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Zhao-Dong Feng
University of Utah, zhaodong_feng@baylor.edu

William C. Johnson
University of Kansas, wcj@ku.edu

Robert F. Diffendal, Jr.
University of Nebraska-Lincoln, rdiffendal1@unl.edu

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Environments of Aeolian Deposition in South-Central Nebraska During the Last Glacial Maximum

Zhao-Dong Feng
Department of Geography
University of Utah
Salt Lake City, Utah 84112
and
Lamont-Doherty Earth Observatory
Columbia University
Palisades, New York 10964

William C. Johnson
Department of Geography
University of Kansas
Lawrence, Kansas 66045

Robert F. Diffendal, Jr.
Nebraska Geological Survey
University of Nebraska
Lincoln, Nebraska 68588

Abstract
The Peoria loess of south-central Nebraska, deposited approximately during the last Glacial Maximum, can be subdivided into three zones: an upper laminated loess and a lower massive loess, separated by a dark gley zone in which bison bones and spruce charcoal are found. The lower Peoria unit is characterized by high organic matter content, relatively high bulk density, and common root channels. The upper Peoria unit has rhythmic patterns of two orders: strongly gleyed and weakly gleyed zones alternating in couplets about 2-5 m thick, and coarse- and fine-grained laminae of second order, about 2-4 mm thick. The strongly gleyed zones are relatively low in magnetic susceptibility and contain lenses with abundant fossil plant debris. They may have formed in active zones on top of permafrost during relatively cold and probably moist intervals, with magnetic susceptibility secondarily lowered in the redox environment. Magnetic susceptibility also indicates the possible existence of first-order rhythmic patterns in the lower massive loess. Each of the ten susceptibility oscillations within Peoria loess has a mean duration of about 1000 years, assuming that the loess was deposited between approximately 20,000-22,000 and 10,000-10,500 yr BP. The second-order laminae, close to the expected mean annual accumulation rate of Peoria loess, may be due to seasonal variation in wind intensity or to secondary grain sorting of niveoeolian deposits.

Keywords: Peoria loess, dust, Great Plains, last Glacial Maximum

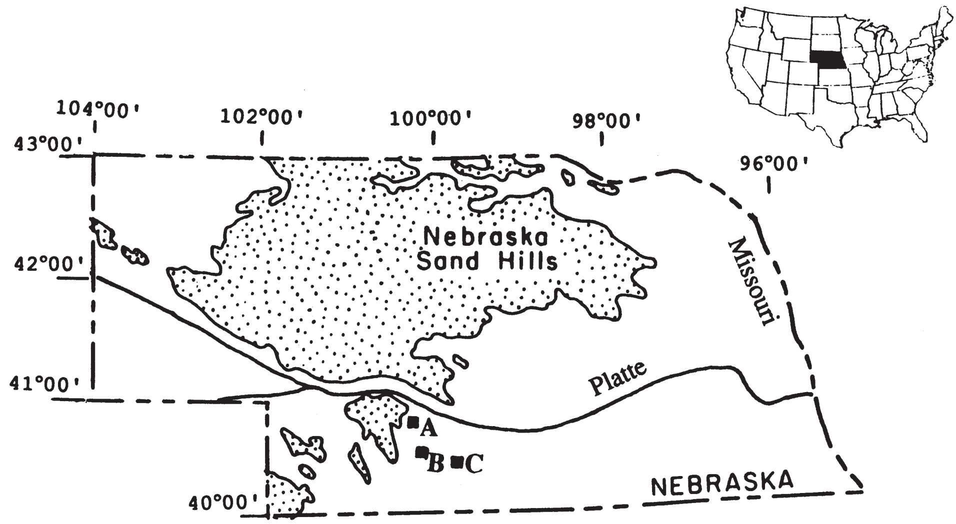

Figure 1. Study sites in south-central Nebraska: (A) Bignell Hill section, (B) Eustis Ash Pit section, (C) Buzzard Roost section.

