GSA DATA REPOSITORY ITEM DR2011261 D. Fox et al.

SUPPLEMENTAL FIGURE CAPTIONS

Supplemental Figure 1. Modern meteorological data for Meade, KS (A, C) and Scott City, KS (B, D) and measured meteoric water $\delta^{18}O$ values (E) and estimated carbonate $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ 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 $\delta^{18}O$ values for each month based on monthly temperatures for Scott City in (B), the monthly or mean monthly meteoric water $\delta^{18}O$ values for Lake Scott State Park in (E), and the calcite-water fractionation factor of Kim and O'Neil (1997). Estimated carbonate $\delta^{18}O$ 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 $\delta^{13}C$ and $\delta^{18}O$ values from the Clarendonian section (Ogallala Formation). Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). Thin black line and dark grey box indicates mean $\delta^{13}C$ value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C_3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C_3 end-member based on enrichment of Passey et al. (2002) and $\delta^{13}C$ of C_3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C_4 biomass in the region ± 1 standard deviation (Supplemental Table 1). Arrows indicate positions of samples.

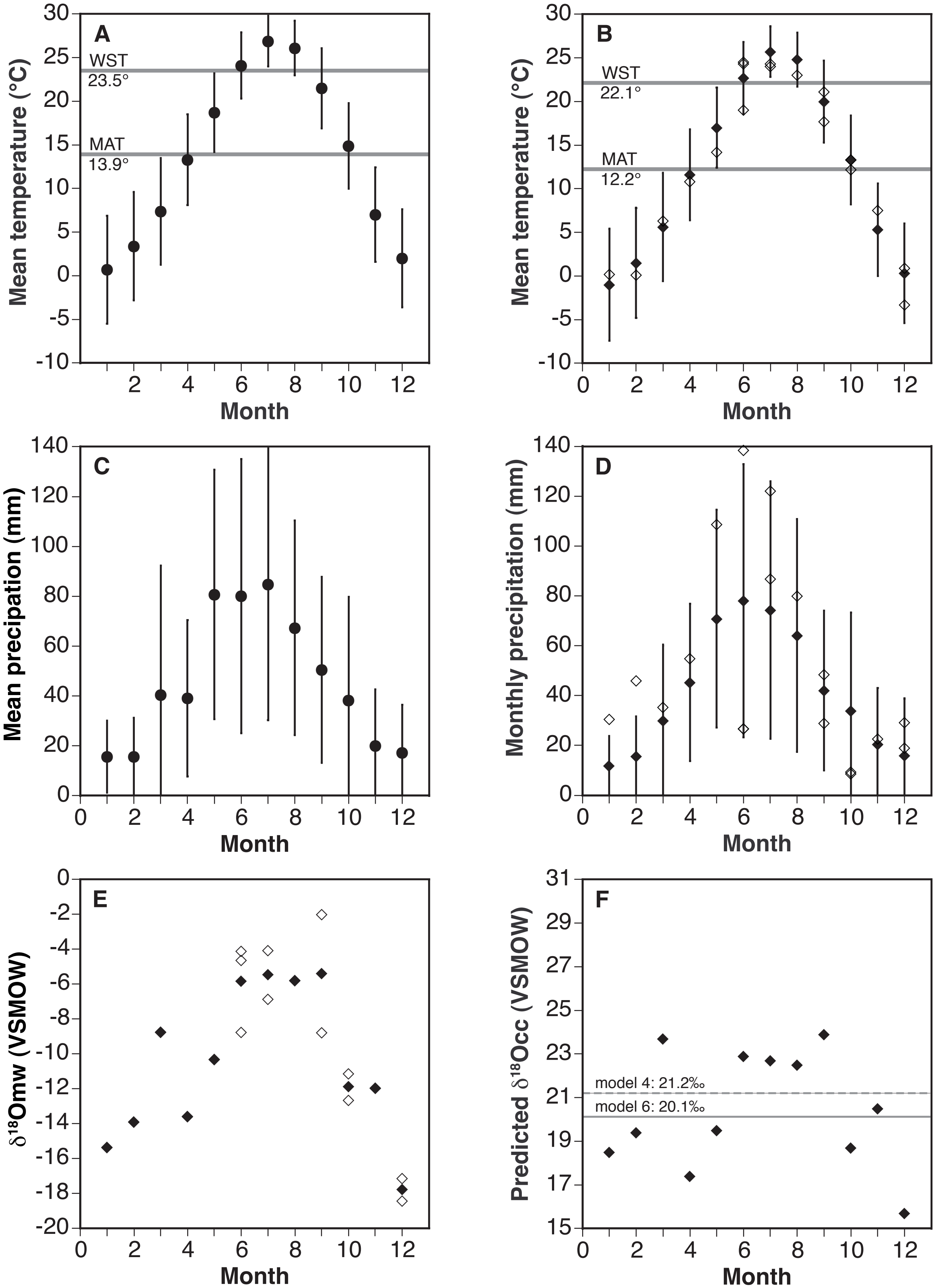
Supplemental Figure 3. Carbonate $\delta^{13}C$ and $\delta^{18}O$ values from the Hemphilian section (High Banks). Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). Thin black line and dark grey box indicates mean $\delta^{13}C$ value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C_3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C_3 end-member based on enrichment of Passey et al. (2002) and $\delta^{13}C$ of C_3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C_4 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 $\delta^{13}C$ and $\delta^{18}O$ 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 $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). Thin black line and dark grey box indicates mean $\delta^{13}C$ value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C_3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C_3 end-member based on enrichment of Passey et al. (2002) and $\delta^{13}C$ of C_3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C_4 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.

