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Surficial Geologic Map of the Evansville, Indiana, and Henderson, Kentucky, Area

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Indiana, Kentucky, and Illinois State Geological Surveys

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CONVERSION TABLE

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)

Introduction

We mapped deposits of Quaternary age in the Evansville, Ind., and Henderson, Ky., area according to their origin and age (fig. 1). The work focused on unconsolidated fluvial and lake deposits that fill the incised Ohio River bedrock valley because urban infrastructure rests on these deposits, and the deposits can shift or amplify energy waves during strong earthquakes. Wind and gravity deposits in the hilly terrain were also mapped (fig. 2). Properties of the deposits, systematically determined by field methods, are useful for assessing seismic and flood hazards and for planning urban development.

Seismologists are using the map and seismic wave velocities to make probabilistic seismic hazard maps of the region (Haase, Choi, and Nowack, 2006; Haase, Nowack, and Choi, 2006; Haase and others, in press). The hazard maps help predict if geologic deposits are likely to liquefy and (or) amplify ground shaking caused by earthquakes (Choi and others, 2008; T.L. Holzer, T.E. Noce, and M.J. Bennett, unpub. data, 2008). Such responses are related to properties and topographic position of the mapped geologic deposits (Youd, 1991). The map area is located within the Wabash Valley seismic zone and is about 125 mi northeast of the New Madrid seismic zone (fig. 3). Proximity of the cities of Evansville and Henderson to epicenters of historic strong earthquakes (Munson and Munson, 1996), which characteristically produce energy waves that travel great distances through the mid-continental crust, raises concerns that future events comparable to the strong 1811–1812 New Madrid earthquakes could imperil life and infrastructure in the map area.

The geologic map can also help urban planners delimit flood-prone areas, which include Ohio River floodplains, sloughs, and river terraces; outwash terraces; creek floodplains; and low parts of lake plains. Photographs of the historic 1937 flood[1] capture striking scenes of flooded outwash terrace deposits in the Evansville South quadrangle (figs. 4, 5).

Unconsolidated Pleistocene glacial outwash and loess conceal bedrock strata of Pennsylvanian age in the map area. In the loess-covered uplands, bedrock crops out only in the deeper ravines, river and creek banks, and road cuts. In the Ohio River valley, outwash and alluvium are thick; test drilling in the river at Henderson, Ky., struck bedrock below 20–82 ft of valley fill (Gallaher, 1964). A sense of the thickness of unconsolidated geologic deposits in the map area is gained by comparing figure 6 (the land surface) with figure 7 (the buried bedrock surface). The bedrock strata dip 16 ft/mi west-northwest into the central Illinois Basin (Harvey, 1956).

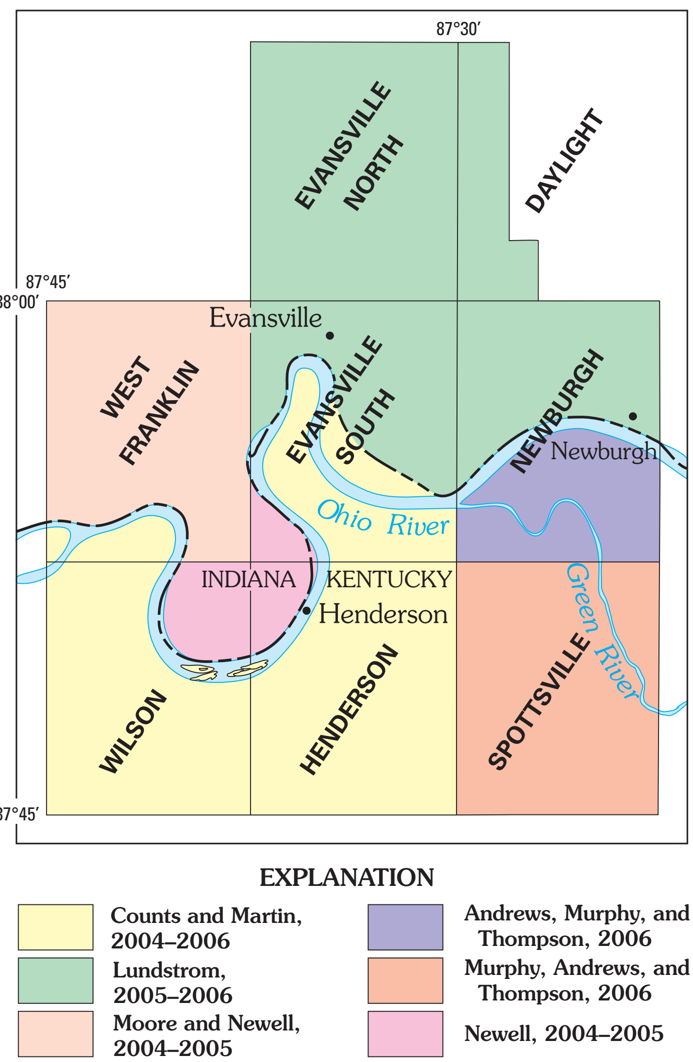

Figure 1. Index to map area showing 7.5-minute quadrangles and areas mapped by authors.

General Characterization of the Quaternary Deposits

Unconsolidated alluvium and outwash fill the Ohio River bedrock valley. Where thickest, in the southeastern part of the West Franklin quadrangle in Indiana, this fill is 108–128 ft thick; under Diamond Island in Kentucky, it is 100–115 ft thick (Harvey, 1956, p. 75 and pl. 5). Comparable thicknesses underlie Griffith Slough and the wide natural levee and floodplain in Kentucky south of Newburgh, Ind. (east-central part of map area). The fill is mainly unconsolidated, fine to medium, lithic quartz sand, interbedded with clay, clayey silt, silt, coarse sand, granules, and gravel. Generally, the fill becomes finer grained upward: a lower part is gravelly sand to sandy gravel, a middle part is mostly sand, and a surficial veneer is silt and clay interspersed with sandy levee deposits. Exceptions to this generalization are common because alluvium grain size varies markedly in horizontal distances of a few meters.

Beneath the unconsolidated fill is some consolidated fill, sparsely sampled and perhaps discontinuous, as revealed in drilling by Fraser and Fishbaugh (1986, p. 15). They locally

[1] http://en.wikipedia.org/wiki/Ohio_River_flood_of_1937

penetrated highly consolidated "mud" (silt and clay), sand, and gravel overlying buried bedrock.

Origins and ages of inferred divisions of the valley fill, from lowest to highest and stated in time-stratigraphic terms, follow. The consolidated basal fill may be glacial outwash of perhaps early Wisconsin Episode or pre-Wisconsin age. Remnants of nonglacial alluvium of the interglacial Sangamon Episode may be present in the valley, but this is speculative. The lower and middle parts of the unconsolidated fill are likely outwash deposited during the middle and late stages of the Wisconsin Episode. The surface veneer is postglacial Ohio River alluvium of Holocene Age, Hudson Episode (Johnson and others, 1997).

Slackwater lake deposits (Qlt on geologic map) underlie flat valleys of creek tributaries to the Ohio River. Slackwater lake (lacustrine) deposits accumulated behind outwash dams and natural levees that formed at the margins of the Ohio River sluiceway. The greatest drilled thickness of clayey lake deposits is 92 ft. The clayey lake deposits are widespread and underlie plains east and northeast of Evansville, the flats around the Evansville Regional Airport, Interstate 164, and much of the Pigeon Creek drainage (figs. 8, 9). In Kentucky, they underlie wide, flat-bottom tributary creek valleys around Henderson.

Drilling and cone penetrometer soundings in the lake deposits (http://earthquake.usgs.gov/regional/nca/cpt/data/index.php?map=evansville) detected mainly silt and clayey silt containing layers of sand in the lower half, and granules and pebbles generally near the base of the lake deposits (figs. 10–13). Laminar clay and silt, containing worm burrows, paleosol structures, fresh-water snails, and the ostracode *Cyclocypris ovum*, indicate accumulation in quiet, low-energy environments of shallow slackwater lakes and marshes. Fossil wood samples collected from DH-1 in Little Creek valley (see label, west-central part of map area), at depths of 21 and 34 ft, were dated at 11,120±40 and 16,650±50 radiocarbon years before present (B.P.) respectively, indicating an age within the Michigan Subepisode of the Wisconsin Episode (Moore and others, 2007). Older slackwater deposits in the map area have an age of 33,100±590 radiocarbon years B.P. based on a date obtained on wood from auger hole 93-102 (see label on map, northeastern Evansville), collected 52 ft below the surface (Woodfield, 1998, p. 52). Lacustrine silt and clay, 39–72 ft thick under the lowest reaches of many tributary creeks, is cut by modern creeks to make lacustrine terrace landforms.

