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Soil geomorphic classification, soil taxonomy, and effects on soil richness assessments

Jonathan D. Phillips [a,*], Daniel A. Marion [b]

[a] Tobacco Road Research Team, Department of Geography, 1457 Patterson Office Tower, University of Kentucky, Lexington, KY 40506-0027, USA
[b] Southern Research Station, USDA Forest Service, P.O. Box 1270, Hot Springs, AR 71902, USA

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Abstract

The study of pedodiversity and soil richness depends on the notion of soils as discrete entities. Soil classifications are often criticized in this regard because they depend in part on arbitrary or subjective criteria. In this study soils were categorized on the basis of the presence or absence of six lithological and morphological characteristics. Richness vs. area relationships, and the general pattern of soil variability and diversity, were then compared to analyses of pedodiversity based on Soil Taxonomy. The study area consists of sixteen 0.13-ha plots on forested sideslopes of the Ouachita Mountains, Arkansas, with a minimum of 20 classified soil pits per plot. An *ad hoc* classification was developed, from the standpoint of soil geomorphology and studies of the coevolution of soils and landscapes, and based on the regional environmental framework. Soils were classified based on (1) underlying geology (shale, sandstone bedrock, or transported sandstone rock fragments), and on the presence or absence of (2) texture contrast subsoils, (3) eluvial horizons, (4) surface and/or subsurface stone lines or zones, (5) lithological contrasts between soil and underlying geology, and (6) redoximorphic features. The soil geomorphic classification (SGC) yielded 40 different soil types (out of 288 possible different combinations of the criteria), compared to 19 different series or taxadjuncts identified by standard soil classification. However, 21 of the SGC soil types had only one or two representatives. Individual plots contained five to 11 different SGC soil types with extensive local variability. A standard power-function relationship between soil richness (S) and area or number of samples (A) provided the best fit for most plots ($S=cA^b$). The exponent b was slightly higher than for the taxonomy-based analysis, but in general the analyses lead to similar conclusions with respect to the relationship between richness and area, and the relative importance of local, within-plot versus regional, between-plot variability. Results support the view that soils can be viewed and treated as discrete entities, that richness assessments are not necessarily extremely sensitive to the classification used, and that highly localized variability may be critical to pedodiversity. The suggested criteria for identifying discrete soil types are given, based on qualitative morphological differences and state factor relations, contiguity, and connectivity.

Keywords: Pedodiversity; Soil richness; Soil classification; Soil geomorphology classification; Richness-area relationship

1. Introduction

In spite of ongoing debate over the extent to which soils can be considered discrete entities, as opposed to a continuum, some treatment of soils as viewed as distinct types is directly relevant to concerns with the identification, analysis, and preservation of pedodiversity. These concerns arise partly due to the relationship between biodiversity and pedodiversity, but also due to increasing concerns with pedo- and geodiversity for their intrinsic values (Richter and Babbar, 1991; Ibáñez et al., 1995; 1998; 2005a, b; Thwaites, 2000; Phillips, 2001b; Amundson et al., 2003; Guo et al., 2003; Bockheim, 2005).

Practical concerns of inventory, mapping, and management of pedodiversity dictate treating soils as discrete entities, though some other aspects of pedodiversity analysis may lend themselves to continuum-based representations. However, even when soils are classified into distinct types, it must be recognized that soil characteristics often do vary more-or-less continuously, and the criteria used to distinguish among soil types or taxa are sometimes arbitrary. For example, thickness of sandy surficial horizons in some soils of the U.S. Atlantic

* Corresponding author.
E-mail address: jdp@uky.edu (J.D. Phillips).

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Coastal Plain varies within a range of 0.2 to >2 m, often over short distances and small areas, but family and series-level demarcations in U.S. Soil Taxonomy are based on arbitrary thickness categories (Gamble et al., 1969; Daniels et al., 1984; Leigh, 1998; Phillips et al., 1999; Phillips, 2001a; Peacock and Fant, 2002). The subdivision of some Ultisols in this region into typic, arenic, and grossarenic families based on thickness limits of sandy A and E horizons is an example of arbitrary subdivision of essentially continuous variation. The perception and treatment of soils as a continuum or as discrete units, and the implications both for applied soil science and theoretical pedology are discussed by Ibáñez and Boixadera (2002); Ibáñez et al. (2005a,b).

