INTRODUCTION

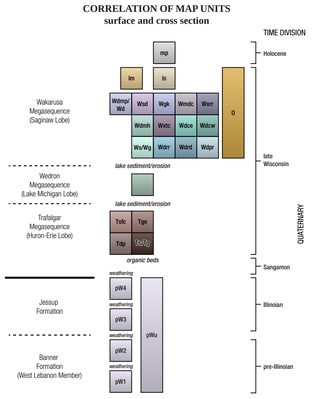
The Nappanee West quadrangle is contained within the southern part of the region formerly occupied by the core of Saginaw Lobe ice in northern Indiana. This map was made using a variety of surface observations and subsurface data. Surface observations were made using field observations, aerial photography, and LiDAR data. Several exposures are present in the map area, primarily in large highwalls of gravel pits, and the predominantly rural character of the landscape preserves numerous key morphological features in sharp detail. Subsurface data include six down-hole geophysical logs with accompanying sample sets collected during the construction of water wells and hundreds of water well records available from the Indiana online water well database (IDNR, 2012).

For this map, a basin-scale sequence-based approach was used to characterize and name map units, in which the entire sedimentary sequence and its morphological elements are the basis for local map units, while the collection of sequences associated with a given ice lobe across its entire extent constitute a "megasequence". A four-part string of characters is used to label map units based on source lobe, depositional system, surface morphology, and other features. Subsurface units in the cross section are labeled with a two- or three-part string.

MAP REFERENCES

Indiana Department of Natural Resources Division of Water (IDNR), 2012, Online water well record database: http://www.in.gov/dnr/water/3595.htm, Division of Water Web Site, date accessed, August 2012.

CORRELATION OF MAP UNITS
surface and cross section



OVERVIEW OF THE MAP AREA

The map area is underlain by unconsolidated deposits of Pleistocene and Holocene age that range from 150 to at least 400 ft thick. The bulk of the Quaternary section is pre-Wisconsin age; late Wisconsin deposits make up the upper 30 to about 125 ft of the section. Landforms and near-surface sequences in the map area record complex interactions and onlap-underlap relations between the Saginaw, Huron-Erie, and Lake Michigan Lobes during the Woodfordian Phase of the late Wisconsin glaciation. The overall map pattern reflects the somewhat asynchronous behavior of ice margins as all three lobes competed for space in north-central Indiana. Within the map area, deposits of only the Saginaw and Huron-Erie Lobes are present at the surface, while Lake Michigan Lobe deposits occur in the subsurface.

The map area is a broad, mostly contiguous, southwest-sloping upland of moderate relief, wherein predominantly clay-rich Saginaw Lobe diamictons cap a relatively thin late Wisconsin sequence that appears to be draped over a pre-Wisconsin surface. The regional southwesterly slope is punctuated by a series of low to moderate relief, mostly WNW- to ESE-trending ridges (fig. 1; Nappanee Ridges), several of which appear to mark stillstands of the Saginaw Lobe margin at various positions, while others probably represent the accentuation of uplands by negative relief of adjacent meltwater-deepened trenches. Two of the largest ridges lie at a sharply discordant angle to the regional landscape grain; however, they trend NE-SW and NNW-SSE, respectively, forming a prominent, several-mile-wide reentrant centered about the Town of Nappanee. Just west of the map area, younger Lake Michigan Lobe deposits truncate and overlie the Saginaw Lobe deposits.

The Trafalgar megasequence (23,000 –15,000 radiocarbon years before present) includes both the oldest and the youngest late Wisconsin glacial sequences in the map area. The earliest Huron-Erie Lobe deposits underlie the Bourbon upland just south of the map area and extend beneath most or all of the map area in the subsurface, where they directly overlie the pre-Wisconsin surface. In the map area the Bourbon sequence is distinctly older than any Saginaw Lobe deposits where it physically underlies them. Other parts of the Trafalgar megasequence are all about the same age or distinctly younger than the Saginaw Lobe deposits. The Trafalgar diamictons (unit **Td**) are typically gray, carbonate-rich loams with a large amount of black shale sand derived from the Antrim Shale (Devonian) and clasts dominated by dark gray to tan Paleozoic limestone and chert from Lake Ontario, to the east of the map area.

