Qualifying the Hydrological Setting of Upper Flow Regime Fluvial Systems of the Triassic Dockum Group of West Texas

Samuel P Walker, Advisor: Dr. John Holbrook

Department of Geological Sciences, Texas Christian University, Fort Worth, Texas 76129

Abstract

The Triassic Dockum Group of the western Texas High Plains is studied in depth paleontologically, but until recently lacked a detailed sedimentological evaluation. Recent research of the Dockum Group in Palo Duro Canyon, Texas, provides new interpretations of the complex fluvial lacustrine strata of the comprising formations based on analysis of individual lithofacies. Identified within the lithofacies assemblages are numerous channel belts composed of upper flow regime bedforms. Observed upper flow regime bedforms in outcrop range from upper plane bed, antidunes, breaking antidunes, chutes and pools, and cyclic steps with increasing flow velocity respectively. These channel belts record extreme flow events from repeating massive storms that perpetuated throughout the Texas region of Triassic Pangea. These unique reservoir-quality channels are interpreted to be resultant of a megamonsoonal climate producing massive pulses of rapid flow allowing for the preservation of upper flow regime bedforms. While these channels are identified in outcrop they have not been quantified in distribution, variability in fill, connectivity and formative discharge.

This study aims to test the megamonsoonal hypothesis by quantifying the discharge of these channels and testing if the distribution density and paleodischarge of these channels is consistent with local dominance of megamonsoonal conditions. Upper flow regime structures are rarely preserved in the rock record and extremely difficult to observe directly during natural formation in modern rivers. Most of the equations used to quantify flow conditions for these structures are derived from flume tank experiments. These are applied to the upper flow regime bedforms found in outcrops of the Dockum Group to reconstruct paleohydrology. Current flume tank research reinforces Kennedy's equations defining relationships between the wavelengths of stable antidune apexes (λ), mean flow depth (h_m) and mean flow velocity (U). These equations are modified to account for different upper flow regime structures formed under increasing velocity and discharge identified in outcrop. Bedform distribution, size, and type are variables determined from outcrop measurement. Paleoflow velocities, Froude numbers and relative water depths are determined with an observed margin of error. Scaling relationships and field measurements provide constraints on channel cross sectional area and channel-belt density. This data along with grain size distribution provides tangible numbers for calculating formative discharge.

Introduction

This study aims to apply observations and equations derived from flume tank experiments to outcrops to characterize how these fluvial sediment bodies fill and quantify their paleoflow parameters. Using flume tank and modern examples of bedform deposition and distribution patterns the conditions under which these channels formed are inferable. Kennedy's 1969 flume tank derived equations define relationships between the wavelengths of stable antidune apexes (λ), mean flow depth (h_m) and mean flow velocity (U) to quantify the paleohydrualics of these super critical flows. Channel dimensions are measured to further quantify the discharge that these unique supercritical fluvial bodies can transport into the basin. This is obtained through the well-known relationship between formative discharge (Q), channel cross-sectional area (A) and flow velocity (U). These observations and measurements provide results on how supercritical channels can fill and how their flows can vary.

While supercritical flows are quantified in flume tank experiments and bedforms are periodically observed in outcrop this study attempts to provide frontier advancements by combing the two to better understand how these systems are deposited in the rock record and preserved in stratigraphic architecture. The abundance of supercritical flow deposits in the outcrops of the Dockum Group provide an ideal environment to study these channel bodies.

Study Area

The area of interest for this study extends across three counties of the Texas High Plains Briscoe, Hall and Randal County. Most of the research and field work focusses on the outcrops of Palo Duro Canyon State Park and the roadcuts of south State Highway 207 (Figure 1). These locations provide ample opportunity to study these supercritical flow deposits found within the formations of the Dockum Group.

