MINE SOIL CLASSIFICATION AND MAPPING ISSUES ON PRE- AND POST-SMCRA APPALACHIAN COAL MINED LANDS[1]

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Abstract. Soils formed on lands mined for coal in the Central Appalachians are currently classified by *Soil Taxonomy* primarily as Typic Udorthents, which does not distinguish these unique anthropogenic soils from other weakly developed natural soils. In this study, we evaluated the effectiveness of currently utilized mine soil series for describing and classifying a range of mine soil pedons in southwest Virginia. Using established series concepts, we mapped and classified approximately 450 ha of mine soils in an area that had been reclaimed in accordance with the U.S. Surface Mining, Control, and Reclamation Act (SMCRA) of 1977. We also used current series concepts to reclassify mine soils in an adjacent and overlapping 250 ha that had been mined prior to SMCRA, and had been mapped using older (non *Soil Taxonomy*) mine soil classification criteria in 1980. Established mine soil series concepts provided adequate information on particle-size and reaction class, but did not adequately describe drainage class, rock type or parent materials. Classification differences occurred on well-drained soils primarily at the family level and below. There were no established series to describe mine soils with impeded drainage, densic layers, and shallow or moderately deep depth classes, all of which commonly occurred in this study area, and are important criteria for separating soil series. Cambic horizons were also described, and generate classification issues at the order level. Using current taxonomic/mapping procedures, none of these dissimilar soils would be considered limiting inclusions to the dominant soil in the map unit. Since reaction class, drainage class, densic contacts, and soil depth directly affect soil management, we feel that it is important to recognize these features by establishing new mine soil series or phases of established series. Older, pre-SMCRA mined lands are much more complex in short-range landform variability than more modern reclaimed landscapes. This pattern of soil landscape variability and associated differences in land use capability is effectively captured by large scale mapping such as that employed by this study.

Additional Key Words: Drainage class, cambic horizon, densic contact.

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Introduction

Until the mid-1970's, Appalachian mine soils resulting from coal surface mining were usually identified in published soil surveys as "strip mines" or "mine dumps" (e.g. Perry et al., 1954). In later surveys, mine soils were often mapped simply as "Udorthents", although some authors described different types of spoil that might be encountered in land mapped as "mine dumps" (Patton et al., 1959), or made attempts to differentiate mine soils on the basis of rock type and soil reaction (Wright et al., 1982). During the 1970's and 1980's, USDA-NRCS in several states began to use soil series to map mine soils. The first soil series on lands mined for coal was the Kamina series in 1972, in Oklahoma (Sencindiver and Ammons, 2000). Alabama established two coal mine soil series in 1974 and 1977, and Ohio established three in 1978. The first coal mine soil series in the central Appalachian region were established by West Virginia in 1984. By 2000, there were 30 soil series established in the USA for coal mine soils (Sencindiver and Ammons, 2000). All these series are classified within the Entisol order, and all mine soils series currently being used in the Appalachian coal mining region are classified as Typic Udorthents. Several researchers, however, have questioned whether current mine soil classification provides enough information on the intrinsic properties and future land use interpretations of these mine soils, and whether or not other taxonomic classes (e.g. Inceptisols) are possible (Sencindiver, 1977; Shafer, 1979; Ciolkosz et al, 1985; Indorante et al., 1992; Dunker and Barnhisel, 2000).

In one of the first major studies of mine soil classification, Sencindiver (1977) examined pedons in six eastern and Midwestern states and used these data to propose that a new suborder, Spolents, be created for mine soils and added to then existent *Soil Taxonomy* (Soil Survey Staff, 1975). As defined, Spolents would possess at least three of the following properties: disordered rock fragments; color variegation not associated with horizonation or redoximorphic features; splintered or sharp edges on rock fragments; bridging voids (open air pockets) between rock fragments; a thin surface horizon generally higher in fines than other horizons; local pockets of dissimilar material; artifacts; carbolithic (black, high carbon) rock fragments; and irregular distribution of organic matter (not associated with fluvial process) with depth (Smith and Sobek, 1978). At the great group level, Udispolents would represent mine soils in humid climates separated by dominant rock type. Proposed families of Udispolents were determined by particle-size, mineralogy, reaction, and soil temperature regime. A simplified set of soil reaction classes was proposed in lieu of those used in *Soil Taxonomy*: extremely acid (pH <4.0); acid (pH 4.0-5.5); neutral (pH 5.6-8.0); and alkaline (pH > 8.0). In follow-up studies, mine soils in West Virginia (Thurman and Sencindiver, 1986) and Missouri (Ammons and Sencindiver, 1990) were mapped and identified to the family level using the proposed Spolent criteria. In both studies, it was concluded that this system provided more information about potential land use than did the established mine soil series used in those areas.

While the research efforts cited above have used the Spolent concept to classify and map mine soils, and the Spolent concept has been incorporated in the 4th Circular Letter for the International Committee for Anthropogenic Soils (ICOMANTH; available on-line at http://clic.cses.vt.edu/icomanth), it has not yet officially been proposed as an amendment to Soil Taxonomy. However, a proposal to add the Spolent concept to *Soil Taxonomy* will be made pending favorable responses to the 4th Circular Letter, which was distributed in January of 2003. Selected Udispolent subgroup concepts have been used to develop established mine soil series in West Virginia, although these series are currently classified as Udorthents which are the closest taxa available in *Soil Taxonomy* (Sencindiver and Ammons, 2000). The USDA-NRCS in Virginia is currently mapping its coalfield counties with mine soil series established in West Virginia and Ohio.

