QUATERNARY RECORD AT CAGLES MILL, PUTNAM COUNTY, INDIANA

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ABSTRACT. Indiana's most time-transcending stratigraphic section of Quaternary deposits is probably the exposure in the wall of the emergency spillway at Cataract Lake in Putnam County, Indiana. The oldest sediments, whose probable age is early Pleistocene, consist of residuum mixed with loess. The overlying middle Pleistocene sequence consists of a basal loess, a thin and discontinuous (0–50 cm) glaciolacustrine unit, and several meters of lodgment till.

Late Pleistocene sediments include an Illinoian till/outwash sequence and three late Sangamonian through late Wisconsinan units deposited primarily by eolian processes. Eolian units apparently include both the early Wisconsinan Roxana Silt and the late Wisconsinan Peoria Loess.

There are several buried soils in the section, including the very well-developed Yarmouth Soil and Sangamon Soil. There is also a pre-Yarmouth soil, probably early Pleistocene, which developed in mixed residuum and loess. The three youngest soils are late Sangamonian (Chapin Soil), middle Wisconsinan (Farmdale Soil) and post-Wisconsinan (present surface soil); all these younger soils are welded to each other and to the Sangamon Soil.

Keywords: Glacial geology, Quaternary geology, paleosol, stratigraphy, general geology

The most useful stratigraphic sections reveal as much geologic history as possible, are well exposed, and are accessible. The walls of the Grand Canyon rate high for their long record (Precambrian through Permian), the excellent exposure (nearly 100%), and accessibility (merely walk the trails). For Quaternary geologists, the emergency spillway for the Cagles Mill Dam (forming Cataract Lake; Fig. 1) is, in a sense, Indiana's "grand canyon." It is Indiana's most complete record of Pleistocene events (early Pleistocene to late Wisconsinan). The spillway was established in 1954 for a distance of about 300 m; throughout most of this length there is a magnificent exposure of the Pennsylvanian Mansfield Formation (Huff 1985; Hasenmueller & Bleuer 1987).

Pleistocene sediments are best exposed near the east end of the north side of the spillway where they fill a paleovalley that was eroded into the Mansfield Formation probably early in the Pleistocene. This valley is about 18 m deep at the point where it was intersected by the cutting of the spillway. The paleovalley and the Pleistocene sediments it contains can be traced to the southeast on the south side of the spillway cut.

The Pleistocene part of the Cagles Mill exposure (hereafter known as the Cagles Mill section) has drawn some attention from geologists since it became available for study. Most descriptions of the section are brief (Wayne 1954, 1958; Bhattacharya 1962; 1963; Wayne 1963; Schneider & Wayne 1967; Hasenmueller & Bleuer 1987) (Table 1). To our knowledge, a detailed characterization and interpretation of the Cagles Mill Pleistocene sediments and soils has never been published before.

As part of an ongoing investigation of buried soils and Quaternary stratigraphy in central Indiana, we have closely studied this exposure as one of our key stratigraphic sections and certainly one of the most complete and most accessible. In this paper, we share our data and our interpretations on this extraordinary stratigraphic section, adding much detail to that published previously, particularly information on the buried soils within the section. With this paper, we hope to render this exposure much more useful to all geologists and other interested people who visit there.

Our presentation here is really geared to three audiences. First, a brief review is presented for the reader who has only a casual