Two quasi-linear areas underlain by "transitional" sediments (Qlot and Qotp) were mapped between outwash terraces of the Pleistocene glacial sluiceway and the slackwater-lake basins. These deposits are termed transitional because we infer that, in late Pleistocene time, they accumulated in water having kinetic energy that transitioned, or alternated, between highly energetic sluiceway floods and quiet slackwater lakes. High-energy flow deposited sandy outwash on natural dams

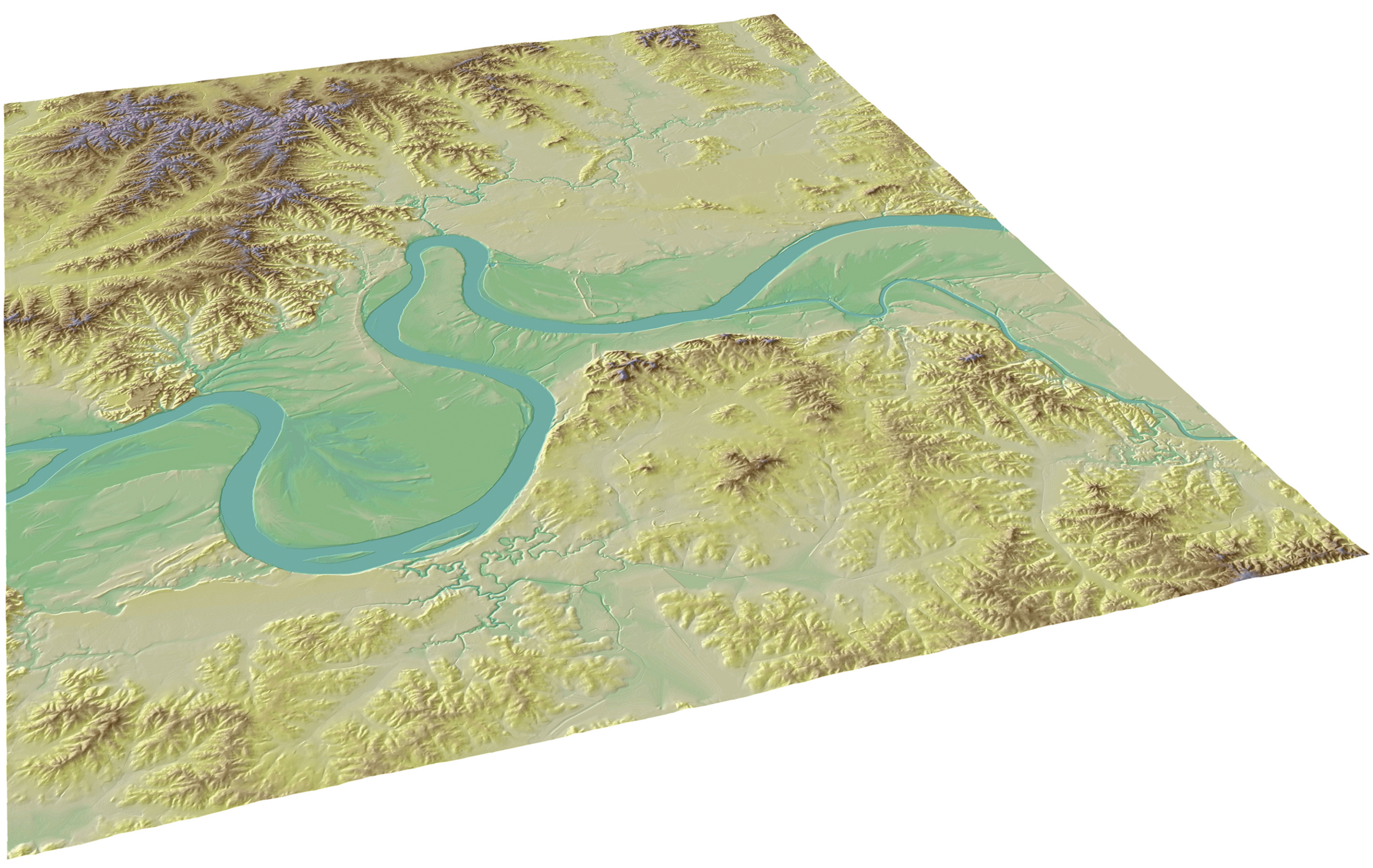

Figure 2. Digital elevation model of map area, oblique view from the south.

and paleolevees that flanked the sluiceway and on small deltas formed by breaches in the paleolevees, funneling sand into the low-energy slackwater lakes outboard of the sluiceway. Mostly clayey and silty sediment accumulated in the quieter slackwater lakes.

Vertical sequences of the transitional sediments, as observed in cone penetrometer tests, consist of tens of feet of clay and silt layers (low-energy slackwater lakes) interbedded with fine sand (high-energy floods). They now underlie broad, subtle highs that rise about 10 ft above the adjacent lake plains and floodplain. Of the two quasi-linear areas being described, one area extends from north Evansville east-southeastward to Newburgh, Ind., and is mapped as deposits of lakes and outwash terrace (Qlot) and paleolevee deposits (Qotp). The second area, south of the river, extends from the west edge of the map area (west of Geneva, Ky.) to north of Henderson and is mapped as paleolevee deposits (Qotp).

An understanding of the sluiceway environment in which the transitional sediments accumulated explains how the sandy paleolevees were built up. During the last glacial period (Wisconsin Episode), glacial meltwater discharge frequently exceeded the capacity of the sluiceway channels, flooding adjacent floodplains (in the modern Ohio River valley). At the margins of the channels, the energetic flood waters quickly lost current velocity and carrying capacity, and deposited much sand. This repetitive process built up sandy paleolevees immediately outboard of the channels and contributed to the raising of the sluiceway, which was receiving huge quantities of outwash. The smaller average discharges of tributary creeks that carried silt and clay and that attempted to drain into the sluiceway aggraded their floodplains more slowly and thus

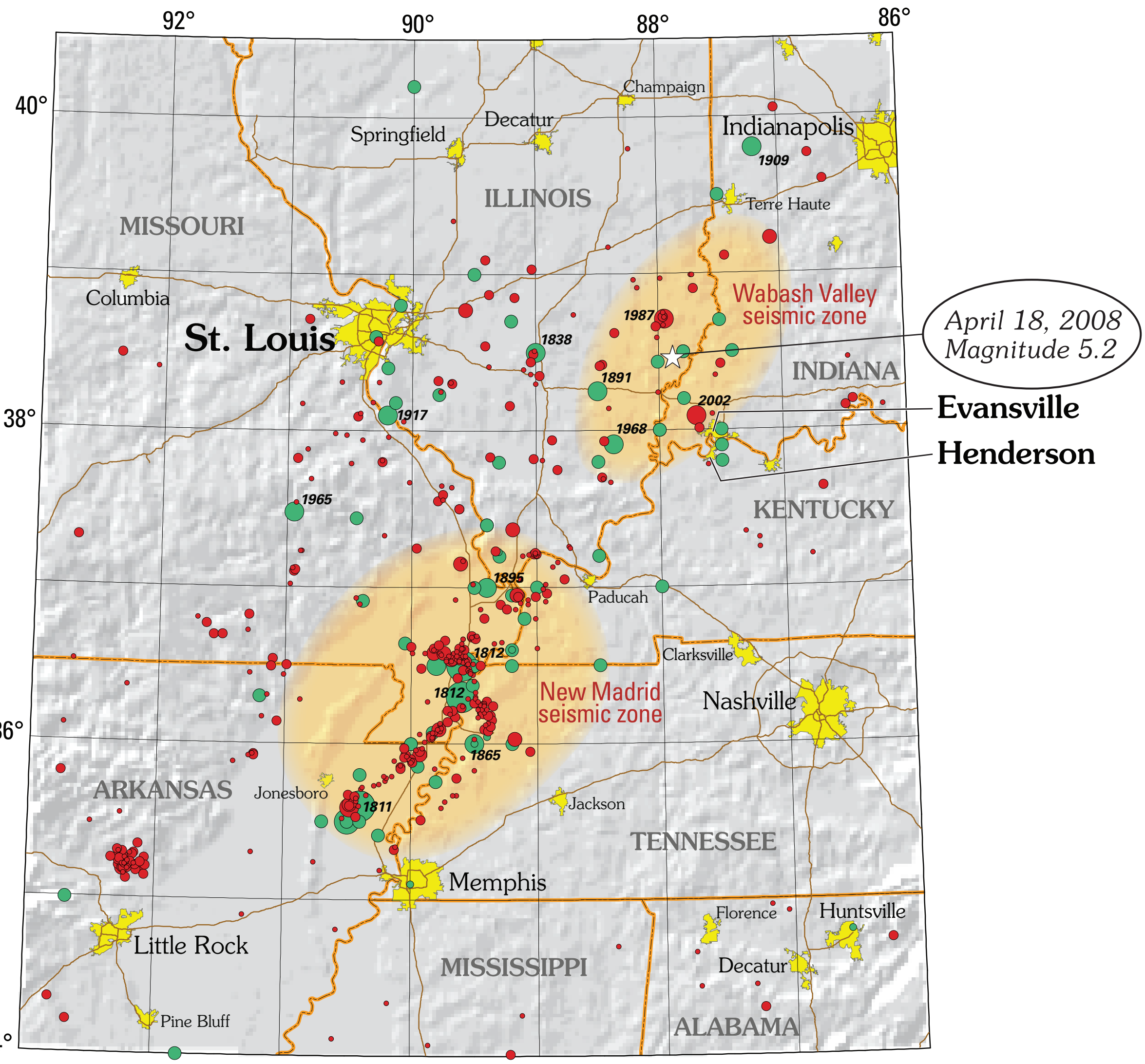

Figure 3. New Madrid and Wabash Valley seismic zones, showing historic earthquakes as circles. Red circles are earthquakes that occurred from 1976 to 2002 having magnitudes >2.5, located using modern instruments (University of Memphis). Green circles are earthquakes prior to 1974. Larger earthquakes are represented by larger circles. Pale-yellow patches show larger urban areas. Modified from Gomberg and Schweig (2002).

were dammed as lakes behind the higher paleolevees. The result of this process is seen under the quasi-linear transitional areas, in the sand interlayered with silt and clay.

