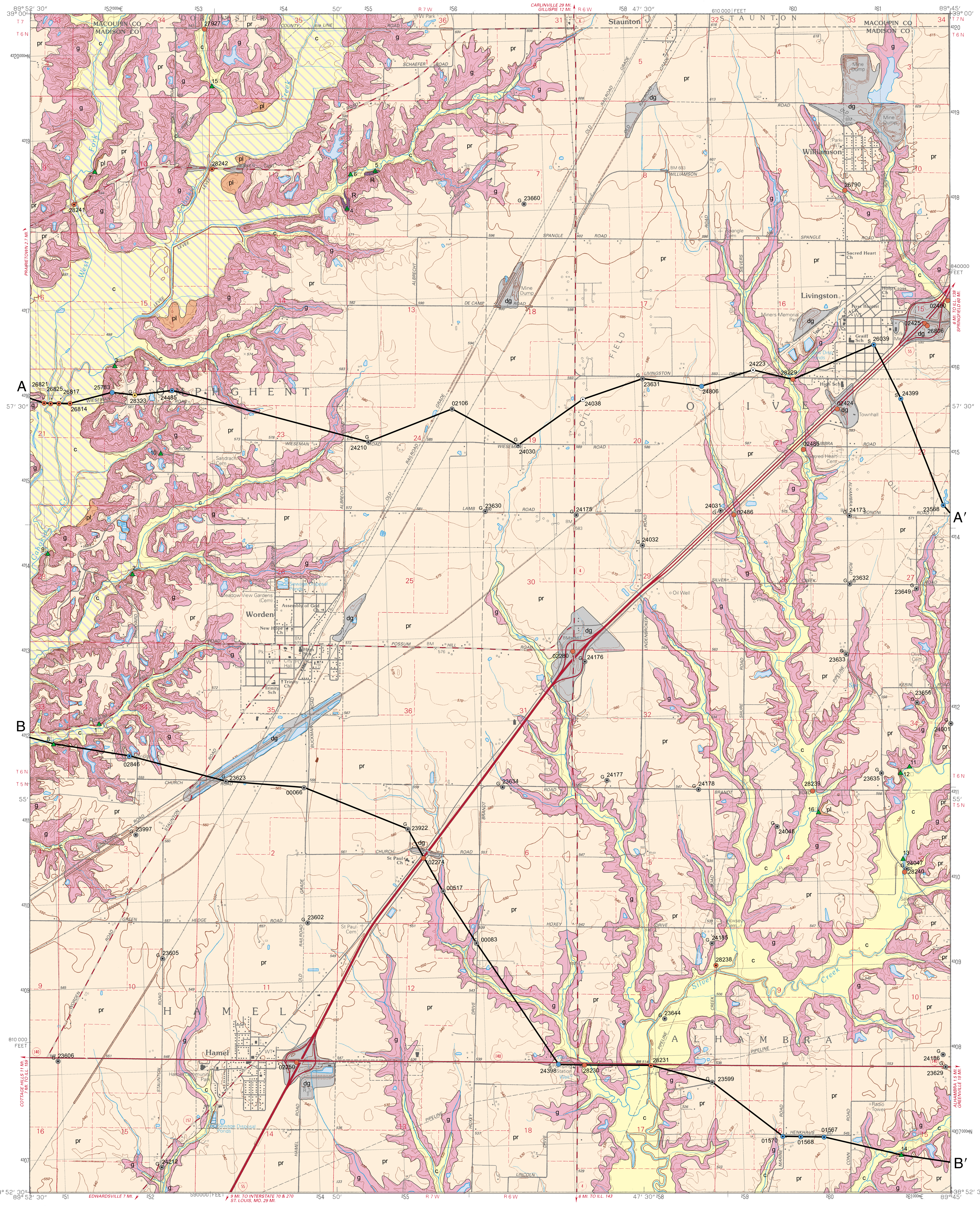
Department of Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY
William W. Shilts, Chief

