SUPPLEMENTAL FIGURE CAPTIONS

Supplemental Figure 1. Modern meteorological data for Meade, KS (A, C) and Scott City, KS (B, D) and measured meteoric water δ¹⁸O values (E) and estimated carbonate δ¹⁸O values (F) for Scott City, KS. (A) Mean monthly temperature for Meade, KS for 1949-2008 with 94.7% coverage of days. Bars are ± 1 standard deviation around each mean. (B) Monthly temperature data for Scott City, KS. Filled diamonds are long-term mean monthly temperature for 1895-2009 with 98.3% coverage of days. Bars are ± 1 standard deviation around each mean. Open diamonds are mean monthly temperatures at Lake Scott State Park from 1990-1992 from Vachon (2006) for months in which the δ¹⁸O value of meteoric water was measured. Temperature was not measured in every month continuously through the interval and was measured for some months in more than one year. (C) Long-term mean monthly precipitation for Meade, KS for 1949-2006, excluding 1973, which has incomplete precipitation data. Bars are ± 1 standard deviation around each mean. (D) Monthly precipitation data for Scott City, KS. Filled diamonds are long-term mean monthly precipitation for 1895-2009 and bars are ± 1 standard deviation around each mean. Open diamonds are measured monthly precipitation amounts at Lake Scott State Park from 1990-1992 from Vachon (2006). Precipitation was not measured in every month continuously through the interval and some months in the interval were sampled in more than one year. (E) Measured δ¹⁸O values of meteoric water at Lake Scott State Park from Vachon (2006). Open diamonds are values for the same month in different years and filled diamonds are values for months sampled only once in the interval or the mean for months sampled in more than one year. (F) Estimated carbonate δ¹⁸O values for each month based on monthly temperatures for Scott City in (B), the monthly or mean monthly meteoric water δ¹⁸O values for Lake Scott State Park in (E), and the calcite-water fractionation factor of Kim and O’Neil (1997). Estimated carbonate δ¹⁸O values for models 4 and 6 are described in the text. Abbreviations: MAT, mean annual temperature; WST, warm season temperature (May-October). Long-term meteorological data for Meade and Scott City, KS are from the Summary of the Day for each weather station (www.ncdc.noaa.gov/oa/ncdc.html).

Supplemental Figure 2. Carbonate δ¹³C and δ¹⁸O values from the Clarendonian section (Ogallala Formation). Thick black lines are reduced major axis regressions for δ¹³C and δ¹⁸O values on meter level (dependent variable). Thin black line and dark grey box indicates mean δ¹³C value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C₃ ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C₃ end-member based on enrichment of Passey et al. (2002) and δ¹³C of C₃ biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C₄ biomass in the region ± 1 standard deviation (Supplemental Table 1). Arrows indicate positions of samples.

Supplemental Figure 3. Carbonate δ¹³C and δ¹⁸O values from the Hemophilian section (High Banks). Thick black lines are reduced major axis regressions for δ¹³C and δ¹⁸O values on meter level (dependent variable). Thin black line and dark grey box indicates mean δ¹³C value ±1
standard deviation for 20 Holocene paleosol carbonates from arid climate C3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C3 end-member based on enrichment of Passey et al. (2002) and δ13C of C3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C4 biomass in the region ± 1 standard deviation (Supplemental Table 1). Arrows indicate positions of samples. HB1, HB2: positions of the High Banks faunas. Lithologic symbols as in Suppl. Fig. 2.

Supplemental Figure 4. Carbonate δ13C and δ18O values from the early Blancan sections (measured sections for Saw Rock, Keefe, and Fox Canyons not shown). Thick black lines are reduced major axis regressions for δ13C and δ18O values on meter level (dependent variable). Thin black line and dark grey box indicates mean δ13C value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C3 end-member based on enrichment of Passey et al. (2002) and δ13C of C3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C4 biomass in the region ± 1 standard deviation (Supplemental Table 1). Arrows indicate positions of samples. Bish Gr, BG: Bishop gravel. CC1 and CC2: prominent caliches traceable between outcrops along Cimarron River. XIT 1a, XIT A-E, B, R: positions of XIT, Bishop, and Ripley faunas, respectively. Two unlabeled fauna symbols between CC1 and CC2 levels in Alien Canyon section indicate positions of Wiens (lower symbol) and Vasquez and Newt faunas. Lithologic symbols as in Suppl. Fig. 2.