The Wakarusa megasequence (22,000–17,500 radiocarbon years before present) encompasses all of the Saginaw Lobe deposits in the map area. These deposits are at the surface over the core of the map area and over a broader area that extends northeast through much of northern Elkhart and southwestern Lagrange Counties. In the map area, Wakarusa sediments cap the surface throughout all of the Nappanee Ridges terrain. These deposits are oldest in the south, where the region truncates the Bourbon upland and become progressively younger to the northeast, where they are about the same age or slightly older than the adjacent Huron-Erie Lobe outwash fans. The Wakarusa diamictons (unit **Wd**) are characteristically brown clay loams with a moderate carbonate content. They are readily recognized by the large amount of Michigan Basin bedrock lithologies, notably green-gray shale and iron concretions of the Coldwater Shale (Mississipian) and light-colored quartzose sandstones of the Marshall Formation (Mississipian) from Saginaw Bay, north of the map area.

Lake Michigan Lobe deposits do not crop out within the map area, though they are present at the surface over a wide area immediately to the west. In the western part of the map area, however, greenish-gray diamicton thought to be of Lake Michigan Lobe or northwestern source occurs in the subsurface in several boreholes. The diamicton overlies gray "Bourbon" diamicton of the Huron-Erie Lobe (from which it is distinguished with some difficulty) and underlies the brown, clayey Wakarusa diamicton.

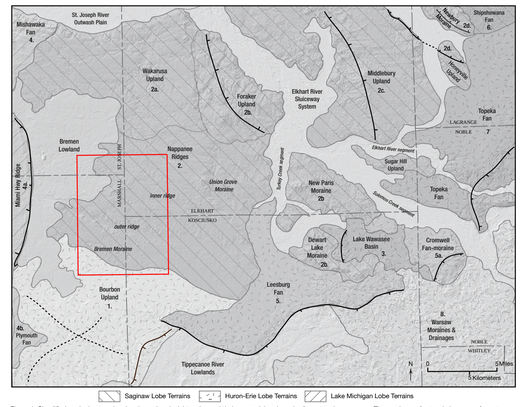


Figure 1. Simplified geologic map showing the major glacial terrains and their source lobes in and adjacent to the map area. The numbers refer to relative ages of events that produced the terrains, with 1 being the earliest. The hachured lines represent significant ice margin positions of the late Wisconsin lobes. The Elkhart River Sluiceway System, Tippecanoe River Lowland, and Bremen Lowland are polygenetic sluiceways and lake basins whose ages and origins may span most or all of the time. The Nappanee West 7.5-minute quadrangle is outlined in red.

DESCRIPTION OF SURFACE MAP UNITS

Late Glacial and Holocene Surficial Sediments

mp Muck, sedge peat, sphagnum peat, and marl. Organic sediments occur in large, saturated upland depressions; low-gradient channels entrenched by meltwater and commonly hosting local drainage divides; and backswamps in abandoned channels in outwash plains. Thickness ranges widely, from less than 3 ft in backswamps in sluiceway systems to tens of feet in large, wet depressions and deeply entrenched meltwater channels. The mineral composition of the muck at any given place generally reflects the dominant textural attributes of the sediment that surrounds and underlies the deposit.

Late Wisconsin Surficial Sediments (undifferentiated by lobe or sequence)

lm/ Wdpr Muddy deposits of interlobate glacial lakes. Silt, clay, and some fine-grained sand. Widespread in and adjacent to the Bremen Lowland (fig. 1) at elevations of 825 ft or less in the northwestern part of the map area, where one or more shallow lakes were impounded, initially against the receding Saginaw Lobe ice margin and later against the Lake Michigan Lobe to the west, and lake mud was deposited over an irregular surface on Wakarusa diamictons (**Wdpr**). This unit is characterized by nearly flat lake-bottom topography punctuated by small hills and ridges of clayey Wakarusa diamicton that became impounded by Huron-Erie Lobe outwash fans, meltwater, and/or ice. Exists in a lateral facies relationship with unit **lm**, with much of unit **ls** potentially representing a distal deltaic facies of the Leesburg outwash fan (fig. 1). Occurs at elevations of 820 to 830 ft.

