Geologic Controls on Sealing Capacity; Defining Heterogeneity Relative to Long-Term CO2 Storage Potential in Wyoming

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Abstract

A rigorous geologic characterization of confining zones is fundamental for defining long-term, low risk storage potential at potential CCUS sites. At a University of Wyoming CCUS study site on the Rock Springs Uplift in southwest Wyoming, investigators have identified three confining zones associated with two characterized reservoirs. The lowest-risk seal has been identified as a well-cemented, lower Triassic siltstone.

The lithologies of the three confining zones vary and include a lower Triassic siltstone, a lower Pennsylvanian mixed-marine formation, and an upper Mississippian micritic limestone. The Mississippian limestone retains primary petrographic textures, and records relatively consistent stable and radiogenic isotopic ratios. Measured capillary displacement pressures are >1,254psi. Paleokarst identified at the top of the limestone suggests the likelihood of regional thickness variations. The petrography of the lower Pennsylvanian mixed-marine formation indicates deep-burial diagenesis, an observation that is corroborated by depleted stable isotopes. Radiogenic isotope ratios were variable as a result of the differing facies. Measured capillary displacement pressures are >1,000psi. Detrital clastic grains in the lower Triassic siltstone are largely unaltered, unlike the matrix minerals. Variable stable isotope ratios of cement, and the presence of mixed illite-muscovite clays, suggest that these minerals underwent deep-burial diagenetic alterations. Radiogenic isotope ratios were variable as a result of mineralogic heterogeneity. Measured capillary displacement pressures are >940psi.

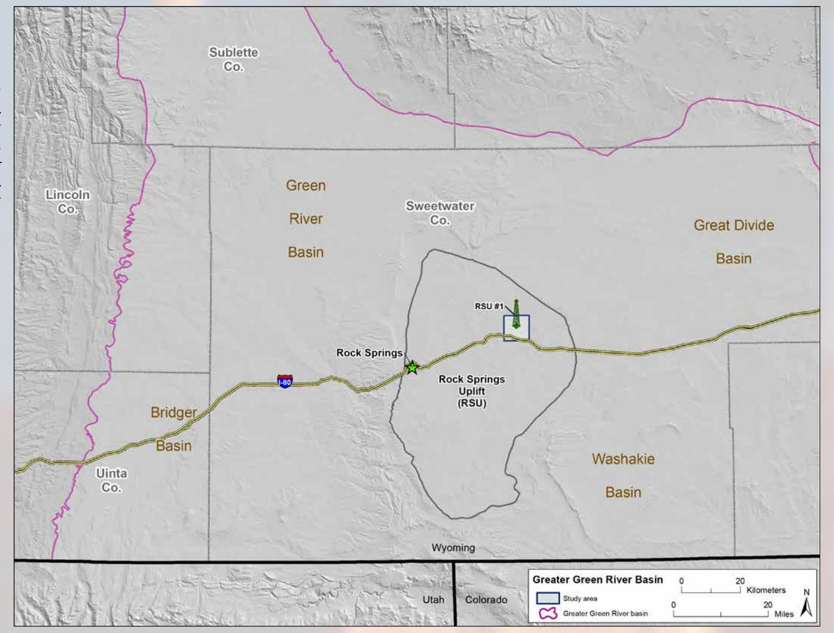
Though the geologic character of the investigated confining zones varied, each was shown to be capable of sealing the characterized reservoirs. For the lower Triassic siltstone and lower Pennsylvanian mixed-marine formation, diagenetic alteration was shown to have enhanced sealing characteristics. The lower Triassic siltstone was identified as the lowest-risk seal due to a combination of its depositional and burial histories.

Problem Statement: Define the geologic characteristics of the lowest-risk sealing lithology.

