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THE RELATIONSHIP BETWEEN GLACIAL GEOLOGIC PROCESSES AND PEATLAND DISTRIBUTION IN INDIANA

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ABSTRACT. Peat-filled depressions are not randomly distributed in Indiana. The higher frequency of kettles and peatlands in northern Indiana is attributed to the dynamic processes of glacial retreat rather than potential influences of pre-glacial topography. Ninety percent of Indiana's peatlands occur in the northern moraine and lake region of the state. Within this region, peatlands were significantly more frequent inside the former boundaries of the Saginaw Lobe than peatlands occurring outside of this area. An analysis of peatland distribution and specific glacial drift types in Noble County showed that peatlands were significantly more frequent in mixed till and stratified drift in lineated form associated with collapse of sub-ice tunnels and open ice-walled channels. Four other drift types contained significantly fewer peatlands than expected.

Keywords: Bog, fen, glacial geology, Indiana, kettle, lake, peatland, wetland

Although peat deposits occur in many places around the world, the northern latitudes of the former Soviet republics, Canada, and the United States have the largest coverage (Lucas 1982). The abundance of peatlands in these northern regions is the result of poor drainage, limited water circulation, and cool, humid climates on a local or regional scale. Where the regional climate is characterized by cool humid summers, long winters, and abundant even rainfall, peatlands may form relatively unbroken expanses that blanket flat or gently rolling topography. But in areas with less favorable climates, such as the Midwest interior of the United States, the distribution of peatlands is usually dictated by microclimates provided by isolated geographic features.

While recognizing the importance of regional climate in peatland initiation, Taylor (1907) states that the glacial topographic features of Wisconsinan Age are a greater factor than climate in the geographic position of the peat deposits of the Midwest. Because peatlands in lower Michigan, Indiana, and other midwestern states are restricted to these isolated glacigenic depressions, their distribution can be attributed to specific glacial and fluvioglacial processes. Most investigators associate the formation of these peat-filled depressions with the melting of isolated blocks of buried glacial ice. Some have hypothesized that the formation of ice-block depressions was favored by pre-glacial valleys that slowed the melting of ice and became receptacles for outwash from surrounding uplands, thus increasing the chances for ice to become buried (Flint 1971). Andreas (1985) proposed that pre-glacial valleys may have facilitated the formation of kettles in Ohio and consequently determined the distribution of the associated peatlands. The objectives of the present study are to determine the present and historic distribution of Indiana peatlands and investigate the potential influence of specific glacial events and pre-glacial topography on peatland distribution in Indiana.

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STUDY AREA

The study area includes the part of Indiana covered with glacial drift of Wisconsinan age—approximately the northern two-thirds of the State. Evidence for drifts from at least two previous glaciations in Indiana, the "Kansan" (often a collective term for pre-Illinoian drifts) and Illinoian, has been reported (Melhorn 1997). Most of these, with the exception of portions of the Illinoian drift in southern Indiana, have been covered or obliterated by Wisconsinan drifts. The drifts in northern Indiana range from 15–150 m thick (Wayne 1956). The thickest deposits (averaging 90 m thick) occur throughout the interlobate area of the former Saginaw and Erie Lobes in northeast Indiana. The drift becomes shallower to the west and south, where it averages 45 m thick. The bedrock underlying this unconsolidated material is composed chiefly of shale—relatively friable sedimentary deposits of Devonian and Mississippian Age (Howe 1997). The lime-rich glacial drift imparts a strongly alkaline reaction on the groundwater and, consequently, that of the lakes and wetlands of the region.

METHODS

Data sources.—Determination of the current and pre-settlement distribution of peatlands in Indiana was obtained from three sources: 1) a list of 68 peatlands registered with the Indiana Natural Heritage Database of the Indiana Department of Natural Resources, Division of Nature Preserves (IDNR-DNP), 2) an inventory of commercial peat deposits (potential and active) in Indiana compiled by Schneider & Moore (1978), and 3) soil surveys of the United States Department of Agriculture (USDA) for all 92 Indiana counties. Each data source was treated separately in the statistical analyses due to the potential differences in the types of peatlands represented in terms of soil classification and vegetation composition and structure.

Mapping.—Peatland distribution was compared to maps of pre-glacial river valleys (Gutschick 1966), late-Wisconsinan glacial coverage (Wayne 1966), and the distribution of Quaternary geologic units (Gray 1989) by digital overlay of the maps. The aerial coverage of the various geologic units used in the statistical analyses was determined cartographically.

