SUPPLEMENTAL FIGURE CAPTIONS

Supplemental Figure 1. 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 text). 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. 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.

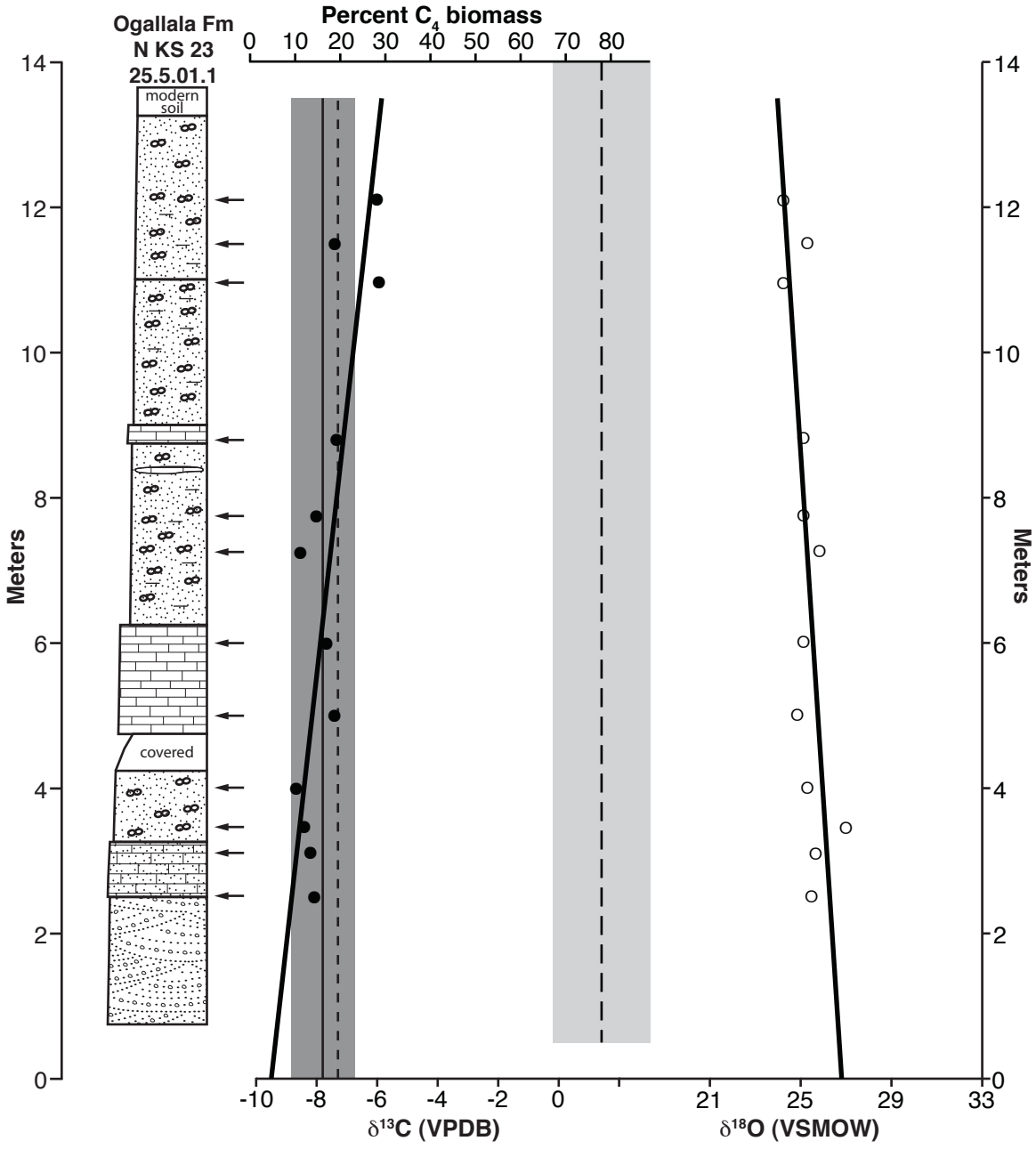
Supplemental Figure 2. Carbonate $\delta^{13}C$ and $\delta^{18}O$ values from the Hemphilian section (High Banks). Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). Thin black line and dark grey box indicates mean $\delta^{13}C$ 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 text). 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 Hemphilian in Fig. 3C. 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. 1.

