57^{th} Midwest Friends of the Pleistocene

At the edge of the Laurentide Ice Sheet: Stratigraphy and Chronology of Glacial Deposits in Central Indiana

Clayton Section, late 1950s or early 1960s

Trip Leaders

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Welcome and Overview

Welcome to Bloomington, Indiana, for the 57th Friends of the Pleistocene Field Conference. The last time the FOP was held in Bloomington was 1957 and was led by W.D. Thornbury and W.J. Wayne, titled *Study of Kansan, Illinoian, and early Tazewell tills, loesses, and associated faunas in south-central Indiana*. The guidebook was 27 pages long and included an elaborate road log. Our trip, titled *At the edge of the Laurentide Ice Sheet: Stratigraphy and Chronology of Glacial Deposits in Central Indiana*, will consider similar issues, but our work is not as ambitious as that of Thornbury and Wayne. Unlike our predecessors in 1957, which held the meeting at a time when radiocarbon dating was still in its infancy and OSL not even a consideration, we will focus on the *chronology* of the Laurentide Ice Sheet (LIS) before and after the Last Glacial Maximum (LGM) and how new age control integrates with earlier chronology.

As our title implies, we will focus on the so-called “terminal moraine” (mostly as described by Leverett and Taylor, 1915) between Bloomington and Indianapolis and discuss the processes and chronology of the LIS about 24 ka (see Fig. 1).

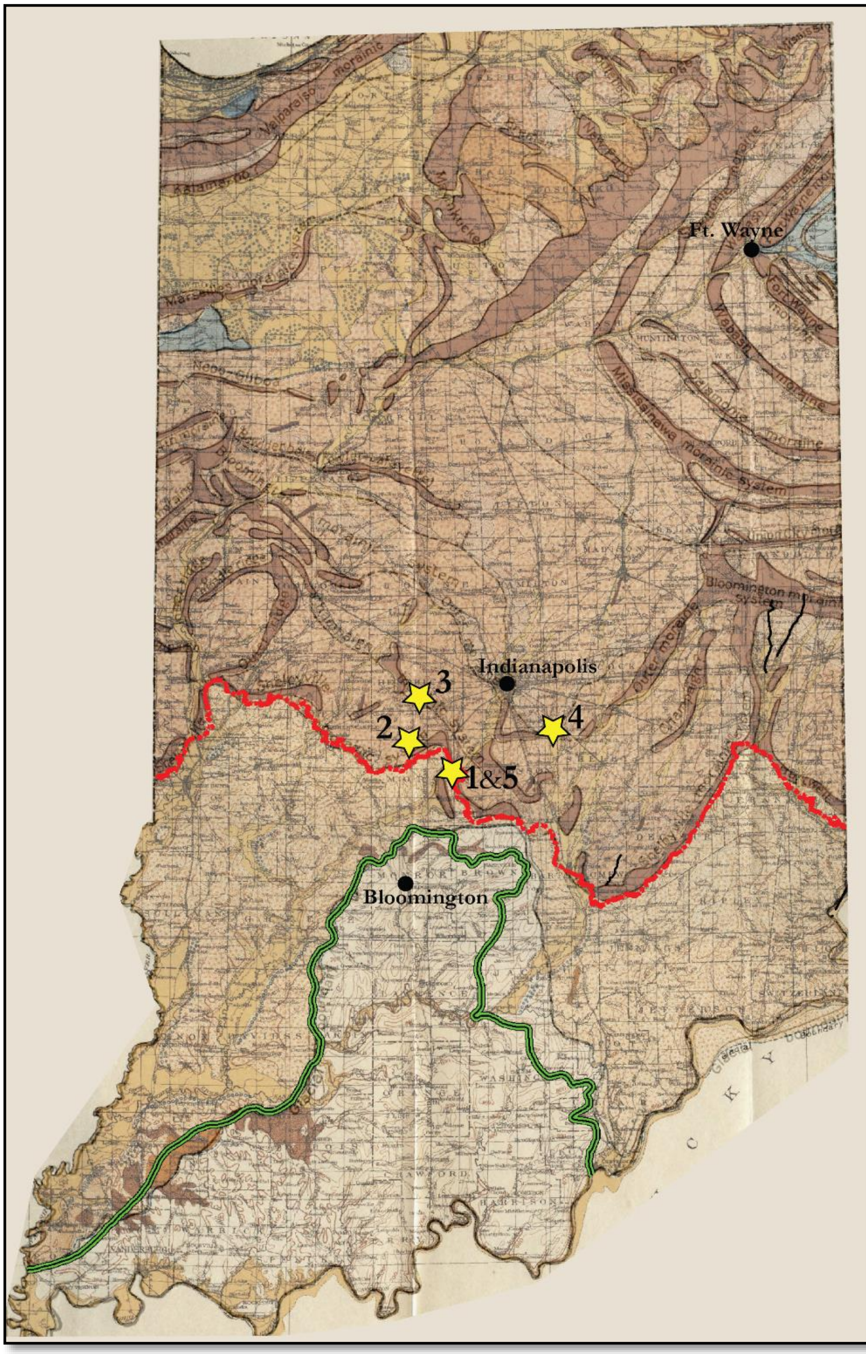


Figure 1. Map of Indiana with named moraines and maximum extent of the LIS during the Wisconsin (red line) and Illinoian (green line) stages. Moraines after Leverett and Taylor (1915). Field trip stops numbered, shown by yellow stars.

We will address questions like: What does the "terminal moraine" look like in central Indiana? When did the LIS arrive? What was the advance and retreat rates of LIS flow? How do new dating methods (AMS, ^{14}C, and OSL) affect our ability to resolve LIS dynamics? These are but a few of the questions we hope to discuss.

The maximum extent of the LIS during the LGM, the so-called 'Terminal moraine', has been studied from the beginning of scientific thought on continental glaciation. It was mapped by Chamberlin (1882) as part of his *Preliminary Paper on the Terminal moraine of the Second*

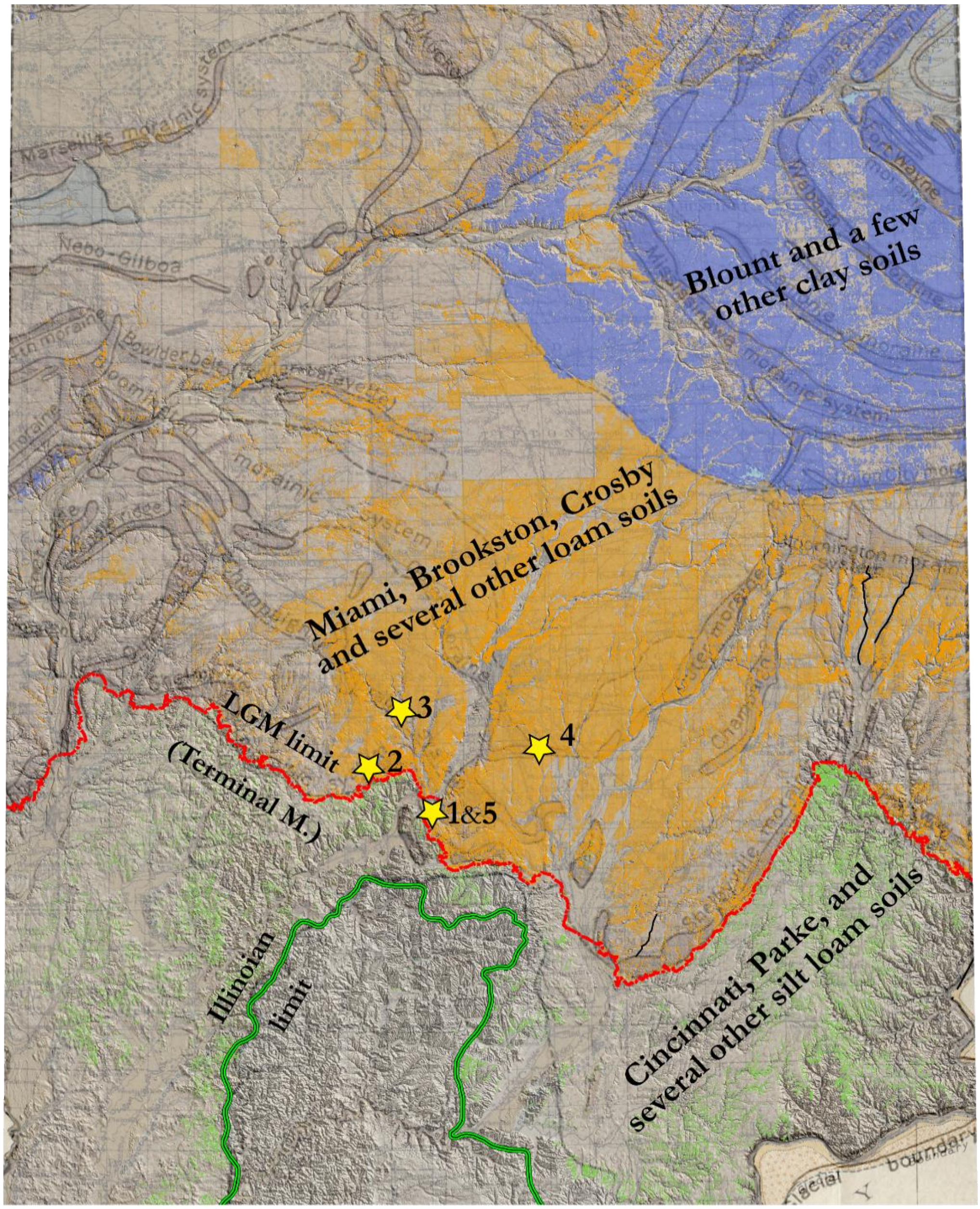


Figure 2. Map of central Indiana showing distribution of till-based soil series, named moraines, and maximum extent of the LIS during the Wisconsin (red line) and Illinoian (green line) stages. Wisconsin tills are shown in orange and blue; Illinoian till soils are shown in light green. These soil seris that characterize the Wisconsin and Illinoan regions (green and orange, respectively) rarely overlap Moraines after Leverett and Taylor (1915). Field trip stops numbered, shown by yellow stars.

Glacial Epoch USGS report and the position has changed little in Indiana since then. Leverett and Taylor (1915) tinkered with the position, as have several others during the 20th century, including that shown on maps in this guidebook based on Gray (1989). Gray and Letsinger (2011) provide a historical framework for the location of the glacial boundaries in Indiana. From its initial description, a couple of oddities have been noted about the terminal moraine in Indiana. First, the moraine did not have what even in the 19th century was considered typical morphology. No distinct, relatively continuous ridges where noted. Second, no outwash fans that could be traced to the terminal moraine could be identified. Such morphosequences are today expected at least in places on active ice margins. Chamberlin was the first to note and publish about a lack of outwash, which would be expected from an active ice margin. Leverett noted this oddity as well.

> "The Wisconsin drift border in Indiana, like that in Illinois, appears to have had remarkably weak outwash. … [that] nothing found along the valleys of the large rivers, the East White and White, seems clearly referable to the drainage at the maximum extent of the Wisconsin glaciation. Each valley carries a gravel plain, but much of the gravel has been bought from the moraines well within the Wisconsin drift border." (Leverett and Taylor, 1915:82).

That latter observation is similar to our observation and will be discussed in more detail at Stop 4. Leverett also relates a theory expounded by Chamberlin at the GSA meeting in 1903 in way of explaining the lack of outwash from the terminal moraine its presence from younger sequences.

