EVALUATING CYCLES IN DISTAL FLOODPLAIN DEPOSITION WITHIN THE EARLY PALEOGENE HANNA BASIN, WYOMING, U.S.A.

Christine Shonnard[1], James Chisholm[2], Ellen D. Currano[3], Regan Dunn[4], Brady Z. Foreman[5], Marieke Dechesne[6], and Jay Zambito[7]

[1]Beloit College, [2]California State University of San Bernardino, [3]Department of Botany, University of Wyoming, Laramie Wyoming, USA, [4] Integrative Research Center, Field Museum of Natural History, Chicago, Illinois USA, [5]Department of Geology, Western Washington University, Bellingham Washington, USA, [6]United States Geological Survey, Denver Colorado, USA, [7] Department of Geology, Beloit College, Beloit Wisconsin, USA

Beloit College Geology

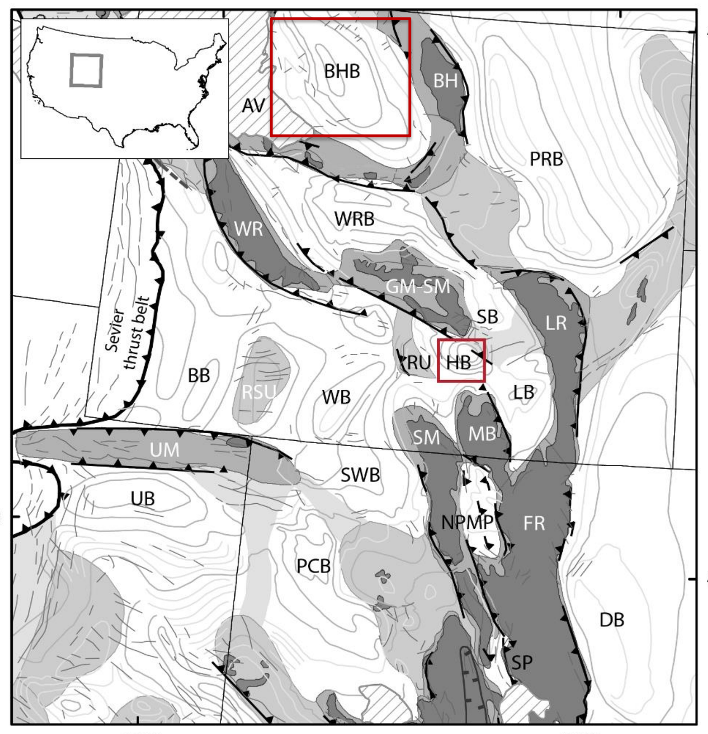

FIGURE 1. Locations of the Hanna Basin (HB) and the Bighorn Basin (BHB) in Wyoming. (Dechesne et al., in review).

BACKGROUND

- Both the Hanna and Bighorn Basins of Wyoming contain distinctive patterns of early Paleogene alluvial deposition (Aziz et al., 2008; and Abels et al., 2013, 2016; Kraus and Gwinn, 1997; Figure 1).
- The Hanna Formation of the Hanna Basin is notable for its repetitive pattern of sandy units interbedded with finer organic-rich shales, siltstones, and carbonaceous strata (Figure 2).
- The Willwood Formation of the Bighorn Basin contains weakly developed red-bed paleosols stacked between sandy fluvial avulsion deposits (Abels et al., 2013; Figure 2).

AIM

- Analyze depositional cycles in the Hanna Formation
- Compare these to those of the Bighorn Basin to reveal any common depositional patterns and hypothesize on their potential controls.
- Try to separate allogenic and autogenic controls of cyclical sedimentation patterns (Abels et al., 2013).
- Hypothesize whether there were local, regional, or even global climatic controls on basin deposition.