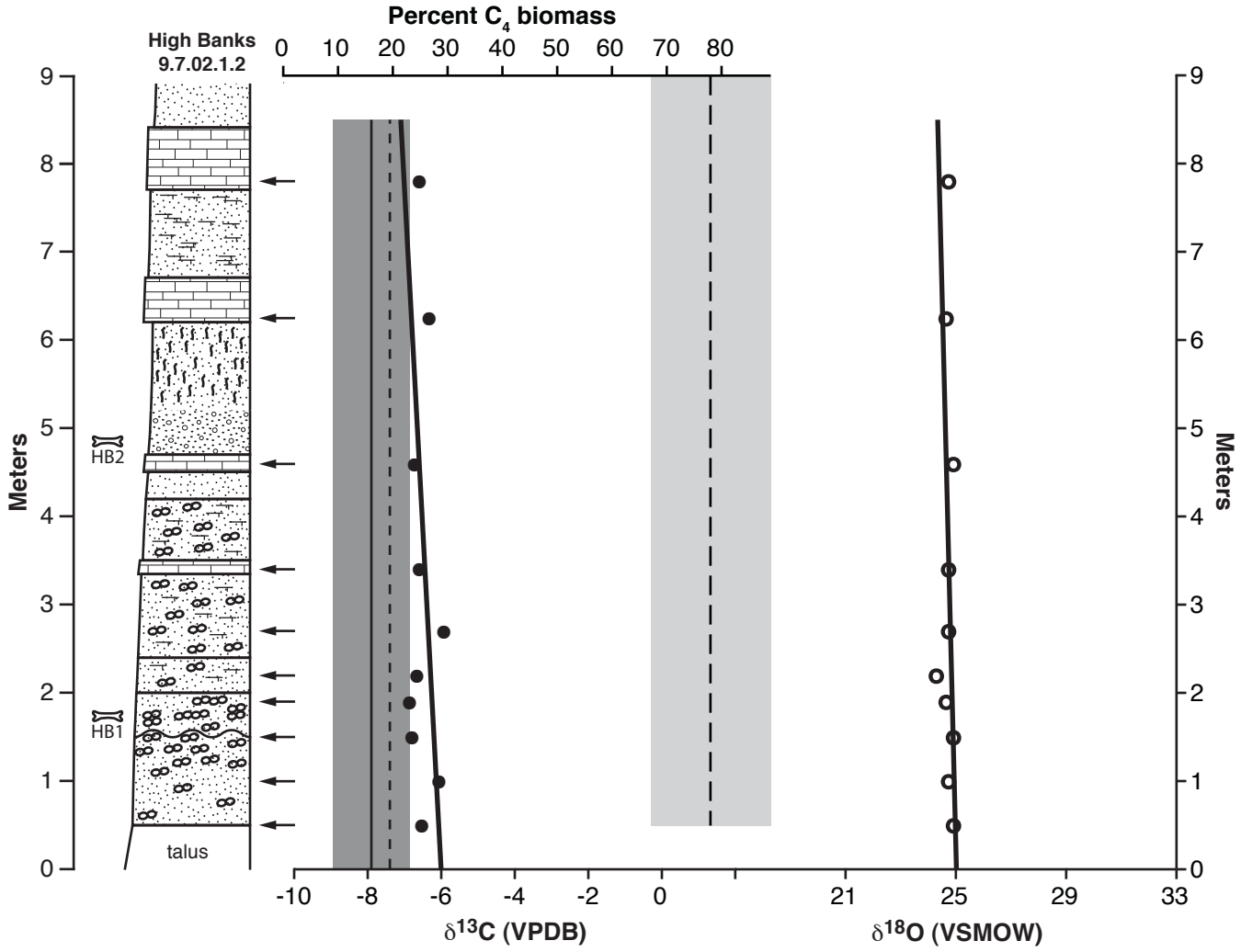
Supplemental Figure 3. Carbonate $\delta^{13}C$ and $\delta^{18}O$ values from the early Blancan sections (measured sections for Saw Rock, Keefe, and Fox Canyons not shown). Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). 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 text). 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 early Blancan in Fig. 3C. 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. 1.

