Quarterly Technical Report

Reactive Multiphase behavior of CO_2 in Saline Aquifers beneath the Colorado Plateau

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Principal Authors: R. G. Allis (Utah Geological Survey)
J. Moore (Energy & Geoscience Institute)
S. White (Industrial Research Limited)

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Submitted By: University of Utah, Salt Lake City UT 84108
In Collaboration With: Utah Geological Survey, PO Box 146100, Salt Lake City UT 84114
Industrial Research Ltd, PO Box 31-310, Lower Hutt, New Zealand

Disclaimer

ABSTRACT

Field and laboratory investigations of naturally occurring CO_2-reservoirs are being conducted to determine the characteristics of potential seal and reservoir units and the extent of the interactions that occur between the host rocks and the CO_2 charged fluids. Efforts have focused on the Farnham Dome field, located in central Utah, and the Springerville-St. Johns field in Arizona and New Mexico. The Springerville-St. Johns field is particularly significant because of the presence of extensive travertine deposits that document release of CO_2 to the atmosphere. CO_2 accumulations at both fields occur in sedimentary rocks typical of CO_2 reservoirs occurring on the Colorado Plateau. The main achievements during this quarter were: 1) a soil gas flux survey at the Springerville-St Johns field, 2) collection of some soil gas for chemical and isotopic analysis from this field, and 3) collection of travertine samples from an elevation range of over 1000 feet (330 m) for dating the time span of carbonate-saturated spring outflow at this field. Analytical results and interpretations are still in progress. When available they will allow contrast with soil gas measurements from Farnham Dome natural CO_2 field in central Utah, which were reported in the previous quarterly report.

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Fig. 2. Location of the Springerville-St. Johns CO_2 field, with some CO_2 wells and the structural high highlighted. Note the travertine deposits that occur over a 400 km^2 area, and range in elevation from 5860 feet (1787 m) near the Little Colorado River, to 6970 feet (2127 m) above sea level on a plateau to the west (near well 11-21 St).

Fig. 3. Pressure trends in the vicinity of the Springerville-St Johns field. The red squares are from wells on the field, and they imply a reservoir that is liquid-dominated and outflowing at about 5850 feet above sea level (about 1790 m asl), the elevation of Salado Springs. This is also the elevation of what appears to be the youngest travertine deposits.

Table 1. Preliminary listing of average soil gas CO_2 flux measurements from sites around the Springerville-St Johns CO_2 field. The units are $g/m^2/day$. At each site approximately 10 readings were made on a grid within an area typically 100 m by 100m.

Table 2. Listing of the travertine samples collecting for radiometric dating. The range in elevation is over 300 m, which suggests that there should have been a significant reservoir pressure difference and a significant age difference between the time of deposition at high elevation, and that at low elevation today.

EXECUTIVE SUMMARY

CO_2 flux measurements were made at 27 sites around the Springerville-St Johns CO_2 field. Sites where leakage was most likely to occur were selected. On average, about ten measurements were made at each site over an area approximately 100 m by 100 m. Measurements were made adjacent to bicarbonate-rich springs, on and adjacent to some of the travertine domes that occur in the northwest side of the field, and over structurally high areas of the field where reservoir rocks come closest to the surface. Results are still being interpreted, but a preliminary interpretation of the gas fluxes which range from 0.1 to 50 g/m^2/day are that significant reservoir gas leakage areas were not detected. The highest gas fluxes occurred in swampy ground adjacent to bicarbonate springs, and these fluxes are consistent with shallow soil CO_2 generation rather than a deep CO_2 flux. The implications of these results are still being considered. Earlier soil gas measurements at Farnham Dome also found no evidence of significant CO_2 soil gas flux. Accepting these results at face value, they may be positive for the future sequestration industry because they demonstrate that CO_2 can be stored at depth over geologic time.