Wind-deposited loess (Qel) mantles the bedrock upland and is 10–50 ft thick. The loess is predominantly Peoria Silt (Ruhe and Olson, 1980), estimated to date from about 22,000 to 12,000 years ago (table 1; Counts and others, 2005; Don McKay, Illinois State Geological Survey, written commun., 2006). Small deposits of topographically high, eolian dune sand (Qes) are present in the southwestern part of the map area, south of the Ohio River.

The mapped unconsolidated deposits likely are younger than about 55,000 years. They bury older Quaternary deposits. The latter, and the Sangamon Geosol (formed mostly during the Sangamon Episode, about 127,000–75,000 or 130,000–55,000 years ago), rarely crop out in the map area.

Historical Synopsis of the Quaternary Deposits

The valley fill and loess were derived indirectly from continental ice sheets. Although the Pleistocene Epoch ("Ice Age") is defined by growth and retreat of ice sheets in the Great Lakes region and north-central Indiana, no known evidence suggests that the map area itself was ice covered. Nonetheless, voluminous outwash moved through and accumulated in the map area and the Ohio River valley owing to an effectively moist, cool periglacial climate (Webb and others, 1993), intensified glacial weathering, and great discharges of glacial meltwater. The ancestral Ohio and Wabash Rivers were braided sluiceways carrying meltwater heavily loaded with entrained sediment. Sometime during the Illinois Episode about 200,000–127,000 years ago, an ice sheet advanced to

Figure 4. Aerial view to north-northeast of flooded neighborhoods along Pigeon Creek in Evansville, Ind. Confluence with Ohio River in extreme lower right corner of photograph. (Photograph taken by 113th Photo Section 38th Division Aviation, Indiana National Guard on February 2, 1937. Photograph courtesy of the Willard Library, Evansville, Ind.)

12 mi northwest of the map area (Fullerton and others, 2003) and deposited a terminal moraine composed of the Butlerville Till Member of the Jessup Formation (Gray and others, 1991). The effects of the Illinois Episode in the map area are unclear, although outwash, older than the outwash shown on this geologic map, probably was deposited in the Ohio River bedrock valley. If so, most of this older outwash was eroded from the valley during the subsequent interglacial Sangamon Episode because the existing valley fill is young—deposited during the Wisconsin Episode that followed the Sangamon. During cool Wisconsin climates, the Laurentide ice sheet advanced southward in the East White Sublobe of the Huron-Erie Lobe, terminating between Indianapolis and Bloomington approximately 21,000 years ago (Fullerton, 1986). Concurrently (Michigan Subepisode), the braided, Ohio River sluiceway conveyed debris-laden meltwater into the map area, deposited copious valley train (Thornbury, 1950; Wayne, 1958; Woodfield and Fenelon, 1994), and raised the valley floor. During low water, westerly winds blew silt from the braidplain onto surrounding hills, forming thick loess deposits (Fehrenbacher and others, 1965). The concurrent rapid buildup of paleo levees and outwash in the sluiceway impounded tributary creeks, causing their valleys to fill with slackwater lakes (Kvale and Archer, 2007). Into these lakes, sediment carried by the creeks accumulated in thick sequences of silt and clay laminae. When lake levels dropped, marshes and mudflats covered the valley floors, as indicated by earthworm chimneys and soil structures (figs. 10–11) in the lacustrine layers.

When the ice sheets retreated northward from the Great Lakes region, the Wisconsin Episode ended and the current interglacial period, the Hudson Episode, began. Sediment load in the Ohio River diminished and braided channels changed to a large meandering channel, which eroded the valley fill. This lowered base level and increased river downcutting, leaving remnants of earlier floodplains as terraces that now stand higher than the modern floodplain. Tributary creeks, energized by the lower river level, breached the dams at their mouths, cut laterally into the slackwater-lake sediments, sculpted lacustrine terraces, and deposited silty and clayey stream alluvium on their floodplains.

Figure 5. Eighth Street, looking north from Locust Street, Evansville, Ind., during the 1937 flood. In the foreground are the C & EI Railroad depot and freight office. Scene of this photograph is now occupied by the Evansville Civic Center Complex. See red star on geologic map for approximate location. (Photograph courtesy of the Willard Library, Evansville, Ind.)

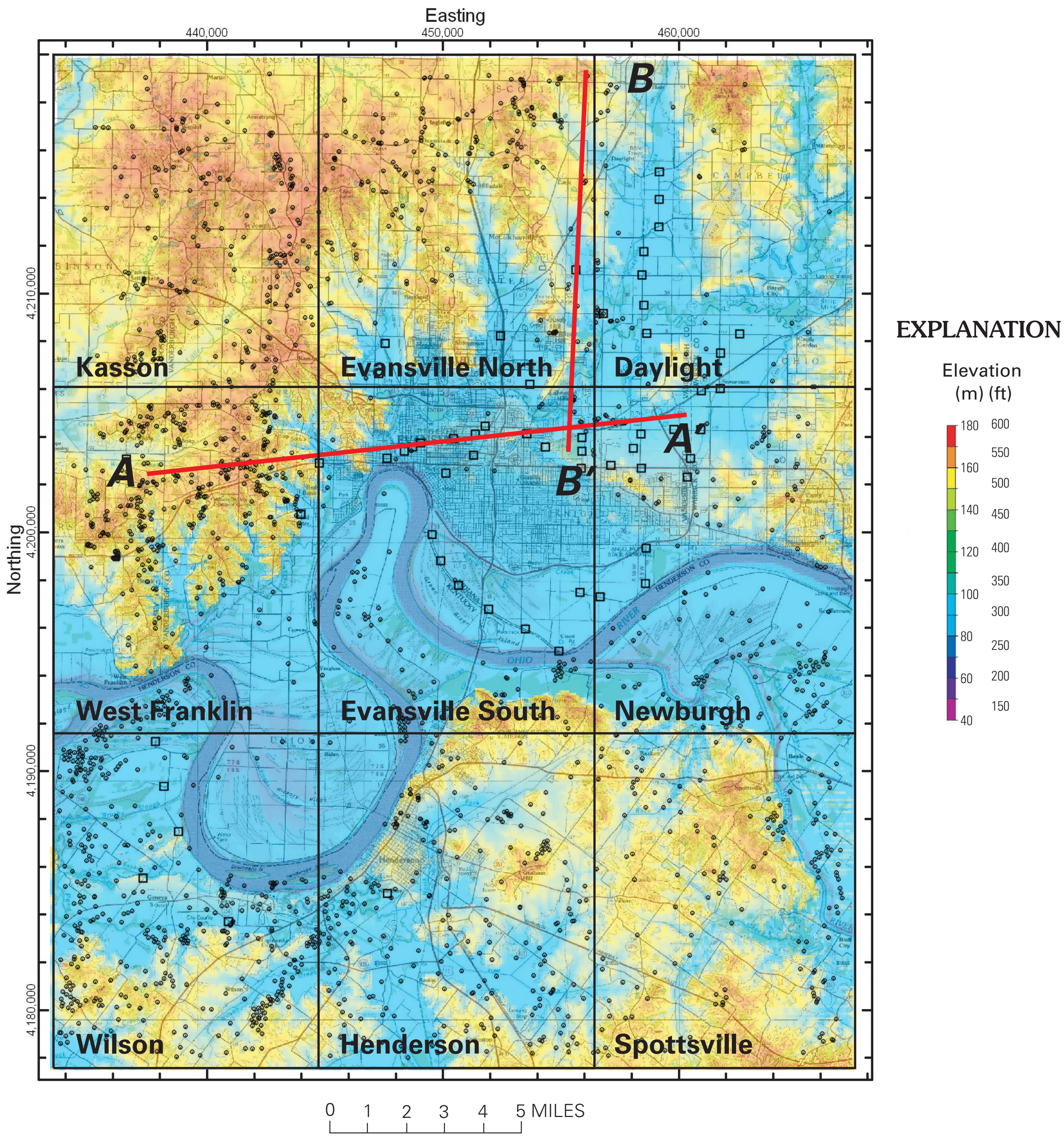

Figure 6. Depiction of the land surface. Color-contoured digital elevation model draped on a base map, showing locations of drill holes (small circles), cone-penetrometer tests (squares), and cross section lines *A–A´* and *B–B´* (see figs. 8, 9). Nine USGS 7.5-minute quadrangles that center on the geologic map area are shown.