Surficial Geology of Worden Quadrangle
Madison County, Illinois

David A. Grimley
2004

Illinois Preliminary Geologic Map
IPGM Worden-SG



QUATERNARY DEPOSITS

Description	Unit	Interpretation/Occurrence
HUDSON EPISODE (~12,000 years before present (B.P.) to today)		
Fill or removed earth; sediment of various types; up to 60 feet thick	Disturbed ground (dg)	**Disturbed sediment** such as in interstate interchanges and former coal mine spoil piles
Silty clay to silt loam to sandy loam; sandy beds common near base of unit; gray to brown to dark brown; massive to well stratified; soft; organic-rich in places; noncalcareous; up to 20 feet thick	Cahokia Formation (hatchured where underlain by Equality Fm.) (c)	**Fine-grained alluvium** (river deposits) in floodplains; coarser beds are common where overlying till, outwash or bedrock
WISCONSIN EPISODE (~75,000 - 12,000 years B.P.)		
Silty clay to silt loam to fine sand; gray to yellowish brown to brown; massive to stratified; soft; leached to calcareous; up to 20 feet thick	Equality Formation (cross sections only) (e)	**Lake deposits** below Cahokia Formation in Cahokia Creek valley; deposited by backflooding of Mississippi River during glacial times
Silt loam; yellowish brown to gray to brown; massive to blocky structure; friable; leached; contains modern soil in upper 3 to 4 feet; up to 12 feet thick, but typically 7 to 10 feet thick	Peoria and Roxana Silts (pr)	**Loess**; some slope deposits and redeposited loess; upper and thicker portion is Peoria Silt (yellowish brown to gray); lower portion is Roxana Silt (brown with pink hue to gray); total thickness greatest to the southwest
ILLINOIS EPISODE (~200,000 - 130,000 years B.P.)		
Sand, fine to coarse, with some gravelly, silty or loamy zones; stratified; may include silty clay loam in upper few feet of near-surface units; up to 15 feet thick	Pearl Formation (pl)	**Outwash**; deposited by glacial meltwater streams; occurs above or intertongues with Glasford Formation on uplands or in terraces; may contain weathering profile of Sangamon Geosol; covered by up to 5 feet of loess or weathered silt on surficial map units
Diamicton, pebbly loam with sand and gravel lenses (up to 20 feet thick and hundreds of feet wide) common in upper portion; light olive brown to dark gray; mostly massive, stiff to very stiff to hard, and calcareous; lower third can be more clay-rich (silty clay loam diamicton); upper few feet can be multicolored and more clayey (weathered); up to 100 feet thick	Glasford Formation (g)	**Till and ice marginal sediment**; upper half contains more sorted sediment; lower portion is primarily basal till; may include some lake sediment; crops out along slopes; may contain Sangamon Geosol weathering profile; covered by up to 5 feet of loess or weathered silt on surficial map units
PRE-ILLINOIS EPISODE (~700,000 - 450,000 years B.P.)		
Diamicton, pebbly silty clay loam with sand and gravel bodies (up to 40 feet thick); dark gray to dark greenish gray, may be oxidized to olive brown; massive to weakly laminated; mainly stiff; shale and coal fragments common, especially in lower portion; leached to calcareous; up to 75 feet thick	Omphghent member Banner Formation (in cross sections only) (b-o)	**Till and ice marginal sediment**; may contain Yarmouth Geosol weathering profile in upper 10 feet (but commonly truncated); mainly basal till, but may include debris flows and lake sediment in basal portions
Silty clay loam (primarily) with beds of very fine sand near base of unit; dark greenish gray; faintly laminated; mainly noncalcareous; up to 25 feet thick	Canteen member Banner Formation (in cross sections only) (b-c)	**Fine-grained alluvium and lake deposits** (preglacial or early glacial); sandy beds are more common towards base of unit; may contain buried soil in upper portion; in places includes a basal colluvial zone; unconformably overlies bedrock or weathered bedrock

PRE-QUATERNARY DEPOSITS

Description	Unit	Interpretation/Occurrence
PALEOZOIC BEDROCK		
Sandstone, shale, limestone, coal, and underclay; various colors including dark greenish gray, light yellowish brown, light gray and black; laminated to bedded to massive; noncalcareous to calcareous	Near-surface bedrock (R)	**Bedrock exposures or bedrock** within 5 feet of land surface on surficial map; exposures are primarily thin beds of limestone and sandstone, but shale and siltstone are most common at depth (in cross-sections)

Data Type

- Outcrop
- Stratigraphic boring
- Water well
- Engineering boring
- Coal boring
- Oil and Gas boring
- SG: Boring with samples (S) or geophysical log (G); dot indicates to bedrock
- Contact
- Inferred contact
- A—A′ Line of cross section
- Water

Note: Numeric labels indicate the county number, a portion of the 12-digit API number on file at the ISGS Geological Records Unit. (Outcrop labels indicate field number.)