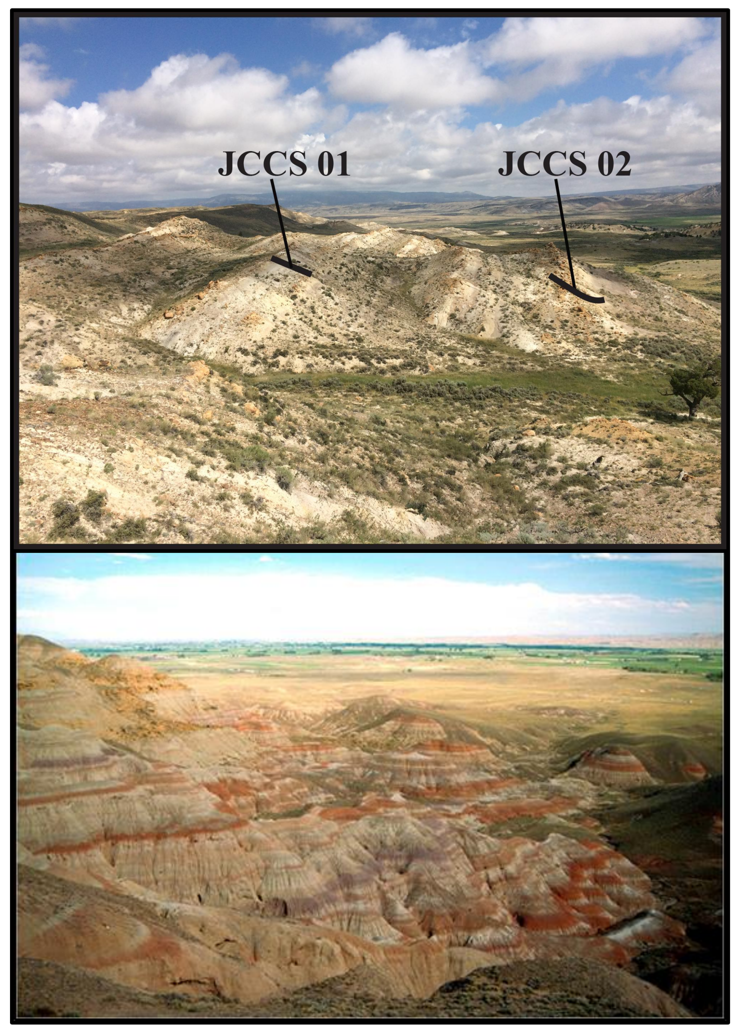

FIGURE 2. TOP: Section overview of the Leg 17 area, showing the locations of the two stratigraphic sections JCCS-01 and JCCS-02. Picture facing towards the south-east. Picture courtesy of Jay Zambito. BOTTOM: Overview of Polecat Bench, including the Willwood Formation, Bighorn Basin. Picture courtesy of W. Clyde.

METHODS

- Analyzed the stratigraphy, lithology, geochemistry (X-ray fluorescence; n=40), δ13C bulk organic carbon (n=30), and total organic carbon (TOC; n=30) of 2 cycles in the Upper Hanna Formation.
- Estimated paleovegetation cover using Leaf Area Analysis (5 locations).
- Reconstructed paleoclimate using CALMAG (Nordt and Driese, 2010) and $PPM_{1.0}$ (Stinchcomb et al., 2016) methods.

RESULTS

- JCCS-01 (13.68 m thick) and JCCS-02 (24.93 m thick)
- Concentrations of Al, Si, Ti, and Zr correlate with observed grain size (Figure 3).
- The $\delta^{13}C$ values range between -24‰ and -28‰ and show minor, structured fluctuations up-section (Figure 3).
- There are no strong relationships between TOC, $\delta^{13}C$, or paleoclimate reconstructions (Table 1).

TABLE 1. R^2 values for linear regressions between $\delta^{13}C$, % total organic carbon (TOC), mean annual temperature (MAT), and mean annual precipitation (MAP) reconstructions.

Section	r² value						
	$\delta^{13}C$				$PPM_{1.0}$ MAP		
	TOC (%)	CALMAG MAP	$PPM_{1.0}$ MAP	$PPM_{1.0}$ MAT	$PPM_{1.0}$ MAT	CALMAG MAP	CALMAG MAP vertisols only
JCCS-01	4×10^{-7}	0.1783	0.4099	2×10^{-5}	0.0293	0.0173	0.2186
JCCS-02	0.0004	0.0041	0.0949	0.1159	0.4041	0.0092	0.5361

TABLE 2. A comparison of mean annual precipitation (MAP) and mean annual temperature (MAT) values from the Hanna and Bighorn Basins collected through geochemical methods and paleobotanical methods (leaf area analysis = LAA, and leaf margin analysis = LMA).