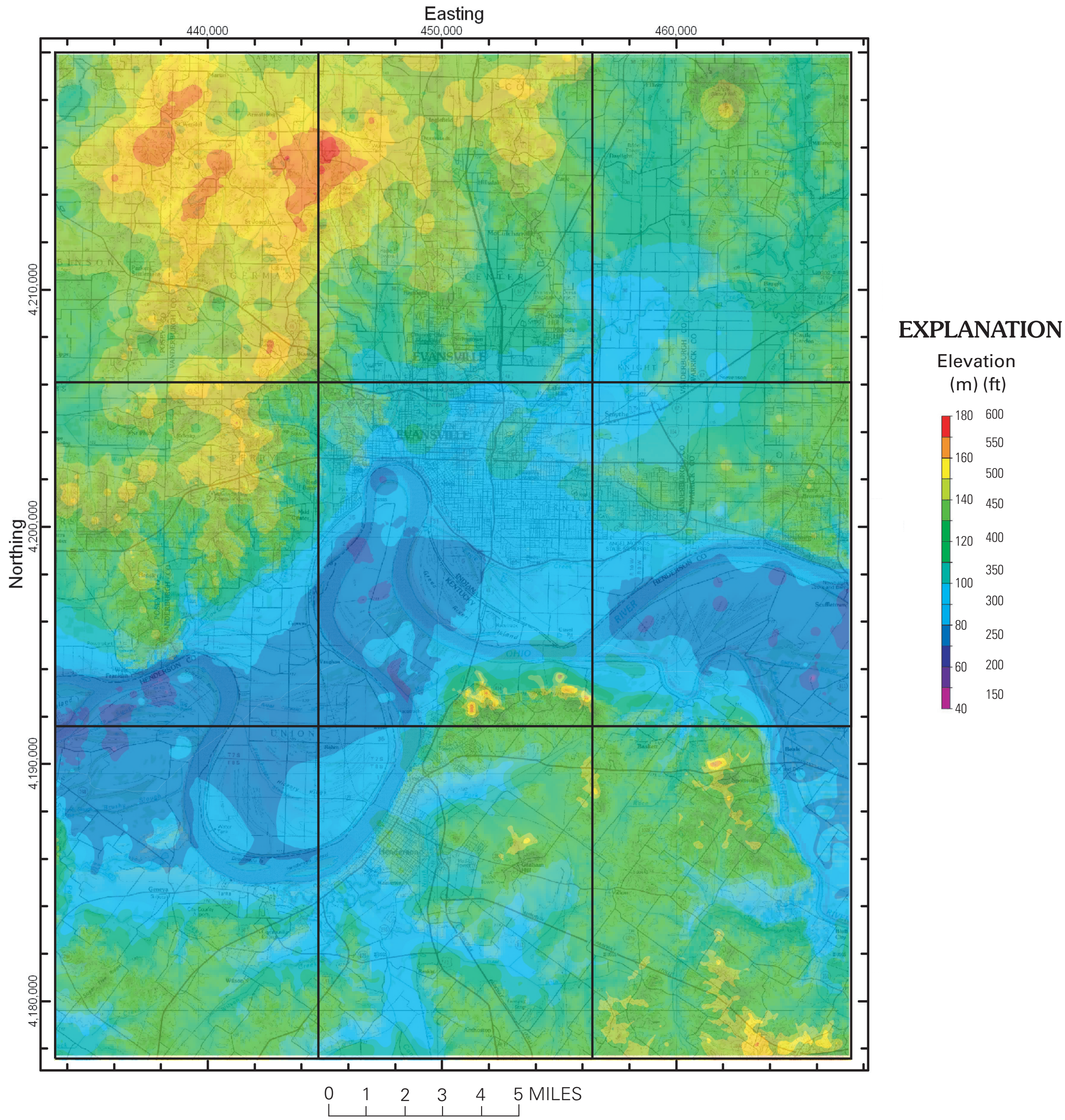

Figure 7. Depiction of the buried bedrock surface. Color-contoured illustration was made using data from more than 2,000 water-well drill logs processed by RockWare GIS software (see “Methods” section of report for details).

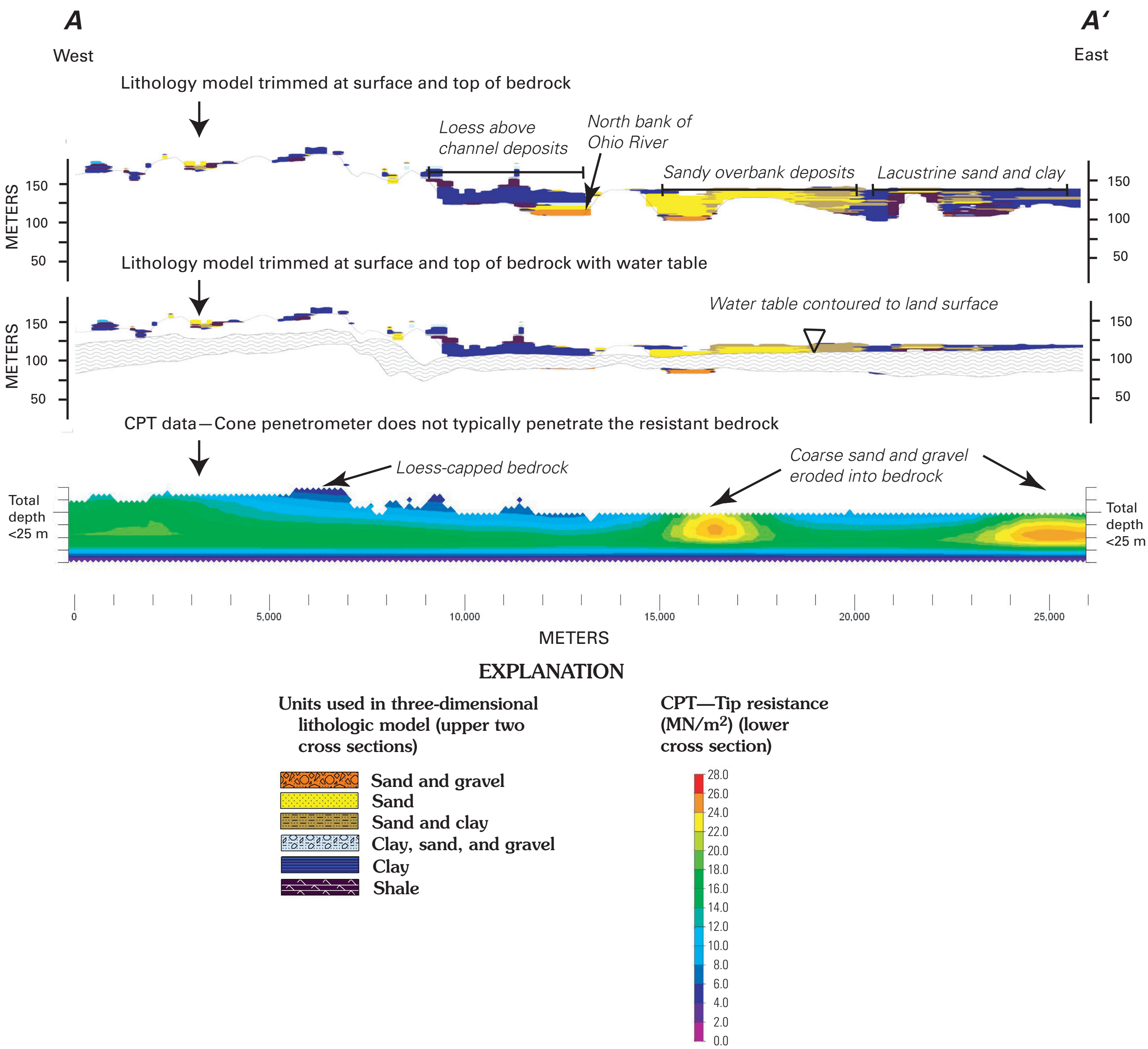

Figure 8. Cross section *A–A´* (line of section shown in fig. 6). The two upper sections that depict variation of grain-size classes (lithology) were generalized from drillers' descriptions in drill-hole logs. The third cross section depicts grain-size classes derived from cone penetrometer test (CPT) data. Warm colors (yellow and orange) represent abundant sand and gravel; cool colors (blue and green) represent prevalent silt and clay. Section lines are vertical slices that cut a three-dimensional lithologic model (grain-size classes) made with RockWare software (see "Methods" section of report for details). Inverted triangle points to top of water table. Vertical exaggeration x20.