Given both the tendency of soils to vary continuously, the practical necessity of categorization, and the fact that some soil bodies do represent unambiguously different objects, a key value judgement in pedodiversity studies, as Ibáñez et al. (2004) put it, is "whether the selected classes are different enough to be considered separate types of objects." We have argued in the past that even where arbitrary classificatory criteria must be resorted to, soil taxa often represent pedologically and geomorphologically significant differences, and that the spatial analysis of such discrete bodies is worthwhile (Phillips, 1998; Phillips and Marion, 2005). This view follows in a tradition of the study of soil-landscape relationships, environmental correlations, and spatial patterns based on soil maps (e.g. Fridland, 1976; Hole and Campbell, 1985).

Arbitrary classification categories are perhaps inevitable in a taxonomic scheme meant to apply over large areas and a wide variety of soil landscapes. However, within a particular region or soil landscape it may be possible to categorize distinctly different, discrete, soil types based on objective factors such as the presence or absence of specific features without recourse to arbitrary dividing lines such as depth categories, pH or cation exchange capacity ranges, depth of redoximorphic features, etc. The purpose of this paper is to develop and apply such a classification to soils in the Ouachita Mountains, Arkansas. Further, we seek to compare pedodiversity based on soil richness vs. area relationships using this geomorphology-based classification with previous analyses based on Soil Taxonomy. While pedodiversity studies have focussed–as does this work–on richness (the number of different soils), other aspects of pedodiversity such as evenness and similarity may also be important.

Pedodiversity is concerned with the variety and variability of soils as three-dimensional bodies rather than the variability of specific soil properties. The utility of spatial analyses of the soil cover, treated as discrete entities, has been ably demonstrated by, e.g., Fridland (1976), Grzebyk and Dubrucq (1994), Hole and Campbell (1985), Ibáñez (1994), Ibáñez et al. (1990, 1995, 1998), and McBratney (1998). Not all pedologists fully accept the notion that there exist qualitatively, categorically different types of soil that can be so identified and classified in a way analogous to biological taxonomy (though the identification of regionally-specific geologic formations may be a more apt analogy). However, the study of pedodiversity is based on the assumption that it is reasonable to identify qualitatively different types of soil, and that study of these entities provides insight not obtainable from the analysis of separate soil properties. This is based on the premises that: (1) soil classifications integrate multiple soil properties and are thus more robust reflections of soil variability; and (2) classification, though imperfect and sometimes arbitrary, ideally comprises systematic, replicable, rule-based techniques for grouping similar and distinguishing dissimilar soils. This reasoning may also apply more generally to factors such as lithology and vegetation formations.

1.1. Richness — area analysis

We are concerned here with a single aspect of pedodiversity: soil richness, the number of different soils. Biogeographers have long used relationships between species richness and area to examine biodiversity; this approach has been adapted to soils (Beckett and Bie, 1978; Ibáñez et al., 1995, 1998; Phillips, 2001b; Guo et al., 2003).

The most common form of the $S=f(A)$ relationship is a power function:

$$S = cA^b = cN^b \tag{1}$$

where S is the number of soil types, A the area, and c is the expected richness in a single unit area. The exponent b represents the rate at which richness increases with area. In our study design the number of samples N is a direct surrogate for area.

The small plots in this study, chosen to be as homogeneous as possible, represent elementary areas (Phillips, 2001b) — spatial units that are essentially uniform relative to the scale of soil mapping. Denoting each elementary area or plot with the subscript i,

$$S_i = c_iN_i^bi. \tag{2}$$

$\sum N_i=N$, and $S=m \sum S_i$, where the summation is over all i, and m (<1) is an adjustment factor for taxa counted in more than one plot ($m=S/\sum S$).

Thus

$$S = \overline{c_iN_i^b}imn \tag{3}$$

where the overbar indicates mean values for c, N, b, and n is the number of elementary areas.

For instance, if the first plot has 20 sample points and four soil series, then the first pair of data points in developing the relationship would be $S=4$ and $N=20$. If the second area has 15 samples and one additional soil not found in the first area, the second pair of points would be $S=5$, $N=35$, and so on.

The ratio b_i/b indicates the relative importance of intrinsic variability within the plots versus between-plot variations.

The theory behind the analysis is discussed more fully by Phillips (2001b), and the method is applied to the study area using Soil Taxonomy to identify soils by Phillips and Marion (2005). The latter results will be compared to the results of this study.