Introduction

The thickest and most extensive loess unit in the central Great Plains is the Peoria loess. It is bracketed by two stratigraphic units: the underlying Gilman Canyon Formation and the overlying Brady Soil. The Gilman Canyon Formation, a pedocomplex, was formed as the Laurentide ice sheet advanced (Mickelson et al., 1983; Wright, 1984; Feng et al., 1994a); the Brady Soil developed when the Laurentide ice sheet was dissipating (Caspall, 1970; Wright, 1984; Martin, 1990; Johnson and May, 1992). The Peoria loess, deposited approximately during the last Glacial Maximum, is as thick as 44 m in south-central Nebraska and it could be the thickest eolian deposit of that period in the world. It probably has preserved a detailed record of ice sheet dynamics farther north and of the relationship of changing climates to landscape evolution during the last Glacial Maximum. We have studied selected localities to see if such information is preserved.

Existing knowledge on the Great Plains environment during the last Glacial Maximum is limited and controversial. Botanical remains in the central Great Plains—such as pollen, opal phytoliths, and plant macrofossils (Wright, 1970; Wells, 1983; Fredlund et al., 1985; Fredlund and Jaumann, 1987)—have been interpreted as indicative of an environment dominated by coniferous forests in a cool and moist climate. However, fossil pollen assemblages from the Cheyenne Bottoms of central Kansas point to an arid environment from about 20,000 to 12,000 yr BP (Fredlund, 1991), in agreement with the conclusion of Lugn (1968) that the loessial environment was desertlike.

Our field investigation was conducted at three sites in south-central Nebraska (Figure 1). We measured laminations, color and texture, distribution of carbonate nodules, and presence of fossil plant debris. Magnetic susceptibility on 330 samples from the three sections was measured in the laboratory as outlined by Thompson and Oldfield (1986). Each sample

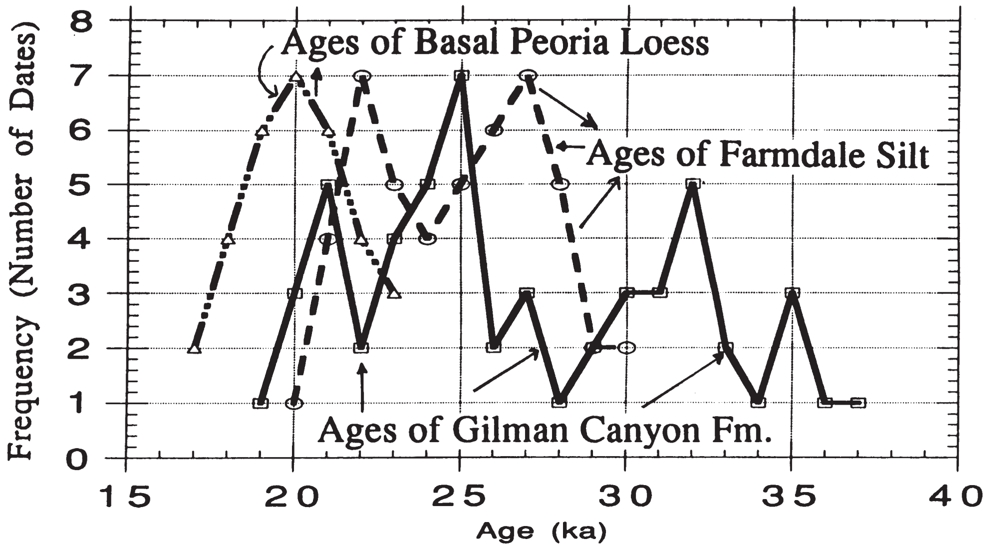

Figure 2. Frequency distributions of the radiocarbon ages of the Gilman Canyon Formation in the central Great Plains, the Farmdale Silt, and basal Peoria loess in the Midwest showing that the Peoria loess began accumulating about 20 ka.

was measured three times. Radiocarbon ages (Table 1) were obtained on soil humate and fossil plant debris by the Beta Analytic and the University of Texas radiocarbon laboratories.

Stratigraphy

The Peoria Loess of Nebraska was earlier described as a yellowish tan to buff, homogeneous, calcareous silt (Schultz and Stout, 1945, 1948). Schultz and Tanner (1957) noticed a dark gley zone within the loess at the Buzzard's Roost section. The loess was then subdivided into three zones: lower and upper zones, separated by a dark gley zone (Souders et al., 1971).

