Patterns in early Eocene paleosol morphology in the southern Bighorn Basin, (Wyoming, U.S.A.)

Eve Lalor[1], Brady Foreman, Western Washington University, Geology Department, 516 High St, Bellingham, Washington, 98225. [1]lalore@wwu.edu

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Introduction

-The Eocene Willwood Formation in the Bighorn Basin, Wyoming contains paleosols that span rapid, global warming events and contain numerous paleoclimatic proxies that record hydrologic responses to climate perturbations.
-Studies of PETM paleosols in the basin indicate an overall drying and decrease in soil moisture of about 40% (Kraus and Riggins, 2007), but the soil response to subsequent Eocene hyperthermals such as the ETM2 remains unconstrained.
-This study measures a 60 m of vertically-stacked floodplain paleosols spanning the ETM2 hyperthermal event.
-Qualitative indications of soil moisture are discussed on this poster, while quantitative geochemical proxies to gain paleo-rainfall estimates comprise the next phase of research.
-This study will test whether the post-PETM hyperthermals caused climatic drying in proportion to their smaller size, which would imply a scaling relationship between carbon-related warming and hydrologic response.

Geologic Setting: Bighorn Basin

-Structural basin surrounded by Laramide uplifts (Fig. 1) formed during Laramide Orogeny, Late Cretaceous to Early Eocene
-During the early Paleogene, meandering rivers deposited the Paleocene Fort Union Formation and the Eocene Willwood Formation
-These formations contain three distinct facies: sandy channel deposits, heterolithic crevasse splay deposits with weak soil development, and fine-grained floodplain material with moderate to strong soil development
-The strata are well exposed in badlands in the basin (Fig. 2)
-This study focuses on the paleosols within the Willdwood Formation exposed in the Fifteenmile Creek field area northwest of Worland, WY in the southern portion of the basin. (Fig. 1)

Figure 2: Typical topography and exposure of paleosols in the field area. The two distinct red paleols in the photo are the two thick red soils at ~47 and ~50 m on the strat column. Field assistants for scale.

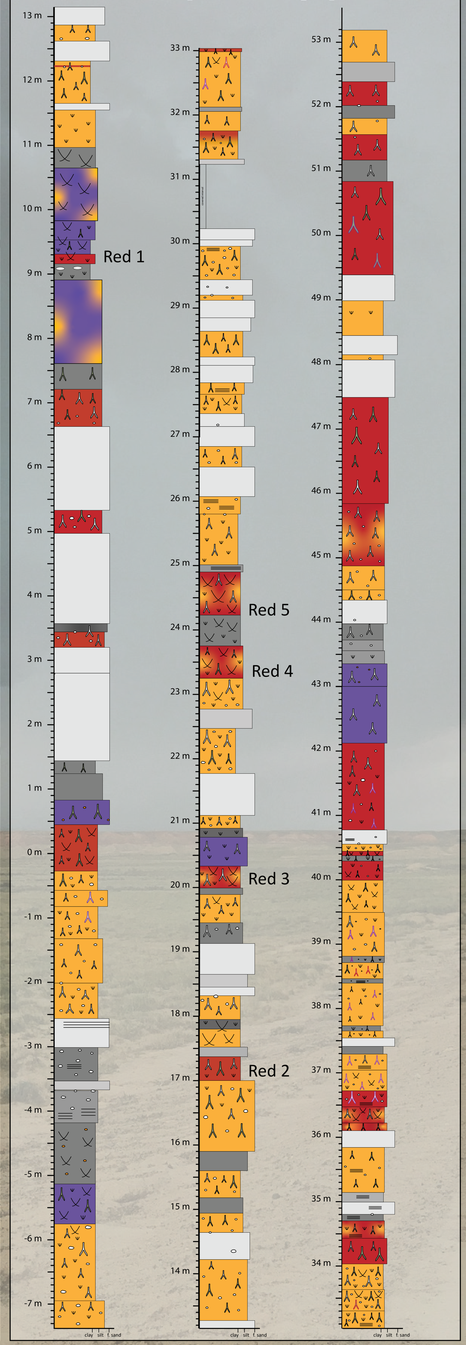
Figure 1: Above, the Bighorn Basin's location in Wyoming and the surrounding states. Left, the field area's location within the Basin.

Column Key

Unit Colors
- yellow-brown paleosols
- red paleosols
- purple paleosols
- grey paleosols
- yellow-purple mottling (Fig. 6)
- red-yellow mottled paleosols
- splay deposits

Symbols
- slickensides (Fig. 7)
- laminations
- clay cutans
- carbonate nodules
- iron nodules
- carbonate root traces (Fig. 8)
- drab halo root traces
- root traces with red/purple halo (Fig. 9)

Shuster Flats Composite Stratigraphic Column



Discussion

This interpretation of the timing of ETM2 is based on unpublished ETM2 isotope data from collaborators (Will Clyde). Our own isotope curve from this study is pending.
Pre-ETM2: Up to ~10 m and Red 1.
-variation of wet and dry soil types, distinct red soils and red/purple vertisols, Red 1 extensively laterally continuous (Fig. 10)
Interpretation: variable drainage, long periods of soil development
During ETM2: Peak is ~23.5 m at Red 4.
-sequence of yellow-brown paleosols and grey splay deposits with weak pedogenic development (Fig. 10), "red" layers usually weather red in outcrop but are <50% red in fresh rock, pedogenic carbonate nodules common in this interval
Interpretation: well-drained, but shorter-lived soil profiles
Post-ETM2/H2: above ~50 m.
-return of distinct red beds, shift to sandier soils, abundant, thick red beds that continue above measured section (Fig. 11)
Interpretation: longer periods of soil profile development, change in deposition to sandy soils may improve drainage, but carbonate is less common.