Base map compiled by Illinois State Geological Survey from digital data provided by the United States Geological Survey. Topography compiled from imagery dated 1986. Field checked 1988. Map edited 1991.

North American Datum of 1983 (NAD 83)
Projection: Transverse Mercator
10,000-foot ticks: Illinois State Plane Coordinate system, west zone (Transverse Mercator)
1,000-meter ticks: Universal Transverse Mercator grid system, zone 15

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SCALE 1:24 000

BASE MAP CONTOUR INTERVAL 10 FEET
SUPPLEMENTARY CONTOUR INTERVAL 5 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Released by the authority of the State of Illinois: 2004

Geology based on fieldwork by D. Grimley, 2003-2004.

Digital cartography by M. Barrett, Illinois State Geological Survey.

This Illinois Preliminary Geologic Map (IPGM) is a lightly edited product, subject to less scientific and cartographic review than our Illinois Geological Quadrangle (IGQ) series. It will not necessarily correspond to the format of IGQ series maps, or to those of other IPGM series maps. Whether or when this map will be upgraded depends on the resources and priorities of the ISGS.

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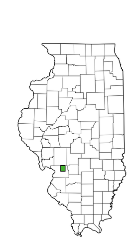

ADJOINING QUADRANGLES
1 Bunker Hill
2 Gillespie South
3 Mount Olive
4 Prairietown
5 New Douglas
6 Edwardsville
7 Marine
8 Grantfork

APPROXIMATE MEAN DECLINATION, 2004

ROAD CLASSIFICATION
- Primary highway, hard surface
- Secondary highway, hard surface
- Light-duty road, hard or improved surface
- Unimproved road
- Interstate Route
- U.S. Route
- State Route

Introduction

The surficial geology map of the Worden 7.5-minute Quadrangle, located in Illinois about 25 miles northeast of St. Louis, provides an important framework for land and groundwater use, engineering assessment, economic development, and geological studies. This study is part of a broader geologic mapping program undertaken by the ISGS for 7.5-minute quadrangles in developing areas of the St. Louis Metro East region (Grimley, 2002; Phillips, 2004; Grimley and McKay, 2004).

The Worden Quadrangle is located in northeastern Madison County, about 10 to 20 miles northeast of the Mississippi River valley (fig. 1) and the maximum ice margins during the Illinois and pre-Illinois episodes (Grimley et al., 2001). Glacial ice in southwestern Illinois generally advanced from the northeast, originating from the Lake Michigan basin during the Illinois Episode and from the Lake Michigan basin and/or more eastern Great Lakes Region during pre-Illinois episodes (Willman and Frye, 1970). Deposits of both glacial episodes have been reported by McKay (1979), Stohr et al. (1987), and Phillips (2004) in the immediate surrounding area (within 10 miles). Glacial ice did not reach the study area during the Wisconsin Episode; however, glacial meltwaters from the upper Mississippi River drainage basin deposited outwash throughout the middle Mississippi Valley. This outwash was the source for loess deposits (windblown silt) which blanket uplands of southwestern Illinois.

Methods

Surficial Map
The surficial geology map is based in part upon soil parent material data (Goddard and Sabata, 1982), supplemented by field data from outcrops, drill cores obtained for this STATEMAP project, and boring logs from Illinois Department of Transportation (IDOT) borings, other engineering test borings, and water-wells. Map contacts were also adjusted according to the surface topography, geomorphology, and observed landform-sediment associations.

Cross Sections
The cross sections portray the deposits as would be seen in a slice through the earth down to bedrock (vertically exaggerated 20x). The lines of cross section are indicated on the surficial map. Data used for subsurface unit contacts (in approximate order of quality) are from studied outcrops, stratigraphic test holes, engineering boring records (IDOT and Madison County Highway Department), coal test borings (many with various geophysical logs), water-well records, and oil-well records. Units less than 5 feet in maximum thickness are not shown on the cross sections. The full extent of wells that penetrate deeply into bedrock is not shown.