2. Study area and methods

2.1. Study area

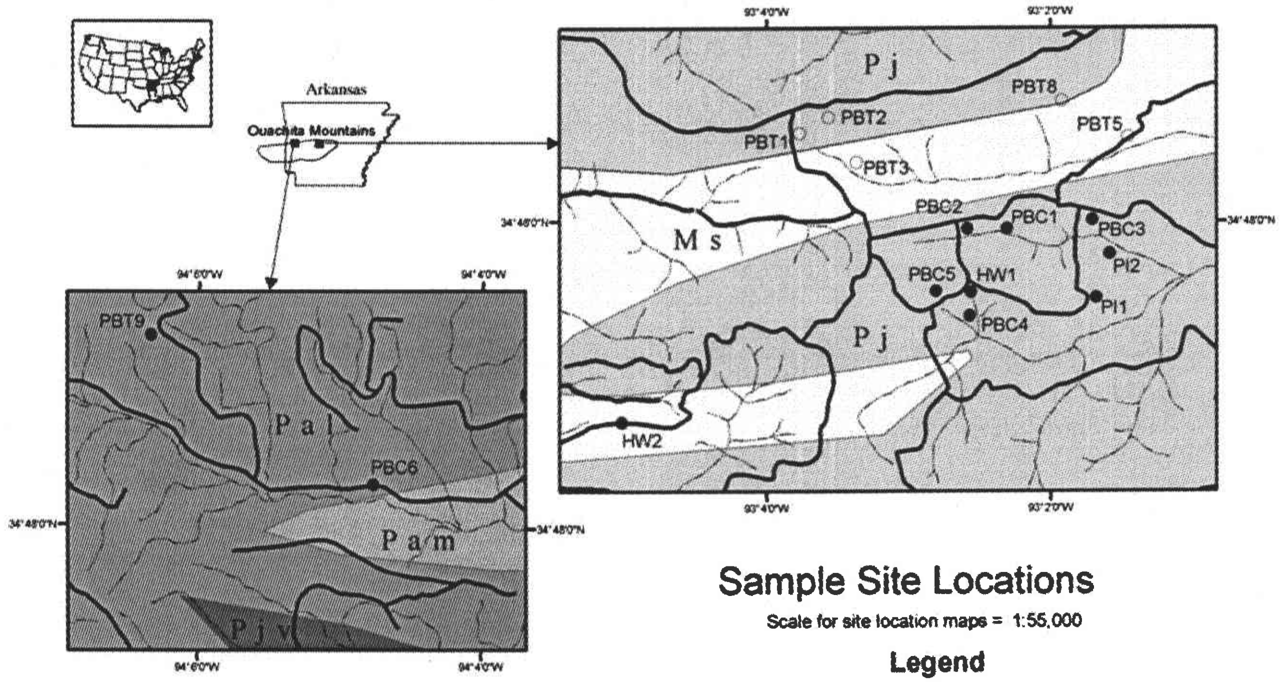
The study area is in the Ouachita Mountains, which consist of parallel, east–west trending ridges with intermontane basins in west-Central Arkansas and eastern Oklahoma (Fig. 1). The study plots are in the Ouachita National Forest and have been the sites of a number of interrelated pedological, geomorphological, and ecological studies since 2001 (Adams, 2005; Phillips et al., 2005a,b; Phillips and Marion, 2004, 2005, 2006). The climate is humid subtropical with mean annual precipitation of 1300–1400 mm.

The Ouachitas are characterized by extensively faulted and folded Paleozoic sedimentary rocks (Stone and Bush 1984), the strata of which are typically alternating layers of sandstone and shale, with lesser amounts of quartz, novaculite, and chert (Jordan et al. 1991). Sample sites are within the Stanley Shale, Jackfork Sandstone, and Atoka Formations (Fig. 1). All three lithologic units are extensive in the Ouachita Mountains, and all consist of sometimes steeply dipping, extensively faulted, intermixed beds of fine- to medium-grained sandstones and fine-grained shales. The formations differ in age (Mississippian vs. Lower Atokan) and in the relative proportions of each lithology (Jordan et al. 1991; McFarland 1998). Near-surface and exposed shales are deeply weathered and highly erodible; the sandstones are noticeably less altered and more durable. The more resistant sandstones, quartz, and novaculites occupy the ridgetops, while side slopes are often underlain by shale, with sandstone outcrops common.

Soils are predominantly Hapludults. Surface textures are generally loam or sandy loam; subsoil ranges from sandy clay loam to clay (Phillips and Marion, 2005). Broad textural variations reflect the extent to which the parent material is dominated by sandstone or shale.

The sample sites are forested, with contemporary vegetation including oak-hickory (i.e., hardwood-dominated), shortleaf pine (pine-dominated), and oak-pine (mixed pine-hardwood) forest types. The pine-dominated sites include both pine-bluestem savannas, apparently the dominant community on southern exposures at the time of settlement by non-native peoples, and sites where shortleaf pine dominates the overstory, but where hardwoods may dominate the mid- and understory (USDA Forest Service 1999).