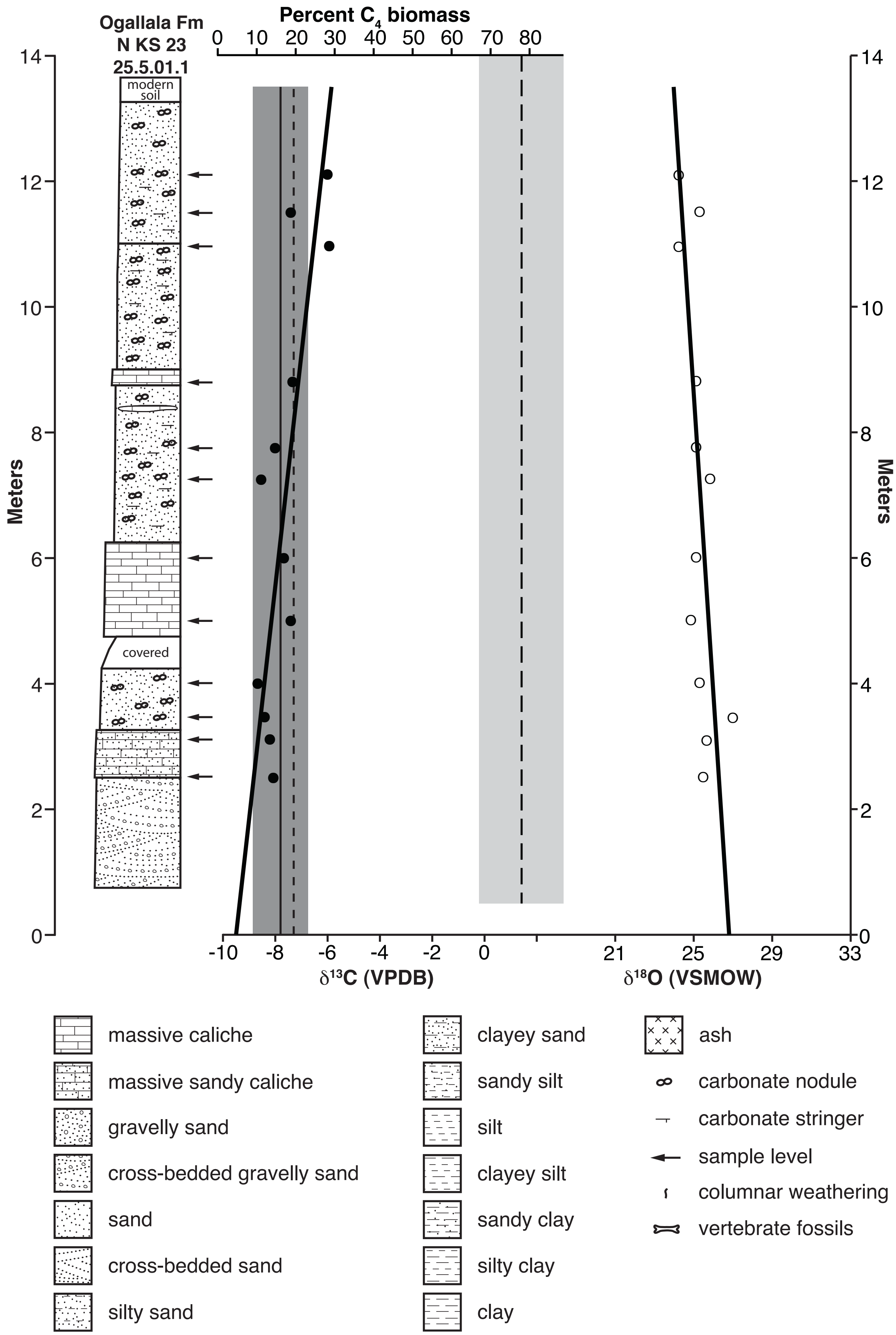
Supplemental Figure 5. Carbonate $\delta^{13}C$ and $\delta^{18}O$ values from the middle Blancan sections. Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). Thin black line and dark grey box indicates mean $\delta^{13}C$ value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C_3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C_3 end-member based on enrichment of Passey et al. (2002) and $\delta^{13}C$ of C_3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C_4 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.

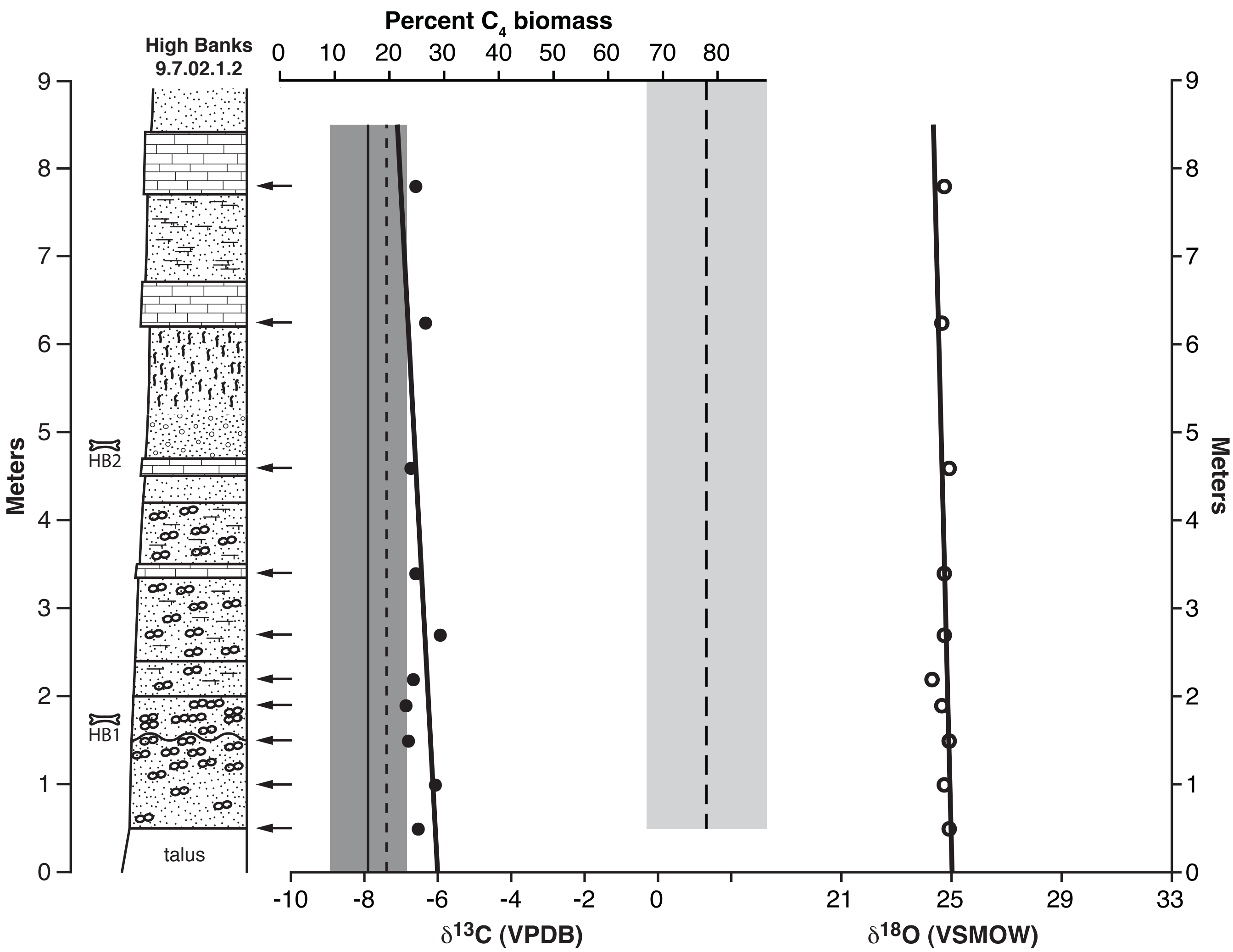
Supplemental Figure 6. Carbonate $\delta^{13}C$ and $\delta^{18}O$ values from the late Blancan-Irvingtonian sections. Lower percent C_4 tick marks are for late Blancan and upper tick marks are for early Irvingtonian. Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). Thin black line and dark grey box indicates mean $\delta^{13}C$ value ±1 standard deviation for 20 Holocene paleosol carbonates from arid climate C_3 ecosystems in North America, Russia, and the eastern Mediterranean (sources in Fox et al., 2010). Short dashed line indicates arid C_3 end-member based on enrichment of Passey et al. (2002) and $\delta^{13}C$ of C_3 biomass for the Clarendonian in Fig. 3C of Fox et al. (2010). Long dashed line and light gray box indicates mean modern abundance of C_4 biomass in the region ± 1 standard deviation (Supplemental Table 2) and is positioned relative to the early Irvingtonian (upper) percent C_4 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.

