Soilscape Analysis of Contrasting Glacial Terrains in Wisconsin

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Abstract. Two Woodfordian glaciated regions in Wisconsin were analyzed to determine the impact of variable loess thickness and contrasting till texture on soil pattern and landscape properties. Each region consisted of a ground moraine/end moraine/outwash plain landform sequence. Data were compiled from soil and topographic maps. In addition to using standard methods of soilscape analysis, I used a natural soil drainage index, calculated from taxonomic data, to determine regional variability and pattern of soil wetness. Results indicate that soilscape variation within each region was large. There were no statistically significant differences, therefore, that could be attributed to known soil-forming processes or to parent material variability. Stratifying the data by geomorphic subregion rather than by region reduced the within-unit soil variability and resulted in numerous significant soilscape differences between subregions. The implication is that soilscape variability is large at the regional scale but converges rapidly with decreasing size of study area.

Key Words: soil landscape, soil wetness, soil taxonomy, drainage index, Wisconsin.

THE past several decades have witnessed the inception and advance of soilscape analysis (Hole 1978), largely through the increased availability and use of Soil Conservation Service (SCS) published soil maps and the increased availability of 1:24,000 topographic maps. Both are important planning and inventory sources for farmers, resource managers, and environmentalists. Recently, Francis Hole and his colleagues have used SCS maps in landscape study, focusing on delineation of soil landscape regions and analysis of soil pattern as it varies across the landscape. Hole and Campbell (1985) refer to this science as soil landscape (soilscape) analysis. Such research provides an important link between the disciplines of pedology and geomorphology.

Studies of the soil landscape strive to improve understanding of landscape-soil-human interactions. These analyses assume that the soil mapper has accurately conveyed the pedogenic pattern to the SCS map, which is usually the primary data source. Hole (1953, 1978) is perhaps best credited with the development of the science and its vocabulary in the United States. A Russian school of soilscape study was initiated by Fridland and colleagues (Fridland 1965, 1972, 1974). Recent applications of soilscape analysis are exemplified in Pavlik and Hole (1977) and Haberman and Hole (1980). Related research may be found in Nichols (1975), Campbell (1979), and Gersmehl and Napton (1982). Although there is a large body of literature that focuses on soil variability within defined "units" (e.g., Troedsson and Tamm 1969; Beckett and Webster 1971; Alban 1974; Nortcliff 1978; Campbell 1979), the approach used here stresses soil pattern variability across the landscape within which homogeneous units might be delineated. Pattern becomes an independent variable, replacing soil "property."

The purpose of this research is to describe, compare, and contrast soil pattern and landscape characteristics of two glacial landform regions in Wisconsin. The landscapes were selected because the landforms are similar in age and genetic history, yet they differ in the presence or absence of eolian silts (loess) covering the glacial drift. In addition, the texture of the till differs between the regions. This study seeks (1) to ascertain the soil landscape parameters that best characterize and differentiate the geomorphic regions and subregions and (2) to determine the magnitude and degree of spatial variation of soilscape parameters. One hypothesis is that pedologic, hydrologic, and geomorphic parameters will be similar between the two major regions as a result of their similar geo-

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morphic histories. A second hypothesis is that significant differences in these parameters, explained in part by loess thickness and till texture, will be found when comparisons are made between the smaller subregions.

Study Areas

Two study areas, one in southern Adams County (155.4 km^2) and the other centering on the city of Walworth in Walworth County (103.6 km^2) were selected for soil landscape analysis (Fig. 1). Each region is composed of three landform assemblages in a sequence, which I refer to as geomorphic subregions: a ground moraine, an end moraine, and an outwash plain. Glacial deposits in the regions are of Woodfordian age (c. 13,000 B.P.; Mickelson et al. 1973). Both landscapes typify the Wisconsinan drift plains of the upper Midwest. Mean relief/km^2 ranges from 10 to 30 m, depending upon subregion. The Walworth County region has slightly lower local relief than does Adams County, although the difference is not significant. The glacial end moraines are rolling and exhibit the greatest local relief of the three types of subregions.

The main differences between the two regions are (1) the presence or absence of a loess cap and (2) till texture. Adams County soils are developed in sandy drift without substantive