Eight samples of travertine from the extensive deposits at Springerville-St Johns field were collected for radiometric dating. The elevation span of these deposits is over 330 m, which points to large changes in reservoir pressure over time, as spring waters shifted to lower elevation. Results of the dating have not been received yet. The implied pressure decline of at least 33 bars (3.3 MPa, equivalent to 330 m of head loss), suggests our model for the evolution of the CO_2 system needs to be modified. Down- cutting by the Little Colorado River may have played an important role because the present reservoir pressure is in equilibrium with the local River elevation, and the river has exposed some of the reservoir

rocks. The results and interpretations from this new work will provide constraints for new numerical modeling of the evolution of the physical and chemical changes of this natural CO_2 system.

EXPERIMENTAL

Not applicable

RESULTS AND DISCUSSION

During this quarter, the focus of work was on the natural CO_2 field at Springerville-St Johns, near the New Mexico-Arizona state line (Figures 1, 2). In particular, a soil gas flux survey was carried out from May 9 to 14, 2004. This followed a soil gas flux survey of the Farnham Dome CO_2 field (Central Utah) the previous month, and reported for the last quarter (White et al., 2004). Travertine samples were also collected and sent for radiometric dating.

Soil Gas Flux Measurements

The survey was led by Dr Deb Bergfeld (USGS). The soil gas flux measurements were made using a Westsystems flux meter containing a LI-COR 820 infrared gas analyzer (IRGA). The IRGA was calibrated at the start of the field survey using CO_2–free air and 1000 ppm CO_2 standards. IRGA accuracy is reported as $<2.5\%$ of the reading, which for this study would indicate a maximum measurement error of 11 ppm. The IRGA is connected to an accumulation chamber (AC) that uses a fan to mix of gases returning from the IRGA with those in the chamber. CO_2 measurements are made by placing the AC over a site and pressing it onto the surface to obtain a seal. Chamber gases are pumped from the AC through a desiccant to the IRGA and are returned to the AC in a closed loop. CO_2 concentration data were collected for a minimum of 2 minutes at each site. Atmospheric pressure (P) and temperature (T) were recorded at each grid node. The CO_2 flux (F) in units of grams of CO_2 per m^2 per day ($g\ m^{-2}\ d^{-1}$) is calculated using equation 1, where R is the gas constant, V is the system volume, A is the area of the AC footprint, and k is a constant for unit conversion.

Expected measurement errors are reported from laboratory experiments as under-representing actual values by 12% (Evans et al., 2001), or varying by ± 10% (Chiodini et al., 1998).

$$F = k\left[\frac{P}{RT}\times\frac{V}{A}\times\frac{dc}{dt}\right] \qquad 1$$

Twenty seven sites were selected to give a wide geographic spread, a range of surface geologic units, and had a bias towards those areas where CO2 may be leaking to the surface (e.g. adjacent to springs, travertine deposits). Sites included the most deeply exposed section of cover rocks above the reservoir, and potential leakage zones adjacent to known faults. Each site typically comprised a minimum of 10 measurements on a grid pattern with 25 – 50 m spacing. An arithmetic average soil gas flux and a standard deviation was calculated for each site. A summary of the data is given in Table 1. We have not yet plotted the fluxes onto a map.

The average soil fluxes range from 0.1 to 50 g/m^2/day. Those sites with fluxes in excess of 10 g/m^2/day are all situated adjacent to springs and in areas where the surface is heavily grassed and locally swampy. Disturbance of the soil at one site with a shovel produced gas bubbles from the saturated soil. Holding the flux chamber over the bubbles showed the gas to contain significant CO_2. H_2S could also be smelled. Although the spring waters are known to have high bicarbonate concentrations (White et al., 2004), our preliminary interpretation is that the soil gas is biogenic and originating from the soil itself, rather leakage than from the deep CO_2 reservoir. A sample of this gas was taken, but the analytical results are not yet available.