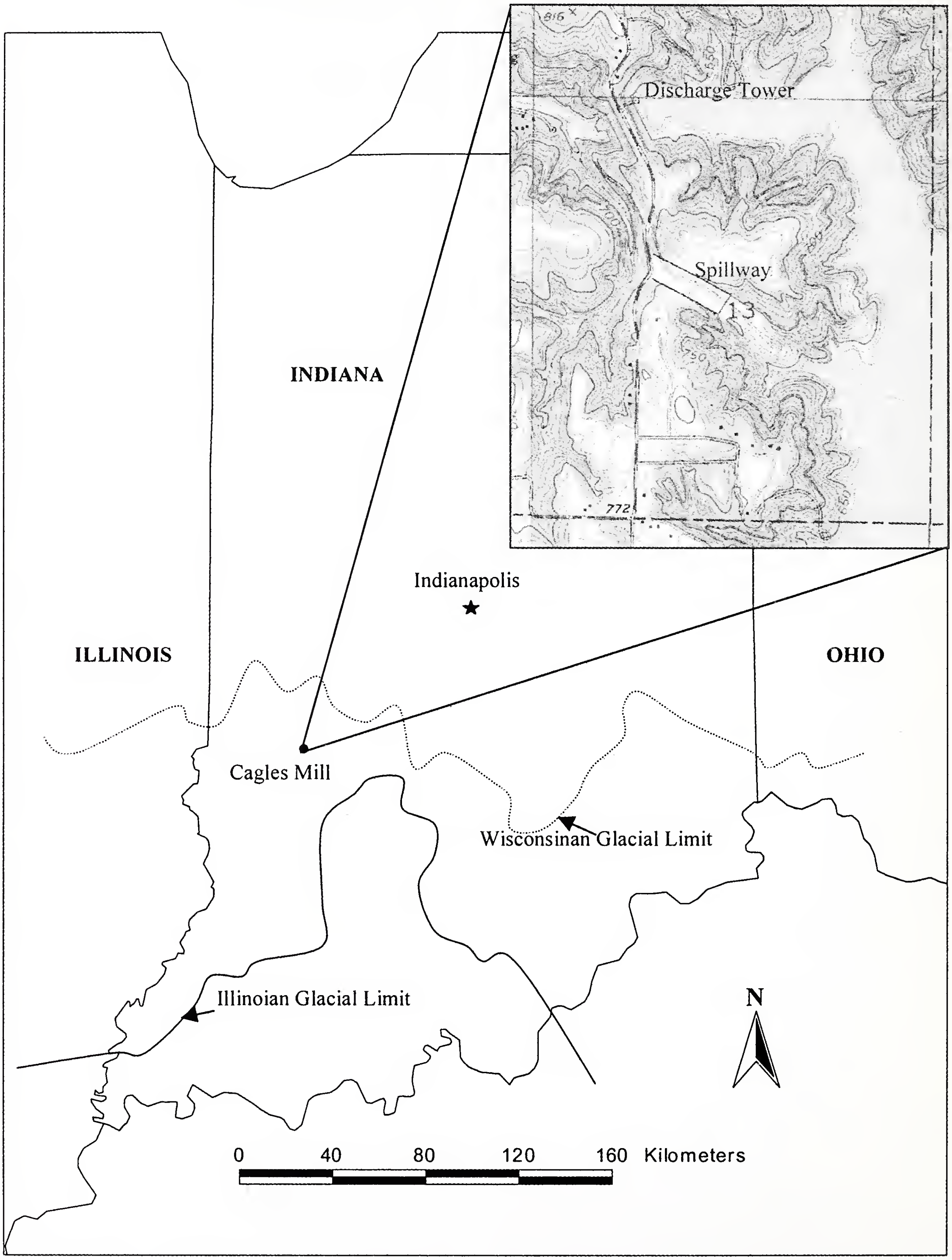

Figure 1.—Location of the Cagles Mill stratigraphic section. Inset map shows Cataract Lake, the Cagles Mill dam, and the emergency spillway cut. The arrow marks the location of the Cagles Mill section, which is in the SE1/4, NW1/4, Sec 13, T12N, R5W The inset map is from the Poland, Indiana, 7.5-minute U.S. Geological Survey topographic quadrangle.

Table 1.—A comparison of the interpretation of lithologic units in the Cagles Mill section by Wayne (1958) and Schneider and Wayne (1967) with those by the authors. Thicknesses of the units are given in meters in the brackets. [a] Complete geologic-pedologic descriptions are given in Table 2. Units are numbers following the work of Wayne (1958) and Schneider & Wayne (1967). [b] We recognize two silty units, the lower having a greater sand content. We correlate the lower unit with the Roxana Silt and the upper unit with the Peoria Loess. [c] This unit may be of late Sangamonian age. [d] This unit of Schneider and Wayne includes an oxidized subunit over an unoxidized subunit. In Wayne (1958) the two subunits were given unit status. The two subunits are of about equal thickness (~2 m). [e] This unit is the Cagles Loess, named by Wayne (1958) for this locality.

Unit	Wayne (1958) and Schneider & Wayne (1967)	Unit	Hall & Anderson[a] (this paper)
	Wisconsinan		Wisconsinan
10	[0.9] Yellow-brown clayey silt, noncalcareous	10B	[0.7] Yellow-brown sandy silt, noncalcareous[b]
		10A	[0.4] Yellow-brown sandy silt, noncalcareous[b]
	Illinoian		Illinoian
9	[3.6] Brown till, fractured, noncalcareous	9	[0.2] Yellow-brown sandy clay, noncalcareous[c]
8	[1.6] Light brown till, sandy, clayey, calcareous	8	[0.5] Yellow-brown sandy clay, gravelly, noncalcareous
7	[1.8] Dark-gray till, very pebbly, sandy, clayey, calcareous	7A	[3.5] Yellow-brown diamicton (till), calcareous
		7B	[1.5] Grayish-brown diamicton (till), calcareous
	Pre-Illinoian		Pre-Illinoian
6	[1.1] Brown to greenish-gray clay, silty, sandy, noncalcareous	6	[0.7] Yellow-brown sandy silt, noncalcareous
5	[2.6] Brown till, sandy, silty, noncalcareous	5	[2.8] Yellow-brown diamicton, (till) slightly calcareous
4	[4.5] Reddish brown over brownish gray till, sandy, silty, calcareous; wood fragments[d] in lower part	4	[3.7] Grayish-brown diamicton, (till) calcareous
3	[0.7] Brownish-gray clay, laminated, calcareous, wood fragments throughout	3	[0.1] Brownish-gray clayey silt, laminated, calcareous
2	[0.9] Grayish brown silt; wood, peat, humus at top[e]	2	[0.8] Grayish-brown silt, wood, molluscs, other organics
1	[3.6] Colluvium and bedrock	1	[0.5] Colluvium, loess, bedrock

interest in the topics of glacial stratigraphy and buried soils. Second, for glacial geologists and other Quaternary scientists who want to have more information, the remainder of this paper provides a more detailed summary of our work on the Cagles Mill section as part of our nearly 10-year effort to study Quaternary paleosols in Indiana. Finally, for those who seek a truly in-depth analysis of our data on the Cagles Mill section, we provide references to the pertinent literature (Hall 1992, 1994, 1999; Hall et al. 1998; Hall & Anderson 2000, in press; Hall & Zbieszkowski 2000). In this paper we do not attempt to repeat the in-depth analyses of our extensive previous work. Unless otherwise referenced, the results and interpretations presented in this paper are our own and are based upon the detailed studies cited above. Specific references from our work are cited in some places in the text to facilitate the reader's search for more information.

OVERVIEW OF STRATIGRAPHY

From the base to the top, the Pleistocene section (Fig. 2) consists of: unit 1) the older of two pre-Illinoian loesses mixed with sandstone residuum derived from the Mansfield Formation, unit 2) a younger pre-Illinoian loess (the Cagles Loess of Wayne 1963), unit 3) pre-Illinoian lacustrine sediments, unit 4) a pre-Illinoian till (glacial diamicton), unit 5)

Table 2.—Pedologic characteristics of the Cagles Mill Section. * Surface soil mostly eroded leaving a thin silty Bt, underlain by an older buried soil that forms a fragipan (25–112 cm). The fragipan character is expressed by a massive appearance, hard dry consistence, and vertical fractures filled with light gray silt. This older soil is probably the Farmdale Soil, which in turn is underlain by the Sangamon Soil (from 112 cm downward). *Abbreviations:* Geologic unit LW = Later Wisconsin, EW = Early Wisconsin, LS = Late Sangamonian, Ill = Illinoian. Soil Horizon Bt = textural (argillic) B horizon, Bx = fragipan, b = buried horizon. Dry color (and elsewhere): ND = no data available. Size of mottles c = coarse (>15 mm), m = medium (5–15 mm), f = fine (<5 mm). Abundance of mottles: a = abundant (>20% of soil surface),