Supplemental Figure 5. Carbonate δ13C and δ18O values from the middle Blancan sections. Thick black lines are reduced major axis regressions for δ13C and δ18O values on meter level (dependent variable). Thin black line and dark grey box indicates mean δ13C value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C3 end-member based on enrichment of Passey et al. (2002) and δ13C of C3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C4 biomass in the region ± 1 standard deviation (Supplemental Table 1). Arrows indicate positions of samples. WB, M: positions of the Wheelbarrow and Mustang faunas, respectively. Lithologic symbols as in Suppl. Fig. 2.

Supplemental Figure 6. Carbonate δ13C and δ18O values from the late Blancan-Irvingtonian sections. Lower percent C4 tick marks are for late Blancan and upper tick marks are for early Irvingtonian. Thick black lines are reduced major axis regressions for δ13C and δ18O values on meter level (dependent variable). Thin black line and dark grey box indicates mean δ13C value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C3 end-member based on enrichment of Passey et al. (2002) and δ13C of C3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C4 biomass in the region ± 1 standard deviation (Supplemental Table 2) and is positioned relative to the early Irvingtonian (upper) percent C4 tick marks. Arrows indicate positions of samples. HRA: Huckleberry Ridge Ash (2.10 Ma);
CTB, Cerro Toledo B ash (1.47-1.23 Ma). N72, Bor, AA, NE: positions of Nash 72, Borchers, Aries A, and Aries NE faunas, respectively. Lithologic symbols as in Suppl. Fig. 2.
Supplemental Table 1. Stable isotope data from paleosol carbonates from the Meade Basin. Some sections do not have continuous sample numbers because not all field samples were analyzed. Statistical summaries are presented for NALMAs in text Table 1.

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Supplemental Table 2. Regression statistics for ordinary least squares linear regressions with meter level of samples in composite sections for each biostratigraphic interval as independent variables and $\delta^{18}$O values of paleosol carbonates as dependent variables. Bold indicates statistically significant regressions with slopes significantly different from 0.0 at $\alpha=0.05$.

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Supplemental Table 3. Results of one-way ANOVAs with post hoc Scheffé test for multiple comparisons for $\delta^{18}O$ values in biostratigraphic intervals. Three separate ANOVAs were run, one with all data in each interval ($F=33.2, p<0.001$, upper entries in each row in the top of the table), one with the outliers in the Late Blancan-Early Irvingtonian interval ($\delta^{18}O>-29‰$) excluded ($F=58.5, p<0.001$; lower entries in each row in the top of the table), and one with the outliers excluded and the Hemphillian and Clarendonian data combined ($F=77.1, p<0.001$; bottom of the table, results for other intervals not included in this table).

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<th>sd</th>
<th>n</th>
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<th>Middle Blancan</th>
<th>Early Blancan</th>
<th>Hemphillian</th>
<th>Clarendonian</th>
<th>L Blancan-E Irvingtonian</th>
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Middle Blancan          | 22.1  | 0.69  | 27   | 0.74           |               |               |             |              |                           |                |               |             |              |
| Early Blancan           | 21.8  | 0.87  | 106  | <0.001         | 0.585          |               |             |              |                           |                |               |             |              |
| Miocene (Meade)         | 25.1  | 0.59  | 22   | <0.001         | <0.001        | <0.001        | N/A         |              |                           |                |               |             |              |

N/A indicates no data available for that interval.
Supplemental Table 4. Results of Mann-Whitney U tests for differences in mean $\delta^{18}$O values of paleosol carbonates in each biostratigraphic interval. For each interval, the upper numbers are the Mann-Whitney U statistic (left) and the Z statistic (right; used for calculating p-value if n<20) and the lower number is the p-value. Entries in bold indicate statistically significant differences at $\alpha=0.05$.

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### Supplemental Table 5. Regression statistics for least squares linear regressions with δ¹⁸O values of paleosol carbonates as independent variables and δ¹³C values of paleosol carbonates as dependent variables. For the Late Blancan-Early Irvingtonian data, the first row is the regression for all data and the second row is the regression without the three outlier δ¹⁸O values >29‰, which corresponds to the line in Fig. 10. Bold indicates statistically significant regressions with slopes significantly different from 0.0 at \( \alpha=0.05 \).

<table>
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<th>δ¹³C values</th>
<th>slope</th>
<th>intercept</th>
<th>R²</th>
<th>s.e.</th>
<th>F</th>
<th>p-value</th>
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<td>0.99</td>
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<th>s.e.</th>
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