

PS Progradational Slope Architecture and Sediment Partitioning in the Outcropping Mixed Siliciclastic-Carbonate Bone Spring Formation, Permian Basin, West Texas*

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Abstract

Slope-building processes and sediment partitioning in mixed carbonate-siliciclastic sediment routing systems are poorly understood but are important constraints on the spatial and temporal distribution of reservoir-forming elements. The Bone Spring Formation of the Delaware Basin in west Texas is a mixed carbonate and clastic system that acts as a prolific hydrocarbon reservoir. The Bone Spring Formation consists of cyclic shelf-to-basin deposits of sandy turbidites to carbonate turbidites and mass-transport deposits that were sourced from the shelf margin during Leonardian time (~275 Ma). Much research has focused on the distal deposits of the Bone Spring Formation, but there has been little research on the proximal staging area that outcrops in Guadalupe Mountains National Park (GUMO). Our research aims to describe the stratigraphic architecture of the Bone Spring Formation in GUMO in order to delineate the staging area and the dynamics of carbonate and siliciclastic sediment delivery to the basin. Using drone-derived 3D models and measured sections, we document slope-building processes and intermixing of siliciclastic and carbonate lithofacies in the outcropping Bone Spring Formation. Bed orientations and regional surfaces identified several slope-building clinothems that vary from siliciclastic-rich to carbonate-rich and show significant variability in slope propagation direction. These results suggest that the temporal and spatial distribution of siliciclastic-rich lithofacies in the staging area likely impact the stacking patterns of siliciclastic and carbonate lithofacies in the basin. Additionally, the presence of a significant shift in clinothem orientation corresponds to the clinothem containing the highest frequency of failure surfaces and submarine channel deposits, suggesting that entry points of coarse-grained carbonate material to the basin may be related to slope morphology. These results suggest that the dynamics of the upper-slope environment are a primary control on reservoir-forming elements in the basin. Our work provides a better understanding of slope building processes of mixed lithology clinothems, specifically in steep carbonate margins with periodic siliciclastic input. Our characterization of the outcropping Bone Spring Formation aids in reservoir prediction for future development in the Bone Spring Formation and similar targets in the Delaware and Midland basins like the Spraberry and Wolfcamp Formations.

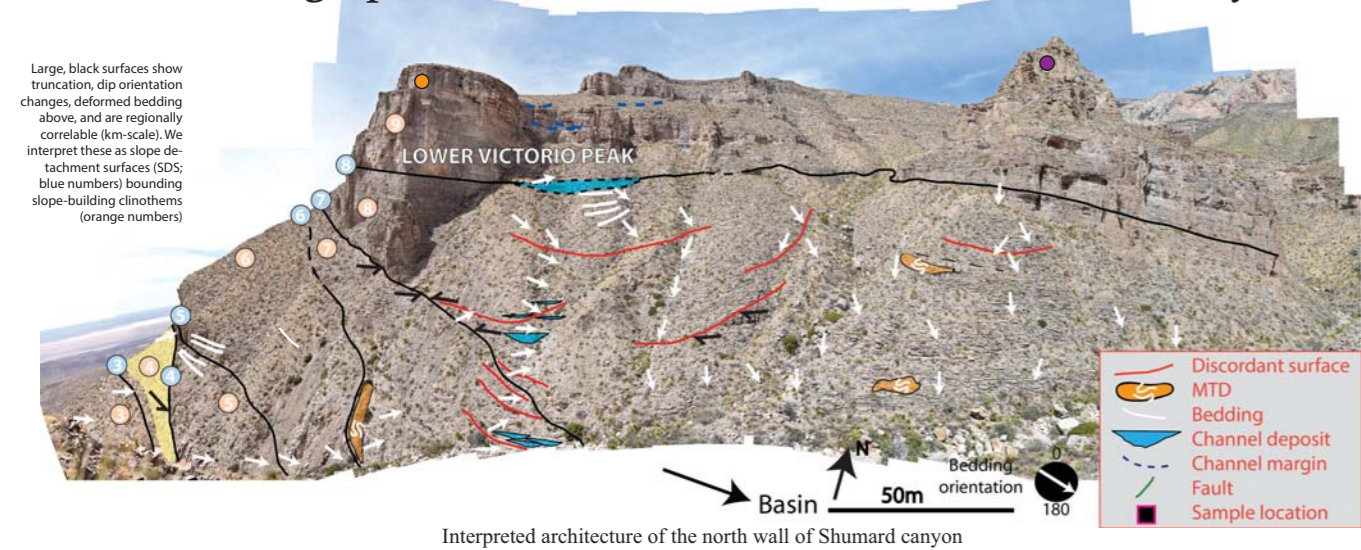
Progradational Slope Architecture and Sediment Partitioning in the Outcropping Mixed Siliciclastic-Carbonate Bone Spring Formation, Permian Basin, west Texas

Wylie Walker^{1,2}, Zane Jobe^{1,2}, Rick Sarg², Lesli Wood² - ¹Chevron Center of Research Excellence (CoRE), ²Colorado School of Mines, Golden, CO

1 Minute Poster - The Bone Spring Formation of the Delaware Basin is a mixed siliciclastic-carbonate shelf-to-basin system that shows large-scale cyclicity between siliciclastic-rich intervals (Bone Spring sands) and carbonate-rich intervals (Bone Spring carbonates) in the basin. However, within these members there is significant variability in composition and depositional process. This study constrains the stratigraphic architecture and sediment partitioning on the outcropping Bone Spring upper slope. Results suggest that seismic-scale slope detachment surfaces (SDS) and mixed-lithology clinothems identified on the outcrop can elucidate slope building processes and sediment partitioning in a mixed system and lead to a better understanding of depositional variability in the Bone Spring Fm. basinal deposits