In 2001 16 sample plots were established along transects regularly monitored by Forest Service personnel, including 10 on oak-pine, four on pine-dominated, and two on hardwood-dominated sites. Each was circular with a radius of 20 m (66 ft) and an area of 0.127 ha. Three to four backhoe-excavated soil pits and 20 smaller "posthole" pits were excavated at each plot,



Label	Plot	Label	Plot
PBT1	3000p2	PBC4	3514p12
PBT2	3100p1	PBC5	3428p34
PBT3	3200p4	HW1	Hardwood 1
PBT5	4025p40	HW2	Hardwood 2
PBT8	3826p28	PI1	AC 1
PBC1	3627p34	PI2	Flattop
PBC2	3514p8	PBC6	Poteau Control
PBC3	3912p10	PBT9	Pine-Bluestem

Fig. 1. Study area.

and topography was surveyed at a detailed (1 m) scale. The posthole pits are in the form of 10 paired samples per plot. The edges of the paired pits were <1 m apart, and selected to be uniform in terms of elevation, slope gradient, and slope curvature. The sites are mainly on side slopes (as opposed to ridgetops or valleys); one site straddles a minor ridgetop. Soil and topographic mapping, rock fragment distributions, regolith stratrigaphy, and inventories of uprootings, stumps, snags, and woody debris were carried out in our earlier studies (Phillips and Marion 2004, 2005, 2006; Phillips et al. 2005a,b).

2.2. Soil geomorphology classification

The intent here is not to propose a generally-applicable classification, or to explore the effects of taxonomic structures themselves on assessments of richness. In effect we are exploring how an *ad hoc* classification based on the presence or absence of specific features known to be relevant at our study sites, compares to U.S. Soil Taxonomy with respect to assessments of soil richness.

Twenty soil pits at each plot were previously classified on the basis of U.S. Soil Taxonomy, and using an *ad hoc* 12-category classification of the vertical distribution of rock fragments (Phillips and Marion, 2005; Phillips et al., 2005a). For this study a more general classification was developed. Classification criteria were intended to be (1) objective, requiring no subjective judgements other than those that are normal and unavoidable in field-based soil geomorphology and pedology; (2) based on presence/absence of specific features or straightforward categorization of lithologies (i.e., sandstone vs. shale vs. quartz); and (3) relevant to pedologic variations, soil-landscape relationships, and soil/regolith formation as outlined in previous studies (Phillips and Marion, 2004; Phillips et al. 2005a,b). The soil geomorphic classification is, therefore, *ad hoc*, and not necessarily applicable outside the study area or to pedodiversity based on criteria other than gross soil morphology. We were unable to completely eliminate arbitrary thresholds, but they are limited to binary distinctions (such as rock fragment contents in 2, 4 below) or to application of generally accepted principles for recognizing features such as E horizons and redoximorphic features.

The six selected criteria are below, with 2–6 based on presence or absence of the indicated feature:

1. Underlying geology. At the study sites this is categorized as either shale, sandstone bedrock, or transported sandstone rock fragments.
2. Vertical texture contrasts with subsoils at least three textural classes finer than surface horizons. A separate category was established for pedons where rock fragment content was >50%, with the same lithology as the underlying bedrock.
3. Eluvial (E-) horizons, recognized as horizons below the mineral surface of the soil, with texture no finer than the overlying layer, and with Munsell value and chroma lighter than the overlying layer. Note that while we term these eluvial horizons and believe that is indeed their origin, the criterion depends only on specific observable properties.
4. Surface and/or subsurface stone lines or zones. These were defined on the basis of a local rock fragment content that was (a) ≥70%; (b) ≥20% higher than adjacent layers.
5. Lithological contrasts between the soil and underlying geology, identified on the basis of rock fragments differing in fundamental lithology (shale, sandstone, quartz) from that of bedrock underlying the soil.
6. Redoximorphic features within the solum.

The pedological and geomorphological significance of these features in the study area is discussed elsewhere (Phillips and Marion, 2005, 2006; Phillips et al. 2005a,b).

2.3. Field methods

Full soil profile descriptions were made for at least three soil pits at each plot. In addition, at each of the 20 posthole pits, the following information was collected at a minimum:

- Texture of the surface and subsoil horizons, using hand-texturing methods.
- Presence or absence and vertical position of stone lines or zones, based on volume estimates of rock fragment content using strike tests with a 2 mm diameter metal rod.
- Presence of E-horizons, as described in item 3 above.
- Presence of low-chroma (Munsell-chroma <3) above R or Cr layers.
- Lithology of underlying bedrock.
- Lithology of rock fragments, based on breaking at least six clasts per pit with a geological hammer.