Statistical analyses.—Chi-square Goodness of Fit tests comparing peatland frequency and distribution to landscape physiography were conducted by constructing "1 × 2" Chi-square tables (df = 1). Expected values were based on a null hypothesis that peatlands would be equally distributed across all physiographic units. After the area of each respective physiographic unit (e.g., Saginaw Lobe, buried river valleys, Quaternary diamicton) was determined, its percent coverage was calculated. The expected frequency for peatlands in each unit was determined by multiplying the percent aerial coverage of each unit by the total number of peatlands in the respective analysis.

The portion of Indiana covered by Wisconsinan glacial deposits was analyzed to determine the relationship between peatland distribution and buried river valleys. Thirty-five percent of that area is underlain by known buried river valleys [based on the map by Gutschick (1966)]. Since it must be assumed that some inaccuracies occur in the mapped locations of pre-glacial river valleys, comparison of the underlying valleys with existing peatlands was based on relative "association." Peatlands which were within, or in contact with, the border of a buried river valley were considered associated.

Another analysis of peatland frequency was restricted to the Northern Moraine and Lake Region (Mallott 1922) to study the influence of the Saginaw Lobe. The expected distribution of peatlands for the Chi-square test was based on the estimated aerial coverage of the former Saginaw Lobe which was determined to be 36% of the Northern Moraine and Lake Region.

A spatial analysis of the most characteristic peatland soil, Houghton Muck, was conducted for Noble County, Indiana by combining information from the 53 soil maps for the county and comparing the distribution of peatlands and other wetlands to Quaternary geologic units (Gray 1989). A digital map overlay and subsequent Chi-square analysis was then conducted.

RESULTS AND DISCUSSION

Peatland frequency & distribution in Indiana.—Sixty-two peatlands (90%) registered in the IDNR-DNP Natural Heritage Database (Fig. 1, Table 1) occurred in the Northern Moraine and Lake Region of Indiana. No peatlands occurred south of the Wisconsinan glacial boundary. Schneider & Moore (1978) report 265 commercial quality peat deposits in Indiana. All are restricted to the area north of the Wisconsinan glacial boundary (Fig. 2). Two hundred and forty-one (91%) occur in the Northern Moraine and Lake Region, and 24 (9%) occur within the Tipton Till Plain (Fig. 2). These percentages are similar to those discussed above for registered peatlands.

The concentration of Indiana peatlands, as well as other wetlands and lakes, in the Northern Moraine and Lake Region is not simply a function of the presence of glacial deposits. Glacial deposits cover most of Indiana. Some

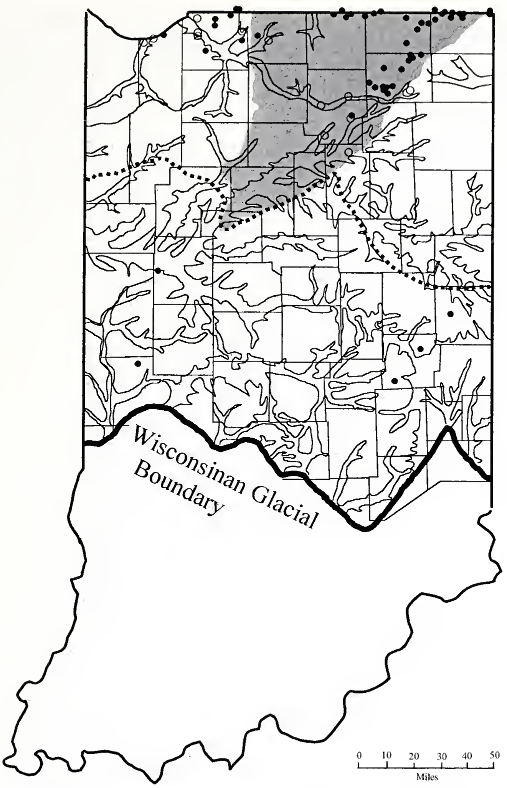

Figure 1.—Map of Indiana showing 1) extent of Wisconsinan glacial deposits (thick, solid line), 2) margin of the Northern Moraine and Lake Region (dotted line), 3) extent of the former Saginaw Lobe circa 15,000 ybp (shaded area), the distribution of buried river valleys as determined by Gutschick (1966), and 4) the distribution of 68 peatlands registered with the Indiana Division of Nature Preserves. A solid dot (●) is a peatland not associated with a known pre-glacial valley, and an open dot (○) is a peatland situated over or extremely close to a known pre-glacial valley.