Mixing of older and younger carbon materials during and after development of the Gilman Canyon Formation makes accurate age estimates difficult (Schaetzl and Sorenson, 1987). In particular, the pedocomplex was in many cases initiated in the top of a calcareous reddish soil and the inorganic carbon probably has made the base age too old. In the top portion, penetration of younger organic matter from the overlying Peoria Loess might have made the ending age too young. However, owing to the nature of the pedocomplex, including soil cumulic A horizons that formed as eolian deposition continued, the radiocarbon ages of soil humate might be closer to the mean residence time in the pedocomplex than in many other soils. This argument is supported by the facts that the radiocarbon ages become younger sequentially from the base to the top of the pedocomplex at the Eustis Ash Pit site (Johnson, unpublished data) and that the older ages usually were derived from the lower portion and younger ones from the upper portion. There is now a reliable way for assuming the acceptability of all the ages, but statistical comparisons allow for estimates of the age range of the pedocomplex.

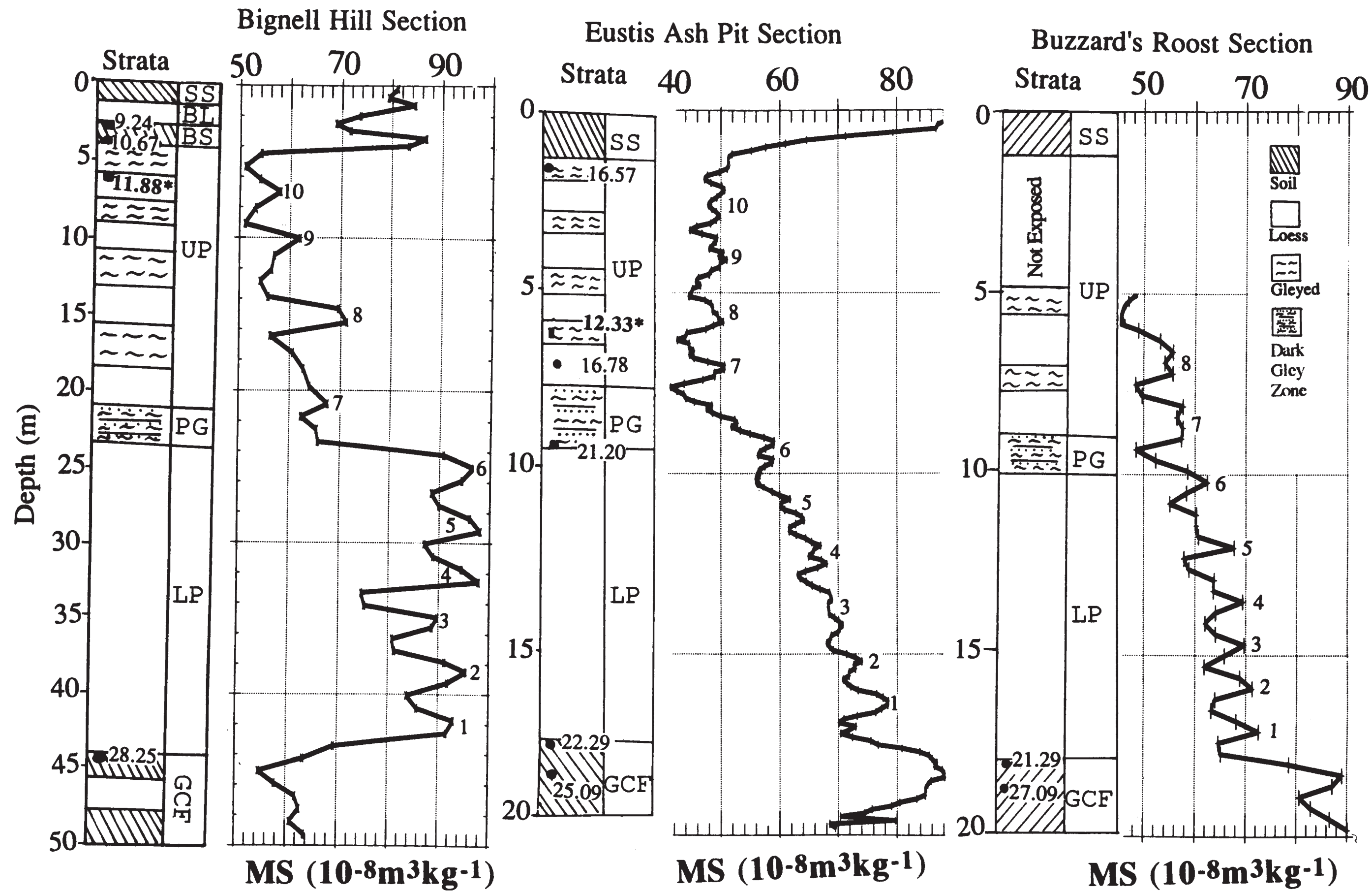

Figure 3. Lithostratigraphy, dates, and magnetic susceptibility curves for the three sections: SS) surface soil; BL) Bignell loess; BS) Brady Soil; UP) upper Peoria; PG) Dark Gley Zone; LP) lower Peoria; GC) Gilman Canyon Formation. Numbers in the stratigraphic columns are the ^{14}C ages, and the organic fragment ages are denoted by an asterisk. The numbers 1-10 mark the sequential order of magnetic susceptibility peaks.

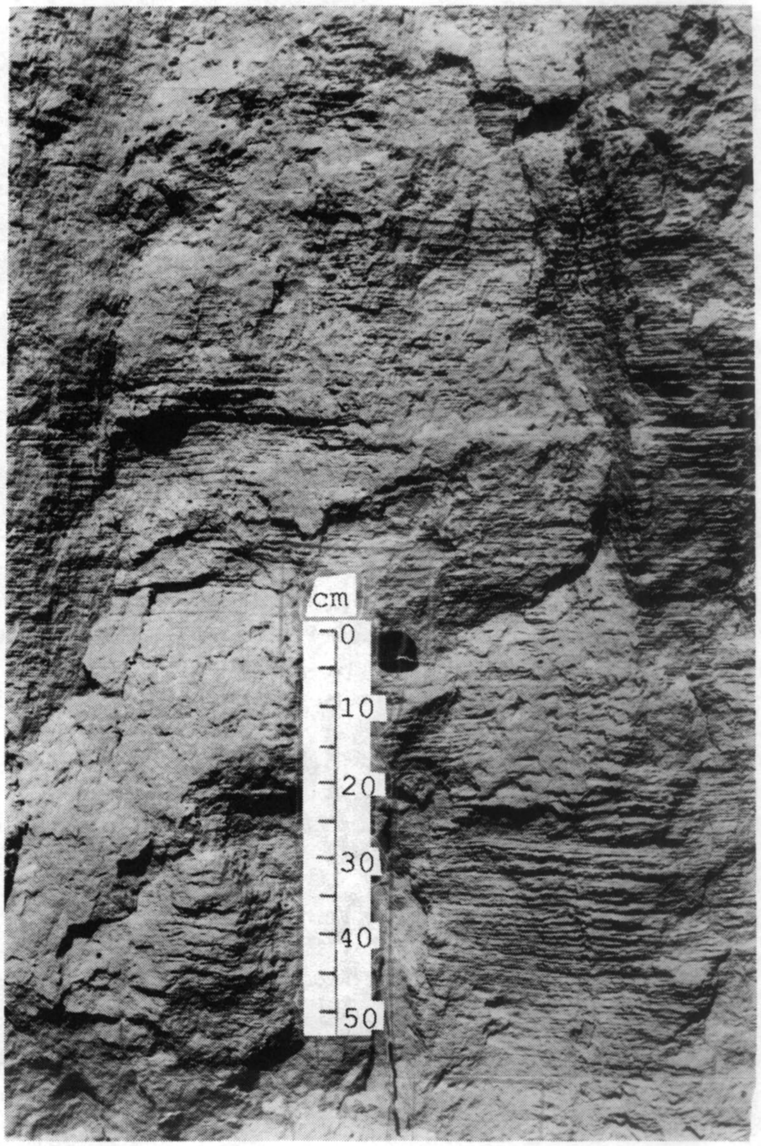

Figure 4. Second-order rhythmic patterns (about 4 mm thick) of the upper Peoria loess at the Bignell Hill section. Notice the camera cap (5 cm) to the right of the scale.

