The Geochemical Characterization of Reservoir Fluids: Defining the Fluid and Rock System and Identifying Changes to Baseline Conditions Due to Well Completion

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Abstract

The characterization of fluids in targeted reservoirs is essential to understanding the existing fluid and rock system. Formation fluids were collected on two occasions from a potential CO_2 storage site in southwest Wyoming and analyzed for dissolved gas, geochemical, and isotopic compositions. The objective is to determine baseline conditions, fluid evolution, hydraulic isolation, temporal variations, and geochemical responses to well completion and the introduction of non-native fluids.

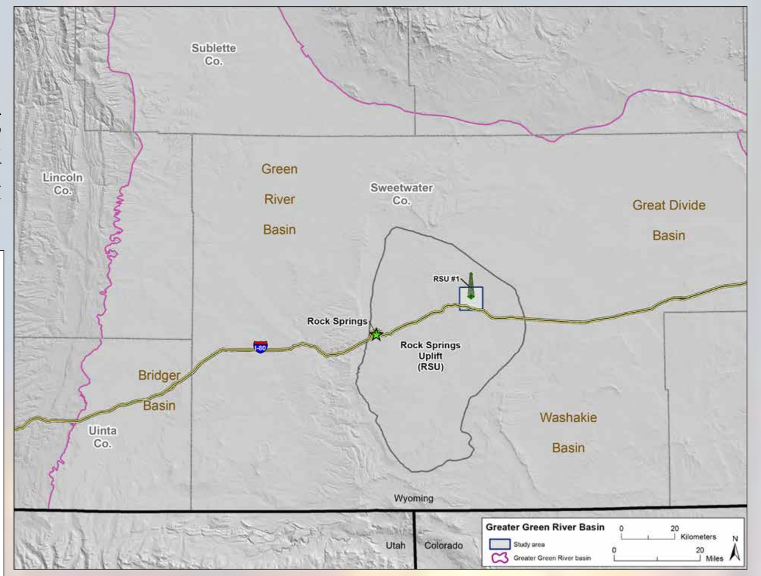
Fluids sampled at the Rock Springs Uplift (RSU) CO_2 storage site from the Mississippian Madison Limestone and Pennsylvanian Weber Sandstone are sodium-chloride type with total dissolved solid concentrations that range between 85,000 and 120,000 mg/L. Preexisting data suggest that high saline brines are found across the structure, though some inconsistencies arise.

Conservative analyte compositions are enriched with respect to seawater evaporation curves, this highlights that these brines have evolved significantly through increased water and rock reactions. The compositions of dissolved gases and water quality were found to be unique to each formation, suggesting that these reservoirs are isolated from each other. Notable differences are recorded in some constituent concentrations between sampling events, specifically increasing bromine, hydrogen sulfide and aromatic organics. These alterations were introduced during well completion and injection testing. Consequently, obtaining unbiased samples of target formation fluids from deep characterization wells may be challenging during CCUS characterization projects.

Study Site and Targeted Stratigraphy

Figure 1:

Study site and RSU#1 well location (in box) in southwest Wyoming on the northeast flank of the Rock Springs Uplift