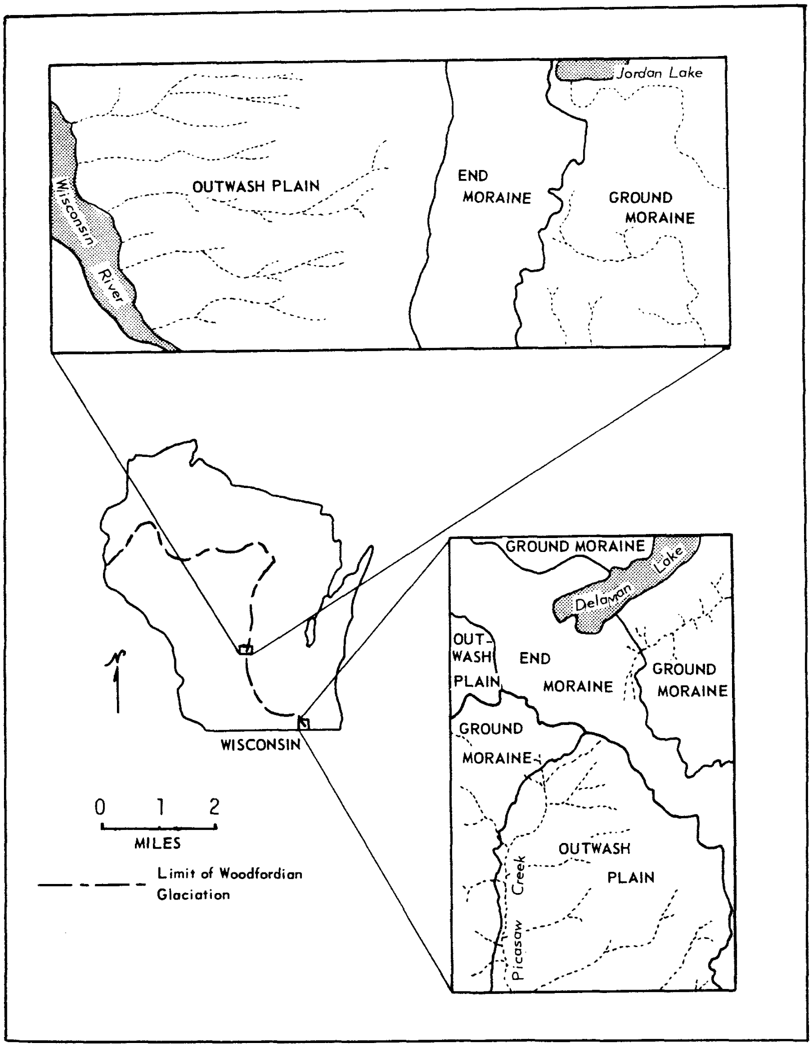


Figure 1. Study area locations. Adams County region is at the top of the figure, Walworth is at the bottom.

additions of loess. In Walworth County, pedogenesis has occurred in 30–150 cm of loess (depending upon slope and erosion) over loamy tills. This study focuses on the effect that these differences, especially in loess thickness, have upon soil type, pattern, and wetness.

Both Adams and Walworth counties have published modern soil surveys (Haszel 1971; Jakel 1980). The mapping scales of the soil surveys are, however, different. Adams County is mapped at 1:20,000 whereas Walworth County is mapped at the larger 1:15,840 scale. Although this dissimilarity may affect soilscape properties of the regions as interpreted from the maps, there are several reasons for using these counties in the present analysis. First, similar geomorphology coupled with contrasting loess thickness and till texture has already been noted and provides interesting independent variables for the analysis. Second, the counties lie essentially within the same major climatic zone, eliminating the need to adjust for soil moisture in different climates. Third, glacial deposits and soils are similar in age and were formed from the same glacial ice lobe (Green Bay Lobe). Finally, these counties meet the predetermined criteria of having (1) well-defined end moraines, i.e., not extensive and complex end morainic systems, (2) broad, unpitted outwash plains, and (3) few drumlinoid features on the ground moraines. These counties present, therefore, perhaps the best sites in Wisconsin for the study of contrasting soilscapes, despite the mapping scale differences. Other counties with equal or better potential were considered for this study but lacked modern soil survey information.

The Adams County region is part of the central sandy uplands and plains of Wisconsin (Hole 1976). In general, upland soils are very sandy. Many low kettles on the ground moraine are sufficiently wet to have accumulated organic soils. Oak (*Quercus* spp.) and pine (*Pinus* spp.) forest vegetation is native to the region, and much of the area remains forested today. Pine plantations are common. Irrigation is necessary for row crops such as potatoes and beans and is prevalent on the flat, sandy outwash plain. Table 1 lists the major soils of the geomorphic subregions. The influence of the sandy drift on many of the soils is reflected by the abundance of Udipsamments and Quartzipsamments, as well as Arenic and Psammentic subgroups of other Great Groups.

Table 1. Major Soils of Geomorphic Regions in the Study Areas

Soils of:	Series	Subgroup
Adams County		
Ground moraine	Coloma	Alfic Udipsamments
	Okee	Arenic Hapludalfs
	Kewaunee	Typic Hapludalfs
	Houghton	Typic Medisaprists
	Poygan	Typic Haplaquolls
End moraine	Wyocena	Typic Hapludalfs
	Coloma	Alfic Udipsamments
Outwash plain	Billett	Mollic Hapludalfs
	Plainfield	Typic Udipsamments
	Richford	Psammentic Hapludalfs
	Boone	Typic Quartzipsamments
Walworth County		
Ground moraine	Miami	Typic Hapludalfs
	McHenry	Typic Hapludalfs
	Dodge	Typic Hapludalfs
	St. Charles	Typic Hapludalfs
End moraine	Miami	Typic Hapludalfs
	Casco	Typic Hapludalfs
	St. Charles	Typic Hapludalfs
	Dodge	Typic Hapludalfs
	Fox	Typic Hapludalfs
Outwash plain	Plano	Typic Argiudolls

Source: Taken in part from Hole (1976), Jakel (1980), and Haszel (1971).

The Walworth County region is dominated by forest soils (Hapludalfs) on sloping end and ground moraines (Table 1). Plano silt loam (Typic Argiudolls) comprises 90 percent of the loess-covered outwash plain, which originally had tallgrass prairie vegetation (Curtis 1959). Most soils in Walworth County are in the fine-silty or fine-loamy textural families (Haszel 1971). Corn, soybean, and forage crop agriculture represents the dominant land usage. Eroded sola are common on the end moraine, known locally as Marengo Ridge.

Although the geomorphology of the two regions is similar, small, notable differences are present. The Walworth outwash plain drains into Piscasaw Creek (Fig. 1) and is very flat, with only slight fluvial dissection at its outer margins. Proximity to the Wisconsin River, on the other hand, has resulted in deep stream incision at the outer margins of the Adams outwash plain. Extremely low local relief is present only in a section of the outwash plain near the end moraine (Fig. 1). Analysis of the ground moraine geomorphology reveals a second interregional contrast. The Adams ground moraine has numerous areas of low-lying glaciolacustrine sediments; these deposits are rare in Walworth County. Other geomorphic differences between the two regions are minimal.

