Revista Mexicana de Ciencias Geológicas, v. 21, núm. 1, 2004, p. 54-70

Paleopedology of soils in thick Holocene loess, Nebraska, USA

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ABSTRACT

Bignell Loess is a Holocene loess unit that has accumulated in the central Great Plains since 9,000 ^{14}C yr BP. The Brady Soil separates Bignell Loess from last glacial Peoria Loess and thick sections, which can reach 6 m thickness, may contain four buried soils beneath the modern surface soil. The Brady Soil has A/B/C horizonation, including a thick dark A and a blocky or prismatic structured B horizon. The Brady soil is intensely burrowed, probably by nymphs of cicada species, which require woody vegetation. Secondary carbonate is present in all genetic horizons and was emplaced post burial. The Holocene soils are dominated by A horizon characteristics, namely dark colors, but blocky or prismatic structured B horizons occur in several sections. Secondary carbonate is present in most, but not all Holocene soils. Three phases of loess deposition and soil formation are evident from the thick proximal stratigraphic sections presented here. Initial rates of Bignell Loess deposition were low relative to the rate of soil formation, producing a basal aggraded A horizon above the Brady Soil, that is capped by a increment of loess with minimal pedogenic features. The middle portion of the Bignell Loess is finer textured and contains multiple dark buried soils. The final increment of loess is coarser and contains the weakly expressed modern surface soil. Climatically, termination of Brady Soil formation marks a shift to drier Holocene climates with a decrease in woody species, episodes of new loess deposition and soil formation, and secondary carbonate accumulation.

Key words: Bignell Loess, Brady Soil, paleopedology, Holocene.

RESUMEN

El Loess Bignell es una unidad de loess holocénico que se ha acumulado en la parte central de las Grandes Planicies desde 9,000 años AP (de acuerdo a análisis de ^{14}C). El Suelo Brady separa al Loess Bignell del Loess Peoria del último glacial, y secciones gruesas, que pueden alcanzar 6 m de espesor, pueden contener cuatro suelos sepultados debajo del suelo superficial moderno. El Suelo Brady muestra un perfil A/B/C, con un horizonte A, grueso y oscuro y otro B con estructura en bloques o prismática. Este suelo ha sido intensamente bioturbado (cavado), probablemente por ninfas de la especie cicada, que requieren vegetación boscosa. En todos los horizontes genéticos se presenta carbonato secundario, emplazado después del sepultamiento. Los suelos Holocénicos están dominados por las características del horizonte A, mostrando colores obscuros, pero en varias secciones se presentan horizontes B con estructura en bloques o prismática. En la mayoría pero no en todos los suelos Holocénicos, se tienen carbonatos secundarios. A partir de las gruesas secciones estratigráficas cercanas, aquí presentadas, son evidentes tres fases de depositación de loess, y formación de suelo. Las tasas iniciales de depositación del Loess Bignell fueron bajas en relación con las de formación del suelo, produciendo un horizonte A basal, agradado, encima del Suelo Brady, que está cubierto por loess, con mínimas características pedogénicas. La porción central del Loess Bignell muestra una textura fina y contiene múltiples suelos *obscuros, sepultados. Su parte superior es más gruesa e integra al suelo superficial moderno, débilmente expresado. Climáticamente, la finalización de la formación del suelo Brady marca un cambio hacia climas del Holoceno más secos, con una disminución de especies boscosas, episodios de nueva depositación de loess, formación de suelo y acumulación secundaria de carbonatos.*

Palabras clave: Loess Bignell, Suelo Brady, paleopedología, Holoceno.

INTRODUCTION

The Great Plains of North America contains a widespread record of Holocene drought and resulting eolian activity. Many sand dune fields were probably active between 9,000 and 5,000 calendar yr BP (Forman *et al.*, 2001), although stratigraphic records of this interval are not preserved in many areas. There is a better record of brief episodes of activity during the late Holocene, including the past 1,000 years (see review in Forman *et al.*, 2001). Loess deposition was also widespread in portions of the central and northern Great Plains during the Holocene (Clayton *et al.*, 1976; Olson *et al.*, 1997; Johnson and Willey, 2000; Mason and Kuzila, 2000). While previous research has established a broad understanding of the chronology, distribution, and driving climatic mechanisms for Holocene loess deposits on the Great Plains, very little has been published regarding the paleopedology of these loess deposits. The paleopedology of Holocene loess deposits can provide an important record of climate change and landscape responses such as loess deposition and soil formation.

In the central Great Plains region of eastern Colorado, central Nebraska, and northern Kansas, Holocene loess is referred to as Bignell Loess and is separated from last glacial (Wisconsin age) loess by the Brady Soil, which formed during the Pleistocene–Holocene transition (Schultz and Stout, 1948; Johnson and Willey, 2000). Multiple buried soils within the Bignell loess have been recognized previously (Thorp *et al.*, 1951; Johnson and Willey, 2000), but only one section along Mirdan Canal in central Nebraska has been described in detail (Mason and Kuzila, 2000). The Mirdan Canal section contains the Brady Soil, and within the Bignell Loess, three buried soils and the modern surface soil. The buried soils have varying degrees of morphological expression, most typically A/C horizonation. The uppermost soil, radiocarbon dated to 3,010 ± 90 ^{14}C yr BP expresses B horizon morphology. The entire section of Bignell Loess and soils is approximately 4 m thick and accumulated since 8,790 ± 250 ^{14}C yr BP and more likely 9,330 ± 130 ^{14}C yr BP, in response to variations in climate (Mason and Kuzila, 2000).

In North Dakota, Holocene loess is included in the Oahe Formation, and thick sections crop out along bluffs of the Missouri River (Clayton *et al.*, 1976). Clayton *et al.* describe thick sections of the Oahe Formation with multiple buried soils that, while not precisely dated, overlie 13,000 ^{14}C yr BP glacial deposits and contain archaeological material that indicate sedimentation and soil formation occurred episodically into the late Holocene. A maximum of three buried soils have been reported in the Oahe Formation, and most consist of A/C horizonation. The base of the Holocene sediments does contain a well-expressed soil called the Leonard Paleosol, which is temporally equivalent with the Brady Soil. The Leonard Paleosol expresses some B horizon characteristics, has darker colors than either the modern surface A horizon or any other A horizons in the Oahe Formation, and has distinctive faunal burrows that are absent from the overlying soils. Clayton *et al.* (1976) interpret the darker colors and faunal burrows to indicate that the Leonard Paleosol formed in an environment with more moisture relative to the Holocene. Holocene age loess that is equivalent to the Oahe Formation exists in South Dakota (Ahler *et al.*, 1974), but details on the paleopedology are scarce.

In southwest Kansas, Olson *et al.* (1997) reported a middle to late Holocene loess unit. The loess buries a truncated soil with radiocarbon ages between 6,700 and 6,000 ^{14}C yr BP. The soil is clay enriched relative to the overlying and underlying loess, but contains minimal evidence of clay illuviation. Olson *et al.* (1997) note that their study documents a period of landscape stability and soil formation during the middle Holocene, which previously was not formally recognized in the Bignell Loess.

This paper reports new data from an investigation into the age, source, and pedogenic properties of Bignell Loess in the central Great Plains. Specifically, this paper reports the occurrence and pedologic characteristics of multiple buried soils within thick proximal sections of late Wisconsin Peoria Loess and Holocene Bignell Loess in Nebraska. The sections described here provide a high-resolution record of Holocene loess deposition and soil development in central North America.