Table 1
Soil geomorphology based classification used in this study

Substrate or underlying bedrock geology
1: shale
2: sandstone bedrock
3: transported sandstone boulders or cobbles
Vertical texture contrast
0: absent
1: present, subsoil rock fragment content <60% or lithologically contrasting with underlying bedrock
2: present, subsoil rock fragment content ≥60%; same lithology as bedrock
Eluvial horizon
0: absent
1: present
Lithological contrast
0: absent
1: present
Stone line or zone
0: absent
1: subsurface only
2: subsurface and surface
3: surface only
Redox features (low chroma)
0: absent
1: present

A six-digit code is assigned to each soil profile as described below. Specific criteria are described in text. For example, a code of 111100 indicates a soil with shale underlying geology, a vertical textural contrast, an eluvial horizon, a lithological contrast, no stone lines or stone zones, and no low-chroma mottles.

Table 2
Frequency of particular morphological properties in study soils (n=320)

Property	Number	Percentage
Underlying lithology		
Shale	237	74
Sandstone	61	19
Transported sandstone	22	7
Vertical texture contrast	311	97
Eluvial (E) horizon	58	18
Lithological contrast	307	96
Low-chroma mottling	3	<1
Stone lines or stone zones	200	62
Surface only	121	38
Subsurface only	18	5
Surface and subsurface	61	19

- Depth to the top of the uppermost (presumed) B-horizon, with identification of the latter based on at least two of the following: texture contrast of at least two textural classes; color contrast of at least two units of Munsell hue, value, and/or chroma; subangular blocky structure in contrast with overlying structure.
- Depth to bedrock.

This data allowed the application of the six classificatory criteria to each pit. A six-digit code was assigned to each sample as shown in Table 1.

2.4. Analysis

The richness of the individual plots and for the study area as a whole were used to examine S vs. A relationships. Linear, logarithmic, and exponential functions were applied as well as the standard power function. Other indications of soil variability and diversity examined include total and per plot richness, and the number of adjacent, paired samples with had different soil types.

These results were then compared with identical analyses performed using Soil Taxonomy rather than the SGC and published earlier (Phillips and Marion, 2005).

3. Results

3.1. Soil morphology

A typical pedon in the study area is relatively thin (<1 m) with a loam or sandy loam surface and a thick (>3 cm) litter layer and O horizon. Most have yellowish brown to red B horizons (the dominant Munsell hue is 7.5YR). Clay loam was the most common subsoil texture, but the latter ranged from sandy clay loam to clay. Some pedons have C horizons similar in texture and color to the B, but containing noticable amounts of weathered and unweathered shale. These are general tendencies and there was substantial variation in all properties.

The underlying geologic material is predominantly shale (74% of pits). All but nine profiles (97%) have vertical textural contrasts. In 28 cases (9%) high rock fragment contents with the same lithology as the underlying strata occurred in the finer subsoils, but 86% of the soils had texture contrasts without this characteristic.

Most pits (82%) did not have eluvial horizons. The vast majority (96%) displayed lithological contrasts, and all but three pits lacked low-chroma mottles. Stone lines or zones were present in 62% of the profiles, most commonly at the surface. These characteristics are summarized in Table 2.

3.2. Soil geomorphology classification variability

The six criteria in the soil geomorphology classification (Table 1) allow for 288 possible combinations. Of these, 40 different types were found, compared to 19 different series or series taxadjuncts identified by standard soil classification. However 21 of the 40 SGC types had just one or two occurrences. If these are lumped into other categories, the richness is identical to that identified using Soil Taxonomy.

Individual plots (20 pits each) had five to 13 different soil geomorphology types, similar to the four to 11 different soil series found by Phillips and Marion (2005). The slightly higher value for the SGC is attributable to the effects of SGC types with just one or two occurrences.

The paired pits showed different soil types in adjacent pits more than 58% of the time (109 of 160 pairs). This is also similar to the soil taxonomy results, where 60% of the paired pits showed different soils.