Materials and Methods

Soil Conservation Service map sheets (Haszel 1971; Jakel 1980) were compiled into a mosaic for each study area. Although no soil map is completely accurate and without mapping unit inclusions of dissimilar soil series, I believe that the data accurately represent the pedologic pattern, perhaps at the expense of great detail. Nonetheless, the SCS maps are the best data source currently available for this study. Geomorphic boundaries were delineated using soils, topographic, and geologic data (Hadley 1974; Hadley and Pelham 1976). Sampling points were randomly assigned and stratified by the six geomorphic subregions (minimum of 26, maximum of 51 sampling points per subregion). Points were located both on SCS map sheets and USGS 1:24,000 topographic maps. The following landscape features were recorded for each point (data source is given in parentheses):

(1) Relief (maximum elevation minus minimum elevation) per km^2 using circular quadrats (topographic map).

(2) Area (km^2) of the mapping unit containing point (SCS map) by cut and weigh method. The entire mapping unit was weighed, even if it extended beyond the margins of the quadrat.

(3) Slope of the mapping unit: A, B, C, D, or E slope (SCS map).

(4) Presence of interior vs. exterior drainage (topographic map).

(5) Number of mapping units (whole or part) per km^2 (SCS map).

(6) Number of series per km^2 (SCS map).

(7) Taxonomic contrast across the boundary of the mapping unit in the four cardinal directions (SCS map). Maximum contrast (index value = 9) occurs where soils of different orders abut at the boundary (e.g., Udoll vs. Udalf or Aquoll vs. Ochrept). Suborder contrast (e.g., Udalf vs. Aqualf) is assigned a value of 8, while subgroup contrast (e.g., Aquic Udipsamment vs. Typic Udipsamment) is 6. At the lower end of the scale, soils that differ only in slope receive a value of one (see Fig. 2). It is possible to have a taxonomic contrast of zero where two similarly classified series adjoin (e.g., Briggsville and Kewaunee, which are both fine, mixed, mesic Typic Hapludalfs). A complete discussion of the taxonomic contrast index is found in Hole (1978) and Hole and Campbell (1985, 62).

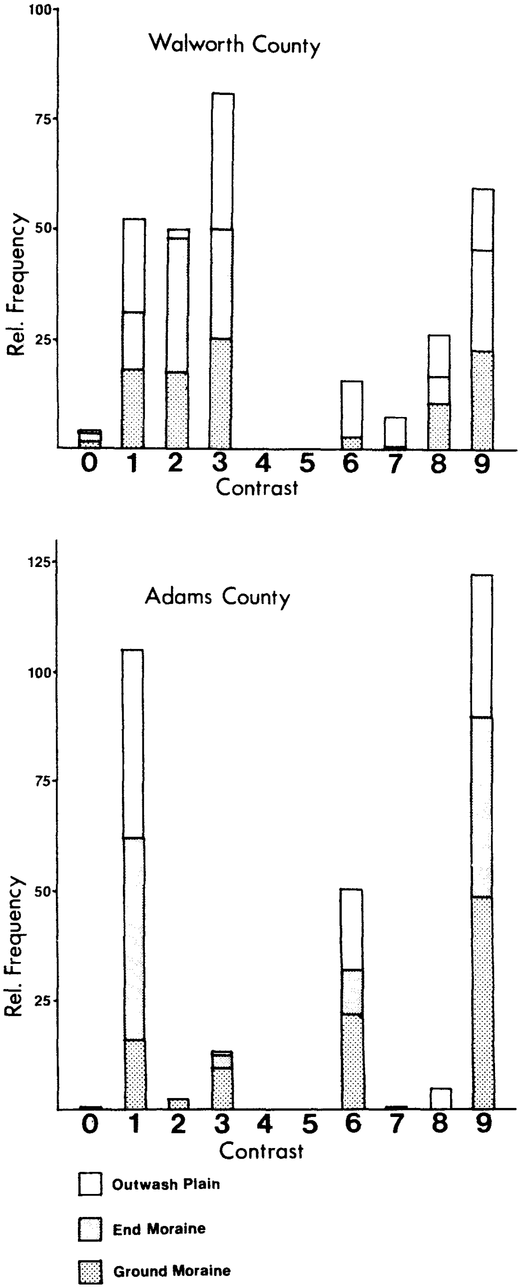


Figure 2. Frequency histograms of boundary contrast. In order to negate the effect of having more sampling points in Adams County, the relative frequency of boundary contrast, by subregion, is used on the vertical axis. Contrast types are: (0) no taxonomic contrast, (1) slope contrast, (2) erosion class contrast, (3) textural family contrast, (4) mineralogy contrast, (5) soil temperature regime contrast, (6) subgroup contrast, (7) Great Group contrast, (8) suborder contrast, and (9) order contrast.

In addition to analyzing soil pattern and geomorphic characteristics, I examined natural soil wetness by soil landscape region. A measure of natural soil wetness, both the lack of moisture and its excess, is important to those involved with agriculture, waste disposal, housing site suitability, habitat quality, and many other issues.

A natural soil wetness index, hereafter referred to as a drainage index (DI), was assigned to each soil mapping unit in the study areas. The natural soil drainage index scheme was modified from Hole (1978) and Hole and Campbell (1985, 65–67). The DI is based on *natural* soil wetness, as determined from taxonomic classification and is not affected by artificial drainage, irrigation, or climatic variation unless these inputs have changed the soil morphologically and taxonomically over long periods of time. Because the DI includes more information than just drainage class, it is a better measure of wetness for some purposes than is the present taxonomic scheme (Table 2).