Geological unit	Soil horizon	Depth (cm)	Moist color	Dry color	Color	Size	Abundance
sandy silt	Bt*	0–25	10YR 4/6	10YR 7/6	10YR 5/8	m	u
(L. Wisc. loess)					10YR 7/4	m	u
sandy silt	BC1	25–66	10YR 5/6	10YR 8/4	10YR 7/4	m-c	c
(M. Wisc. loess)	(E′)				10YR 5/8	m-c	c
sandy silt	2BC2	66–112	10YR 5/6	10YR 8/3	10YR 7/4	c	c
(loamy sed.)	(2B′x)				10YR 5/8		
sandy clay	3Bt1b	112–135	10YR 4/6	10YR 8/3	7.5YR 5/8	m	c
(outwash)					10YR 7/4	m	u
sandy clay	3Bt2b	135–150	10YR 4/6	ND	7.5YR 5/8	m-c	a
(outwash)					10YR 2/1	m-c	c
					10YR 7/4	m-c	u
sandy clay	4Bt3b	150–187	10YR 4/6	10YR 5/8	7.5YR 5/8	m-c	a
(outwash)					10YR 2/1	m-c	c
					10YR 7/4	m-c	u
diamicton	4BCb	187–290	10YR 6/6	10YR 7/4	10YR 6/8	m-c	a
(Ill. till)					10YR 7/3	m-c	c
diamicton	4CBb	290–420	10YR 5/4	10YR 7/4	10YR 6/8	f-m	c
(Ill. till)					10YR 7/3	m-c	u
diamicton	4Cb	420–537	10YR 5/6	10YR 6/8	10YR 6/8	f-m	c
(Ill. till)					10YR 7/3	m-c	u
		500–510	10YR 4/6	10YR 4/5			
diamicton	4Db	537–687	10YR 4/2	10YR 8/4	10YR 6/8	f	u
(Ill. till)							
sandy till	5Btb	687–755	10YR 5/6	10YR 5/6–8		c	
(coll. loess)				10YR 6/1			
diamicton	6Bcb	755–925	10YR 5/8	10YR 6/8	10YR 7/1	c	a
(Pre-Ill. till)							
diamicton	6CB1b	925–965	10YR 5/6	10YR 7/4	10YR 4/6	f-m	a
(Pre-Ill. till)							
silt	7CB2b	965–1001	10YR 5/4	10YR 6/4	10YR 4/6	f-m	a
(Pre-Ill. silt)							
diamicton	8CB3b	1001–1030	10YR 5/6	10YR 7/4	10YR 4/6	f-m	a
(Pre-Ill. till)							
diamicton	8DCb	1030–1139	10YR 5/3	10YR 7/3	10YR 4/6	f-m	c
(Pre-Ill. till)							
diamicton	8Db	1139–1380	10YR 4/2	10YR 6/1			
(Pre-Ill. till)							
silt	9Db	1380–1388					
silt	Ab	1388–1392					
silt	Eb	1392–1400					
silt	Cb	1400–1465					
sandy silt	Btb	1465–1485					
sandy silt	BRgb	1485–1510					

Table 2. Extended.— c = common (2–20% of soil surface), u = uncommon (>20% of soil surface). Soil texture: L = loam, SCL = sandy clay loam, SIL = silt loam, SL = sandy loam. Grade of soil structure: 1 = weak, 2 = moderate, m = massive (no structure). Size of soil structure: pl = platy, sbk = subangular blocky. Degree of expression of clay films: 1 = few (5–25%), 2 = common (50%), 3 = many (50–90%). Thickness of clay films: k = thick, mk = moderately thick, n = thin (See Soil Survey Staff, 1998). Morphology of clay films: br = bridges, co = coatings on grains > 2 mm, pf = on ped faces, po = in tubular or interstitial pores. Distinctness of boundary: a = abrupt (within less than 2.3 cm), c = common (between 2.5 and 6 cm). Topography of boundary: i = irregular, s = smooth, w = wavy.

Matrix textural class	% > 2.0 mm	Grade	Size	Type	Clay films	Dry	Moist	Wet	HCL rx	Horizon boundary
SIL	0	2	c	sbk	3, mk, pf 2, n, po + br	sh	fr	so, p	none	a, s
SIL-L	0 0	2	m-c	pl	1, n, po + pf	sh	fi	so, p	none	c, s
L	1–2	2	c	sbk	1, n, po + pf	h	fr	ss, p	none	a, w
SCL	2	2	m-c	sbk	1, n, po	h	fr	ss, p	none	a, i
SCL	5	2	c	sbk	2, k, pf	sh	fr	s, p	none	a, w
SCL	30	2	vc	sbk	2, n, po 1, mk, pf		fr	ss, p	none	c, w
L-SL	9	1	m	sbk	1, k, pf 1, mk, po	h	fr	ss, ps	none	c, -
L	8	m			v1, n, pf	h	fi	ss, ps	sl	c, -
L	8	m				h	fr	ss, ps	m	g, -
L	8	m				h	fi	s, p	st	a, w
L-SICL	<1	2	c	abk	2, k, pf	h	fr	ss, p	vsl	c
CL-L	5	1–2	c	abk	2, mk, pf + po	h	fr	s, p	vsl	c, w
L	7–8	m				h	fr	vss, ps	vsl	a, w
SIL	<1	m				sh	fr	so, ps	vsl	a, s
SIL/L	7–8	m				sh	fr	vss, ps	vsl	a, w
L	7–8	m				h	fi	ss, p	vsl	d
SCL	7–8	m				h	fi	ss, p	es	
SIL									es	
SILT									es	
SILT									es	
SILT									es	
SIL									st	
SIL									vsl	

pre-Illinoian colluvium, unit 6) an Illinoian till, unit 7) Illinoian outwash, unit 8) a probably late Sangamonian sandy unit, probably mainly of eolian origin, unit 9) a probably early Wisconsinan sandy loess, and unit 10) the late Wisconsinan loess. In formal stratigraphic terms, units 1 through 5 would be placed in the Cloverdale Member and units 6 through 8 in the Butlerville Member of the Jessup Formation of Wayne (1963). However, a more useful stratigraphic framework for regional correlations would be that used in Illinois (Johnson 1986). The pre-Illinoian units 2 through 5 probably belong to the Harmattan Till Member or the Hillery Till Member of the Banner Formation deposited ~ 560–450 ka. Units 6 through 8 are probably the Vandalia Till Member of the Glassford Formation. Unit 9 is the Roxana Silt, and unit 10 is the Peoria Loess.