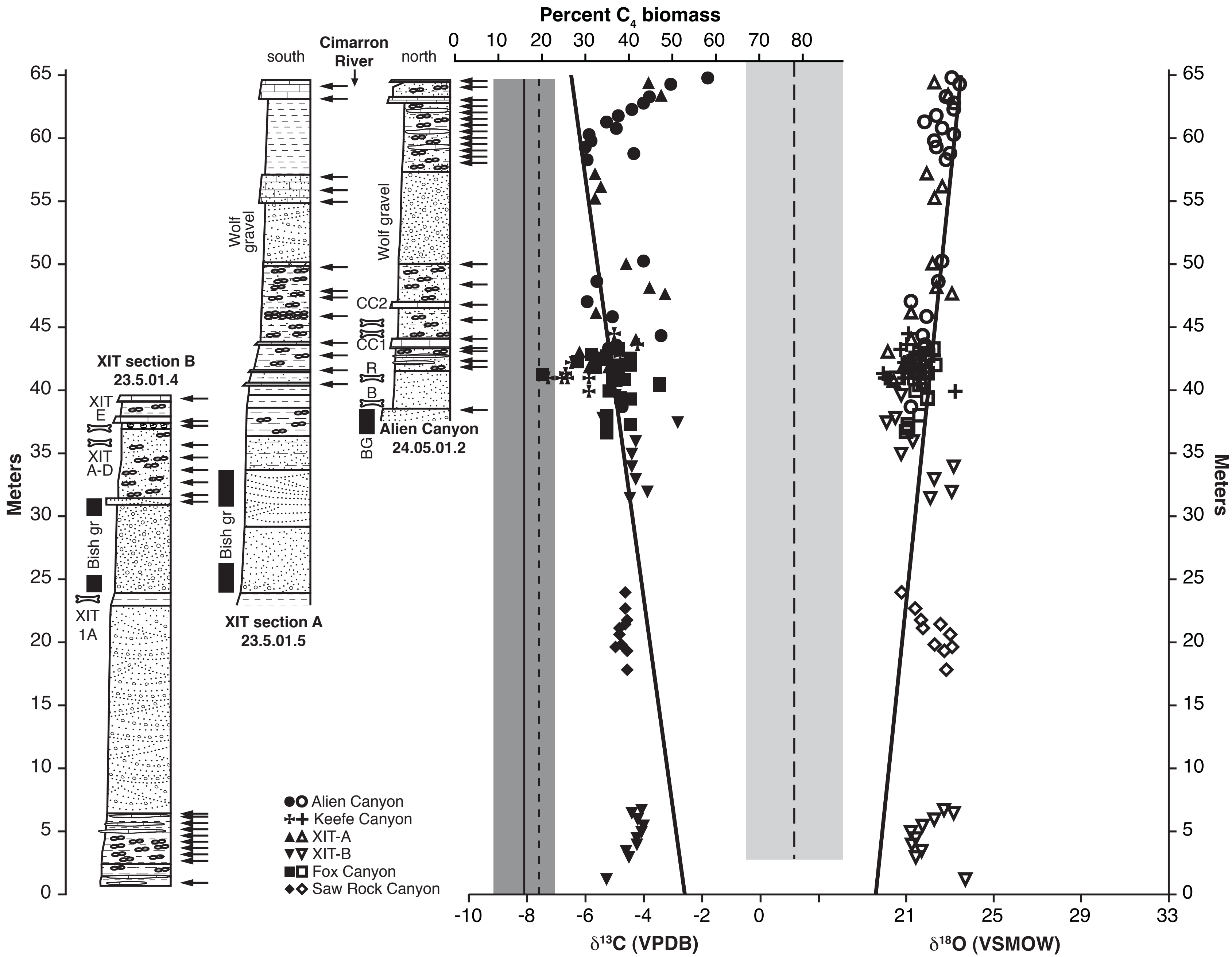


A
WST
23.5°
MAT
13.9°
Mean temperature (°C)
Month
B
WST
22.1°
MAT
12.2°
Mean temperature (°C)
Month
C
Mean precipation (mm)
Month
D
Monthly precipitation (mm)
Month
E
δ18Omw (VSMOW)
Month
F
model 4: 21.2‰
model 6: 20.1‰
Predicted δ18Occ (VSMOW)
Month