SCS mapping units were assigned a DI value ranging from zero for a dry rock outcrop to 99 for open water. Calculation of the DI involved first assigning a base value to the soil from its suborder designation and then using other taxonomic data to modify this number (Tables 2 and 3). Poorly drained soils (e.g., Typic Haplaquepts) were initially assigned a base DI of 70; well-drained soils, such as Entic Hapludalfs, received a DI value of 40. Modifications of this base value were derived from Great Group, subgroup, textural family, and slope-class modifiers and either add to or subtract from the base (Table 3). Because the DI was developed for Wisconsin soils, extension of this scheme beyond the state will require revisions. Examples of the DI modification procedure for soils of the study areas are presented in Table 4.

Table 2. Assigned Base Drainage Index Values for Wisconsin Soils

Drainage class	DI	Suborder classification
	99	Open water
Very poorly	90	Saprists, Hemists, Fibrists, Folists
	80	
Poorly	70	Aquods, Aquolls, Aqualfs, Aquents, Aquepts
Somewhat poorly	60	
Moderately well	50	Fluvents
	45	Udolls, Borolls, Albolls[a]
Well	40	Udalfs, Ochrepts, Orthents, Boralfs, Orthods, Humods
	30	
Excessively	20	Psamments
	10	
	0	Rock outcrop

[a] Udolls, Borolls, and Albolls occupy both the well-drained and moderately well drained positions on the landscape. They are therefore assigned an intermediate DI value of 45.

Table 3. Modifiers of Base Drainage Index Values for Wisconsin Soils

Modifier type	DI change from base value
Great Group modifier	
Gloss-	+5
Udi-, Boro-, Hapl-, Ochr-, Medi-	+0
Dystr-, Eutr-, Argi-, Camb-	+0
Quartzi-	−4
Psamm-	−9
Subgroup modifier	
Aquic, Aquollic, Histic, Hydric	+10
Cumulic	+7
Fluventic	+5
Typic, Mollic, Udic, Alfic, Entic	+0
Limnic, Dystric, Eutric	+0
Terric	−3
Arenic	−7
Udollic (for aqu- suborders only)	−8
Psammentic (except Psamments or Psamm- Great Groups)	−9
Aeric, Lithic	−10
Textural family modifiers	
Clayey	+4
Fine-silty, Coarse-silty, Loamy, Fine-loamy	+0
Coarse-loamy (except Arenic soils)	−2
Sandy, Sandy-skeletal (except Arenic subgroups and Psamm- soils)	−4
Combinations (e.g., Fine-silty over Clayey: use (0 + 4)/2 = 2	Average value
Slope class modifiers	
A (0–2 percent)	+0
B (2–6 percent)	−2
C (6–12 percent)	−5
D (12–20 percent)	−10
E (20–30 percent)	−15
F (>30 percent)	−20

Soil DI values were recorded for sampling points at grid locations in the Adams and Walworth study areas. The sampling point density from the grid was 64 per sq. mi. (one point per 4.05 ha^2). This sampling procedure resulted in more than 2300 and 3500 data points in Walworth and Adams Counties, respectively. At each point, the mapping unit type was recorded and assigned a DI value. Using these data, a three-dimensional mesh diagram of soil wetness

Table 4. Demonstration of the DI Scheme for Selected Mapping Units

Mapping unit	Series	Suborder	Base[a] DI	Great[b] Group	Subgroup[b]	Textural[b] family	Slope[b] class	Base DI minus modifiers = final mapping unit DI
BlA	Billett	Udalfs	40	Hapl- (+0)	Mollic (+0)	Coarse loamy (−2)	A (+0)	40 + (0 + 0 − 2 + 0) = 38
PfB	Plainfield	Psamments	20	Udi- (+0)	Typic (+0)	na	B (−2)	20 + (0 + 0 − 2) = 18
EvB	Elkmound	Ochrepts	40	Dystr- (+0)	Lithic (−10)	Loamy (+0)	B (−2)	40 + (0 − 10 + 0 − 2) = 28
RaA	Radford	Udolls	45	Hapl- (+0)	Fluventic (+5)	Coarse-silty (+0)	A (+0)	45 + (0 + 5 + 0 + 0) = 50
Sm	Sebewa	Aquolls	70	Argi- (+0)	Typic (+0)	Fine-loamy over Sandy Skeletal (0−4)/2 = −2	A (+0)	70 + (0 + 0 − 2 + 0) = 68
SpA	Sparta	Udolls	45	Hapl- (+0)	Entic (+0)	Sandy (−4)	A (+0)	45 + (0 + 0 − 4 + 0) = 41

[a] From Table 2.

[b] From Table 3; number in parentheses is DI modifier of base DI value.

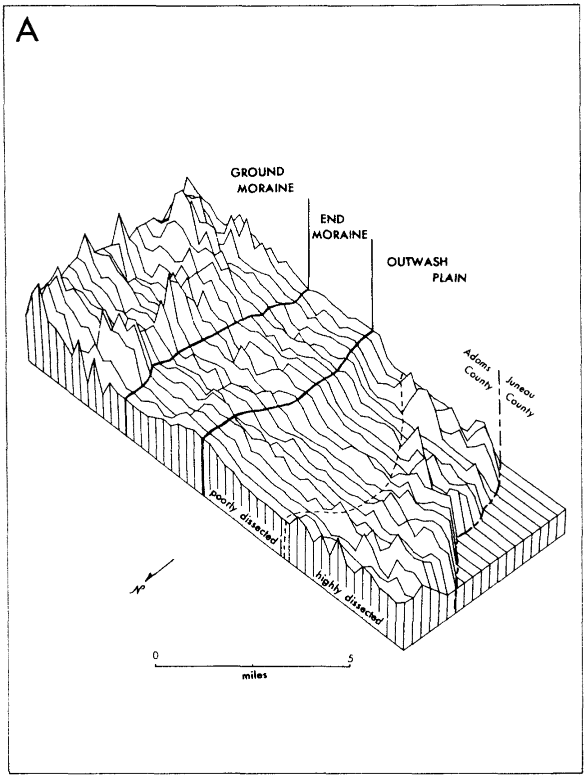
was generated for the two areas. The vertical axis represents DI values and increases upward. Adjacent values (blocks of four) were averaged to avoid excessive detail. Differences in means for the two major regions and six subregions were analyzed.