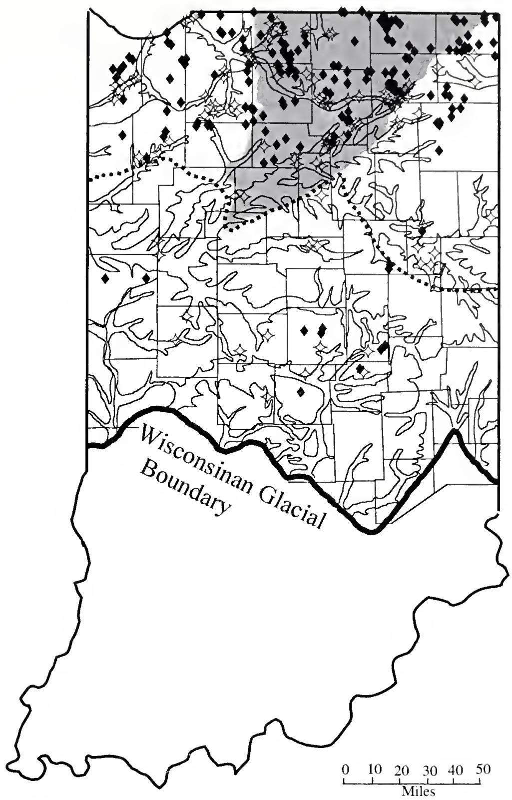

Figure 2.—Map of Indiana showing 1) extent of Wisconsinan glacial deposits (thick, solid line), 2) margin of the Northern Moraine and Lake Region (dotted line), 3) extent of the former Saginaw Lobe circa 15,000 ybp (shaded area), the distribution of buried river valleys as determined by Gutschick (1966), and 4) the distribution of 265 commercial quality peat deposits (from Schneider & Moore (1978)). A solid diamond (♦) is a peat deposit not associated with a known pre-glacial valley, and an open diamond (◊) is a peat deposit situated over or extremely close to a known pre-glacial valley.

other factor or factors must be responsible for the creation of kettles and other depressions favorable to peat formation.

Indiana peatland distribution and buried river valleys.—Andreas (1985) proposed that Ohio peatland distribution is related to pre-glacial (buried) river valleys. Andreas's study is the only known study in our region that is concerned with the relationships between peatland distribution and glacial and pre-glacial landforms. She referenced previous theories that ice masses remained frozen longer in pre-glacial valleys, and that this condition facilitated kettles and other depressions favorable to peatland development.

The distribution of peatlands in Indiana was compared to the location of pre-glacial valleys (Figs. 1, 2). Although the 68 registered peatlands considered in the present study seem to reflect the overall distributional pattern of peat in Indiana (Fig. 1), they probably do not represent an independent sample. The fact that these peatlands are extant and protected may be because some factors hindered their drainage for agriculture and other development. Therefore, these peatlands were treated separately from a potentially more independent

Table 1.—Location and physiography of Indiana peatlands registered in the Indiana Division of Nature Preserves Database. *A* = Alluvium; silt, sand and gravel deposits of and along present streams (includes some colluvium along valley margins); *BD* = Beach and dune sand along present and recently abandoned beaches; *LS* = Lake sand, beach sand, and slack-water sand and silt deposits of broad, shallow post-glacial lakes (Includes much washed ablation drift and many small areas of dune sand); *S* = Dune sand; *O* = Undifferentiated outwash, mainly as valley train; sand and gravel Atherton Formation in part; *OF* = Outwash-fan deposits; sand and gravel; *OP* = Intensely pitted outwash deposits, principally in fan form but including also some kame terrace, sand gravel; *TG* = Mixed drift; till and stratified drift in chaotic form; *TT* = Mixed drift, till and stratified drift in lineated form indicating collapse associated with subice tunnels and open ice-walled channels; *TW* = Clay-loam to silt-loam till of Wedron Formation; *MW* = areas of morainal topography (Wedron Formation); *TC* = Silty clay-loam to clay-loam till of Lagro Formation; *TC/M* = Thin clay-loam till over buried morainal topography; *TB* = Loam till of Trafalgar Formation; *MB* = Areas of morainal topography (Trafalgar Formation). An asterisk denotes peatlands associated with buried river valleys.