Basin	Location	MAP (cm/yr)	Method	MAT (°C)	Method	Estimated m level in L17
Hanna Basin	Eocene D[a]	108+46.9, -32.7	LAA	21.9 ±3.8	LMA	180
	Eocene E[b]	132+56.9, -39.7	LAA	19.1 ±3.7	LMA	376
	JCCS-01	163.24 ±10.8	CALMAG	14.14 ± 3.4[c]	MAT $PPM_{1.0}$	270
		106.92 ± 41.6[c]	$PPM_{1.0}$			
	JCCS-02	170.49 ± 10.8	CALMAG	14.74 ± 3.3[c]	MAT $PPM_{1.0}$	220
		115.91 ± 40.5[c]	$PPM_{1.0}$			
Bighorn Basin	Elk Creek Section [i]	.		16.4 ± 2.7[d]	LMA	N/A
	400-ky after the PETM			18.2 ± 2.3 [h]	LMA	
	PETM	Lower flora: 80 +114, -56 and 41[h]	LAA	20.1 ± 2.8[e]	LMA	
		Upper flora: 144 +206, -100 and 132 [h]	LAA	26 [g]	Apatite oxygen isotope composition	
		123 +177, -86 [h]	LAA	19.8±3.1 [h]	LMA	
	Latest Paleocene	173 +75, -52 [f]	LAA	16.4±2.9[d]	LMA	

[a] Site D location is just after the PETM, 40 m below JCCS-02. (Azevedo Schmidt, 2018).
[b] Site E is about 100 m above JCCS-01. (Azevedo Schmidt, 2018).
[c] The upper and lower limit values for $PPM_{1.0}$ were calculating by taking the average of the differences between the high and low estimates and the best estimate.
[d] Wing et al., 2000
[e] Wing et al., 2006
[f] Diefendorfet al., 2015
[g] Fricke et al., 2004
[h] Wing et al., 2005
[i] 112 m above the base of the PETM.