Results and Discussion

Soil Wetness

In order to visualize the spatial variability of soil wetness across the regions, mesh diagrams of DI values were constructed (Fig. 3). Analysis of the three geomorphic subregions in Adams County reveals marked visual contrast for soil DI values (Fig. 3a). The wettest soils, showing up as high peaks, are most common on the ground moraine. These areas correspond to glaciolacustrine sediments on the till sheet or to low kettles where Saprists have accumulated. DI variability is indicated by the coefficient of variation. Wilding, Schafer, and Jones (1964) and Indorante and Jansen (1981) found the coefficient of variation (CV) to be useful for comparing variability within sampling units. The coefficient of variation in DI is greatest on the ground moraine (Table 5). In general, DI values are lower in the well-drained Wyocena and Coloma soils on the end moraine (Table 1). Outwash plain soils in Adams County can be further subdivided into three groups. Near the end moraine, dissection of the outwash plain is minimal; Billett and Richford soils are prevalent. Their presence is reflected by a low plateau of DI values (35) near the end moraine. Beyond this apron, Psamments are dominant (primarily Plainfield sand). A low, level area of DI values (15) is present in the center of the outwash plain, where these soils are common. Finally, stream dissection at the margin of the outwash plain has resulted in the inclusion of many wet fluventic soils (e.g., Adrian muck, Terric Medisaprists; Algansee loamy sand, Aquic Udipsamments); hence there are many DI peaks present.

In contrast to Adams County, Walworth geomorphic subregions are not as readily discernable from the mesh diagram of DI values (Fig. 3b). The outwash plain is composed almost entirely of Plano soils (0–3 percent), reflected by a broad plateau of DI values near 45. High peaks along the western boundary of the outwash plain are due to soils associated with Piscasaw Creek (Fig. 1), primarily Elburn silt loam (Aquic Argiudolls) and Drummer silty clay loam (Typic Haplaquolls). As in Adams County, the coefficient of variation for DI values is greatest on the ground moraine. High peaks represent Pella (Aquolls) and Houghton (Saprists) soils. Miami (Udalfs), Dodge (Udalfs), and St. Charles (Udalfs) are the dominant upland soils



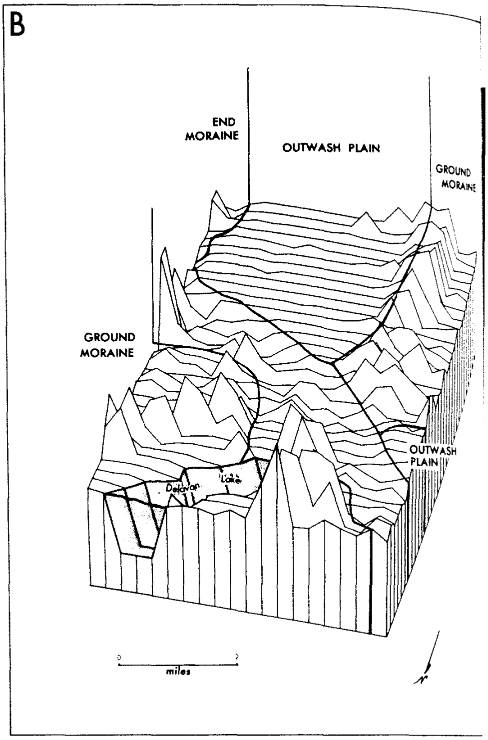


Figure 3a. Mesh diagram of drainage indices (DI values) for Adams County region. High peaks indicate wet soils. Note subdivision of outwash plain into poorly and highly dissected areas.
Figure 3b. Similar diagram for Walworth County.

between wet kettles. In general, DI values are lower on the end moraine than on the outwash plain or ground moraine because steeper slopes reduce the DI (see Table 3).

Statistical comparisons of DI values by region and geomorphic subregion point to the overall heterogeneity of soil wetness throughout the areas, something Hole and Campbell (1985, 65) call "soil moisture regime diversity." A *t*-test for difference in mean DI values between the Adams and Walworth regions was not statistically significant $p = 0.10$. This finding suggests that intraregional variation exceeds between-region differences. In contrasts of soil wetness between pairs of geomorphic subregions in the two counties, internal variation was again dominant. Only two comparisons showed statistically significant differences (Table 6): (1) the Walworth ground moraine was significantly wetter than the Adams ground moraine (DI values were 42.9 and 38.6 respectively) and (2) the Walworth outwash plain was wetter than the Adams outwash plain (47.4 vs. 24.8). The Walworth County end moraine was wetter than that of Adams County (38.8 vs. 25.0), although the comparison was not significant at the 0.10 level. Loamy tills as well as the loess cap are the primary reasons for the wetter soils in Walworth County. Lower local relief in Walworth County (17.2 vs. 24.6 m/km^2; Table 5) may also have contributed to increased overall wetness by reducing runoff. Soils in depressions within Adams County are usually poorly drained but are not extensive enough to be statistically meaningful. Rather, they act only to increase the CV within the subregion.