3.3. Richness/area relationships

A standard power-function relationship between soil richness (S) and area or number of samples (N) provided the best fit for most plots ($S=cN^b$), as shown in Table 3. The power

Table 3
Results of richness-area analysis

Plot	N	C	b	R^2
4025p40	9	1.25	0.65	0.96
3100p1	5	1.03	0.52	0.96
3200p4	5	1.03	0.54	0.99
3826p28	10	0.86	0.80	0.81 [a]
3000p2	9	1.10	0.68	0.98
3428p34	9	1.20	0.65	0.97
3514p12	5	1.23	0.51	0.94 [a]
3514p8	10	0.98	0.72	0.92 [a]
3912p10	6	1.31	0.61	0.89 [b]
3627p34	11	1.10	0.73	0.98 [a]
HW1	13	1.10	0.79	0.98 [a]
AC1 6	1.07	0.60	0.98	
HW2 9	1.05	0.57	0.98	
Flattop	7	1.09	0.65	0.94 [a]
Pine/blue	5	1.16	0.54	0.94 [a]
Poteau	10	1.24	0.73	0.97
Mean	8.1	1.12	0.65	
Overall	40	1.11	0.65	0.98

Column n is the number of different soil types in the plot. Columns c and b represent coefficients of the relationship $S=cN^b$ where S is the number of soil types and N the number of samples. There are 20 data points (soil pits) in each sample plot.

[a] A linear relationship provided a slightly better R^2 for this plot.

[b] A logarithmic relationship provided a slightly better R^2 for this plot.

function was the best fit for the entire data set (R^2=0.98), and for eight of the individual study plots. The power-function form yielded a coefficient of determination of at least R^2=0.81 in every case (Table 3). Table 4 is a plot-by-plot comparison of the number of soil types and the b exponent for soil taxonomy and the SGC.

The exponent b was slightly higher than for the taxonomy-based analysis, but in general the analyses lead to similar conclusions with respect to the relationship between richness and area, and the relative importance of local, within-plot versus regional, between-plot variability as indicated by the ratio of the mean exponent for the elementary areas and the b value for the entire data set. The ratio for the SGC is 1.0, while for Soil Taxonomy b_i/b=1.15. Results support the view that soils can be viewed and treated as discrete entities, and that highly localized variability may be critical to pedodiversity.

4. Summary

The differences in soil richness assessments based on soil taxonomy and the SGC are summarized in Table 4. The two classifications do not yield substantially different results with respect to the number of different soil types, or with respect to richness-area relationships. Use of the SGC rather than soil taxonomy would also lead to the same conclusions with respect to the nature and causes of local soil variability drawn in earlier work (Phillips and Marion, 2005). The correspondence between the SGC and soil taxonomy is shown in Table 5.

5. Soils as discrete entities: proposed criteria

Here we propose criteria for considering soil pedons as discrete entities rather than variants in a soil continuum, and consider our results in the context of these principles. These criteria are not intended for application to soil taxonomic and classification schemes, but rather, to field and soil map assessments of pedodiversity and soil-landscape structure. Such criteria (these or otherwise) would be useful not only in pedodiversity assessments, but also for lumping or splitting soil map units for specific applications or analyses. This is a different analytical problem from quantitative analyses of soil spatial variability, where sample independence and spatial autocorrelation would need to be accounted for in sampling. Rather, these criteria are intended, given descriptions of two or more pedons, to facilitate the judgement of whether the soils "are different enough to be considered separate types of objects" (Ibáñez et al., 2005a).

Table 4
Comparison of number of soil types and soil richness exponent by plot for soil geomorphology and standard taxonomic classifications

	Soil geomorphology		Taxonomy	
Plot	*n*	*b*	*n*	*b*
4025p40	9	0.65	7	0.62
3100p1	5	0.52	6	0.56
3200p4	5	0.54	4	0.49
3826p28	10	0.80	6	0.57
3000p2	9	0.68	8	0.70
3428p34	9	0.65	6	0.54
3514p12	5	0.51	5	0.68
3514p8	10	0.72	7	0.62
3912p10	6	0.61	5	0.51
3627p34	11	0.73	8	0.73
HW1	13	0.79	6	0.64
AC1	6	0.60	7	0.59
HW2	9	0.57	6	0.73
Pine/blue	5	0.54	4	0.40
Poteau	10	0.73	10	0.76
Overall	40	0.65	19	0.53

There are 20 data points (soil pits) in each sample plot.

Table 5
Correspondence (number of sample pits) between soil series and series taxadjuncts defined using Soil Taxonomy (vertical axis) and the soil geomorphology classification (horizontal axis)

	110/110	110/100	110/120	110/130	111/100	111/120	111/130	120/200	210/000
Bengal	0	3	3	4	0	0	0	0	0
Bismarck	0	0	0	0	0	0	0	6	0
Bismarck-Bt	0	4	0	8	0	0	0	0	0
Carnasaw	1	3	0	2	2	0	1	0	0
Clebit	0	0	0	0	0	0	0	0	0
Clebit-Bt	0	0	0	0	0	0	0	0	2
Endsaw	1	0	0	0	0	0	0	0	0
Honobia	1	13	12	19	4	6	4	0	0
Littlefir	0	1	0	1	0	0	0	0	0
Nashoba	0	0	0	0	0	0	0	0	0
Pirum	0	0	0	0	0	0	0	0	5
Sherless	4	33	0	29	12	2	5	0	0
Sherwood	0	0	0	0	0	0	0	0	0
Stapp	0	0	0	0	0	0	1	0	0
Townley	3	11	0	16	0	0	3	0	0
Tuskahoma*	0	6	0	5	0	0	0	0	0
Udorthent	0	0	0	0	0	0	0	0	1