There are six buried soils in the Cagles Mill section (Fig. 2). From oldest to youngest, these soils and their parent material units are soil A) an unnamed early Pleistocene soil developed in unit 1 and into the underlying bedrock, soil B) an unnamed soil in the upper few cm of unit 2, soil C) the Yarmouth Soil developed in units 4 and 5, soil D) the Sangamon Soil developed in units 6 and 7, soil E) the Chapin Soil in unit 8, soil F) the Farmdale Soil in unit 9, and soil G) the surface soil developed in unit 10. The most extensively developed soils are the interglacial Yarmouth Soil (Soil C) and Sangamon Soil (Soil D). Soil A is moderately well-developed, about comparable to the surface soil (Soil G). Soil B is represented only by an A-horizon. Soil F (Farmdale Soil) is also weakly developed compared to all the other soils except soil G. Soil E (Chapin Soil) may be detected only upon close observation because it is welded to the Sangamon Soil, making the two soils appear as only one. The Farmdale Soil is also welded to the Chapin-Sangamon Soil, and the surface soil is welded to the Farmdale Soil. Thus, there is a stack of four soils at the top of the Cagles Mill exposure; this soil is thus the surface soil–Farmdale–Chapin–Sangamon Soil, encompassing time from the late Illinoian to the present (~ 150 ka) and climates varying from perhaps 3–5 °C warmer to 6–10 °C colder than at present. The lithologic and pedologic characteristics of the section are described and interpreted below by considering sediments and soils formed during certain blocks of time.

QUATERNARY EVENTS

Pre-Glacial to early Pleistocene. (1.65 MA (?) to ~ 780 ka)—The sediments at Cagles Mill fill a pre-glacial valley in the bedrock. This valley later served to direct the flow of pre-Illinoian and Illinoian glaciers. We do not know when stream erosion ceased in the Cagles Mill paleovalley and when the site received its first Quaternary sediments that were preserved. Fragments of the underlying Mansfield Sandstone were incorporated into these earliest sediments, probably by frost heaving. Mixed loess and residuum (Fig. 2) are commonly reported in Ohio soils that were believed to be developed under cold, periglacial conditions (Everrett et al. 1971; Amba et al. 1990; Frolking 1988; Szabo 1997).

Was the first loess sedimentation preceded by the weathering of bedrock? Both the in-place bedrock and the sandstone fragments mixed upward into the oldest loess unit are iron-stained in yellows and reds, crumbly, and appear to be extensively weathered. However, these materials were later the parent materials for Soil A, as noted above. Thus, their weathering could have occurred either prior to or after initial loess deposition. The extensive

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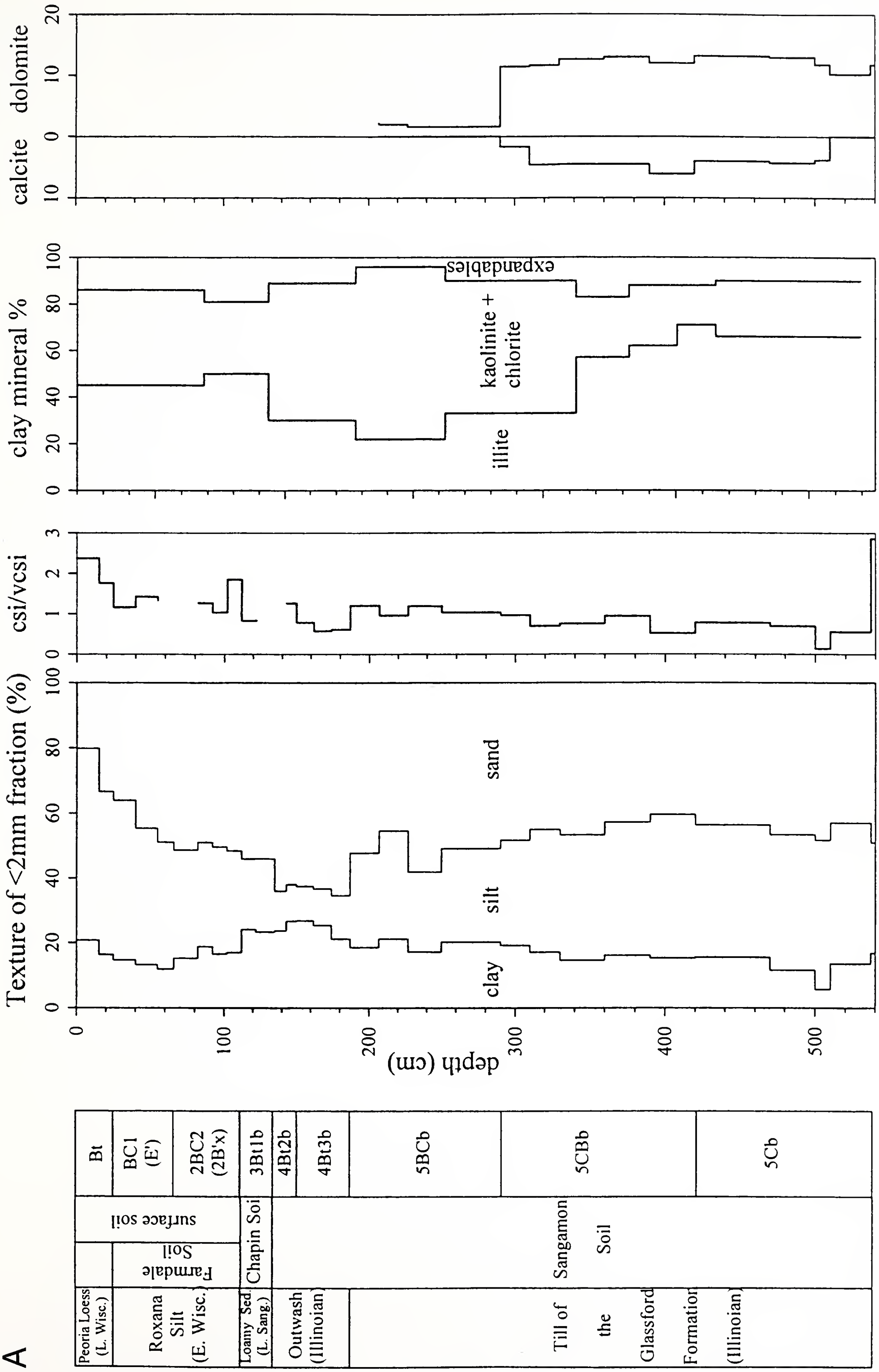
Figure 2.—Columnar section and plots of selected soil characteristics. Columnar section shows lithologic units, their inferred ages, soil-stratigraphic units and soil horizons. Soil-horizon symbols follow standard practices of the NRCS. An exception is the downward numbering of soil horizons through several soils; an alternate numbering system for the Yarmouth Soil would start over again with the first parent material being numbered 1, etc. See text for a discussion of the interpretations of lithologic units and soil horizons. Note thick clay bulges for both the Sangamon Soil and the Yarmouth Soil. For the Sangamon Soil, the upward increase in the coarse silt (16 to 31μ) to very coarse silt (31–62μ) ratio is an indicator of the presence of loess mixed into the original parent material. No such trend exists for the Yarmouth Soil.