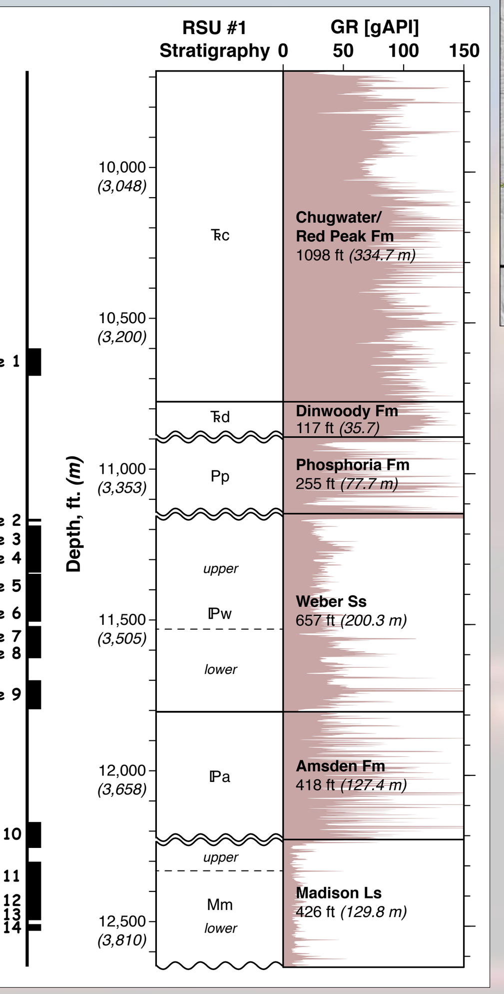
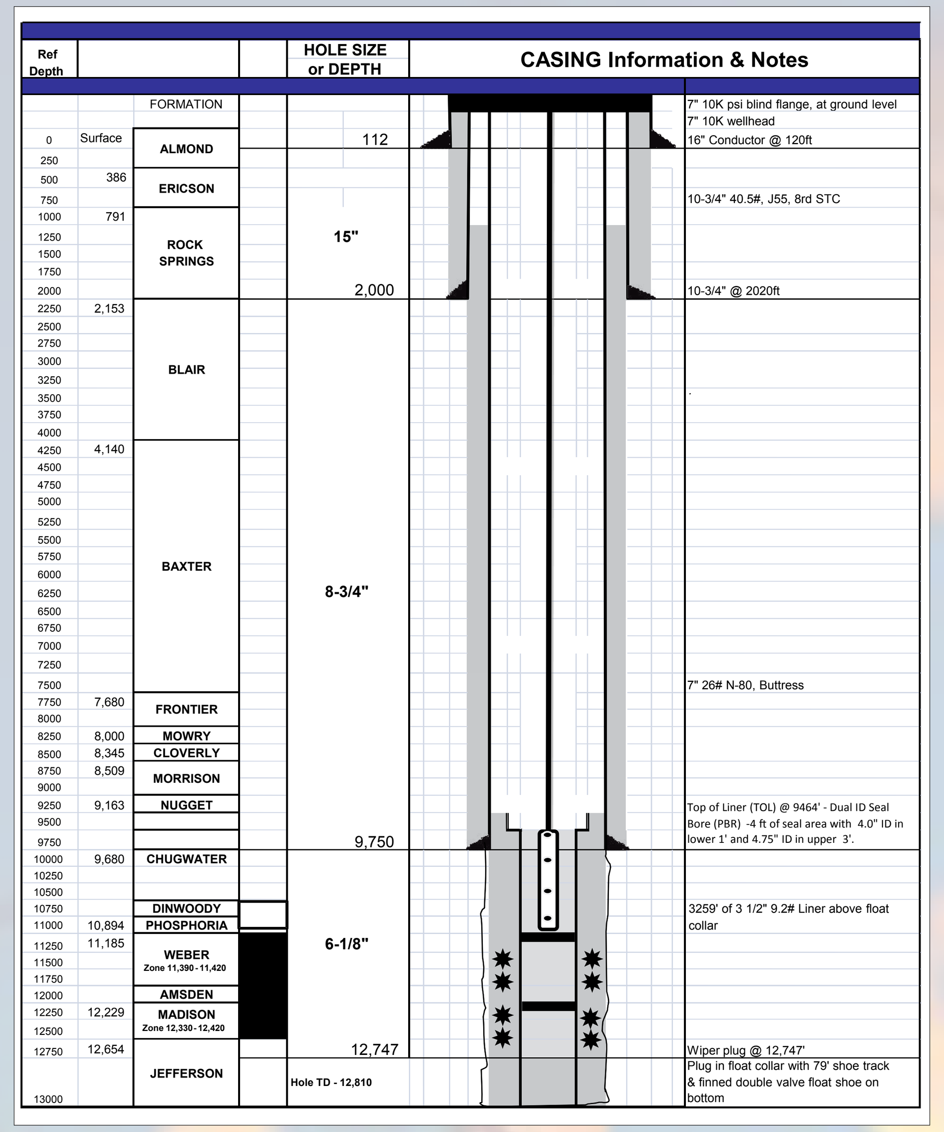


Figure 2:

Stratigraphic column and associated gamma ray log for the study site's targeted sealing stratigraphy and associated reservoirs. Targeted seals (the Triassic Red Peak Formation, Pennsylvanian Amsden Formation, and the upper portion of the Mississippian Madison Limestone) are highlighted in red.