NEBRASKA PHYSIOGRAPHY, CLIMATE, AND GENERAL SOILS BACKGROUND

The State of Nebraska is located in the central Great Plains of North America. Most of the State is blanketed by considerable thickness of Quaternary loess, eolian sand, or alluvium (Figure 1). Underlying are Tertiary sediments and sedimentary rocks that dip and thin to the southeast. In

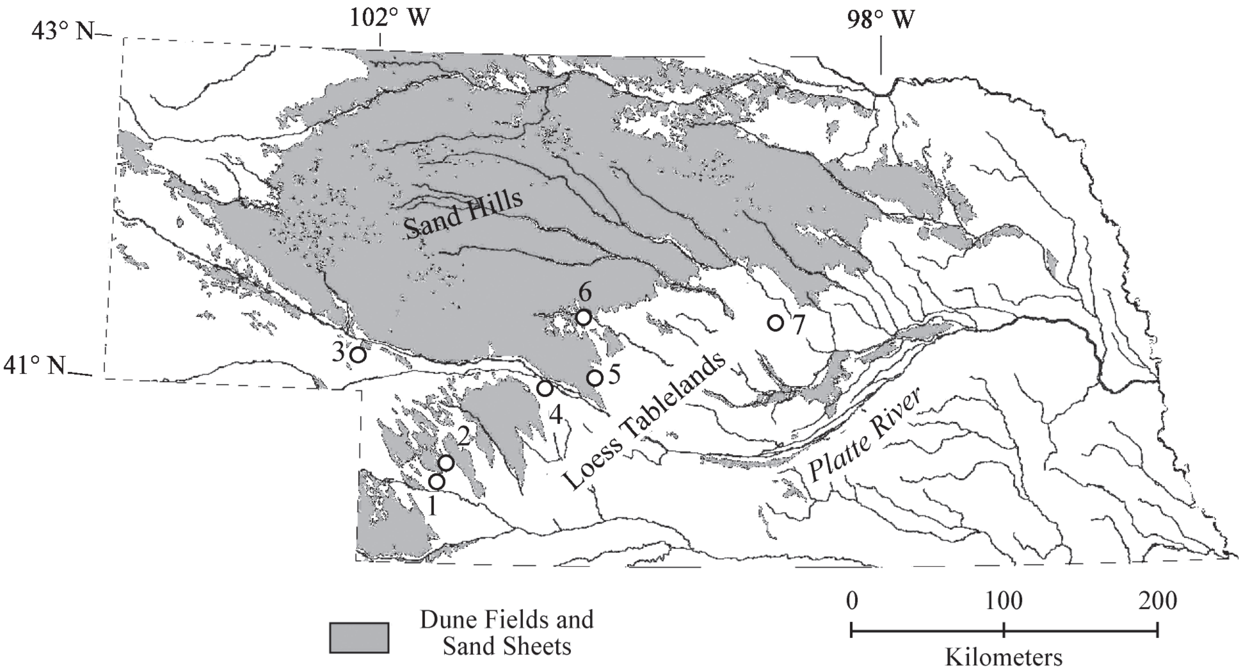

Figure 1. Map of Nebraska showing location of study sites relative to the major sand dune areas and drainage network. Excepting the river valleys and some areas in the western panhandle, all areas in white are loess covered. Sites: 1: Wauneta Road Cut; 2: Cliff Dwellers Canyon; 3: Dankworth Canyon; 4: Moran Canyon; 5: County Line Ranch; 6: Logan Road cut. Site 7 is Mirdan Canal of Mason and Kuzila (2000).

eastern Nebraska Cretaceous bedrock underlies the Quaternary sediments. The Republican, Platte, and Missouri Rivers and their many tributaries drain the State.

The Nebraska Sand Hills occupy much of the central part of the state and form the largest sand dune area in the western hemisphere (Bleed and Flowerday, 1990, p.1). Other sand dune areas, such as the Lincoln County dune field and the Wray dune field lie south of the Sand Hills. A relatively sharp line demarcates the boundary between the Sand Hills (and similar dune areas) and loess, especially last glacial Peoria Loess, to the south and east. At the boundary, loess thickness often exceeds 30 m and eastward the deposits thin systematically, with locally increased thickness adjacent to major river valleys (Mason, 2001).

The topography of loess-covered regions consists of extensive flat uplands, locally known as ‘tables’, separating drainages. The tables are largest south and east of the Platte River, in many cases covering hundreds of km^2. In thicker loess near the Sand Hills-loess border, the landscape is highly dissected and loess canyons separate small isolated tables. Well-drained surface soils formed in loess in this region include Typic and Aridic subgroups of Argi- and Haplustolls, as well as Inceptisols and Entisols on eroding hillslopes.

The climate of Nebraska ranges from subhumid in the southeast to semiarid in the west. Nebraska exhibits a strong east to west precipitation gradient with minimal change in mean annual temperature. Precipitation varies from 800 mm in the southeast to <400 mm in the western part of the state. Most precipitation falls as rain during the April through September growing season and is stored for evapotranspiration. Mean annual temperatures vary from 8ºC in the south to 11ºC in the north; seasonal extremes can be large. Additionally, wind is a persistent climatic feature of Nebraska and in combination with periodic or prolonged drought and the available sediment supply, dust transport can easily occur. Muhs *et al.* (1996, p. 145) describe adjacent northeast Colorado as being near “a climatic boundary that separates active from stable sand”. Forman *et al.* (2001) suggest that a 30% decrease in precipitation could reactive many sand dune fields on the Great Plains. The flat loess-covered tables extending across Nebraska thus hold the potential to capture a Holocene climate record of loess deposition and soil formation.

STUDY SITES AND METHODS

Our study area extends >200 km along the Sand Hills-loess border (Figure 1). Modern precipitation varies by 145 mm between the westernmost (Dankworth Canyon) and easternmost (Mirdan Canal) sites, with the general trend of increasing precipitation to the northeast (Table 1). Stratigraphic sections were described and sampled from road cuts or cores. Thick sections of Bignell Loess can be found in road cuts at the edges of tables located at the boundary between loess and dune sand (Figure 1; Table 1). At table

Table 1. Location and climate data for sites discussed in text. Climate data from High Plains Regional Climate Center (http://hpccsun.unl.edu/products/historical.htm).

Site	Latitude and Longitude	Mean annual Temperature (ºC)	Mean annual precipitation (mm)	Reporting Station
Wauneta Road Cut	40º 29′ 59″ N 101º 25′ 10″ W	9.7	495	Wauneta
Cliff Dwellers Canyon	40º 35′ 44″ N 101º 21′ 22″ W	9.7	495	Wauneta
Dankworth Canyon	41º 14′ 10″ N 102º 4′ 53″ W	9.5	442	Oshkosh
Moran Canyon	41º 01′ 29″ N 100º 38′ 38″ W	9.2	501	North Platte
County Line Ranch	41º 07′ 56″ N 100º 14′ 42″ W	10.3	549	Gothenburg
Logan Road Cut	41º 28′ 41″ N 100º 18′ 35″ W	9.5	556	Arnold
Mirdan Canal	41º 27′ 13″ N 98º 49′ 37″ W	9.7	587	Mason and Kuzila (2000)

edges where no road cut exists or that were not exposed because of slumping or vegetation cover, we extracted a 7.6 cm diameter core near the edge of the table using a hydraulic soil coring machine. In addition to the thick stratigraphic sections reported in this paper, we collected cores from a series of transects across most of the loess covered region in south-central Nebraska as part of our effort to characterize the extent and pedogenic properties of Bignell Loess.

Pedogenic features were described using standard terminology (Soil Survey Staff, 1993). Samples were collected from each genetic horizon we described, and horizons thicker than 20 cm were subdivided to maintain close interval sampling. This paper largely reports field data of stratigraphy and pedologic characteristics, but some laboratory results are included. Analyses presented here include sand (>63 µm) by wet sieving and organic carbon (OC) by loss on ignition (Konen *et al.*, 2002).

BIGNELL LOESS IN NEBRASKA: DISTRIBUTION, SOURCE, AND CHRONOLOGY

Bignell Loess thickness in Nebraska reaches at least 6 m, but is typically 2–4 m thick in proximal sections. Away from the thick proximal sites, Bignell Loess thins to a featheredge in south central and eastern Nebraska, where it is incorporated into the modern soil of stable flat tables (Kuzila, 1995), and an even thinner increment may be present but not detectable farther east and south. Our observations indicate Bignell Loess is not recognizable on hillslopes in rolling topography; it has evidently been eroded. The thickness and grain size trends of Bignell Loess generally follow those of the late Wisconsin (last glacial) Peoria Loess, with the proximal edge corresponding to the Sand Hills-loess boundary (Mason *et al.*, 2002). The distribution pattern indicates westerly or northwesterly winds transported the dust.

The thickness and distribution trends of Bignell Loess are not associated with river valleys in the region, but rather, are related to Holocene dune activity in the Sand Hills and adjacent dune fields (Mason *et al.*, 2002). This contrasts with previous work, which described the thickest sections, including the Bignell Hill type section, on the bluffs of the Platte River Valley, long assumed to have been the source of the dust (Schultz and Stout, 1945; 1948; Dreeszen, 1970; Pye *et al.*, 1995).