ls Sandy deposits of interlobate glacial lakes. Fine- to medium-grained sand, with minor silt and clay. Maximum known thickness is about 10 to 12 ft. Occurs in the southern part of the map area in deeply entrenched Saginaw Lobe channels and adjacent lowlands that became impounded by Huron-Erie Lobe outwash fans, meltwater, and/or ice. Exists in a lateral facies relationship with unit **lm**, with much of unit **ls** potentially representing a distal deltaic facies of the Leesburg outwash fan (fig. 1). Occurs at elevations of 820 to 830 ft.

0 Undifferentiated outwash. Sand and gravel, chiefly in the form of channel fills, terraces, and sheetlike bodies found in or near entrenched meltwater channels, around the margins of large kettle lakes, and as irregular upland deposits. Observed thickness typically less than 25 ft, but may appear much greater at places where surface outwash is superposed on older sand and gravel bodies.

Trafalgar Megasequence (Huron-Erie Lobe): Diamicton Units

Tdp Loam-textured diamicton with a thin veneer of silt or sandy loam at places. Occupies a low-lying, gently rolling plain at the toe of the Bourbon upland. The underlying diamicton occurs in uniform sections 30 to 60 ft thick, and is interpreted to be basal till. It typically overlies a sheet of sand and gravel that, in turn, lies on the pre-Wisconsin surface. Some areas are scoured or "washed" by meltwater, creating quasi-streamlined erosional channels with a thin veneer of outwash sand and gravel, organic sediment, and lake mud.

Trafalgar Megasequence (Huron-Erie Lobe): Outwash Fans and Ice-Contact Stratified Drift

Tsfc Collapsed outwash fan composed chiefly of coarse, locally pebbly sand. The front and sides of this fan terminate abruptly and irregularly in short scarps. The surface is irregular. This unit is mapped near the toe of the Bourbon Upland in the southwestern corner of the map area. This small area is part of much larger outwash fan systems south of the map area. The fan appears to have been deposited on and against stagnant ice that subsequently melted, causing the fan to collapse. The thickness of sand underlying this collapsed surface is typically 15 to 30 ft, but can change abruptly. The outwash (20 to 30 ft thick) overlies loamy Huron-Erie Lobe diamicton (unit **Td** in cross section).

Tge Esker. Winding, north- to northwest-trending ridge of gravel and sand protruding through the surface of the outwash fan (unit **Tsfc**) in the extreme southwest corner of the map area. The irregular summit of the ridge stands between 10 and 30 ft above the fan surface. The esker extends for at least another mile south into the Bourbon quadrangle. Sparse data indicate that the gravel may be about 50 ft thick, which means the esker extends well below the surface of the surrounding outwash fan. The esker is inferred to be partly buried by, and thus older than, the fan (unit **Tsfc**).

Wakarusa Megasequence (Saginaw Lobe): Diamicton-Based Map Units

Wdcw Meltwater-washed channels floored by clayey diamicton, and locally capped by small bodies of outwash, lake mud, and organic sediment. This unit occurs in the Nappanee Ridges region (fig. 1), where it forms shallow and typically narrow channels that parallel the fronts of several diamicton-cored ridges. Each ridge-channel pair probably represents a minor end moraine or other short-lived stillstand of the ice margin, with the channels originating as ice-marginal channels that were occupied briefly by meltwater. The sequence beneath the channel floors is generally similar to that elsewhere in the Nappanee ridges—a stack of diamictons with tabular bodies of granular sediment occurring at places along stratigraphic boundaries. The surface-capping Wakarusa diamicton is eroded in the channels and, thus, somewhat thinner than in adjacent uplands. Collapsed outwash fan lobes are composed chiefly of coarse, locally pebbly sand.