Our preliminary conclusion is that no sites show a significant leakage reservoir CO_2. This is surprising given the spring outflows from the reservoir with high bicarbonate concentrations, and the extensive travertine deposition at the Springerville-St Johns field. The result appears to be similar to that found over the Farnham Dome CO_2 field, which was also found not to be obviously leaking CO_2. Accepting these results at face value, they may be positive for the future sequestration industry because they demonstrate that CO_2 can be stored at depth over geologic time.

Travertine Sample Collection

Travertine samples were collected from 8 sites around the Springerville-St Johns field (Table 2). Extensive travertine covers the northwest portion of the field, and they range in elevation from 1790 to over 2120 m above sea level. The most recent travertine appears to be adjacent to the Little Colorado River, near the 1790 m asl elevation, based on morphological appearance. This is the elevation that the hydrostatic pressure trend in the reservoir extrapolates to, indicating that the springs are the outflow of the reservoir (Figure 3). The elevation range of the travertine deposits is at least 330 m, implying the reservoir pressure pressure has declined by at least this amount (33 bar or 3.3 MPa) since travertine deposition began. Because of interest in how rapidly the pressure decline occurred, samples of travertine have been sent for radiometric dating. We suspect that downcutting by the Little Colorado River may be an important factor contributing to the reservoir pressure decline.

CONCLUSIONS

Results of both the soil gas flux survey and the travertine dates should provide important constraints on the physical and chemical changes that have occurred, and be valuable for refining the numerical simulation of the evolution of the system. The numerical model that was presented in White et al. (2004) is about to be modified, and results may be available for the next quarterly report. These changes with time in the CO_2-fluid-rock system at Springerville-St Johns may also provide insight on the processes that could control the fate of injected CO_2 in future sequestration projects.