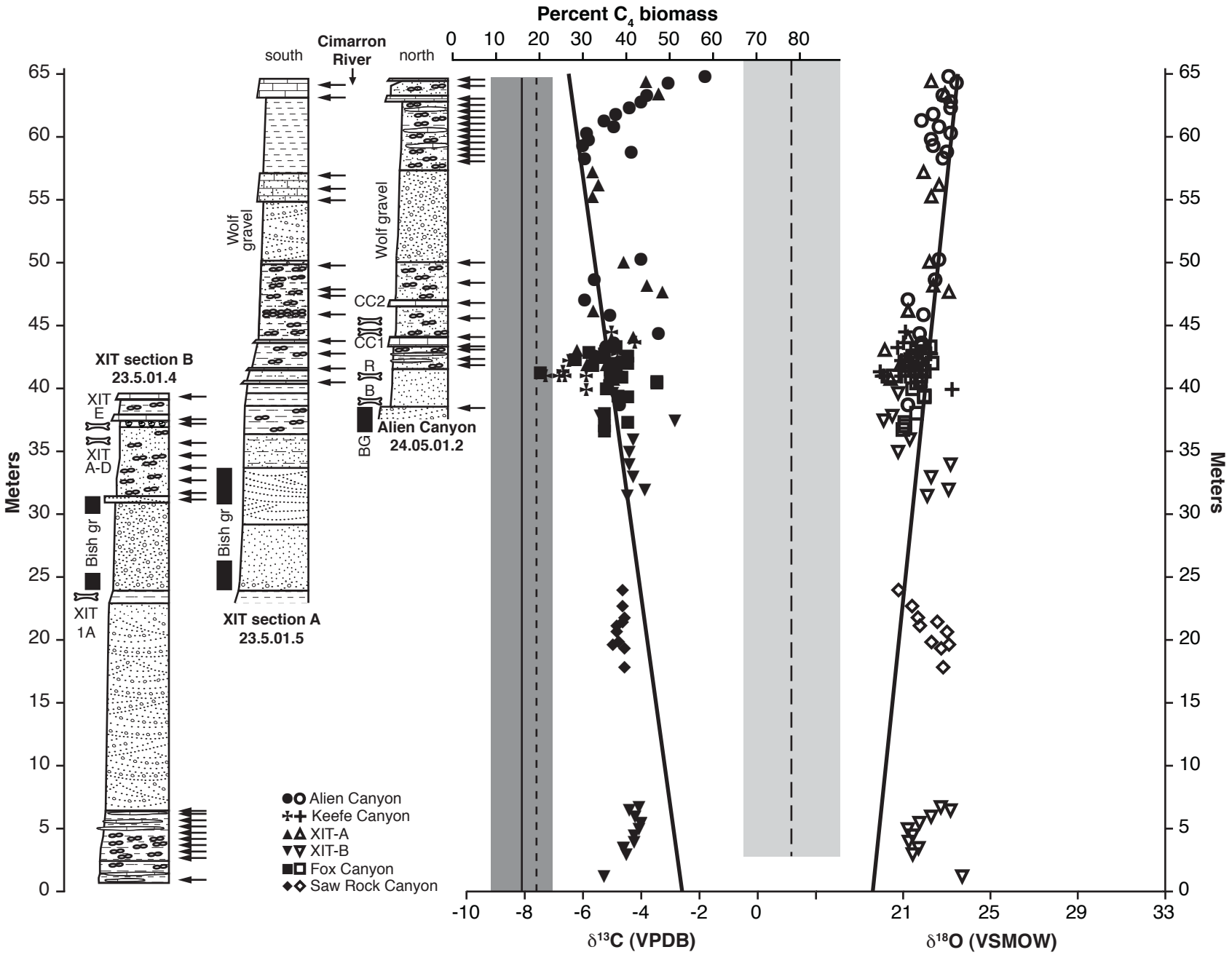
Supplemental Figure 4. Carbonate $\delta^{13}C$ and $\delta^{18}O$ values from the middle Blancan sections. Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ values on meter level (dependent variable). Thin black line and dark grey box indicates mean $\delta^{13}C$ 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 text). 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