Wdce Entrenched channels that cut through the regional diamicton sequence of the Nappanee Ridges. This unit makes up the steep walls of two prominent WNW- to ESE-trending channels that separate three parallel ridges in the region near the city of Nappanee. The depth of incision is 40 to 50 ft and locally more. As a result, the channel walls cut completely through the Wakarusa diamictons into underlying Huron-Erie Lobe till of the Bourbon sequence. Thin, greenish-gray diamicton of the Wedron Megasequence (Lake Michigan Lobe) may also be present in the walls of the far western part of the southernmost channel, in German Township (Marshall County). The channels do not appear to penetrate the pre-Wisconsin surface. Small- to medium-sized outwash terraces commonly hang on the channel walls, and a much larger set of terraces floors the western end of the southernmost channel. Elsewhere, the channel walls terminate against terraces of lacustrine sediment (**lm**, **ls**) or in thick organic deposits (**mp**). The channel walls are somewhat dissected and locally exhibit a collapsed appearance, indicating that they are probably veneered with debris flows.

Wdmh High-relief hummocky end moraines cored by thick clayey diamicton interbedded with sporadic lenses of sand and gravel. This unit makes up the Bremen Moraine (fig 1). The Bremen Moraine stands 50 to 60 ft above adjacent lowlands at its highest point. It is broad and features strong hummocky topography just outboard of its summit area, where this unit is mapped. The clayey Wakarusa diamicton that cores the moraine is 25 to 50 ft thick. This unit includes tabular to irregular bodies of gravel and sand at various horizons. A widespread sheet of sand and gravel as much as 25 ft thick persists in the subsurface just below the summit of the moraine, and appears to be a proglacial outwash apron that was overridden as the Saginaw Lobe margin advanced onto the moraine. The surface material of this unit consists chiefly of supraglacial diamicton and some lake sediment. Compact basal till appears to be more abundant at depth.

Wdpr Rolling plains of diamicton. Together with units **Wdrd** and **Wdrr**, this unit composes the typical landscape of the Nappanee Ridges region and accounts for a large proportion of the gently southwest-sloping upland surface. The landscape contains low, rolling hills and ablation hummocks and long, straight slopes having grades less than 5 percent. Scattered shallow depressions occur throughout but are never abundant. The sequence below this unit is typified by a very thick stack of late Wisconsin and pre-Wisconsin diamictons, capped by 20 to 30 ft of clayey Saginaw Lobe supraglacial sediment and basal till. Thin units of sand and gravel occur sporadically along stratigraphic boundaries, the two most common being at the base of the Wakarusa diamictons and along and just below the pre-Wisconsin surface. Local relief does not exceed 10 ft except for an isolated group of ridges in the center of the unit that stand 15 to 20 ft above the surrounding plain. Individual ridges are seldom more than a half-mile long, but multiple ridges are commonly aligned along vague arcuate to linear belts and may be paralleled by shallow drainages that may or may not be connected to other channels. The local relief of the ridges corresponds to a thickening of the clayey Wakarusa diamicton.

Wdrd Dissected, diamicton-cored ridge. This unit makes up the front of the "outer" Nappanee ridge south of the town of Nappanee, lying along the northern flank of the deeply entrenched channel that separates this ridge from the Bremen Moraine further south. It occupies the same geomorphic position as unit **Wdce** but is not as steep and has a better integrated and more intricate network of longer ravines, whose fingers extend well into the adjacent summit area of the ridge. The underlying geology consists of the same thick diamicton sequence found elsewhere in the Nappanee Ridges region and, like unit **Wdce**, the slope cuts across that sequence, bringing older units close to the surface at lower elevations. The unit has a more varied assemblage of near-surface sediments than the adjacent ridge crest, however, including a considerable number of small outwash bodies along drainages and on mid-slope terraces. The dissection of this landscape likely occurred shortly after it was deglaciated, when ice stood near the summit of the ridge and meltwater was directed downslope into the adjacent trench.