Surficial Deposits

The surficial can be divided geomorphically into two terrains: upland areas, containing predominantly glacial and windblown sediments, and valleys and terraces, containing predominantly waterlain sediments near the surface. There area also older concealed deposits, whose occurrence and thickness is closely related to the bedrock surface topography (fig. 2).

Uplands
Uplands, including sloping areas, comprise about 88 % of the quadrangle's area. The uplands, blanketed by up to 12 feet of loess (windblown silt), are underlain at depth by thick glacial till and ice-marginal deposits. The loess (Peoria and Roxana Silts) is generally 7 to 10 feet thick on uneroded uplands, but is thinner on the many eroded sloping areas (see map and cross sections). The thickest loess occurs on flat uplands in the southwestern portion of the quadrangle, closer to the Mississippi Valley from which the loess was derived (fig. 1). During the last glaciation (Wisconsin Episode), silt-size particles from Mississippi Valley meltwater deposits were periodically windswept and carried in dust clouds eastward to vegetated upland areas where particles gradually settled out across the landscape. The loess deposits are typically a silt loam to heavy silt loam where unweathered. However, in the modern soil solum, generally the upper 3 to 4 feet, the loess is altered to a heavy silt loam or silty clay loam (Goddard and Sabata, 1982). The Peoria Silt is the upper and younger loess unit and the Roxana Silt, with a slight pinkish hue and slightly more clayey, is the lower loess unit (Hansel and Johnson, 1996). With the total loess thickness here typically less than 10 feet, both loess units are slightly to moderately weathered and leached of carbonates. Their physical properties are relatively similar and thus the units are mapped together.

On many sideslopes and ravines, where the loess has been eroded to less than 5 feet, the underlying diamicton (a massive, poorly sorted mixture of clay, silt, sand, and gravel), weathered diamicton, and associated sorted sediment are mapped as the surficial unit (Glasford Formation). The Glasford diamicton, interpreted mainly to be till, is interspersed with sand and gravel lenses that can be tens or hundreds of feet wide and up to 15 feet thick (based on outcrops and boring logs). Glasford Formation at or near land surface is common in northwestern and southeastern portions of the quadrangle where highly erodible, sloping topography is common. The Glasford Formation can be as much as 100 feet thick; however, 50 to 75 feet is more typical. Sand and gravel is more commonly interspersed within upper portions of the unit, but it can also be present at the unit base (see cross sections). Diamicton in the lower third of the Glasford Formation can be slightly more clayey (pebbly silty clay loam) than most of the unit (typically pebbly loam). This lower Glasford Formation generally has a slightly lower illite and carbonate content, probably due to the local incorporation of weathered and clay-rich pre-Illinois Episode till, paleosols, and Pennsylvanian shale. The basal zone of the Glasford Formation is similar in composition to what has been termed the Smithboro Member (Jacobs and Lineback, 1969); however, no physical evidence was observed here for two separate Illinois Episode ice advances. Therefore, the clayey facies is here attributed to a basal zone in glacial ice that contained higher concentrations of locally derived substrate.

In its uppermost portion, the Glasford Formation contains a buried interglacial soil (known as the Sangamon Geosol) that exhibits alteration features such as root pores, fractures, oxidation or color mottling, strong soil structure, clay accumulation, and/or clay skins. Such alteration features, most prevalent in the upper few feet of the Glasford Formation, help to distinguish it from overlying loess deposits. Additionally, the Glasford Formation is more stiff, with higher unconfined compressive strength [Qu], higher average blow counts [N], and a lower moisture content [w%] than loess deposits (Table 1). The upper 5 to 10 feet of Glasford till is somewhat less stiff and more weathered and may have a higher water content than the remainder of the unit, which was deposited subglacially under the entire weight of glacial ice. The basal 10 to 25 feet of the Glasford Formation is also typically not as stiff and may have a higher moisture content compared to most of the unit (very stiff).

Although rare, bedrock outcrops of sandstone and limestone were observed at sites 4f and 5f (Secs. 11 and 12, 6N-7W). Near such areas of high bedrock, Illinois Episode till rests directly on bedrock; the pre-Illinois units having been eroded. Areas of disturbed ground occur throughout the quadrangle, along railroads, interstates and in mine dumps (from former underground coal mines), but they are most common in the northeastern portions of the map. Some areas of disturbed soil are less than 10 feet, but interstate interchanges can have 15 to 20 feet of fill and mine dump piles are up to 60 feet in height (Secs. 3 and 10, 6N-6W).