A
calcite
dolomite
clay mineral %
expandables
kaolinite +
chlorite
illite
csi/vcsi
Texture of <2mm fraction (%)
sand
silt
clay
depth (cm)
Bt
BC1 (E')
2BC2 (2B'x)
3Bt1b
4Bt2b
4Bt3b
5BCb
5CBb
5Cb
surface soil
Farmdale Soil
Chapin Soil
Sangamon Soil
Peoria Loess (L. Wisc.)
Roxana Silt (E. Wisc.)
Loamy Sed. (L. Sang.)
Outwash (Illinoian)
Till of the Glassford Formation (Illinoian)

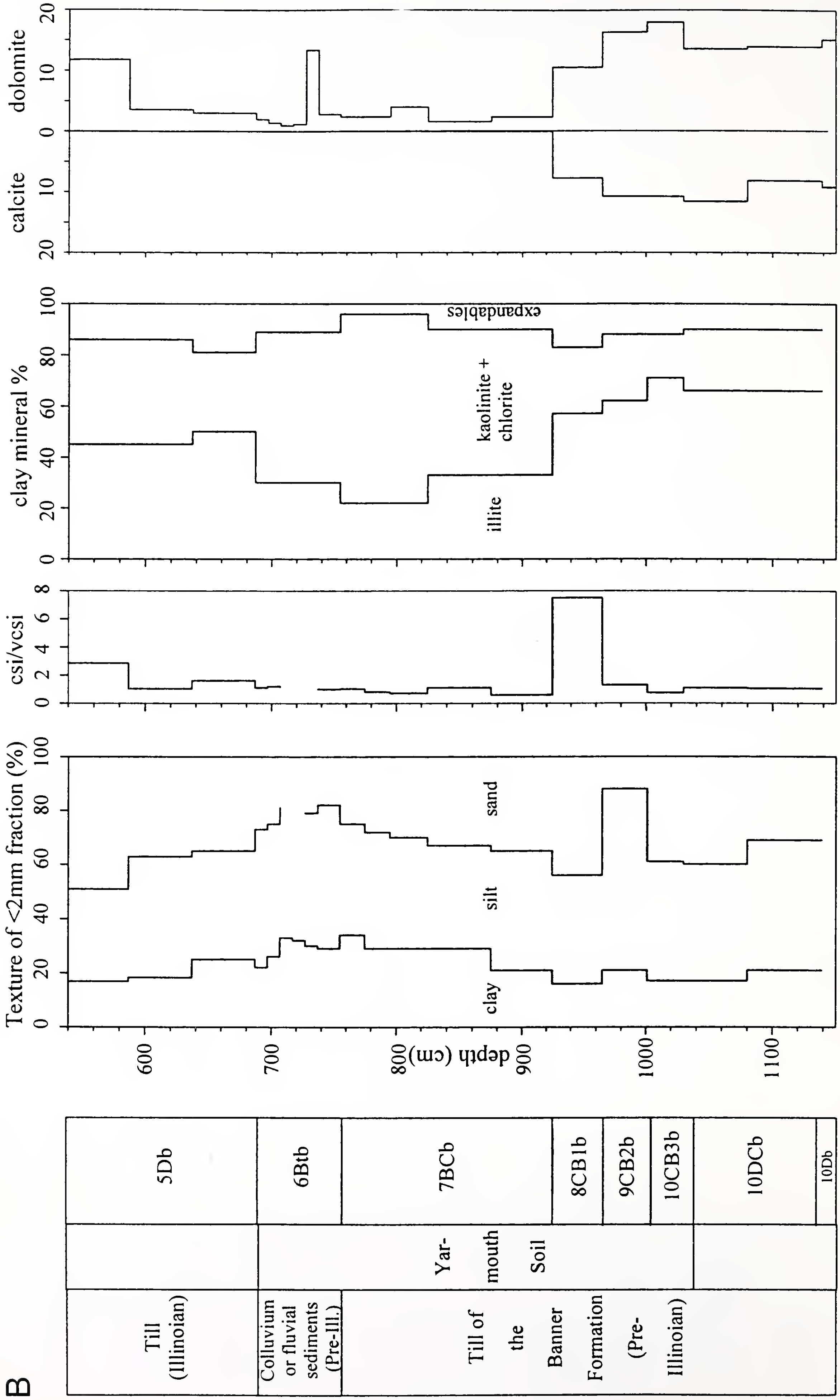


Figure 2.—Continued.