Peatland	County	Elevation	Drift type	Peatland type
Blueberry Bog	Elkhart	263.6	OP	Basin, Bog
Umbrella Sedge Bog	Elkhart	228.6	OP	Basin, Bog
Bristol Fen	Elkhart	235.6	S	Basin/Riparian, Fen
Elkhart Bog	Elkhart	235.6	O	Basin, Bog
Leatherleaf Shrub-Carr	Elkhart	237.7	S	Basin, Bog
Disko High Bogs	Fulton	268.2	TG	Basin, Fen
New Castle Fen	Henry	310.8	O	Riparian, Fen
Knightstown Fen	Henry	301.7	O	Riparian, Fen
Kiser Lake Fen*	Kosciusko	266.6	OP	Basin, Fen
Backwaters Fen	Kosciusko	259.9	OP	Basin, Fen
Stafford Lake Site	Kosciusko	264.8	TG	Basin, Bog
Little Arethusa Bog*	Kosciusko	264.2	TG	Basin, Bog
Burket Bog*	Kosciusko	249.9	TT	Basin, Bog
Chapman Lake Wetlands*	Kosciusko	252.3	O	Basin, Bog
Springfield Fen Site	La Porte	210.3	O	Basin, Fen
Trail Creek Fen*	La Porte	185.9	O	Riparian, Fen
Mt. Pleasant Bog	La Porte	244.7	MW	Basin, Bog
Autumn Bog	La Porte	265.1	MW	Basin, Bog
Pinhook Bog*	La Porte	249.9	TG	Basin, Bog
Lost Bog*	La Porte	252.9	TG	Basin, Bog
Thompson Bog	La Porte	231.9	MW	Basin, Bog
Fish Creek Fen	La Porte	211.8	OF	Riparian, Fen
Yellow Birch Wetland	La Porte	222.5	MW	Basin, Fen
Shoemaker Bog	La Porte	233.1	OF	Basin, Bog
Mill Creek Fen*	La Porte	220.9	OF	Basin, Fen
Olin Lake Site	Lagrange	274.3	TG	Basin, Fen
Cline Lake Fen	Lagrange	280.4	TB	Basin, Fen
Shipshewana Fen	Lagrange	249.9	S	Riparian, Fen
Fawn River Fen	Lagrange	262.1	S	Riparian, Fen
Yost Pond	Lagrange	252.9	OP	Basin, Bog
Tamarack Bog Site	Lagrange	277.3	O	Riparian, Fen
Martin Fen	Lagrange	280.4	O	Riparian, Fen
Lane Lake Fen	Lagrange	268.2	O	Basin, Fen
Mounds Fen*	Madison	256	O	Riparian, Fen
Long Swamp Woods	Noble	275.8	TT	Basin, Bog
Leatherleaf Bog	Noble	285.3	TC	Basin, Bog
Indian Village Bog	Noble	274.3	OF	Basin, Bog
Christlieb Bog*	Noble	286.5	TC/M	Basin, Bog
Bush Cinquefoil Site	Noble	285.0	TC/M	Basin, Fen
Dutch Street Bog	Noble	289.6	O	Basin, Bog
Cletus Stump Bog	Noble	271.3	OP	Basin, Bog
Hickory Bog	Noble	289.6	TC	Basin, Bog

Table 1.—Continued.

Peatland	County	Elevation	Drift type	Peatland type
Svoboda Fen	Noble	289.6	TB	Basin, Fen
Tamarack Bog	Noble	274.3	TC	Basin, Bog
Eagle Lake Wetlands	Noble	267.0	O	Basin, Fen
Sylvan Lake Site	Noble	279.2	O	Basin, Fen
Wolf Lake Site	Noble	274.3	TT	Basin, Fen
Clock Creek Site	Noble	270.1	O	Riparian, Fen
Turkey Run Site	Parke	155.5	A	Riparian, Fen
Portage Fen*	Porter	185.9	BD	Riparian, Fen
Cowles Bog	Porter	182.9	BD	Basin/Riparian, Fen
Garyton Wetland*	Porter	189.0	LS	Basin, Fen
Cabin Creek Raised Bog	Randolph	320.0	TB	Riparian, Fen
Kankakee Fen Site	St. Joseph	218.8	O	Basin, Fen
New-Oak-Road Bog*	St. Joseph	251.5	TW	Basin, Fen
Ropchan Memorial Bog	Steuben	292.6	TG	Basin, Bog
Handy Lake Site	Steuben	316.7	TC/M	Basin, Fen
Seven Sisters Site	Steuben	298.7	TG	Basin, Bog
Nevada Mills Bog	Steuben	298.7	TB	Basin, Fen
Beaverdam Lake	Steuben	284.4	OP	Basin, Fen
Beechwood Site	Steuben	317.0	O	Basin, Fen
Tamarack Lake Site	Steuben	289.3	TG	Riparian, Fen
Steuben County Notable #37A	Steuben	294.1	TG	Basin, Bog
Marsh Lake Wetlands	Steuben	294.7	TG	Basin, Fen
Binkley Fen	Steuben	295.7	MB	Basin, Fen
Lime Lake Site	Steuben	286.5	OP	Basin, Fen
Big Swamp	Steuben	317.0	O	Basin, Fen
Flint Creek Fen	Tippecanoe	161.5	O	Riparian, Fen
Laketon Bog*	Wabash	225.6	O	Basin/Riparian, Fen

source provided by Schneider & Moore (1978) for commercial peat. A Chi-square Goodness of Fit Test of the relationship between buried valleys and registered peatland distribution in Wisconsinan deposits indicated that registered peatlands are not significantly more frequent over buried valleys (Table 2). Similarly, analysis of Schneider & Moore's (1978) commercial peat data shows that these deposits are not significantly more frequent over buried river valleys within the Wisconsinan glaciated region of Indiana (Table 3).