Bignell Loess accumulated episodically throughout the Holocene. The average of numerous radiocarbon ages from humus at the top of the Brady Soil indicates deposition began approximately 9,000 ^{14}C yr BP (Johnson and Willey, 2000). This age is supported by new Optical Stimulated Luminiscence (OSL) ages from the Bignell Hill Type section (unpublished data, J.A. Mason), along with numerous other Thermoluminescence (TL) and ^{14}C ages (*e.g.*, Maat and Johnson, 1996; Muhs *et al.*, 1999). Deposition continued through the late Holocene, based on a radiocarbon age of *ca.* 3,010 ± 90 ^{14}C yr BP from the first buried soil below 53 cm depth at Mirdan Canal (Mason and Kuzila, 2000).

LATE QUATERNARY SOIL STRATIGRAPHY

The Brady soil is the only formally defined late Pleistocene or Holocene soil stratigraphic unit in loess in Nebraska or surrounding states. A temporally equivalent soil occurs in dunes, lunettes, alluvial fans, and alluvium in the region (see references in Johnson and Willey, 2000). Buried soils above the Brady Soil and within the Bignell Loess have been recognized for some time (*e.g.*, Thorp *et al.*, 1951), but none are described in the formal definition (Reed and Dreeszen, 1965).

We report here that Bignell Loess contains several buried soils in thick proximal settings, especially associated with cliff-top (loess lip) landforms. While van Nest (2002) cites studies indicating the climatic uncertainty of cliff-top deposits, other studies (White, 1960; David, 1970) have noted the sensitivity of cliff top positions and the high-resolution records they contain. We report several proximal and cliff-top deposits that have a similar stratigraphic and pedologic record, which we believe records a regional climatic signal. Furthermore, part of this research not reported here indicates that as loess thickness decreases from proximal edges, buried soils are still a component of the Bignell Loess, although the resolution of individual soils is more difficult as the stratigraphic section is compressed. Expanded stratigraphic sections are more useful for high-resolution paleoclimatic interpretation (*e.g.*, Huang *et al.*, 2002).

THE BRADY SOIL

The Brady Soil is a morphologically distinct stratigraphic and paleoenvironmental marker in the central Great Plains (Dreeszen, 1970; Martin, 1993; Muhs *et al.*, 1999; Johnson and Willey, 2000; Mason and Kuzila, 2000). The Brady Soil is regionally extensive and is recognized in northeastern Colorado, northern Kansas, and central Nebraska, where it formed in Peoria Loess and was buried by Bignell Loess. The age of the Brady Soil, especially at the Bignell Hill type section, has been the subject of many geochronology studies (Dreeszen, 1970; Maat and Johnson, 1996; Muhs *et al.*, 1999). In addition to Bignell Hill, Johnson and Willey (2000) report the average age of the Brady Soil established from radiocarbon analyses of the upper and lower 5 cm of the Brady A horizon from 13 sites in Nebraska and Kansas. The mean duration of pedogenesis is 1,434 ^{14}C yr (2,041 cal yr), extending from *ca.* 10,500 to 9,000 ^{14}C yr BP. Application of the OSL technique at the Bignell Hill type section also support the radiocarbon analyses, indicating soil formation for <2,000 calendar yr (unpublished data, J.A. Mason).

Morphologically, the Brady Soil has A, B, and C horizon morphology in all sections studied (Table 2). The strength of expression is typically greater than the modern surface soil, indicating that the modern soil is either very young (*i.e.*, <2000 yr) or that the modern environment of the Great Plains is less conducive to soil formation than during formation of the Brady Soil.

In thick stratigraphic sections the A horizon is dark colored, ranging from very dark grayish brown (10YR 3/2) to brown (10YR 4/3). The texture is almost invariably silt loam that is aggregated as weak to moderate, fine or medium subangular blocks. In many sections, the horizon has prismatic structure that parts to blocky or granular structure. The prisms likely originated from subsoil structural processes being overprinted on the original Brady A horizon after it was buried. The thickness of the A horizon generally decreases as modern precipitation increases to the north and east along the border region (Figure 2).

The persistence of dark colors in the Brady soil is not due to high levels of OC. The Brady Soil A horizon commonly only has <0.50 % OC. Modern surface A horizons typically have three to five times the OC content (Figure 3), yet are often nearly the same color. We suggest the dark color of the Brady Soil results from OC remaining in the form of recalcitrant clay–organic matter complexes. Although we have not studied the OC chemistry, studies of Mollisols in the region indicates these soils contain a pool of recalcitrant OC with a turnover time of 200–1,500 yr (Parton *et al.*, 1987). Since loess accumulation is relatively slow, and in an oxidizing environment, the potential for preservation of humus is low and the dark colors must be associated with chemically recalcitrant OC. Some buried soils have mottled areas in buried A horizons that probably represent areas of localized OC retention.

Almost invariably, secondary calcium carbonate occurs in the A and other horizons of the Brady Soil. In most sections, the carbonate can be traced downward along structure faces from the overlying soils in Bignell Loess into the Brady A horizon, indicating the carbonate was emplaced during or after formation of the overprinted prismatic structure. The most common form of the carbonate is as threads or filaments that are probably root traces, but soft masses also occur.

The B horizon is most often described as a structured Bw or Bk, but Bt is also used. Typically, the B horizon is a brown or yellowish brown (10YR 4/3, 10YR 5/3, or 10YR 5/4) silt loam with moderate to weak, usually fine subangular blocky or prismatic structure. Thickness of the B horizon is variable (Figure 2), and is usually subdivided on the basis of coarsening and/or weakening structure with depth, along with variations in faunal burrows, secondary carbonate, or ped coatings. The faces of peds commonly have patchy dark coats or stains (10YR 3/1) that appear in the field as very thin clay–humus coatings. We do not yet have thin section data for these soils, but Mason and Kuzila (2000) noted the occurrence of clay cutans in the Brady Soil at Mirdan Canal, and Blecker *et al.* (1997) described prominent, discontinuous clay cutans on ped faces of early Holocene alluvial soils further west in Colorado. The amount of illuvial clay is <1%, not sufficient to classify as an argillic horizon. Nevertheless, the occurrence of illuvial clay is significant because its presence requires the leaching of carbonates before clay translocation can occur (Jenny, 1980; Bronger *et al.*, 1998).

Evidence of carbonate leaching from the Brady Soil is difficult to interpret in the field. The content of detrital carbonate in Nebraska Peoria Loess is often as low as 2–4% (unpublished data, J. A. Mason) Highly reactive secondary carbonate is typically pervasive, although it probably does not represent a large percentage of soil mass. Some profiles do not effervesce (*e.g.*, Moran Canyon) and Muhs *et al.* (1999) report lower calcium carbonate equivalent values in the Brady Soil in Colorado, presumably related to leaching.

Lower, transitional BC horizons are typical and are often the thickest horizons in the Brady Soil (Figure 2). Pedogenic modification of the loess is mostly limited to blocky or fine prismatic structure development, modest color development (10YR 5/3 versus 2.5Y 5/3 for C horizon), and secondary carbonate.

A special feature of the Brady Soil not previously noted is the occurrence of a zone of pervasive burrowing in the A and upper B horizons (Figure 4). We have noted these burrows in every Brady Soil in thick stratigraphic sections. The burrows are typically 0.5 to 1 cm in diameter, occasionally smaller, and extend from the Brady Soil surface into the B horizon, as much as about 90 cm beneath the former Brady surface. The depth of burrows is greater in the areas that are drier today. Commonly a transitional (AB or BA) horizon is described on the basis of mixed colors and large volume of burrows. The burrows are backfilled

Table 2. Pedologic description of thick Bignell Loess sections.