> "In explanation of [the] apparent weakness of discharge on the ice border Chamberlin has suggested that at the culmination of the Wisconsin stage of glaciation arid conditions may have prevailed to such an extent as to favor evaporation rather melting or liquefying of the marginal portion of the ice sheet, and that evaporation gave place to liquefaction as the humidity increased." (Leverett and Taylor, 1915:82)

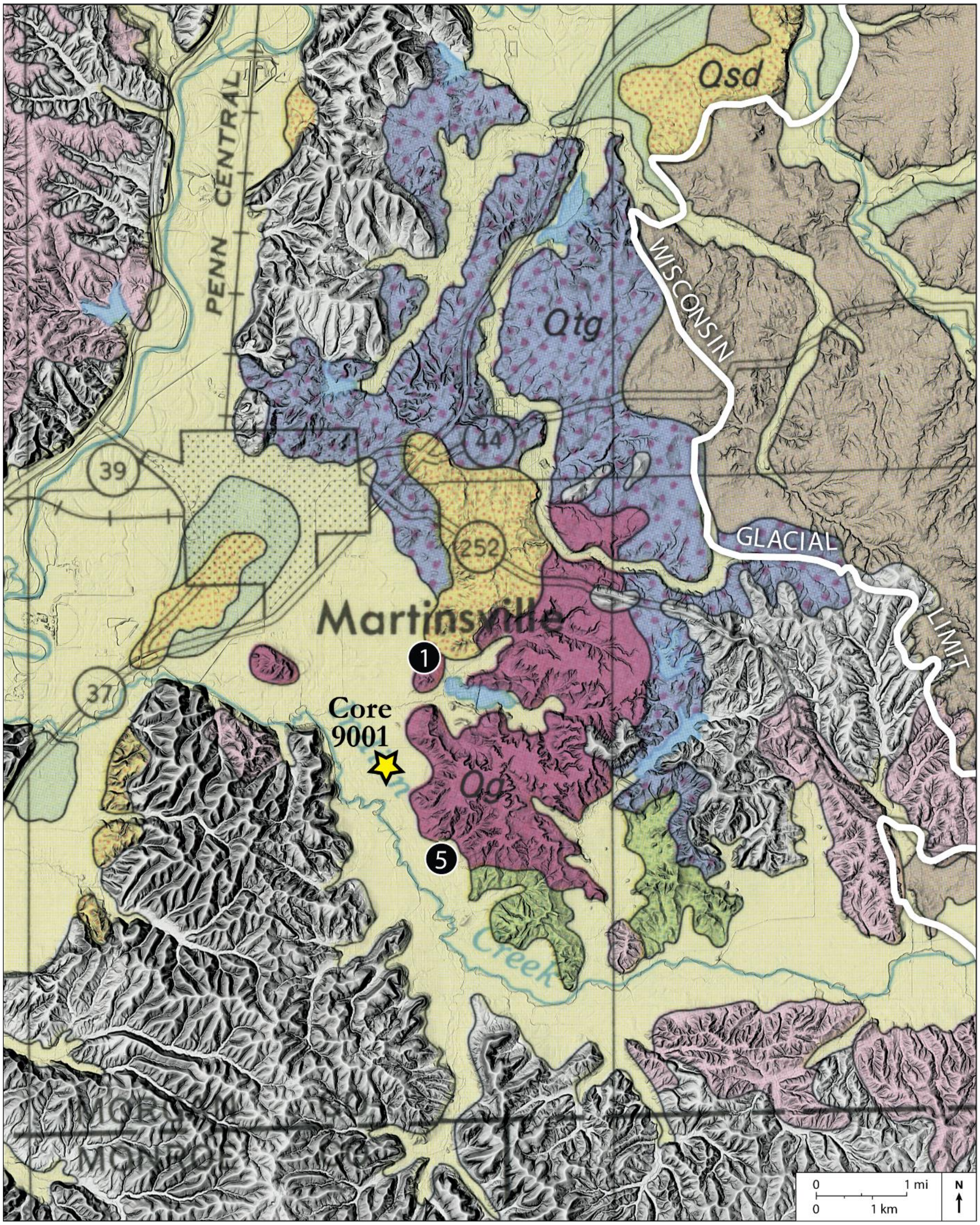
What a story. Even so, Leverett actually offered no better explanation and perhaps related this as what he thought was a reliable explanation.

Leverett also noted that the terminal moraine was not comprised of distinct, relatively continuous morainal ridge(s). This observation still holds true today—even LIDAR does not show distinct morainal ridges along the LGM ice limit. Such an observation along with a lack of outwash begs the question: what is the terminal moraine in central Indiana and does it even exist? Leverett concluded that it did exist despite a lack of distinct morphology or expected outwash. He noted the very clear boundary between specific types of soil that were Wisconsin in age versus those that were Illinoian. These he learned from talking to farmers rather than the soil maps we used today. Soil associations have since become standard practice in the mid-continent. Figure 2 shows the association of "Wisconsin" soil types (orange and blue) and "Illinoian" soil types (green) that were probably the associations that informed his "terminal moraine." Note the distinct soil boundary along the Union City Moraine (boundary between orange and blue in Fig. 2). That association has been linked to the maximum extent of post-Erie Interstade LIS by many, but is a topic for another trip (one that Grahame Larson and I led in 1988).

Our focus will be on the LIS margin and events associated with +/- 3,000 years before and after the "Terminal moraine." We will look evidence for the rate of advance of the LIS between about 29 ka and 24 ka and learn the it was <100 m/yr north of Indianapolis but slowed to ~25 m/yr between there and the LGM limit (terminal moraine). We will study the field evidence of a significant readvance of the ice sheet ~21,500 years ago and ask what this event tells us about the dynamics of the LIS as it left the LGM "terminal" position. This idea was clarified and synthesized in 1963 in *Pleistocene Formations in Indiana: Indiana Geological Survey Bulletin 25* by Wayne. Later, Wayne (1965) and Gooding (1975) presented results on the chronology and stratigraphy of LIS fluctuations in central Indiana, which we will discuss. And these discussions are only the Saturday Trip!

On Sunday, we will look at pre-Wisconsin outwash higher up in the valley near Stop 1, and discuss its age and consider how it may have differed from outwash related to the "terminal moraine". More importantly, we will discuss whether pre-Wisconsin outwash filled the West Fork White River valley and if so, how it could have been removed to allow LGM outwash to fill the valley about 24 ka.

While we cannot promise you that we are always right in our interpretations, we can promise you good science and very lively discussions (some might even get contentious) at every stop!



Surficial geologic map near Stops 1 and 5 (Gray et al., 1979). See foldout map for regional location of stops.

Stop 1: Wisconsin Outwash Near Martinsville, Indiana.

Bill Monaghan; contributions from Henry Loope, Jose Luis Antinao, Sebastien Huot

Location: Stop 1 occurs along Cramertown Loop in Morgan County. The site is located on the eastern margin of the White River outwash, about 2 km east of the town of Martinsville. It also lies about 8 km downstream (south) of the late Wisconsin last glacial maximum (LGM; terminal moraine) in south-central Indiana near Indianapolis.

Purpose: The purpose of this stop is to examine the evidence of the age and volume of outwash in the White River. We frame our discussion on the results of a deep core (16-9001) located about 2 km SSW of Stop 1.

We will examine evidence for:

- the time that outwash began to accumulate in the White River valley;
- the time that outwash ceased accumulating in the valley;
- the depositional rate of outwash.

We will also discuss the outwash sequence in terms of:

- the formation and age of the LGM margin (terminal moraine);
- outwash deposition related to the LGM margin (moraine) chronology and formational properties and processes related to the moraine;
- the rate that the Laurentide ice sheet (LIS) advanced through Indiana.

Finally, we will discuss valley-margin eolian sediments in relationship to accretion of outwash and final abandonment of its deposition in the valley.

Description and results from Core 16-9001. A continuous, solid-earth GeoProbe core was collected about 2 km SSW of Stop 1 in what is today the valley of Indian Creek, a tributary of the White River. The core was approximately ~23 m long and extended nearly to the bedrock, which occurs about 30 m below surface at this location, based on a geophysical (Tromino) survey. The sediments within the core consist predominantly of silt with interbedded fine-medium sand. A few coarser layers (medium-coarse sand) also occur within the sequence. Organic matter occurs within the sequence and provides a fine-scaled accelerator mass spectrometry (AMS) radiocarbon chronology to the vertical sequence, particularly from 16 to 21 m and near 5 m depth. Unfortunately, a ~2.25 m interval where no sediment was recovered occurs between 13 and 15.75 m deep within the cores. This lack of recovery occurred because of heaving sand. Accelerator mass spectrometry ages in the core indicate that:

- Outwash deposition began by about 26.7 ka, which precedes the formation of the LGM (terminal) moraine by 2,500 to 3,000 years;
- 7 m of sediment progressively accumulated between 26.7 and 25.5 ka;
- No ages were recovered associated with the LGM margin (i.e., ~24 ka);

- The upper 5 m of sediment accumulated after ~22 ka;
- Sedimentation rates vary from about 1.3 mm/yr (base) to 10.5 mm/yr (19–20 m);
- Higher sedimentation rates seems to be associated with coarser-grained deposition;

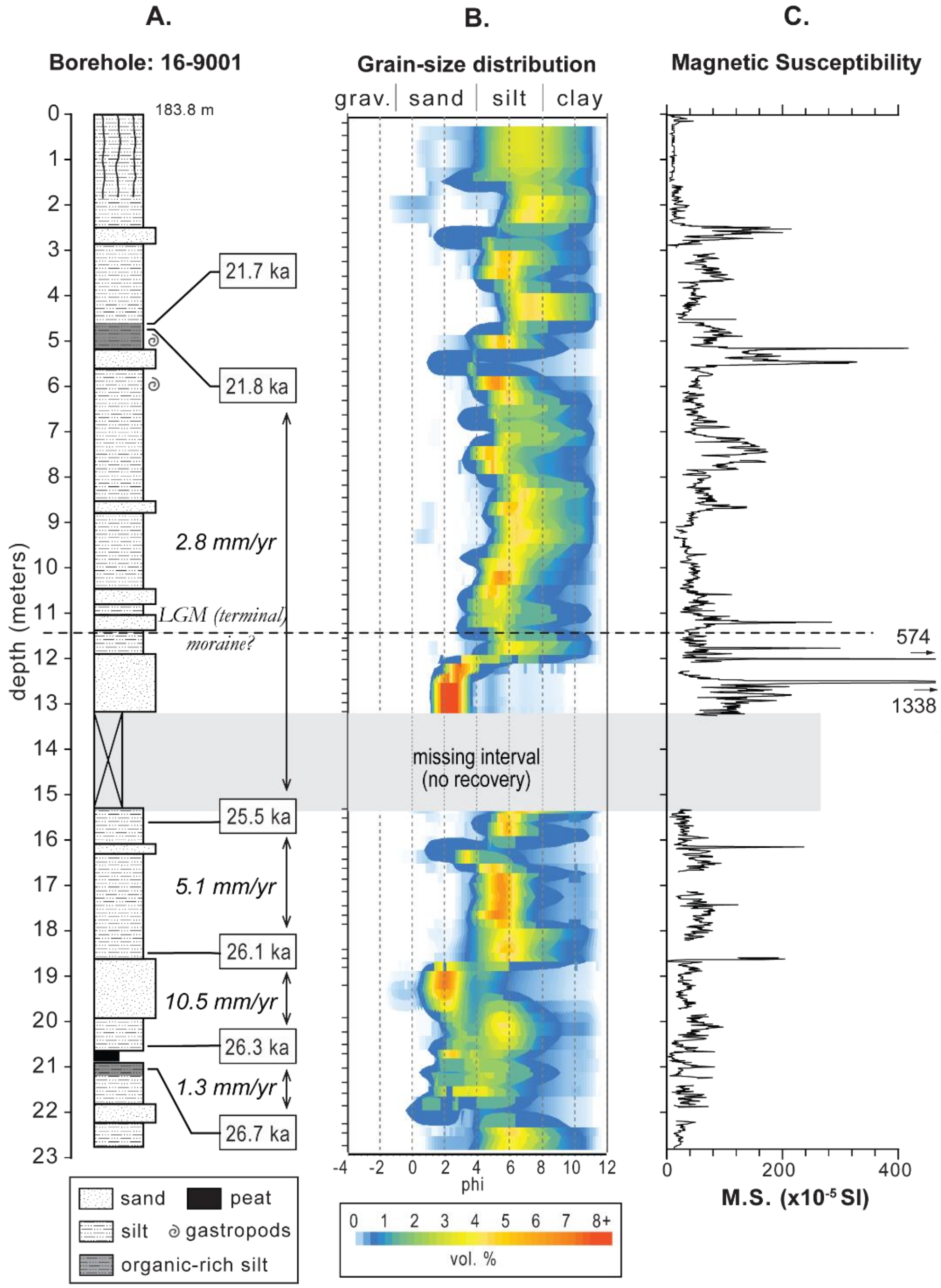


Figure 1-1. Stratigraphy, chronology, and sedimentology of borehole 16-9001. A) Stratigraphic log with calibrated radiocarbon ages. B) heatmap based on particle size distribution determined by laser diffraction. Sample depths are noted by tick marks on left side of graph. C) magnetic susceptibility (1 cm sampling interval).

- Wisconsin-age outwash has apparently filled the entire valley, which suggests that earlier outwashes eroded from the valley before 24 ka. This issue will be discussed at Stop 5 (e.g., extent of Illinoian outwash).