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



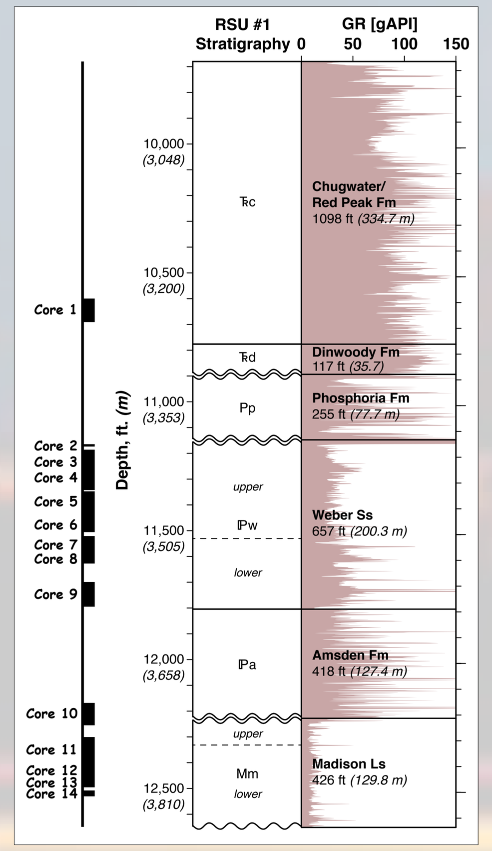


Figure 2:

Stratigraphic column and 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 pink.