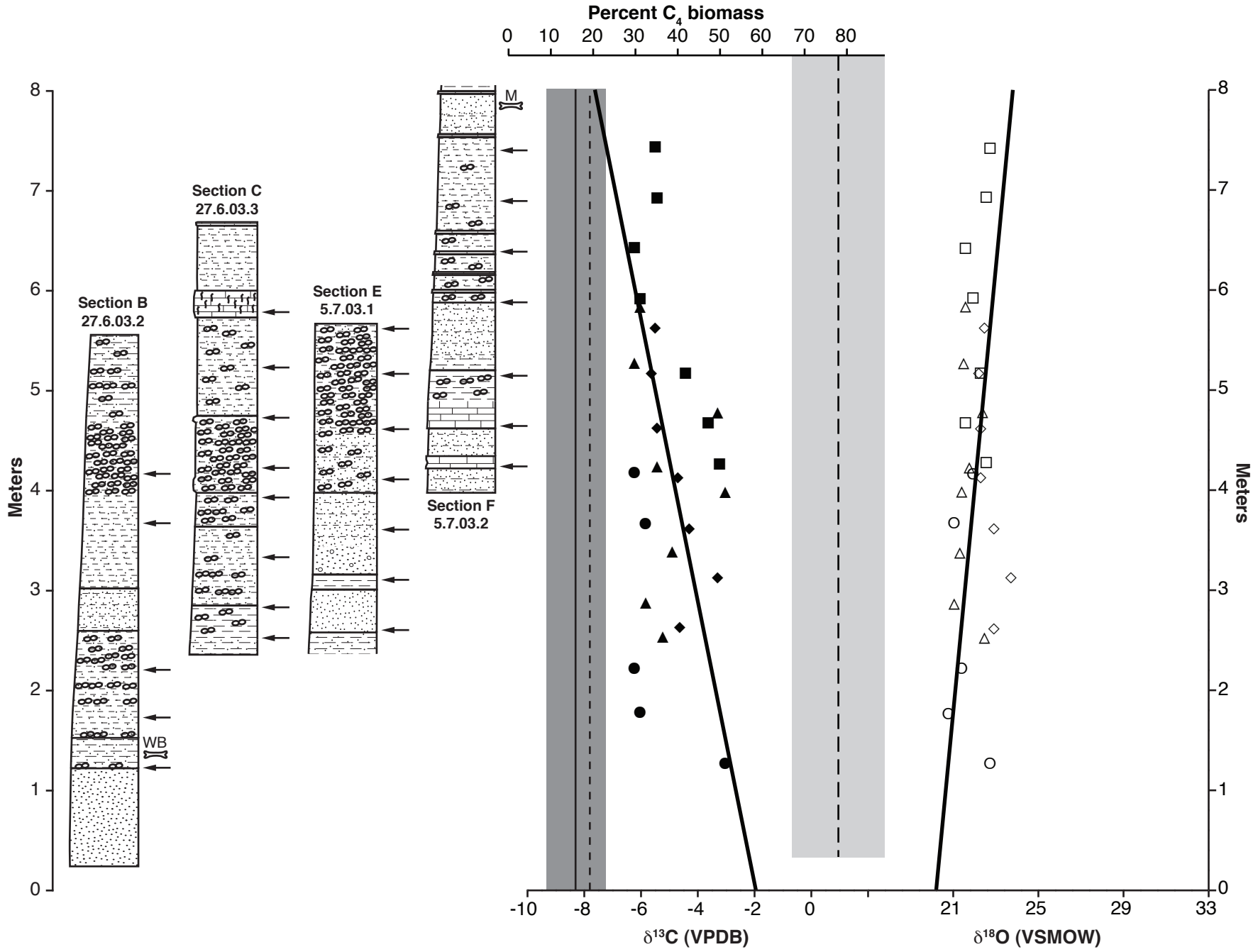
middle Blancan in Fig. 3C. Long dashed line and light gray box indicates mean modern abundance of C_4 biomass in the region ± 1 standard deviation (Supplemental Table 1). Arrows indicate positions of samples. WB, M: positions of the Wheelbarrow and Mustang faunas, respectively. Lithologic symbols as in Suppl. Fig. 1.