If pre-glacial valleys facilitated the formation of post-glacial depressions, then it would be expected that central Indiana, being underlain by the most distinct and numerous pre-glacial valleys, would harbor as many peatlands as other areas of the state; but it does not. The peatlands that are disjunct—those occurring near the southernmost boundary of the Wisconsinan glaciation—were probably formed in the depressions in the more uneven topography resulting from development of relatively significant moraines. The latter is un-

Table 2.—Chi-square table showing that the frequency of peatlands registered with the Indiana Division of Nature Preserves, is not significantly greater over river valleys buried by Wisconsin-age deposits ($df = 1$; $\alpha = 0.001$).

Location in Wisconsin-age deposits	Observed (f)	Expected (f_e)	$f - f_e$	$(f - f_e)^2$	$(f - f_e)^2/f_e$
Buried river valleys	14	23.8	−9.8	96.04	4.04
Other areas	54	44.2	9.8	96.04	2.17
Total	68	68	0		6.21

Table 3.—Chi-square table showing that the frequency of commercial quality peat deposits (Schneider & Moore 1978), is not significantly greater over river valleys buried by Wisconsin-age deposits (df = 1; α = 0.001).

Location in Wisconsin-age deposits	Observed (f)	Expected (f_c)	$f - f_c$	$(f - f_c)^2$	$(f - f_c)^2/f_c$
Buried river valleys	105	92.75	12.25	150.06	1.62
Other areas	160	172.25	−12.25	150.06	0.87
Total	265	265	0		2.49

common in central Indiana; and hence, peatlands are uncommon there.

For pre-glacial depressions to influence post-glacial features, they would have to endure three glacial advances: the Kansan (pre-Illinoian), Illinoian, and the Wisconsinan. The ability of relatively minor pre-glacial depressions to affect post-Wisconsinan topography, in Indiana at least, is questionable. These pre-glacial valleys would have long ago been filled with glacial debris. Groundwater flow in these thick glacial deposits might result in subsidence caused by dissolution of some till constituents, which could create depressions suitable for peatland formation. This, however, is probably insignificant and does not explain the scarcity of peatlands and other wetlands in central Indiana where buried river valleys abound.

Regional glacial processes.—Indiana peatland distribution, indicative of kettles and other glacial depressions, seems more related to glacial processes. Inspection of Gutschick's (1966), Wayne's (1966), and Gray's (1989) maps, with comparison to Indiana peatland distribution, seems to illustrate a greater relationship with specific glacial features and processes than pre-glacial topography.

The association of peat, peatlands, and their kettle, kame, and esker complexes to the Saginaw Lobe of the Laurentide Ice Sheet (approximately 15,000 ybp) is pronounced. Within the Northern Moraine and Lake Region, commercial quality peatlands [as determined by Schneider & Moore (1978)] were significantly more frequent within the former boundaries of the Saginaw Lobe (Fig. 2, Table 4), than peatlands occurring outside of this area. Peatlands registered with the Indiana Division of Nature Preserves were also significantly more frequent within the Saginaw Lobe region (Fig. 1, Table 5).

Although several histosols are referred to as peat, the most characteristic peatland soil is Houghton Muck. Houghton Muck is generally restricted to the northern third of the state and constitutes 149,009 acres (62,087 ha) for the State (see Swinehart 1997). Counties with the greatest coverage of Houghton Muck are in northeast and north-central Indiana. These counties are all found within the region formerly occupied by the Saginaw Lobe (Figs. 1, 2) and comprise 41.3% of the total coverage of Houghton Muck in Indiana. This is further evidence of the role of the Saginaw Lobe in

Table 4.—Chi-square table showing that the frequency of commercial quality peat deposits (Schneider & Moore 1978), is significantly greater within the area formerly occupied by the Saginaw Lobe, than other areas within the Northern Moraine and Lake Region in Indiana (df = 1; α = 0.001).

Location in northern moraine and lake region of Indiana	Observed (f)	Expected (f_c)	$f - f_c$	$(f - f_c)^2$	$(f - f_c)^2/f_c$
Saginaw Lobe	130	83.52	46.48	2160.39	25.87
Other Lobes	102	148.48	−46.48	2160.39	14.55
Total	232	232	0		40.42

Table 5.—Chi-square table showing that the frequency of peatlands registered with the Indiana Department of Natural Resources, Division of Nature Preserves, is significantly greater within the area formerly occupied by the Saginaw Lobe, than other areas within the Northern Moraine and Lake Region in Indiana ($df = 1$; $\alpha = 0.001$).