Discussion and Regional Significance. The AMS ages from core 16-9001 indicate that outwash began filling the White River valley well before the LIS reached its LGM position at 24 ka. Glacial drainage began in the valley soon after 27 ka (Figs. 1-1 and 1-2) and continued relatively continuously until at least 25.5 ka. For most of this period, sedimentation rates varied from 5 to 10 mm/yr. No dates were obtained from 15 to 5 m, which spans ~3,500 years surrounding the LGM. Although no dates were recovered for 1,500 to 2,000 years before and after the LGM, the

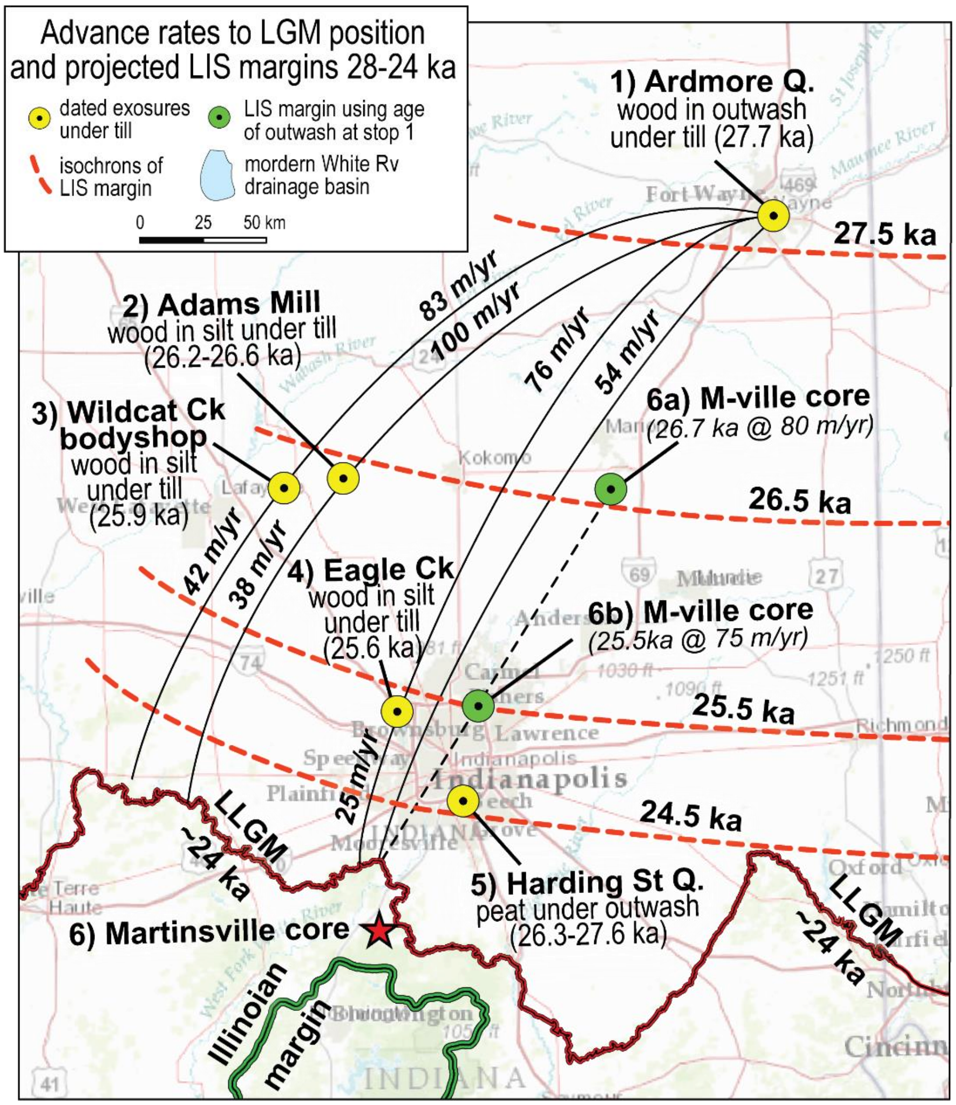


Figure1-2. Reconstructed LIS margins showing the general rates of advance for the LIS as it flowed through Indiana. The map is based on the age of organic matter from sediment below till or the age of organic matter within the outwash of the Martinsville core. The yellow dots are sections that include organic matter beneath till and the green dots mark the position of LIS based on the age of organic matter in the outwash and an assumed rate of advance in m/yr using the rates of advance derived for those times using the sections 1-5.

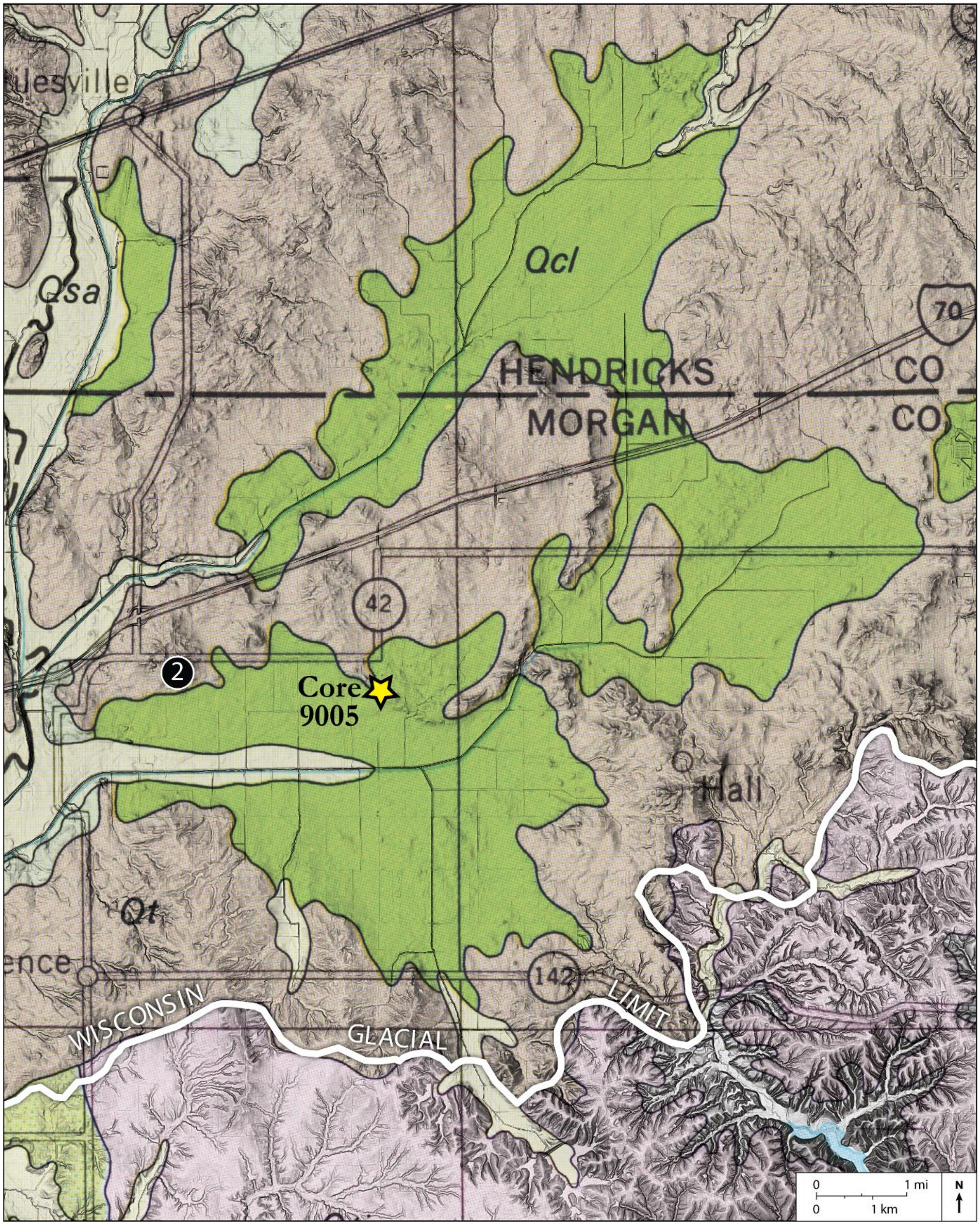
sedimentation rate may be considerably lower during the LGM than prior to 25.5 ka (<3 mm/yr and 5–10 mm/yr, respectively; Fig. 1-1), which begs the question: Why?

The age of wood fragments in silt or outwash deposits below till in several exposures (i.e., Ardmore Quarry, Adams Mill/Wildcat Creek Body shop, Eagle Creek, and Harding Street Quarry; Fig. 1-2) sheds light on this question. Taken together, these exposures, along with the chronology of outwash at Stop 1, provide estimates for the LIS advance rate and how it varied through time and space. By comparing the age and distance of exposures that include organic matter below till from each other and the LGM margin (terminal moraine), isochrones can be constructed that outline the geometry and chronology of the LIS before arriving at the LGM south of Indianapolis.

These data suggest that:

- The LIS margin passed over Ft. Wayne ~27.7 ka, which is ~200 km from the LGM and indicates that the average rate of advance of the LIS in Indiana is about 54 m/yr.
- This rate varied; between Ft. Wayne and Kokomo (i.e., Adams Mill/Wildcat Creek exposures; Fig. 1-2) the rate was in the 80 to 100 m/yr range, but slowed dramatically when it reached Indianapolis (i.e., Eagle Creek, Fig. 1-2) to ~25 m/yr.
- When meltwater first began to flow into the White River drainage (26.7 ka; Fig. 1-2), the LIS was likely near the town of Muncie, which lies at the northern limit of the White River drainage basin (northern green dot; Fig. 1-2). The youngest age before the LGM in the sequence (25.5 ka; Fig. 1-1) would place the LIS margin just north of Indianapolis (southern green dot; Fig. 1-2).
- Peat at the Harding Street Quarry was buried related to a LIS margin between these green dots (Fig. 1-2).

The observations noted above are significant and probably reflect processes related to the LIS as it approached the LGM in Indiana.



Surficial geologic map near Stop 2 (Gray et al., 1979). See foldout map for regional location of stops.

Stop 2. Glacial Lake Eminence

Henry Loope and Bob Autio, contributions from Bill Monaghan, Jose Luis Antinao, Sebastien Huot

Location: The glacial Lake Eminence basin (ca. 80 km^2) is located within ~5 km north of the late Wisconsin maximum limit in western Morgan County (Fig. 2-1) and it located within the present-day Mill Creek basin. Depth to bedrock (Mississippian Borden Group) ranges from ~10 to 40 m (~40 to 120 ft) in the Lake Eminence basin and is part of a larger southwest-northeast trending bedrock trough ~50 km in length that potentially is a tributary valley to the northward-draining Noblesville Valley Section of the Lafayette Bedrock Valley system (Teays-Mahomet Bedrock Valley) (Bleuer, 1989). The northern ca. two-thirds of the Mill Creek drainage basin is dominated by Wisconsin till at the surface. The southern one-third is mainly Illinoian till and glaciolacustrine sediment with thicknesses generally less than ~20 m (~65 ft).

Purpose: The purpose of this stop is to present new chronology (Figs. 2-2, 2-3) constraining the formation of glacial Lake Eminence and ice advance and retreat near the late Wisconsin maximum limit.

Description: The recognition of a glacial lake in the present-day Mill Creek basin has been noted for more than 140 years (Collett, 1875; Brown, 1883; Edmondson, 1911; Malott, 1922).