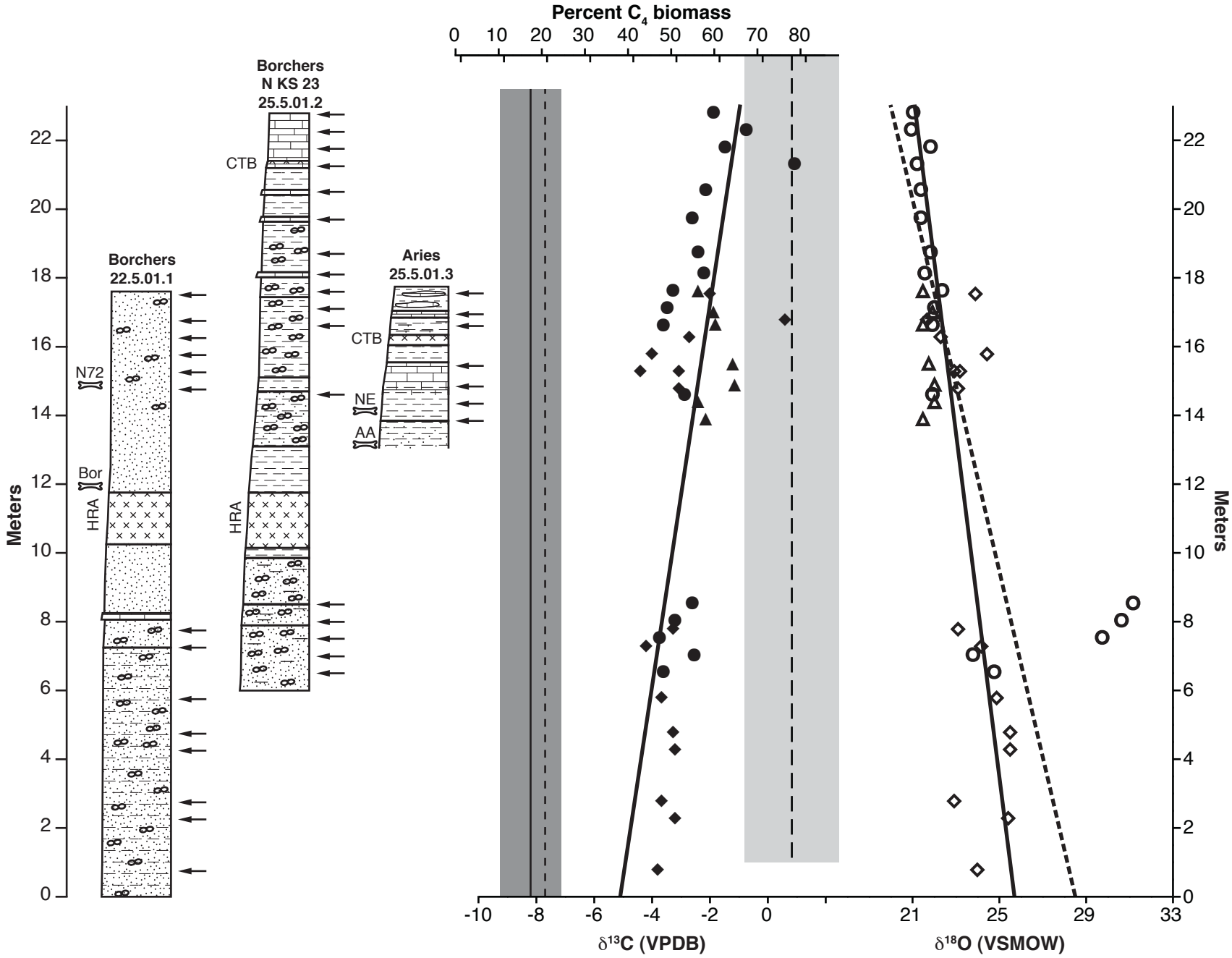
Supplemental Figure 5. Carbonate $\delta^{13}C$ and $\delta^{18}O$ values from the late Blancan-Irvingtonian sections. Lower percent C_4 tick marks are for late Blancan and upper tick marks are for early Irvingtonian. Thick black lines are reduced major axis regressions for $\delta^{13}C$ and $\delta^{18}O$ 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 text). 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 late Blancan and Irvingtonian in Fig. 3C. 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. 1.


Ogallala Fm
N KS 23
25.5.01.1
Percent C_4 biomass
0 10 20 30 40 50 60 70 80
modern soil
covered
Meters
14
12
10
8
6
4
2
0
-10 -8 -6 -4 -2 0
21 25 29 33
$\delta^{13}C$ (VPDB)
$\delta^{18}O$ (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 C_4 biomass
High Banks
9.7.02.1.2
0 10 20 30 40 50 60 70 80
Meters
HB2
HB1
talus
-10 -8 -6 -4 -2 0
21 25 29 33
$\delta^{13}C$ (VPDB)
$\delta^{18}O$ (VSMOW)


Percent C_4 biomass
0 10 20 30 40 50 60 70 80
south
Cimarron River
north
Meters
65 60 55 50 45 40 35 30 25 20 15 10 5 0
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
-10 -8 -6 -4 -2 0
δ^{13}C (VPDB)
21 25 29 33
δ^{18}O (VSMOW)


Percent C4 biomass
0 10 20 30 40 50 60 70 80
Meters
0 1 2 3 4 5 6 7 8
Section B
27.6.03.2
Section C
27.6.03.3
Section E
5.7.03.1
Section F
5.7.03.2
WB
M
-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
CTB
HRA
Borchers
22.5.01.1
N72
Bor
HRA
Aries
25.5.01.3
CTB
NE
AA
Meters
0 2 4 6 8 10 12 14 16 18 20 22
-10 -8 -6 -4 -2 0
δ13C (VPDB)
21 25 29 33
δ18O (VSMOW)
Meters