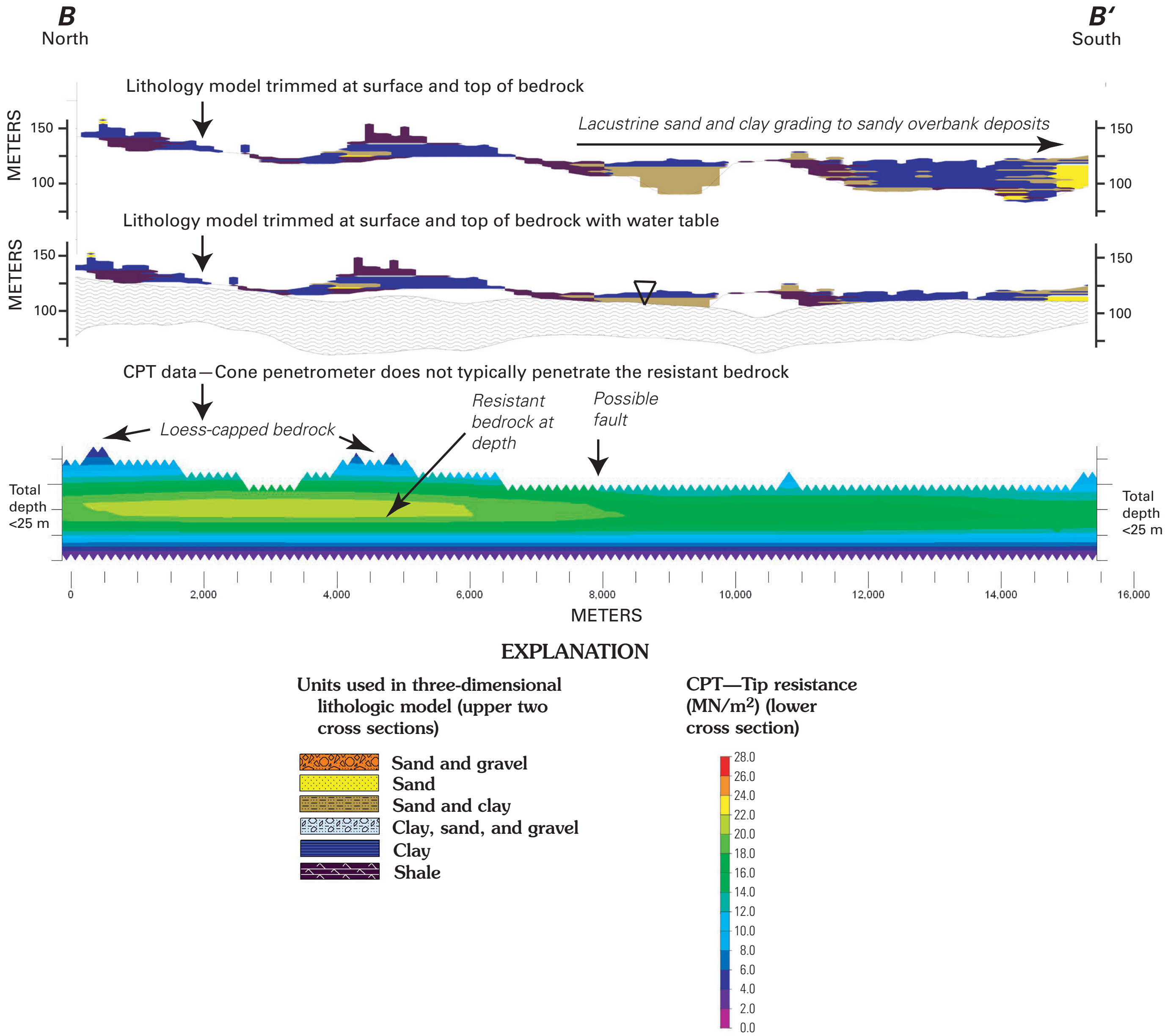

Figure 9. Cross section *B–B*´ (line of section shown in fig. 6). The two upper sections that depict variation of grain-size classes (lithology) were generalized from drillers' descriptions in drill-hole logs. The third cross section depicts grain-size classes derived from cone penetrometer test (CPT) data. Warm colors (yellow and orange) represent abundant sand and gravel; cool colors (blue and green) represent prevalent silt and clay. Section lines are vertical slices that cut a three-dimensional lithologic model (grain-size classes) made with RockWare software (see "Methods" section of report for details). Inverted triangle points to top of water table. Vertical exaggeration x20.

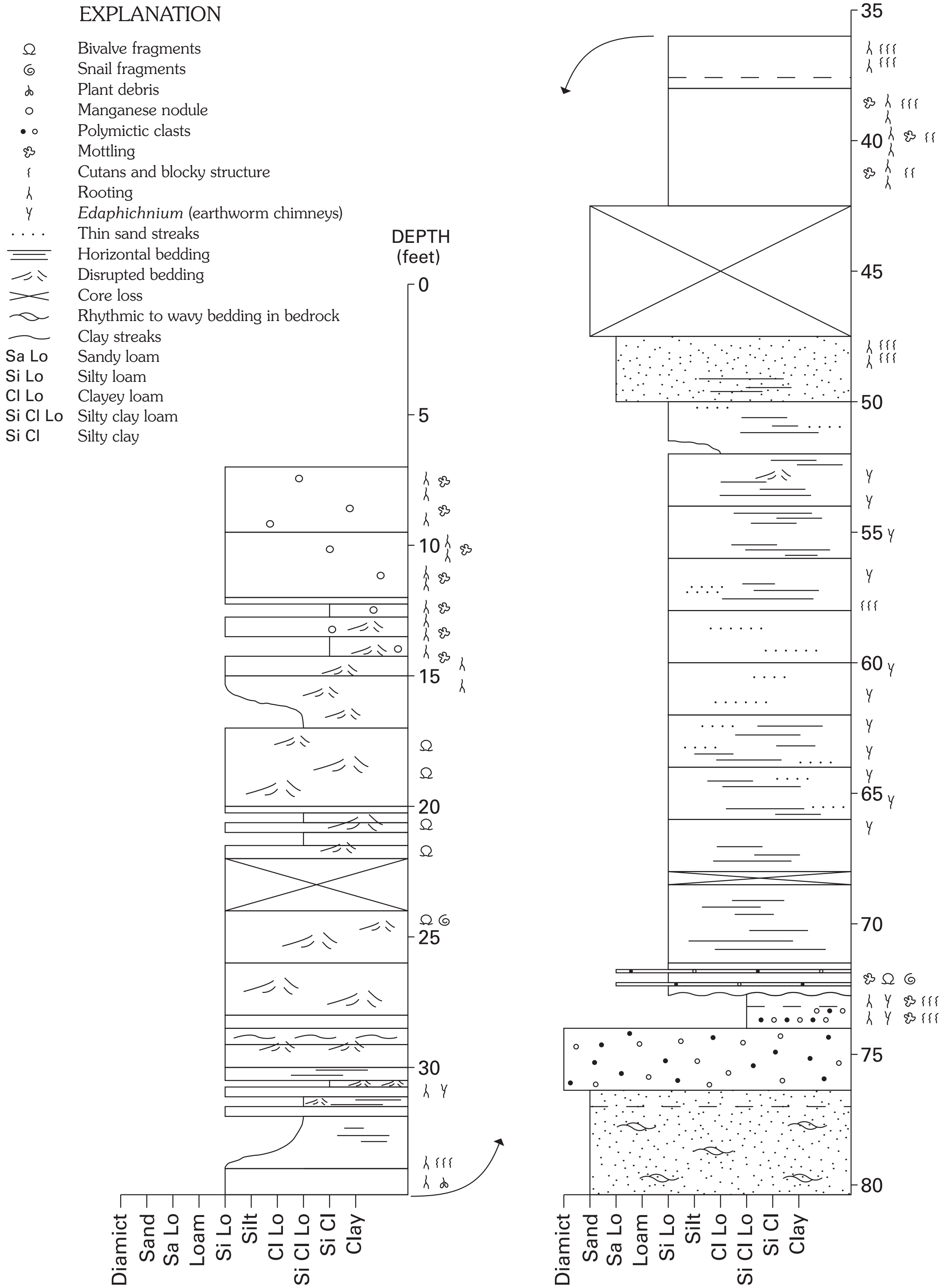

Figure 10. Graphic lithologic log of Illinois State Geological Survey 2.5-inch-diameter wireline drill core, Bosse Field, Garvin Park, Evansville, Ind. (location shown on geologic map). Drilled August 2, 2005. Core hole collared in unit Qlot and penetrates unit Qlt at depth (described by Erik Kvale).