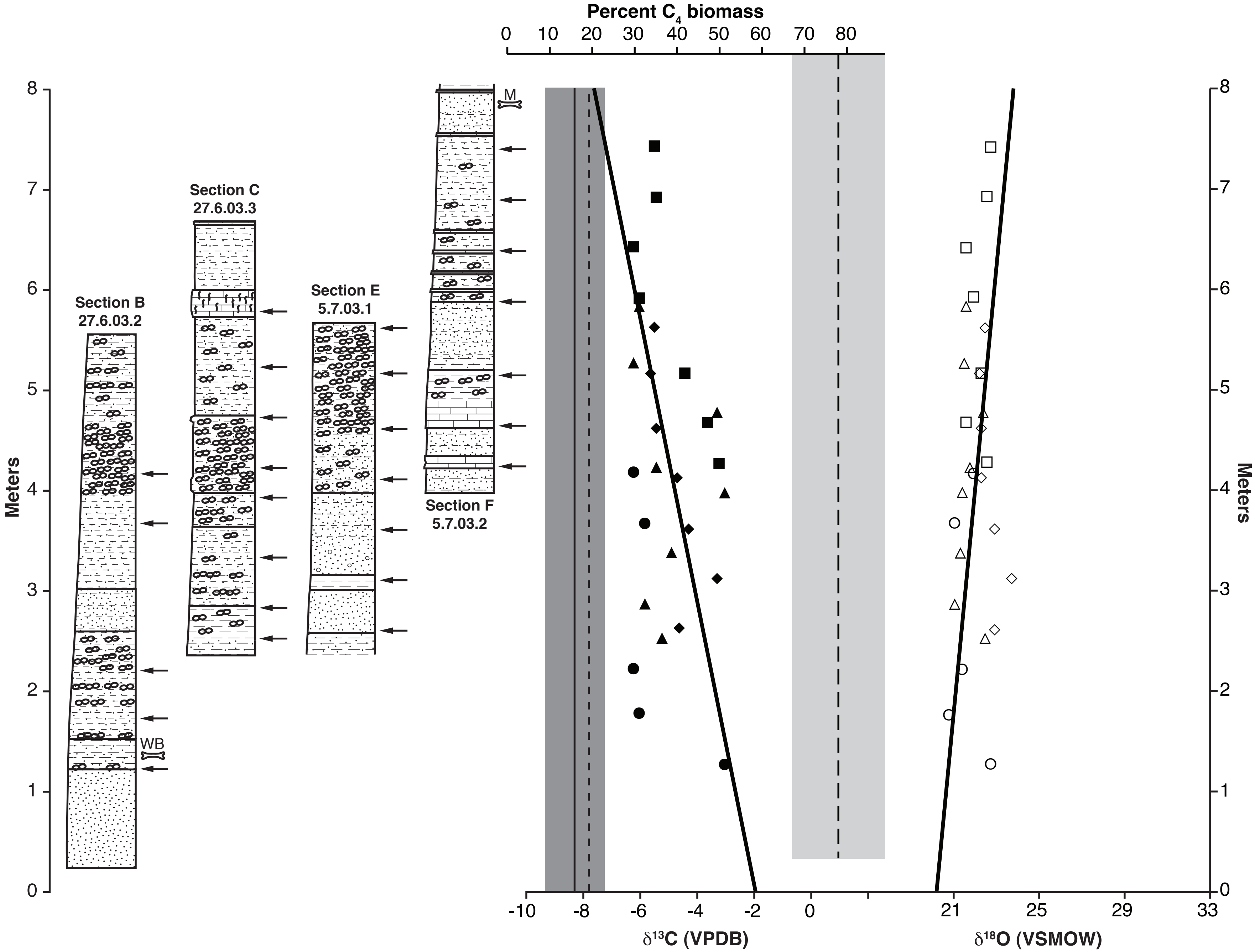

Ogallala Fm
N KS 23
25.5.01.1
Percent C4 biomass
0 10 20 30 40 50 60 70 80
14 12 10 8 6 4 2 0
Meters
modern soil
covered
-10 -8 -6 -4 -2 0
21 25 29 33
δ13C (VPDB)
δ18O (VSMOW)
massive caliche
massive sandy caliche
gravelly sand
cross-bedded gravelly sand
sand
cross-bedded sand
silty sand
clayey sand
sandy silt
silt
clayey silt
sandy clay
silty clay
clay
ash
carbonate nodule
carbonate stringer
sample level
columnar weathering
vertebrate fossils

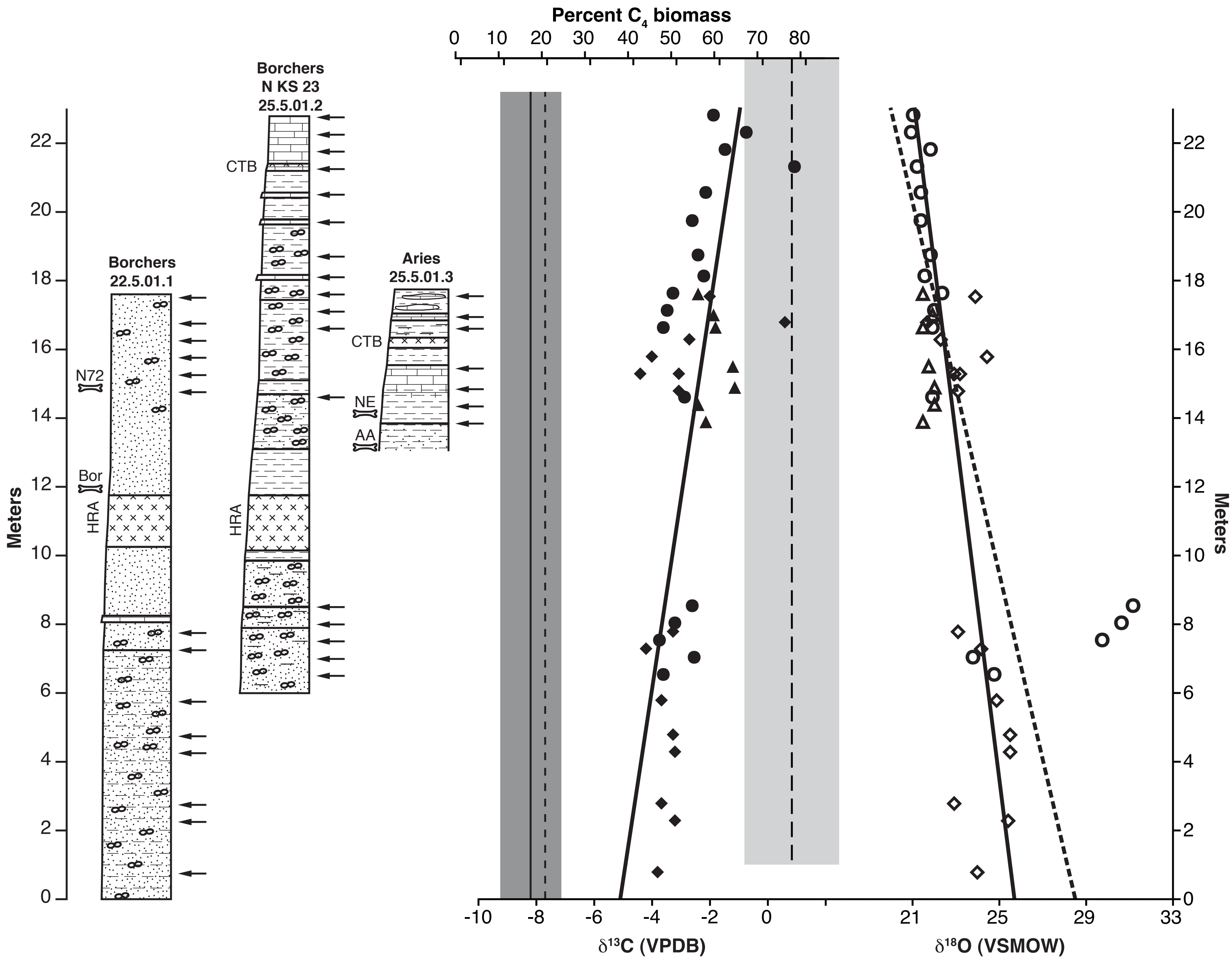


Percent C4 biomass
High Banks
9.7.02.1.2
0
10
20
30
40
50
60
70
80
9
8
7
6
5
4
3
2
1
0
Meters
HB2
HB1
talus
-10
-8
-6
-4
-2
0
21
25
29
33
δ13C (VPDB)
δ18O (VSMOW)
Meters



Percent C4 biomass
0 10 20 30 40 50 60 70 80
Meters
Cimarron River
south
north
Wolf gravel
Wolf gravel
CC2
CC1
R
B
BG
Alien Canyon 24.05.01.2
XIT section B 23.5.01.4
XIT E
XIT A-D
Bish gr
XIT 1A
Bish gr
XIT section A 23.5.01.5
Alien Canyon
Keefe Canyon
XIT-A
XIT-B
Fox Canyon
Saw Rock Canyon
δ13C (VPDB)
δ18O (VSMOW)
-10 -8 -6 -4 -2 0
21 25 29 33
0 5 10 15 20 25 30 35 40 45 50 55 60 65


Percent C4 biomass
0 10 20 30 40 50 60 70 80
Section B
27.6.03.2
Section C
27.6.03.3
Section E
5.7.03.1
Section F
5.7.03.2
M
WB
Meters
0 1 2 3 4 5 6 7 8
-10 -8 -6 -4 -2 0
δ13C (VPDB)
21 25 29 33
δ18O (VSMOW)



Percent C4 biomass
0 10 20 30 40 50 60 70 80
Borchers
N KS 23
25.5.01.2
Borchers
22.5.01.1
Aries
25.5.01.3
CTB
CTB
N72
NE
AA
Bor
HRA
HRA
Meters
Meters
0 2 4 6 8 10 12 14 16 18 20 22
-10 -8 -6 -4 -2 0
21 25 29 33
δ13C (VPDB)
δ18O (VSMOW)

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.