All radiocarbon ages of the Gilman Canyon Formation available for the central Great Plains are plotted in Figure 2, with 90% of the ages falling between 35,000 yr BP and 20,000 yr BP (Dreeszen, 1970; Souders et al., 1971; Martin and Dort, 1987; May and Soulders, 1988; Gottula and Souders, 1989; May, 1989; Johnson, 1990; Johnson et al., 1990; Martin, 1990; Souders and Kuzila, 1990; Feng, 1991; May and Holen, 1993). The stratigraphic equivalent of the Gilman Canyon Formation in the Midwest is the Farmdale Silt or Robein Silt. It has has been dated between 20,000 and 30,000 yr BP (Coleman, 1969, 1970, 1972, 1973; Liu and Coleman, 1981; Liu et al., 1986; Curry, 1989). The basal Peoria loess, rich in organic matter, in the

Midwest has been dated between 17,000 and 23,000 yr BP with a single mode of 20,000 yr BP (Ruhe, 1977). According to the foregoing discussions, deposition of the Gilman Canyon Formation probably ended about 22,000-20,000 yr BP (Johnson, 1990; May and Holen, 1993; Feng et al., 1994b). Ages from the Brady Soil overlying the Peoria Loess range from 12,500 to 8,000 yr BP with a mode of about 10,500 yr BP in the central Great Plains (Caspall, 1970; Dreezsen, 1970; Luteneggar, 1985; Martin and Dort, 1987; Diffendal and Leite, 1989; Souders and Kuzila, 1989; Johnson, 1990, 1993; Martin, 1990; Johnson and May, 1992; Feng et al., 1993b).

Bignell Hill Section

The Bignell Hill section, located in southeastern Lincoln County, Nebraska (40° 51′ 05″ N, 100° 28′ 20″ W), was first described by Schultz and Stout (1945, 1948) as the type locality of the Brady Soil and Bignell Loess. The 50-m-thick section is exposed to the bottom of the Gilman Canyon Formation, which contains upper and lower units separated by a loess layer. The upper part, about 1 m thick, is calcareous and organic-rich. The lower part, about 2 m thick, is noncalcareous and organic-rich.

The lower Peoria Loess is massive and relatively homogeneous. A dark gley zone occurs at a depth of 21-23 m (Figure 3). The upper Peoria Loess, 4-21 m below the land surface, has rhythmic patterns of two orders: strongly gleyed and slightly gleyed couplets that are 3-5 m thick (Figure 3) and coarse-grained and fine-grained laminae (second order) that are 4 mm thick (Figure 4). Fossil root channels spread laterally. The strongly gleyed zones contain lenses with abundant fossil plant debris (mainly grass stems). The lenses are normally 2-3 cm long, 1-1.5 cm wide, and 1-1.5 cm high (thick). The overlying Holocene sequence here includes the Brady Soil, Bignell Loess, and surface soil. The Bignell Loess is relatively dark and exhibits no laminations.

The upper portion of the Gilman Canyon Formation here is dated 28,250 ± 620 yr BP (Johnson, 1993) (Table 1). The Brady soil was first dated at 9160 ± 250 and 9750 ± 300 yr BP but both ages were considered to be contaminated (Dreeszen, 1970). Two ages of 10,670 ± 130 and 9240 ± 90 yr BP (Table 1) recently were obtained on the lower and upper 5 cm, respectively, of the Ab horizon (Johnson and May, 1992). A *Picea glauca* twig buried at a depth of 7 m was AMS dated at 11,880 ± 90 yr BP. If the age range of the Peoria Loess (22,000-20,000 to 10,500-10,000 yr BP) is acceptable, the second order laminae (about 4 mm) may represent annual layers (Figure 4).