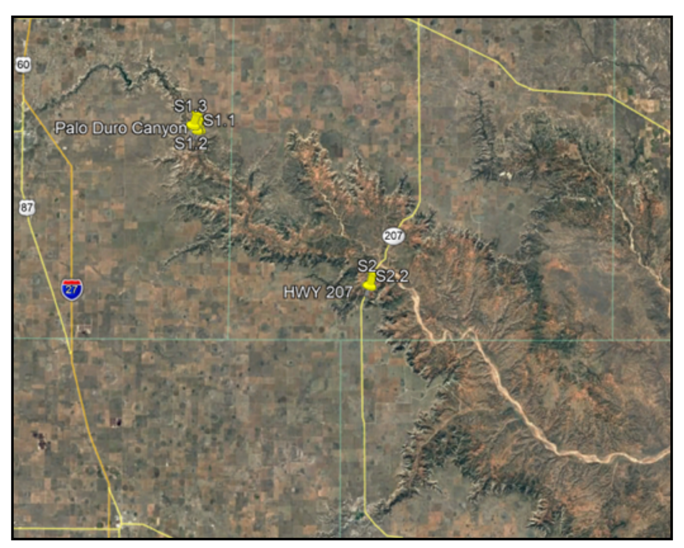

Figure 1, Google Earth image showing field locations with pins

Geologic History

The Late Triassic Dockum Group (Carnian and Norian Age) is a complex fluvial-dominated system driven by runoff from the surrounding topographic highs of Pangea during this time. Paleoclimate models and local observation of supercritical flow deposits suggests that these fluvial systems are driven by extreme precipitation from a megamonsoonal climate perpetuating throughout the Texas region of Triassic Pangea (Van der Voo et al., 1976; Perish, 1993; Winguth and Winguth, 2013; Lamb, 2019). These storms provide significant waxing and waning flow energy observed within the formations of the Dockum Group.

The Dockum Group contains two sequences composed of four formations, the Santa Rosa Sandstone, Tecovas Formation, Trujillo Sandstone, and the Cooper Canyon Formation. The lower sequence is sourced from the north and northeast by the Ouachita Orogenic Belt and the Amarillo-Wichita uplift (Cramer, 1973; Lehman and Chatterjee, 2005). Paleocurrent direction and abundance of metamorphic rock fragments in the upper sequence of the Dockum Group suggests that transitioning from Carnian to Norian Age the source area shifts to the south-southeast (Lehman and Chatterjee, 2005). This shift in sediment source is supported by the rifting of Pangea and the reactivation of paleohighs (Dickenson et al., 2010).

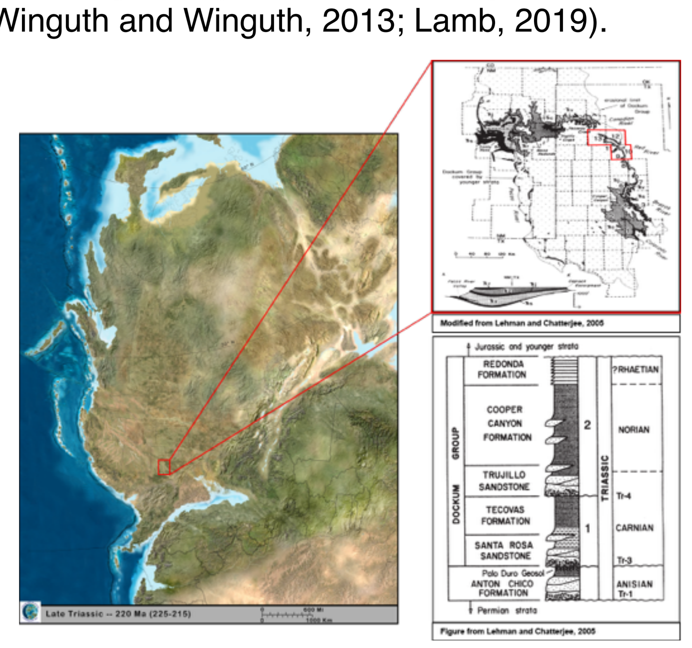

Figure 2, Regional map of Triassic Pangea with Dockum Group extent and stratigraphic column

Variability of Upper Flow Regime Stratigraphic Architecture

Moving up section of a typical supercritical flow fluvial system fill with increasing Froude Number resultant from increasing flow velocity and or decreasing water depth provides a distinctive architecture. With increasing Froude Number, a typical section shifts from subcritical bedforms to supercritical bedforms with possible cross bedding to sigmoidal cross bedding at the base transitioning into upper plane bed with parting laminations eventually into antidunes and possibly chute and pool structures. Figure 3 provided by Fielding (2006) shows line drawings of bedforms under increasing flow strength. However, these fluvial bodies can vary greatly under different conditions.

Within the Dockum Group, multiple different types of fill styles have been identified within the Tecovas Formation and Trijullo Sandstone. Figure 4 represents one type of valley-confined supercritical sheet flow fill identified within the Tecovas Formations showing bedforms deposited under decreasing flow energy. Figure 5 depicts an unconfined supercritical sheet slow consisting of multigenerational supercritical pulses amalgamating within the same sheet flow body. Given the highly amalgamating nature of these flows and the intensity at which they come on they provide unique stratigraphic architecture on a larger scale such as multivalley complexes, figure 6.