Supplemental Table 1. Modern abundance of C_4 biomass in Kansas and northwestern Oklahoma based on published $\delta^{13}C$ values of modern and Holocene soil organic matter (SOM) and percentage C_4 based on modern vegetation (biomass), SOM, and phytoliths from soil. Percent C_4 based on reported $\delta^{13}C$ values for SOM is calculated by mass balance assuming the fractionations of Passey et al. (2002) and $\delta^{13}C$ of atmospheric CO_2 based on age: modern=8.0‰, pre-modern=-6.5‰, age ranging from modern to specific pre-modern age=7.25‰ (i.e., midpoint of modern and pre-anthropogenic values). References: 1, Johnson et al., 2007; 2, Arbogast and Johnson, 1998; 3, Fredlund and Tieszen, 1997; 4, Kelly et al., 1991; 5, Olson and Porter, 2002; 6, von Fischer et al., 2008.

Location	$\delta^{13}C$ (VPDB)	Percent C_4	Substrate	Age	Comment	Ref
Konza Priaire, KS	-18.1	53	SOM	modern	core 8, core top	1
Konza Priaire, KS	-14.6	78	SOM	?Holocene, pre Peoria Loess	core 8, -20 cm (A horizon)	1
Konza Priaire, KS	-17.3	59	SOM	modern	core 1, core top	1
Konza Priaire, KS	-13.8	84	SOM	?Holocene, pre Peoria Loess	core 1, -20 cm	1
Konza Priaire, KS	-16.8	62	SOM	modern	transect C1B mean; range -15.4 to -17.5‰	1
Konza Priaire, KS	-13.6	85	biomass	modern	transect C1B; mean value	1
Konza Priaire, KS	-16.5	64	SOM	modern	transect SB; mean value	1
Konza Priaire, KS	-13.8	84	biomass	modern	transect SB; mean value	1
Konza Priaire, KS	-17.5	57	SOM	modern	landscape mean; range -14.4 to -24.3‰	1
Konza Priaire, KS	-15.8	69	biomass	modern	C4A, mean	1
Beisel-Steinle, KS	-13.4	86	SOM	modern to 3480	welded modern/Brady soils, max. $\delta^{13}C$	1
Great Bend Sand Prairie, KS	-12.5	93	SOM	modern to 2000	min $\delta^{13}C$ estimated from Fig. 10, ref. 2	2
Great Bend Sand Prairie, KS	-18.0	54	SOM	modern to 2000	max $\delta^{13}C$ estimated from Fig. 10, ref. 2	2
Freedom, OK	-14.1	82	SOM	modern		3
Woodward, OK	-18.6	61	SOM	modern		3
Rockefeller Prairie, KS	-15.2	74	SOM	modern		3
Konza Prairie, KS	-14.4	80	SOM	modern		3
Hays, KS	-16.6	64	SOM	modern		3
Hays, KS		83	biomass	modern	percent C_4 reported, ±5%	4
Hays, KS		89	biomass	modern	percent C_4 reported, ±4%	4
Hays, KS		80	SOM	modern	percent C_4 reported	4
Hays, KS		79	soil phytolith	modern	percent C_4 reported, ±11%	4
Cimarron Bend, KS	-13.4	86	SOM	1290		5
Cimarron Bend	-16.0	68	SOM	1515		5
Cimarron Bend	-16.6	64	SOM	1172		5
Cimarron Bend	-15.6	71	SOM	1630		5
Cimarron Bend	-18.9	47		6675		5

Cimarron Bend	-17.6	56		6465		5
Cimarron Bend	-18.3	51		4085		5
Cimarron Bend	-17.2	59		8250		5
Tallgrass Prairie, OK	-16.3	66	SOM	modern	SOM-A	6
Land Institute, KS	-15.3	72	SOM	modern	SOM-A	6
Fall Leaf Prairie, KS	-18.3	52	SOM	modern	SOM-A	6

Mean ± 1 s.d. (all data, $\delta^{13}C$ n=29, percent C_4 n=33)	-16.0±1.84‰	75±12.8%
Mean ± 1 s.d. (modern, $\delta^{13}C$ n=16, percent C_4 n=20)	-16.1±1.62‰	78±10.9%

References cited

Arbogast, A.F. and Johnson, W.C., 1998, Late-Quaternary landscape response to environmental change in south-central Kansas: Annals of the Association of American Geographers, v. 88, p. 126-145.

Fredlund, G.G. and Tieszen, L.L., 1997, Phytolith and carbon isotope evidence for late Quaternary vegetation and climate change in the southern Black Hills, South Dakota: Quaternary Research, v. 47, p. 206-217.