Petrography of Triassic Sealing Lithology

Triassic Red Peak Formation

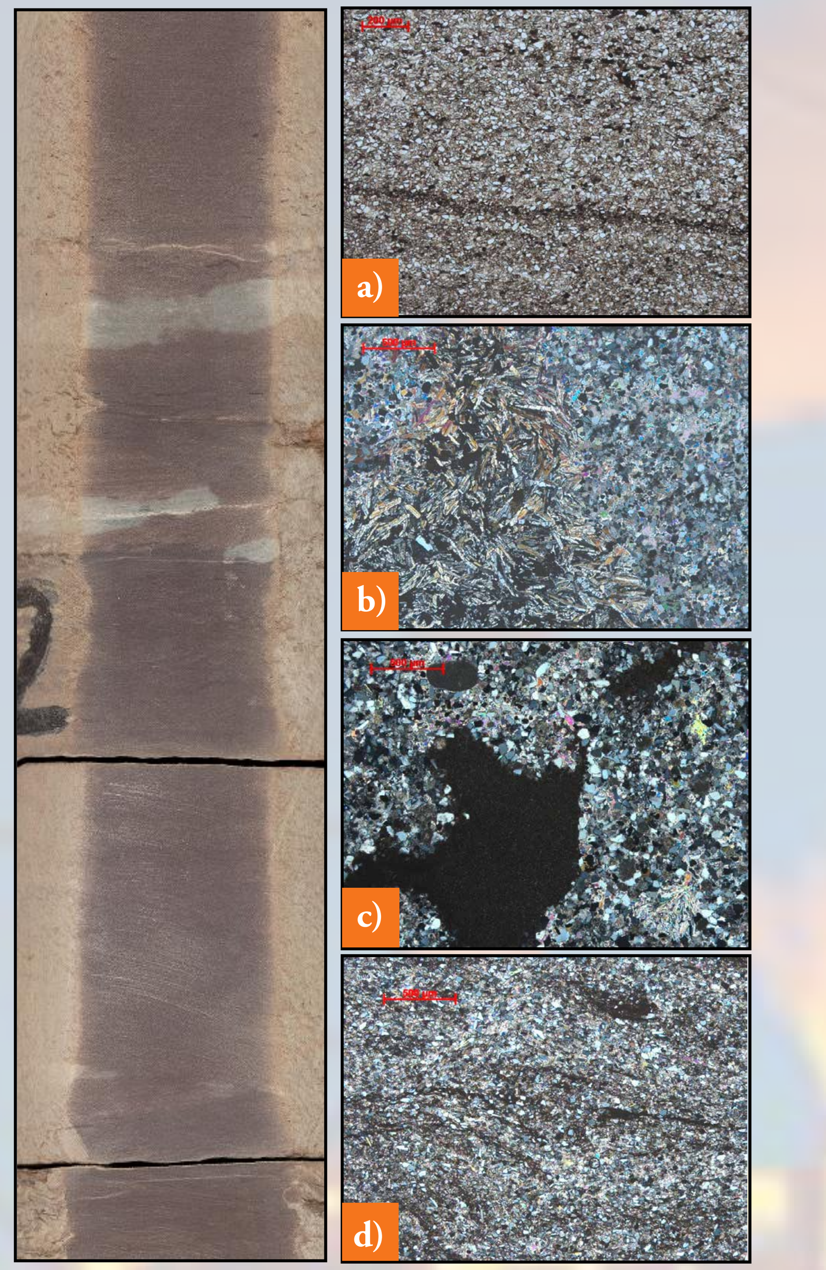


Figure 3:

Core from the Red Peak formation. Note the crossbedding and zones of reduction

Red Peak Facies

- **a)** 10,601' (5x, ppl) - Formation type-section, laminated red bed siltstone
- **b)** 10,638' (5x, xpl) - Massive anydrite and halite nodule in carbonite and anhydrite cemented siltstone
- **c)** 10,633' (5x, xpl) - Shale/mudstone intraclasts in anhydrite cemented siltstone
- **d)** 10,680' (5x, ppl) - Siltstone with disturbed laminations (bioturbation or soft-sediment deformation)

Petrographic Conclusions: Though facies vary, much of the unit is homogeneous (as geologically possible) and contains secondary minerals, such as carbonite and anhydrite, that enhance sealing capacity.