Depth interval (feet)	Unit	Description	Interpretation
0–6.5		NO DESCRIPTION	Disturbed soil, fill.
6.5–9.5	1	Mottled silt loam; gray (10YR 6/1) and brownish yellow (10YR 6/6); section is mottled heavily and rooted; manganese oxide around rootlets; weak horizontal bedding is preserved.	Soil formed in loess.
9.5–11	2	Mottled silt loam; gray (10YR 6/1) and brownish yellow (10YR 6/6); section is mottled heavily and rooted; manganese oxide around rootlets; no bedding preserved.	Soil formed in loess.
11–13.5		LOST CORE	
13.5–15	3	Alternating bands of yellowish-brown (10YR 5/6) silt loam and dark-brown (10YR 3/3) silty clay loam; silty clay loam has organics; strong mottling with manganese oxide nodules; clay skins and roots throughout; disrupted and distorted bedding looks like dewatering but not as intense as in lower units; noncalcareous except for 13.3- to 13.5-ft interval.	Soil development in marshy setting with input of loess; thixotropic.
15–17	4	Silty loam interlayered with silty clay loam; silty clay loam at base of interval grades upward to silt loam; silt loam is massive and dewatered as in unit 3; redoxomorphic colors; oxidized patches are strong brown (7.5YR 5/6); rooting in upper part of interval; some relict horizontal bedding in patches; very calcareous.	(1) Lake deposits with reworked soil or (2) soft sediment deformation or (3) rooted zone.
17–18		LOST CORE	
18–20	5	Massive silt loam; dewatered; distorted beds; calcareous; contains gastropods; oxidized zones are strong brown (7.5YR 5/6) and reduced zones are light yellowish brown (2.5YR 6/3) to pale yellow (2.5 YR 7/4).	Thixotropic lake silt.
20–22	6	Massive silt loam to silty clay loam; oxidized zones are brown (7.5 YR 4/4) and reduced zones are olive (5Y 5/3.5); dewatered; calcareous; contains gastropod shells; clay-rich zones have more oxidized hue.	Thixotropic lake silt.
22–24		LOST CORE	
24–26	7	Silt loam; grayish brown (10YR 5/2); contains small gastropod shell fragments; massive and dewatered. Silty clay loam in center of interval is brown (7.5YR 5/4); ostracodes; very calcareous; similar to unit 6.	Thixotropic lake silt.
26–28	8	Massive silt loam; incorporated reddish clasts; contains dewatering pipes and shearing.	Thixotropic lake silt.
28–30	9	Upper unit: massive to weakly bedded silt loam;15 cm thick; minor mud chips weather out, all very calcareous. Middle unit: interbedded silt loam and bands/streaks of darker silty clay that are broken and disrupted; basal contact is disrupted by fluids escaping from lower unit into middle unit. Lower unit: massive to weakly bedded silt loam; 25 cm thick; minor mud chips weather out.	Fluctuating lake levels; thixotropic behavior; middle unit is varve-like.
30–32	10	Basal unit is 3-cm-thick silt loam to silty clay loam; dark grayish brown (2.5Y 4/2); mostly massive; very calcareous. Overlain by silty clay loam with remnant horizontal bedding that looks dewatered. Overlain by silt loam with root traces and *Edaphichnium* (earthworm chimneys). Overlain by 30 cm of silty clay that has many thin silt streaks; small flame structures (dewatering) capped by massive to laminated silt loam. Entire interval is very calcareous and has no vivianite.	Shallow lake with fluctuating water levels; weak paleosol at base.
32–34	11	Silt loam; massive; noncalcareous; paleosol with weak blocky structure; transitions from silt loam to silty clay loam that is weakly laminated and calcareous; laminated unit has clay skins and subhorizontal organic remains; possibly a reworked soil.	Reworked soil over older paleosol.
34–36	12	Silt loam; minor rooting; weak structure; contains clasts as much as 1 cm in diameter that look like clay skins that formed along root traces; some woody material and minor vivianite.	Soil.

Figure 11 (above and following two pages). Log of Illinois State Geological Survey 2.5-inch-diameter wireline drill core, Bosse Field, Garvin Park, Evansville, Ind. (location shown on geologic map). Drilled August 2, 2005. GPS location lat 37.99245°N., long 87.56391°W. Hole is collared in unit Qlot and penetrates interbedded lacustrine sediment and outwash (unit Qlt) at depth. Described November 1, 2005, by Erik Kvale, Ned Bleuer, and Ron Counts. Total depth 80.4 ft.

Depth interval (feet)	Unit	Description	Interpretation
36–37.6	13	Silt loam; well-developed soil with blocky structure; capped by a massive, 4-cm-thick silt to silt loam; overlain by another noncalcareous paleosol with abundant rooting. Appears to have sharp basal contact with massive olive (5Y 4/3) silt; subtle change in blocky structure of paleosol (change in water table?); paleosol at base of interval is lighter shade of olive (5Y 5/3).	Floodplain soils.
37.6–42.5	14	Silt loam; dark brown (10YR 3/3); well-developed paleosol; redoxomorphic colors; well-developed root traces; thick clay skins; 1-mm-diameter vitrinitic coal clast; degree of soil development increases upwards; minor primary bedding near top.	Repeated flood events that are pedogenically modified.
42.5–47.5	15	LOST CORE (very sandy interval).	
47.5–50	16	Loam to loamy sand; olive (5Y 4/4); coarse to medium sand streak 1 cm thick near 48 ft; muscovite abundant; roots and clay skins appear in upper half of interval; pedogenic zones (soils) alternate with laminated intervals.	Floodplain with river channel migrating nearer.
50–52	17	Silt loam; laminated with sand streaks and silt; clay content increases in lower half of core; no knobby texture; minor vivianite associated with white mineral.	Marshy lake.
52–54	18	Silt loam; abundant silt streaks, many are disrupted; unit has knobby appearance (*Edaphichnium*?); abundant vivianite in upper half of unit; when core is dry, brick-red bands (mottles) appear (fluctuating water levels). Silt streaks are more abundant in upper half of core.	Shoreline, peat bog, or marshy lake.
54–56	19	Silt loam; olive (5Y 4/3); knobby *Edaphichnium* or burrowed pellets overlie the laminated interval; contact is sharp; lowest 8 cm is laminated and represents top of unit 20.	Shoreline.
56–58	20	Calcareous silt loam; olive (5Y 4/3); (soils are less calcareous); laminated with intervals of pellets (transported?) and silt cutans with angular blocky structure (near base at 58 ft); laminated interval contains streaks of fine to very fine sand that are as thick as 0.5 cm. Contacts at thickest sand intervals are very sharp.	Cycles of wetting and drying: high-energy sand inputs (floods) into low-energy, shallow pond or lake that periodically dries out.
58–60	21	Silt loam; dark gray (5Y 4/1) and olive gray (5Y 4/2); one distinct, 3-cm bed of normally graded fine sand; vivianite present. Lacks *Edaphichnium* (earthworm chimneys); vivianite associated with concentrated zone of organics (leaf litter?); very slight reaction with acid.	Ohio River deposit.
60–60.5		LOST CORE	
60.5–62	22	Silt loam; dark gray (5Y 4/1) to olive gray (5Y 4/2); vivianite common; similar to unit 23 except for the presence of distinct depositional packages consisting of 2 cm of massive silt underlain by few millimeter-thick sand lenses, underlain by 4 cm of laminated to massive mud, underlain by a possible narrow zone of pellets. Upper part of unit 22 is more pelletized with some homogenization of the diffuse fine sand streaks, possibly representing burrowing.	Pond with some in-situ shoreline pellets and bioturbation.
62–64	23	Silt loam; dark gray (5Y 4/1) and olive gray (5Y 4/2); vivianite stains (typical of low oxygen environment); similar to unit 22, but has more sand streaks. Definite knobby look to this unit (knobs are interpreted as *Edaphichnium*). Pellets are stratified. Burrows are not in situ and so likely are transported; sand streaks made of coarse sand, grain-size quartz, coal, and rock. Sand grains may be from floods out of the Ohio River and pellets out of local topsoil. Large rust-colored clast at base of one pelleted interval.	Pond with *Edaphichnium* that are transported by increases in water depth or storm activity.
64–66	24	Silt loam; dark gray (5Y 4/1) and olive gray (5Y 4/2). Gradually changes back and forth to more laminated then more knobby (*Edaphichnium*?). Some minor sand-size muscovite and coal fragments. Single-grain sand streaks in coarser interval. Very similar to unit 25.	Pond that experiences seasonal water fluctuations.

Figure 11—Continued. Log of Illinois State Geological Survey 2.5-inch-diameter wireline drill core.

Depth interval (feet)	Unit	Description	Interpretation
66–68	25	LOST CORE 66.85–68 ft (probably similar to unit 26); olive-gray (5Y 4/2) silt loam. Weak horizontal laminations with organic layers less than 1 mm thick. Organic layers have carbonized platy material, a beetle carapace, and white mineral (possibly weathered bone); coal fragments are sparse.	Shallow puddle or pond.
68–68.5	26	LOST CORE, except for remnants of coarse- to medium-grained sand, quartz, and coal particles.	
68.5–71.5	27	Silty loam with varying clay and sand content; horizontal bedding becomes more massive with increasing sand content. Abundant, unknown white mineral present. Sandy zones may be distal expressions from the sandy zones in unit 28. Noncalcareous.	Delta front to prodelta or distal fan.
71.5–72.7	28	Interlayered sand and heavy silt loam. Unit is massive; reduced zones in massive silt loam interval are dark gray (5Y 4/1) and matrix is dark brown (10YR 3/3). Mottled: matrix is oxidized and brown (7.5 YR 4/4) and has reduced, dark-greenish-gray (5BG 4/1) splotches. Shell fragments and one complete snail present. Interval is noncalcareous except for shell fragments and includes three conspicuous sand layers, which range from 0.15 to 0.3 in. thick. Sand layers contain clasts that include coal pebbles and rounded shale clasts as much as 1 cm in diameter with sand matrix. Upper sand layers are overall fine-grained quartz with light-bluish-gray (5B 7/1) gleys around shells; some quartz sand is rounded, medium to coarse grain size; no perturbation. Single sand grain layer lies at basal contact (at 72.7 ft). Above this layer 0.25–0.5 in. of dark-brown (7.5 YR 3/3) clay; basal contact is sharp and erosive; 0.5 in. of relief on basal contact.	Delta front or proximal fan from a slope failure.
72.7–74	29	Upper zone (72.7–73.2 ft) is noncalcareous, silty clay loam; fine, distinct mottling throughout upper 6 in.; well-developed, fine subangular blocky peds. Color is olive (5Y 5/3) with light-olive-gray (5Y 6/2) clay skins on peds; thin discontinuous cutans; dominated by *Edaphichnium* (earthworm pellets and chimneys). Lower zone (73.2-74 ft) has manganese coats on ped faces; root tubules in upper 1 in.; upper 1 in. includes 20 percent clasts of weathered, angular siderite clasts. Siderite clasts are in 1.5- to 3-in.-thick zones of sandy granular particles with interlayered silty clay loam similar to that of upper zone. Clasts in granular zones are primarily yellowish red (5YR 5/6).	Well-developed soil with ground-water fluctuations.
74–76.4	30	Apparent sharp basal contact; mix of Tertiary and Pennsylvanian sediments; weakly stratified diamict; contains rounded quartzite and siderite clasts. Matrix is dark greenish gray (5BG 4/1); clay rich and reduced; medium to fine subangular blocky structures; peds appear to be slightly reworked. Oxidized colors are strong brown (7.5YR 4/6) to reddish yellow (7.5 YR 6/6). More clast dominated and contacts with the matrix are horizontal (ground-water barriers).	Lowest valley fill with a paleosol. (1) Debris flow(?) or (2) water-saturated environment or (3) transported soil(?).
76.4–80.4	31	Pennsylvanian bedrock: thinly interbedded sandstone and mudstone; bedding is very rhythmic; upper 6 in. of interval is pedogenically modified.	Tidal rhythmites(?).