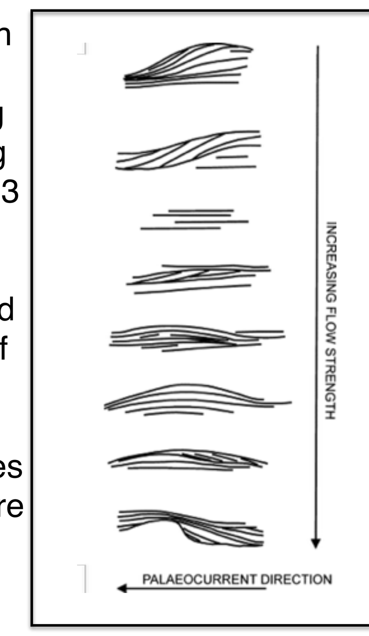

Figure 3, From Fielding, (2006) Upper flow regime bedroom line drawings shifting from transitional sigmoidal dunes to antidunes and chute and pool structures.

Figure 4, Supercritical valley-confined sheet flow showing transition of internal structures with 1. planar laminations 2. antidune bedrooms 3. climbing ripples 4. overbank fines.

Figure 5, Supercritical unconfined multigenerational sheet flow showing five distinct flow conditions confined within one sheet flow. 1. typical red, fine-grained sandstone with upper plane bed laminations 2. erosional boundary with overlying poorly-sorted, coarse-grained sigmoidal bedding 3. laterally continuous moderately sorted supercritical flow 4. sharp boundary transitioning back into typical red, fine-grained sandstone with upper plane bed laminations 5. gradual transition into floodplain muds.

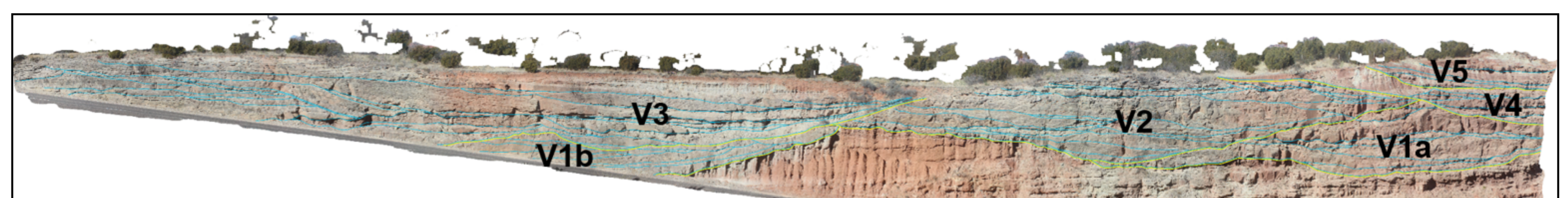

Figure 6, Trujillo Sandstone multivalley complex scouring into the underlying Tecovas Formation.Valleys are marked in green with V1a through V5, internal channel bodies are marked in blue.

Multivalley Complex and Allocyclic Driving Forces

Figure 6 depicts a multivalley complex within the Trujillo Sandstone cutting into the underlying Tecovas Formation at the State Highway 207 Location. The Multivalley complex is defined by the observations of multilateral and amalgamating valley fills over lying a regionally smooth to near-smooth erosional surface resultant from repeating cycles of valley incision and aggradation followed by unconfined channel avulsion redirecting and repeating the process (Holbrook, 2001). For valley amalgamation, significant fluctuation in sediment and water discharge must occur suggesting climate as the allocyclic driving force.

The identification of two or more channel stories along with supercritical fluvial bodies within each valley of the multivalley complex further supports a megamonsoonal climate during the Late Triassic. Preservation of upper flow regime bedforms within the confined fluvial bodies represents waning energy of significant flow transitioning from suspended to bedload transport due to a shifting monsoonal climate

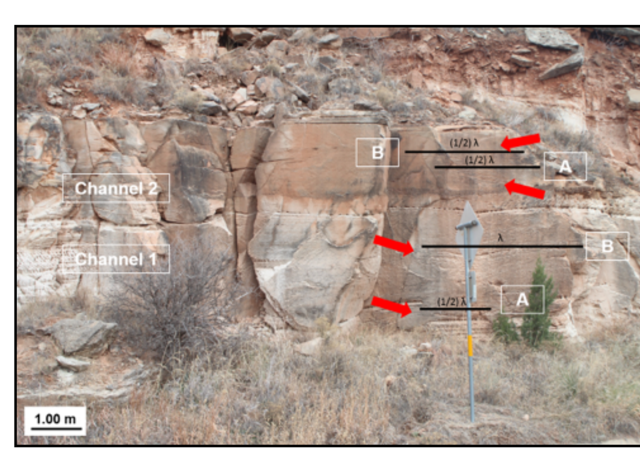

Figure 8, Tecovas Formation supercritical flow deposit. Two channels are shown with antidune sets labeled and shown with red arrows. The black bar shows the wavelength distance