Wdrr Broad, low, rolling diamicton-cored ridges. In some places, the relief of the ridges corresponds to a thickening of the Wakarusa diamicton that cores them, but in others the ridges appear to be situated over highs on the pre-Wisconsin surface, which is seldom more than 50 ft below the surface in this region and locally within 30 ft. Some, and perhaps all, of these ridges originated as minor end moraines. Small patches and sheetlike bodies of sand and gravel occur in and adjacent to south-trending high-level drainages leading into unit **Wdrd**.

Wakarusa Megasequence (Saginaw Lobe): Outwash Fans, Deltas, Ice-Contact Stratified Drift, and Related Meltwater-Deposited Units

Wsd Broad, undulating ridge composed of sand and some silt. This NE- to SW-trending ridge is about a mile wide and several miles long. It is composed almost entirely of silty sand and fine- to medium-grained sand up to 60 to 70 ft thick. Some pebbly sand is reported in well records in the highest parts of the ridge. The ridge stands 10 to 25 ft above the terrain to the east, but as much as 50 to 60 ft above the low-lying lake plain to the west. The ridge is closely associated with units **Wmdc** and **Wmdp** and constitutes the head of a fan-delta system marking the active western margin of the Saginaw Lobe as it stood along the edge of a proglacial lake in the Bremen Lowland (fig. 1). A much smaller, somewhat lobate body of sand, interpreted to be a small delta, in the southern part of the quadrangle is also assigned to this unit.

Wmdc Collapsed, hummocky upland with a planar summit, underlain by lacustrine mud and fine-grained sand. The unit lies immediately outside of unit **Wsd**; the upland surfaces of the two are contiguous, defining a smooth, gently WNW-sloping delta topset. Unit **Wmdc** was deposited over one or more blocks of stagnant ice; it occupies a reentrant in the Bremen Lowland, bounded on the north by a rolling diamicton-cored upland and on the east by the sandy ridge of unit **Wsd**. Small, uncollapsed areas within the unit define a near perfectly smooth top surface that dips gently and regularly west-northwest at about 15 ft per mile. The lake sediment that makes up the unit appears to be as much as 25 to 30 ft thick and somewhat sandier at the eastern end, becoming progressively thinner and more muddy lakeward. Clayey diamicton of the Saginaw Lobe underlies the lake sediment and may be intercalated with it in strongly collapsed areas. The gradational southern and western boundaries of the unit blend into the more distal parts of the delta and undifferentiated lacustrine sediments of the Bremen Lowland, respectively (units **Wmdp/Wd** and **lm/Wdpr**).

Wmdp/ Wd Low-relief lake plain underlain by lacustrine mud and deltaic outwash deposited over a rolling diamicton surface. This unit is characterized by nearly flat lake-bottom topography punctuated by small hills and ridges of clayey Wakarusa diamicton that extend upward through the lake sediment. Local relief is rarely more than 5 to 10 ft. The surface of this landscape slopes very gently westward at about 5 to 7 ft per mile and thus appears to be a more distal continuation of the westward-sloping delta surface associated with units **Wsd** and **Wmdc**. The lake mud appears to be less than 10 ft thick, being thickest in the broad flats and diminishing to nothing adjacent to diamicton hills. Clayey Wakarusa diamicton (some of which is probably waterlain) forms the immediate substrate and caps a thick stack of older diamictons that includes much pre-Wisconsin sediment. This landscape is similar to and transitional with that of the adjacent lacustrine unit **lm/Wdpr**. The chief distinction is the lower elevation of the latter, which continued to collect meltwater and sediment from the Lake Michigan Lobe well after the Saginaw Lobe withdrew from the basin.

Wgk Conical hill composed chiefly of gravel. Gravel thicknesses greater than 130 ft were observed in some wells high on the hill. Thick diamicton is commonly reported in wells lower on the flanks, and basal till of the Huron-Erie Lobe (presumably the Bourbon sequence) is exposed at the base of the deformed gravel at an elevation of about 875 ft. Beds of coarse gravel exposed in a large gravel pit on the west side of the hill dip away from the summit at angles as great as 40 degrees, indicating deposition against walls of ice. The feature is a classic moulin kame. Features indicate that the kame is situated on a buried topographic high on older units. Several much smaller kames, less than 40 ft tall, occur near the crest of the Bremen Moraine in the southern part of the Nappanee Ridges region.