Location in northern moraine and lake region of Indiana	Observed (f)	Expected (f_e)	$f - f_e$	$(f - f_e)^2$	$(f - f_e)^2/f_e$
Saginaw Lobe	46	22.32	23.68	560.74	25.12
Other Lobes	16	39.68	−23.68	560.74	14.13
Total	62	62	0		39.25

creating depressions suitable for peat formation.

The importance of the Saginaw Lobe to kettle and peatland formation is due to its unique manner of deterioration. Unlike the adjacent Erie and Michigan Lobes which receded actively (ablation simply exceeded accumulation), the Saginaw Lobe was apparently cut off by outwash channels on all sides (Wayne 1966). This resulted in stagnation and downmelting (Bleuer 1974). The importance of these processes in the Saginaw Lobe region is supported by the presence of mixed stratified drift in chaotic form and the lack of uniform ground and end moraines (Gray 1989). As the Saginaw Lobe deteriorated, it likely became highly fragmented, and large blocks of ice were separated from the main mass of ice. Superglacial sediment, which accumulates on the marginal zone of a glacier during down-melting (Clayton & Moran 1974), probably buried isolated blocks of ice. The presence of the Lake Michigan and Erie Lobes on either side of the Saginaw Lobe created large outwash channels for the flow of meltwater, further contributing to the burial of isolated ice-blocks. This burial insulates the ice and facilitates kettle formation. The abundance of classic kettle depressions around the periphery of the former Saginaw Lobe is evidence of these interlobate processes.

Local glacial processes and Quaternary geologic units.—Registered peatland distribution was compared to post-glacial topography. Sixty-eight percent of the peatlands are associated with interlobate moraines, primarily the Packerton and Valparaiso, the former harboring the greater percentage. The remaining peatlands in the Northern Moraine and Lake Region are otherwise distributed about the margins of the former Saginaw Lobe. Six registered peatlands occur within the southern portions of the Tipton Till Plain.

Comparing registered peatland distribution to specific glacial landforms as determined by Gray (1989) showed 44% (30) occurring in outwash deposits, 23% (16) occurring in till, 21% (14) occurring in mixed drift (till and outwash), and 12% (8) occurring in sand, lacustrine, or alluvial deposits (Table 1). Peatland elevations ranged from 155.5–320.0 m with a mean of 262.4 m (SD = 35.7). The elevation of Indiana peatlands seems to be relatively consistent within the 215–275 m levels. No significant associations were noted between peatland distribution and regional elevation.

To gain further insight into the factors contributing to peatland formation, a more detailed spatial analysis was conducted on the wetlands of Noble County. Noble County was chosen because it intersects the interlobate area in northeast Indiana, contains the greatest percent coverage of peat of any Indiana county, and represents a great diversity of glacial drift-types. Classification of the kettles was based on the contents of the basins: those occupied by Houghton Muck (peatlands), those occupied by emergent vegetation and/or humified histosols, and those containing open water (lakes). The spatial analysis was based on occurrence only, and not size, of the respective wetlands. Peatlands, other wetlands, and lakes were found throughout the county except for the extreme northwest corner (Fig. 3).

The observed frequency and distribution of peatlands in the various drift-types across the

Table 6.—Glacial drift types and associated peatlands, other wetlands, and lakes in Noble County, Indiana. Drift type follows Gray (1989): *TC/M* = Thin clay-loam till over buried morainal topography; *O* = Undifferentiated outwash, mainly as valley train; sand and gravel Atherton Formation in part.; *MB* = Areas of morainal topography; *TB* = Loam till of Trafalgar Formation; *TC* = Silty clay-loam to clay-loam till of Lagro Formation; *TT* = Mixed drift; till and stratified drift in lineated form indicating collapse associated with subice tunnels and open ice-walled channels; *OP* = Intensely pitted outwash deposits, principally in fan form but including also some kame terrace. Sand gravel; *TG* = Mixed drift; till and stratified drift in chaotic form; *OF* = Outwash-fan deposits; sand and gravel; *G* = Ice-contact stratified drift, sand and gravel as isolated ridges; *MC* = Areas of morainal topography of Lagro Formation; *LS* = Lake sand, beach sand, and slack-water sand and silt deposits of broad, shallow post-glacial lakes. Includes much washed ablation drift and many small areas of dune sand; *TS* = Loam to silty clay loam till. A "+" indicates that the lake or wetland is significantly more frequent than expected probability, and a "−" indicates that the lake or wetland is significantly less frequent than expected probability (df = 1; α = 0.05).