Eustis Ash Pit Section

The 40-m-deep ash pit, located in northernmost Frontier County, Nebraska (40° 49′ 55″ N, 100° 27′ 02″ W), was described stratigraphically by Schultz and Martin (1970) and studied sedimentologically by Fredlund et al. (1985). The Gilman Canyon Formation is organic rich and the lower Peoria Loess is massive and homogeneous. In the lower Peoria unit, fossil root channels (0.5-1 mm diameter, 2-10 cm long) are dense and are vertically oriented. A dark gley zone containing poorly preserved bison bones and greenish-gray lenses (Frankel, 1956; Johnson, 1993) occurs at a depth of 8.3-9.6 m.

Table 1. Radiocarbon Ages (^{13}C corrected) from the Three Sections in South-Central Nebraska.

Section	Depth (m)	Strata	Level	Target	Method	Lab-No.	Age (yr BP)	Reference
Bignell Hill	3.0	Brady	Upper	Humate	^{14}C	Tx7425	9,240 ± 110	Johnson and May, 1992
Bignell Hill	3.5	Brady	Lower	Humate	14C	Tx7358	10,670 ± 130	Johnson and May, 1992
Bignell Hill	7.0	Peoria	Upper	Charcoal	AMS	β-60508	11,880 ± 90	This study
Bignell Hill	44.7	GCF	Upper	Humate	^{14}C	Tx7706	28,250 ± 620	Johnson, 1993
Eustis Ash Pit	2.1	Peoria	Upper	Humate	AMS	β-56958	16,570 ± 80	This study
Eustis Ash Pit	6.5	Peoria	Middle	Charcoal	AMS	β-60567	12,330 ± 70	This study
Eustis Ash Pit	7.0	Peoria	Middle	Humate	AMS	β-589587	16,780 ± 120	This study
Eustis Ash Pit	9.5	Peoria	Middle	Humate	AMS	β-55462	21,200 ± 170	This study
Eustis Ash Pit	17.5	GCF	Upper	Humate	^{14}C	Tx7347	22,290 ± 340	Johnson, 1993
Eustis Ash Pit	18.5	GCF	Middle	Humate	^{14}C	Tx6633	25,090 ± 590	Johnson, 1990
Buzzard's Roost	17.5	GCF	Upper	Humate	^{14}C	β-28826	21,290 ± 290	May and Souders, 1988
Buzzard's Roost	18.0	GCF	Middle	Humate	^{14}C	1-2188	27,900 ± 1200	Dreeszen, 1970

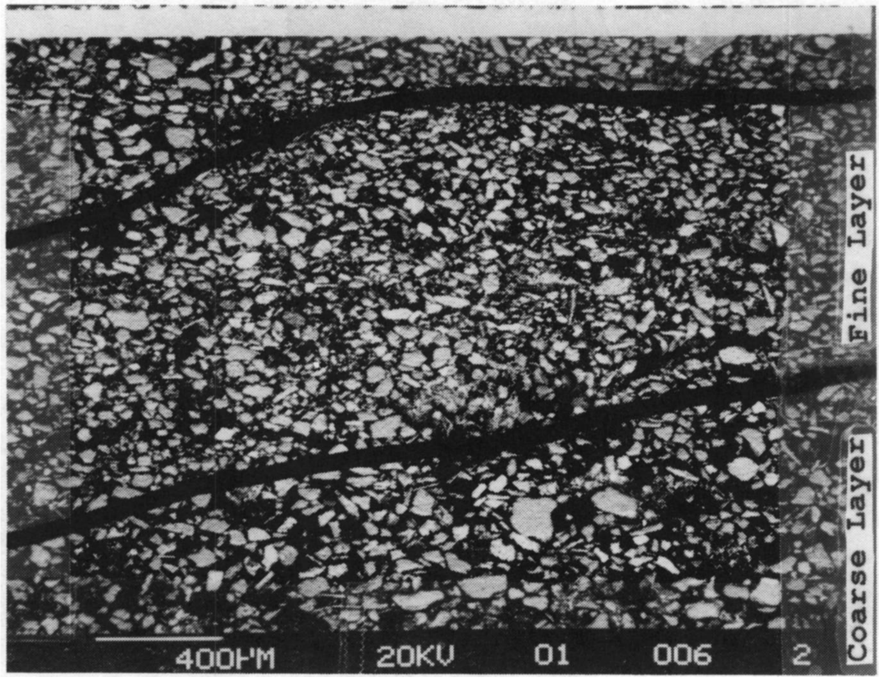

Figure 5. A couplet of the second-order laminae of the upper Peoria Loess at the Eustis Ash Pit section (under SEM). The fine-grained layer is about 0.8 mm thick and the coarse-grained layer about 1 mm thick.