Petrography of Pennsylvanian Sealing Lithology

Pennsylvanian Amsden Formation

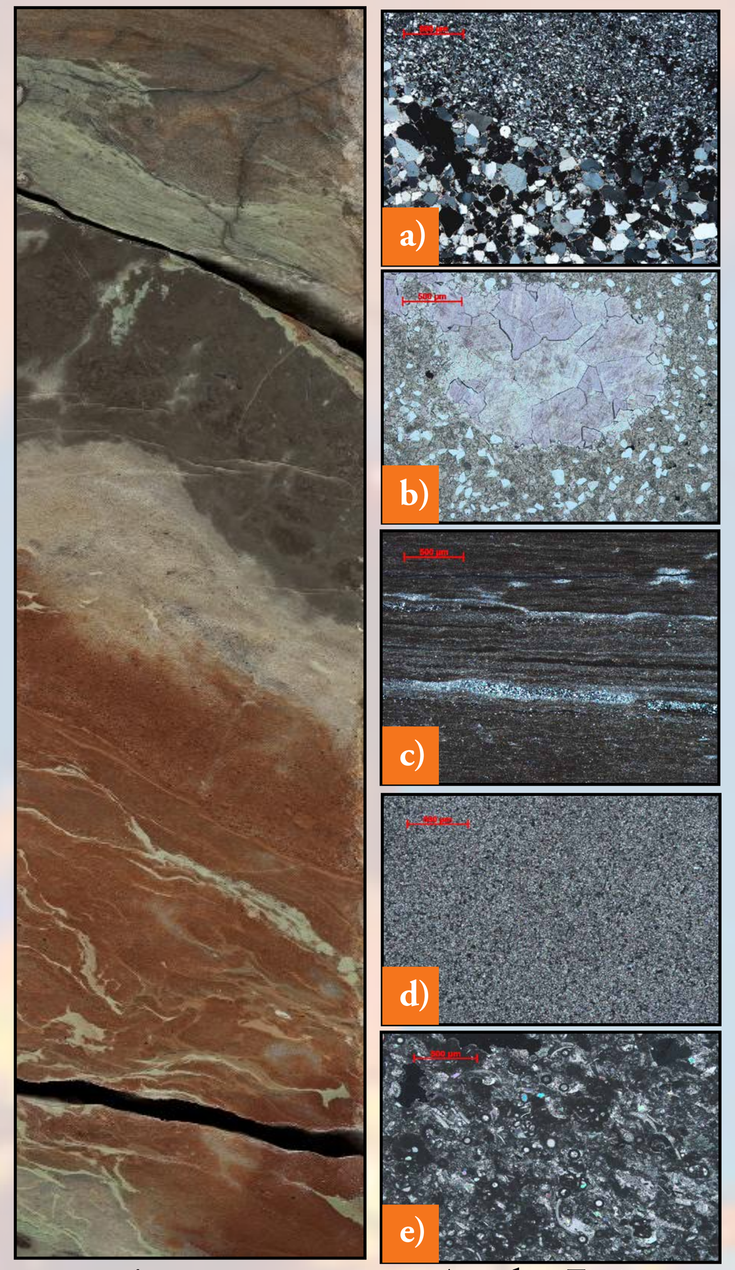


Figure 4:

Core from the Amsden Formation. Note the variegated facies and evidence of alteration

Amsden Facies

- **a)** 12,209' (5x, xpl) - Bimodal sandstone with illite/muscovite matrix; highly altered with no observed feldspars or other reactive minerals
- **b)** 12,182' (5x, ppl) - Clastic carbonate with detrital grains and a vug filled with late-stage ferroan dolomite and calcite
- **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)** 12,228' (5x, xpl) - Fossiliferous, micritic limestone, with minor late-stage calcite. Shells, ooids, and peloids in a micritic matrix. Ooids and vugs show evidence of secondary calcite precipitation

Petrographic Conclusions: Facies and alteration is highly variable.