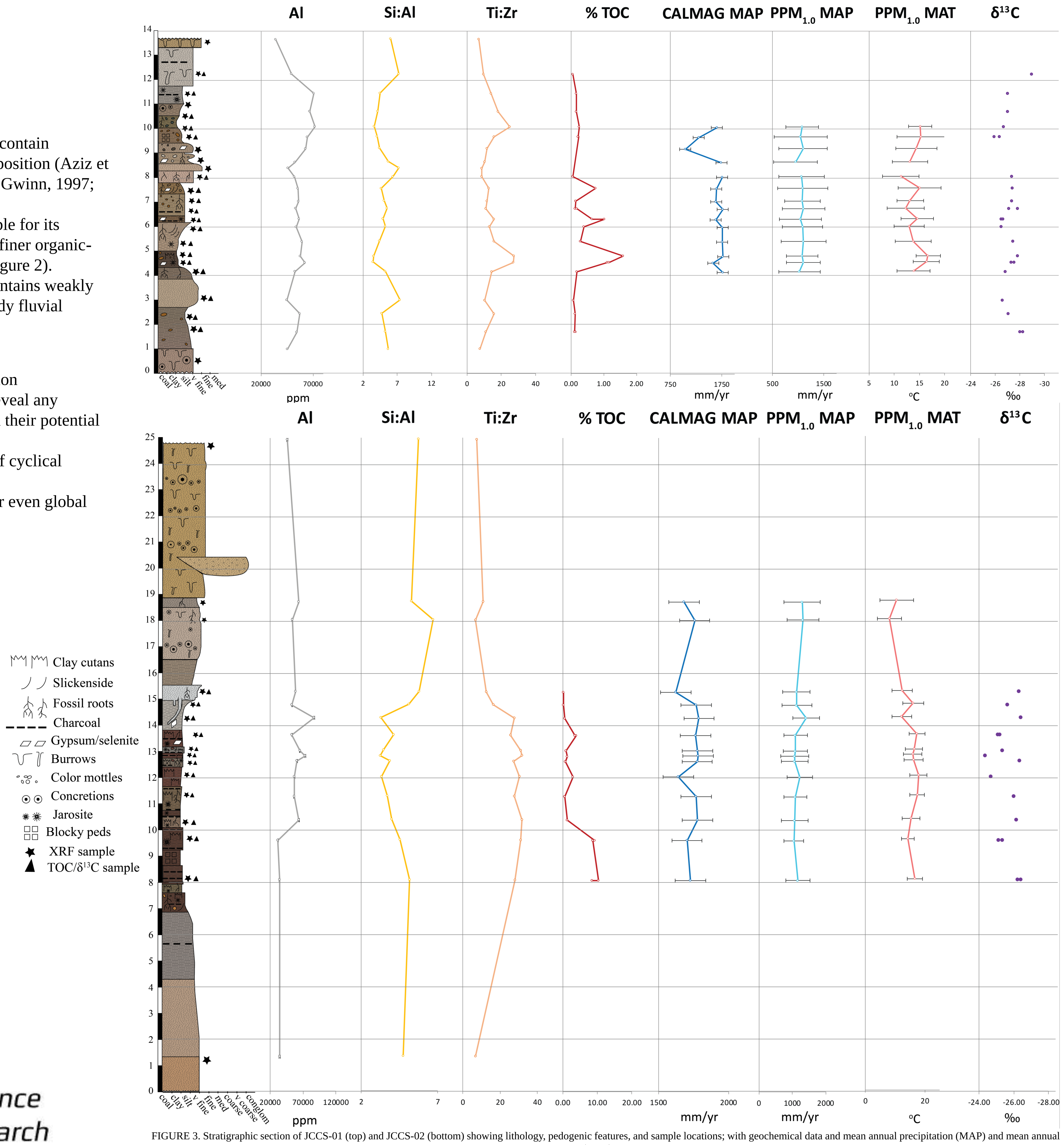

FIGURE 3. Stratigraphic section of JCCS-01 (top) and JCCS-02 (bottom) showing lithology, pedogenic features, and sample locations; with geochemical data and mean annual precipitation (MAP) and mean annual temperature (MAT) reconstructions.

IMPLICATIONS

- The sections each contain two overbank depositional "cycles": ~5 and ~4 m thick in JCCS-01; and ~15, and ~4 m thick in JCCS-02.
- Overall depositional environment: shrinking and expanding palustrine environment. Sandstones represent marginal lacustrine environments and crevasse splays and finer-grained lithofacies represent distal portions of the floodplain.
- Variability of depositional environments could be could be due to climate-induced changes in hydrology and/or autogenic-related changes in sediment supply.
- Cycles may mark periods of avulsion (sandstones) and relative stability of the main fluvial channels (coal-rich, fine-grained units).
- The cycles in the Willwood Formation (4.5 to ~10 m thick) are comparable to or slightly thinner than the Hanna cycles (~4 to ~15 m thick; Abels et al., 2013).
- The poorly vs. well-drained conditions (Hanna Formation and Willwood Formation, respectively) are due to differences in the rate of sediment supply, subsidence in each basin, or overall climate.
- Depositional cycles are likely unrelated to climatic changes or Milankovitch cycles.
- The $\delta^{13}C$ values show no variability up-section correlated with MAT or MAP
- Hanna Basin cycles represent a shorter duration due to rapid subsidence/sedimentation rates (Hajek et al., 2012).
- Overbank cycles in the Hanna Basin are largely driven by autogenic processes, which create cyclical stratigraphy in model systems (Jerolmack and Paola, 2007; Sheets et al., 2007; Hajek et al., 2010).

Acknowledgements:

This research was supported by the Keck Geology Consortium and the National Science Foundation under Grant No. 1659322 and NSF grant EAR 145031 to Ellen Currano. I would like to thank all of those involved in the Keck 2018-19 research project: incredible advisors and mentors Jay Zambito, Brady Foreman, and Ellen Currano, as well as student colleagues James Chisholm, Jake Polsak, Xavier Nogueira, Keifer Nace, and Anthony Semeraro.

References:

Abels, H. A., Kraus, M. J., and Gingerich, P. D., 2013, Precession-scale cyclicity in the fluvial lower Eocene Willwood Formation of the Bighorn Basin, Wyoming (USA): Sedimentology, v. 60, p. 1467-1483, doi: 10.1111/sed.12039.
Abels. H. A., Lauretano, van Yperen, A. E., Hopman, T., Zachos, J. C., Lourens, L. J., Gingerich, P. D., and Bowen, G. J., 2016, Environmental impact and magnitude of paleosol carbonate carbon isotope excursions marking five early Eocene hyperthermals in the Bighorn Basin, Wyoming: Climate of the Past, v. 12, p. 1151-1163, doi: 10.5194/cp-12-1151-2016.
Azevedo Schmidt, L. E., 2018. The effects of depositional environment on plant and insect herbivore communities across the Paleocene-Eocene Boundary, Hanna Basin WY. MS Thesis. University of Wyoming, Laramie, WY.
Aziz, H. A., Hilgen, F. J., van Lujik, G., M., Sluijs, A., Kraus, M. J., Pares, J. M., and Gingerich, P. D., 2008, Astronomical climate control on paleosol stacking patterns in the upper Paleocene–lower Eocene Willwood Formation, Bighorn Basin, Wyoming: Geology, v. 36, no. 7, p. 531–534; doi: 10.1130/G24734A.1.
Dechesne, M., Currano, E.D., Dunn, R.E., Higgins, P., Hartman, J.H., Chamberlain, K.R., and Holm-Denoma, C.S. In review. Depositional patterns of the fluvial to paludal strata of the Hanna Formation across the Paleocene – Eocene boundary, Hanna Basin, Wyoming.
Diefendorf, A. F., Freeman, K. H., Wing, S. W., Currano, E. D., Mueller, K. E., 2015, Paleogene plants fractionated carbon isotopes similar to modern plants: Earth and Planetary Science Letters, v. 429, p. 33-44.
Fricke, H. C., and Wing, S. L., 2004, Oxygen isotope and paleobotanical estimates of temperature and δ18O–latitude gradients over North America during the early Eocene: American Journal of Science, v. 304, p. 612-635, doi: 10.2475/ajs.304.7.612.
Hajek, E. A., Heller, P. L., and Schur, E. L., 2012, Field test of autogenic control on alluvial stratigraphy (Ferris Formation, Upper Cretaceous-Paleogene, Wyoming): GSA Bulletin, v. 124, no. 11/12, p. 1898-1912, doi: 10.1130/B30526.1.
Hajek, E.A., Heller, P.L., and Sheets, B.A., 2010, Significance of channel-belt clustering in alluvial basins: Geolo gy, v. 38, no. 6, p. 535–538, doi:10.1130/G30783.1.
Jerolmack, D.J., and Paola, C., 2007, Complexity in a cellular model of river avulsion: Geomorphology, v. 91, no. 3–4, p. 259–270, doi:10.1016/j.geomorph.2007 .04.022.
Krauss, M. J., and Gwinn, B. M., 1997, Facies and facies architecture of Paleogene floodplain deposits, Willwood Formation, Bighorn Basin, Wyoming, USA: Sedimentary Geology, v. 114, p. 33-54.
Nordt, L. C., and Driese, S. D., 2010, New weathering index improves paleorainfall estimates from Vertisols: Geology, v. 38:5, p. 407-10, doi: 10.1130/G30689.1.
Sheets, B.A., Paola, C., and Kelberer, J.M., 2007, Creation and preservation of channel-form sand bodies in an experimental alluvial system, in Nichols, G.J., Williams, E., and Paola, C., eds., Sedimentary Processes, Environments and Basins: International Association of Sedimentologists Special Publication 38, p. 555–567.
Stinchcomb, G.E., Nordt., L. C., Driese, S. G., Lukens, W. E., Williamson, F. C., and Tubbs, J. E., 2016, A data-driven spline model designed to predict paleoclimate using paleosol geochemistry American Journal of Science, v. 316, p. 746-777, doi: 10.2475/08.2016.02.
Wing, S. L., Bao, H., and Koch, P. L., 2000, An early Eocene cool period? Evidence for continental cooling during the warmest part of the Cenozoic. Pp. 197-237. *In* B. T. Huber, K. G. MacLeod, and S. L. Wing, eds. Warm climates in earth history. Oxford U P, Cambridge).
Wing, S. L., Harrington, G. J., Smith, F. A., Bloch, J. I., Boyer, D. M., and Freeman, K. H., 2005, Transient Floral Change and Rapid Global Warming at the Paleocene-Eocene Boundary: Science v. 320, p. 993-996, doi: 10.1126/science.1116913.
Wing, S. L., Lovelock, E. C., and Currano, E. D., 2006, Climatic and floral change during the PETM in the Bighorn Basin, Wyoming, USA: Climate & Biota of the Early Paleogene. Bilbao, Spain.

KECK Geology Consortium — Learning Science Through Research

KECK Geology Consortium — Learning Science Through Research