Identifying low-risk CCUS reservoirs with limited subsurface geologic data; utilizing stacked reservoirs for inferring seal integrity

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Abstract

Abstract and Study Site: To reduce geologic uncertainties at CCUS sites with minimal subsurface data we suggest a threefold extrapolation strategy using properties from stacked reservoir systems to 1.) Delineate geologic history and formation continuity, 2.) Identify/characterize reservoir(s) brine compositions, and 3.) Identify site-specific seal bypass systems using seismic attribute analysis. We propose that stacked reservoirs systems, common at many CCUS sites, provide a unique way to test lateral seal integrity.

At our study site in the Greater Green River Basin in southwest Wyoming (**Figure 1**), two Paleozoic reservoirs are unconformably separated by the Amsden Formation, complex, near-shore marine deposit. To investigate if this formation acts as an impermeable barrier between the two reservoirs, we first defined the potential seals regional depositional and diagenetic history. This allowed us to prove lateral continuity and regional and historical presence of low-permeability facies within the suggested seal. Then, reservoir fluids were collected and analyzed for geochemical compositions with the goal of assessing the likelihood of inter-reservoir mixing. Both reservoirs have high TDS and notably increased concentrations of conservative elements relative to other samples from Rocky Mountain basins. High concentrations of conservative elements in brine from targeted reservoirs is a potential indicator of a geologically-stable fluid environment, and most likely associated with reservoir confinement (a hallmark of seal integrity). Reservoir fluids also are shown to have distinct gas and organic compositions. Lastly, site-specific seal bypass systems were analyzed through seismic attribute and curvature analyses. These analyses identified two dominant seal bypass types, both of which we were able to relate to older (in-active), regional geologic processes.

Our study suggests that novel data analysis of seismic attributes and fluid compositions from stacked reservoir systems can reduce uncertainties associated with seal integrity. This methodology, coupled with novel process-based geologic observations, are relevant for all Rocky Mountain basins and comparable CCUS sites worldwide.