Drift type*	% area	Area (ha)	Observed (f) peatland	Expected (f_c) peatland	χ^2 Value peatland	Observed (f) wetland	Expected (f_c) wetland	χ^2 Value wetland	Observed (f) lakes	Expected (f_c) lakes	χ^2 Value lakes
TC/M	35	36833.36	303	296.22	0.24	56 (−)	90.18	19.83	40	42.66	0.20
O	14	14895.36	135	119.79	2.25	62 (+)	36.47	20.79	19	17.25	0.21
MB	13	13637.96	85 (−)	109.68	6.37	22 (−)	33.39	4.46	15	15.80	0.05
TB	10	10234.51	57 (−)	82.31	8.61	11 (−)	25.06	8.73	2 (−)	11.85	9.06
TC	7	7647.17	66	61.50	0.59	21	18.72	0.30	6	8.86	0.99
TT	7	6939.88	107 (+)	55.81	50.23	34 (+)	16.99	18.21	25 (+)	8.04	38.29
OP	6	6021.01	38	48.42	2.37	29 (+)	14.74	14.62	12	6.97	3.84
TG	5	4908.70	50	39.48	2.95	19 (+)	12.02	4.26	1 (−)	5.69	4.05
OF	3	2732.43	3 (−)	21.97	16.81	3	6.69	2.09	2	3.16	0.44
G	2	1946.55	6 (−)	15.65	6.06	3	4.77	0.66	1	2.25	0.71
MC	<1	229.72	3	1.85	0.72	0	0.56	0.56	0	0.27	0.27
LS	<1	132.99	1	1.07	0.00	0	0.33	0.33	0	0.15	0.15
TS	<1	30.23	0	0.24	0.24	0	0.07	0.07	0	0.04	0.04
Total	100	106189	854	854		260	260		123	123	