Petrography of Mississippian Sealing Lithology

Mississippian Madison Limestone

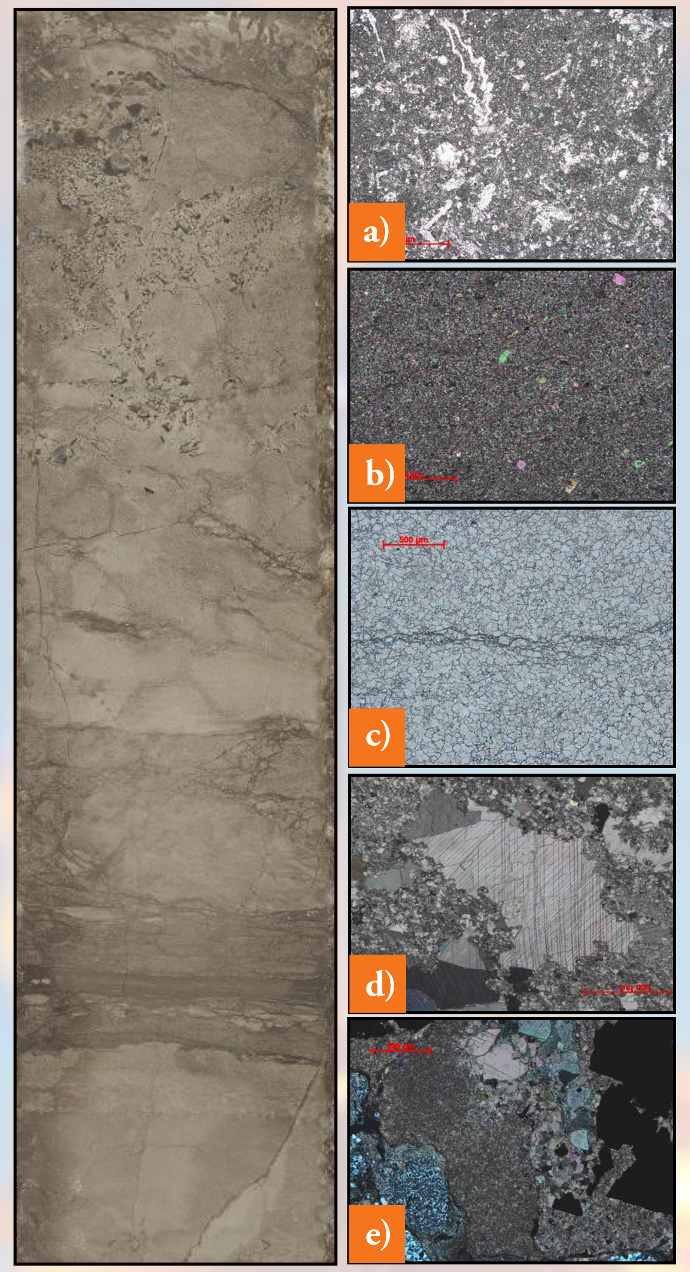


Figure 5:

Core from the upper Madison Limestone. Note the dissolution, fractures, and secondary mineralization

Upper Madison Limestone Facies

- **a)** 12,247' (5x, ppl) - Fossiliferous micritic limestone with little to no alteration
- **b)** 12,233' (5x, xpl) - Micritic limestone with minor fossils and secondary limestone
- **c)** 12,256' (5x, ppl) - Neomorphic calcite with subhorizontal proto-stylolite, pyrite, and minor quartz
- **d)** 12,336' (5x, xpl) - Neomorphic limestone with heavily twinned, high temperature calcite. Note that some twins are bent, indicating deformation post-precipitation
- **e)** 12,329' (5x, xpl) - Collapse breccia within evaporate bed with neomorphic calcite, massive pyrites, ferroan saddle dolomites, chalcedony nodules and dissolution seams, which precipitated by thermal chemical sulfate precipitation at higher temperatures

Petrographic Conclusions: Some secondary alteration increasing the liklihood of lateral discontinuity.