Schematic of UW Stratigraphic Test Well



Schematic of the University of Wyoming stratigraphic test well (RSU # 1 049-037-07154). Perforation intervals are shown with an asterisk

References

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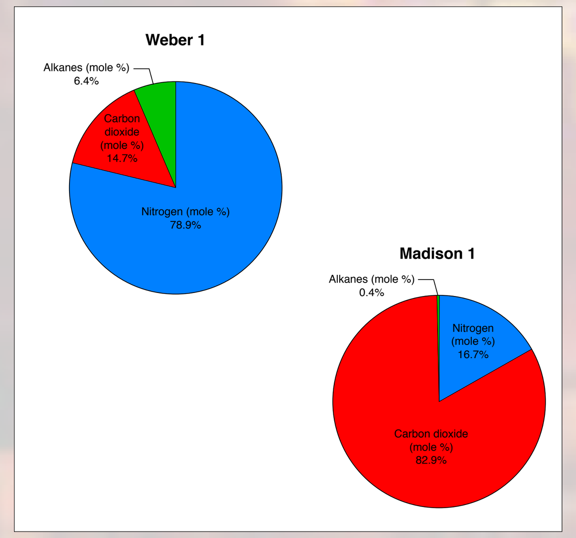
Baseline Water Quality Testing

Analyses (Mg/L unless otherwise indicated)	Weber Formation Energy Labs 08/27/2011	Weber Formation Core Labs 08/27/2011	Weber Formation Energy Labs 12/14/12	Madison Limestone Energy Labs 08/27/2011	Madison Limestone Core Labs 08/27/2011	Madison Limestone Energy Labs 12/03/12
Major Ions						
Bicarbonate as HCO_3	**621**	**720**	**3,690**	**1,420**	**1,610**	**3,190**
Calcium	734	705	539	1,190	1,280	1,630
Chloride	60,900	61,830	57,400	50,300	52,290	51,600
Magnesium	37	40	45	158	170	195
Potassium	–	1,940	1,910	–	4,210	3,780
Silicon	–	26	45.2	–	36	59.5
Sodium	40,700	43,250	36,500	29,000	32,820	27,900
Strontium	–	26	14	–	67	
Sulfate	**11,600**	**10,320**	**6,030**	**2,800**	**2,280**	**1,820**
Sulfide as hydrogen sulfide	**0.04**	--	**127**	**29**	--	**87**
Physical properties						
Chemical oxygen demand	2,420	–	**9,120**	1,940	–	**3,050**
pH	**7.54**	7.11	**6.46**	**7.36**	6.01	**6.43**
TDS^3	89,800	119,155	109,000	75,000	95,126	89,800

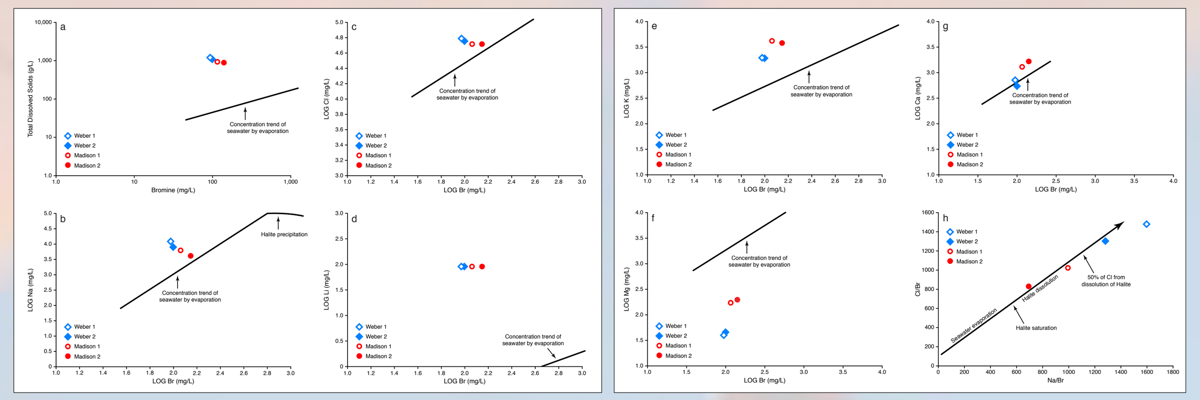
Analyses (Mg/L unless otherwise indicated)	Weber Formation Energy Labs 08/27/2011	Weber Formation Core Labs 08/27/2011	Weber Formation Energy Labs 12/14/12	Madison Limestone Energy Labs 08/27/2011	Madison Limestone Core Labs 08/27/2011	Madison Limestone Energy Labs 12/03/12
Metals						
Aluminum	ND	ND	**3.5**	ND	ND	**1.9**
Arsenic	0.095	–	0.444	1.76	–	0.376
Barium	ND	ND	**14.3**	1	ND	**4.48**
Boron	61.1	–	**71.8**	95.2	–	**101**
Borate	–	81		–	120	
Bromide	–	94	99	–	115	140
Cadmium	ND	ND	0.006	ND	ND	ND
Copper	ND	ND	13.6	ND	ND	1.35
Iron	0.94	2.2	**44.1**	0.54	8.1	**32.2**
Lead	ND	ND	2.91	ND	ND	0.305
Lithium	**92.8**	**100**	**90..5**	**91.9**	**105**	**91.6**
Manganese	0.07	0.07	0.777	0.12	0.35	7.76
Selenium	0.0004	–	0.054	0.013	–	0.041
Zinc	**0.26**	–	**4.58**	**0.4**	–	**2.1**



