe:20060501.

Keating, E.H., Fessenden, J., Kanjorski, N., Koning, D., and Pawar, R., 2010, The impact of CO_2 on shallow groundwater chemistry: Observations at a natural analog site and implications for carbon sequestration: Environmental Earth Sciences, v. 60, p. 521–536, doi:10.1007/s12665-009-0192-4.

Koornneef, J., Ramirez, A., Turkenburg, W., and Faaij, A., 2012, The environmental impact and risk assessment of CO_2 capture, transport and storage—An evaluation of the knowledge base: Progress in Energy and Combustion Science, v. 38, p. 62–86, doi:10.1016/j.pecs.2011.05.002.

Litynski, J., Plasynski, S., Spangler, L., Finley, R., and Steadman, E., 2009, U.S. Department of Energy's Regional Carbon Sequestration Partnership Program: Overview: Energy Procedia, v. 1, p. 3959–3967, doi:10.1016/j.egypro.2009.02.200.

Lowenstern, J.B., Janik, C., Fahlquist, L., and Johnson, L.S., 1999, Compilation of gas geochemistry and isotopic analyses from The Geysers geothermal field: 1978–1991: Geothermal Resources Council Transactions, v. 23, p. 383–390.

Lu, P., Fu, Q., Seyfried, W.E., Hereford, A., and Zhu, C., 2011, Navajo Sandstone-brine-CO_2 interaction: Implications for geological carbon sequestration: Environmental Earth Sciences, v. 62, p. 101–118, doi:10.1007/s12665-010-0501-y.

McClintock, J.B., Angus, R.A., Mcdonald, M.R., Amsler, C.D., and Catledge, S.A., 2009, Rapid dissolution of shells of weakly calcified Antarctic benthic macroorganisms indicates high vulnerability to ocean acidification: Antarctic Science, v. 21, p. 449–456, doi:10.1017/S0954102009990198.

Miller, E., Summerville, J., Buys, L., and Bell, L., 2008, Initial public perceptions of carbon geosequestration: Implications for engagement and environmental risk communication strategies: International Journal of Global Environmental Issues, v. 8, p. 147–164, doi:10.1504/IJGENVI.2008.017265.

Nema, P., Nema, S., and Roy, P., 2012, An overview of global climate changing in current scenario and mitigation action: Renewable & Sustainable Energy Reviews, v. 16, p. 2329–2336, doi:10.1016/j.rser.2012.01.044.

Nightingale, M., Johnson, G., Shevalier, M., Hutcheon, I., and Perkins, E., 2009, Impact of injected CO_2 on reservoir mineralogy during CO_2-EOR: Energy Procedia, v. 1, p. 3399–3406, doi:10.1016/j.egypro.2009.02.129.

Notz, R.J., Tonnies, I., McCann, N., Scheffknecht, G., and Hasse, H., 2011, CO_2 capture for fossil fuel-fired power plants: Chemical Engineering & Technology, v. 34, p. 163–172, doi:10.1002/ceat.201000491.

Pauwels, H., Gaus, I., le Nindre, Y.M., Pearce, J., and Czernichowski-Lauriol, I., 2007, Chemistry of fluids from a natural analogue for a geological CO_2 storage site (Montmiral, France): Lessons for CO_2-water-rock interaction assessment and monitoring: Applied Geochemistry, v. 22, p. 2817–2833, doi:10.1016/j.apgeochem.2007.06.020.

Pearce, J.M., 2006, What can we learn from natural analogues? An overview of how analogues can benefit the geological storage of CO_2, *in* Lombardi, S., et al., eds. Advances in the Geological Storage of Carbon Dioxide: Netherlands, Springer, p. 129–139.

Pearce, J.M., Kirby, G.A., Lacinsha, A., Bateson, L., and Wagner, D., 2011, Reservoir-scale CO_2-fluid rock interactions: Preliminary results from field investigations in the Paradox Basin, Southeast Utah: Energy Procedia, v. 4, p. 5058–5065, doi:10.1016/j.egypro.2011.02.479.

Raynaud, D., Jouzel, J., Barnola, J.M., Chappellaz, J., and Delmas, R.J., 1993, The ice record of greenhouse gases: Science, v. 259, p. 926–934.

Rempel, K.U., Liebscher, A., Heinrich, W., and Schettler, G., 2011, An experimental investigation of trace element dissolution in carbon dioxide: Applications to the geological storage of CO_2: Chemical Geology, v. 289, p. 224–234, doi:10.1016/j.chemgeo.2011.08.003.

Sohrabi, M., Kechut, N.I., Riazi, M., Jamiolahmady, M., and Ireland, S., 2011, Safe storage of CO_2 together with improved oil recovery by CO_2-enriched water injection: Chemical Engineering Research & Design, v. 89, p. 1865–1872, doi:10.1016/j.cherd.2011.01.027.

Stephens, J.C., Bielicki, J., and Rand, G.M., 2009, Learning about carbon capture and storage: Changing stakeholder perceptions with expert information: Energy Procedia, v. 1, p. 4655–4663, doi:10.1016/j.egypro.2009.02.288.

Sundquist, E.T., 1993, Global carbon dioxide budget: Science, v. 259, p. 934–941.

Van Alphen, K., Van Voorst tot Voorst, Q., Hekkert, M.P., and Smits, R.E.H.M., 2007, Societal acceptance of carbon capture and storage technologies: Energy Policy, v. 35, p. 4368–4380, doi:10.1016/j.enpol.2007.03.006.

Walsh, K.J.E., McInnes, K.L., and McBride, J.L., 2012, Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific—A regional assessment: Global and Planetary Change, v. 80–81, p. 149–164, doi:10.1016/j.gloplacha.2011.10.006.

Whittaker, S., Rostron, B., Hawkes, C., Gardner, C., and White, D., 2011, A decade of CO_2 injection into depleting oil fields: Monitoring and research activities of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project: Energy Procedia, v. 4, p. 6069–6076, doi:10.1016/j.egypro.2011.02.612.

Wigley, M., Kampman, N., Dubacq, B., and Bickle, M., 2012, Fluid-mineral reactions and trace metal mobilization in an exhumed natural CO_2 reservoir, Green River, Utah: Geology, v. 40, p. 555–558, doi:10.1130/G32946.1.

Printed in USA