Figure 11—Continued. Log of Illinois State Geological Survey 2.5-inch-diameter wireline drill core.

Depth interval (feet)	Description
0–2	Silt, modern soil, A/B horizon, light yellowish brown (10YR 6/4).
2–4	Clayey silt, modern soil, B horizon, weak, dark yellowish brown (10YR 4/6).
4–7	Silt, yellowish brown (10YR 5/6), very slightly clayey; common small- to medium-size mottles light yellowish brown (10YR 6/4).
7–21	Silt, very fine sandy in parts; color change at 21 ft from yellowish brown (10YR 5/6) in upper part to dark yellowish brown (10YR 4/2); 2-cm-thick strong brown (7.5YR 4/6) horizon at color boundary; paleosol in lacustrine sediment.
21–28	Sand, very fine, silty, and sandy silt, gray (10YR 5/1); easily liquefiable.
28–35	Sand, very fine, and sandy silt, dark grayish brown (2.5Y 4/2), slightly clayey; physical characteristics of silt loam.
35–40	Sand, very fine, and sandy silt; 1-cm-diameter shale pebbles at 40-ft depth.
40–41	Sand, very fine, silty; appears liquefiable.
41–45	Silt, clayey, and silty clay, minor very fine sand; somewhat plastic, not liquefiable.
45–57	Same as 41- to 45-ft interval except firm consistence; somewhat stiff.
57–59	Sand, very fine, gray (10YR 5/1), silty, clayey; plastic, not liquefiable; stiff, firm; contains small white snails.
59–65	Same as 57- to 59-ft interval except contains no snails.
65–67	Silt, sandy; plastic, firm.
67–70	Sand, fine- to medium-grained quartz, dark grayish brown (10YR 4/2); subangular grains, 3–5 percent lithic grains, no mica, mostly 1/8- to 1/4-mm-diameter sand grains, about 15 percent in 1/4- to 1/2-mm-diameter range.
70–75	Sand, mostly fine to medium, about 5 percent coarse; scarce granules; same composition as 67- to 70-ft interval; alluvium.
75–80	Sand, abundant coal grains; alluvium.
80–85	Sand, fine, silty and clayey; plastic; somewhat stiff; lacustrine (?).
85–88	Sand; sample collected in opaque tube for future thermoluminescence analysis; alluvium.
88–90	Sand; alluvium.
90–91	Sand, fine, silty; lacustrine (?).
91–95	Sand, medium to coarse, few granules and small rounded pebbles; one maroon quartzite pebble, 1 cm diameter; alluvium.
95–100	Sand, granules in top 3 in.; 40 percent recovery; alluvium.
100–105	Sand and granules, 5 percent "pea gravel" (2–3 mm diameter); one limestone pebble about 4 cm diameter; alluvium.
105–120	Sand; one layer of plastic clayey silt and fine sand, gray (10YR 5/1), captured in 10-ft-long sampling tube; abundant fine pebble gravel; sample collected for thermoluminescence analysis; alluvium.
120–125	Sand, coarse grained, granules, scarce pebble 2–5 cm diameter; sample in tube.
125–135	Gravel; poor recovery, collected small bag of sand and fine gravel; alluvium.
135–136	Gravel, pebbles; bottom of hole; alluvium.

Figure 12. Log of interbedded paleolevee and lacustrine sediments (unit Qotp). Illinois State Geological Survey CME-75 2.5-in.-diameter wireline drill core, Clay Cemetery, Henderson County, Ky. Drilled August 3, 2005. Logged at drill site by D.W. Moore. GPS location lat 37.82075°N., long 87.70747°W., WGS84 datum. Total depth 136 ft.

Depth interval (feet)	Description
0–1.5	Fill and soil, silty loam (disturbed), light yellowish brown (10YR 6/4).
1.5–4.5	Lost sample.
4.5–8.5	Silt, brownish yellow (10YR 6/6); slackwater lacustrine sediment to bedrock.
8.5–11	Silt, brownish yellow (10YR 6/6), mottled yellowish brown (10YR 5/8).
11–13	No sample recovery.
13–14	Silt and silty clay, dark gray (10YR 4/1), lenses of very fine sand; silt liquefiable.
14–17	Silt, slightly sandy, dark gray (10YR 4/1); liquefiable.
17–21	Sand, very fine, silty, dark gray (10YR 4/1), finely laminated, not plastic, minor clay content.
21–28.5	No sample recovery.
28.5–30	Sand, very fine, gray (10YR 5/1) and dark yellowish brown (10YR 4/6) at 30-ft depth, olive (5Y 5/3) above 30-ft depth; pale-olive (5Y 6/3) paleosol (?) containing common medium to large mottles.
30–32	Sand, fine, silty, slightly clayey, light yellowish brown (10YR 6/4), large mottles light gray (10YR 7/1), FeO concretions(?), or weathered pebbles(?).
32–34	Same as 30- to 32-ft interval, fine root oxidized impressions, paleosol(?).
34–40	Sand, coarse, abundant granules and pebble gravel, brown (7.5 YR 5/4); unconsolidated sample, mixed by drill bit, wet and discontinuous; black organic carbon concentrated in weak concretion-like masses; basal 1 ft of this interval consists of subangular to subround, 1- to 4 cm-diameter, brown, subangular chert (95 percent) pebbles, minor quartz; bed of pebbles resembles “Lafayette gravel” in appearance; depths in sample tube may not correspond to positions in sample tray.
40–43.7	Gravel, same as 34- to 40-ft interval; alluvium.
43.7–46.5	Gravel, chert, subangular, 2–6 cm diameter; alluvium.
46.5–51.95	Bedrock, cored, shale.

Figure 13. Log of slackwater lacustrine deposit (unit Qlt) to 34-ft depth; alluvium below 34 ft. Illinois State Geological Survey 2.5-in.-diameter wireline drill core taken at the Kentucky Geological Survey Western Office, Henderson, Ky. (location shown on map). Drilled August 4, 2005. Logged at drill site by D.W. Moore. GPS location lat 37.81524°N., long 87.59245°W., NAD83. Total depth 51.95 ft.

Table 1. Luminescence data and ages for loess samples, Evansville, Ind.

Sample number	Stratigraphic unit	K (%)	Th (ppm)	U (ppm)	Water content (%)[a]	Cosmic dose rate (Gy/ka)	Total dose rate (Gy/ka)[b]	De (Gy)[c]	n[d]	Age (ka)[e]
UL-Warr-2	Peoria Silt	1.45 ± 0.08	9.00 ± 0.06	2.69 ± 0.05	11 ± 0.5	0.19 ± 0.02	2.46 ± 0.03	45.1 ± 0.50	20 (21)	18.3 ± 0.28
UL-Warr-1	Loveland(?)	2.32 ± 0.03	11.2 ± 0.27	2.49 ± 0.09	5 ± 0.5	0.07 ± 0.01	3.29 ± 0.05	>330 ± 50	27 (30)	>100 ± 15

[a]From field moisture, ages measured at 20–25 percent moisture contact, midway between field and saturation moisture values.

[b]Total dose rate is measured from 15 to 20 percent water content.

[c]Equivalent dose (De) estimate; reported to one sigma, fit to an exponential + linear regression and calculated as a weighted mean.

[d]Number of replicated equivalent dose (De) estimates used to calculate the mean. Second number is total measurements made including failed runs with unusable data.

[e]Lab used fine sand grains (105–90 or 150–125 micrometer size).

The creek alluvium is derived chiefly from loess on surrounding hills. In historic time, land erosion and the consequent silty sedimentation on flat-bottom creek valleys accelerated as European settlers and their descendants cleared the forests and drained wetlands.