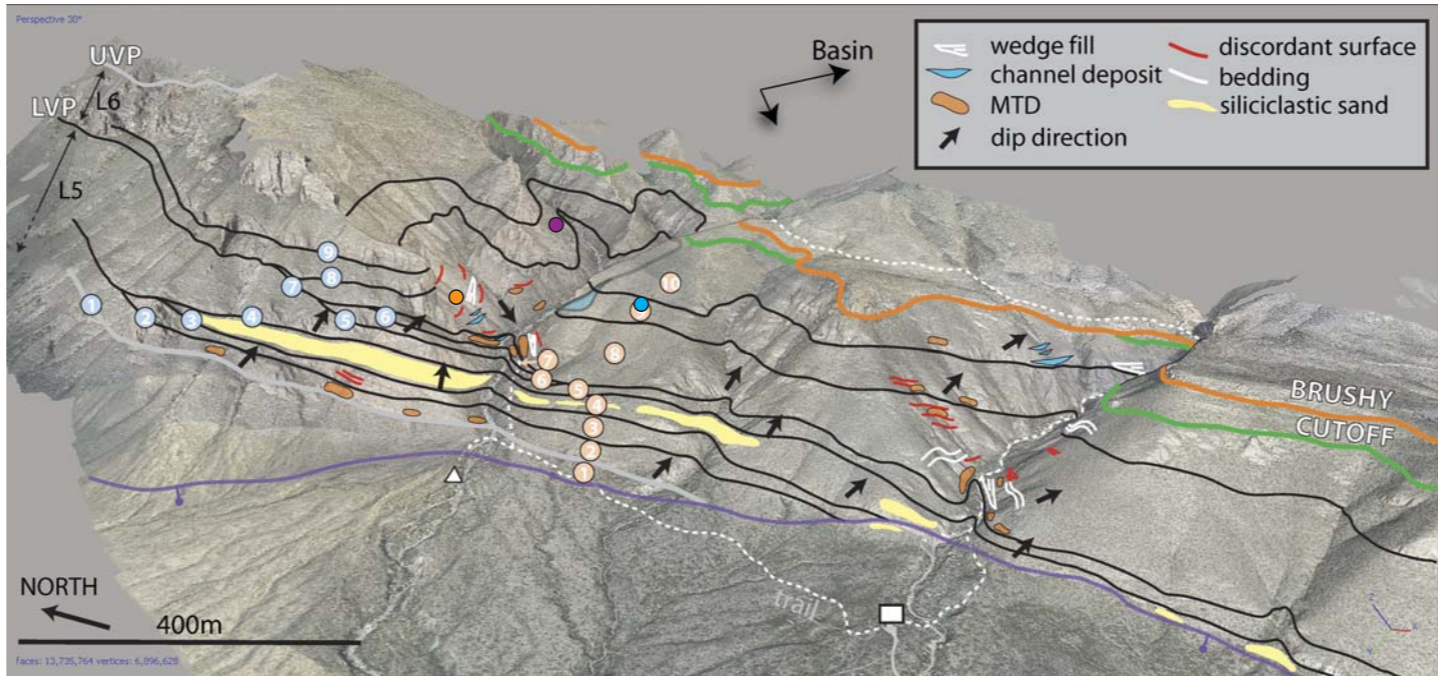


Stratigraphic Architecture - north wall of Shumard Cyn



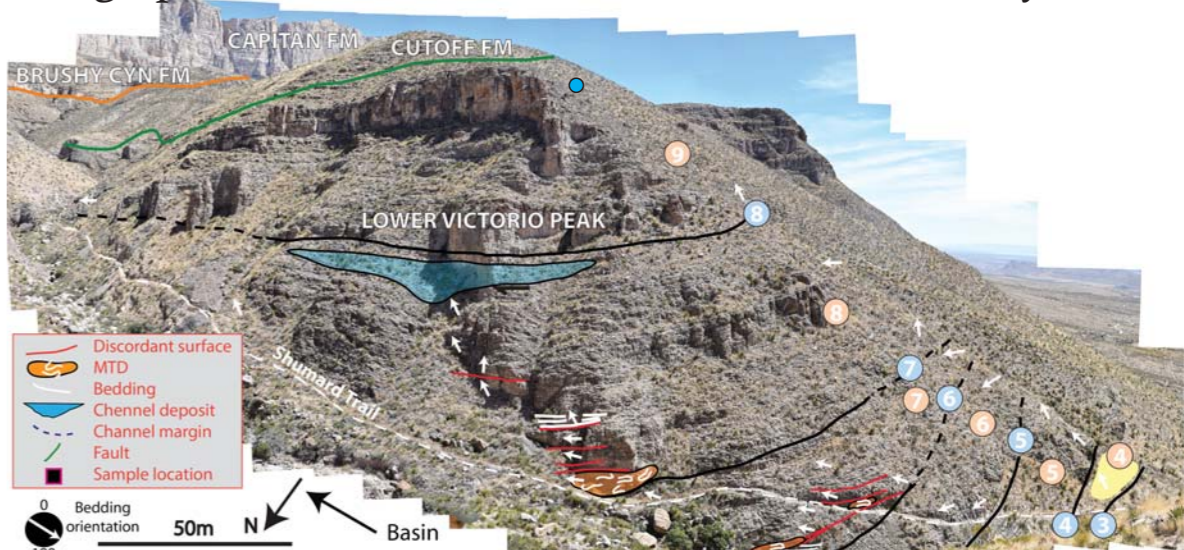
Interpreted architecture of the north wall of Shumard canyon

3-D STRATIGRAPHIC ARCHITECTURE



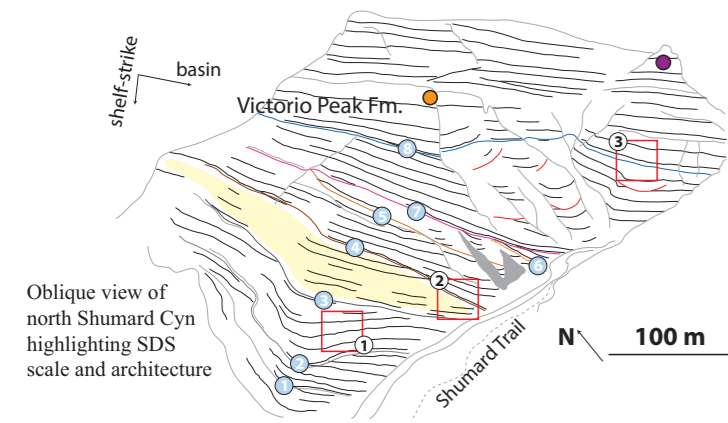
3D architecture of the Bone Spring Fm. in GMNP. Large-scale slope detachment surfaces (SDS) can be mapped (blue #) bounding slope-building clinothems (orange #)