Buried soils	Horizon	Depth (cm)	Color (moist)	Texture[a]	Structure[b]	Ped coatings[c]	$CaCO_3$ features[d]	Reaction in 10% HCl[e]	Cylindrical burrows[f]	Lower boundary[g]
Wauneta Road Cut										
	AC	0 – 24	10YR 4/2	vfsl	1 f sbk → 1 f gr					c
Soil 1	A1b	24 – 35	10YR 2/1	sil	ma			e		c
	A2b	35 – 48	10YR 3/2 & 3/1	l	1 f sbk					g
	ACb	48 – 57	10YR 4/2	l	1 f sbk	1 p 10YR 3/2	1 f threads	e		a
Soil 2	A1b	57 – 70	10YR 3/1 & 4/2	l	2 f sbk	1 p 10YR 3/1		e		c
	A2b	70 – 87	10YR 4/2	sil	2 m sbk → 2 f sbk	2 p 10YR 3/2		e		g
	Bkb	87 – 110	10YR 5/3	l	1 m sbk → 2 f sbk		2 f threads	se		g
Soil 3	Ab	110 – 133	10YR 4/2 & 5/3	l	1 f sbk		1 f threads	se		c
	ABb	133 – 143	10YR 5/3	sil	1 f sbk	3 p 10YR 4/2	1 f threads	se		c
	Bkb	143 – 188	10YR 5/3	sil	1 f sbk	2 p 10YR 4/2	2 f threads	se		c
	C1b	188 – 315	10YR 5/4	vfsl	v1 f sbk			se		g
	C2b	315 – 371	10TR 5/4	sil	v1 f sbk			se	4 cm	g
Soil 4	CAb	371 – 386	10YR 4/3 & 3/2	l	v1 f sbk			se		c
	Akb	386 – 399	10YR 3/2	sil	1 f sbk	1 p 10YR 3/1	3 f threads	se		c
Brady Soil	2Ak1b	399 – 431	10YR 2/1 & 3/1	sil	2 f sbk		3 f threads	se		c
	2Ak2b	431 – 443	10YR 3/1 & 3/2	sil	1 f sbk		3 f threads	se	3 (4 – 8 mm)	g
	2Ak3b	443 – 455	10YR 3/1 & 3/2	sil	2 f sbk		3 f threads	se	3 (4 – 8 mm)	c
	2Bk1b	455 – 473	10YR 5/4	sil	2 f sbk		2 f threads	se	3 10YR 3/1 (5 – 10 mm)	g
	2Bk2b	473 – 489	10YR 5/4	sil	1 f sbk		2 f threads	e	1 (10YR 3/2)	g
	2BCkb	489 – 505	10YR 5/4	sil	1 f sbk		2 f threads	e		g
	2C	505 – 600+	10YR 5/3	sil	v1 f sbk			se		

Table 2. Continued.

Buried soils	Horizon	Depth (cm)	Color (moist)	Texture[a]	Structure[b]	Ped coatings[c]	$CaCO_3$ features[d]	Reaction in 10% HCl[e]	Cylindrical burrows[f]	Lower boundary[g]
Cliff Dwellers Canyon (16G01B)										
	A	0 – 14	10YR 3/2	sil	1 f sbk → 1 f gr					c
	AC1	14 – 21	10YR 4/2	sil	1 f sbk → 1 f gr					c
	AC2	21 – 44	10YR 4/2	l	1 m sbk → 1 f sbk			e		g
Soil 1	Ab	44 – 60	10YR 3/1	sil	1 m sbk			e		c
	Akb	60 – 74	10YR 3/1	sil	1 m sbk		2 f spots, threads	e		c
	Bk1b	74 – 97	10YR 4/2	sil	1 m sbk	1 p 10YR 3/1	1 f spots, threads	se		g
	Bk2b	97 – 114	10YR 4/2	sil	1 f sbk		1 f threads	se	1 (4 – 5 mm)	c
Soil 2	Ab	114 – 137	10YR 4/2 & 3/2	sil	1 f sbk			se		c
	Bwb	137 – 179	10YR 4/2	sil	1 f sbk			se		c
Soil 3	Ab	179 – 198	10YR 3/2	sil	1 f sbk			e		c
	Bwb	198 – 239	10YR 5/3	sil	1 – 2 f sbk	1 p 10YR 4/2		se		g
	BC1b	239 – 288	2.5Y 5/3	sil	1 – 2 f sbk			se		g
	BC2b	288 – 300	2.5Y 5/3	sil	1 f sbk			se		c
Soil 4	CAb	300 – 316	2.5Y 5/3	sil	1 m sbk	2 p 2.5Y 4/2	1 f threads	se		c
	ACkb	316 – 334	2.5Y 4/2	sil	1 m sbk		2 f threads	se		c
	Akb	334 – 346	10YR 3/2 & 3/1	sil	2 f sbk		2 f threads	se		c
Brady Soil	2Akb	346 – 396	10YR 3/1	sil	1 m pr → 2 f sbk	2 p 10YR 2/1	3 f threads+	se		c
	2ABkb	396 – 407	10YR 4/3 & 3/1	sil	2 f sbk		3 f threads+	se	3 10YR 3/1 (2 – 6 mm)	g
	2Bkb	407 – 429	10YR 4/3	sil	2 f sbk	2 p 10YR 3/1	3 f threads+	se	3 10YR 3/1	g
	2BCk1b	429 – 448	2.5Y 5/3	sil	1 f sbk		2 f threads	se		g
	2BCk2b	448 – 488	2.5Y 5/3	sil	1 m sbk → 1 f sbk		1 f spots	se		c
	2BCk3b	488 – 518	2.5Y 6/3	sil	1 m pr → 1 f sbk		2 f threads	se		c
	2C	518 – 720+	2.5Y 6/3	sil						

Table 2. Continued.

Buried soils	Horizon	Depth (cm)	Color (moist)	Texture[a]	Structure[b]	Ped coatings[c]	$CaCO_3$ features[d]	Reaction in 10% HCl[e]	Cylindrical burrows[f]	Lower boundary[g]
Dankworth Canyon										
	A1	0 – 12	10YR 4/2	vfsl	1 f sbk → 1 f gr			e		c
	A2	12 – 22	10YR 4/2	vfsl	1 f sbk → 1 f gr			e		c
	A3	22 – 32	10YR 3/2	vfsl	1 f sbk → 1 f gr			e		a
Soil 1	Ab	32 – 40	10YR 2/2	vfsl	2 f pr → 1 f sbk			e		c
	ABb	40 – 64	2.5Y 3/2	vfsl	2 m pr → 2 m sbk			e		c
Soil 2	Ab	64 – 73	2.5Y 3/2	vfsl	2 f sbk			e		c
	Bwb	73 – 84	2.5Y 4/2	vfsl	2 m pr → 1 f sbk		1 f threads	e		c
Soil 3	A1b	84 – 107	2.5Y 3/2	sil	2 c pr → 2 m sbk		3 f threads, patches	se		a
	A2b	107 – 112	2.5Y 3/1	sil	2 c pr → 1 f sbk		2 f threads	se		a
	AB1b	112 – 116	2.5Y 4/2	vfsl	2 c pr → 1 f sbk		2 f threads	se		a
	AB2b	116 – 120	2.5Y 3/2	vfsl	2 c pr → 1 f sbk		2 f threads	se		a
	AB3b	120 – 134	10YR 3/2	sil	1 f pr → 1 f sbk		1 f threads	e		a
Soil 4	A1b	134 – 140	10YR 3/2	sil	1 f sbk		1 f threads	e		a
	A2b	140 – 154	2.5Y 4/2	vfsl	1 f sbk		2 f threads	se		a
Soil 5	A1b	154 – 190	2.5Y 3/1	vfsl	2 m pr → 2 m sbk		2 f threads	se		c
	BC1b	190 – 298	2.5Y 5/2	vfsl	1 m sbk			se		c
	BC2b	298 – 316	2.5Y 5/2	vfsl	1 m sbk			se		c
Soil 6	Ab	316 – 334	2.5Y 3/2	sil	1 m sbk			se		c
	Akb	334 – 355	10YR 3/2	sil	2 m sbk		3 f threads	se		g
Brady Soil	2Akb	355 – 401	10YR 3/2	sil	2 f pr → 2 m sbk	3 p 10YR 3/1	3 f threads	se		g
	2Bk1b	401 – 430	10YR 5/3	sil	2 f sbk		3 f threads, patches	se	2 10YR 3/1	g
	2Bk2b	430 – 455	10YR 5/3	vfsl	1 f sbk		2 f threads	se		g
	2BCb	455 – 480	10YR 5/3	vfsl	1 f sbk			se		g
	2C	480+	10YR 5/3	vfsl	v1 f sbk			se		

Table 2. Continued.