	210 100	210 030	210 120	210 130	211 120	311 120	320 120	Other
Bengal	0	0	0	0	0	0	0	0
Bismarck	0	0	0	0	0	0	2	4
Bismarck-Bt	0	0	0	0	0	1	0	0
Carnasaw	0	0	0	0	0	0	0	0
Clebit	0	0	0	0	4	0	12	0
Clebit-Bt	0	1	0	0	0	1	0	0
Endsaw	0	0	0	0	0	0	0	0
Honobia	0	0	0	0	1	0	0	0
Littlefir	0	0	0	0	0	0	0	0
Nashoba	0	1	7	0	4	0	0	0
Pirum	13	2	6	11	0	3	0	0
Sherless	0	0	0	0	0	0	0	0
Sherwood	0	1	1	0	0	0	0	0
Stapp	0	0	0	0	0	0	0	0
Townley	0	0	0	0	0	0	0	0
Tuskahoma*	0	1	0	0	0	0	0	0
Udorthent	0	0	0	0	0	0	0	7

To reduce the size of the table, SGC classes with four or fewer total members have been lumped into the most closely related class or lumped into the "other" column.

5.1. Criteria

We propose that any pair of soil pedons, map units, or samples (pits or augerings) may be considered to be discrete entities and thus different soil types if they exhibit significant quantitative differences in at least one soil property, and at least two of the following characteristics:

- *Qualitative morphological differences* such as presence or absence of diagnostic horizons, lithological contrasts, and multiple horizon sequences.
- *Qualitative difference in factors of soil formation*, such as water-spreading vs. water-gathering hillslopes; granite vs. basalt parent material; and forest vs. grassland vegetation communities.
- *Non-Contiguity:* the considered soils are never spatially adjacent unless a clear, abrupt landscape boundary such as a geologic contact or slope break is also present.
- *Non-Connectivity:* no direct matter or energy fluxes genetically connect the soils, which are not members of the same catena or part of a single factor sequence (toposequence, climosequence, biosequence, etc.).

5.2. Discussion

The quantitative criterion is generally easily met, due to the intrinsic (and often continuous) variation of many soil properties. The significance of the variation can be judged on the basis of statistical significance.

The qualitative morphology difference is based on the notion that soils with qualitative morphological differences are different entities. Two soils that differ, for example, with respect to the depth, thickness, clay content, or cation-exchange capacity of apparently clay-enriched subsoils would not meet this criterion. However, pedons which differ with respect to the presence of a finer-textured subsurface horizon would meet the criterion. Also, if such horizons in two pedons differ with respect to qualitative morphological features such as prismatic vs. blocky structure, or presence/absence of clay films, the qualitative morphology criterion could be met.

Similarly, qualitative differences in state factors requires not just (for example) differences in slope gradient or curvature, but qualitative variations such as concave vs. convex profiles or contours. Qualitative differences in climate–even microclimate–are unlikely and difficult to prove at the site or landscape scale, except perhaps in regions of very steep climatic gradients. Qualitative biotic differences imply clear differences in biotic communities, rather than more subtle gradations in factors such as populations, densities, or relative abundance of species. Qualitative differences in parent material we intend to mean different lithologies (e.g. shale vs. limestone) or different underlying materials (e.g. alluvium vs. colluvium vs. residuum) as opposed to, for instance, alluvium of varying textures or variations within a single lithology.

At the site or landscape scale, discretely different soils should not be spatially contiguous unless the soil boundary coincides with an abrupt landscape boundary such as a long-lived land use boundary (for example a forest-field edge), geologic feature such as a fault, fracture, or lithological contact, or an abrupt break of slope. Such a boundary implies qualitative differences in state factors across the boundary as described above.

Continuous or quasi-continuous variation may occur in catenas or along climo-, bio-, topo-, or chronosequences. Two soils which are part of the same catena or sequence would not be considered discretely different soils by our criteria unless they also met at least two of the three other criteria above.

5.3. Ouachita soils

The SGC was not originally designed and applied with these criteria in mind, but does reflect them reasonably well. The nature of the classification is such that the qualitative morphological difference rule is always met. SGC types varying with respect to underlying geology and redox features will also meet the state factor criterion.