Stratigraphic Architecture - south wall of Shumard Cyn



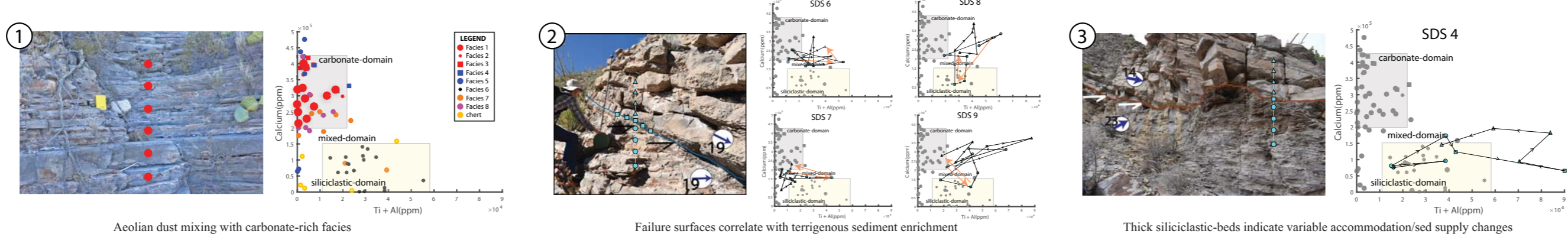
Interpreted architecture of the south wall of Shumard canyon

SDS SURFACES



Oblique view of north Shumard Cyn highlighting SDS scale and architecture

SEDIMENT PARTITIONING



Aeolian dust mixing with carbonate-rich facies

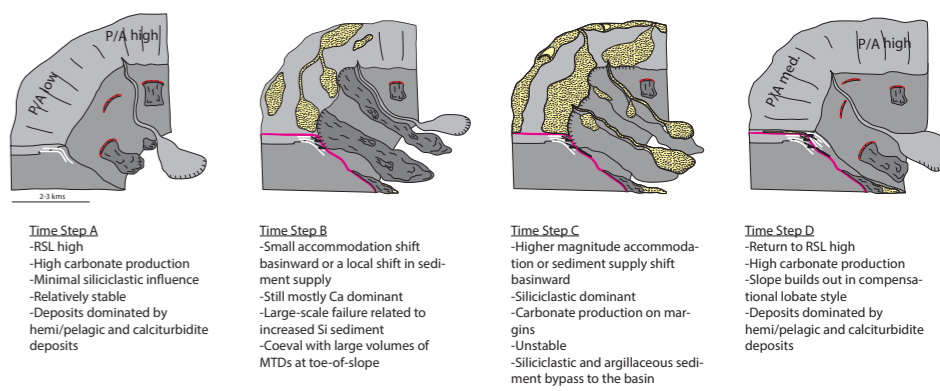
Failure surfaces correlate with terrigenous sediment enrichment

Thick siliciclastic-beds indicate variable accommodation/sediment supply changes

CONCLUSIONS AND IMPLICATIONS

- Clinothems of mixed lithology build the Victrio Peak-Bone Spring shelf and slope margin. The margin builds out in a “failure and fill” style, resulting in lobate, compensationally-stacked packages that create a rugose margin.
- Slope detachment surfaces on the Bone Spring Fm. outcrops in Guadalupe Mountains National Park record large-scale failure of the margin as the result of siliciclastic sediment increase related to local accommodation or sediment supply shifts.
- Clinothems, SDS, and sediment partitioning on the upper Bone Spring slope aid in reconstructions of the shelf margin. These reconstructions elucidate slope-building processes in a mixed siliciclastic-carbonate sediment routing system and provide a better understanding of compositional heterogeneity in the basinal deposits.

SLOPE EVOLUTION



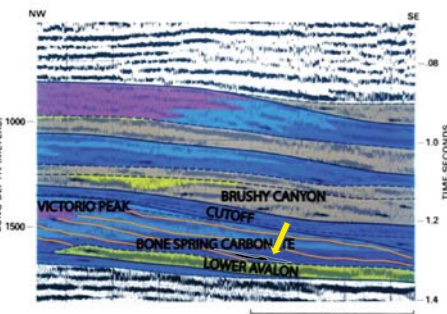
Time Step A
-RSL high
-High carbonate production
-Minimal siliciclastic influence
-Relatively stable
-Deposits dominated by hemi/pelagic and calciturbidite deposits

Time Step B
-Small accommodation shift
-basinward or a local shift in sediment supply
-Still mostly Ca dominant
-Large-scale failure related to increased Si sediment
-Coeval with large volumes of MTDs at toe-of-slope

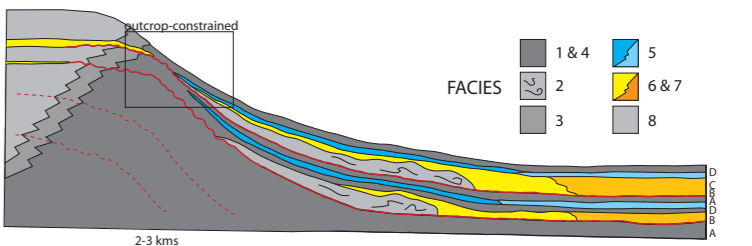
Time Step C
-Higher magnitude accommodation or sediment supply shift
-Slope builds out in compensational lobate style
-Carbonate production on margins
-Unstable
-Siliciclastic and argillaceous sediment bypass to the basin

Time Step D
-Return to RSL high
-High carbonate production
-Slope builds out in compensational lobate style
-Deposits dominated by hemi/pelagic and calciturbidite deposits

Seismic cross-section of the north-west Delaware shelf. Clinoform surfaces within the prograding carbonate package are analogous to the SDS in this study. Results from this study suggest a predicted increase in sub-seismic siliciclastic and argillaceous sediment associated with SDS. From Sarg, 198



Schematic cross-section of predicted stratigraphy based on slope reconstructions. SDS are part of clinoform geometries that correlate to mixed lithologies and different depositional styles in the basin