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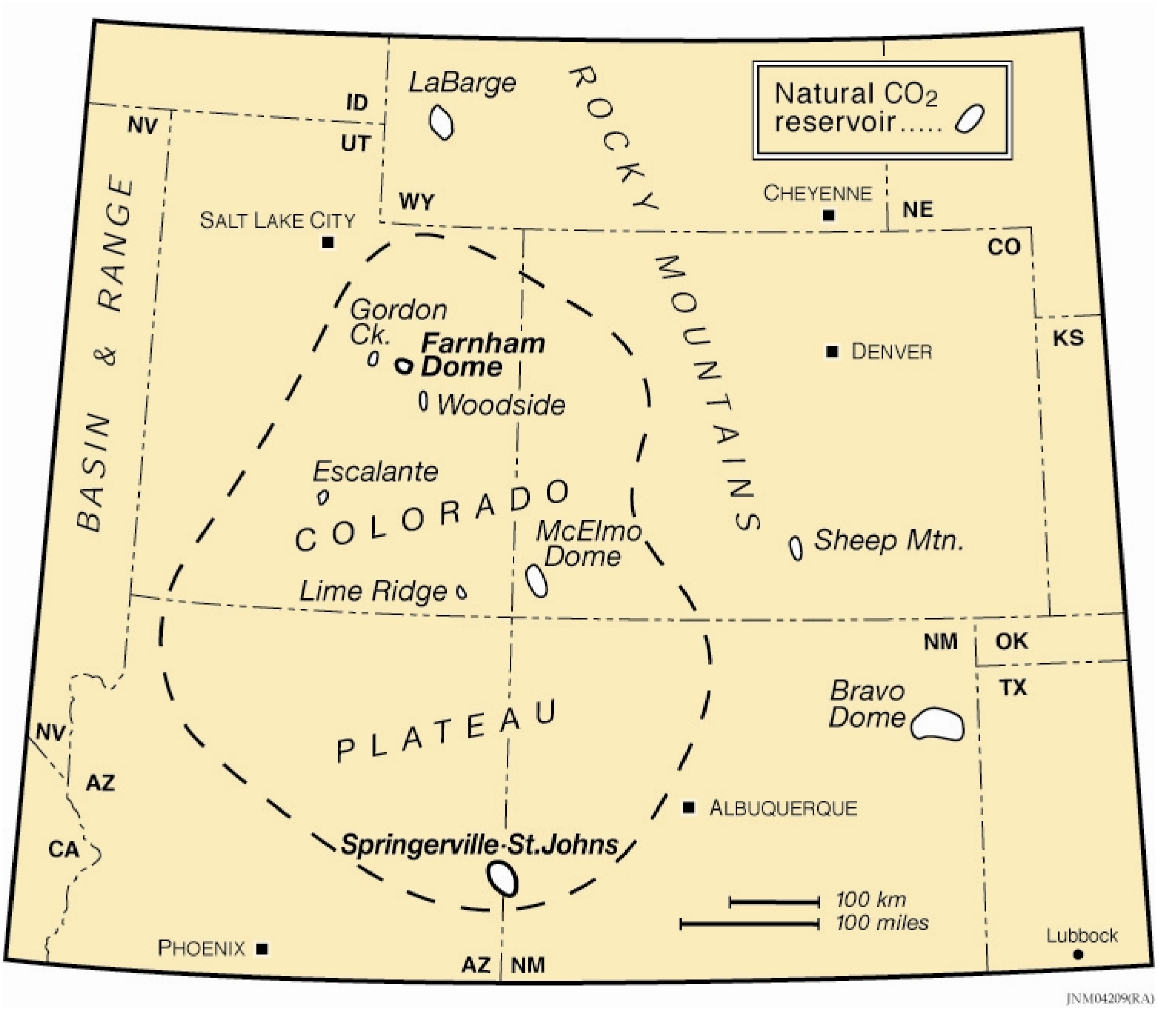
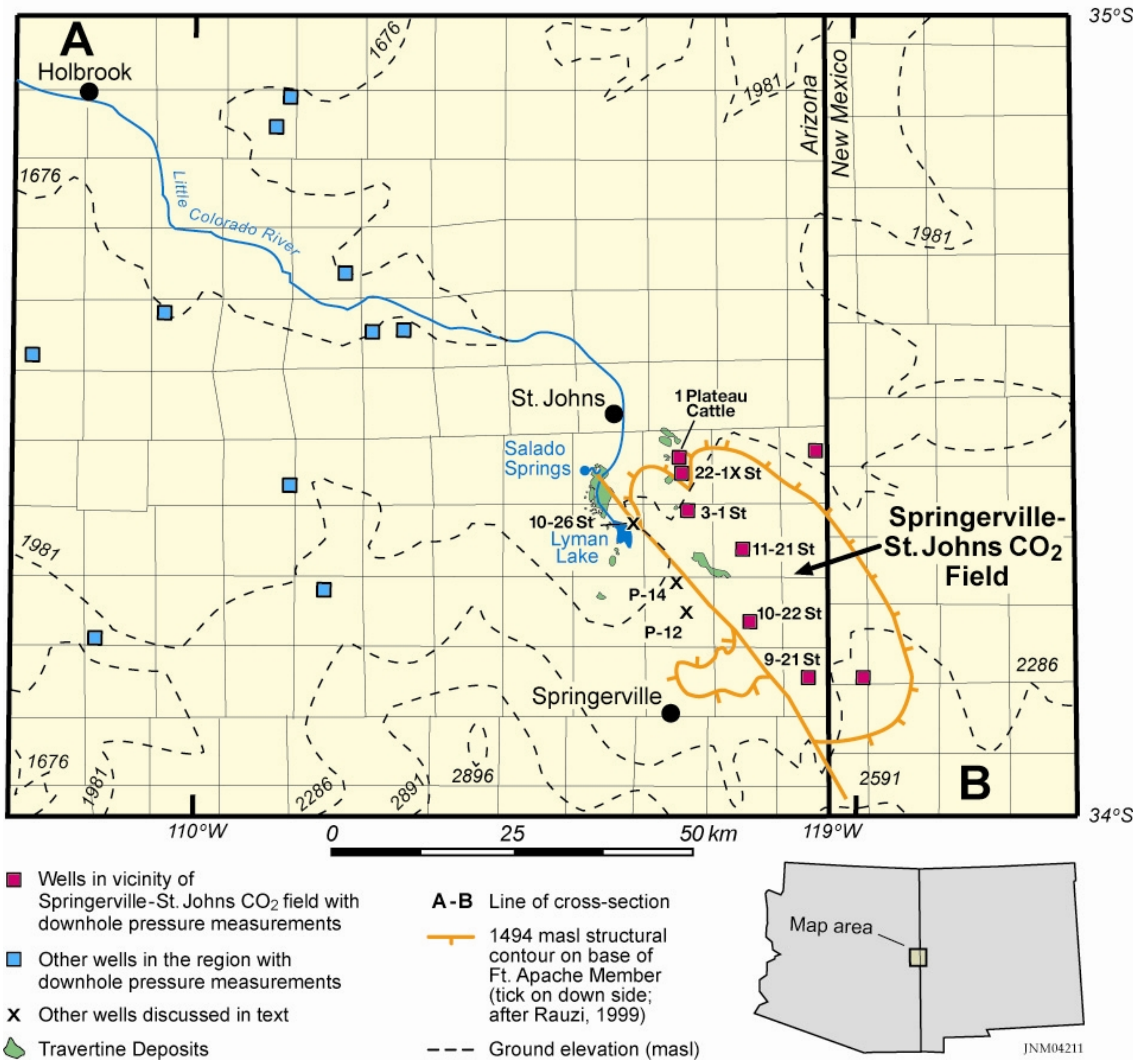