Buried soils	Horizon	Depth (cm)	Color (moist)	Texture[a]	Structure[b]	Ped coatings[c]	$CaCO_3$ features[d]	Reaction in 10% HCl[e]	Cylindrical burrows[f]	Lower boundary[g]
Moran Canyon (5G01A)										
	A1	0 – 9	7.5 YR 3/1	vfsl	1 f sbk					c
	A2	9 – 36	10YR 3/1	vfsl	1 m pr → 1 f gr					c
Soil 1	Ab	36 – 64	7.5YR 2/1	vfsl	1 f pr →1 f gr					c
	AB1b	64 – 94	10YR 3/2	vfsl	1 m pr → 2 f sbk	1 p 10YR 4/2				g
	AB2b	94 – 123	10YR 3/2	sil	1 m pr → 1 f sbk					g
	AB3b	123 – 148	10YR 3/2	sil	1 m sbk → 2 f sbk					c
	Bk1b	148 – 167	10YR 4/2	sil	1 m sbk → 2 f sbk	2 p 10YR 4/2	2 f threads			c
	Bk2b	167 – 190	10YR 4/2	vfsl	1 m pr → 2 f sbk		2 f threads, patches	e		g
	Bk3b	190 – 222	2.5Y 5/3	vfsl	2 f sbk	1 p 2.5Y 4/2	2 f threads, patches	e		c
Soil 2	BAk1b	222 – 240	10YR 4/3	vfsl	1 m sbk	2 p 10YR 3/2	3 f threads	e		g
	BAk2b	240 – 263	10YR 4/2	vfsl	1 m sbk		2 f threads	e		c
Brady Soil	2Akb	263 – 300	10YR 3/2	sil	1 f sbk	1 p 10YR 3/1	2 f threads	e		c
	2ABkb	300 – 309	10YR 4/3	sil	2 m pr → 2 f sbk		2 f threads	e	2 10YR 3/2	c
	2Btk1b	309 – 322	2.5Y 4/3	sil	3 f sbk	2 c 2.5Y 4/2	2 f threads		2 2.5Y 5/3	g
	2Btk2b	322 – 353	2.5Y 5/3	sil	2 m pr → 2 m sbk	2 c 2.5Y 5/2	2 f threads			g
	2Bkb	353 – 387	2.5Y 5/3	sil	1 m pr → 2 m sbk	2 c 2.5Y 5/2	2 f threads			g
	2BC1b	387 – 405	2.5Y 5/3	sil	1 m pr → 1 m sbk		v1 f threads			g
	2BC2b	405 – 449	2.5Y 5/3	vfsl	1 m pr → 1 m sbk					g
	2C1b	449 – 546	2.5Y 5/3	vfsl	ma					g
	2C	546 – 575+	2.5Y 5/3	vfsl	ma					
County Line Ranch (14G01G)										
	A	0 – 19	10YR 3/1	vfsl	1 f gr					c
	AC	19 – 31	10YR 4/2	vfsl	v1 f gr					c
Soil 1	Ab	31 – 54	10YR 3/2	vfsl	v1 f gr					c
	Bwb	54 – 80	10YR 4/2	vfsl	1 m sbk → 1 f sbk				1 10YR 3/1	c
Soil 2	Ab	80 – 127	10YR 3/2	vfsl	1 m sbk → 1 f sbk					c
	Bwb	127 – 159	10YR 4/2	l	2 m pr → 1 f sbk		2 f threads		1	g
	BCk1b	159 – 207	10YR 5/3	vfsl	1 m sbk		2 f threads			c
	BCk2b	207 – 250	10YR 5/3	vfsl	1 m sbk	1 p 10YR 4/2	2 f threads			c

Table 2. Continued.

Buried soils	Horizon	Depth (cm)	Color (moist)	Texture[a]	Structure[b]	Ped coatings[c]	$CaCO_3$ features[d]	Reaction in 10% HCl[e]	Cylindrical burrows[f]	Lower boundary[g]
County Line Ranch (14G01G) (continued)										
Brady Soil	2Ak1b	250 – 272	10YR 4/3	sil	1 m sbk	1 p 10YR 4/2	2 m threads, patches	se		c
	2Ak2b	272 – 287	10YR 4/3	sil	2 m pr → 2 f sbk	2 p 10YR 4/2	3 m patches, threads	se	?	g
	2Bk1b	287 – 298	10YR 5/3	sil	2 f sbk	2 p 10YR 4/2	3 m patches, threads	se	2 10YR 3/1	g
	2Bk2b	298 – 312	10YR 5/3	sil	1 f sbk	1 p 10YR 4/2	3 f patches			c
	2BCk1b	312 – 356	2.5Y 5/3	sil	1 m sbk		2 f threads			g
	2BCk2b	356 – 401	2.5Y 6/3	sil	1 m sbk		2 f threads			c
	2C	401 – 425+	2.5Y 5/3	sil	ma					
Logan Road Cut										
	A	0 – 42	10YR 3/2	fsl	1 vf gr					c
Soil 1	A1b	42 – 53	10YR 3/1	l	1 f pr → 1 f sbk					g
	A2b	53 – 74	10YR 3/1	l	1 f pr → 1 f sbk					
	AC1b	74 – 97	10YR 4/2	l	1 f sbk					c
	AC2b	97 – 125	10YR 4/2	l	1 f sbk					
	AC2b	125 – 146	10YR 4/2	l	1 f sbk					?
Soil 2	Ab	146 – 177	10YR 3/1	sil	2 f sbk → 2 vf gr					g
	Bwb	177 – 190	10YR 4/2	sil	2 f sbk	1 p 10YR 3/2				c
Soil 3	Akb	190 – 219	10YR 3/2	sil	1 f sbk		3 f threads			g
	Bk1b	219 – 243	10YR 4/3	sil	2 f sbk	1 p 10YR 3/2	3 f threads	e		g
	Bk2b	243 – 263	10YR 4/3	sil	2 f sbk	1 p 10YR 3/2	3 f threads	e		g
Soil 4	BAk1b	263 – 288	10YR 4/2	sil	2 f sbk	2 p 10YR 3/2	3 f threads	e		c
	BAk2b	288 – 330	10YR 4/2	sil	1 f sbk	2 p 10YR 3/1	2 f threads	e		c
Brady Soil	2Akb	330 – 361	10YR 3/2	sil	2 f sbk	2 p 10YR 3/1	3 f threads	e		g
	2Bkb	361 – 380	10YR 5/3	sil	2 f pr → 2 f sbk		2 f threads		3 10YR 3/1	g
	2BCkb	380 – 399	10YR 5/3	sil	1 f pr → 2 f sbk	1 p 10YR 5/2	3 f threads			g
	2C	399+	2.5Y 5/3	sil	ma					

[a] vfsl: very fine sandy loam; l: loam; sil: silt loam; sicl: silty clay loam.
[b] Grade: v1: very weak; 1: weak; 2: moderate; 3: strong. Size: vf: very fine; f: fine; m: medium; c: coarse; shape: gr: granular; sbk: subangular blocky; pr: prismatic.
[c] Abundance: v1: very few; 1: few; 2: common; 3: many; distribution: c= continuous; p: patchy.
[d] Abundance: v1: very few; 1: few; 2: common; 3: many; size: f: fine; m= medium.
[e] e: weak effervescence; se: strong effervescence; ve: violent effervescence
[f] Abundance: 1: few; 2: common; 3: many
[g] a: abrupt; c: clear; g: gradual