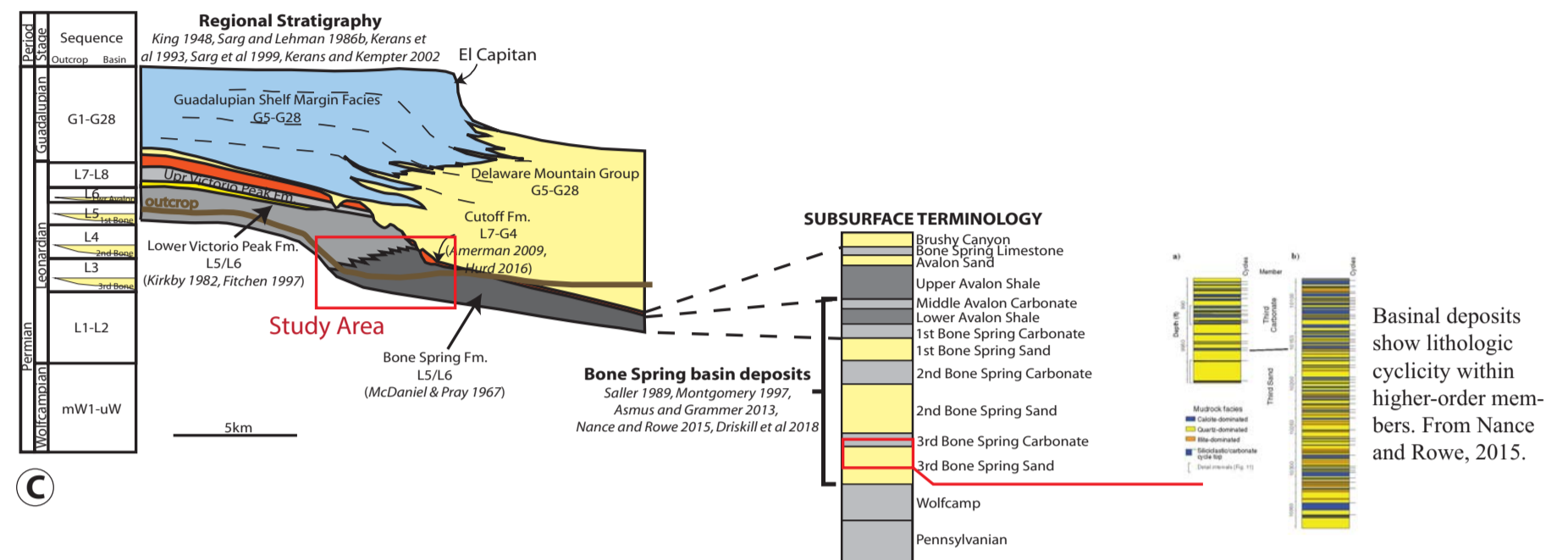
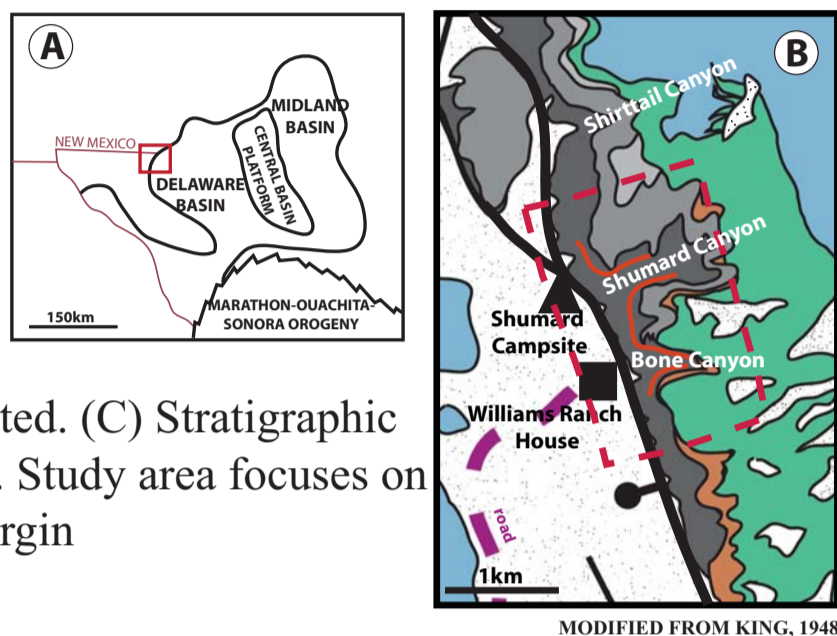


OBJECTIVES

- Constrain the stratigraphic architecture of the Bone Spring Fm. in order to better understand slope-building processes in a mixed siliciclastic-carbonate margin
- Delineate sediment partitioning on the upper slope to elucidate mixed carbonate-siliciclastic sediment delivery to the Delaware Basin
- Improve subsurface predictions of reservoir-forming elements in mixed systems