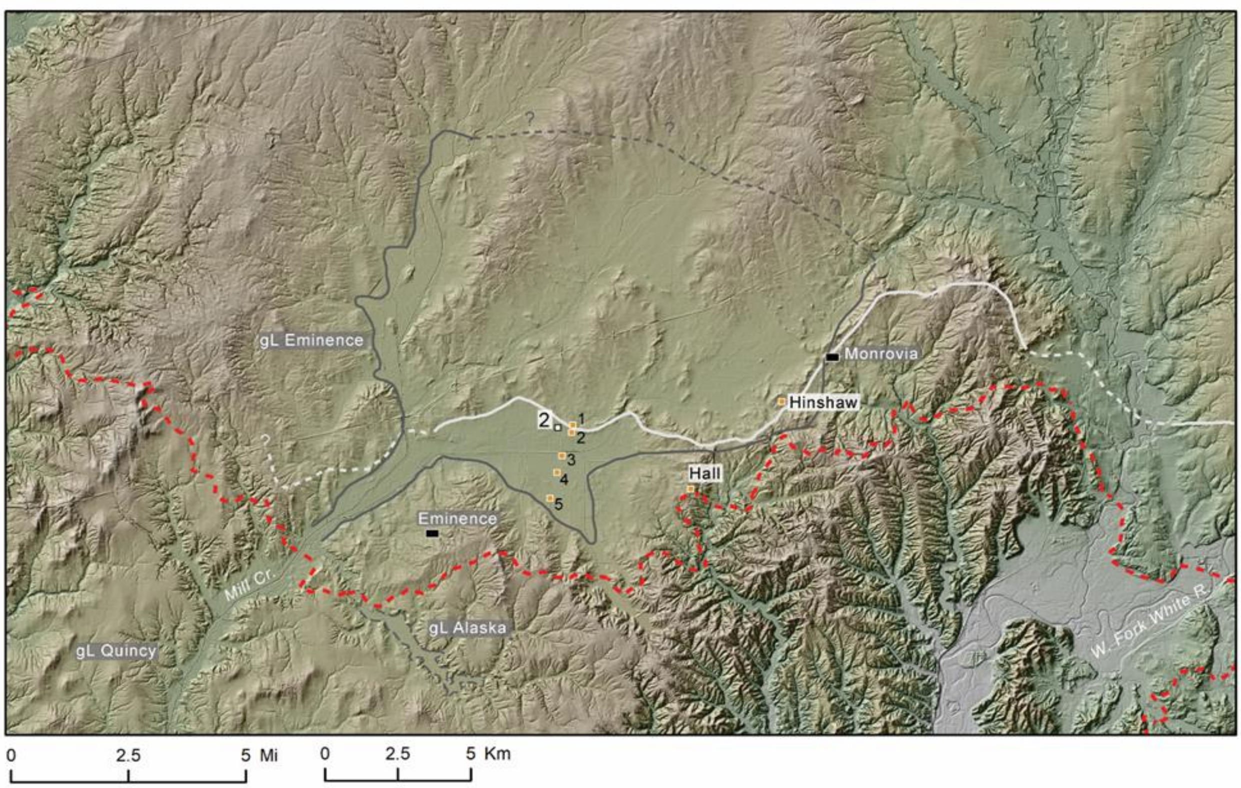


Figure 2-1. Hillshade LiDAR DEM centered on the glacial Lake Eminence basin showing the Wisconsin limit ca. 24.0 k cal yr BP (red dashed line), the limit of the ca. 21.5 k cal yr BP readvance (white line), the approximate extent of glacial lakes (grey lines), and core sites (orange squares).

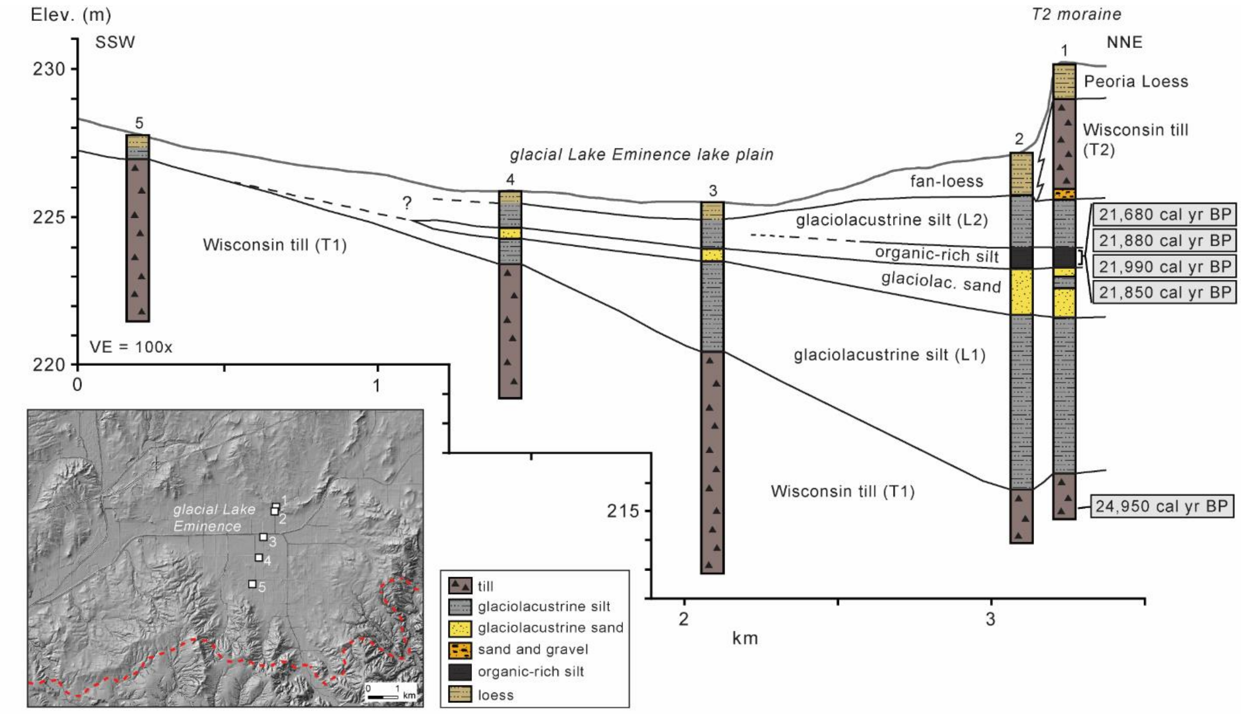


Figure 2-2. Stratigraphy, correlation of units, and radiocarbon ages along a SSW-NNE transect across the southern end of the glacial Lake Eminence basin (from Autio, 1990). Inset hillshade LiDAR DEM shows core locations and late Wisconsin maximum (red dashed line).

Thornbury (1940) formalized the name, glacial Lake Eminence, and recognized that another older glacial lake was present in parts of the Mill Creek basin. This older lake was named glacial Lake Quincy, and Thornbury (1940) differentiated the two based on degree of landscape dissection and depth of carbonate leaching (2–3 m for glacial Lake Eminence and 4–5 m for glacial Lake Quincy). Since Thornbury (1940), only a few studies have investigated the stratigraphy, sedimentology, chronology, and geomorphology of Lakes Eminence and Quincy. Autio (1990) collected 12

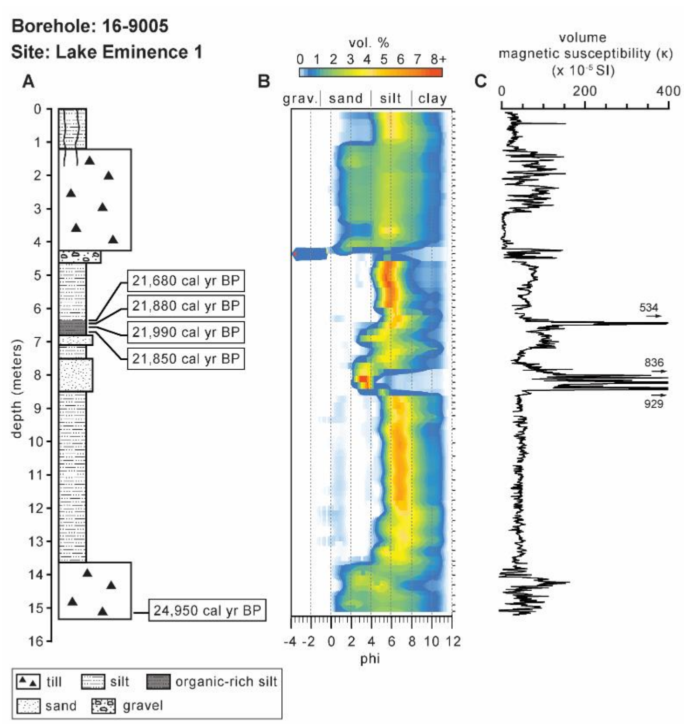


Figure 2-3. Stratigraphy, chronology and sedimentology of borehole 16-9005 (site 1 on transect in Figure 2-1 and 2-2). A) Stratigraphic log with calibrated radiocarbon ages. B) heat map based on particle size distribution determined by laser diffraction. Sample depths are noted by tick marks on right side of graph. C) magnetic susceptibility (1 cm sampling interval).

cores throughout both basins and documented the thickness, spatial extent, particle size, carbonate content, magnetic susceptibility, and clay mineralogy of the lacustrine sediment and till. More recently, Wood et al. (2010) used optical dating to establish the age of glacial Lake Quincy as Illinoian (ca. 135 ka). The focus here will be on five cores collected along a north-south transect across the southern end of the glacial Lake Eminence basin (Autio, 1990; Figs. 2-1, 2-2). The coring transect (Fig. 2-2) indicates that a lower Wisconsin till (T1) is overlain by northward-thickening glaciolacustrine units (L1, L2), which are capped by an upper Wisconsin till (T2) at the north end of the transect. As part of U.S. Geological Survey STATEMAP and Great Lakes Geologic Mapping Coalition projects in Morgan County, we collected a new core at site 1 in 2016 to obtain chronology and a paleoenvironmental record of glacial Lake Eminence. Wood within the lower Wisconsin till returned an age of 24,950 cal yr BP, providing a maximum age for deposition of the lower till. Four ages on wood and *Picea* needles from organic silt between 6 and 7 m depth (Fig. 2-3) constrain the deposition of the upper glaciolacustrine unit (L2) and the upper till (T2). Additionally, 3 optically stimulated luminescence (OSL) ages were obtained from eolian sand on the eastern flank of the glacial lake basin. Ages indicate deposition of eolian sand ca. 24-25 ka (Fig. 2-4).

Significance: The glacial Lake Eminence basin is important because it contains a stratigraphic record of two advances of the Laurentide Ice Sheet. The first is the advance to the late Wisconsin maximum limit, ca. 24.0 k cal yr BP, and the second being a readvance ca. 21.5 k cal yr BP, which crossed the northern two-thirds of the glacial lake basin (Fig. 2-1). Based on the coring transect and LiDAR DEMs, site 1 of the transect records the southern limit of the readvance,