Location	Section number	Sample	NALMA	Meters in composite section	$\delta^{13}C$ (VPDB)	$\delta^{13}C$ intrasample variation	Percent C4	$\delta^{18}O$ (VSMOW)	$\delta^{18}O$ intrasample variation
1. Aries Quarry	25.5.01.3	7	Irvingtonian	17.55	-2.4		56.4	21.5	
1. Aries Quarry	25.5.01.3	6	Irvingtonian	16.95	-1.9		59.7	21.9	
1. Aries Quarry	25.5.01.3	5	Irvingtonian	16.60	-1.8	0.06	60.4	21.5	0.35
1. Aries Quarry	25.5.01.3	4	Irvingtonian	15.45	-1.2		64.4	21.7	
1. Aries Quarry	25.5.01.3	3	Irvingtonian	14.85	-1.1	0.03	65.1	22.0	0.31
1. Aries Quarry	25.5.01.3	2	Irvingtonian	14.35	-2.4	0.04	56.4	22.0	0.10
1. Aries Quarry	25.5.01.3	1	Irvingtonian	13.85	-2.2	0.03	57.7	21.5	0.21
2. Borchers Badlands south	22.5.01.1	23	Irvingtonian	17.50	-2.0	0.31	59.1	23.9	0.32
2. Borchers Badlands south	22.5.01.1	22	Irvingtonian	16.75	0.6		76.5	21.7	
2. Borchers Badlands south	22.5.01.1	21	Irvingtonian	16.25	-2.7	3.41	54.4	22.6	0.56
2. Borchers Badlands south	22.5.01.1	20	Irvingtonian	15.75	-4.0	0.03	45.6	24.4	0.51
2. Borchers Badlands south	22.5.01.1	19	Irvingtonian	15.25	-4.4	0.12	43.0	23.2	0.06
2. Borchers Badlands south	22.5.01.1	19	Irvingtonian	15.25	-3.1	0.27	51.7	22.9	0.05
2. Borchers Badlands south	22.5.01.1	18	Irvingtonian	14.75	-3.1	0.22	51.7	23.1	0.05
2. Borchers Badlands south	22.5.01.1	15	L Blancan	7.75	-3.3	0.06	49.0	23.1	0.04
2. Borchers Badlands south	22.5.01.1	14	L Blancan	7.25	-4.2	0.30	43.0	24.2	0.51
2. Borchers Badlands south	22.5.01.1	11	L Blancan	5.75	-3.7	0.15	46.3	24.9	0.29
2. Borchers Badlands south	22.5.01.1	9	L Blancan	4.75	-3.3	0.01	49.0	25.5	0.05
2. Borchers Badlands south	22.5.01.1	8	L Blancan	4.25	-3.2	0.07	49.7	25.5	0.13
2. Borchers Badlands south	22.5.01.1	5	L Blancan	2.75	-3.7	0.04	46.3	22.9	0.00
2. Borchers Badlands south	22.5.01.1	4	L Blancan	2.25	-3.2	0.08	49.7	25.4	0.17
2. Borchers Badlands south	22.5.01.1	1	L Blancan	0.75	-3.8	0.73	45.6	24.0	0.01
3. Borchers Badlands north	25.5.01.2	17	Irvingtonian	22.75	-1.8	0.14	60.1	21.1	0.08
3. Borchers Badlands north	25.5.01.2	16	Irvingtonian	22.25	-0.7	0.35	67.6	20.9	0.08
3. Borchers Badlands north	25.5.01.2	15	Irvingtonian	21.75	-1.4	0.46	62.8	21.7	0.15
3. Borchers Badlands north	25.5.01.2	14	Irvingtonian	21.25	0.9	0.27	78.5	21.2	0.17
3. Borchers Badlands north	25.5.01.2	13	Irvingtonian	20.50	-2.2	0.39	58.0	21.6	0.32
3. Borchers Badlands north	25.5.01.2	12	Irvingtonian	19.70	-2.6	0.02	54.8	21.4	0.02

3. Borchers Badlands north	25.5.01.2	11	Irvingtonian	18.70	-2.4		56.5	21.8	
3. Borchers Badlands north	25.5.01.2	10	Irvingtonian	18.10	-2.2	0.05	57.6	21.4	0.24
3. Borchers Badlands north	25.5.01.2	9	Irvingtonian	17.60	-3.3	0.00	50.4	22.4	0.10
3. Borchers Badlands north	25.5.01.2	8	Irvingtonian	17.10	-3.5	0.12	49.0	22.1	0.16
3. Borchers Badlands north	25.5.01.2	7	Irvingtonian	16.50	-3.6	0.12	48.3	22.0	0.21
3. Borchers Badlands north	25.5.01.2	6	Irvingtonian	14.60	-2.9	0.01	53.0	21.9	0.05
3. Borchers Badlands north	25.5.01.2	5	L Blancan	8.50	-2.6	0.01	53.6	31.0	0.26
3. Borchers Badlands north	25.5.01.2	4	L Blancan	8.00	-3.2	0.01	49.4	30.6	0.14
3. Borchers Badlands north	25.5.01.2	3	L Blancan	7.50	-3.7	0.10	46.1	29.7	0.11
3. Borchers Badlands north	25.5.01.2	2	L Blancan	7.00	-2.5	0.14	54.2	23.9	0.16
3. Borchers Badlands north	25.5.01.2	1	L Blancan	6.50	-3.6	0.15	46.8	24.7	0.16
4. Wheelbarrow/Mustang B	27.6.03.2	5	M Blancan	4.15	-6.2		30.4	22.0	
4. Wheelbarrow/Mustang B	27.6.03.2	4	M Blancan	3.65	-5.8		33.0	21.1	
4. Wheelbarrow/Mustang B	27.6.03.2	3	M Blancan	2.20	-6.2		30.1	21.4	
4. Wheelbarrow/Mustang B	27.6.03.2	2	M Blancan	1.75	-6.0		31.6	20.8	
4. Wheelbarrow/Mustang B	27.6.03.2	1	M Blancan	1.25	-3.0		51.8	22.8	
5. Wheelbarrow/Mustang C	27.6.03.3	8	M Blancan	5.80	-6.0		31.3	21.6	
5. Wheelbarrow/Mustang C	27.6.03.3	7	M Blancan	5.25	-6.2		30.2	21.5	
5. Wheelbarrow/Mustang C	27.6.03.3	6	M Blancan	4.75	-3.3		49.6	22.4	
5. Wheelbarrow/Mustang C	27.6.03.3	5	M Blancan	4.20	-5.4		35.4	21.8	
5. Wheelbarrow/Mustang C	27.6.03.3	4	M Blancan	3.95	-3.0		51.6	21.4	
5. Wheelbarrow/Mustang C	27.6.03.3	3	M Blancan	3.35	-4.9		38.6	21.3	
5. Wheelbarrow/Mustang C	27.6.03.3	2	M Blancan	2.85	-5.8		32.9	21.1	
5. Wheelbarrow/Mustang C	27.6.03.3	1	M Blancan	2.50	-5.2		36.7	22.5	
6. Wheelbarrow/Mustang E	5.7.03.1	7	M Blancan	5.60	-5.5	0.18	34.9	22.5	0.19
6. Wheelbarrow/Mustang E	5.7.03.1	6	M Blancan	5.15	-5.6	0.17	33.9	22.2	0.17
6. Wheelbarrow/Mustang E	5.7.03.1	5	M Blancan	4.60	-5.4	0.15	35.8	22.3	0.15
6. Wheelbarrow/Mustang E	5.7.03.1	4	M Blancan	4.10	-4.7	0.38	40.5	22.3	0.39
6. Wheelbarrow/Mustang E	5.7.03.1	3	M Blancan	3.60	-4.3	0.10	42.9	22.9	0.10
6. Wheelbarrow/Mustang E	5.7.03.1	2	M Blancan	3.10	-3.3	0.14	49.9	23.7	0.14
6. Wheelbarrow/Mustang E	5.7.03.1	1	M Blancan	2.60	-4.6		40.7	22.9	
7. Wheelbarrow/Mustang F	5.7.03.2	7	M Blancan	7.40	-5.5		35.2	22.8	
7. Wheelbarrow/Mustang F	5.7.03.2	6	M Blancan	6.90	-5.4		35.6	22.6	