Johnson, W.C., Willey, K.L., and Macpherson, G.L., 2007, Carbon isotope variation in modern soils of the tallgrass prairie: analogues for the interpretation of isotopic records derived from paleosols: Quaternary International, v. 162-163, p. 3-20.

Kelly, E.F., Amundson, R.G., Marino, B.D., and DeNiro, M.J., 1991, Stable isotope ratios of carbon in phytoliths as a quantitative method of monitoring vegetation and climate change: Quaternary Research, v. 35, p. 222-233.

Olson, C.G. and Porter, D.A., 2002, Isotopic and geomorphic evidence for Holocene climate, southwestern Kansas: Quaternary International, v. 87, p. 29-44.

von Fischer, J., Tieszen, L.L., and Schimel, D.S., 2008, Climate controls on C3 vs. C4 productivity in North American grasslands from carbon isotope composition of soil organic matter, Global Change Biology, v. 14, p. 1141-1155.

Supplemental Table 2. 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 3. Regression statistics for ordinary least squares linear regressions with meter level of samples in composite sections for each biostratigraphic interval as independent variables and $\delta^{13}C$ values of paleosol carbonates as dependent variables. Bold indicates statistically significant regressions with slopes significantly different from 0.0 at α=0.05.

	slope	intercept	R^2	s.e.	F	p-value
Late Blancan-Early Irvingtonian	0.11	-4.1	0.32	0.99	17.64	**<0.001**
Middle Blancan	-0.19	-4.2	0.07	1.08	1.91	0.179
Early Blancan	-0.004	-4.7	0.01	0.90	0.71	0.402
Hemphillian	-0.001	-6.5	0.00	0.33	0.00	0.979
Clarendonian	0.20	-9.0	0.59	0.61	14.37	**0.004**

Supplemental Table 4. Statistical comparison of Miocene $\delta^{13}C$ data from Meade Basin and different partitions of Miocene $\delta^{13}C$ data from elsewhere in the Great Plains from Fox and Koch (2003, 2004). In those cases for which p-value of Levene's test is >0.05, then the p-value for T-test is calculated assuming equal variances.

Meade Basin			**Data of Fox and Koch (2003, 2004)**							
Hemphillian	Hemphillian		Hemphillian-Clarendonian		Miocene					
	$\delta^{13}C$ (VPDB)	Percent C_4	$\delta^{13}C$ (VPDB)	Percent C_4	$\delta^{13}C$ (VPDB)	Percent C_4				
Mean	-6.7±0.81‰	23.9±5.41%	-6.8±0.76‰	23.6±5.09%	-6.8±0.83‰	23.5±3.0%				
Number	124		153		230					
Levene's test	3.67	3.59	3.43	3.33	5.07	5.67				
	0.058	0.060	0.066	0.070	0.025	0.018				
T-test	1.06 0.291	1.08 0.282	1.27 0.208	1.36 0.175	**2.62 0.019**	**3.36 0.007**				
M-W U test	**354.0 -2.26**	**68.0 -3.04**	**415.5 -2.42**	**402.0 -2.51**	**730.5 -1.96**	**792.5 -1.66**				
	0.024	**0.002**	**0.015**	**0.012**	**0.051**	**0.096**				
Clarendonian	Minium Q., KS (Clarendonian)		Clarendonian		Hemphillian-Clarendonian		Miocene			
	$\delta^{13}C$ (VPDB)	Percent C_4	$\delta^{13}C$ (VPDB)	Percent C_4	$\delta^{13}C$ (VPDB)	Percent C_4				
Mean	-7.0±0.43‰	21.5±2.89%	-6.9±0.46‰	22.1±3.07%	-6.8±0.76‰	23.6±5.09%	-6.8±0.83‰	23.5±3.0%		
Number	7		29		153		230			
Levene's test	2.61	2.53	6.44	6.28	0.88	0.77	0.16	17.99		
	0.124	0.130	0.015	0.016	0.349	0.381	0.690	<0.001		
T-test	-1.74	-1.70	**-2.63**	**-2.59**	**-3.74**	**-4.04**	**-3.51**	**-3.48**		
	0.101	0.107	**0.020**	**0.022**	**<0.001**	**<0.001**	**0.001**	**0.005**		
M-W U test	19.0 -1.95	19.5 -1.90	**68.0 -3.05**	**68.0 -3.04**	**367.5 -3.46**	**342.5 -3.61**	**587.0 -3.36**	**534.0 -3.58**		
	0.056	0.056	**0.002**	**0.002**	**0.001**	**<0.001**	**0.001**	**<0.001**		
Miocene	Hemphillian-Clarendonian		Miocene							
	$\delta^{13}C$ (VPDB)	Percent C_4	$\delta^{13}C$ (VPDB)	Percent C_4	$\delta^{13}C$ (VPDB)	Percent C_4				
Mean ± s.d.	-6.8±0.76‰	23.6±5.09%	-6.8±0.83‰	23.5±3.0%						
Number	153		230							
Levene's test	4.30	5.75	1.75	72.36						
	0.040	0.018	0.187	<0.001						
T-test	**-2.01**	-1.70	-1.82	-1.69						