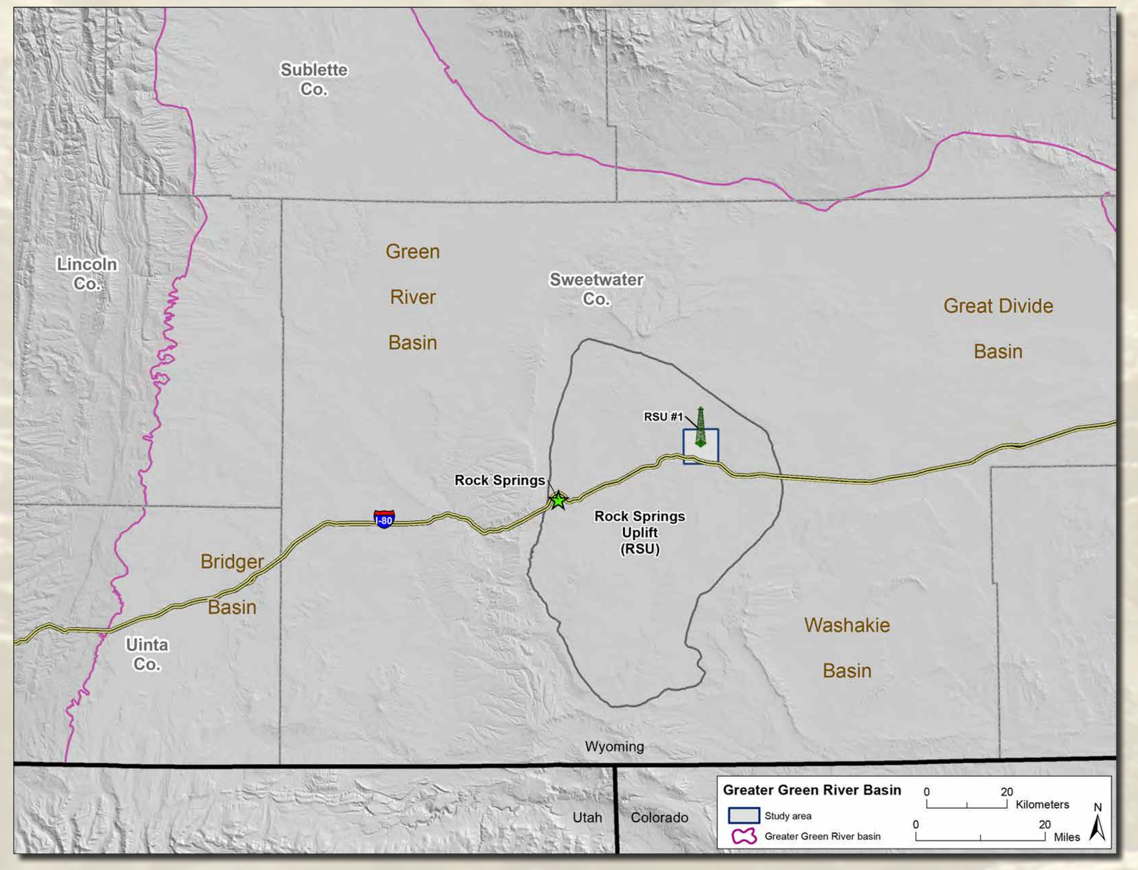


Figure 1: ***Study site*** location with the well and outline of the seismic study

Methodologies

1.) Targeted seals: characterizing regional geologic history and formation continuity of confining lithology from well logs and core

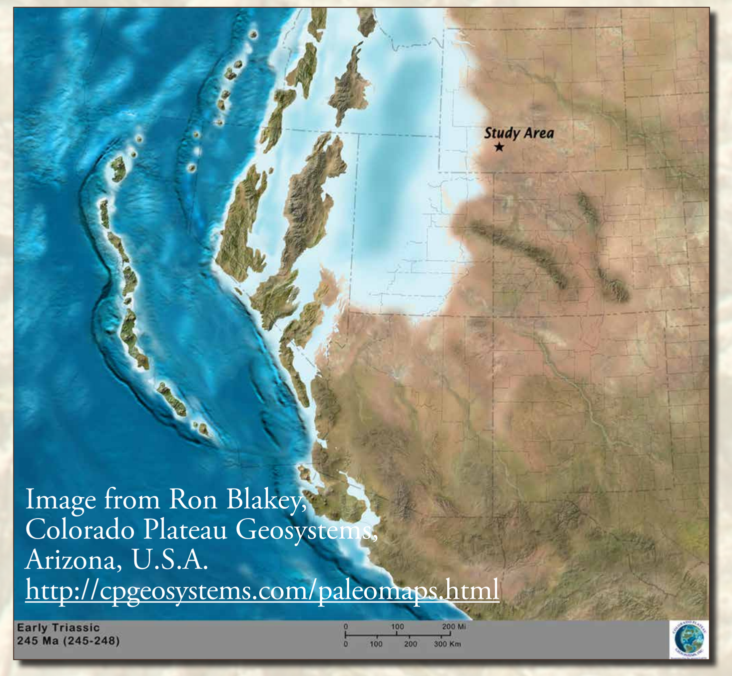


Figure 2: ***Paleogeographic map*** of the western U.S. in the Triassic. Note Wyoming's positon on the margin, which results in thickening and fining of sediment to the west.

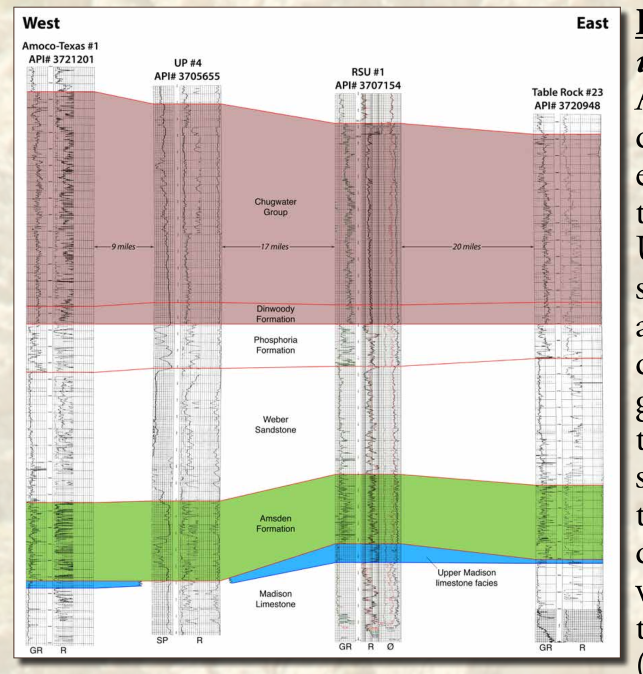


Figure 3: ***Regional well log correlation*** A cross section of deep well logs from east-west across the Rock Springs Uplift: targeted sealing lithologies are highlighted in different colors. The gradual westerly thickening of the sediments is related to gradual offshore deposition along the western border of the paleocontinent (**Figure 2**). Note the heterogeneity in lithology of the Amsden Formation, indicative of its shallow-marine deposition. (GR=Gamma Ray, R=Resistivity, Ø=Density 8)