Valleys and Terraces
Valleys and known terraces (< 5 feet loess cover) occupy about 12 % of the quadrangle's area, but they constitute geologically important and complex areas. Fine-grained postglacial stream deposits (Cahokia Formation) fill most valleys with up to 25 feet of weakly stratified sediments. The Cahokia Formation is generally 15 to 25 feet thick in the broader river valleys (Cahokia and Silver Creek valleys) and 5 to 15 feet thick in the smaller valleys. Although mostly silty clay to silt loam in texture, the Cahokia Formation includes layers of fine to medium sand at depth and channel sand in modern streams. Commonly, the lowermost few feet of the unit is stratified sand or gravel that fines upwards. Sediment in the Cahokia Formation is mostly derived from erosion of loess and the Glasford Formation exposed on uplands and sloping areas. The Cahokia Formation commonly contains buried organic-rich paleosols, buried wood fragments and layers of historically eroded sediment. Due to periodic flooding during postglacial times, areas mapped as Cahokia Formation generally have relatively youthful modern soil profiles (generally lacking B horizons; Goddard and Sabata, 1982) in comparison to upland soil profiles.

Along the Cahokia Creek valley and its major tributaries, a crudely stratified silty clay loam to silty clay (Equality Formation) underlies the Cahokia Formation. Interpreted as Wisconsin Episode lake deposits, the Equality Formation is distinctively soft, has low strength (Qu), and high moisture content (Table 1). Areas suspected to contain Equality sediments in the subsurface are hatchured on the map, and are generally separated from clayey Cahokia Formation by a thin basal layer of sand or gravel. Equality Formation deposits are interpreted as slackwater lake deposits that formed when high levels of glacial meltwater and sedimentation in the Mississippi River valley caused sediment-laden waters to back up into the Cahokia Creek valley. The top elevation of the Equality Formation in this valley never exceeds about 480 feet asl (see cross section A-A'). This unit can be traced in the subsurface downvalley along Cahokia Creek to western Madison County where terraces also occur at about the 480-foot elevation, similar to many terraces adjacent to the Mississippi River valley in the St. Louis vicinity (Grimley, 2002). In contrast, the Equality Formation does not occur in the subsurface along Silver Creek valley (in the Worden Quadrangle) because this valley is part of the Kaskaskia River watershed which also experienced backflooding during the last glaciation, but to a lower elevation (~ 425 feet maximum).

In the Cahokia Creek and Silver Creek valleys, sand and gravel occurs in the subsurface below both the Cahokia and/or Equality Formations (see cross sections). These coarse-grained deposits that overlie the Glasford and/or Banner Formations are interpreted as outwash or ice-marginal sorted sediment related to Illinois Episode glaciation and are correlated to the Pearl Formation (Willman and Frye, 1970). In Madison County, it appears that Pearl sand and gravel is most common along southwest trending valleys (i.e., the Cahokia and Silver Creek valleys) that may have served as proglacial or subglacial meltwater outlets for Illinois Episode glacial ice.

In a few areas within or proximal to the Cahokia or Silver Creek valleys, mappable sand and gravel deposits (Pearl Formation) are found near-surface, covered by about 2 to 5 feet of loess. Such deposits occur on terraces or crops out on slopes between about 500 and 530 feet elevation (10 to 60 feet higher than the Pearl Formations in subsurface valleys). The Pearl Formation in these mapped areas may contain the Sangamon Geosol in its upper portions and, in places, may have some iron or clay cementation around sand and gravel particles. The source of this outwash was likely meltwater from Illinois Episode glacial ice. However, it is not clear if terrace sand and gravel is connective with or was deposited simultaneously with lower elevation sand and gravel in valleys. The high-level Pearl Formation is also most common along southwest trending river valleys.

Concealed deposits (pre-Illinois Episode)
In most areas of the quadrangle, pre-Illinois episode deposits (classified as the Banner Formation) are preserved below the Glasford Formation and above bedrock (see cross sections). The Banner Formation is divisible informally into two units: a silty clay loam diamicton with sand and gravel bodies (Omphghent member; predominant unit) and a greenish-gray, weakly laminated silty clay with some beds of fine sand (Canteen member; lower unit). Both members of the Banner Formation have infilled preglacial bedrock valleys (fig. 2), thereby significantly altering the preexisting landscapes and drainage systems. In only one instance was a pre-Illinois episode unit (Omphghent member) observed in outcrop in the Worden Quadrangle (site 9f; 28-6N-7W), but its occurrence is too limited to map as a surficial unit.