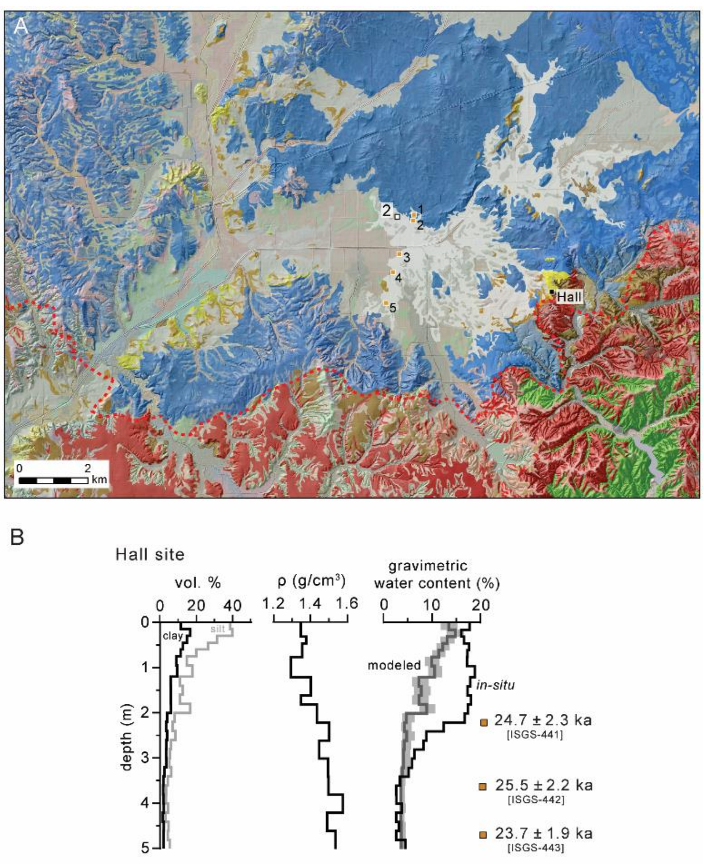


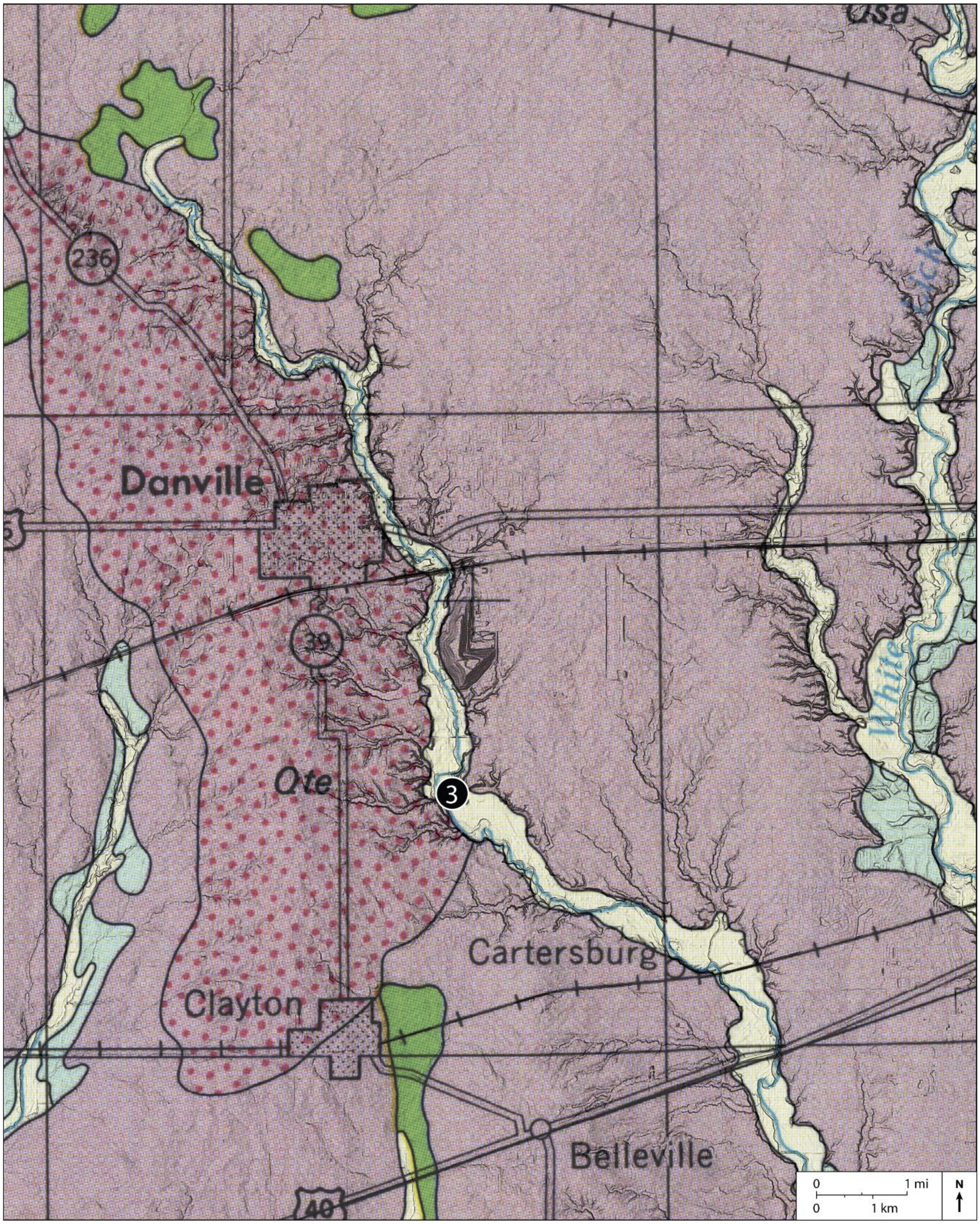
Figure 2-4. A) Soil parent material based on NRCS SSURGO data. Blue represents Wisconsin-age till, red represents Illinoian-age till covered by loess, brown represents thick loess (>5 ft), green represents bedrock (Mississippian Borden Gp. siltstone-sandstone-shale) within 5 ft of the surface, grey represents soils formed in alluvium and/ or loam on lake plains, and yellow represents eolian sand. The dashed red line is the Wisconsin limit. B) Particle size, bulk density, water content, and optical ages from the Hall site eolian dune (black square in A).

which can be traced for ~80 km to the east. The OSL ages on eolian sand (ca. 24-25 ka) from the eastern edge of the lake basin (Hall site) are interpreted to represent deflation of sandy glaciolacustrine sediment when glacial Lake Eminence drained after ice retreated north of the paleo-Mill Creek drainage divide. With this model, the ages should post-date the advance to the late Wisconsin maximum, ca. 24 ka. Perhaps ice retreated rapidly from the maximum position to the north? Or perhaps the errors on the ages allow for less rapid ice retreat but still suggest drainage of the lake prior to a readvance ca. 21,700 cal yr BP.

Discussion and Questions:

The stratigraphy and chronology suggest the following sequence of events:

1) Ice advance to the late Wisconsin maximum sometime after 24,950 cal yr BP;
2) Retreat from the maximum limit allowed the formation of glacial Lake Eminence (L1 in Fig. 2-2) until ice retreated north of the paleo-Mill Creek drainage divide, at which time the lake drained and became subaerial;
3) Ice readvance into the paleo-Mill Creek basin ca. 21,700 cal yr BP and a second phase of the glacial lake (L2 in Fig. 2-2) resulted in an additional 1.5 m of glaciolacustrine sediment deposition. The southern limit of the readvance is between core sites 1 and 2 (Fig. 2-2).
4) How quickly did ice retreat from the terminal moraine northward out of the paleo-Mill Creek drainage? There is a 2,500 year ‘gap’ between the terminal moraine position and the readvance. How much of the 2,500 years is recorded in the lower Lake Eminence glaciolacustrine package (L1 in Fig. 2-2)? What were the paleoenvironmental conditions during this period?



Surficial geologic map near Stop 3 (Gray et al., 1979).
See foldout map for regional location of stops.

Stop 3. Clayton Section

Henry Loope; contributions from Brandon Curry, Dave Grimley, Andy Nash, Tom Lowell, Sebastien Huot, Bill Monaghan, Jose Luis Antinao, Hong Wang, Alex Sodeman, Marni Karaffa

Location: The Clayton section is a cutbank exposure along the West Fork of White Lick Creek, a southward-flowing tributary of the West Fork White River. The surficial geology of the White Lick Creek drainage basin is dominated by Wisconsin till with outwash confined to valleys. This section is roughly 20 km north of the Wisconsin maximum.

Purpose: This section (Figs. 3-1, 3-2) is one of the key glacial exposures in central Indiana, as it is the type section for the Cartersburg Till Member of the Trafalgar Formation (Wayne, 1963), the younger (upper; T2) till of the late Wisconsin till sequence found in central Indiana. This section was first described more than 60 years ago and was included in the 8th Midwest Friends of the Pleistocene trip in 1957 led by William Thornbury and William Wayne. As noted by Thornbury and Wayne, the section contains a fossiliferous silt bed (*Vertigo alpestris oughtoni* bed in Fig. 3-2), which is the focus of recent chronologic work (Fig. 3-3). This section also serves as a key tie point between the glacial stratigraphy and chronology of the Lake Michigan Lobe to the west in Illinois (Curry et al., 2011) and the Erie Lobe to the east in Ohio (Lowell, 1995).

Description: The ~15-m-high section contains two late Wisconsin tills separated by stratified sediments (silt, sand, and sand and gravel), and an upper sand and gravel unit (outwash) that

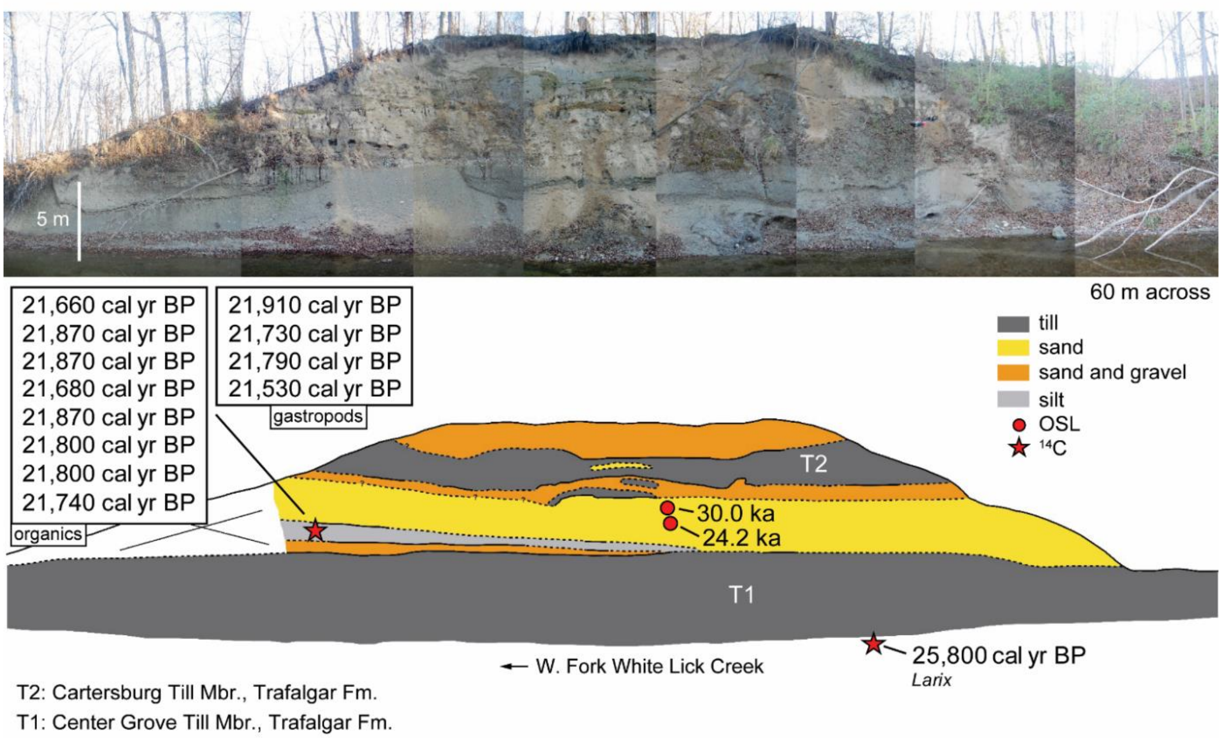


Figure 3-1. Photomosaic, stratigraphy and chronology at the Clayton section.

Figure 3-2. The Clayton section as exposed in the late 1950s and early 1960s (Wayne, 1963).

overlies the upper till (Fig. 3-1). Samples for radiocarbon dating were collected from unoxidized silt between 11.15 and 11.4 m depth. Organics (*Dryas* leaves, *Picea* needles, other macrofossils) and gastropods (*Succinea* and *Discus*) were sampled for radiocarbon dating from this interval. A *Larix* wood fragment was collected at creek level in the lower till. Two samples for optically stimulated luminescence (OSL) were collected from planar-bedded sand at 7.7 and 9.3 m depth. All age control from the Clayton section is shown in Fig. 3-1. Samples for particle size analysis, clay mineralogy, and heavy mineral analysis were also collected. Till fabric data for the lower till (T1) indicate ice advance from the NNE. Additionally, macrofossils (presence of *Dryas* and *Picea*) and gastropods (presence of *Vertigo* and *Columella*) from the silt suggest a terrestrial, cold, and moist boreal environment probably close to the tundra border.

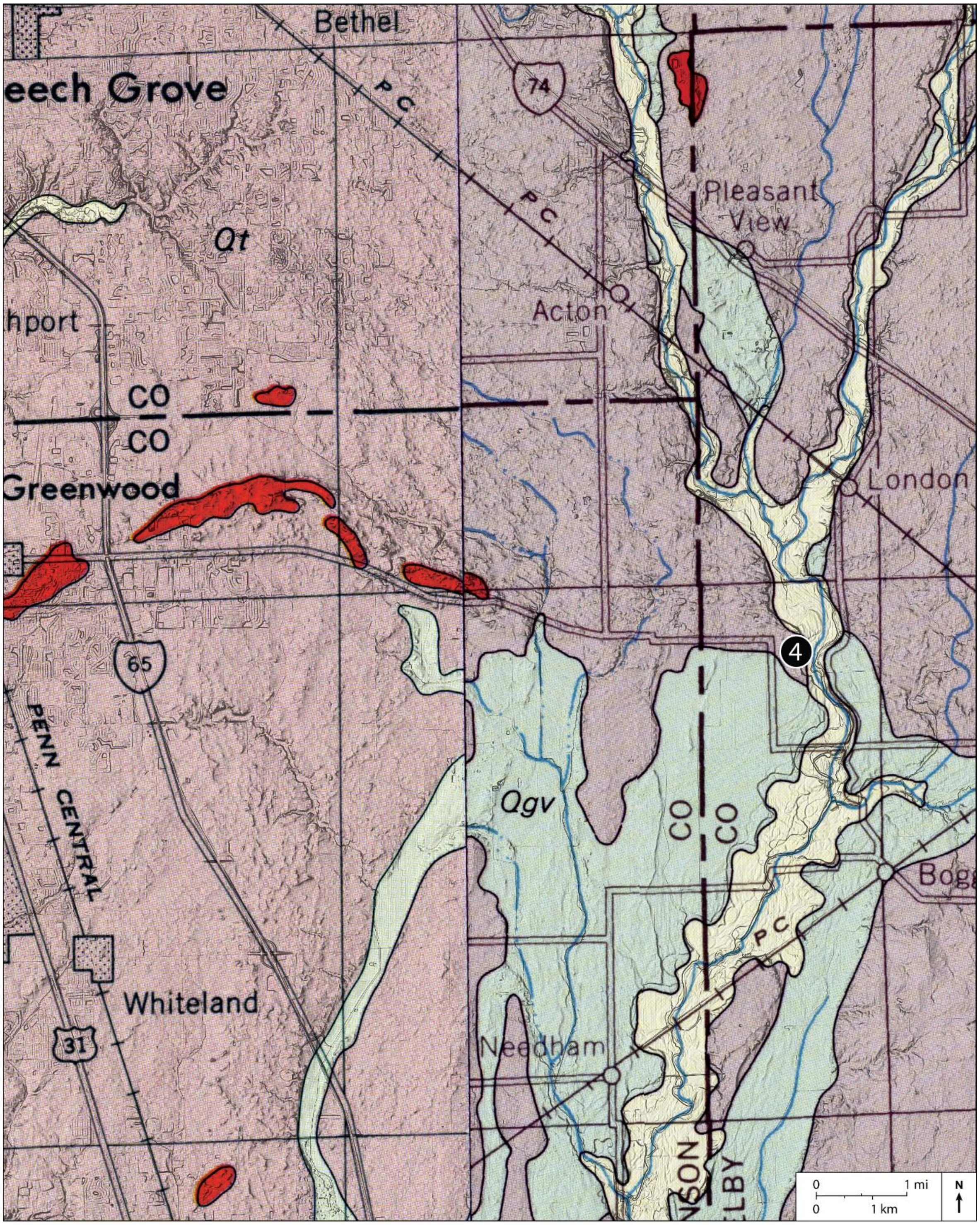
Significance: The stratigraphy and chronology presented here provides a maximum age of ca. 21.5 k cal yr BP for a significant readvance (~30 km) of the Laurentide Ice Sheet in central Indiana. The linkage of the stratigraphy and chronology from the Clayton section and glacial