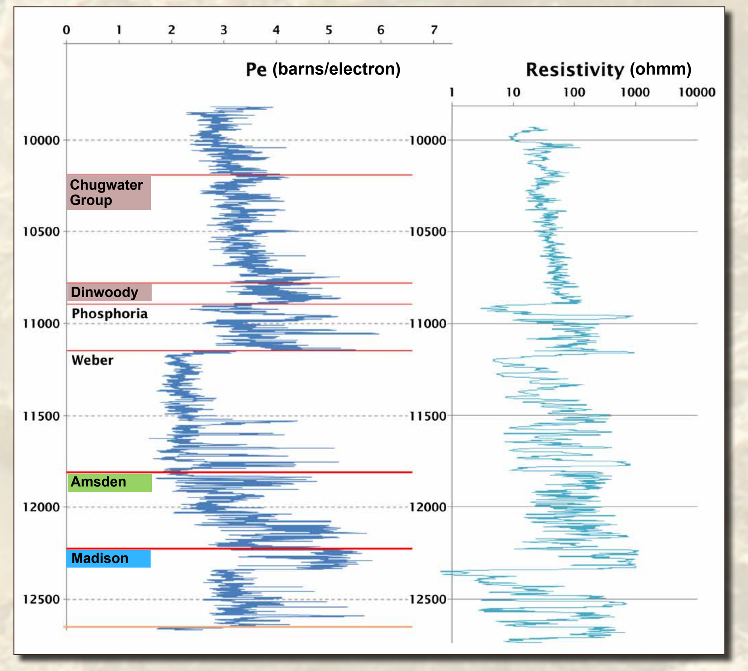


Figure 4: ***RSU #1 logs*** Photoelectric and resisitiviy logs from the RSU#1 well. Note the gradual increasing values of both logs in the Chugwater Group: this is important as we interpret this to reflect increasing cementation at depth. Also of note is the consistency of measurements through the top of the Madison.

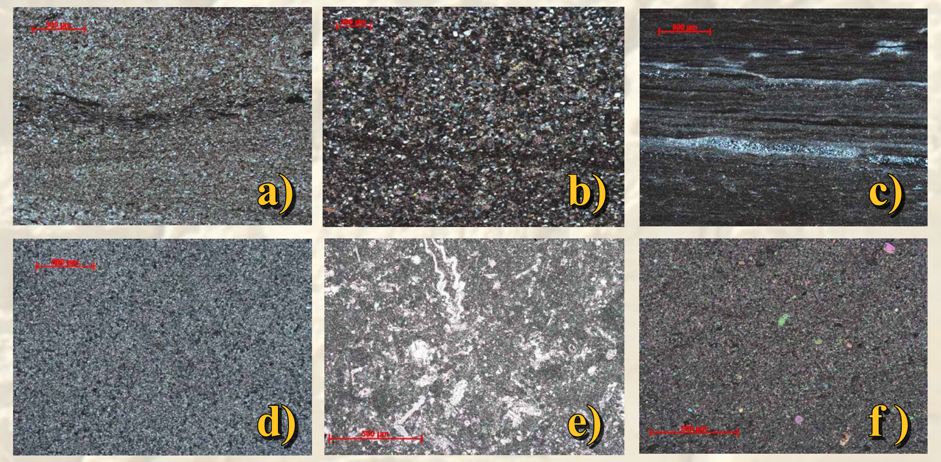


Figure 5: ***Thin section petrography***
a-b: Chugwater Group siltstones at depths of **a.** 10,662.8' (5x ppl), **b.** 10,682.1' (5x xpl) from top. Figures 5a and b represent typical, laminated siltstones of the Chugwater Group. Petrographic porosity is negligible due to cementation.

c-d: Amsden Formation:
c. 12,199' (5x xpl) – Karst-filling silty-claystone (paleosol?) at the base of the Amsden with stratified layers of carbonate and clay and minor detrital clasts. **d.** 12,147' (5x xpl) – Sucrosic dolostone; likely dolomitized micrite.

e-f: Madison Limestone:
e. 12,247' (5x ppl) – Fossiliferous micritic limestone with little to no alteration. **f.** 12,233' (5x xpl) – Micritic limestone with minor fossils and secondary limestone.