7. Wheelbarrow/Mustang F	5.7.03.2	5	M Blancan	6.40	-6.2		30.3	21.6	
7. Wheelbarrow/Mustang F	5.7.03.2	4	M Blancan	5.90	-6.0		31.5	22.0	
7. Wheelbarrow/Mustang F	5.7.03.2	3	M Blancan	5.15	-4.4		42.3	22.3	
7. Wheelbarrow/Mustang F	5.7.03.2	2	M Blancan	4.65	-3.6		47.7	21.6	
7. Wheelbarrow/Mustang F	5.7.03.2	1	M Blancan	4.25	-3.2		50.4	22.6	
8. Keefe Canyon Quarry	24.5.01.3	10	E Blancan	44.25	-5.0		36.9	21.1	
8. Keefe Canyon Quarry	24.5.01.3	9	E Blancan	43.4	-4.2		42.3	21.0	
8. Keefe Canyon Quarry	24.5.01.3	8	E Blancan	43	-5.2		35.6	20.7	
8. Keefe Canyon Quarry	24.5.01.3	7	E Blancan	42.5	-4.8		38.3	22.2	
8. Keefe Canyon Quarry	24.5.01.3	6	E Blancan	42	-6.5		26.8	20.9	
8. Keefe Canyon Quarry	24.5.01.3	5	E Blancan	41.45	-5.1		36.2	21.5	
8. Keefe Canyon Quarry	24.5.01.3	4	E Blancan	41.1	-6.7		25.5	19.9	
8. Keefe Canyon Quarry	24.5.01.3	3a	E Blancan	40.75	-6.8		24.8	20.0	
8. Keefe Canyon Quarry	24.5.01.3	3a'	E Blancan	40.75	-7.3		21.5	20.1	
8. Keefe Canyon Quarry	24.5.01.3	3b	E Blancan	40.75	-5.9		30.9	20.9	
8. Keefe Canyon Quarry	24.5.01.3	3d	E Blancan	40.75	-4.9		37.6	20.1	
8. Keefe Canyon Quarry	24.5.01.3	3e	E Blancan	40.75	-6.6		26.2	21.1	
8. Keefe Canyon Quarry	24.5.01.3	2	E Blancan	40.3	-5.1		36.2	21.6	
8. Keefe Canyon Quarry	24.5.01.3	0	E Blancan	39.7	-5.9		30.9	23.2	
9. Alien Canyon	24.5.01.2	23	E Blancan	64.55	-1.8	0.05	58.5	23.1	0.02
9. Alien Canyon	24.5.01.2	22	E Blancan	64.05	-3.1	0.41	50.0	23.5	0.11
9. Alien Canyon	24.5.01.2	21	E Blancan	63.05	-3.8	0.02	44.9	22.8	0.20
9. Alien Canyon	24.5.01.2	20	E Blancan	62.55	-4.0	0.09	43.6	23.1	0.04
9. Alien Canyon	24.5.01.2	19	E Blancan	62.05	-4.4	0.12	40.9	23.2	0.06
9. Alien Canyon	24.5.01.2	18	E Blancan	61.55	-4.9	0.09	37.8	22.4	0.02
9. Alien Canyon	24.5.01.2	17	E Blancan	61.05	-5.3	0.02	35.0	21.9	0.19
9. Alien Canyon	24.5.01.2	16	E Blancan	60.55	-5.0	0.44	37.2	22.6	0.31
9. Alien Canyon	24.5.01.2	15	E Blancan	60.05	-5.9	0.04	31.0	23.2	0.61
9. Alien Canyon	24.5.01.2	14	E Blancan	59.55	-5.8	0.12	31.3	22.2	0.11
9. Alien Canyon	24.5.01.2	13	E Blancan	59.05	-6.0	0.21	30.2	22.3	0.23
9. Alien Canyon	24.5.01.2	12	E Blancan	58.55	-4.3	0.11	41.5	23.0	0.42
9. Alien Canyon	24.5.01.2	11	E Blancan	58.05	-6.0	0.04	30.4	22.8	0.12
9. Alien Canyon	24.5.01.2	10	E Blancan	50	-4.0	0.10	43.5	22.6	0.21

9. Alien Canyon	24.5.01.2	9	E Blancan	48.4	-5.6	0.05	32.7	22.5	0.05
9. Alien Canyon	24.5.01.2	8	E Blancan	46.8	-6.0	0.24	30.5	21.3	0.08
9. Alien Canyon	24.5.01.2	7	E Blancan	45.6	-5.1	0.24	36.6	21.9	0.10
9. Alien Canyon	24.5.01.2	6	E Blancan	44.1	-3.4	0.11	47.5	21.7	0.16
9. Alien Canyon	24.5.01.2	5	E Blancan	43.35	-4.9	0.05	37.3	21.8	0.27
9. Alien Canyon	24.5.01.2	4	E Blancan	43.1	-5.2	0.01	35.6	21.8	0.27
9. Alien Canyon	24.5.01.2	3	E Blancan	42.35	-5.6	0.27	32.9	21.5	0.10
9. Alien Canyon	24.5.01.2	2	E Blancan	41.85	-4.8	0.00	38.5	21.6	0.02
9. Alien Canyon	24.5.01.2	1	E Blancan	38.45	-4.7	0.01	38.7	21.2	0.10
10 Fox Canyon West	26.6.03.1	4	E Blancan	41.75	-4.5	0.09	40.3	21.1	0.06
10. Fox Canyon West	26.6.03.1	3	E Blancan	40.25	-3.5	0.02	47.0	21.8	0.12
10. Fox Canyon West	26.6.03.1	2	E Blancan	39	-4.5	0.06	40.3	22.0	0.08
10. Fox Canyon West	26.6.03.1	1	E Blancan	37	-4.5	0.02	40.3	21.1	0.02
11. Taylor Mollusc	26.6.03.2	5	E Blancan	41.1	-4.9	1.55	37.6	21.6	0.22
11. Taylor Mollusc	26.6.03.2	4	E Blancan	39.1	-4.8	0.12	38.3	22.0	0.14
11. Taylor Mollusc	26.6.03.2	3	E Blancan	37.7	-5.3	0.04	34.9	21.6	0.28
11. Taylor Mollusc	26.6.03.2	2	E Blancan	36.7	-5.3	0.15	34.9	21.1	0.20
11. Taylor Mollusc	26.6.03.2	1	E Blancan	36.4	-5.3	0.03	34.9	21.0	0.23
12. South of Taylor	26.6.03.3	4	E Blancan	42.25	-4.5	0.01	40.3	21.4	0.24
12. South of Taylor	26.6.03.3	3	E Blancan	41.7	-5.1	0.16	36.2	22.3	0.21
12. South of Taylor	26.6.03.3	2	E Blancan	41.2	-5.1	0.39	36.2	21.5	0.13
12. South of Taylor	26.6.03.3	1	E Blancan	40.65	-4.8	0.22	38.3	21.8	0.14
13. Next North	26.6.03.4	6	E Blancan	43	-4.9	0.11	37.6	22.2	0.23
13. Next North	26.6.03.4	5	E Blancan	42.5	-5.3	0.07	34.9	22.0	0.00
13. Next North	26.6.03.4	4	E Blancan	42	-6.3	0.12	28.2	21.3	0.23
13. Next North	26.6.03.4	3	E Blancan	41.5	-5.7	0.04	32.2	21.2	0.04
13. Next North	26.6.03.4	2	E Blancan	41	-7.5	0.02	20.1	22.0	0.11
13. Next North	26.6.03.4	1	E Blancan	40.65	-5.1	0.18	36.2	21.8	0.35
14. Red Fox	26.6.03.5	7	E Blancan	42.6	-5.8	0.31	31.5	21.6	0.53
14. Red Fox	26.6.03.5	6	E Blancan	42.15	-5.5	1.13	33.6	21.6	0.74
14. Red Fox	26.6.03.5	5	E Blancan	41.65	-5.1	0.02	36.2	21.6	0.06
14. Red Fox	26.6.03.5	4	E Blancan	41.15	-4.9		37.6	21.8	
14. Red Fox	26.6.03.5	3	E Blancan	40.65	-4.7	0.22	38.9	20.5	0.29