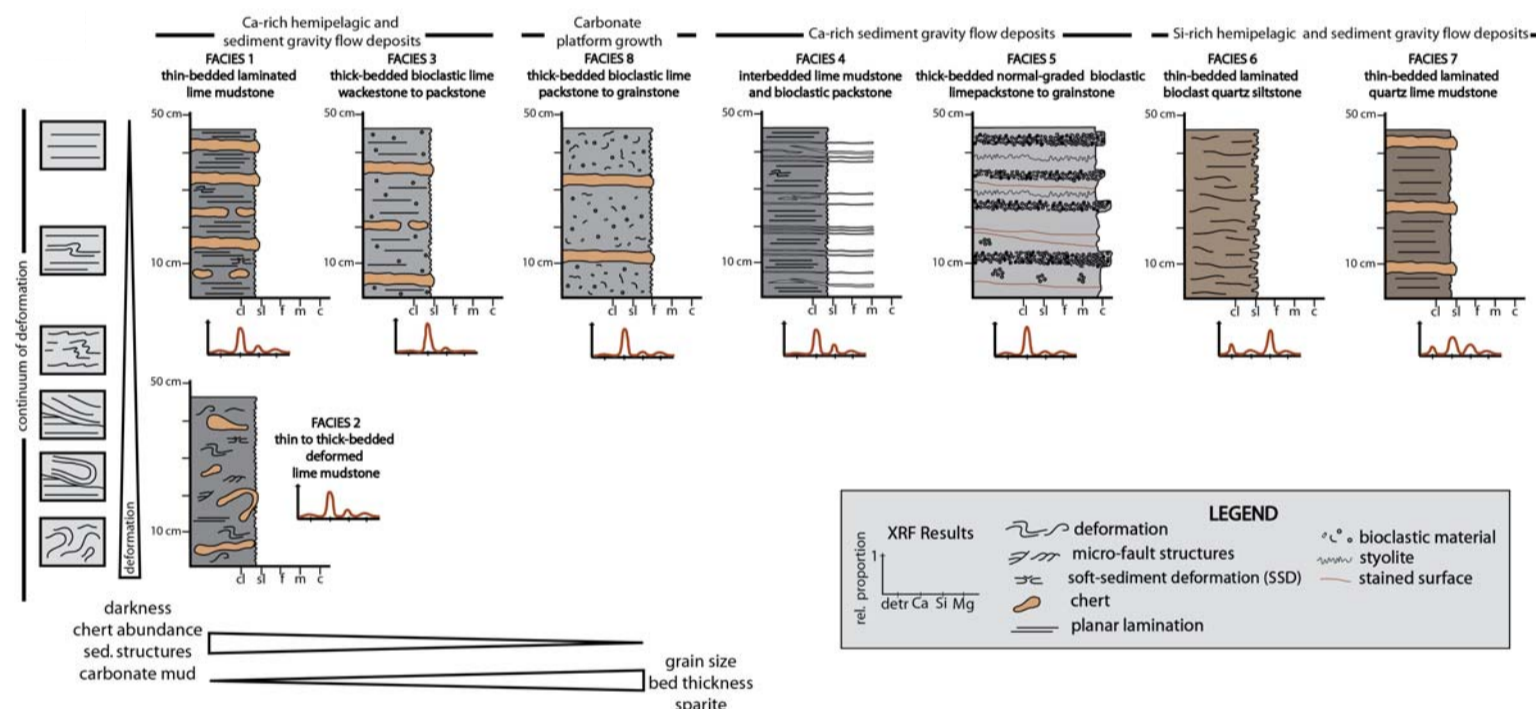
STUDY AREA & GEOLOGIC SETTING

Study area on the western margin of the Delaware Basin (A); Permian-aged outcrops within Guadalupe Mountains National Park (B) with study area and methods indicated. (C) Stratigraphic setting of the study area. Study area focuses on the Leonardian shelf margin

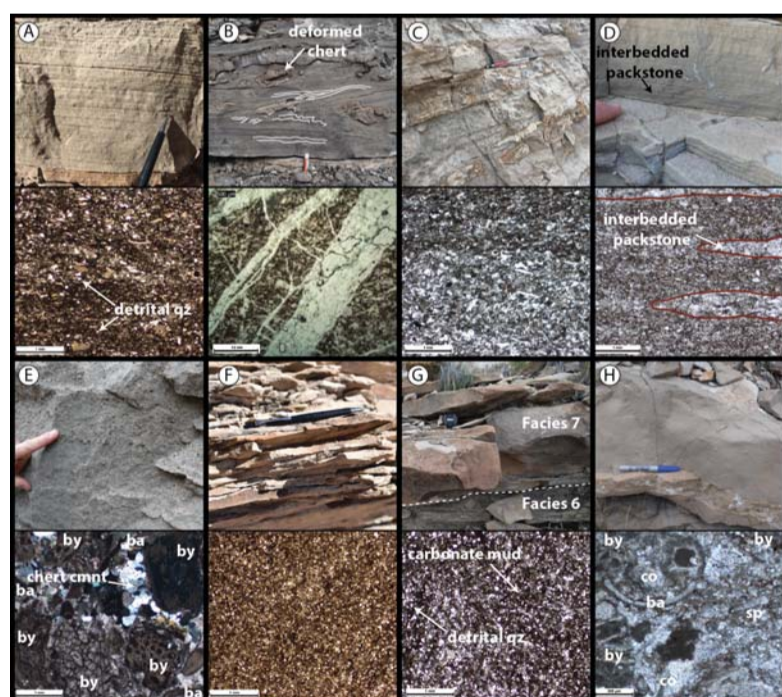
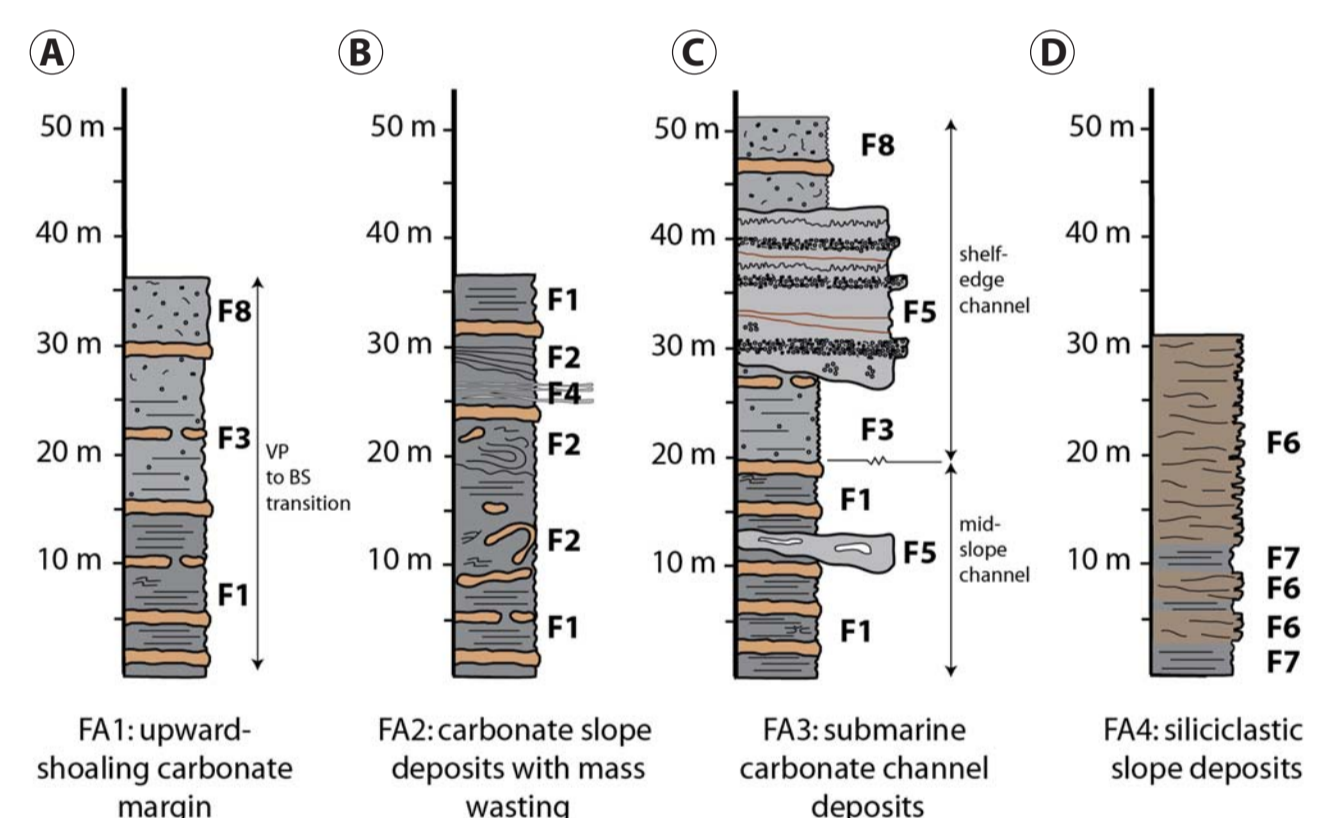