Dissolved Gas Composition

The composition of dissolved gases in Weber and Madison formation fluids is unique to each formation Nitrogen is the dominant gas species (approximately 79%) in fluids from the Weber Sandstone, followed by carbon dioxide (approximately 15%) and alkanes, mostly methane and hexane (approximately 6%). Carbon dioxide is the dominant gas species (approximately 83%) in fluids from the Madison Limestone, followed by nitrogen (approximately 17%) and a minor alkane component (<1%).

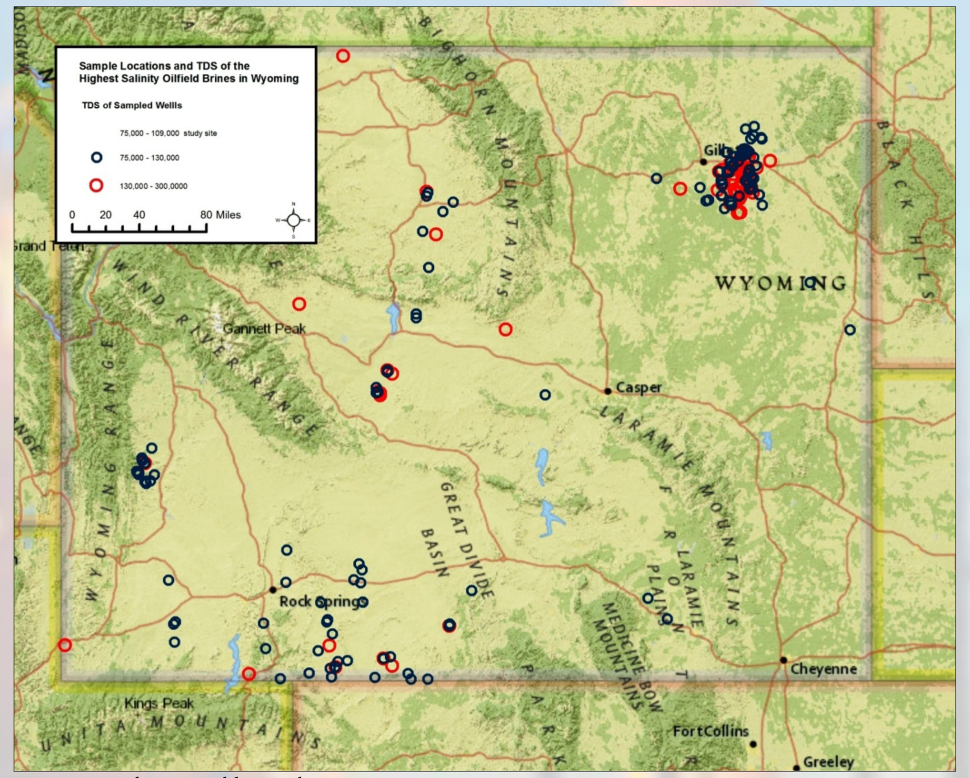
Fluid Evolution



Adapted from Rittenhouse 1967; Engle and Rowan, 2013 (a-g) Plot of log TDS, Na, Cl, Li, K, Ca, Mg versus log bromine relative to the seawater evaporation pathway. (h) Na/Br versus Cl/Br molar ratio plot.