Figure 1. Location of natural CO_2 reservoirs within the Colorado Plateau and Southern Rocky Mountains region of the U.S. The two fields of Farnham Dome (Utah) and Springerville-St Johns (Arizona-New Mexico, which are the mentioned in this report, are highlighted.



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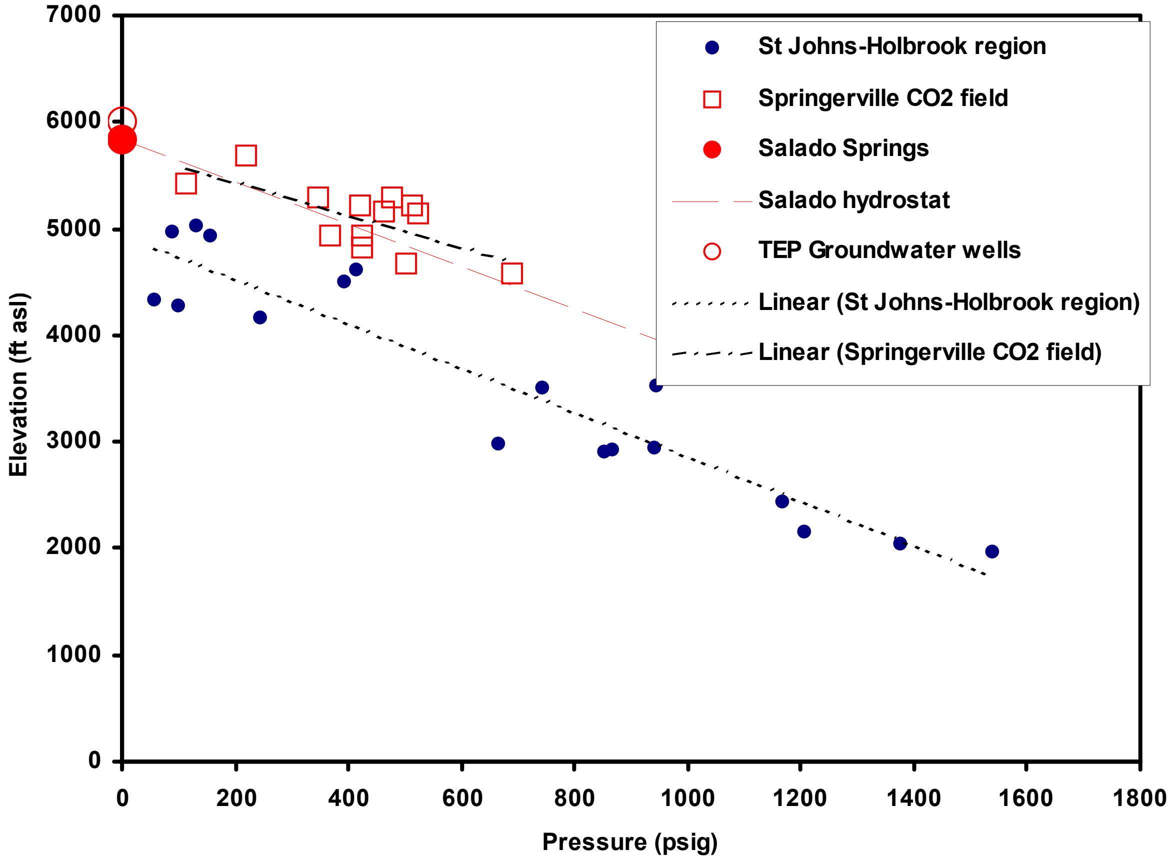