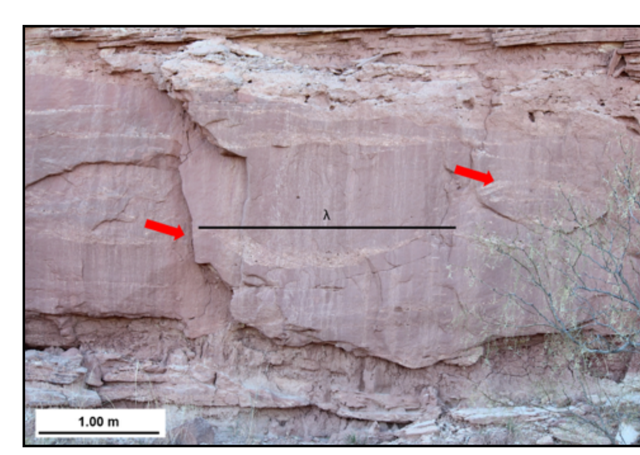

Figure 9, Trujillo Sandstone with gravel antidune. Antidunes are shows with red arrows and the black bar shows the wavelength distance

Calculating Discharge and Slope

Calculating formative discharge of supercritical fluvial bodies requires the implementation of flume tank derived equations from stable antidunes. Kennedy's (1969) equation is used relating the wavelength between crests of stable antidunes (λ), flow depth (h_m) and flow velocity (U) shown in figure 7. An example of outcrop measurement is shown in figurer 8 and 9. From channel cross sectional area (A) and flow velocity (U) formative discharge is calculated. With the preserved upper flow regime bedforms representing waning flow energy and the transition from suspended to bedload transport, maximum and minimum channel slope is estimated.

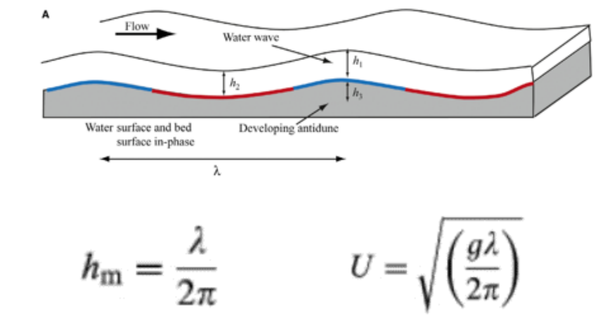

Figure 7 From Froude et al., 2017, diagram showing wavelength between two antidune crests and the relationship to water depth and flow velocity

For maximum slope a modified Shields Diagram, figure 10, is used to obtain bed shear stress (τ_0) from grain size (D). The bed shear stress equation solves for maximum slope (i) (Shields, 1936).

$$i = \tau_0/(g\rho_f R)$$

Where i = dimensionless maximum slope, τ_0 = bed shear stress (Pa), g represents the acceleration to gravity (9.8 m/s^2), ρ_f = fluid density (100 kg/m^3), and R = hydraulic radius (m).

For minimum slope, lower flow regime bedforms are assumed and slope is calculated from grain size (D_{50}) (Holbrook and Wanas, 2014).

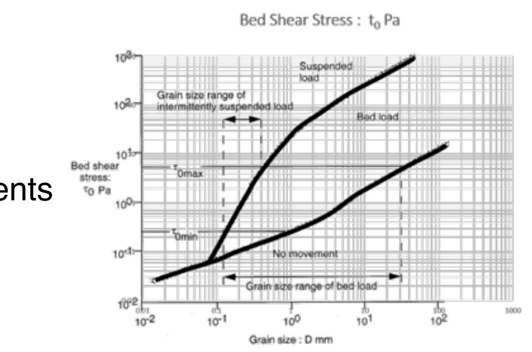

Figure 10, Modified Shieds Diagram From Bridge 2003.

$$S = ((\tau^*_{bf50})(R^*D_{50}))/H_{bf}$$

Where S = dimensionless minimum slope, τ^*_{bf50} = dimensionless shear stress (assumed at 1.86), R^* = dimensionless submerged density (assumed quartz at 1.65), D_{50} = median grain size (mm), and H_{bf} = bankfull depth (m).