The presence of a loess cap has resulted in somewhat wetter soils in Walworth County, especially in comparisons at the subregional level. Because of internal variability, however, between-*region* differences were not significant $p = 0.10$. Despite the lack of statistically valid differences, patterns of soil wetness in the two regions are predictable. Stream bottom soils are wet, and kettles are poorly drained, whereas upland soils are well drained. Spatial variation

Table 5. Descriptive Statistics of Regional Soilscape Parameters

Region	Local relief/ sq km (in meters)	Map unit size (in sq km)	Slope[a]	Map units/ sq km	Series/ sq km	DI[b]	Boundary[c] contrast
Adams County							
Adams	26.4[d]	0.7	2.2	20.2	6.7	39.0	6.2
G. Moraine	0.25[e]	1.86	0.5	0.28	0.31	0.48	0.5
	43[f]	42	43	43	43	998	43
Adams	29.7	0.6	3.1	15.8	3.4	25.0	4.9
E. Moraine	0.36	1.00	0.19	0.28	0.47	0.43	0.78
	26	26	26	26	26	647	26
Adams	13.0	1.8	2.1	13.1	4.2	23.7	4.9
O. Plain	0.41	1.56	0.43	0.33	0.48	0.51	0.73
	18	51	51	51	51	1871	51
Adams	24.6	1.2	2.4	16.2	4.9	25.9	5.4
inclusive	0.40	1.75	0.42	0.35	0.49	0.65	0.65
	87	119	120	120	120	3516	120
Walworth County							
Walworth	15.9	0.9	1.7	25.8	6.4	43.0	4.4
G. Moraine	0.24	1.11	0.35	0.41	0.31	0.27	0.73
	34	34	34	34	34	867	34
Walworth	25.5	0.4	2.6	37.1	6.4	38.8	4.0
E. Moraine	0.47	1.5	0.42	0.35	0.36	0.28	0.78
	36	36	36	36	36	590	36
Walworth	10.1	16.8	1.1	10.2	4.6	47.4	4.5
O. Plain	0.63	0.71	0.27	0.78	0.57	0.20	0.64
	36	36	36	36	36	927	36
Walworth	17.2	6.2	1.8	24.3	5.8	43.7	4.3
inclusive	0.60	1.68	0.55	0.63	0.43	0.25	0.72
	106	106	106	106	106	2384	106

[a] 1 = A slope; 2 = B slope, etc.

[b] Compiled from grid sampling technique.

[c] See text for explanation.

[d] Mean.

[e] Coefficient of variation ($\sigma/\overline{x}$).

[f] Sample size.

in natural soil wetness within regions is the overwhelming influence on soil-geomorphic comparisons and subsumes interregional contrasts.

The lack of significant differences in soil wetness between Adams and Walworth counties may be due to lack of sensitivity in the DI scheme. The index does not take into account variability in the moisture-holding capacity of soils that are similar in taxonomic classification. Future research into regional soil wetness may need to include a measure of water holding capacity (e.g., plant available water, moisture content at "field capacity") for an arbitrary volume of soil (e.g., a pedon 1 m^2 in surface expression and one m deep) in the DI scheme. Also, as Hole and Campbell (1985, 67) state, the DI should be multiplied by a measure of climatic moisture regime if the system is to be extended beyond major climatic boundaries.

A qualitative examination of Fig. 3 shows the variation in soil wetness of some areas and the uniformity of others. This finding has implications for relating community diversity, farming practices, wildlife habitat, and groundwater variability to soil wetness. It is likely that areas of large heterogeneity in soil wetness (e.g., ground moraines) are highly variable in ecologic, geologic, and economic aspects as well. Large-scale irrigation or drainage operations would appear to be less feasible on such landscapes, as compared to regions of outwash plain.

The pattern of DI variability is not a simple function of relief data (see Table 5 and Fig. 3). Note that, although local relief is highest on the Adams end moraine (29.7 m/km^2), DI variability is low (CV = 0.43) because of parent material uniformity and coarse texture. Conversely, drainageways with minimal incision on the Walworth County outwash plain exhibit substantially wetter soils, in part because of finer tex-

Table 6. Interregional and Inter-subregional Soilscape Contrasts Significant at p = 0.10

Subregions compared	Variable	Mean data values, respectively	*t* or *F* value	*t* or *F* value probability
Walworth GM[a] vs. Adams GM	Drainage indices	42.9 vs. 38.6	5.7	0.08
Walworth OP[b] vs. Adams OP	Drainage indices	47.4 vs. 24.8	53.4	0.001
Adams County				
OP vs. both GM and EM[c]	Relief/sq km	42.8 vs. 86.5 and 97.5	26.0	0.001
OP vs. both GM and EM	Map unit size	1.8 vs. 0.7 and 0.6	4.5	0.02
EM vs. both GM and OP	Map unit slope	3.1 vs. 2.2 and 2.1	10.7	0.001
EM vs. OP vs. GM	Number map units/sq km	15.8 vs. 20.2 vs. 13.1	25.5	0.001
GM vs. both EM and OP	Series/sq km	6.7 vs. 3.4 and 4.2	27.9	0.001
Walworth County				
GM vs. EM vs. OP	Relief/sq km	52.2 vs. 83.5 vs. 33.1	32.1	0.001
OP vs. both EM and GM	Map unit size	16.8 vs. 0.4 and 0.9	63.0	0.001
GM vs. EM vs. OP	Map unit slope	1.7 vs. 2.6 vs. 1.1	35.4	0.001
GM vs. EM vs. OP	Number map units/sq km	25.8 vs. 37.1 vs. 10.2	57.9	0.001
OP vs. both GM and EM	Series/sq km	4.6 vs. 6.4 and 6.4	7.4	0.001

[a] Ground Moraine.
[b] Outwash Plain.
[c] End Moraine.

tures and higher local water tables. The more deeply incised stream channels on the Adams County outwash plain lack the large bodies of poorly drained soils present in Walworth County. Again, parent material effects are shown to outweigh relief in predicting soil wetness.