The upper Peoria Loess, 1.5-8.3 m deep, has rhythmic patterns of two orders. Each of the first-order rhythmic patterns consists of strongly gleyed and slightly gleyed couplets that are about 2 m thick. The second order comprises laminae containing a fine-grained layer, about 0.8 mm thick, and a coarse-grained layer, about 1 mm thick (Figure 5). Fossil root channels are sparse and spread laterally. The strongly gleyed zones contain lenses with abundant fossil plant debris (mainly grass stems). The lenses are normally 2-3 cm long, 1-1.5 cm wide, and 1-1.5 cm high (thick). The plant debris, collected by washing on a screen, amounted to about 0.9% by weight in the strongly gleyed zone and about 0.5% in the weakly gleyed zone. Based on loss on ignition, the organic content is about 2% in the strongly gleyed zone and 1.4% in the weakly gleyed zone. The Brady Soil, which caps the Peoria, is not recognized in the region.

The middle part of the Gilman Canyon Formation was dated at 25,090 ± 590 yr BP (Johnson, 1990) and the top at 22,290 ± 340 yr BP (Johnson, 1993) (Table 1 and Figure 3). The preservation of plants debris owing to rapid eolian deposition, probably under a cold and dry environment during the Peoria time, may have minimized the contamination of the Gilman Canyon Formation by younger organic matter and, consequently, the ^{14}C ages from the top Gilman Canyon Formation may be a good estimate for initiation of Peoria Loess deposition. The dark gley zone within the Peoria Loess (9.5 m deep) was dated at 21,200 ± 170 ka, the loess at 7 m depth at 16,780 ± 120 yr BP, and the loess at 2.1 m depth at 16,570 ±

80 yr BP. If the Gilman Canyon Formation terminated about 22,000-20,000 yr BP (Johnson, 1990; May and Holen, 1993; Feng et al., 1994b), the humate ages of the Peoria Loess seem too old. We examined the samples microscopically and found some organic-coagulated aggregates. These aggregates, comprising about 5% of the microscopic field, may have been derived from old organic-rich materials (e.g., Gilman Canyon Formation), which thus made the humate radiocarbon ages too old. We believe that the organic matter uniformly coated on mineral particles, together with all preserved plant debris, formed simultaneously during deposition of the surrounding loess.

Fossil plant debris was collected from a tree-trunk imprint at a depth of 6.5 m in the Peoria Loess. The imprint is bracketed above and below by second-order lamination, which precludes the possibility that the tree penetrated after or before the loess containing the imprint was deposited. The organic debris was well preserved as carbonized organic fragments *(Picea glauca,* as large as 5 cm long), which was AMS dated at 12,330 ± 70 yr BP (Table 1). Tree-trunk imprints can be found occasionally in this section, as well as the Buzzard's Roost and Bignell Hill sections, but the frequency is so low that they probably are not indicative of a closed forest.

Buzzard's Roost Section

This section, only 35 miles southeast of the Eustis Ash Pit section, was stratigraphically described by Frankel (1956) and Schultz and Tanner (1957) and is similar to the Eustis Ash Pit section in that the Gilman Canyon Formation is organic-rich and the lower Peoria Loess is massive and relatively homogeneous. Dense vertical fossil root channels occur in the lower Peoria unit. A dark gley zone occurs at a depth of 8.5-10 m. The top part of the upper Peoria is not exposed (Figure 3). The exposed part of the upper Peoria has rhythmic patterns of two orders: strongly gleyed and slightly gleyed zones alternating in couplets about 2 m thick (first order) and coarse-grained and fine-grained laminae alternating in couplets about 2 mm thick (second order). Fossil root channels are sparse and spread laterally in the upper Peoria. The strongly gleyed zones contain lenses with abundant fossil plant debris and carbonate nodules (0.5-1 cm diameter). The middle Gilman Canyon Formation was dated earlier at 27,900 ± 1,100 yr BP (Dreeszen, 1970) and the upper part recently dated at 21,290 ± 290 yr BP (May and Souders, 1988; May and Holen, 1993).