SHELF AND SLOPE FACIES & DEPOSITIONAL ELEMENTS

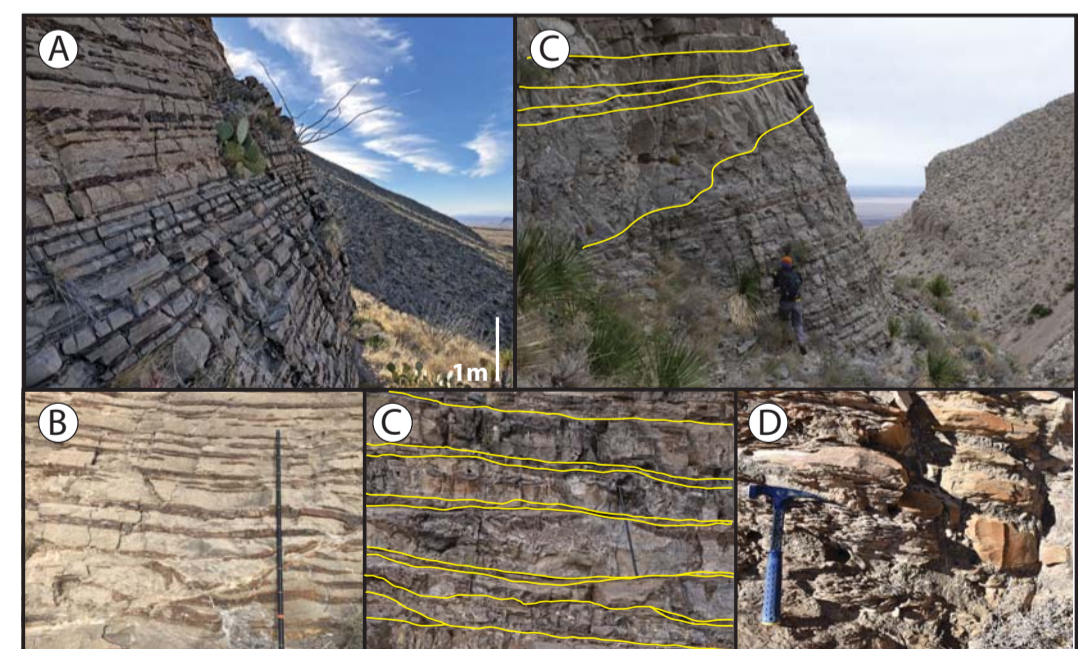
Facies of the Bone Spring Fm. outcrops



Depositional Elements of the Bone Spring Fm. outcrops



Outcrop (top) and thin section (bottom) images of facies in the Bone Spring Fm. (A) Facies 1; (B) Facies 2; (C) Facies 3; (D) Facies 4; (E) Facies 5; (F) Facies 6; (G) Facies 7; (H) Facies 8



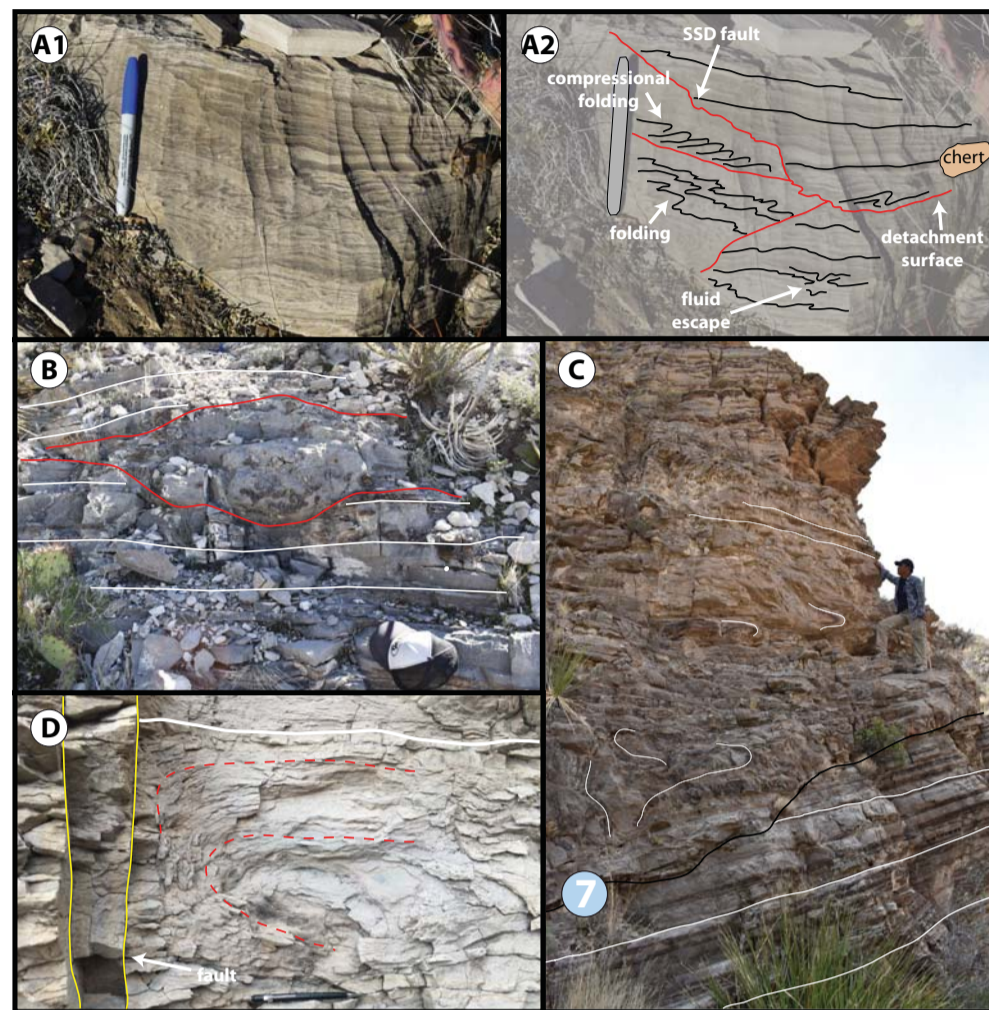
Outcrop images of FA1 (A), FA2 (B), FA3 (C), FA4 (D)