The Omphghent member is interpreted as mainly till, ice marginal sediment, and outwash. In comparison to Glasford till, the Omphghent till is generally more clayey, less sandy, and is not as stiff. The Omphghent till also typically has less illite (in clay mineral fraction), less carbonate, a higher moisture content, and higher natural gamma radiation than Glasford till (Table 1). In some areas, particularly in bedrock valleys, a buried interglacial soil (the Yarmouth Geosol) is preserved in the upper Omphghent member. At the type section for the Omphghent member, a few miles west of this quadrangle (McKay, 1979), a truncated Yarmouth paleosol occurs at the Glasford-Banner contact. Soil development features, including soil structure, horizonation, root pores, clay accumulation, and carbonate leaching can greatly aid separation of the Glasford and Banner Formations. Although the upper Yarmouth soil solum is commonly truncated or eroded by stream or glacial processes, deeper oxidation and fracturing in the upper Banner Formation is sometimes preserved, reminiscent of former interglacial weathering. In the absence of soil development features, various physical properties and compositional data (Table 1) can aid with correlations to sites containing the Yarmouth paleosol. In lower, unweathered portions, the Omphghent till contains abundant shale and fossil spruce wood fragments and has a dark greenish gray color, similar to the local shale bedrock. Overall, physical characteristics of the Omphghent till clearly reflect incorporation of significant amounts of shale and clayey bedrock residuum into pre-Illinois episode glacial ice, a logical interpretation as this was the first ice of the Quaternary Period to cross this area.

Included within the Omphghent member of the Banner Formation is up to 40 feet of moderately sorted, calcareous, fine to medium sand with gravel. This sand and gravel tends to occur at the base of the Omphghent member and is likely proglacial outwash. Its occurrence is most notable on the western side of the ancestral Silver Creek valley. With glacial ice advancing from the east or northeast, a meltwater channel may have developed marginally to the glacier on the west side of the ancient valley.

The Canteen member of the Banner Formation occurs below the Omphghent member in the deepest portions of preglacial valleys (fig. 2, cross sections), generally below 450 feet asl in the ancestral Silver Creek valley and below 420 feet asl in the ancestral Cahokia Creek valley (preglacial valleys loosely follow the present-day valleys but are shifted slightly eastward). The upper elevation of these deposits deepens southward along the valleys' gradients. The Canteen member does not crop out and occurs immediately above bedrock. This unit is interpreted as preglacial Quaternary alluvium and lake sediment because it lacks erratic pebbles and is noncalcareous. Some of this unit might represent slackwater lake deposits related to early Quaternary glaciations in the upper Mississippi drainage basin. It is mainly fine-grained sediment, but includes sandy zones and facies, particularly immediately above the bedrock. It may also include thin basal colluvium rich in angular, local shale fragments or some bedrock residuum. Natural gamma logs hint at slightly higher counts for the Canteen member compared to the Omphghent member. The uppermost 5 feet of the Canteen member sometimes exhibits a greater degree of soil structure development, probably representing a buried soil that formed in a lowland or floodplain prior to deposition of the calcareous Omphghent till.

Near-surface bedrock in the quadrangle consists predominantly of Pennsylvanian shale, siltstone, sandstone, coal, and limestone. The predominant bedrock lithologies below Quaternary deposits in cross sections are shale and siltstone. About 20 % of the quadrangle has been undermined for coal, but no active coal mines exist today.
Economic Resources
Sand and gravel
Economically minable sand and gravel in the Worden Quadrangle was not observed. Any potential sources of usable sand and gravel would be minor and likely limited to the Pearl Formation or extensive sand and gravel bodies within till units (e.g., the Glasford Formation) that are near-surface. However, most sand and gravel units in the quadrangle are limited in thickness, unpredictable in their dimensions, or deeply buried.