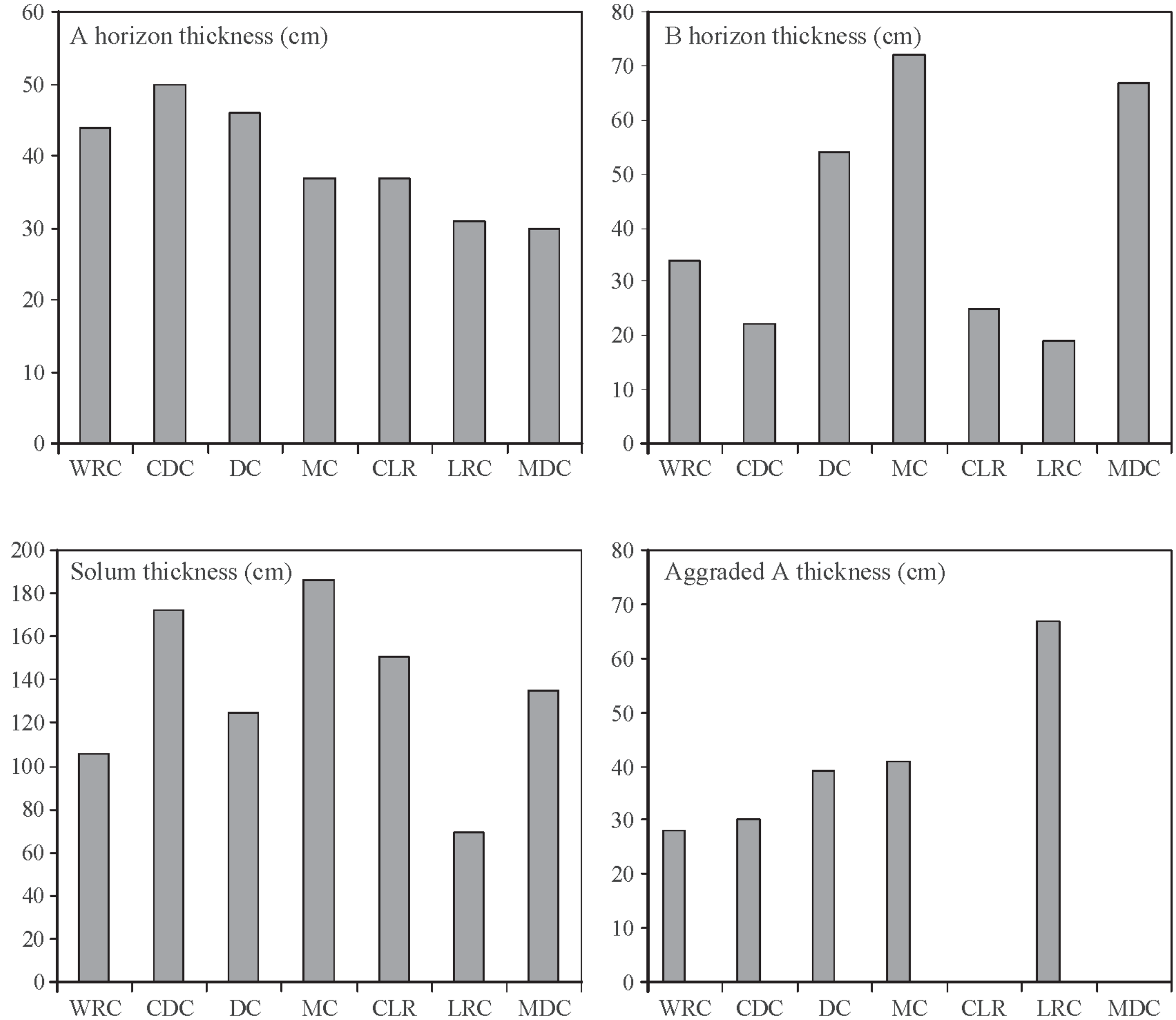

Figure 2. Thickness measures of Brady Soil horizons, illustrating variability we attribute to both pedogenesis and sedimentation. Sites are aligned in a clockwise fashion from the southwest, which roughly follows the increase in modern annual precipitation. WRC: Wauneta Road Cut; CDC: Cliff Dwellers Canyon; DC: Dankworth Canyon; MC: Moran Canyon; CLR: County Line Ranch; LRC: Logan Road Cut; and MDC: Mirdan Canal.

with soil from the same or underlying horizon. Even when filled with soil from the same horizon, the outline of the burrow is evident. In cross section the burrows are elongate channels and in plan view are circular. Many generations of burrows are evident based on crosscutting of burrows. In wind-etched outcrops, the backfilling pattern of the burrows is evident and appears as concave crescentic fills.

Except size, all features of the burrows appear similar to the cicada burrows described in soils and paleosols of the Palouse region in the northwestern United States (McDonald and Busacca, 1990; O'Geen and Busacca, 2001). The burrows are probably similar to those described in the Leonard Paleosol in North Dakota (Clayton *et al.*, 1976), indicating that a large area of the Great Plains must have experienced similar environmental conditions during the terminal Pleistocene. The significance of the burrowed zone may be related to the type of vegetative cover during Brady pedogenesis. O'Geen and Busacca relate the occurrence of modern cicada burrows to the presence of woody vegetation necessary to the life cycle of the cicada. Nymphs that live and burrow below ground need perennial woody tissue for nutrition, and adults lay eggs in above ground wood. In the Palouse, a drier and shrubby environment is indicated by cicada burrows in paleosols, but in the Brady Soil it is not yet clear what the vegetative implications are.

STRATIGRAPHY AND PALEOPEDOLOGY OF HOLOCENE SOILS IN THICK BIGNELL LOESS

Here we present the basic stratigraphic and pedologic characteristics of the thickest proximal sections of Bignell Loess we have found (Figure 5; Table 2). The sites are presented from southwest to northeast along a modern climate gradient where effective precipitation increases.

Wauneta Road Cut

A road cut north of the village of Wauneta, Nebraska, contains the thickest section of Bignell Loess we have described. Bignell Loess in the cut is 5.40 m at its thickest, and adjacent sections along the table edge contain over 6 m of loess exposed in vertical cuts (Figure 6). Due to difficulties in accessing these high vertical cuts, we have not yet described them in pedologic detail. The nearby Hamlet Road Cut, which we have not described in pedologic detail, contains the same stratigraphy.

Above the Brady Soil is Soil 4, an A horizon that is differentiated from the Brady Soil A by a lighter color, coarser texture, and weaker structure (Table 2). We refer to this soil as the basal aggraded A horizon. Pedogenic features decrease in expression upward from the contact with the Brady A, probably because the rate of loess deposition was increasing relative to the rate of pedogenesis. The basal aggraded A horizon occurs in most of the thick sections of Bignell Loess, and its thickness decreases to the northeast (Figure 2).

At Wauneta, the basal aggraded A is overlain by nearly 2 m of coarse textured Bignell Loess with minimal pedogenic features. A finer textured portion of the loess with three discrete buried soils overlies this. The buried soils have thick dark A horizons and two have weakly expressed B horizons. All of the horizons have blocky structure, yet the faces of peds from Soil 3 up to Soil 2 have the appearance of compressed granular structure, resulting from the transformation of A horizons to B horizons as the loess column aggraded. We have noted this in many horizons at every thick section we have studied. Mason and Kuzila (2000) note that buried A horizons with prismatic or subangular blocky macrostructure often contain clusters of microaggregates observable in thin section. We believe the persistence of the granular fabric on ped faces in some horizons reflects a stronger grade of structure at the time of burial, which in turn may reflect combined effects of finer textures and enhanced biologic activity. Finally, the uppermost portion of the Wauneta section is an increment of coarse loess with a very thin modern A horizon.

Cliff Dwellers Canyon (16G01B)

The Cliff Dwellers Canyon site is located north of the Wauneta site. It is a cliff-top site overlooking Cliff Dwellers Canyon that we studied from core. The stratigraphy is nearly the same as at Wauneta, but the increment of loess above the basal aggraded A (Soil 4) is finer textured and much