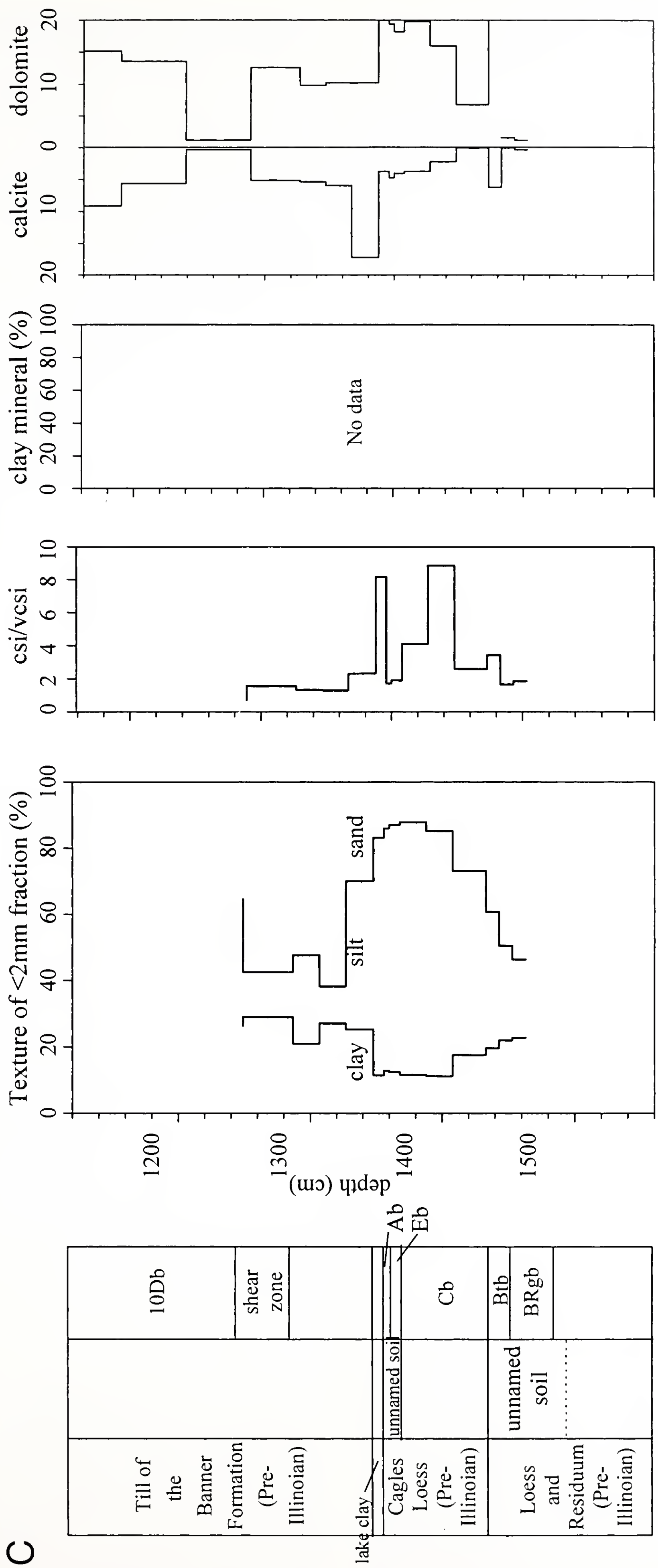


Figure 2.—Continued.

weathering of the sandstone suggests there was pre-loess weathering, but the matter cannot be resolved at present.

The paleosol that developed in this unnamed loess has not previously been described thoroughly even in our own work. Most of the profile consists of a two-part B horizon. The upper part is a Btb horizon of 50 cm with an average increase in percent clay of about 18% clay and a "healed" granular or blocky structure. The Btb contains an average of about 7% dolomite; calcite, if ever present, has been entirely leached. The dolomite may come from the overlying units. Under the Btb horizon is a BRgb horizon of 25 cm which contains a much higher number of rock fragments. Both parts of the B horizon are silty (46–73%), and the dominant hues are 10 YR and 7.5 YR. There is less than 2% dolomite and no calcite. Some of the matrix of the BRgb horizon is gray (gleyed). This soil (and obviously the loess parent material) is older than the middle Pleistocene Cagles Loess; they are probably early Pleistocene (> 780 ka) or older but could be early middle Pleistocene. There have been no known attempts to directly date either the loess or the buried soil.

Middle Pleistocene (780–300 ka).—The earlier Pleistocene sediments and soil were buried by about 0.75 m of loess that Wayne (1958) named the Cagles Loess (Fig. 2c). The Cagles Mill section is its type locality. It should be noted that the Cagles Loess rests upon the loess that is the parent material for Soil A; thus, the Cagles Loess is younger by an unknown, but probably extensive, amount of time. Time must be allowed for the development of a major soil. In contrast, the Cagles Loess shows very little evidence of weathering. It is a grayish-brown silt with less than 2% sand and no detectable coarser material. Carbonates have not been leached from the loess (contains 18–23% by-weight total carbonate), with dolomite dominant over calcite by a factor of about 4.5.

The Cagles Loess has a very weakly developed soil (Soil B) consisting of an A horizon of 4 cm that contains snails, wood, charcoal, and disseminated organic matter underlain by 8 cm that has a lighter color than the loess below and may represent an incipient E horizon. There is no soil structure, buildup of clay, or other evidence of pedogenesis. The soil may have developed over a very short (a few decades) time interval.

Overlying the Cagles Loess is a discontinuous or thin (0–10 cm) unit of light gray laminated lacustrine clay. Deposition was probably in a proglacial lake that had only a limited lateral extent; since the unit is absent in places and pinches out to the west, perhaps the lake was not continuous across the area of the Cagles Mill exposure. The sediments are very high in clay and contain carbonates but less than in the Cagles Loess (about 16%); dolomite dominates over calcite by a factor of about 2. There is some charcoal and disseminated organic matter but no evidence of pedogenesis.

The maximum age of the Cagles Loess and overlying lake sediments is about 780 ka, the age of the Brunhes/Matuyama paleomagnetic reversal, because both sediments have a normal polarity (Bleuer 1976). The lacustrine sediments are overlain by about 7 m of pre-Illinoian till (Hall & Anderson 2000; and other references) that hosts the lower part of the Yarmouth Soil. It is probable that this till correlates with either the Harmattan Till Member or the Hillery Till Member of the Banner Formation. According to Johnson (1986), these tills were deposited about 500 ka. It seems likely that the proglacial till-lacustrine sediments-loess sequence represents the deposits of one pre-Illinoian advance with the proglacial lake sediments and loess being eventually overridden by the glacier. There is a zone of "sheared up" lake sediments in the till about 0.7–1.1 m above the base.