	0.047	0.100	0.070	0.106
M-W U test	1482.0 -0.91	1470.5 -0.96	2156.0 -1.15	2041.5 -1.45
	0.365	0.339	0.252	0.135

Supplemental Table 5. Results of one-way ANOVA with post hoc Scheffè tests for multiple comparisons for all $\delta^{13}C$ values (upper entries in each row, F=81.9, p<0.001) and estimates of percent C_4 biomass (lower entries in each row, F=180.2, p<0.001) in each biostratrigraphic interval. P-values in bold are statistically significant at α=0.05.

$\delta^{13}C$ (VPDB) **Percent C_4**		mean	sd	n	Modern	Late Blancan-Early Irvington	Middle Blancan	Early Blancan	Hemp
Modern (percent C_4 only)		—	—	—					
	C_4	78.1	10.86	20					
Late Blancan-Early Irvingtonian	C	-2.6	1.18	39					
	C_4	54.5	8.26		**<0.001**				
Middle Blancan	C	-5.0	1.10	27		**<0.001**			
	C_4	38.3	7.40		**<0.001**	**<0.001**			
Early Blancan	C	-4.9	0.90	106		**<0.001**	0.997		
	C_4	37.6	6.06		**<0.001**	**<0.001**	0.999		
Hemphillian	C	-6.5	0.31	10		**<0.001**	**0.003**	**<0.001**	
	C_4	25.8	2.09		**<0.001**	**<0.001**	**0.003**	**0.001**	
Clarendonian	C	-7.6	0.91	12		**<0.001**	**<0.001**	**<0.001**	0.105
	C_4	17.4	6.07		**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.166

Supplemental Table 6. Results of Mann-Whitney U tests for differences in mean $\delta^{13}C$ values of paleosol carbonates in each biostratigraphic intervals. 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 α=0.05.

Meade $\delta^{13}C$ (VPDB)	n	Late Blancan-Early Irvington	Middle Blancan	Early Blancan	Hemphillian
Late Blancan-Early Irvington	39	—			
Middle Blancan	27	**83.0 -5.79** **<0.001**			
Early Blancan	106	**151.5 -5.54** **<0.001**	1230.5 -1.12 0.262		
Hemphillian	10	**0.0 -4.84** **<0.001**	**12.5 -4.20** **<0.001**	**58.0 -4.65** **<0.001**	
Clarendonian	12	**0.0 -5.20** **<0.001**	**12.5 -4.56** **<0.001**	**25.5 -5.44** **<0.001**	**18.0 -2.78** **0.004**
Miocene combined	22	**0.0 -6.45** **<0.001**	**25.0 -5.47** **<0.001**	**83.5 -6.84** **<0.001**	N/A

Supplemental Table 7. Results of Mann-Whitney U tests for differences in mean percent C_4 biomass indicated by $\delta^{13}C$ values of paleosol carbonates and estimated $\delta^{13}C$ value of atmospheric CO_2 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 α=0.05.

Meade Percent C_4	n	Modern	Late Blancan-Early Irvington	Middle Blancan	Early Blancan	Hemphillian
Modern	33	—				
Late Blancan-Early Irvington	39	**29.0 -5.78** **<0.001**				
Middle Blancan	27	**0.0 -5.81** **<0.001**	**85.5 -5.75** **<0.001**			
Early Blancan	106	**0.0 -7.08** **<0.001**	**116.0 -8.70** **<0.001**	1374.5 -0.32 0.752		
Hemphillian	10	**0.0 -4.40** **<0.001**	**0.0 -4.84** **<0.001**	**0.0 -4.62** **<0.001**	**39.5 -4.83** **<0.001**	
Clarendonian	12	**0.0 -4.67** **<0.001**	**0.0 -5.20** **<0.001**	**0.0 -4.93** **<0.001**	**14.5 -5.54** **<0.001**	**17.0 -2.84** **0.003**
Miocene (Meade)	22	**0.0 -5.54** **<0.001**	**0.0 -6.44** **<0.001**	**0.0 -5.97** **<0.001**	**54.0 -7.03** **<0.001**	N/A