1.) **Summation**:
- East-west depositional environment benefits potential sealing capacity as seals thicken up-dip
- Well logs identify primary sealing zones in the Chugwater Group and Madison sections
- Petrography shows no porosity and minor alteration in all seals, and increased cementation in the Chugwater Group
- Detailed geologic and burial history of seals lowers uncertainties relative to lateral continuity and burial alteration

2.) Identifying site-specific seal bypass systems using seismic attribute analysis

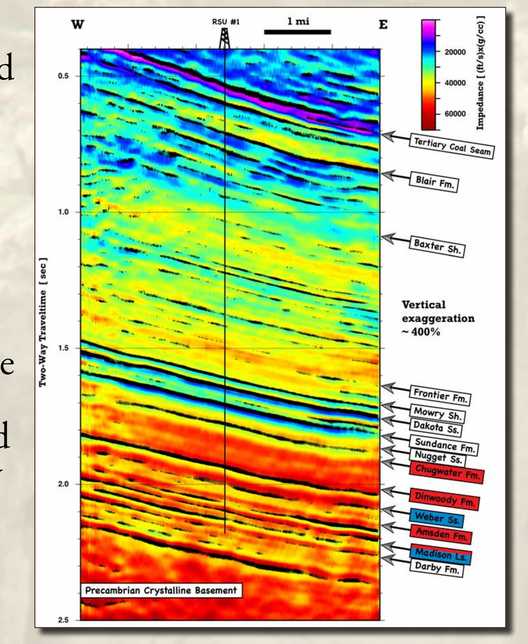


Figure 6: ***Acoustic impedance*** Interpreted west–east profile through the acoustic impedance volume at the RSU #1 well location. The color-coded impedance image is co-rendered with seismic amplitude section. Targeted reservoirs are indicated by blue boxes, seals by red boxes. Note the lateral continuity of selected formations.

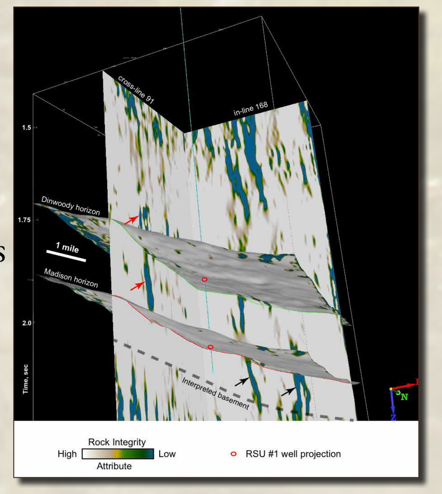


Figure 7: ***Rock integrity*** 3-D perspective display made of two orthogonal vertical sections and two stratal slices at Madison and lower Triassic stratigraphic levels using the Rock Integrity attribute. This analysis has identified a karst collapse feature (marked with red arrowheads) that originates at top of the Madison reservoir and cuts through the rock sequence well above the Dinwoody horizon. Basement-rooted reverse faults are marked with black arrowheads.

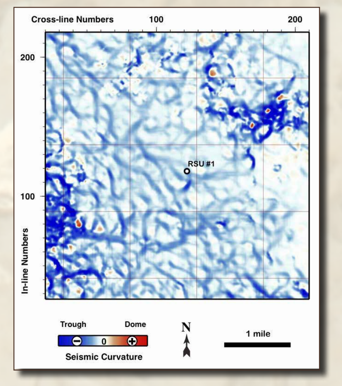


Figure 8: ***Curvature analysis*** Horizon slice through the top of the Madison reservoir from curvature volume generated from post-stack migrated seismic data. These data identify NW-SE deformation trends that are subparallel to strike. A large fault is identified down-dip of the well.

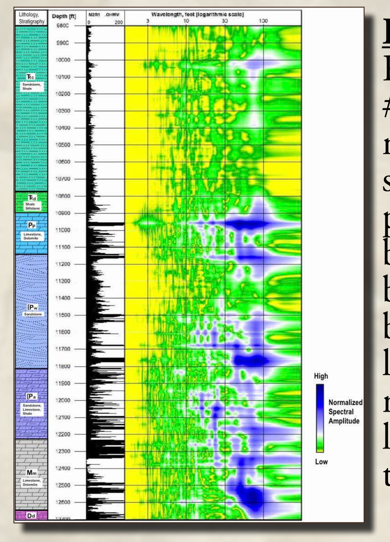


Figure 9: ***Spectrogram analysis*** Resistivity log from the RSU #1 well (black bar graph in the middle panel) and associated spectrogram (right-most panel). Note heterogeneous log behavior (multiple amplitude bursts at different wavelengths) below the base of confining layers (10,900+ feet depth) and relatively homogeneous and low-amplitude spectra within the Triassic sealing lithologies.