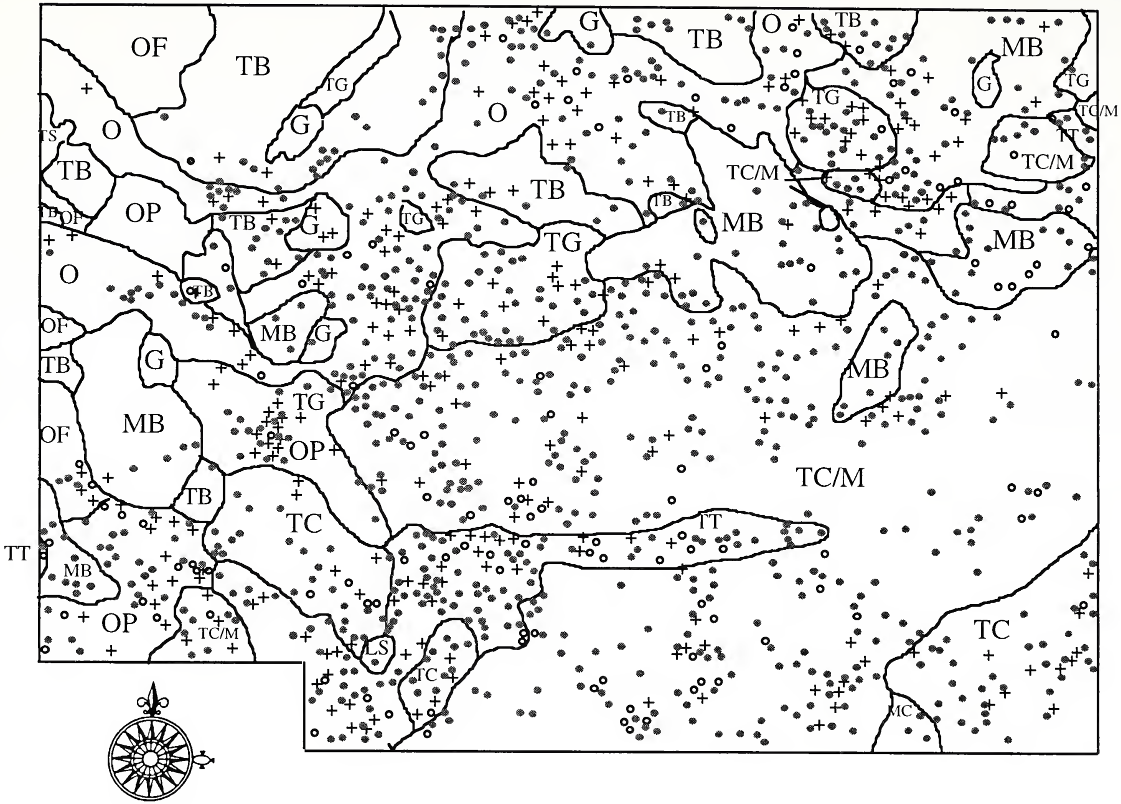

Figure 3.—Map of Noble County, Indiana, showing the location of peat deposits (●), marshes and humified histosols (○), and lakes (+) in relation to glacial drift types. *TC/M* = thin clay-loam till over buried morainal topography; *O* = undifferentiated outwash, mainly as valley train; sand and gravel of Atherton Formation in part; *MB* = areas of morainal topography; *TB* = loam till of Trafalgar Formation; *TC* = silty clay-loam to clay-loam till of Lagro Formation; *TT* = mixed drift; till and stratified drift in lineated form indicating collapse associated with subice tunnels and open ice-walled channels; *OP* = intensely pitted outwash deposits, principally in fan form but including also some kame terrace; sand and gravel; *TG* = mixed drift; till and stratified drift in chaotic form; *OF* = outwash fan deposits; sand and gravel; *G* = ice-contact stratified drift, sand and gravel as isolated ridges; *MC* = areas of morainal topography of Lagro Formation; *LS* = lake sand, beach sand, and slack-water sand and silt deposits of broad, shallow post glacial lakes; includes much washed ablation drift and many small areas of dune sand; *TS* = loam to silty clay-loam till. (Drift types after Gray (1989).

county was similar to expected values, with the exception of *MB* (areas of morainal topography of Trafalgar Formation), *TB* (loam till of Trafalgar Formation), *OF* (outwash fan deposits; sand and gravel), *G* (ice-contact stratified drift, sand and gravel as isolated ridges), and *TT* (mixed till and stratified drift in lineated form associated with collapse of sub-ice tunnels and open ice-walled channels) (Fig. 3, Table 6). *MB*, *TB*, *OF*, and *G* contained significantly fewer peatlands than expected, while *TT* contained significantly more peatlands than expected (Table 6). The dearth of peatlands in some drift-types might be explained by considering the local glacial and fluvio-glacial processes. Both *MB* and *TB* are tills of the Trafalgar formation, mostly resulting from moraines. While ice-blocks can occur in moraines, it seems less likely due to the active manner in which they are created. However, some aspect of the moraines of Lagro Formation, perhaps their high clay content, location over slightly older Wisconsinan tills, and proximity to the interlobe, favored the formation of more numerous peat-filled depressions than moraines of Trafalgar origin.

Reduced frequency of peatlands in *G* is probably due to the relatively high elevation of the ridges and the porous nature of the drift (mainly sand and gravel). The scarcity of peatlands in *OF* is curious, because sediment laden meltwater would likely facilitate the formation of water-filled depressions. The reduced number of peatlands in this drift-type may be primarily a function of proximity to the glacier margins rather than local processes, although, few of the registered peatlands across the state were associated with *OF* (Table 1).

Nearly twice as many peatlands and wetlands, and more than three times as many lakes, occurred in *TT* than random distribution would yield. These statistics suggest that processes associated with ice deterioration and stagnation strongly facilitate the formation of kettles and other depressions. *TT* results from collapse of a large ice tunnel within older drift overlain by till of the Lagro Formation (Gray 1989). The lakes in Chain o' Lakes State Park are an excellent example of the result of this kind of formation process.

The distribution and frequency of peatlands differs substantially from other wetlands. While both peatlands and wetlands were significantly more frequent in *TT*, wetlands additionally were unusually abundant in *O* (undifferentiated outwash, mainly as valley train; sand and gravel), *OP* (intensely pitted outwash), and *TG* (mixed till and stratified drift in chaotic form). All of these areas are likely to be characterized by relatively low elevations, highly permeable materials, and good drainage. Areas such as *TC/M* (thin clay-loam till over buried morainal topography), *MB*, and *TC*, where wetlands were few, contain finer constituents, are less permeable, and probably more conducive to peat rather than muck formation.

CONCLUSIONS

The factors affecting the formation and distribution of peatlands in the southern Great Lakes region are hierarchical. At the coarsest level, glacial processes, such as the stagnation of entire lobes of ice, facilitated the formation of kettles. The local processes that determined the texture and composition of the drift affected drainage and, consequently, the limnology and ontogeny of resulting lakes and wetlands.

It is concluded that peat-filled depressions are not randomly distributed in Indiana. High kettle and peatland frequency in northern Indiana is attributed to the dynamic processes of glacial retreat in that area. Although it has been speculated that buried valleys are responsible for the creation of environments favorable to peatland formation in Ohio, this study proposes that most peatlands in Indiana, regardless of underlying topography, are a direct result of the downmelting of the Saginaw Lobe of the Laurentide ice-sheet and other aspects of dynamic deterioration of glacial ice. These conclusions suggest that microclimates provided by glacial topography may be a more important factor in the distribution of peatlands in temperate regions than regional climate.

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