Economic Resources

Groundwater
Groundwater is extensively used for household, public, and industrial water supplies. Sand and gravel in the Pearl, Glasford, and Banner Formations comprises the most significant Quaternary aquifers (see stippled areas of cross sections). In upland areas, sand and gravel bodies within the upper Glasford Formation are commonly utilized for low yield household water supply. Sand and gravel may also occur at the contact between the Glasford and Banner Formations. Some sand and gravel bodies in the Pearl Formation or Banner Formation are or were once utilized locally for municipal water supply for towns such as Livingston, Worden, Alhambra, and Hamel. The thickest Banner sand occurs in deep bedrock valleys (fig. 2; cross section B-B'), and more specifically it appears to be most prevalent on the western side of the ancestral Silver Creek valley (based on current data).

Environmental Hazards

Groundwater contamination
Surface contaminants pose a potential threat to groundwater supplies in near-surface aquifers that are not overlain by a confining (clayey, unfractured) unit. Shallow sand and gravel aquifers exposed at the surface are most vulnerable to agricultural or industrial contaminants. Confining units, such as clayey till units or lake deposits, can serve to protect aquifers. A summary of factors used to determine the potential for contamination in shallow aquifers in Illinois is provided by Berg (2001).

The potential for groundwater contamination depends on the thickness and character of alluvium, loess, or till deposits covering the aquifer. Groundwater from deep aquifers at the base of the Glasford Formation or within the Banner Formation generally have a lower contamination potential than more shallow aquifers because of protection by the entire thickness of the very stiff and dense Glasford till. Field studies of hydraulic conductivity at a nearby waster disposal site at Wilsonville (fig.1; Herzog and Morse, 1990) have shown that the lower portion of Glasford Formation (more dense, uniform, and unfractured) can be much less permeable than the upper portion (more fractured and with more sand lenses). The buried Pearl Formation aquifer in Cahokia Creek valley is somewhat protected by the generally fine-grained Cahokia and Equality Formations.

Subsidence
Approximately 20 % of the quadrangle's area was undermined for extraction of coal between 1877 and 1964 (Chenoweth and Borino, 2001). Mined-out areas are predominantly in the northeastern portion of the quadrangle near the towns of Livingston and Williamson, and also near the town of Worden. Coal was mined from the Herrin (No. 6) Coal Member of the Carbondale Formation and was extracted by the room and pillar method at depths of about 250 to 325 feet below ground surface. Land subsidence in mined-out areas can be a serious potential problem for developers and construction projects (Treworgy and Hindman, 1991).

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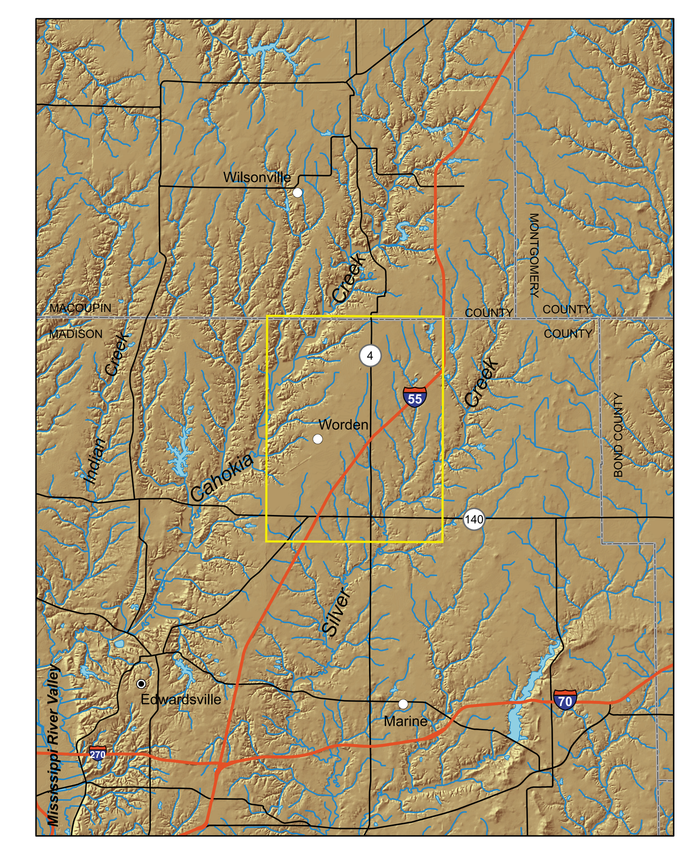

Figure 1 On this shaded relief map of eastern Madison County and nearby areas, the Worden Quadrangle is outlined in yellow.