The unweathered pre-Illinoian till is a dark grayish-brown (10YR4/2) loam or silt loam with about 7% gravel. It is massive and hard and effervesces strongly with HCl. Silt is the dominant grain size (50%), followed by sand (30%) and clay (20%). The dominant clay mineral is illite (65%), followed by expandable clay minerals (25%) and kaolinite plus chlorite (10%).

The till is overlain by about 0.7 m of loamy sediment that hosts the upper part of the Yarmouth Soil. The till/loamy sediment boundary is sharp. Above approximately 0.7 m, the silt/sand ratio decreases abruptly, and sand continues to increase upward. There is no evidence, such as an upward increase in coarse silt/very coarse silt, to indicate that loess was added during pedogenesis. We interpret the sediments as either colluvium or vertically-accreted fluvial sediments. They were probably delivered to the site during the late Yarmouthian as soil development continued.

Turning to the Yarmouth Soil, its profile (Soil C) is very well-developed and is well-oxidized (yellowish-brown, 10YR5/6) though containing large (10–25 cm across) krotovina. The profile was truncated into the Bt horizon, presumably by the Illinoian glacier. The texture varies from loam to silt loam. There is a moderate blocky soil structure with common clay films on ped surfaces. The slight reaction to HCl throughout the B horizon is probably due to precipitation of carbonate derived from the overlying Illinoian till. However, there is a strong reaction at the top of the Db horizon reflecting the depth of leaching of primary carbonates. In comparison with the unweathered till parent material, the Btb horizon has a clay enrichment of 15%. The clay mineralogy of the Yarmouth Soil is dominated by kaolinite, which seems to be the main weathering product as illite declines upward. Even though truncated, the surviving thickness of the solum and the other pedogenic characteristics of this soil are typical of an interglacial soil developed under conditions of good drainage.

Illinoian (300–135 ka).—The Yarmouth Soil is overlain by about 5 m of Illinoian lodgment till (Hall & Anderson 2000, and other references) that hosts the lower part of the Sangamon Soil (Soil D). The till is probably the Vandalia Till Member of the Glassford Formation (Johnson 1986; Fullerton 1986). According to Johnson (1986), this formation was deposited about 190–180 ka. The unweathered Illinoian till is dark grayish-brown (10YR4/2) loam with about 8% gravel. It is massive, hard, and effervesces strongly with HCl. Sand and silt each comprise about 40% of this unit. Illite (45%) is the most abundant clay mineral, followed very closely (40%) by kaolinite + chlorite (mostly kaolinite) and 15% expandable clays. This Illinoian till has similar physical properties to the pre-Illinoian till although it is somewhat sandier and has a much greater amount of kaolinite and less illite. It seems probable that much of the kaolinite was incorporated in the till as the Illinoian ice overrode the kaolinite-rich Yarmouth Soil.

At a depth of 187 cm the till is overlain by 37 cm of sandy gravel (30% gravel by volume) that changes abruptly to a somewhat gravelly (5%) sand from 150–135 cm. This unit could be an ablation till because the matrix contains enough fines to be a sandy clay loam. However, we believe these fines were mostly introduced during pedogenesis (see below). The recognition of a distinct sandy zone overlying a much more gravelly zone also argues against an ablation till origin and in favor of some form of fluvial deposition. Probably, the interval from 187–135 cm is Illinoian outwash capping the lodgment till. It could also be early Sangamonian non-glacial alluvium, but a Sangamonian age seems less likely because the unit hosts the very well-developed part of the Sangamon Soil (see below).

Sangamonian and Wisconsinan (135–10 ka).—*Lithologic complexities:* The unit interpreted as Illinoian outwash is overlain by 135 cm of sediments that decrease in sand and increase in silt upward in the stratigraphic section. In most of this interval (120–0 cm), the soil texture changes from loam to silt loam. From 135–120 cm the texture is sandy clay loam because of the introduction of fines during pedogenesis; without the added fines, this zone would also probably be a sandy loam (Hall 1999; Hall & Anderson 2000; and other references). Within the silty zone are detectable parent-material boundaries at depths of 120 cm and 15 cm. Thus, there are at least five different parent materials within the Sangamon Soil and younger welded soils; these parent materials are at depths of 0–15 cm, 15–120 cm, 120–135 cm, 135–187 cm and below 187 cm. We have interpreted the lowest two of these units as Illinoian outwash over till, but what are the upper three units?

The interval from 120–135 cm is a loamy sediment similar to that which occurs in association with the Sangamon Soil at many localities in southwestern Indiana (Hall 1973; Harlan & Franzmeier 1977; Norton & Franzmeier 1978; Tremicoldi et al. 1994). Both the sand and the silt may be mostly eolian, with the sand mostly derived from local sources (Hall 1973; Hall & Anderson 2000). That much of the silt is eolian in this unit and also in younger units is suggested by the upward increase in the coarse silt/very coarse silt ratio. The sediments of the 120–135 cm interval are probably late Sangamonian but could be very early Wisconsinan. The sediments of the

15–120 cm interval are probably a loess, the early Wisconsinan Roxana Silt. The loess above 15 cm is the late Wisconsinan Peoria Loess.

Pedologic complexities: The complexities in the sediments in the upper part of the Sangamon Soil are paralleled or exceeded by complexities in the soils. There are probably four soils that are stacked and welded. As welding occurs, the horizons of former soils, now buried, may be altered and become horizons of the younger soil (Hall et al. 1998; Hall 1999; Hall & Anderson 2000, in press). Thus, instead of the conventional approach of describing a sequence of buried soils from oldest to youngest (as followed earlier in this paper), we believe that, because of the overprinting of a younger soil down into an older soil, a more logical approach is to begin with the surface soil and work downward into the Sangamon Soil developed in Illinoian lodgment till.

The uppermost soil horizon in the exposure is the Bt horizon of the surface soil. The land surface slopes southward toward the top of the spillway wall, and this has caused erosion of the A and E horizons, (and probably the upper part of the B horizon) of the surface soil. A complete solum of about 1 m can be examined by digging a soil pit in flatter terrain above the spillway wall. In the Cagles Mill exposure, the interval from 15–75 cm is now a transitional horizon of the surface soil, i.e., one in which there are both B-horizon and C-horizon characteristics. Because the majority of its characteristics are more B-horizon-like, it should be called a BC horizon. However, this horizon is also an eluvial horizon (has lost clay) as part of a fragipan; as such, it actually should be designated an E′ horizon. And, finally, this horizon was probably once the A horizon of the middle Wisconsinan Farmdale Soil before overprinting by the surface soil (Hall 1999; Hall & Anderson 2000).