Formation fluid evolution

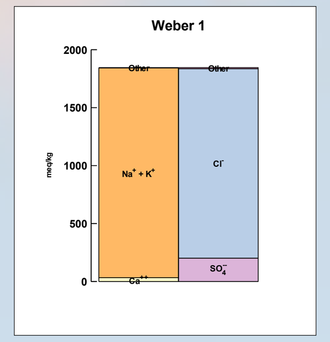
Comparative analysis of solutes in formation fluids suggests that the interaction of reservoir rocks and formation fluids, via dissolution of evaporite and other minerals, has had a large influence on the evolution of the formation fluids. The evidence of dissolution and high TDS suggests that the formation fluids and the reservoir rock have been in contact for a relatively long period of time. The differences in solute concentrations between formation fluids suggest that fluids from the Weber and the Madison are in equilibrium with the reservoir rock, and are not likely mixed or mixing. This indicates that both reservoirs are reasonably stable, and both exhibit the ability to hold and retain fluids; these conditions are ideal for CCS, as they indicate a low likelihood of unforeseen migrations or leakage.



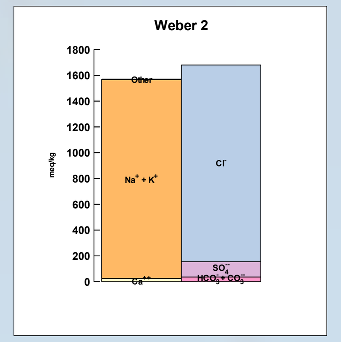
From J. Fred McLaughlin et al., 2013

Salinities of deep brines are consistent across the RSU. Indicating that the reservoirs across the RSU have a fluid evolution history similar to the fluid retrieved from RSU #1

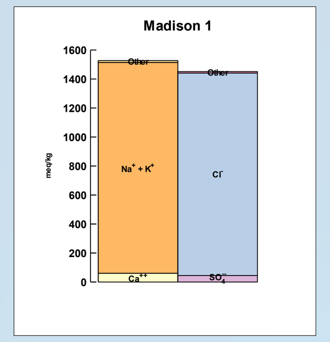
Changes in Water Chemistry From Well Completion



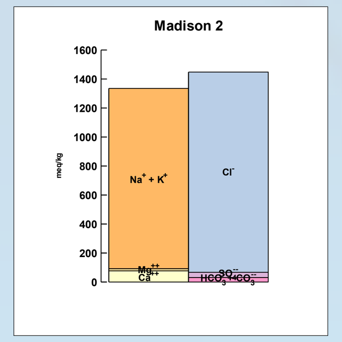
First Sample (2011)



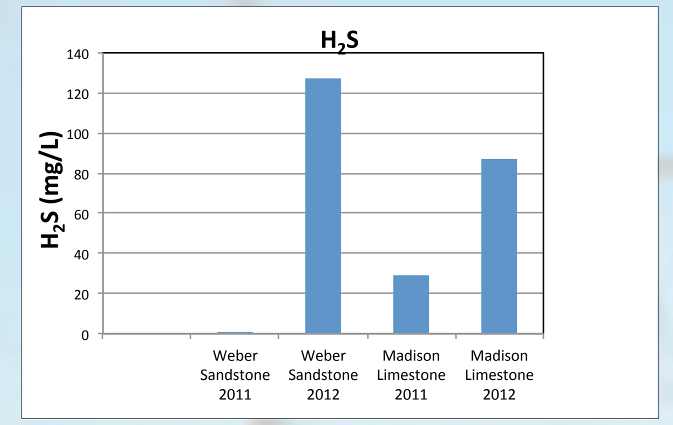
Second Sample (2012)



First Sample (2011)