Soil Landscape Comparisons

Soil and landscape patterns were analyzed to highlight possible interrelationships and contrasts (see Tables 5 and 6). Most interregional contrasts between the Adams and Walworth county study areas were not significant. Student's *t*-tests of regional means for relief/km^2, map unit size, map unit slope, number of series, and number of map units/km^2 revealed only two significant comparisons: (1) 24.3 mapping units/km^2 (Walworth) vs. 16.0 (Adams) and (2) 5.8 series/km^2 (Walworth) vs. 5.0 (Adams). These contrasts almost certainly reflect mapping intensity and scale rather than actual pedologic differences between the two soilscapes. Wetness comparisons between subregions, as discussed above, often were not significant. Lack of meaningful contrast on a regional scale allows one to accept the hypothesis that the two areas are pedologically similar, despite obvious parent material differences. An interesting extension of this analysis might examine similar landform assemblages that differ in age. Statistically significant contrasts in geomorphic and pedologic parameters between subregions, however, are abundant (Table 6).

The lowest series densities are encountered on the Walworth outwash plain (4.6/km^2) and the Adams end moraine (3.4/km^2). This may be explained in two ways. Both subregions are relatively undissected, well drained, and geomorphically homogenous (i.e., neither contains glaciolacustrine sediments or extensive Holocene fluvial deposits). Whereas the low series density on the Walworth outwash plain is probably "real," comparable values on the Adams end moraine may reflect lower mapping intensity in the densely forested area, which would have more unmapped inclusions. High numbers of series/km^2 are found on the Walworth end and ground moraines as well as on the Adams ground moraine, where geomorphic (slope, erosion, parent material, drainage) and vegetational heterogeneity have resulted in complex soil patterns.

Outwash plains in both regions exhibit the highest mean mapping unit size, especially the Walworth outwash plain where several large bodies of Plano silt loam dominate the soilscape (Table 5). Map unit size variation is greatest for the Adams ground moraine where large bodies are present on uplands and small units are mapped on steep slopes and in small kettles (see CV in Table 5). In both Adams and Walworth counties, the steepest slopes and greatest relief are encountered on the end moraines. Deep fluvial dissection of the Adams outwash plain is evident in the relief data (Table 5). The slope data show that the Adams outwash plain is one full slope unit (A vs. B slope; 1.1 vs. 2.1 mean slope) steeper than the Walworth subregion.

Boundary contrast can be used as a rough surrogate for the "pedologic diversity" of a landscape. Soilscapes with many soil orders will, by necessity, have numerous mapping unit boundaries where unlike orders abut. These "high contrast" boundaries often are zones of rapid transition from one suite of soil-forming processes to another related though dissimilar suite of processes. For example, where an Alfisol on a slope meets an Aquoll in a kettle, one could postulate a rapid change from processes such as oxidation, lessivage, erosion, and floralturbation to such processes as reduction, melanization, cumulization, and lack of substantive mixing. Boundaries of low contrast, as for example where a fine-loamy Hapludalf mapping unit is found next to a fine-silty Hapludalf, suggest greater similarities of process and soil evolution. Differences across such boundaries are more often inherited than developmental.

Figure 2 illustrates the boundary contrast frequencies for the six subregions and summarily for Adams and Walworth counties. Soil boundaries in Adams County occur primarily between soils of different orders (contrast = 9) and where different slope classes have been delineated within a polypedon (contrast = 1). Map unit boundaries at many levels are found in Walworth County because of greater mapping intensity and soilscape complexity. The boundary contrast mode of 3 in Walworth County reflects textural class contrast, usually between fine-silty and fine-loamy soils. The latter are present on eroded slopes where underlying till is near the surface. Order contrast is low in Walworth County as a result of the dominance of Alfisols on ground and end moraines and Mollisols on the outwash plain (Table 1). Erosion class contrast is common in Walworth but not Adams County. Two factors could explain this: (1) in Walworth County steeper slopes on end and ground moraines are more likely to be farmed in row crop agriculture and (2) accelerated erosion of Psamments in Adams County is not mapped as often as it occurs because of the relative similarity between eroded and uneroded pedons.

The Adams end moraine provides a unique area for examination of boundary contrast. Here a soilscape is dominated by two series representing two different orders. Nearly 88 percent of the soil boundaries are at the order (=9) or slope (=1) level. The former represent boundaries between Coloma and Wyocena soils (Table 1); the latter exemplify slope mapping unit boundaries within one series. Compare this landscape with the Walworth County outwash plain, where boundary contrast is observed at many levels (Fig. 2). Although one large body of Plano soil dominates this landscape, small bodies of strongly contrasting soils are present, as shown by contrasts of 6 and larger. These two landscapes demonstrate that pedologic diversity, as exemplified by boundary contrast, often cannot be predicted from simple morphometric appearance. As with DI values, heterogeneity of the "high relief" Adams County end moraine is much less than the Walworth County outwash plain.

Drainage integration, as indicated by degree of internal vs. external drainage, was similar for both regions. Nearly 22 percent of all sampling points in Walworth County exhibited internal drainage (ground moraine: 14.7 percent; end moraine: 47.2 percent; outwash plain: 2.7 percent). In Adams County 25 percent internal drainage was observed (ground moraine: 20.9 percent; end moraine: 76.9 percent; outwash plain: 2.0 percent). The nonintegrated, deranged drainage of the ground and end moraines stands in marked contrast to the parallel drainage nets of the outwash plains. Interregional comparisons of drainage integration were not statistically significant; the low values of internal drainage for the Adams outwash plain reduces the county mean to the Walworth County level.