Geochemical Results

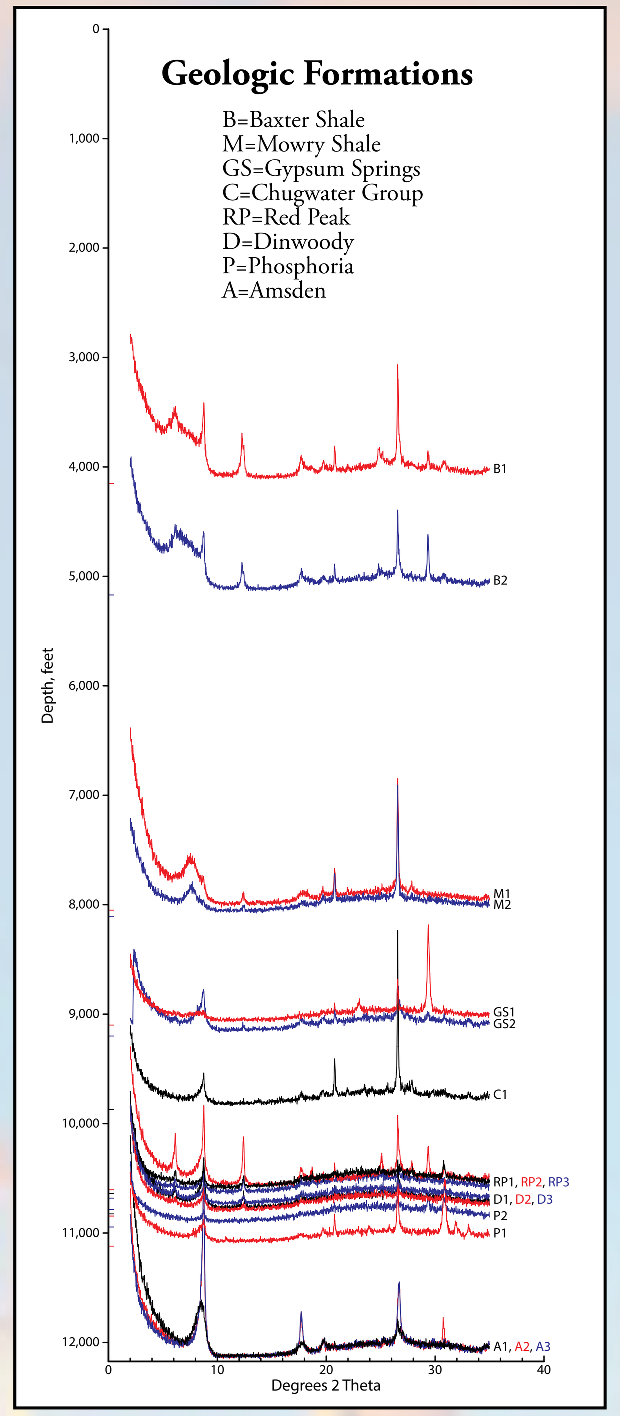


Figure 6:

XRD diagrams from shale, clay and siltstones at the study site by depth. These diagrams show that mixed layer clays are dominant above 9,000', altering to potassic clays and chlorite below 9,000'. Alteration from mixed clay to potassic clay has been shown to increase regional sealing capacity, and has been used for the exploration of hydrocarbons in Laramide basins (ex: Jiao and Surdam, 1994). Targeted seals are below 9,000'

Figure 7:

Isotopic ratios of strontium versus depth for assorted seals and reservoir rocks. Increased radiogenic ratios are noted in clastic sediment, as well as dolomites relative to adjacent limestones. Sr variance in the Red Peak is a result of varied clastic compositions; Sr variance in the Amsden is related to differing lithofacies; Sr variance in the Madison is related to dolomitization.

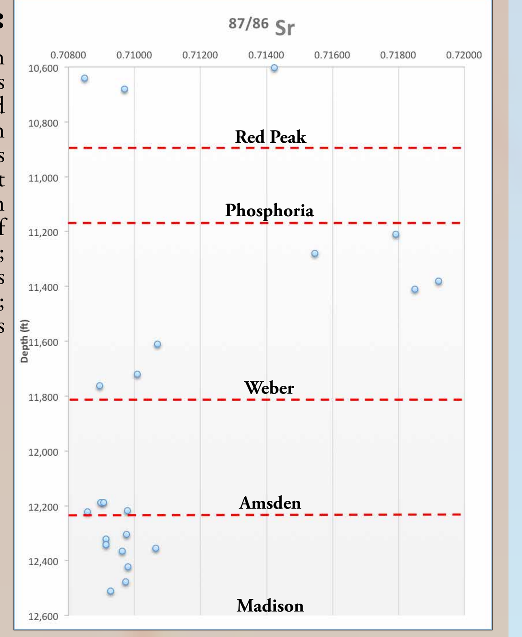
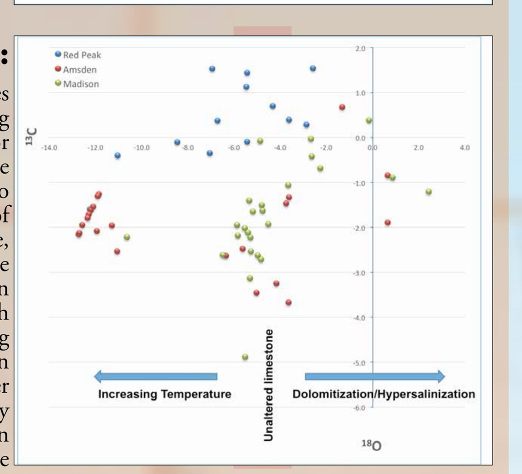


Figure 8:



Stable isotopic analyses from carbonates of sealing lithologies. Dolomites for all sealing lithologies are enriched with respect to oxygen, indicative of precipitation in near-surface, hypersaline waters. A large proportion of Amsden samples are depleted with respect to oxygen, indicating carbonates precipitated in the presence of higher temperature brines. Many Red Peak and Madison samples show little evidence of post-depositional alteration, relative to Amsden samples. Carbon isotopes can fluctuate based on organic content, oxidation, reduction, methanogenesis, and decarboxylation.