14. Red Fox	26.6.03.5	2	E Blancan	40.15	-3.5		47.0	21.6	
14. Red Fox	26.6.03.5	1	E Blancan	39.65	-5.2	0.05	35.6	21.4	0.13
15. XIT-B	23.5.01.4	20	E Blancan	39.35	-5.0	0.11	36.9	20.8	0.47
15. XIT-B	23.5.01.4	19	E Blancan	37.4	-5.4		34.2	20.5	
15. XIT-B	23.5.01.4	18	E Blancan	37.15	-2.9	0.93	51.3	20.1	0.94
15. XIT-B	23.5.01.4	17	E Blancan	35.65	-4.3		41.6	21.3	
15. XIT-B	23.5.01.4	16	E Blancan	34.65	-4.4		40.9	20.8	
15. XIT-B	23.5.01.4	15	E Blancan	33.65	-4.4		40.9	23.2	
15. XIT-B	23.5.01.4	14	E Blancan	32.65	-4.3		41.6	22.3	
15. XIT-B	23.5.01.4	13	E Blancan	31.65	-3.9		44.3	23.1	
15. XIT-B	23.5.01.4	12	E Blancan	31.15	-4.5		40.3	22.1	
15. XIT-B	23.5.01.4	11	E Blancan	6.4	-4.1		43.0	22.7	
15. XIT-B	23.5.01.4	10	E Blancan	6.15	-4.4		40.9	23.2	
15. XIT-B	23.5.01.4	9	E Blancan	5.65	-4.2		42.3	22.3	
15. XIT-B	23.5.01.4	8	E Blancan	5.15	-4.0	0.04	43.6	21.8	0.31
15. XIT-B	23.5.01.4	7	E Blancan	4.65	-4.1		43.0	21.2	
15. XIT-B	23.5.01.4	6	E Blancan	4.15	-4.3	0.29	41.9	21.5	0.34
15. XIT-B	23.5.01.4	5	E Blancan	3.65	-4.3	0.29	41.9	21.3	0.27
15. XIT-B	23.5.01.4	4	E Blancan	3.15	-4.6	0.01	39.6	21.7	0.40
15. XIT-B	23.5.01.4	3	E Blancan	2.65	-4.5	0.11	40.3	21.5	0.04
15. XIT-B	23.5.01.4	1	E Blancan	0.9	-5.3		34.9	23.7	
16. XIT-A	23.5.01.5	14	E Blancan	64.1	-3.9	0.13	44.4	22.3	0.21
16. XIT-A	23.5.01.5	13	E Blancan	63.1	-3.4	0.04	47.8	22.9	0.05
16. XIT-A	23.5.01.5	12	E Blancan	56.9	-5.7		32.1	21.9	
16. XIT-A	23.5.01.5	11	E Blancan	55.85	-5.5		33.7	22.6	
16. XIT-A	23.5.01.5	10	E Blancan	54.95	-5.7		32.4	22.3	
16. XIT-A	23.5.01.5	8	E Blancan	49.75	-4.6		39.3	22.2	
16. XIT-A	23.5.01.5	7	E Blancan	47.85	-3.8		44.7	22.4	
16. XIT-A	23.5.01.5	6	E Blancan	47.35	-3.3		48.2	23.1	
16. XIT-A	23.5.01.5	5	E Blancan	45.85	-5.6	0.14	32.6	21.2	0.04
16. XIT-A	23.5.01.5	4	E Blancan	43.75	-4.3		41.7	21.2	
16. XIT-A	23.5.01.5	3	E Blancan	42.75	-6.2		29.0	20.1	
16. XIT-A	23.5.01.5	2	E Blancan	41.55	-5.2		35.3	20.9	