ACKNOWLEDGEMENTS

FAILURE AND DEFORMATION IN THE BONE SPRING

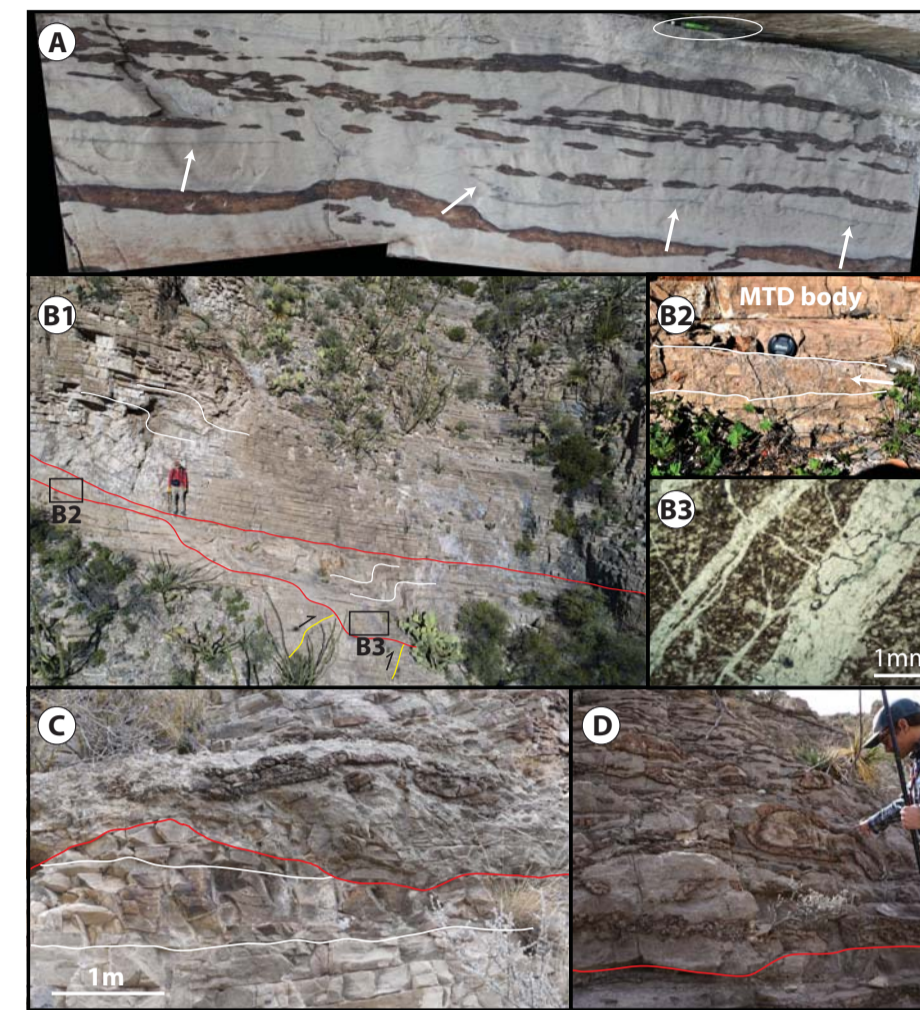
- Observing failure and deformation in carbonate-rich deposits of the Bone Spring Fm. can lead to better identification of these deposits in core and well-log, and can lead to better reservoir model parameters like scale, heterogeneity, reservoir and mechanical properties, and potential compartmentalization.

Scale of Failure



Outcrop images of different scales of deformation recorded on the upper slope Bone Spring Formation. (A1) Micro-scale deformation (sub-meter). (A2) Line drawing of A1 showing soft-sediment deformation and detachment surfaces. (B) Meso-scale (meter-scale) deformation. Carbonate-rich debrite deposit (red) eroding into undeformed strata (white). (C) Meso-scale deformation. Debrite sitting on top of SDS 7 with folds visible. Note chert mimics bedding. (D) Meso-scale siliciclastic-rich deformation.

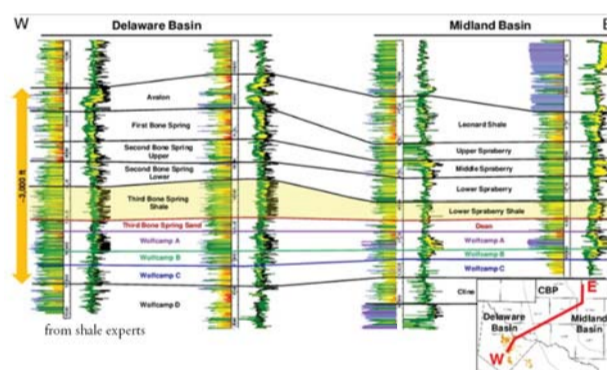
Style of Failure



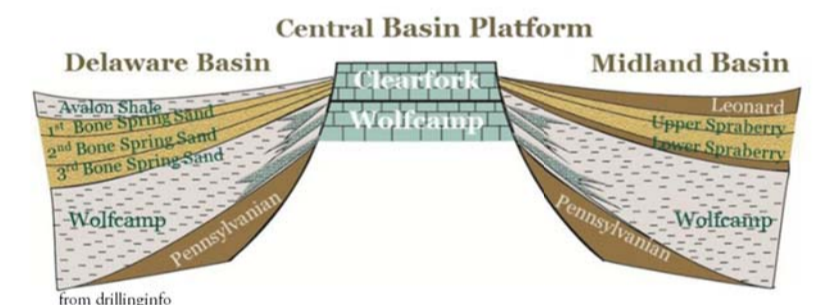
Outcrop images of different styles and characteristics of deformation. (A) Micro-scale creep. Individual lamina indicated by white arrows. Creep is the most common style of deformation on the upper-slope, indicating steep slope angles. (B1) Meso-scale slump deposits. Two slump deposits separated by decollement surfaces (red). Meso-scale slump deposits on the upper-slope indicate high yield strength of carbonate material. Locations of B2 and B3 indicated. (B2) Brecciation at the base of slump deposits indicates basal shear during transportation. (B3) Thin section showing fracturing within slump deposits are calcite-cemented. (C) Debris flow deposits (debrites) are common in the Bone Spring. Debrites commonly show basal erosion, indicating high basal shear. (D) Debrite with chert nodule. Chert characteristics often mimic matrix bedding and can be a good indicator of deformation style.

SEQUENCE STRATIGRAPHIC CONCEPTS

Are these good stratigraphic models for the Permian Basin?