Magnetic Susceptibility

Magnetic susceptibility measures magnetization temporarily induced in a rock by an applied low-amplitude magnetic field. The strength of the susceptibility signal depends on the concentration and grain size of magnetic minerals (Thompson and Oldfield, 1986). Mullins (1977) suggested that magnetic susceptibility enhancement occurs due to *in situ* conversion of a small proportion of the weakly magnetic forms of iron oxides and hydroxides to strongly magnetic magnetite and maghemite. Specifically, repeated redox cycles release iron from weakly magnetic minerals, and strongly magnetic minerals are generated by microbial activities.

Magnetic susceptibility was measured at 50- to 80-cm intervals in the Bignell Hill section, at 10-cm intervals in the Eustis Ash Pit section, and at 30-cm intervals in the Buzzard's Roost section (Figure 3). The susceptibility in the Bignell Hill section records the first-order rhythmic pattern. In the upper portion, susceptibility is higher in the weakly gleyed zones than in the strongly gleyed zones. The dark gley zone in the middle Peoria loess appears to be a transitional zone, where a drastic decrease of the susceptibility occurs upward. The susceptibility indicates the possible existence of a first-order rhythmic pattern in the lower massive loess as well. The Brady Soil, Bignell Loess, and surface soil also are expressed by susceptibility fluctuations.

As in the Bignell Hill section, the susceptibility in the Eustis Ash Pit section is higher in the weakly gleyed zones than in the strongly gleyed zones within the upper Peoria Loess. The dark gley zone in the middle Peoria Loess also functions as a transitional zone where susceptibility decreases upward. The susceptibility also indicates the possible existence of a first-order rhythmic pattern in the lower massive loess.

In the exposed portion of the upper Peoria Loess in the Buzzard's Roost section, two couplets of strongly gleyed and weakly gleyed zones alternate in intervals about 2 m thick and also are indicated by magnetic susceptibility. The susceptibility also indicates the possible existence of a first-order rhythmic pattern in the lower massive loess. These ten susceptibility peaks are significant statistically (at the 95% confidence level) and operationally, and probably are comparable among the three sections, based on the stratigraphic correlation of the first-order rhythmic patterns.

Discussions and Conclusions

The upper Peoria Loess has rhythmic patterns of two orders: strongly gleyed and weakly gleyed zones and coarse- and fine-grained laminae. The strongly gleyed zones contain lenses with abundant fossil plant debris and carbonate nodules. The lenses containing many grass imprints and grass debris might be the remains of isolated grass patches under tundra vegetational conditions and the carbonate nodules might have accumulated at the bottom of active layers in permafrost environments. Magnetic susceptibility might have been secondarily lowered in the redox environment of the active layer. The fossil plant debris indicates that the loess was deposited sufficiently rapidly under these conditions not to have decomposed or oxidized the plant debris completely. The thickness of the second-order laminae is close to the expected mean accumulation rate of the Peoria Loess, implying that the second-order laminae may have been formed by seasonal variation in wind intensity or by grain sorting of niveoeolian deposits. The dark gley zone in the middle Peoria Loess, containing bison bones and spruce charcoal, probably corresponds to the 14,000-15,000-yr-BP climatic amelioration documented by pollen and insect assemblages in the Midwest (Schwert and Ashworth, 1988). Magnetic susceptibility data not only reflect the first-order rhythmic patterns in the upper Peoria, but also indicate the possible existence of first-order rhythmic patterns in the massive lower Peoria. Each of the ten susceptibility oscillations within the Peoria Loess has a mean duration of about 1,000 years, which may be a response to the sequence of glacial advances from 21 to 10 ka in the Great Lakes region (Mickelson et al., 1983).

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