Figure 3-3. Clayton section organics from the inter-till silt. One radiocarbon age from *Dryas* leaves yielded an age of 17,900±150 ^{14}C yr BP. Two ages from *Picea* needles yielded ages of 18,000±150 ^{14}C yr BP and 18,050±150 ^{14}C yr BP,. Three other macrofossil samples gave ages of 17,950±130 ^{14}C yr BP, 18,050±150 ^{14}C yr BP, and 18,050±150 ^{14}C yr BP. Scale box in each photo is 1 cm on each side. Photos by B.B. Curry.

Lake Eminence (Stop 2) is an important result from this work. We interpret these sites as recording the same two advances of the ice sheet, with the lower till (T1) representing advance to the maximum limit and the upper till (T2) representing a readvance that terminated in the glacial Lake Eminence basin (at core site 1 at the northern end of the coring transect at Stop 2). The advance that deposited the upper till (T2) is also recorded at two other sites (Plainfield and Ward Quarry) in central Indiana where we have obtained maximum ages below till (21.6 and 21.5 k cal yr BP).

Discussion: There are several important discussion points:

- How does the new chronology presented here fit in with chronology from the Decatur and Peoria sublobes of the Lake Michigan Lobe in Illinois and the Miami and Scioto sublobes of the Erie Lobe in Ohio? Is there synchronicity between sublobes (suggestive of a common driver)?
- The chronology presented here implies the ice sheet stayed within 40 km of its maximum extent for almost 5,000 years (ca. 25 to 20 k cal yr BP). What does this say about the (internal) dynamics of the ice sheet and (external) climate surrounding the global last glacial maximum?
- A ~4,000 year gap between maximum ages for the lower (T1) and upper (T2) tills. Is this the duration of ice-free conditions? Or perhaps the complete stratigraphy of glacial events is not recorded here? How does this record fit with other sites containing a record of Erie and Lake Michigan lobe fluctuations near the late Wisconsin maximum?



Surficial geologic map near Stop 4 (Gray et al., 1979).
See foldout map for regional location of stops.

Stop 4: Greenwood Moraine and Outwash Morphosequence Near Greenwood, Indiana.

Bill Monaghan; contributions from Sebastien Huot, Paul Hanson, Henry Loope, Jose Luis Antinao, Ed Herrmann, John Talley, Doug Edmonds

Location: Stop 4 occurs along Rocklane Road near the border with Johnson County (west) and Shelby County (east) border. The locale lies southeast of Indianapolis and several km east of the city of Greenwood. It is located on the proximal margin of a set of outwash aprons/sandar that derive from the Greenwood Moraine (Fig. 4-1). We are visiting here because this Stop 4 represents the first clear moraine-outwash morphosequences (i.e., outwash that grade from a very clear moraine) inside (north of) the LGM position (i.e., terminal moraine). Only a relatively small (<8–10 km-long outwash plain) outwash remains apparent, most of the downstream portions have been truncated and eroded by younger meltwater discharge that derive from more northern ice margins.

Purpose: The purpose of this stop is to examine the ages and stratigraphic relationships for the first, clear moraine-outwash morphosequence that formed after the LGM in central Indiana.

We will examine evidence for:

- The age and thickness of the outwash associated with the Greenwood Moraine;
- The duration of outwash deposition within these morphosequences;
- The ultimate destination (flow path) for the outwash from the Greenwood Moraine.

We will also discuss the outwash sequence in terms of:

- The formation and age of the Greenwood Moraine using the age of outwash with a morphosequence approach and the applicability of this concept elsewhere in the Midwest and Great Lakes regions;
- The usefulness of OSL ages on outwash for defining advances and retreats of the LIS, particularly near the time of the LGM;
- The relationship of the Greenwood morphosequence to the readvance we just examined at Clayton (Stop 3) and Lake Eminence (Stop 2);

Finally, we will discuss valley-margin eolian sediments in relationship to deposition of outwash and final abandonment of its deposition in the valley.

Description and Results. Because no natural exposures or gravel pits occur within or near the Greenwood outwash, GeoProbe cores were collected along several transects from a very proximal position adjacent to the moraine to more distal positions along the southward-grading outwash plain (Fig. 4-1). Three outwash surfaces grade from the Greenwood Moraine, although each was probably deposited at chronology similar times (Fig. 4-1). The coring locales (A–E, Fig. 4-1) were chosen to provide OSL chronology for the deposition of the outwash in proximal (within <1 km of the moraine) and more distal (>4 km) locales. Because of the morphosequence relationship of the outwash and moraine, we hoped to provide an age for the Greenwood

Moraine ice margin and relate this position to the chronology of retreat/readvance defined at other sites recorded ice retreats/readvances (Clayton, Plainfield, Ward Quarry).

Pilot cores were taken from locales, then opened and described in the field. Specific intervals in the core were identified for sampling because they included the best sedimentary context for OSL methods. The GeoProbe was moved <1 m from the pilot hole and a new hole was advanced to the top of the OSL sample interval. A shielded core was then pushed into the outwash, extracted, and returned to the lab. The sediments within these cores consist of fine to coarse sand and sand and gravel, interbedded with silty fine sand. The shielded core tube was opened in darkroom conditions and the finer sand beds were collected and sent for OSL age determination. Both infrared stimulated luminescence (IRSL) and OSL age analyses were undertaken. Some of the OSL ages were problematic and not particularly consistent, but they do provide some insights in the post-LGM dynamics of the LIS.

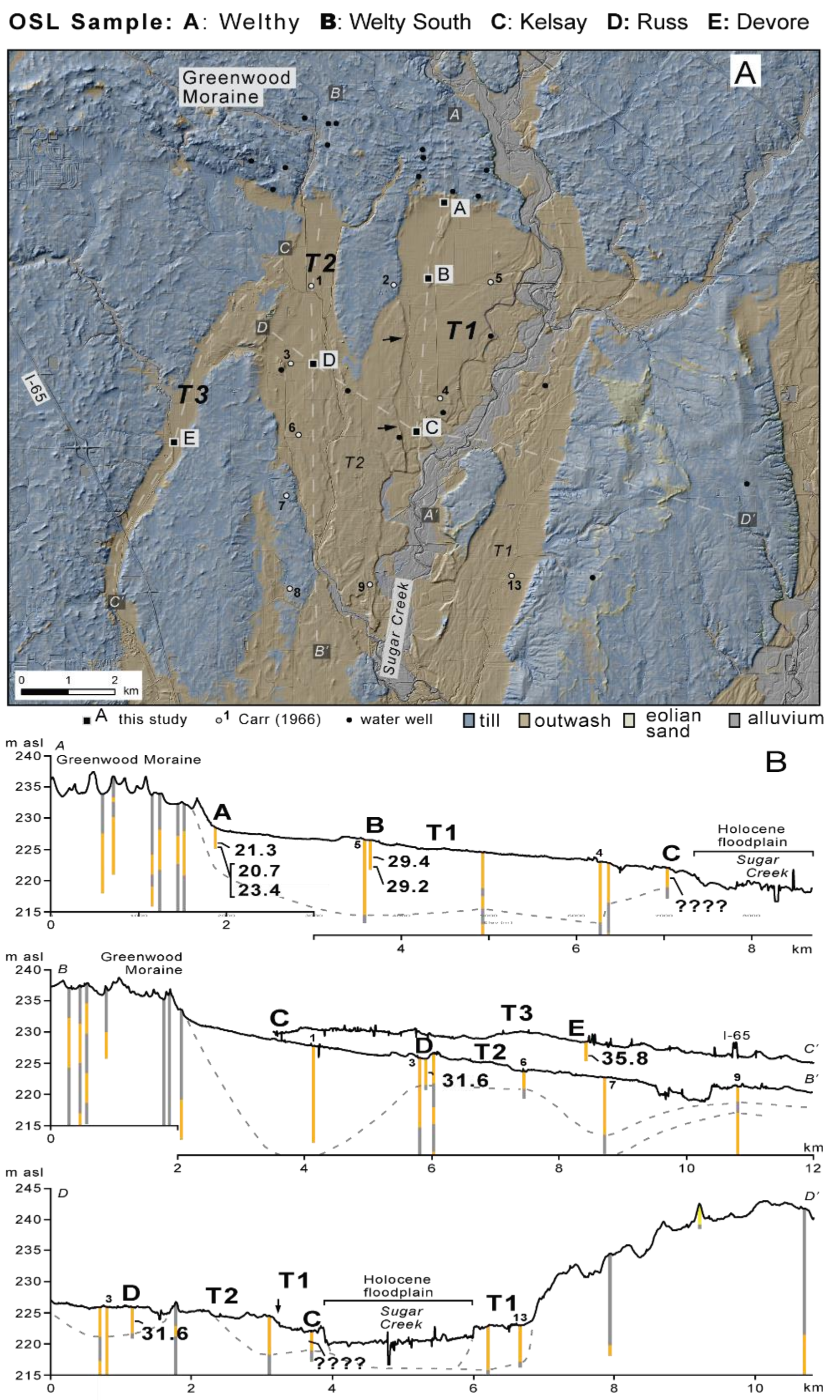


Figure 4-1. Morphosequences of the Greenwood Moraine near Greenwood, Indiana. A) Map showing the distribution of surficial deposits and core and OSL sample locales. T1 is the youngest and T3 is oldest morphosequence; ice-margin for T1 and T2 surfaces is Greenwood Moraine, T3 moraine is unknown. B) Cross sections showing the ages and stratigraphic position of the OSL ages. Note some OSL ages are not completed. Bedrock depth is 25-55 m.

Several points and conclusions of the OSL age of outwash include:

- The most proximal sample from the youngest fan (sample A on T1 sequence; Fig. 4-1) indicates, based on mean ages, that outwash was deposited 21.3 to 23.4 ka, which overlaps with ages from Clayton, Plainfield, and Ward Quarry.