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site	avg flux	std dev	location description
2	9.5	8.8	
3	5.5	4.8	
4	20.8	14.3	near Lyman Lake dam
5	1.2	1.2	E8
6	0.1	0.5	well P-11
7	2.8	1.8	well P-8
8	3.7	2.1	near P-13 along small spring
9	4.4	2.4	north of power plant
10	3.9	1.6	well P-11
11	3.0	1.1	near P-4
12	2.9	1.7	Coyote Wash
13	1.2	1.5	Decker Lake E. of dam
14	2.2	1.8	Twin cinder cones
15	3.1	1.8	gravel pit east of twin cones
16	23.5	13.1	western limit next to spring
17	49.1	36.1	Tvt mound with cracks
18	8.5	7.5	about 1 mile norht Salida Springs
19	0.6	1.0	east of small development, north of Lyman Lake
20	14.9	9.1	Reservoir S. of St. Johns
21	5.7	1.9	Henry Platt springs
22	1.4	1.9	Ridgeway #22-1x well
23	0.8	1.3	5 mile NE of Springerville powerplant, Co. rd. 6100
24	2.2	1.5	cold water well
25	4.3	2.0	Aztec corral
26	1.7	1.6	triple junction
27	2.6	1.6	Coyote Wash
28	13.7	11.5	ranch house

Table 1. Preliminary listing of average soil gas CO_2 flux measurements from sites around the Springerville-St Johns CO_2 field. The units are g/m^2/day. At each site approximately 10 readings were made on a grid within an area typically 100 m by 100m.

Sample #	mE	mN	Height (ft)	Height (m)
1	647247	3810848	5955	1816
2	646712	3808968	5880	1793
3	662651	3798459	6970	2126
4	648682	3811171	5870	1790
5	647386	3806761	5900	1800
6	648539	3808007	6159	1878
7	657506	3814477	6240	1903
8	646838	3808876	5860	1787

note: present elevation of Salado Springs is 5840 ft

Sample #	
1	Travertine dome near Salado Spgs; sample 1 m below rim, in vent
2	from east side of Dome, half way from summit; near Little Colorado River
3	Voight's Mesa; from travertine slab 100 m from central crater, west side of summit.
4	upper flank of travertine slab on north-facing slope above L. Col. River
5	dome, 10 m in height on flood plain adjacent to L. Col River; sample from flank; dome has prominent hollow vent
6	dome on alluvial bench above sample 6; sample 30 cm below rim, inside crater
7	older vent area either side of road east of St Johns. Sample from northern side
8	small dome adjacent to L. Col R., was active historically (notch cut in side)

Table 2. Listing of the travertine samples collecting for radiometric dating. The range in elevation is over 300 m, which suggests that there should have been a significant reservoir pressure difference and a significant age difference between the time of deposition at high elevation, and that at low elevation today.