Table 1 shows the calculated values for channel dimensions, antidune wavelength, flow depth, flow velocity and discharge. Variability in slope is shown in figure 11. Also included in Table 1 are measurements from a modern analog, the Burdekin River in Queensland Australia.

Location Formation	Grain Size D_{50} (mm)	Channel Width (m)	Channel Height (m)	Antidune wavelength (λ) (m)	Velocity (m/s) U = ((gλ)/(2π))^(1/2)	Flow depth (m) hm = λ/2π	Froude Number Fr = U/((g*hm)^(1/2))	Discharge (m^3/s) Q=UA	Minimum Slope	Maximum Slope
Palo Duro										
Trujillo Sandstone										
Channel 1	0.2	87.9	4.3	1.64	1.60	0.26	1	604.66	0.00014	0.00024
Channel 2	2	118	2.02	2.29	1.89	0.36	1	450.59	0.00304	0.02526
Channel 3, Figure 9	2.3	117	2.3	2.15	1.83	0.34	1	492.91	0.00307	0.02662
channel 4	2.3	112	2.7	2.9	2.13	0.46	1	643.30	0.00261	0.02268
Tecovas Formation										
Channel 1, Antidune Set A, Figure 10	0.25	102.68	2.66	2.36	1.92	0.38	1	524.15	0.00029	0.00058
Channel 1, Antidune Set B, Figure 10	0.25	102.68	2.66	3.18	2.23	0.51	1	608.44	0.00029	0.00058
Channel 2, Antidune Set A, Figure 10	0.25	103.9	2.08	4.16	2.55	0.66	1	550.63	0.00037	0.00074
Channel 2, Antidune Set B, Figure 10	0.25	103.9	2.08	4.71	2.71	0.75	1	585.90	0.00037	0.00074
Channel 3	0.24	49.2	2.4	5.62	2.96	0.89	1	349.69	0.00031	0.00064
South Highway 207										
Trujillo Sandstone										
Channel 1	0.2	85	2.34	4.49	2.65	0.71	1	526.49	0.00026	0.00044
Channel 2	0.2	55	1.8	3.4	2.30	0.54	1	228.04	0.00035	0.00058
Tecovas Formation										
Channel 1	0.7	48	2.39	1.44	1.50	0.23	1	171.97	0.00090	0.00427
Channel 2	0.2	14.8	1.75	1.71	1.63	0.27	1	42.31	0.00035	0.00058
Modern Analog *										
Burdekin River Maximum Discharge		300	25	15	4.84	2.39	1	36286.08		0.0007
Burdekin River 1994 Flood Discharge		550	2.8	16	5.00	2.55	1	7695.09		0.0007
Burdekin River 1996 Flood Discharge		330	2.2	12.6	4.43	2.01	1	3219.25		0.0007

Table 1, *Analog from Alexander et al., 1999

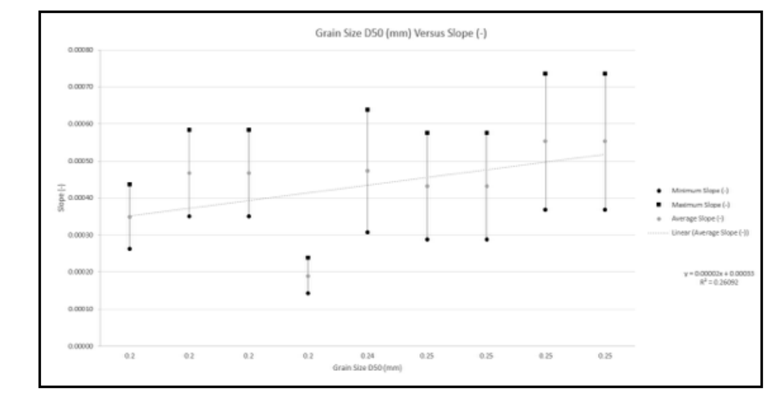

Figure 11, Variability in slope

Conclusions

1. Similar to typical, subcritical fluvial bodies, parameters exist on how supercritical fluvial bodies build and appear in stratigraphic architecture.
2. The presences of multivalley complexes containing more than two channel stories as well as supercritical flow deposits further supports a megamonsoonal climate as being the allocyclic driving force.
3. The supercritical fluvial systems identified in this study within the Tecovas Formation and Trujillo Sandstone are quantifiable and comparable to modern analogs.