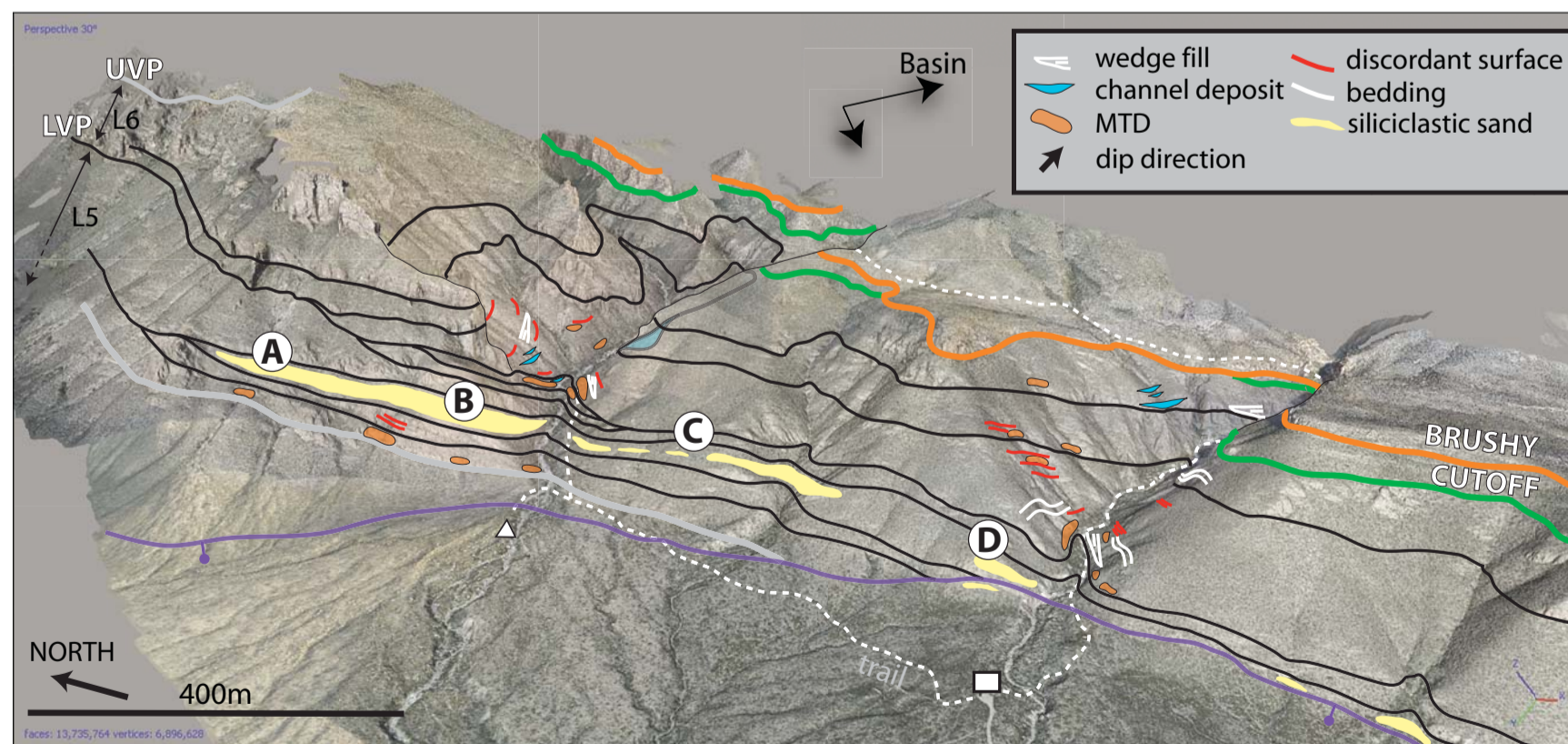
These models correlate sand and carbonate packages across the entire sub-basins. While in some instances these may be reasonable higher-order correlations, they do not capture the sub-member heterogeneity documented in the Permian Basin. Additionally, these models rely on dominantly allogenic processes, but are autogenic processes more important than original assumed in the Permian Basin?



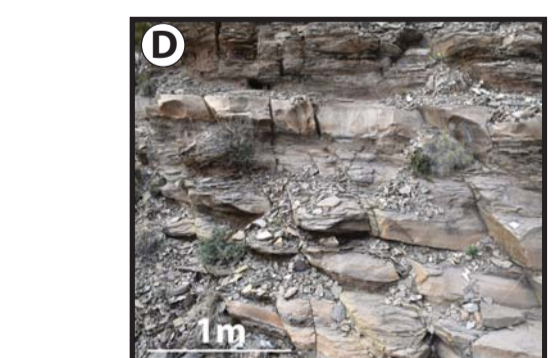
Interbedded siliciclastic-rich (F6) and mixed (F7) beds showing sedimentary structures



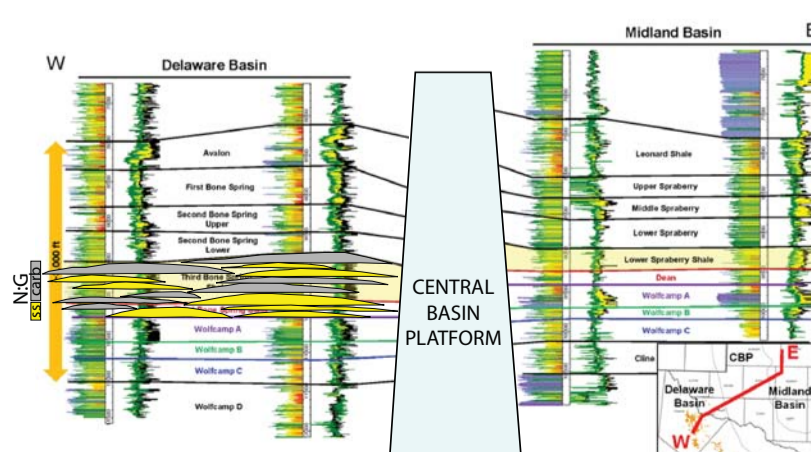
Thick beds (5-10 meters) of siliciclastic facies (F6)



The sand-rich clinothem may provide insight into allogenic and autogenic processes in the Bone Spring. Sand shows a discontinuous nature laterally, is highly interbedded with mixed carbonate facies, and is encased in a higher-order carbonate package. These results suggest that autogenic processes are likely important in building the stratigraphy of the basinal deposits.



Siliciclastic beds become more interbedded with carbonate facies and more discontinuous laterally



Here we provide an alternative stratigraphic interpretation based on the outcrop observations in this study and documented heterogeneity in the basin (Saller et al., 1989; Montgomery, 1997a, b; Asmus and Grammer, 2013; Nance and Rowe, 2015; Driskill et al., 2018). In this interpretation, autogenic and allogenic processes are working concurrently to build the basinal stratigraphy. Note that there are higher-order packages of high net-to-gross (N:G) sand or carbonate, but within these members carbonate and siliciclastic deposits are depositing contemporaneously.