Sealing Potential

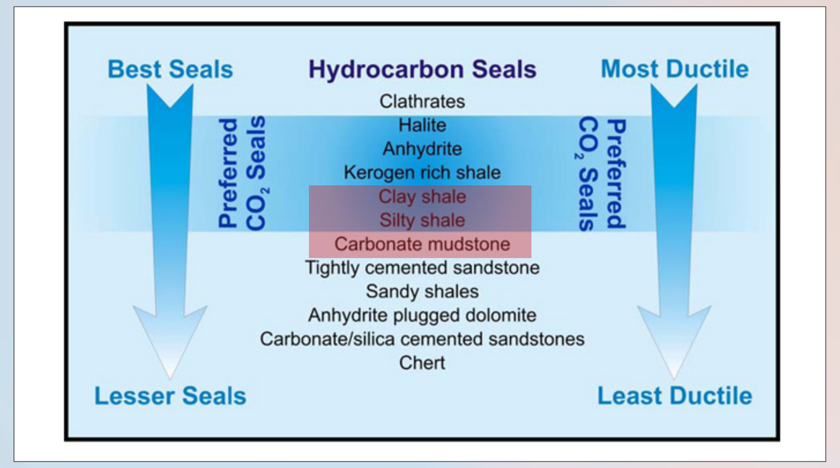


Figure 9:

Idealized seal chart by lithology. Lithology types from this study are highlighted by red box. (Figure modified from IEAGHG, March 2009)

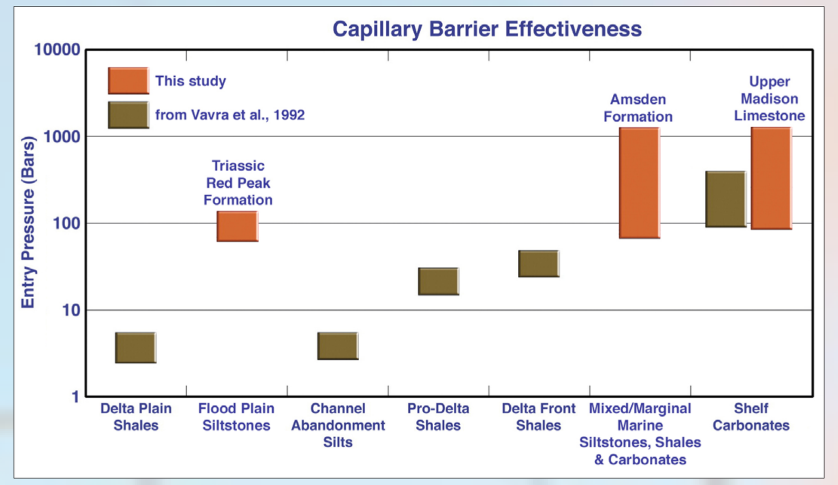


Figure 10:

Capillary Effectiveness of differing Sealing Lithologies:
Previous studies have identified a correlation between lithology and sealing potential. This study shows comparable (and the highest) sealing potential between marine sediments, but continental sediments (i.e. the Red Peak Formation) at our study site has enhanced sealing potential relative to other investigated siltstones.
(adapted from Vavra, et al., 1992)

Conclusions

- Alteration and diagenesis have been shown to influence all formations (**Figures 3-8**).
- Petrographic and stable isotopic analyses show that the Amsden Formation has been subjected to a relatively high-amount of post-burial alteration, while Red Peak was subjected to the least-amount. (**Figures 4, 7, and 8**).
- Burial-related illitization of clays in the Triassic Red Peak formation, as well as carbonate cementation, have enhanced sealing capacity (**Figures 3, 6, and 8**).
- This study identifies the Triassic Red Peak formation as the lowest-risk seal due to its diagenetic history, which increased cementation. This formation shows greater sealing potential than other published analogues (**Figure 10**).

References

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- Jiao, Zung Sheng, and Ronald C. Surdam. "Stratigraphic/diagenetic pressure seals in the Muddy Sandstone, Powder River basin, Wyoming." (1994): 297-312.
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