2.) **Summation**:
- Seismic analysis identified two seal bypass systems:
  - Fractures, faulting and warping
  - dissolution pipes related to karsting
- Seismic analysis identified high level of continuity in Triassic Chugwater and Dinwoody confining layers
- Identifying primary seal bypass systems have allowed us to identify timing of the events/processes, relative to geologic history

3.) Characterize brine compositions from stacked reservoirs

Figure 10a-c: ***Chemical composition of reservoir fluids*** Diagrams showing variations in brine geochemical compositions between the Weber and Madison reservoirs. Though these brines are primarily NaCl, there are notable differences in concentrations and trace elements such as K and Ca.

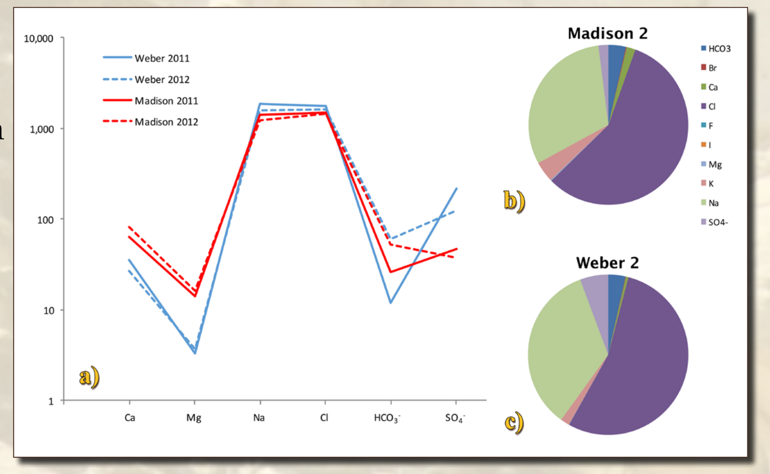
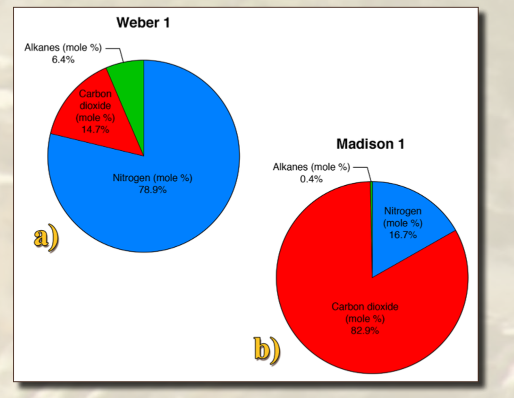


Figure 11a-b: ***Dissolved gas contents*** from Weber and Madison brines. These fluids do not suggest similar source and/or evolution.



3.) **Summation**:
- Brine chemistries differ, most notably in concentration and trace components
- Dissolved gases indicate separate sources and/or evolution of the fluids
- Geochemical analysis of stacked reservoir fluids shows no evidence of hydraulic communication

Conclusions

The sealing potential of stacked reservoir systems can be evaluated to decrease geologic uncertainty in sites with limited data through the following methodology;

1.) Well log and core analysis to define the regional depositional, geologic, and diagenetic history of seals relative to enhancing or diminishing sealing capacities.

2.) Advanced seismic attribute analysis to define seal bypass systems that could impact sealing formations.

3.) Fluid analysis from stacked reservoirs to indicate hydraulic connectivity.

At our study site, this methodology has allowed us to conclude that,
- Regional petrophysical analysis suggests that the Chugwater Group has the lowest geologic uncertainty of seal failure due to increased cementation and up-dip thickening
- Seismic attribute analysis identified primary seal bypass systems, specifically fault and fracture systems and karst features. Geologic history studies suggest seal bypass are >40 M.A., increasing the likelihood of annealing.
- Detailed brine analysis suggests inter-reservoir confinement, proving that with the Amsden and/or Madison are effective local seals.
- Integrated analysis of all three data sets indicates a low probability of seal failure at our study site. Though two types of seal bypass mechanisms were identified, both can be attributed to relatively old geologic events with adequate time for annealing/closure. This interpretation is validated by the diagenetic history of the core (mineralogy/timing) and differences in formation fluid compositions that indicate distinct fluid history (and closure) between reservoirs.

Selected References

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