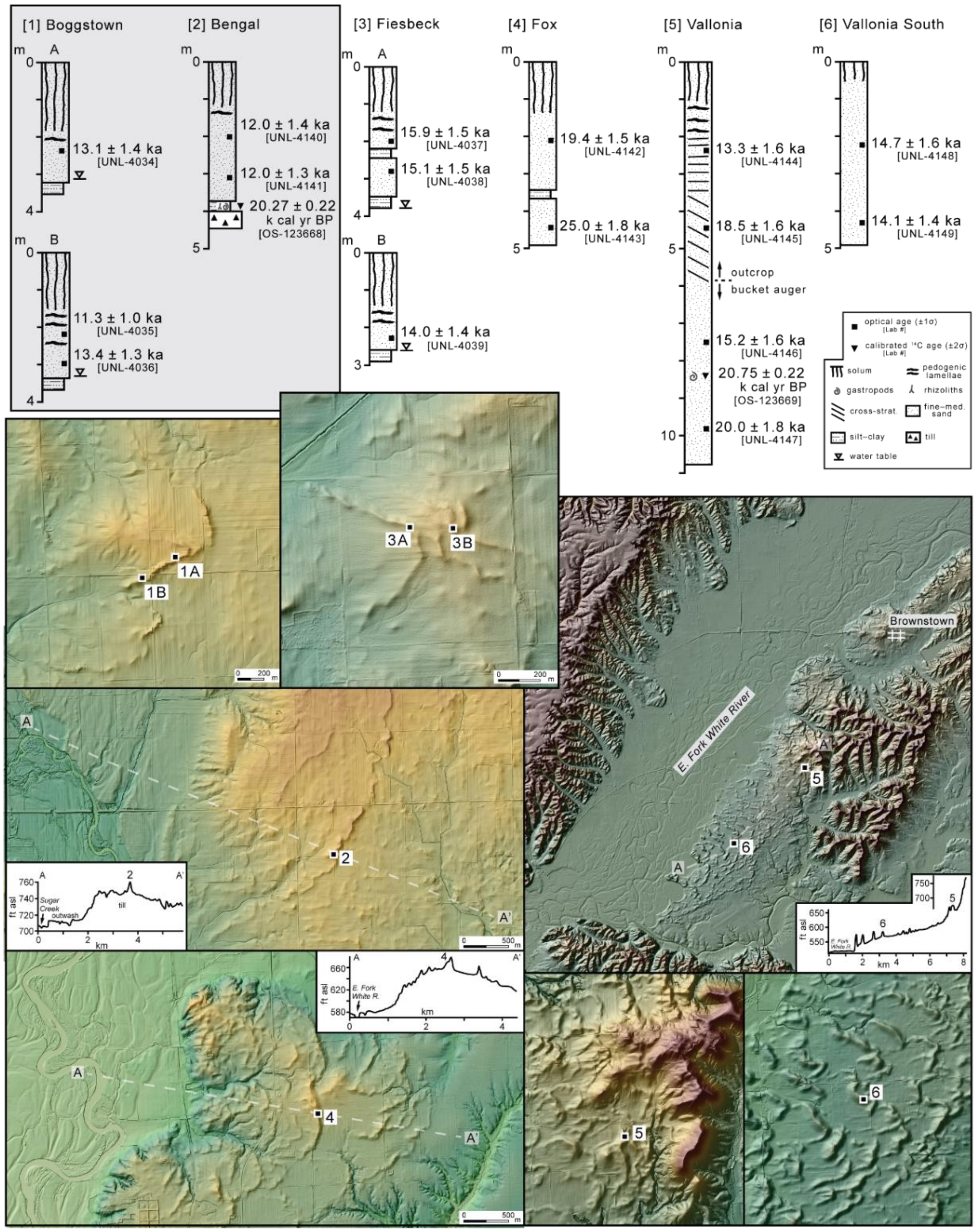


Figure 4-2. OSL ages of dunes south of the Greenwood morphosequence. The Boggstown and Bengal locales are southeast of the Greenwood study area. Other dunes occur further south (up to 100 km) along the eastern edge of the East Fork White River valley.

- However, samples 1 km south from the most proximal locale on T1 (Site A), yielded ages that were 7 to 8 ka older (sample B on T1 sequence; 29 ka; Fig. 4-1) and predated the LGM by about 5 ka
- The older fans (T2 and T3) have even older OSL ages. These samples (sample D on T2 and sample E on T3 sequence; Fig. 4-1) range between ~31 and 36 ka.
- Although the samples from the three outwash surfaces (T1, T2 and T3) are in correct chronological order, except for ages at site A, they are very much too old.

Another indirect way to determine the timing of active sedimentation on the Greenwood outwash plain was pursued using the ages of a set of parabolic dunes located south and east of Stop 4 (Fig. 4-2) and along the eastern side of the East Fork White River valley.

Discussion and Regional Significance.

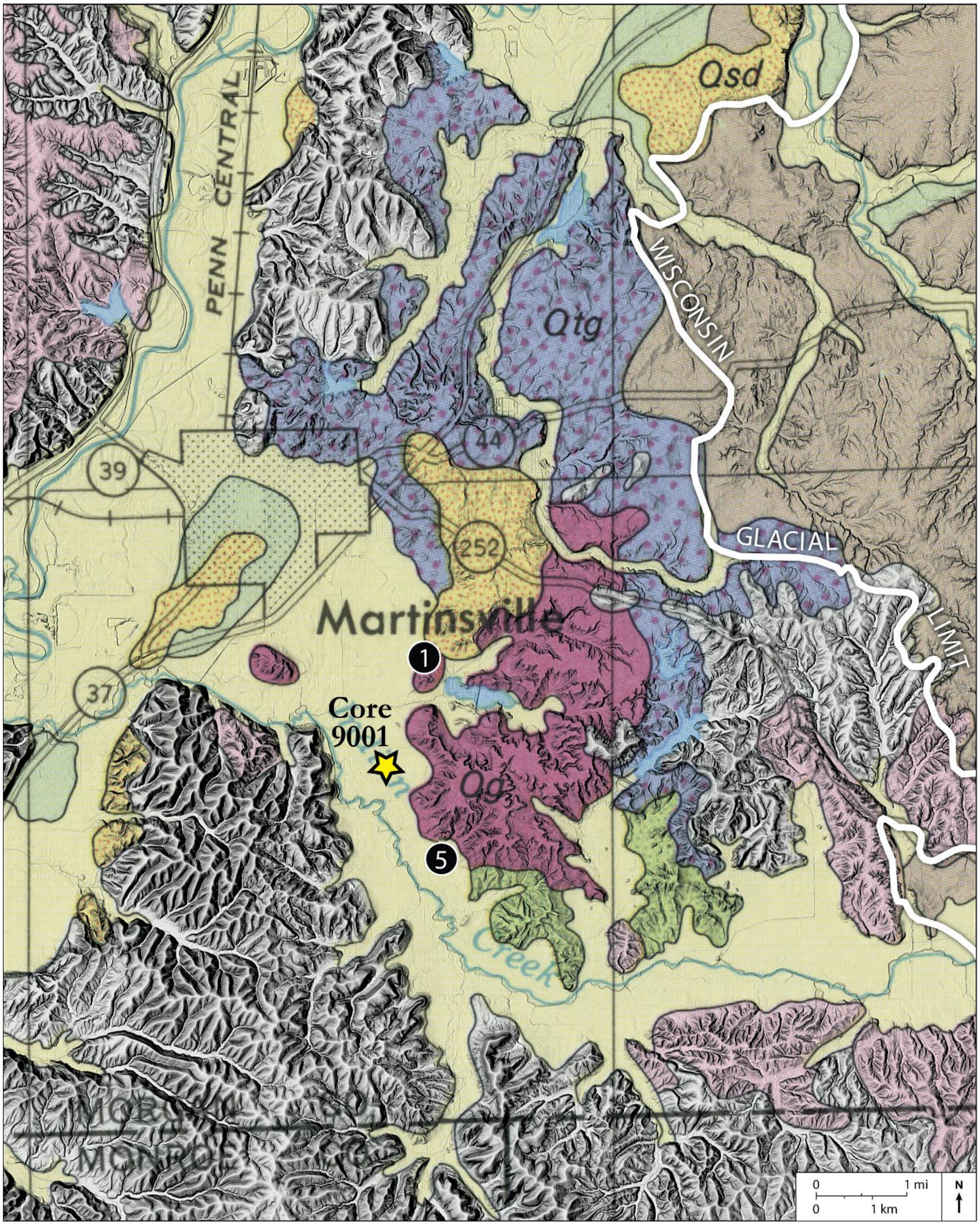
The OSL ages of outwash are problematic, particularly for older (e.g., LGM-aged) samples. The OSL ages for the morphosequences are not conclusive as to their absolute age or relative stratigraphic positions. Consequently, age relationships of the Greenwood Moraine to Clayton, Plainfield, and Ward Quarry is uncertain. The inherent errors for OSL ages are not absolute but rather are relative to the age of the sample (typically about 10% of the age). For older samples, even the 1-sigma error is often greater than the interval of interest. Consequently, in the case of the outwash, the potential age of the Greenwood morphosequence span the entire interval from prior to the LGM position (terminal moraine), through the Clayton-Plainfield-Ward Quarry retreat/readvance, and into the Erie Interstade. What can we do about this? Problems include but are not limited to:

- Incomplete bleaching of samples,
- Poor understanding of water content history, particularly for samples from gravel pits and other natural and constructed exposures (i.e., road cuts),
- Poor understanding of burial history,
- Problems with changes in groundwater chemistry, such as the radium problem (U-series disequilibrium), and the inherent heterogeneity of clast mineralogy of outwash deposits.

Potential solutions to help cut down the influence of some of the factors noted above include :

- Focus on single-grain methods, which should help the counting statistics for poorly or partly bleached grains.
- Collect samples from cores, so that water content can be better estimated.
- Use statistical techniques, such as Bayesian analyses of ages, for outwash sequences that fall within bounding events or occur within a known relative age sequence based on crosscutting relationships of the sequences.

Our hope that eolian sand deposits occurring east of the Greenwood morphosequence would help to establish when the outwash surfaces were active was disappointing (see Boggstown and Bengal locales, Fig. 4-2). The idea about the relationship between dune deposition and outwash was that the dunes formed during or just after active deposition of outwash. Dunes would have been activated or formed because the outwash plains included only limited vegetation and could have supplied the sand for dune formation. Sand on the outwash plain was blown eastward, and then deposited as dunes during the waning stages of outwash or just after the outwash plain was abandoned. In fact, the ages of these dunes indicate that they were active much later, mostly from 12 to 13 ka, and were probably related climatic and vegetation conditions during the Younger Dryas. However, a radiocarbon date from a gastropod (Succineidae) within silt containing rhizoliths (interpreted as loess) beneath a ~4 m-high sand dune(Bengal dune, site 2 in Fig. 4-2) indicates that the area was deglaciated prior to about 21 ka, which is consistent with the 21 to 23 ka ages from site A (proximal site on the T1 surface; Fig. 4-1).



Surficial geologic map near Stops 1 and 5 (Gray et al., 1979).
See foldout map for regional location of stops.

Stop 5. Pre-Wisconsin outwash, Dean Quarry, East Mahalasville Road, Morgantown, Indiana

Jose Luis Antinao; contributions from Sebastien Huot, Henry Loope, Bill Monaghan

Location: The Dean Quarry is located about 1 mile SSE of Stop 1 (near Taggart Crossing) in the Martinsville 1:24,000-scale USGS Topo Quad (Loope, 2016) and is accessible via Mahalasville Road and a 100-yard driveway to the owner's farm facilities. The buses will park there, and we will continue on foot an extra 200 yards to the pit entrance, marked by several boulder-size carbonate-cemented outwash pieces, a picnic table, and a roped fence. The top of the pit is