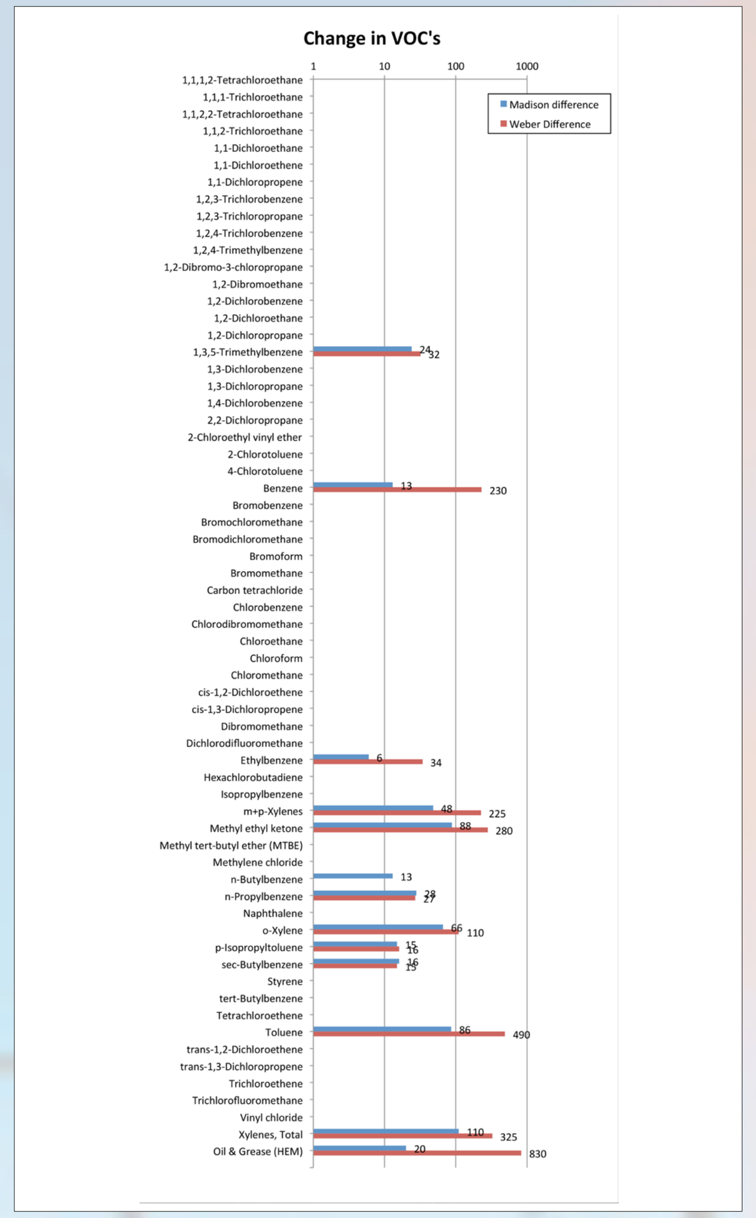


Second Sample (2012)



Geochemical differences from well completion

The first set of samples collected had very low concentrations of H_2S (Madison, 29 mg/L; Weber, 0.04 mg/L). The second set of samples measured much higher concentrations of H_2S (Madison 87 mg/L, Weber 127 mg/L). Interestingly, the sulfate concentrations decreased between the first and second sample set (Table 1). This may suggest that perhaps water circulated during drilling, completion, and work-over of the well may have introduced sulfate reducing bacteria (SRB). SRB ingest sulfate and organic acids and generate H_2S. Souring the reservoir. (e.g. Ligthelm et al. 1991).



Change in VOC's between sample sets

Formation fluids were analyzed for 63 volatile organic compounds (VOC's). The first sample set (August, 2011) detected six VOC's in both Weber and Madison brines. This increased to fourteen in the second round of sampling (December, 2012). With the exception of BTEX compounds, when a VOC was detected similar concentrations were measured in both reservoirs. This indicates that some VOC's were contaminants likely introduced during later work in the wellbore. Benzene, toluene, and xylenes were not detected in the first round of sampling but were measured in the second round; concentrations were much higher in the Weber. Ethylbenzene was found in equal concentrations in both formations in the first sample set (20 µg/L), but more than doubled in the Weber in the second round (50 µg/L).

Conclusions

- Analysis of the target formation brines has generated a geochemical and water quality baseline at the study site. As a result of those analyses the WYDEQ has classified the brines of the Madison and Weber as class VI (unsuitable for use). In addition, the water quality analyses recorded elevated concentrations of some metals.
- The sodium and chloride of the brines are enriched beyond what is possible from evaporation of seawater. This suggests increased water-rock interaction and dissolution of minerals adding to the salinity.
- Dissimilarities in the water chemistry and dissolved gas analyses suggest that the Amsden formation and Upper Madison Limestone isolate the Middle Madison injection zones from the Weber injection zones.
- Hydrogen sulfide concentrations in the reservoir dramatically increased between the first and second sampling series. Although the cause of this increase is unknown, it is recommended that careful consideration be given to reservoir management during CO_2 injection Additionally, H2S monitoring should be an element of water production scenarios.

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