The interval from 66–112 cm is also now part of the BC horizon of the surface soil and an illuvial horizon (B′X) of the fragipan. In addition, this horizon was also probably once a part of the Farmdale Soil, perhaps the E horizon. The interval from 112–135 cm is now apparently the upper part of the Sangamon Soil (see below). However, this interval differs significantly in grain size from the underlying Illinoian outwash and till; most likely this sediment was deposited by eolian processes during the late Sangamonian as soil development continued. Because this unit was affected by pedogenesis, but less so than the Sangamon Soil below, it has sometimes been recognized as a separate soil, for which we use the term Chapin Soil of common use in Illinois. In cumulative soils, development occurs toward the land surface as that surface is built up through deposition. A and E horizons are turned into B horizons. This is the likely fate of the interval from 120–135 cm. Then, the Chapin-Sangamon Soil was buried in the early Wisconsinan by the Roxana Silt.

The Sangamon soil: Suppose that the original A and E horizons of the Chapin-Sangamon Soil have by now been completely converted to horizons of the surface soil and cannot be easily described as paleosol horizons. If so, then the characteristics of the Sangamon Soil noted here are for the Bt horizon and underlying horizons. Also, we note the importance of the parent-material change from outwash to till at 135 cm. Like the Yarmouth Soil, the Sangamon Soil is very well-developed and well-oxidized (strong brown, 7.5YR5/8). The texture of the Bt horizon is sandy clay loam changing to loam in the BC, CB, C, and D horizons. The Bt horizon has a moderate subangular blocky soil structure with common clay films on ped faces. There is no carbonate in the profile until the CB horizon at 290 cm. There is a moderate reaction in oxidized till (C horizon) at 420 cm and a strong reaction at the top of the D horizon. In comparison with the unweathered till parent material, the Btb horizon has a clay enrichment of about 10%.

The clay mineralogy of the Sangamon Soil is dominated by illite in the C and D horizons, but kaolinite is about equally abundant in most of the B horizon, then increases somewhat in the upper Bt horizon as expandable clays also increase and illite declines. Much of the kaolinite in this profile may be inherited from the parent material or, in the case of the uppermost horizons, contributed from the atmosphere as part of an eolian influx. The weathering story seems to be the conversion of illite to expandable clays.

The characteristics of the Sangamon Soil are certainly indicative of an interglacial soil developed under good drainage. With truncation of both the Yarmouth Soil and the Sangamon Soil profiles, changes in parent material within both, and soil welding (at least for the Sangamon Soil), it is difficult to compare the two interglacial soils, but both have similar surviving thicknesses, soil structure, clay enrichment, and depth of leaching of carbonates.

Wisconsinan loesses: Late Wisconsinan glaciers reached their maximum extent 17 km northeast of Cagles Mill; the site has not been glaciated since the Illinoian. However, the lithologic units at the top of the section (0–66 cm) are loesses whose presence can be attributed to the pattern of loess distribution in western Indiana. The outwash on the flood plains of glacial sluiceway valleys are the apparent source for loess that thins eastward and also decreases in mean grain size with distance from the Wabash Valley (Hall 1973; and references therein) except where other loess sources (e.g., East and West Forks of the White River) are responsible for adding locally to loess thickness. The nearby Eel River Valley probably served as a local source at Cagles Mill.

The lower part of the loess (25–66 cm) in the Cagles Mill section is much sandier (Fig. 2) than the upper part (0–25 cm in the section, but ~ 1 m on flatter terrain). The difference in the coarse silt to very coarse silt ratio (csi/vcsi) is pronounced. The situation found here is common in western Indiana (Hall 1973; Hall & Anderson 2000): a silty upper part widely accepted as the late Wisconsinan Peoria Loess and a sandy (sometimes called "gritty") lower part alternately interpreted as the early Wisconsinan Roxana Silt or a sandy facies of the Peoria. In the latter case, the sand has been interpreted as eolian (along with the silt component of the sandy loess), mixed up from the substratum materials, or part of or derived from "pedisediment," i.e., material transported over an erosion surface of regional extent. The issues of origin of the sand and, more importantly, age and stratigraphic position of the sandy loess, remain unresolved. We and others have documented the occurrence of the Roxana Silt elsewhere in central Indiana, and we believe it should be present at Cagles Mill, particularly if the Eel River Valley was available as a source during the early Wisconsinan, as seems likely.

CONCLUSIONS

The Cagles Mill section reveals more about the Pleistocene history of central Indiana than other stratigraphic sections we have studied. Lithologic units can be related directly or indirectly with the Wisconsinan, Illinoian, and probably two pre-Illinoian glaciations. Near the base of the exposure, loess mixed with residuum was weathered into a well-developed soil. This soil probably reflects soil development under interglacial conditions that followed deposition of the loess during an early Pleistocene glaciation. Deposition of the Cagles Loess, thin glaciolacustrine beds, and a thick lodgment till occurred during a second pre-Illinoian glaciation. Loamy sediment above this pre-Illinoian till probably represents colluvium or vertically accreted deposits. Accretion probably coincided with the development of the Yarmouth Soil, with the profile extending into the underlying till.

A second lodgment till was deposited during the Illinoian; it was buried by a thin unit of either ablation till or outwash before formation of the Sangamon Soil began. In the late Sangamonian, a loamy unit was added during pedogenesis; it is probably of eolian origin. This unit contains the late Sangamon or Chapin Soil, which is welded to the Sangamon Soil. During the early Wisconsinan, the "gritty" Roxana Silt was deposited, and during the middle Wisconsinan, the Farmdale Soil formed in the Roxana Silt and welded to the Chapin-Sangamon Soil. The last deposition in the section was the late Wisconsinan Peoria Loess in which the surface soil formed and was welded to the older soils.

The Yarmouth Soil and the Sangamon Soil are both very well-developed, as would be expected of interglacial soils. Cagles Mill remains an excellent location to study the history of the Pleistocene in Indiana.

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Manuscript received 2 November 1998, revised 19 July 1999.