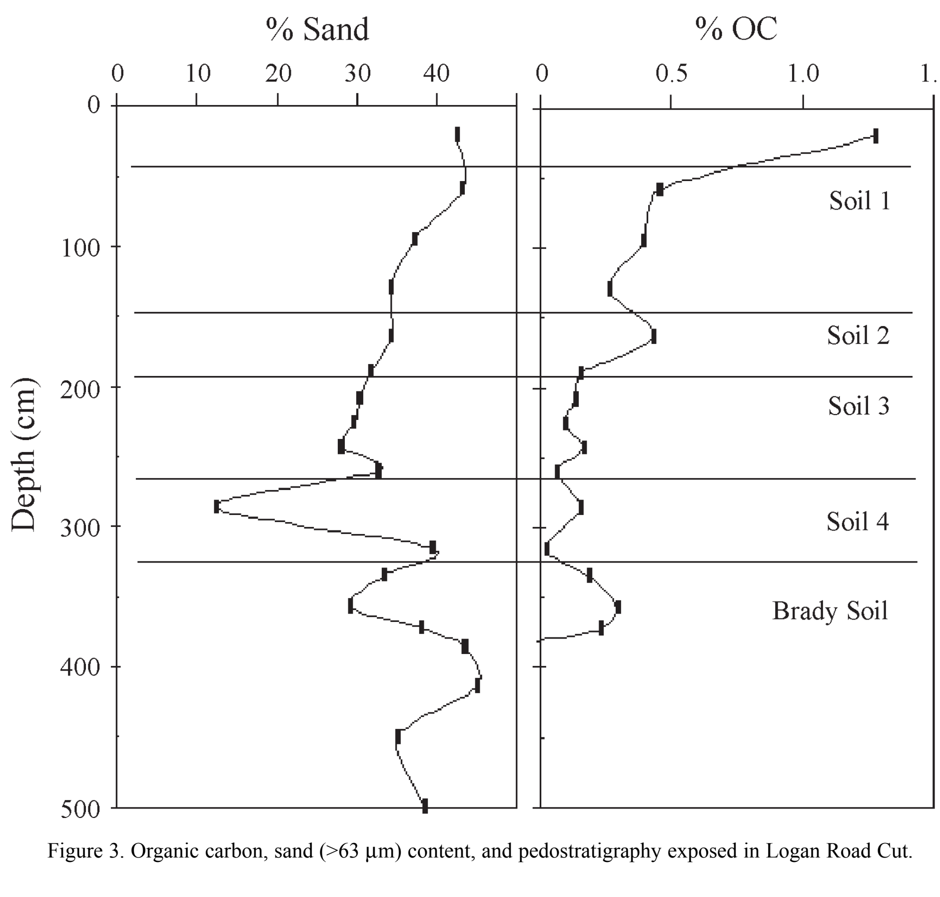

Figure 3. Organic carbon, sand (>63 µm) content, and pedostratigraphy exposed in Logan Road Cut.

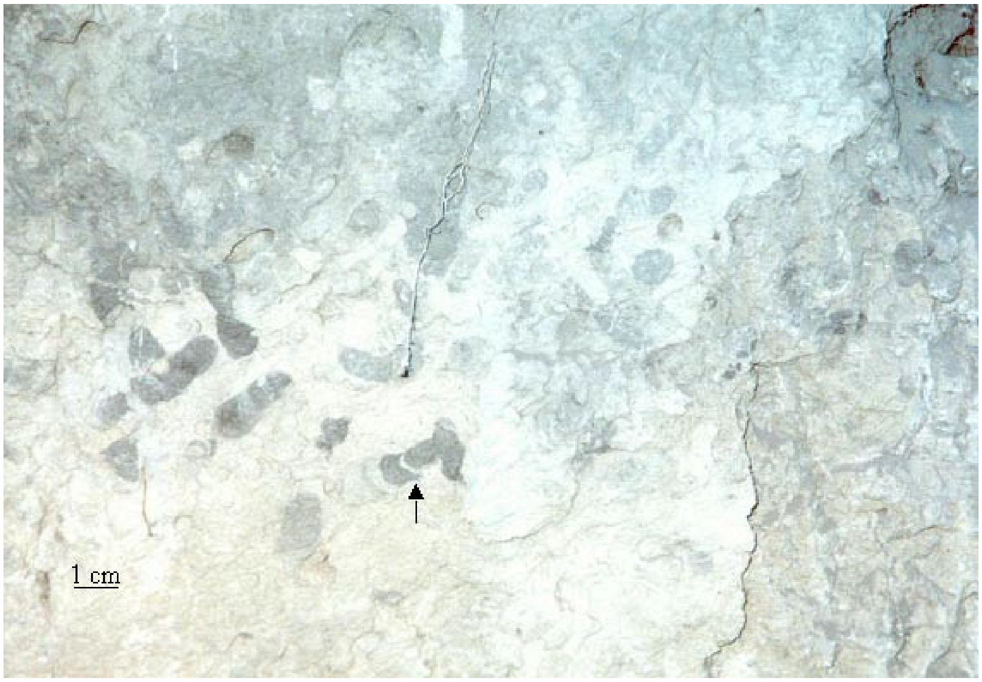

Figure 4. Photograph of lower portions of the burrowed zone typical of the Brady Soil. Burrows stand out best where color contrasts are greatest, namely where A horizon soil is filling burrow in B horizon. The density of burrowing is not as evident in the dark horizon at the top of the photo, but most of the volume of soil is burrowed. View shows both cross section and plan views of burrows. Arrow points to a crescentic-shaped fill of light colored soil, which in addition to size, suggests cicada nymphs as the burrowing insects.

less thick. Finer textures are present throughout and more of the ped faces were noted to have compressed granular fabric. The distribution of secondary carbonate is not continuous through the section, being present in Soil 4 where it extends down into the Brady Soil, and Soil 1, even though the Bignell Loess is calcareous.

Dankworth Canyon

The Dankworth Canyon exposure is located at the head of a canyon cutting into a large table west of the confluence of the North and South Platte Rivers. It is the westernmost site we have studied and differs from the other sections by the occurrence of a pedocomplex that contains up to five buried A horizons in the middle of the Bignell loess (illustrated as a thick dark zone in Figure 5). The basal aggraded A is present here, followed by the pedocomplex, and the section is capped by a coarser textured increment of loess. The pedocomplex is dominated by A horizon characteristics, but some lighter colored and blocky structured horizons are present, although all horizons were noted to have the appearance of compressed granular structure on the faces of blocks or prisms. We interpret the pedocomplex and abrupt boundaries between horizons in the pedocomplex to imply that loess was deposited in pulses, and that the rate of loess deposition was not high enough to overwhelm the rate of pedogenesis.

Moran Canyon (5G01A)

The Moran Canyon site is located near the mouth of Moran Canyon, which extends into very thick and dissected loess tablelands south of the Platte River and at the eastern boundary with the Lincoln County dune field. The canyon is located just west of the Bignell Hill type section of the Brady Soil and Bignell Loess. The Moran Canyon Site includes an outcrop of the Brady Soil and part of the Bignell Loess, however, the section reported here was described from a core collected just above the outcrop.

The section contains just two buried soils above the Brady Soil and with only 263 cm of Bignell Loess is the thinnest proximal section we present. A basal aggraded A horizon is present and the overlying buried soil, in the middle of the stratigraphic section, contains finer textures than the earliest and latest phases of the Bignell Loess. Also significant about this site is that the Brady Soil was described with a Bt horizon.

County Line Ranch (14G01G)

The County Line Ranch site is located on the Odencranze Table on the Lincoln–Custer County line east of the Sand Hills. The site is a cliff-top site that was studied from core. This site only contains two buried soils with B horizons within the Bignell Loess. Both soils are formed in finer textured loess relative to the basal and upper portions of the section. This site does not contain a basal aggraded A horizon above the Brady Soil. The boundary between the Brady and overlying Bignell Loess is clear, possibly resulting from erosion of a basal aggraded soil or very rapid deposition of loess.

Logan Road Cut

The Logan Road Cut section is located in southeastern Logan County, Nebraska (Figure 1) and is the easternmost section we present here. The Mirdan Canal section is further east, but south of the loess border. We have found one other thick section on Judkins Table just to the east of this site, but we have not found any exceptionally thick sections of Bignell Loess further east along the sand loess border. It is not clear if thick proximal sections were never deposited or simply not preserved in the rolling eastern Sand Hills-loess hills border region.

The Bignell Loess section at Logan Road Cut contains four buried soils above the Brady Soil, with the same general stratigraphy observed at the other sites. All of the buried soils are easily recognized by dark A horizon colors and are separated by lighter increments of loess or subsoil (Table 2). Soils 2 and 1 both have A horizons that are darker than the modern surface A, even though organic carbon content is low (Figure 3). A basal aggraded A horizon is present, as is a middle portion of the Bignell that is finer textured and contains buried soils, and the section is capped by a thin increment of coarser loess with only the modern A horizon formed in it.

DISCUSSION

Pedogenic processes and paleoclimatic interpretation of the Brady Soil and Holocene soils

The macromorphology indicates that humus input, structure development, faunal bioturbation, and carbonate leaching (in some profiles) were the dominant pedogenic processes operative in the formation of the Brady Soil. In contrast, the macromorphology of the Holocene soils indicates the dominant pedogenic processes were humus input, structure development, and carbonate accumulation. Thin sections from Mirdan Canal show illuvial clay in the Brady B horizon, but not in overlying soils (Mason and Kuzila, 2000), indicating this process was not active in this region during the remainder of the Holocene, as climate became drier. Carbonate leaching and clay illuviation has been noted in <3,500 yr BP loess-derived soils of the Caucasian Piedmont that receive 800 mm precipitation (Alexandrovsky *et al.*, 1999).