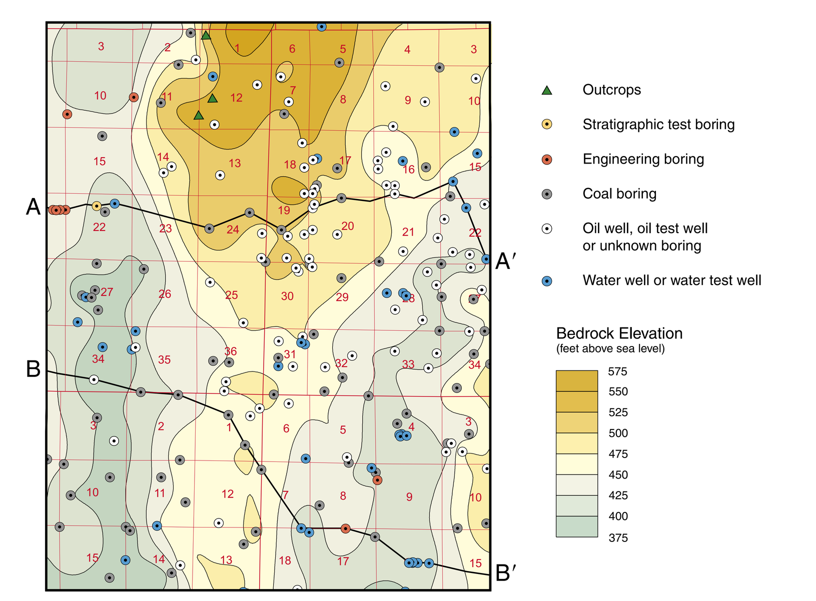

Figure 2 Bedrock topography of the Worden Quadrangle. Section boundaries are shown in red and cross section lines are shown in black.

Table 1 Physical and chemical properties of selected map units (typical ranges listed)

UNIT	w (%)	Qu (tsf)	N	sand	silt	clay	clay mineralogy	natural gamma	MS
Cahokia Fm.	19 - 29	< 0.25 - 1.25	0 - 9	variable texture			n.d.	variable	n.d.
Equality Fm.	23 - 33	< 0.25 - 1.0	0 - 7	typically silty clay loam			high expandables	high	n.d.
Peoria and Roxana Silts	19 - 26	0.75 - 1.75	5 - 10	0-5	65-85	15-30	high expandables	mod.	5 - 70
Pearl Fm.	14 - 21	< 0.25 - 0.50	4 - 30	n.d.	n.d.	n.d.	n.d.	low	n.d.
Glasford Fm. *	9 - 20	2.0 - 8.0	10 - 40	30 - 42	37 - 44	19 - 30	60 - 65 % illite	mod.-high	20 - 70
Omphghent m. *	16 - 29	0.75 - 4.0	7 - 25	21 - 30	41 - 53	24 - 30	50 - 57 % illite	high	20 - 40
Canteen m.	n.d.	1.5 - 4.5	n.d.	n.d.	n.d.	n.d.	high expandables	mod. to high	10 - 20
shale bedrock	10 - 20	3.5 to > 4.5	> 50	n.d.	n.d.	n.d.	n.d.	very high	10 - 20

Engineering Properties: based on hundreds of data measurements from 30 to 40 geographically dispersed engineering borings
w = % moisture content = mass of water / mass of solids (dry)
Qu = unconfined compressive strength
N = blows per foot (Standard Penetration Test)

Grain Size and Mineralogy: based on a more limited dataset (< 20 samples) from stratigraphic borings and outcrops
sand = % > 63 µm; silt = % 4 - 63 µm; clay = % < 4 µm (proportions in the < 2 mm fraction)
clay mineralogy = proportions of expandables, illite, and kaolinite/chlorite (in < 4 µm clay mineral fraction); these calculations using Scintag diffractometer calculations indicate about ¼ more illite than previous results by H.D. Glass with General Electric X-ray diffractometer

Geophysical Data: based on high resolution data from stratigraphic borings (includes ~ 25 coal borings with gamma logs)
natural gamma = relative intensity of natural gamma radiation
MS = magnetic susceptibility (x 10^{-5} SI units)

n.d. = no data available
* properties for Glasford Fm. and Omphghent m. are mainly for calcareous till (excludes sand and gravel lenses and strongly weathered zones)