16. XIT-A	23.5.01.5	2a	E Blancan	41.55	-5.9		31.1	20.8	
16. XIT-A	23.5.01.5	1	E Blancan	40.45	-5.0	0.34	37.2	20.4	0.03
17. Saw Rock Canyon	23.5.01.2	10	E Blancan	23.7	-4.7	0.02	38.9	20.7	0.32
17. Saw Rock Canyon	23.5.01.2	9	E Blancan	22.45	-4.7	0.02	38.9	21.3	0.23
17. Saw Rock Canyon	23.5.01.2	8	E Blancan	21.55	-4.6	0.27	39.6	21.6	1.16
17. Saw Rock Canyon	23.5.01.2	7	E Blancan	21.2	-4.7	0.06	38.9	22.5	0.42
17. Saw Rock Canyon	23.5.01.2	6	E Blancan	20.9	-4.9	0.10	37.6	21.7	0.02
17. Saw Rock Canyon	23.5.01.2	5	E Blancan	20.4	-4.9	0.07	37.6	22.9	0.08
17. Saw Rock Canyon	23.5.01.2	4	E Blancan	19.6	-4.8	0.02	38.3	22.2	0.07
17. Saw Rock Canyon	23.5.01.2	3	E Blancan	19.35	-5.0	0.01	36.9	23.0	0.21
17. Saw Rock Canyon	23.5.01.2	2	E Blancan	19.1	-4.6	0.00	39.6	22.7	0.03
17. Saw Rock Canyon	23.5.01.2	1	E Blancan	17.6	-4.6	0.12	39.6	22.8	0.04
18. High Banks	9.7.02.2	10	Hemphillian	7.80	-6.5		25.2	24.8	
18. High Banks	9.7.02.2	9	Hemphillian	6.25	-6.3		27.0	24.7	
18. High Banks	9.7.02.2	8	Hemphillian	4.60	-6.7		24.5	25.0	
18. High Banks	9.7.02.2	7	Hemphillian	3.40	-6.5		25.3	24.8	
18. High Banks	9.7.02.2	6	Hemphillian	2.70	-5.9		29.8	24.8	
18. High Banks	9.7.02.2	5	Hemphillian	2.20	-6.6		24.8	24.4	
18. High Banks	9.7.02.2	4	Hemphillian	1.90	-6.8		23.5	24.7	
18. High Banks	9.7.02.2	3	Hemphillian	1.50	-6.8		23.7	25.0	
18. High Banks	9.7.02.2	2	Hemphillian	1.00	-6.0		28.8	24.8	
18. High Banks	9.7.02.2	1	Hemphillian	0.50	-6.5		25.6	25.0	
19. Ogallala Fm, N KS 23	25.5.01.1	12	Clarendonian	12.10	-6.0		28.3	24.3	
19. Ogallala Fm, N KS 23	25.5.01.1	11	Clarendonian	11.50	-7.4		18.8	25.3	
19. Ogallala Fm, N KS 23	25.5.01.1	10	Clarendonian	10.95	-5.9		29.0	24.3	
19. Ogallala Fm, N KS 23	25.5.01.1	9	Clarendonian	8.80	-7.3		19.3	25.2	
19. Ogallala Fm, N KS 23	25.5.01.1	8	Clarendonian	7.75	-8.0		15.0	25.2	
19. Ogallala Fm, N KS 23	25.5.01.1	7	Clarendonian	7.25	-8.5		11.2	25.9	
19. Ogallala Fm, N KS 23	25.5.01.1	6	Clarendonian	6.00	-7.6		17.1	25.2	
19. Ogallala Fm, N KS 23	25.5.01.1	5	Clarendonian	5.00	-7.4		19.0	24.9	
19. Ogallala Fm, N KS 23	25.5.01.1	4	Clarendonian	4.00	-8.7		10.3	25.3	
19. Ogallala Fm, N KS 23	25.5.01.1	3	Clarendonian	3.45	-8.4		12.4	27.0	
19. Ogallala Fm, N KS 23	25.5.01.1	2	Clarendonian	3.10	-8.2		13.5	25.7	

19. Ogallala Fm, N KS 23	25.5.01.1	1	Clarendonian	2.50	-8.1		14.4	25.5

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 $\alpha=0.05$.

	slope	intercept	R^2	s.e.	F	p-value
Late Blancan-Early Irvingtonian	-0.26	26.7	0.40	1.93	25.13	**<0.001**
Middle Blancan	0.04	21.9	0.01	0.70	0.27	0.605
Early Blancan	0.006	21.6	0.01	0.87	1.05	0.309
Hemphillian	-0.007	24.8	0.01	0.19	0.08	0.791
Clarendonian	-0.13	26.2	0.39	0.59	6.36	**0.030**

Supplemental Table 3. Results of one-way ANOVAs with post hoc Scheffè 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).

$\delta^{18}O$ (VSMOW)		mean	sd	n	L Blancan-E Irvingtonian	Middle Blancan	Early Blancan	Hemp
Late Blancan-	all data	23.3	2.47	39				
Early Irvington	without outliers	22.7	1.37	36				
Middle Blancan		22.1	0.69	27	**0.009**			
					0.137			
Early Blancan		21.8	0.87	106	**<0.001**	0.912		
					<0.001	0.744		
Hemphillian		24.8	0.18	10	**0.040**	**<0.001**	**<0.001**	
					<0.001	**<0.001**	**<0.001**	
Clarendonian		25.3	0.72	12	**<0.001**	**<0.001**	**<0.001**	0.933
					<0.001	**<0.001**	**<0.001**	0.798
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

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 $\alpha=0.05$.

$\delta^{18}O$	n	Late Blancan-Early Irvington all data (n=39)	Late Blancan-Early Irvington w/out outliers (n=36)	Middle Blancan	Early Blancan	Hemphillian
Late Blancan-Early Irvington						
Middle Blancan	27	380.0 -1.91 0.056	380.0 -1.47 0.141			
Early Blancan	106	**1222.5 -3.77 0.001**	**1222.5 -3.22 0.001**	1160.5 -1.52 0.130		
Hemphillian	10	**69.5 -3.12 <0.001**	**39.5 -3.75 <0.001**	**0.0 -4.63 <0.001**	**0.0 -5.22 <0.001**	
Clarendonian	12	**67.5 -3.70 <0.001**	**31.5 -4.40 <0.001**	**0.0 -4.93 <0.001**	**0.0 -5.67 <0.001**	**23.0 -2.45 0.014**
Miocene (Meade)	22	**137.0 -4.39 <0.001**	**71.0 -5.21 <0.001**	**0.0 -5.98 <0.001**	**0.0 -7.37 <0.001**	N/A

Supplemental Table 5. Regression statistics for least squares linear regressions with $\delta^{18}O$ values of paleosol carbonates as independent variables and $\delta^{13}C$ 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 $\delta^{18}O$ values >29‰, which corresponds to the line in Fig. 10. Bold indicates statistically significant regressions with slopes significantly different from 0.0 at α=0.05.

$\delta^{13}C$ values		slope	intercept	R^2	s.e.	F	p-value
Late Blancan-	all data	-0.21	2.2	0.19	1.08	8.44	**0.006**
Early Irvingtonian	without outliers	-0.54	9.7	0.37	0.98	19.91	**<0.001**
Middle Blancan		0.76	-21.7	0.22	0.99	7.22	**0.013**
Early Blancan		0.36	-12.7	0.12	0.85	14.04	**<0.001**
Hemphillian		-0.17	-2.3	0.01	0.33	0.08	0.787
Clarendonian		-0.99	17.5	0.62	0.59	16.07	**0.002**
All data	all data	-0.13	-1.8	0.02	1.59	3.58	0.060
	without outliers	-0.30	1.9	0.07	1.55	13.43	**<0.001**
Interval means	all data	-0.87	15.0	0.55	1.47	3.65	0.152
	without outliers	-0.75	12.2	0.39	1.71	1.88	0.264

Percent C_4		slope	intercept	R^2	s.e.	F	p-value
Late Blancan-	all data	-1.58	91.5	0.23	7.37	10.72	**0.002**
Early Irvingtonian	without outliers	-3.94	144.3	0.41	6.56	23.79	**<0.001**
Middle Blancan		5.13	-74.9	0.23	6.63	7.39	**0.012**
Early Blancan		2.41	-15.0	0.12	5.72	14.00	**<0.001**
Hemphillian		-0.70	43.2	0.004	2.22	0.03	0.867
Clarendonian		-6.64	185.5	0.61	3.96	15.85	**0.003**
All data	all data	-1.05	62.8	0.02	11.34	4.77	**0.030**
	without outliers	-2.29	90.4	0.08	11.04	15.87	**<0.001**

Interval	all data	-5.71	168.7	0.41	12.49	2.09	0.244
	without outliers	-6.60	188.9	0.56	10.87	3.87	0.144