The Brady Soil formed for approximately 2,000 yrs and it is more strongly expressed than the modern surface

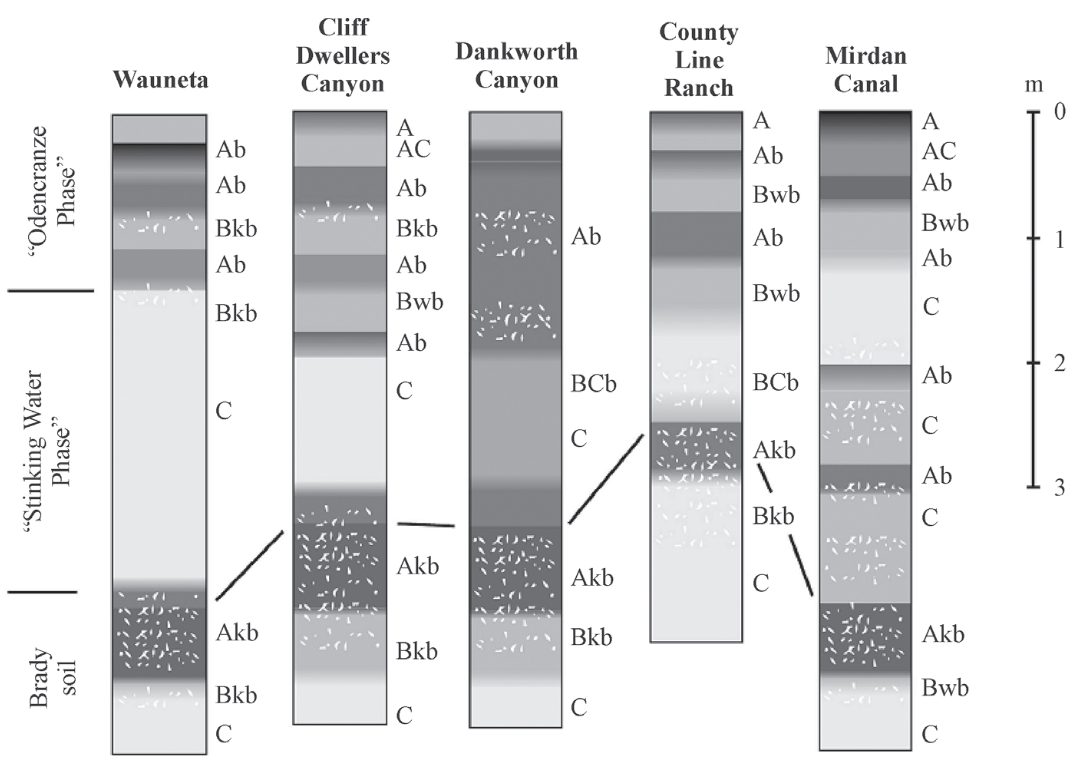

Figure 5. Stratigraphy and generalized pedologic characteristics of several thick proximal sections of Bignell Loess in central and southwest Nebraska. See Figure 1 for locations of sections. Mirdan Canal section (on right) is from Mason and Kuzila (2000).

Figure 6. Photograph of a thick stratigraphic section adjacent to Wauneta Road Cut. The lowermost dark band visible is the Brady Soil and two prominent buried soils are evident above the Brady. Bignell Loess is approximately 6 m thick in this section.

soil or any of the Holocene soils formed in the Bignell Loess. The greater strength of expression can be interpreted to indicate either climatic conditions were more conducive to pedogenesis or the Holocene soils formed over much shorter intervals. Forthcoming OSL age control on many of these sections will allow us to fully test these hypotheses. The age of 3,010 ± 90 ^{14}C yr BP on the uppermost buried soil at Mirdan Canal provides a maximum age estimate for the final phase of Bignell Loess deposition and subsequent modern soil formation, supporting the climate hypothesis. However, multiple episodes of sand dune activity within the past <800 yrs in the Sand Hills (Stokes and Swinehart, 1997) suggest the uppermost portion of Bignell loess, hence the modern soil, may be very young.

A climate more conducive to pedogenesis is indicated by evidence such as a thick dark A horizon, illuvial clay in the B horizon in some profiles, and intense faunal burrowing. The thick dark A horizons indicate the environment experienced more effective precipitation and was likely dominated by grassland. The burrows, assuming they are associated with cicadas, imply that woody vegetation and an infrequent fire regime were likely significant co-components of the ecosystem. The large volume of Brady A and upper B horizons burrowed suggests a period of significant landscape stability and ecosystem productivity, especially given the age constraint of approximately 2,000 yrs. The paucity of faunal burrows in the overlying Bignell Loess and buried soils is a likely indicator of a drier climate during the Holocene and possibly the establishment of a fire regime that discouraged woody vegetation. Other evidence of drier Holocene climates include secondary carbonate emplaced after burial of the Brady Soil, along with the geomorphic evidence provided by the Bignell Loess, which indicates drier conditions.

All of these paleoclimatic interpretations are supported by evidence from across the Great Plains. OC and phytoliths in some alluvial soils in adjacent Colorado suggest that early and middle Holocene climates were more conducive to plant productivity (Blecker *et al.*, 1997), and the stable C isotope composition of Brady Soil OC indicates a mix of C3 and C4 vegetation (Johnson and Willey, 2000; Muhs *et al.,* 1999). It is not clear from the stable C isotope data whether arboreal species were present or if the C3 signature is associated with northern cool season grasses.

Paleoenvironmental interpretation of soils in Bignell Loess

Repeated phases of Bignell Loess deposition and soil formation are evident from the sections presented here (Figure 5). While the record in each section is not identical and attempting to correlate individual soils is not practical with current age control or more specific fingerprints, three general environmental phases emerge from the stratigraphy and paleopedology of the sections. We believe the loess sequences presented here demonstrate that these phases record a regional climate signal.

The first environmental phase occurs as a basal aggradation phase just above the Brady Soil. Four of the five sections presented here contain an A or transitional A (AB, BA, or AC) horizon that is directly above the Brady A. The basal A soil represents the earliest phases of Bignell accumulation when either ecosystem productivity was high enough or dust deposition slow enough that humus production and aggregation could develop topsoil characteristics during loess deposition. Continued increase in the rate of loess deposition or climate shift to drier conditions eventually lead to a decrease in pedogenic expression in the new loess and the A became an AC higher in the section. Similar phenomena have been noted in other aggrading landscapes (McDonald and Busacca, 1990; Almond and Tonkin, 1999; Kemp, 1999). In most of our sections, the basal aggraded A is eventually overlain by an increment of coarse loess with minimal pedogenic features (*i.e.*, BC or C horizon). We informally refer to this phase of aggradation as the "Stinking Water Phase", named after Stinking Water Creek, which flows below the loess escarpment at Wauneta. The climatic implication is a period of regional drought beginning in the early Holocene that persisted through the middle Holocene. This record contrasts with the climate record from the Loess Plateau of China, where development of the cinnamon soil (S0) occurred under a warmer and more humid climate during the middle Holocene (8,500–3,100 yrs BP) (Huang *et al.*, 2002; Xiao *et al.*, 2002).

The second environmental phase is marked by the occurrence of finer textures, darker colors, and multiple buried soils in the middle portions of the Bignell loess. The darker colors are associated with buried soil A horizons and the finer textures are evidently related to sedimentology. Most textures are silt loam, often similar to adjacent horizons, but definitely having either greater clay or lesser sand content. Until we have age control to correlate with known climatic events on the Plains, we can only surmise that the climate was more conducive to pedogenesis, but that periodic drought and loess deposition was still an integral component of the environment. We refer to this phase as the "Odencranze Phase", named after the Odencranze Table (County Line Ranch site) where well expressed buried soils bracketed by coarser loess occur.

The third and most recent environmental phase is the occurrence of a weakly expressed modern surface soil in a zone of coarser loess. The loess often has a sandy texture and the soil morphology is an A or AC horizon. The morphology indicates that the modern soil is young and/or that the climate has not been conducive to soil formation, perhaps both. The coarse nature of the loess implies renewed local sediment transport in the latest Holocene.

ACKNOWLEDGEMENTS

This paper is based on research supported by the National Science Foundation, Geography and Regional Science and Geology and Paleontology Programs, grants BCS-0079252 and BCS-0079320.

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Manuscript received: March 12, 2002
Corrected manuscript received: May 15, 2002
Manuscript accepted: May 25, 2002