Conclusions

Contrasts in loess cover and till texture on regions with similar geologic histories did not affect the Wisconsin soilscape to the extent that soil landscape characteristics in Walworth and Adams counties are statistically different. The similarity between the two regions may be related to the constructional, youthful characteristics of both landscapes. Landform assemblages of Illinoian age (>130,000 B.P.) might yield very different results and would be an interesting topic for further study. Internal heterogeneity of soilscape characteristics in both regions is large. In analyses of landscape parameters over large regions, internal variation usually supersedes between-region differences, resulting in lack of statistical significance. My hypothesis that soilscapes are similar between regions despite parent material effects is thus supported. This conclusion agrees with Gersmehl and Napton's (1982) statement that inventory error increases with size of soil landscape study area. Such data can be used to evaluate ideal scales at which landscapes could be studied.

Statistically significant differences in soil landscape parameters between subregions were numerous. Geomorphic subregions, or landform assemblages, differ markedly in soil wetness, relief, series density, and other parameters. This supports the hypothesis that subregions are more internally homogeneous and distinct than are larger regional landscapes. These findings suggest that future studies of soil landscapes should be conducted at subregional scales where management decisions and landscape analysis interpretations are important. Subregions as defined here may even need to be further subdivided (e.g., ground moraine into glaciolacustrine plains, till plains, drumlin fields, and recessional moraines) and studied at larger scales.

This study supports the idea that pedologic diversity is often not related to readily observable landscape qualities such as relief. Landscapes of high relief may be pedologically and hydrologically more homogeneous than more subdued counterparts.

The techniques outlined above may be useful in delineating soilscape and geomorphic region boundaries where other techniques are inadequate or impossible. In addition, these methods may have application in discovering new subsets of soil and geomorphic regions not now recognized. For example, ground moraine may be subdivided into pedologic regions such as wet with Histosols, wet without Histosols, heterogeneous, mostly well-drained, and well-drained and excessively well-drained subject to erosion.

Finally, this research provides data of a kind not before published. These data show the complexity of the natural soilscape and demonstrate that all genetically related geomorphic landscapes are not cut from the same pedologic "fabric." The importance of soilscape analysis lies in this conclusion.

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References

Alban, D. H. 1974. Soil variation and sampling intensity under red pine and aspen in Minnesota. USDA Forest Service Research Paper NC 106.

Beckett, P. H. T., and Webster, R. 1971. Soil variability: A review. *Soils and Fertilizers* 34:1–15.

Campbell, J. B. 1979. Spatial variability of soils. *Annals of the Association of American Geographers* 69:544–56.

Curtis, J. T. 1959. *The vegetation of Wisconsin.* Madison: University of Wisconsin Press.

Fridland, V. M. 1965. Makeup of the soil cover. *Soviet Soil Science* 4:343–54.

———, ed. 1972. *Soil combinations and their genesis.* Moscow: Nauka Publishers. Trans.: New Delhi: Amerind Publishers.

———. 1974. Structure of the soil mantle. *Geoderma* 12:35–41.

Gersmehl, P. J., and Napton, D. E. 1982. Interpretation of resource data: Problems of scale and spatial transferability. Paper read at the Annual Conference of the Urban and Regional Information Systems Association, Minneapolis, Minn.

Haberman, G. M., and Hole, F. D. 1980. Soilscape analysis in terms of pedogeomorphic fabric: An exploratory study. *Soil Science Society of America Journal* 44:336–40.

Hadley, D. W. 1974. Surficial deposits of Walworth County, Wisconsin. Wisconsin Geological and Natural History Survey. Open-file Map, scale 1:62,500.

Hadley, D. W., and Pelham, J. H. 1976. Glacial deposits of Wisconsin: Sand and gravel resource potential. Wisconsin Geological and Natural History Survey, and State Planning Office. Open-file map, scale 1:500,000.

Haszel, O. L. 1971. *Soil survey of Walworth County, Wisconsin.* USDA-SCS. Washington, D.C.: U.S. Government Printing Office.

Hole, F. D. 1953. Suggested terminology for describing soils as three-dimensional bodies. *Soil Science Society of America Proceedings* 17:131–35.

———. 1976. *Soils of Wisconsin.* Madison: University of Wisconsin Press.

———. 1978. An approach to landscape analysis with emphasis on soils. *Geoderma* 21:1–23.

Hole, F. D., and Campbell, J. B. 1985. *Soil landscape analysis.* Totowa, N.J.: Rowman and Allanheld.

Indorante, S. J., and Jansen, I. J. 1981. Soil variability on surface-mined and undisturbed land in southern Illinois. *Soil Science Society of America Journal* 45:564–68.

Jakel, D. E. 1980. *Soil survey of Adams County, Wisconsin*. USDA-SCS. Washington, D.C.: U.S. Government Printing Office.

Mickelson, D. M.; Clayton, L.; Fullerton, D. S.; and Borns, H. W., Jr. 1973. The late Wisconsin glacial record of the Laurentide ice sheet in the United States. In *Late Quaternary environments of the United States*. Vol. 1. *The late Pleistocene*, ed. S. C. Porter, pp. 3–37. Minneapolis: University of Minnesota Press.

Nichols, J. D. 1975. Characteristics of computerized soil maps. *Soil Science Society of America Proceedings* 39:927–32.

Nortcliff, S. 1978. Soil variability and reconnaissance soil mapping: A statistical study in Norfolk. *Journal of Soil Science* 29:403–18.

Pavlik, H. F., and Hole, F. D. 1977. Soilscape analysis of slightly contrasting terrains in southeastern Wisconsin. *Soil Science Society of America Journal* 41:407–13.

Troedsson, T., and Tamm, C. O. 1969. Small-scale spatial variation in forest soil properties and its implications for sampling procedure. *Studia Forestalia Suecica* 74 (Stockholm).

Wilding, L. P.; Schafer, G. M.; and Jones, R. B. 1964. Morley and Blount soils: A statistical summary of certain physical and chemical properties of some selected profiles from Ohio. *Soil Science Society of America Proceedings* 28:674–79.