Methods

In making the geologic map, we inferred origins of deposits from observation of landforms, from geomorphic principles, and from subsurface data. Characteristics of subsurface deposits were interpreted from drilling data, cone-penetrometer testing (CPT), and analysis of databases of water-well drilling records. We used four drilling methods to sample buried deposits: 2.5-inch-diameter coring with a CME-75 wireline rig, 4-inch solid-stem auger, 6-inch hollow-stem auger with split-spoon sampler, and a Giddings soil probe. CPT sampled creek alluvium (Qa) and lacustrine deposits (Qlt), to depths of 39–72 ft, at 58 sites (fig. 6). CPT used hydraulic rams mounted in a heavy truck that pushed a 3.6-cm-diameter probe (cone) into the deposits[2]. Sensors in the cone detected soil resistance to penetration, recording soil-behavior classes, which are derived from Robertson and Campanella (1984). Fifty-eight graphic data logs of CPT and their locations in the map area are illustrated at the web site (http://earthquake.usgs.gov/regional/nca/cpt/data/index.php?map=evansville). Shear-wave velocities were acquired and are not discussed here, but appear at the web page, as well as an explanation of CPT technology. A Giddings rig that hydraulically pushed a 4-ft-long, hollow steel tube sampled Quaternary deposits at 15 sites (not shown) to depths of 34 ft, averaging 22 ft. Giddings sites, located near some CPT sites, provided physical samples.

Figures 6–9 were made using RockWare GIS earth science software. The buried bedrock surface elevation illustration (fig. 7) was made from recorded elevations at which bedrock was reached in more than 2,000 water wells described in the iLITH database of the Indiana Geological Survey (Brown and others, 2000) and in a database of the Kentucky Geological Survey. Cross sections of the geologic deposits (figs. 8, 9) were derived from a three-dimensional lithologic model produced by RockWorks14. We made this model by generalizing the drillers' logs to six classes of grain sizes of deposits. Sections *A–A′* and *B–B′* were extracted from the model along the lines of section. The diverse descriptions from the drillers' logs had to be generalized into a few, manageable grain-size classes in order to make the lithologic model.

The topographic break between the Ohio River floodplain (Qafp) and the river terrace (Qat) was placed with the aid of a high-resolution, color digital elevation model image plotted at 1:24,000 scale.

[2]http://earthquake.usgs.gov/regional/nca/cpt/ [click on USGS CPT Data tab at top of page for explanation of CPT methodology]

Colors of surficial deposits were determined using the Munsell Soil Color Charts (Munsell Color, 1973). Colors of bedrock were determined using a rock-color chart (Geological Society of America, 1970). Grain size was estimated in the field (comparison to standard grain-size chart, American Geological Institute).

Depths in drill holes are reported in feet. Elevations on the topographic base map are in meters. Radiocarbon ages, reported in radiocarbon years before present, were obtained on fossil wood and snails collected from sites (DH-1, IGS auger hole 93-102, and fossil wood radiocarbon site) shown on the geologic map.

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Glossary

age, estimated Approximate age in calendar years, not well constrained by radiometric or other quantitative geochronology; for example, the mapped surficial deposits (excluding QTg and Pz) are likely no older than 55,000 years.

alluvium Sediment deposited by flowing water in channels and on floodplains of rivers and creeks.

colluvium Unsorted regolith derived from weathered bedrock, sheetwash sediment, and thin loess moved downslope by gravity.

cone penetrometer Instrumented, pointed cone on the end of a steel rod; hydraulically pushed from a heavy truck downward at 2 cm/s; pressure-sensitive devices in the cone record resistance and friction of subsurface soil (geologic deposits), every 5 cm of depth. From these data, grain size and nature of the deposit are deduced (see figs. 8, 9).

contact Line on a geologic map that separates one map unit (depicting a type of geologic deposit) from another unit. Where a deposit grades horizontally into another deposit with no perceptible break, the mapping geologist draws the contact where the change from mostly one deposit to mostly another is estimated to occur.

diachronic (time transgressive) Class of time that identifies when a geologic formation or group was deposited and recognizes that it was deposited earlier or later in one area than when it was deposited in another area; for example, 24,000 years ago a group of tills was deposited in southern Indiana and 12,000 years ago those same named tills (recognized as a formation) were deposited in northern Indiana. The time interval of deposition of those tills falls between 24,000 and 12,000 years, which may be called the Michigan Subepisode, a diachronic time unit.

eolian Deposited by wind.

episode A diachronic unit of geologic time used to convey a sense that the beginning and end dates of formation of a geologic unit do not coincide in different geographic places (Johnson and others, 1997). Episodes (for example, Hudson Episode and Wisconsin Episode) are parts of the Quaternary Period.

facies Characteristics of a deposit reflecting the conditions of its origin.

fluvial (alluvial) Relating to, or produced by, the action of a creek (stream) or river.

geosol Ancient soil generally buried by younger sediment, recognized by its soil characteristics, and afforded status as a formal stratigraphic unit; used to correlate geologic deposits from place to place.

GIS Geographical Information System; a system that captures, stores, analyzes, and presents data linked to geographical position.

granitoid Field term for a light-colored, coarse-grained plutonic rock containing quartz and feldspar as essential components and minor mafic (dark, magnesium and iron rich) minerals; rock that looks like granite, but strictly may not be if analyzed by laboratory techniques.

Hudson Episode Post-glacial, diachronic time interval; the current interglacial interval at the end of the Quaternary Period.

lacustrine Relating to, or deposited in, a lake, pond, or slackwater environment.

loess Wind-blown silt, clay, and very fine sand eroded from alluvium in valleys and deposited downwind mainly as a uniform mantle.

Michigan Subepisode Diachronic time interval based on widespread evidence of continental-scale ice sheet advance and retreat and concurrent outwash and loess deposition in the Great Lakes region; in the map area, it is approximately equivalent to the late Wisconsin interval of some scientists.

micrometer One-millionth of a meter; one-thousandth of a millimeter; 0.00004 inch.

Munsell colors Standard color chips published by the Munsell Company and used in the field to standardize the description of soil and sediment. Example: brown (10YR 4/3).

natural levee Fine sandy and coarse silt deposit between river and floodplain and 3–6 ft higher than floodplain; the levee forms when the velocity of overbank floodwater diminishes as water leaves the main channel, causing localized deposition of sand and silt; premodern levees are paleolevees.

newton, meganewton A newton (N) is the force that accelerates 1 kg mass 1 m per second per second; a meganewton (MN) is one million newtons (about 145 lbs/in.^{2}). Meganewton appears in figures 8 and 9 in the abbreviated term MN/m^2 (a unit of pressure) on the scale showing cone penetrometer test (CPT) tip resistance.

outwash Sediment derived from glaciers and transported and deposited by meltwater.

pedogenic Formed in the soil zone by soil processes.

radiocarbon years before present (B.P.) Conventional reporting unit of age analyses on organic samples (collected from a sedimentary deposit). This "raw age" is based on assumptions that the amount of radiocarbon in the atmosphere has been constant and that the half life of radiocarbon is 5,568 years. Radiocarbon years B.P. are not equivalent to historical years B.C. or A.D. A web site, http://www.radiocarbon.ldeo.columbia.edu/index.htm, discusses the relation of historical ages of fossils to their radiocarbon ages.

regolith Unconsolidated residual or transported clay, silt, sand, and rock fragments overlying bedrock.

relief (topographic) Difference in elevation of land; used in a relative sense on this map; the contrast between hilly uplands and flat river floodplains.

Sangamon Geosol A *stratigraphic unit*; an old soil (paleosol) in sediments or on a relict land surface; it mainly formed during the warm interglacial time, called the Sangamon Episode, the duration of which varies somewhat from place to place; scientists approximate it as 127,000–75,000 or 130,000–55,000 years ago.

scarp Abrupt, steep slope that separates adjoining, flat (or nearly so) land surfaces and is the result of erosion or faulting.

scrollwork topography (also, swell and swale) Riverine landform; a series of long, parallel, crescentic ridges and troughs that forms along the inner bank of a river bend as the channel migrates down and across the valley.

slackwater environments Low-energy lakes, ponds, and marshes impounded in tributary creek valleys behind rapidly aggrading outwash in the main channels of the glacial Ohio River. Such environments existed about 35,000–11,000 years ago when the Ohio River glacial sluiceway sporadically flooded with outwash, raising the level of the river bed and floodplain.

slough Poorly drained, perennial, shallow channel that conveys floodwater to and from the floodplain and that may contain bogs, ponds, and cypress swamps in places not altered by human activities. Large, perennial sloughs are called bayous.

sluiceway Main drainage pathway of meltwater from wasting continental glaciers of the Wisconsin Episode; the sluiceway closely coincides with the modern Ohio River valley.

terrace Relatively level land formed by ancestral river flow, bounded by a steep front that faces the river; in the map area, most terraces are former floodplains, but some are former lake beds.

thixotropy Property of a material, illustrated when a clay or gel weakens when shaken and increases in strength upon standing.

toe slope Lowest part of a hillslope.

unconformity A significant gap in time when no deposits accumulated at a place or where the accumulated deposits were eroded later. Unconformities are recognized in a sequence of sedimentary layers as a surface of erosion.

valley train Outwash in a long, narrow deposit in a valley far beyond the terminal moraine of an active continental ice sheet.

wireline core drilling Technique whereby a long cylinder (or core) of rock or sediment is pulled from a drill hole without first pulling out the steel drill pipe used to cut the core.

Wisconsin Episode A time-transgressive interval of continental glaciation in the Great Lakes region that followed the interglacial Sangamon Episode and that preceded onset of the current Hudson Episode interglacial. The Wisconsin Episode spanned approximately 75,000–12,000 years ago, which can vary somewhat when inferred from evidence at one geographical place compared to that at another place.

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