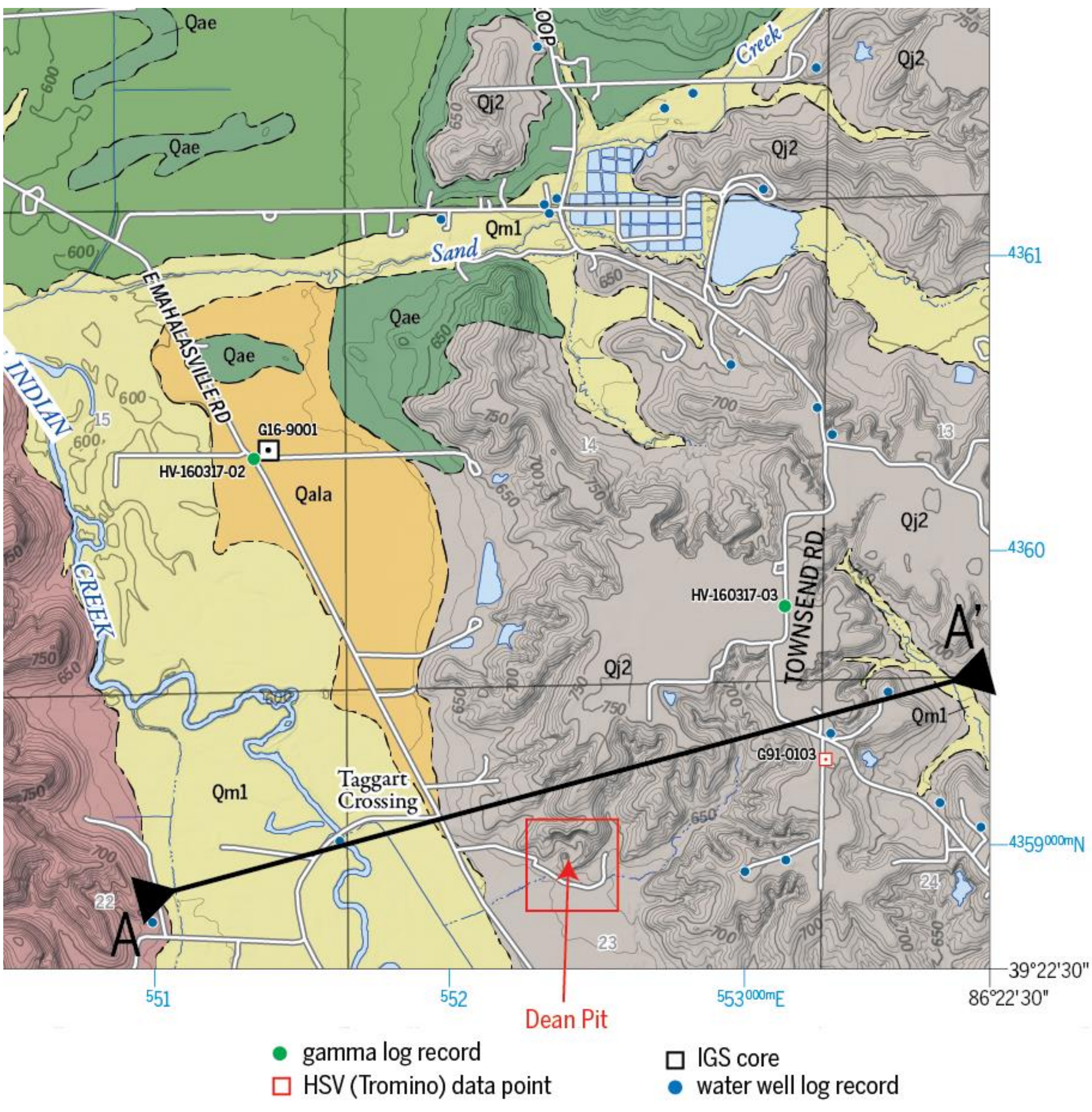


Figure 5-1. Cropped portion of "Preliminary Geologic Map showing the Quaternary Geology of the Martinsville Quadrangle" (Loope, 2016) showing location of Dean Pit. Location of section AA' in Fig. 5-2 is shown. Note location of core 16-9001 discussed in Stop 1.

partially visible from Mahalasville Road, but most of the pit can be seen only when entering via a curved access trail. Property owners have used gravel and granular aggregate from this pit as fill for their local roads.

Purpose: The purpose of this stop is to examine and discuss implications of a newly found outcropping sequence of pre-Wisconsin outwash. We will discuss the sedimentology, structures, and age of the outwash, including new geochronology data at the base of the pit, and the implications for sediment infilling of the West Fork White River and Indiana Creek valleys.

Description: The pit lies at the edge of an elevated pre-Wisconsin unconsolidated sediment plain that extends east of Martinsville (Fig. 5-1), and whose top sits at about 750 to 770 feet (Fig. 5-2). The pit is located midslope on an eroded spur of this pre-Wisconsin plain. Indian Creek valley can be clearly seen standing at the entrance to the trail, directly to the south of the pit. The top of alluvium in Indian Creek where core G16-9001 (discussed in Stop 1) was drilled sits at about 610 feet immediately south of the pit. North of Sand Creek (Fig. 5-1), the pre-Wisconsin plain is dissected and covered by a variable thickness of Wisconsin-age eolian deposits (Unit Qae of Loope, 2016). The gently rolling surface is restricted to the northeast by the Wisconsin Terminal Moraine position, and to the east by outcrops of Mississippian siltstones and shales that form an elevated relief above 780 feet.

The entire sequence of outwash sediments in the pit have been included in the pre-Wisconsin Jessup Formation (Wayne, 1963; Loope, 2016). About 50 feet of a sandy gravel and gravelly sands are exposed here (top at 695, bottom at 645 feet). The entire sequence is glaciofluvial, with horizontal and partially cross-bedded features that display faulting on the west side, displacing gravel beds down to the southwest.

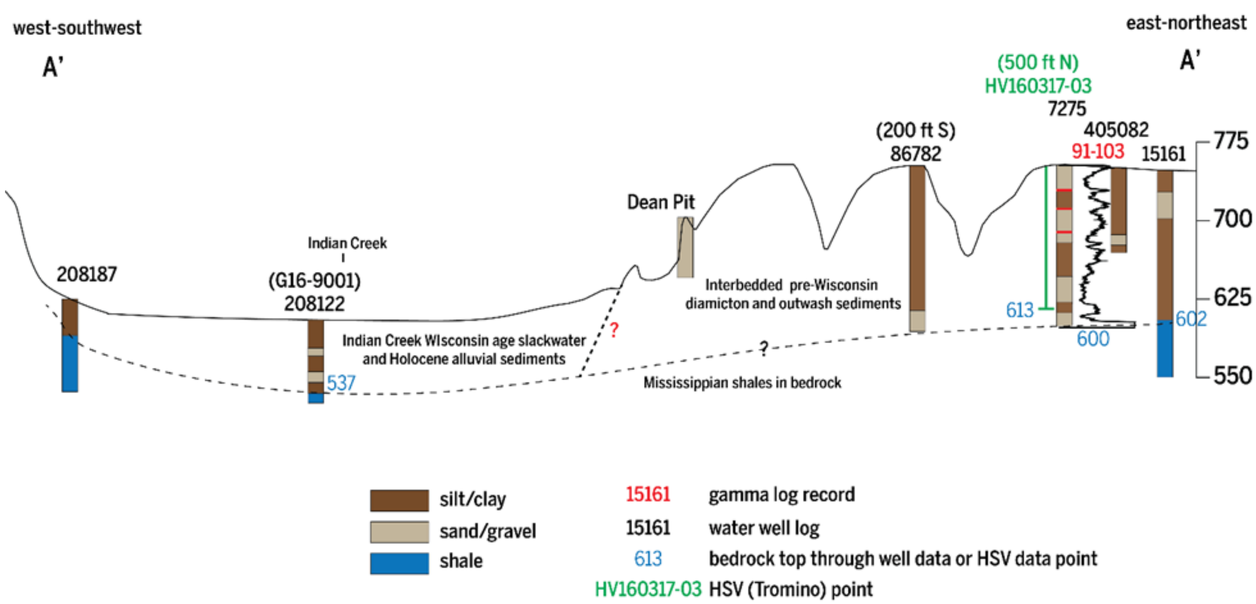


Figure 5-2. Geologic cross section through Indian Creek and the Townsend Road upland, showing location of Dean Pit in relation to lithologies inferred from well logs and gamma log records

The soil developed on the sediments at the top of the quarry is mostly a silt loam (Pike and Parke silt loams, USDA, Soil Conservation Service, 1981), with clay loam and sandy clay loam up to 80 inches deep. These soils gradually give way to upper gravels that have carbonate induration, in places resembling well-bedded sandy gravel blocks 2 to 3 m in size, in a sandy matrix. We will stop briefly at the entrance of the pit to observe a few of these carbonate-cemented sandy gravel blocks that have fallen from the top of the sequence and that were moved here.

The area north of Sand Creek was mapped as mainly outwash owing to the presence of many water wells with sand and gravel layers appearing throughout the sequence (Unit Qj2 in Fig. 5-1; Loope, 2016). South of Sand Creek, closer to the pit and below the pre-Wisconsin surface, data collected from water well descriptions (Fig. 5-2) suggest that interbedding of fine grain and mixed lithologies (diamicton?) with sand and gravel is common. A gamma-log record for well 91-103 near water well 7275, on top of the Townsend Road surface, is consistent with the above mentioned interbedding of fine-grained and sand-gravel packages (Fig. 5-2). Three luminescence samples were taken to test the age of the sandy gravel sequence in the pit, which was assumed to be Illinois Episode (MIS6). The samples were tested for their IRSL signal at 50°C in feldspars, accounting for fading in the signal, commonly observed in IRSL dating. Sample MAH-3 taken at a depth of 9 m (right side of the pit wall), tested preliminarily at 240±20 ka BP for the lower portion of the sequence, at the very end of MIS8.

Significance: The pit and the set of well records around it suggest that there is a complex history represented in this portion of the landscape. Structures at the left of the pit wall (Fig. 5-3) could be interpreted as the collapse of ice-walled channels or settling of rapidly eroding deposits. This is intriguing, because the thick infill in Indian Creek, just 1 mile from here (Figs. 5-1, 5-2) is mostly Wisconsin age (Stop 1), with more than 70 feet of infill in the valley (~530 feet asl), as described for core 16-9001. If the pre-Wisconsin outwash had a free surface top at ~750 feet, it would mean that ~200 feet of sand and gravel must be removed from the valley between MIS8 and, at most, MIS2.

The above mentioned scenario implies that large discharges flowed down Indian Creek, a relatively small catchment. An alternate interpretation is that, if ice-walled terraces are present

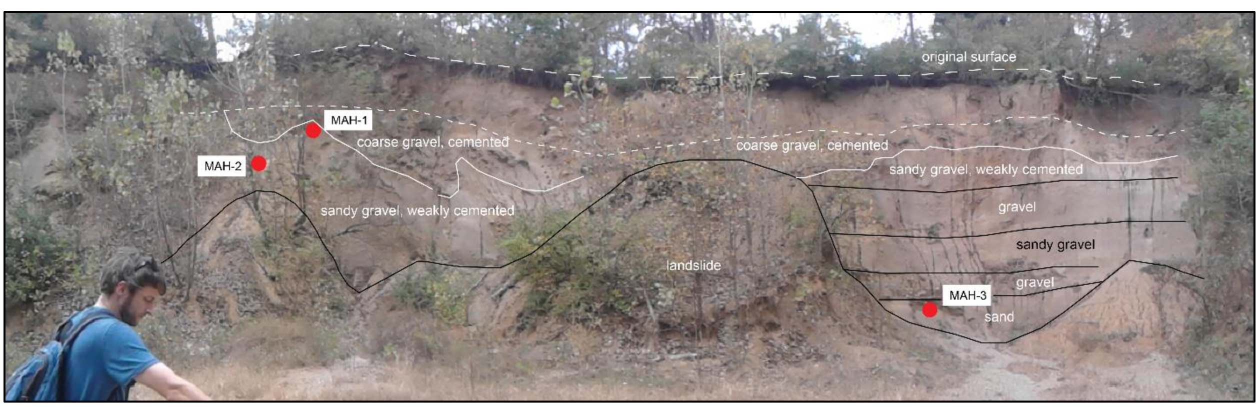


Figure 5-3. View of Dean Pit, highlighting bedding and structures observed. Location of IRSL samples is shown with red circles.

here (suggested by collapse features in the pit), then the lowlands were a direct effect of glacier activity and dead ice and, therefore, erosion between MIS6 and MIS2 was minor in Indian Creek.

Discussion: MIS8 (and possibly 6) sediments fill the eastern Martinsville basin to >150 feet and up to 200 feet above bedrock, while little evidence for these sediments is found in the Indian Creek valley or south of it, or to the west side of the West Fork White River, west of Martinsville. So where have all the sediments gone? A large incision event must have happened before the deposition of Wisconsin dunes north of here.

One possibility for such removal of sediments is that at some time between MIS8 and MIS2, the opening of a bedrock gorge (where the West Fork White River changes course to the west then south again near Centerton) allowed sudden release and erosion downstream, west of the Mississippian highlands north of Martinsville, lowering base level for the paleo-Indian Creek drainage. This possibility implies that, at least at MIS8 and perhaps MIS6, there were sediments flowing down east of the highlands. At some point in time, either till or proximal outwash blocked the eastern outlet, then after overtopping the sill near Centerton, all drainage was rerouted throughout the west passage. This possibility is consistent with fine-grained deposits that appear east along Indian Creek at a similar elevation than the pre-Wisconsin outwash upland. These fine-grained deposits were interpreted as lacustrine by Gray et al. (1979), terming them either ice-ponded or slackwater deposits, depending if ice or glaciofluvial deposits blocked the outlet.

As stated above, a second possibility is that the pre-Wisconsin outwash sediments were deposited at an ice-walled kame terrace or as a glaciodeltaic feature in a stagnant ice setting. Ice advancing from the north throughout Martinsville would have reached and blocked Indian Creek. No obvious deltaic deposition features have been identified in the area, but to the southeast, the highly dissected lacustrine sediments have an upper surface grading to the Townsend Road surface at 750 feet. These features support the interpretation of an impounded lake at Indian Creek. Well logs ~1 km SE describe penetration in fine-grained sediments (descriptions include mostly clays) (Gray et al., 1979).

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