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*Constraining fracture stratigraphy in grain-rich mixed carbonate slope deposits for subsurface applications*

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Outcrop studies are essential for characterizing fractured carbonate systems, as they provide the most comprehensive understanding of how vertical and lateral facies variability and associated diagenetic processes affect fracture size and fracture network geometry (and thus fluid flow) at multiple scales. The Pinery Member of the Permian-aged Bell Canyon Formation, located on the toe-of-slope of the Capitan Reef system in the Guadalupe Mountains of West Texas, contains various architectural elements that are well exposed for fracture-stratigraphy characterization. While published studies have linked burial diagenesis to fracture network enhancement, the original depositional controls on burial-fracture-network development remain poorly constrained. This study describes the fracture stratigraphy along depositional strike and dip in the grainstone and rudstone-dominated Pinery Member. In the proximal toe-of-slope setting, upslope-shingling carbonate debris-flow deposits exhibit compensational stacking with downslope-dipping carbonate turbidite complexes, while the distal toe-of-slope is organized into a poorly-confined interbedded grainstone debrite and turbidite complex.

Most fractures are interpreted as Mode I open fractures that form orthogonal sets and are oriented with regional tectonic trends. Mineralized fractures are rarely observed in the heavily weathered outcrop faces and follow the same orientation trends as Mode I fractures. Fracture heights range from 0.01 m to 12 m, are characterized by an exponential distribution, and are constrained by a combination of bed thickness and stratal architecture, vertical facies stacking patterns, and tectonic overprint. Bed-bound and intra-bed fractures are more evident in thin to medium-bedded grainstone turbidites on the distal toe-of-slope, and increasing fracture heights exhibit a weak positive correlation with increasing bed thickness. Fracture heights also exhibit a weak positive correlation with increasing grain content (Dunham texture). The smallest fracture heights (up to 0.6 m) are associated with mud-rich turbidite caps and debrites, and larger fracture heights (up to 6.0 m) are associated with stacked and backfilling medium to very thick-bedded grainstone and rudstone debrites and turbidites. The largest fracture heights (> 6.0 m) are associated with tectonic overprint from Basin and Range extension and are more prevalent in the thicker proximal toe-of-slope rudstone complexes. There is no correlation between fracture height and grain size.

From sedimentological and fracture observations in the field, we postulate that (i) mud-rich carbonate facies at the caps of grain-rich turbidites or in off-axis deposits are mechanical boundaries, (ii) tabular turbidite and debrite architectures promote the development of shorter bed-bound fractures, particularly in the distal toe-of-slope setting,

(iii) thick, massive debrite complexes promote taller bed-bound fractures in the proximal toe-of-slope setting, and (iv) thick, vertically stacked geometries with similar grain content promote taller throughgoing fractures through the processes of burial and/or tectonic activity. Geomechanical testing on these toe-of-slope facies is the focus of future efforts to constrain the depositional controls on rock strength.

Results of this study have implications for predicting facies- and tectonics-controlled fracture network geometry in subsurface applications for oil and gas reservoirs, carbon storage, enhanced geothermal, and groundwater reservoir characterization.

## **Biography**

Rachel Aisner Williams is currently a Geology Ph.D Candidate at the Colorado School of Mines, working on an integrated sed/strat, geomechanics, fracture (fracture stratigraphy) and data analytics thesis in Permian-aged mixed carbonate and siliciclastic slope deposits in the Guadalupe Mountains, USA. The goal of this research is to determine if depositional stratal geometries on the slope affect fracture size, spacing, and intensity for subsurface characterization applications.

Williams career goal is to apply her interdisciplinary technical background to subsurface characterization projects in an industry, consulting, or research role in the low carbon energy space or oil and gas upon graduation in 2026.