Figure 10: The laterally-extensive red/purple layer of Red 1 is seen in the foreground and background, overlain by the yellow-grey interval. Figure 6: The interval of thick, red paleosols at the top of the section and above.

Comparison to PETM Paleosol Response

-Kraus et al, 2013 measured a 70 m PETM section in the southern Basin at the HWY 16 field site, east of Worland, Wyoming
-a yellow/grey stratigraphic interval was identified during the body of the PETM isotope excursion, with a lower red interval before the PETM and an interval of distinct, continuous red beds during and post-recovery
-qualitatively, this same pattern is seen in the Fifteenmile Creek ETM2 section, which may imply a similar soil moisture response during both hyperthermals
-same study found a decrease in paleoprecipitation during PETM using geochemical rainfall estimates

Figure 11: Stratigraphic column through the PETM section by Kraus et al, 2013.

Climatic History: Early Paleogene Hyperthermals

-Hyperthermals are rapid global warming episodes recognized in the rock record by negative carbon isotope excursions (CIEs) that imply large-scale carbon release (Fig. 3)
-The Paleocene-Eocene Thermal Maximum (PETM) at 56 Ma lasted ~200kyrs and saw 5-8°C warming worldwide (McInerney & Wing, 2011, and references therein)
-Many have studied the PETM section in the Bighorn Basin including the changes to floodplain paleosols (e.g. Kraus et al, 2013, see PETM section)
-The Eocene Thermal Maximum 2 (ETM2) at 53.5 Ma was half to one-third the magnitude of the PETM
-Other researchers (Will Clyde) have identified the ETM2 and H2 CIEs in the Fifteenmile Creek field area
-The goal of this study is to capture the change in soil moisture in floodplain paleosol in response to the ETM2/H2 hyperthermals.

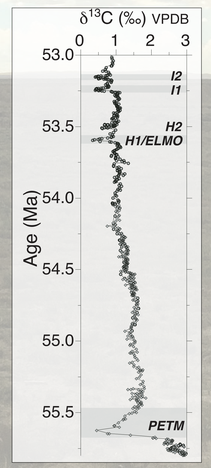


Figure 3: Carbon isotope curve from ODP 1051 showing the PETM, ETM2, and later hyperthermal CIEs. From Nicolo et al, 2007.

Field Methods

Correlation
The strata are exposed along a North-South erosional face along the north fork of Fifteenmile Creek. Multiple sites were selected to build a composite stratigraphic section, with the oldest layers in the south and the younger layers to the north.

Digging
Trenches were dug down to fresh rock using a pick and shovel (Fig. 4) and then brushed clean of debris.

Measuring and Describing
Paleosol horizons were distinguished by color or grain size and measured with a Jacobs staff.
Features noted:
Munsell Color: Bright colors represent drier conditions, while drab colors indicate waterlogging
Carbonate: nodules or carbonate root traces indicate drier conditions
Clay cutans: indicate enough moisture to translocate clay particles
Slickensides: indicate seasonal wetting and drying

Sampling
We collected bulk soil samples from each horizon, as well as carbonate nodules where found (see ongoing research section)

Figure 4: The author digging one of her trenches. Figure 5: Field assistants Bo Ward and Anna Schlueger posing with a trench and a trail of sample bags.

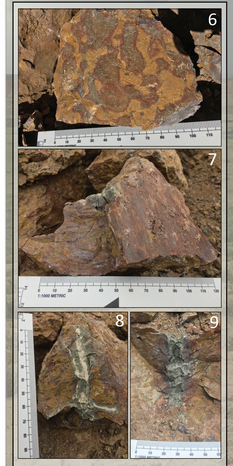


Figure 6: Distinct yellow-brown mottling in a purple-grey paleosol.- Figure 7: A wedge- shaped ped showing slickensides all around. Figure 8: A carbonate rhizolith. Figure 9: Root trace with a purple and red halo.

Ongoing Research

-The bulk soil samples will be sent for XRF analysis to gain major element abundances for molecular weathering ratios to be entered into proxies for Mean Annual Precipitation (MAP) and Temperature (MAT), including: CIA-K (Sheldon et al, 2002), CALMAG (Nordt and Driese, 2010), and $PPM_{1.0}$ (Stinchcomb et al, 2016)
-pedogenic carbonate isotope analysis to capture ETM2 CIE
-We hypothesize that the paleo-precipitation results will reflect a climatic drying of proportional magnitude to smaller size of the ETM2 hyperthermal as compared to the PETM.

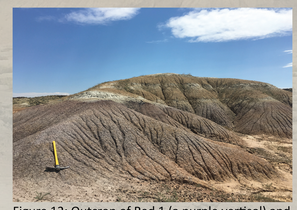


Figure 12: Outcrop of Red 1 (a purple vertisol) and the base of the yellow-grey interval.

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