In many cases the non-contiguity criterion was also met, along with the state factor criterion, as SGC soil types were separated by geologic contacts, slope breaks at local topographic summits and depressions, and rock outcrop boundaries. In some cases, however, immediately adjacent samples with no corresponding difference in state factors differed in terms of SGC class. In general, these variations are apparently associated with local effects of individual trees (Phillips and Marion, 2005; Phillips et al., 2005a,b), and in some specific instances this is demonstrably the case. This would meet the state factor criterion — but this would be difficult or impossible to judge in most cases and most studies, and certainly could not be discerned from soil maps.

Except in the case of redox features (the least important criterion in the SGC), the differences in the SGC criteria are not related to any obvious catenary relationships. However, the systematic downslope movement of rock fragments and their subsequent mixing into the regolith is an important process in the area (Phillips et al., 2005a; Phillips and Marion, 2006). These processes influence both the stone line/stone zone and the lithological contrast criteria. Thus we cannot claim that SGC classes are unrelated to matter or energy fluxes among the soil types.

6. Discussion

Assessment and conservation of soil diversity–particularly soil richness–dictates the identification of discrete soil entities. While this is not always problematic, soil variation may be continuous rather than discrete, and soil classifications must often resort to arbitrary criteria — for instance, the 35% base saturation criterion which separates the Ultisol and Alfisol orders in U.S. Soil Taxonomy, or the limiting horizon depth and thickness criteria often employed at the family and series level. In soil richness and pedodiversity studies it is critical to determine the extent to which identified soil types represent fundamentally different entities as opposed to arbitrary divisions of a continuum. If two or more different, independently applied classifications produce comparable results, the implication is that measurements of richness are not uniquely associated with the taxonomy applied.

On Ouachita Mountain sideslopes, a classification with minimal reliance on arbitrary quantitative divisions leads to essentially the same conclusions with respect to soil richness and spatial variability as similar analyses using soil series. This is partly due to the similarity of some of the differentiae between Soil Taxonomy and the SGC. Both, for example, recognize different soils on shale and sandstone. Other factors such as the presence or absence of texture contrasts or eluvial horizons are reflected indirectly in taxonomy.

Another possible reason for the similar results is related to the practical aspects of field soil surveying and mapping. Soil Taxonomy and other soil classification systems indeed rely on quantitative criteria — some of which require laboratory analyses. Within a given region such as the Ouachita Mountains, however, the application of the formal taxonomic criteria results in a population of taxa. The distinctions among members of that population, on a practical basis, are based on soil-landscape correlations that are typically closely related to soil geomorphology. This indicates that at the landscape scale, where observed morphological features and soil-landscape relationships guide soil classification, assessments of soil richness are not necessarily uniquely linked to the categorization employed.

The 19 taxa mapped in the study area by Phillips and Marion (2005), for example, differ in a number of physical and chemical criteria. But the taxa (along with other taxa potentially found in the region) all differ with respect to at least one morphological criterion that can be determined in the field. While two of these, related to thickness and rock fragment content, involve arbitrary quantitative subdivisions, they are also closely related to geologic settings.

The close correspondence of richness analyses between the SGC (or a similar *ad hoc* classification) and Soil Taxonomy in this study might therefore be more likely within a given landscape, physiographic setting, or ecoregion than over broader scales.

7. Conclusions

Analysis of soil richness depends on a treatment of soils as discrete entities. Soil classifications are often criticized in this regard because they depend in part on arbitrary or subjective criteria. In this study soils were categorized on the basis of the presence or absence of six lithological and morphological characteristics, with no subjective criteria or imposed thresholds or subdivisions. Richness vs. area relationships, and the general pattern of soil variability and diversity, were then compared to analyses of pedodiversity based on Soil Taxonomy. The soil geomorphic classification (SGC) yielded results similar to standard soil classification with respect to total soil richness and richness per plot. A standard power-function relationship between soil richness (S) and area or number of samples (A) provided the best fit for most plots ($S=cA^b$), and a good fit for all plots. As compared to richness-area analysis based on Soil Taxonomy, the exponent b was slightly higher, but in general the analyses lead to similar conclusions with respect to the relationship between richness and area, and the relative importance of local, within-plot versus regional, between-plot variability. These results show that analyses of soil richness are not necessarily contingent on the soil classification used. Results support the view that soils can be viewed and treated as discrete entities, and that highly localized variability may be critical to pedodiversity. Suggested criteria for identifying discrete soil types include qualitative morphological differences and state factor relations, contiguity, and connectivity.

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