Wxrr Low, rolling to hummocky ridge composed of sand, Wakarusa diamicton, and some lacustrine mud. Local relief is 25 to 30 ft thick. This east- to west-trending feature lies between the rim of a deep channel (**Wdce**) to the south, a prominent ridge of sand to the northeast (**Wsd**), and a shallow drainage along the fringe of the Bremen Lowland/lake plain to the north (fig. 1). Its morphology and position relative to surrounding features suggest that it was deposited in or on stagnant ice and could be an extension of the delta system mapped to its north and east (units **Wsd**, **Wmdc**, and **Wmdp**).

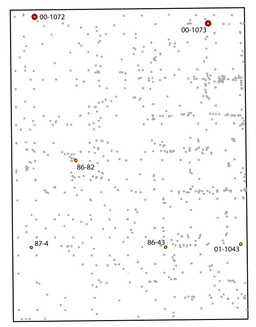
Wwtc Narrow, deep (10 to 20 ft) tunnel valley with strongly collapsed and chaotic topography. The tunnel valley cuts completely through the host Wakarusa sediments into older sequences below. The composition of the walls and floor is varied and unpredictable. The walls consist of a chaotic jumble of collapsed diamicton with numerous patches and terraces of sand and gravel. The floor of some segments appear to be cut into older diamictons having a veneer of sand and gravel, while other segments are underlain by deep, narrow bodies of gravel, but much of the floor detail is obscured beneath bodies of organic sediment and irregular masses of collapsed wall sediment.

Latest direction of meltwater flow.

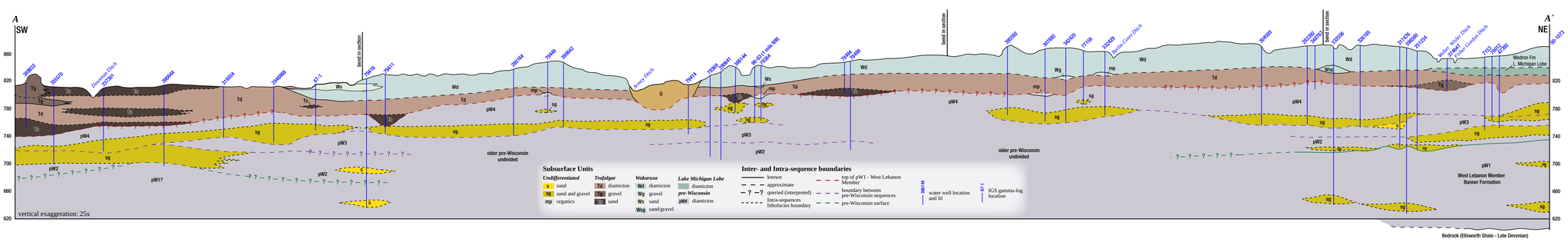
Relic drainageway across uplands.

Approximate contact.

Diamicton hummock protruding through lake basin.



Map showing the Nappanee West 7.5-minute quadrangle and the distribution of data points in the map area.



ACKNOWLEDGMENTS

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Basemap features from the U.S. Geological Survey (USGS) topographic quadrangle maps, scale 1:24,000 with updates from 2011 aerial photography.

Marshall County road features from Indiana Department of Transportation Roads data (2005). Road features for all other counties from Indiana Department of Homeland Security Street Centerlines data (2012)(maps.indiana.edu).

Hydrographic features from USGS National Hydrography Dataset High Resolution data (2008) (maps.indiana.edu) modified using 2011 aerial photography and LiDAR data.

Contours and shading based on Indiana LiDAR data from 2011 compiled by M. R. Johnson.

Projection: Universal Transverse Mercator (UTM), Zone 16N.

Horizontal Datum: North American Datum of 1983 (NAD83).

Digital cartography by Matthew R. Johnson and Laura A. Montgrain

Quarternary Geology of the Nappanee West 7.5-Minute Quadrangle, Indiana

By

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