Discussion

While this study provides frontier insights into describing and quantifying supercritical fluvial deposits in outcrops using flume tank derived equations there remains significant margins for error. Stratigraphic architecture of upper flow regime fluvial systems can vary widely because the Froude Number determines bedform type, which can be influenced by a combination of both flow depth and flow velocity. Changing either of these two variables can resulting in a different order of internal structures. When applying flume tank derived equations to outcrop there is a loss of lab-quality variable control providing an increased margin of error.

The modern analog presented on this study has a much greater discharge value than those observed within the Dockum Group. This can be explained by the massive size of the Burdekin river and that it is a single continent draining river. For the fluvial systems observed within the Tecovas Formation and Trujillo Sandstone the waning flow is measured. These channels are also much smaller in size and multiple channels can flow simultaneously. Given this scaling relationship the values for the Dockum Group are comparable to those of the Burdekin.

References

Alexander, Jan, Chris R. Fielding, and Geoff D. Pocock., 1999, Flood behavior of the Burdekin River, tropical north Queensland, Australia. Geological Society, London, Special Publications 163.1

Bridge, J. S., 2003, Alluvial Rivers and Floodplains. Blackwell

Cramer, S.L., 1973, Paleocurrent study of the Upper Triassic Sandstone, Texas High Plains: Unpubl. Masters thesis. West Texas State Univ., 31 p.

Dickinson, William R., et al. "Late Triassic Texas Uplift Preceding Jurassic Opening of the Gulf of Mexico: Evidence from U-Pb Ages of Detrital Zircons." Geosphere, vol. 6, no. 5, 2010, pp. 641–662., doi:10.1130/ges00532.1.

Fielding, Christopher R. "Upper Flow Regime Sheets, Lenses and Scour Fills: Extending the Range of Architectural Elements for Fluvial Sediment Bodies." Sedimentary Geology, vol. 190, no. 1-4, 2006, pp. 227–240., doi:10.1016/j.sedgeo.2006.05.009.

Froude, Melanie J., et al. "Interpreting Flash Flood Palaeoflow Parameters from Antidunes and Gravel Lenses: An Example from Montserrat, West Indies." Sedimentology, vol. 64, no. 7, 2017, pp. 1817–1845., doi:10.1111/sed.12375.

Holbrook, John. "Origin, Genetic Interrelationships, and Stratigraphy over the Continuum of Fluvial Channel-Form Bounding Surfaces: an Illustration from Middle Cretaceous Strata, Southeastern Colorado." Sedimentary Geology, vol. 144, no. 3-4, 2001, pp. 179–222., doi:10.1016/s0037-0738(01)00118-x.

Holbrook, John, and Hamdalla Wanas. "A Fulcrum Approach to Assessing Source-To-Sink Mass Balance Using Channel Paleohydrologic Parameters Derivable from Common Fluvial Data Sets with an Example from the Cretaceous of Egypt The Fulcrum Test of Mass Balance in Stratigraphic Successions." Journal of Sedimentary Research, GeoScienceWorld

Kennedy, J F. "The Formation of Sediment Ripples, Dunes, and Antidunes." Annual Review of Fluid Mechanics, vol. 1, no. 1, 1969, pp. 147–168., doi:10.1146/annurev.fl.01.010169.001051.

Lamb, G., 2019, An architectural analysis and depositional interpretation of the Dockum Group in the West Texas High Plains: Unpubl. Masters thesis. Texas Christian University., 94 p.

Lehman, Thomas, and Sankar Chatterjee. "Depositional Setting and Vertebrate Biostratigraphy of the Triassic Dockum Group of Texas." Journal of Earth System Science, vol. 114, no. 3, 2005, pp. 325–351., doi:10.1007/bf02702953

Parrish, Judith Totman. "Climate of the Supercontinent Pangea." The Journal of Geology 101.2 (1993): 215-33. Print.

Shields, A. 1936. Application of similarity principles and turbulence to bed load movement. Hydrodynamics Laboratory Publications No. 167

Van der Voo, R., F. J. Mauk, and R. B. French. 1976. Permian-Triassic continental configurations and the origin of the Gulf of Mexico. Geology 4:177-180

Winguth, Arne, and Cornelia Winguth. "Precession-Driven Monsoon Variability at the Permian–Triassic Boundary — Implications for Anoxia and the Mass Extinction." Global and Planetary Change, vol. 105, 2013, pp. 160–170., doi:10.1016/j.gloplacha.2012.06.006.