The landforms on which Appalachian mine soils occur are a product of varying mining and reclamation methods, which have changed dramatically with time. Older (pre-1977) Appalachian surface coal mines are primarily contour mines, in which coal was mined from a horizontally bedded seam that outcropped on the side of a ridge or mountain. Overburden materials (blasted rock and soils) are excavated from above the outcrop to expose the coal seam (Ramani and Grim, 1978). Before passage of the 1977 Surface Mining Control and Reclamation (SMCRA), reclamation of these areas was minimal. Overburden materials were bulldozed over, and frequently off the edge of the bench created by mining the coal seam. The resulting landform consisted of an exposed rock highwall, a bench from which the coal had been removed, and a steep and often unstable outslope below the bench (Ramani and Grim, 1978; Daniels and Zipper, 1988). After the passage of SMCRA, mined areas were mandated to be returned as close as possible to approximate original contour, including covering of highwalls and the placement of topsoil, or a topsoil substitute, at the surface of the regraded area (Figs. 1, 2 and 3). The natural soils of the Appalachians are often thin, rocky, and infertile by agronomic standards, so suitable pre-tested (and agency approved) blasted rock overburden materials are commonly employed as a topsoil substitute (Daniels and Zipper, 1988).

Researchers studying acid mine drainage prediction from differing Appalachian overburden materials have documented the fact that overburden strata located near the surface (6-12 m) of the geologic column are more highly weathered and oxidized than deeper rock strata (Smith and Sobek, 1978; Grube et al., 1982; Sobek et al., 2000). This oxidized overburden can generally be identified by soil chromas of ≥ 3. Surface mines constructed before SMCRA tended to be relatively shallow because of equipment and technology limitations. Thus, material from the top of the geologic column was removed preferentially, and the overburden produced from these mines generally contained a relatively high percentage of oxidized and/or partially oxidized spoil materials. Overburden from deeper in the geologic column is unweathered and unoxidized, and generally has a chroma of ≤ 2.5, because the materials are reduced. Because of their unweathered state, these materials may also contain higher amounts of alkaline materials such as carbonates, although they can also contain significant levels of acid-producing pyritic sulfur (Sobek et al., 2000). Improvements in mining technology since the early 1980's have allowed deeper cuts into these unoxidized materials in both contour and mountaintop removal mines. The current mined landscape in the Central Appalachians consists of a mosaic of older pre-SMCRA mined lands with relatively narrow benches and highwalls intermixed with more recent mined areas that have been returned to approximate original contour or completely reconfigured by mountaintop removal and valley fill procedures (Figs. 1, 2, and 3).

Our overall research objective was to map, characterize, and classify an area of post-SMCRA mine soils to determine how well the established mine soil series concepts currently being used in the central Appalachian region described the existent mine soils. Our secondary objective was to contrast the level of detail and discrimination of contrasting mine soil landscape properties obtainable using modern USDA-NRCS mapping criteria (Soil Survey Staff, 1993) versus the older methods employed in the early 1980's. As a part of this overall effort, we also used current series concepts to attempt to classify the older previously mapped and characterized pre-SMCRA area (now destroyed because of re-mining) that overlapped the current mapped area.

Materials and Methods

The study area was located on the Powell River Project Education Center, about 11 km northwest of Norton, Virginia. The Powell River Project is cooperative among Virginia Tech, the southwestern Virginia coal industry, and local governments, and was designed to provide an interdisciplinary research and demonstration area for reclamation and land-use planning in Southwest Virginia. The underlying bedrock is of Pennsylvanian age, and is composed of horizontally bedded sandstone, siltstone, and coal beds of the Wise formation (Nolde et al., 1986). The majority of strata are cemented by a complex of carbonate, Fe, and silica intergranular cements (Howard, 1979), and are generally low in pyritic-S, although acid-forming materials are present in some strata below and between coal seams. Dominant native soil series include the deep and very deep Shelocta (Fine-loamy, mixed, active, mesic Typic Hapludults) and moderately deep Gilpin (Fine-loamy, mixed, active, mesic Typic Dystrudepts) soils. The climate is humid-temperate with an evenly distributed average precipitation of approximately 125 cm. The native vegetation is mixed hardwoods. Reclaimed benches are dominated by tall fescue (*Festuca arundinacea* schreb.), sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don], and other herbaceous revegetation species along with common woody species such as white pine (*Pinus strobus* L.), black locust (*Robinia pseudoacacia* L.) and red maple (*Acer rubrum* L.)

Approximately 250 ha of mine soils were mapped and studied in 1980 in an area (Fig. 1) that had been extensively contour mined between the late 1950's and 1977, before the passage of SMCRA. The mapped areas were located on four mining bench levels (Fig. 1), which corresponded to the Phillips, Low Splint, Taggart-Taggart Marker, and Upper Standiford (Wilson)-Lower Standiford coal seams (Brown, 1952). These mine soils were located on the exposed highwall-bench-outslope landform that is typical of pre-SMCRA mined lands in the Appalachians. The exposed benches were relatively flat, while outslopes were very steep ($\geq$ 50%).

Before the 1980 mapping, the mine soils were sampled at 245 randomly distributed points. Backhoe pits were excavated in typical locations based on the data from this random sampling and on field observations. Mine soils were described in place during the fall of 1980, and the details of the physical, chemical, and morphological properties of these soils are summarized in Daniels and Amos (1981). The area was then mapped by detailed (Order 1) standards at a scale of 1:4800, using mapping criteria that were extensively modified from those employed at the time by USDA-SCS (SCS) in Virginia (USDA-SCS, 1975). The original SCS criteria were modified to support detailed soil mapping and associated interpretive requirements. The 1975 SCS criteria included pH, slope,

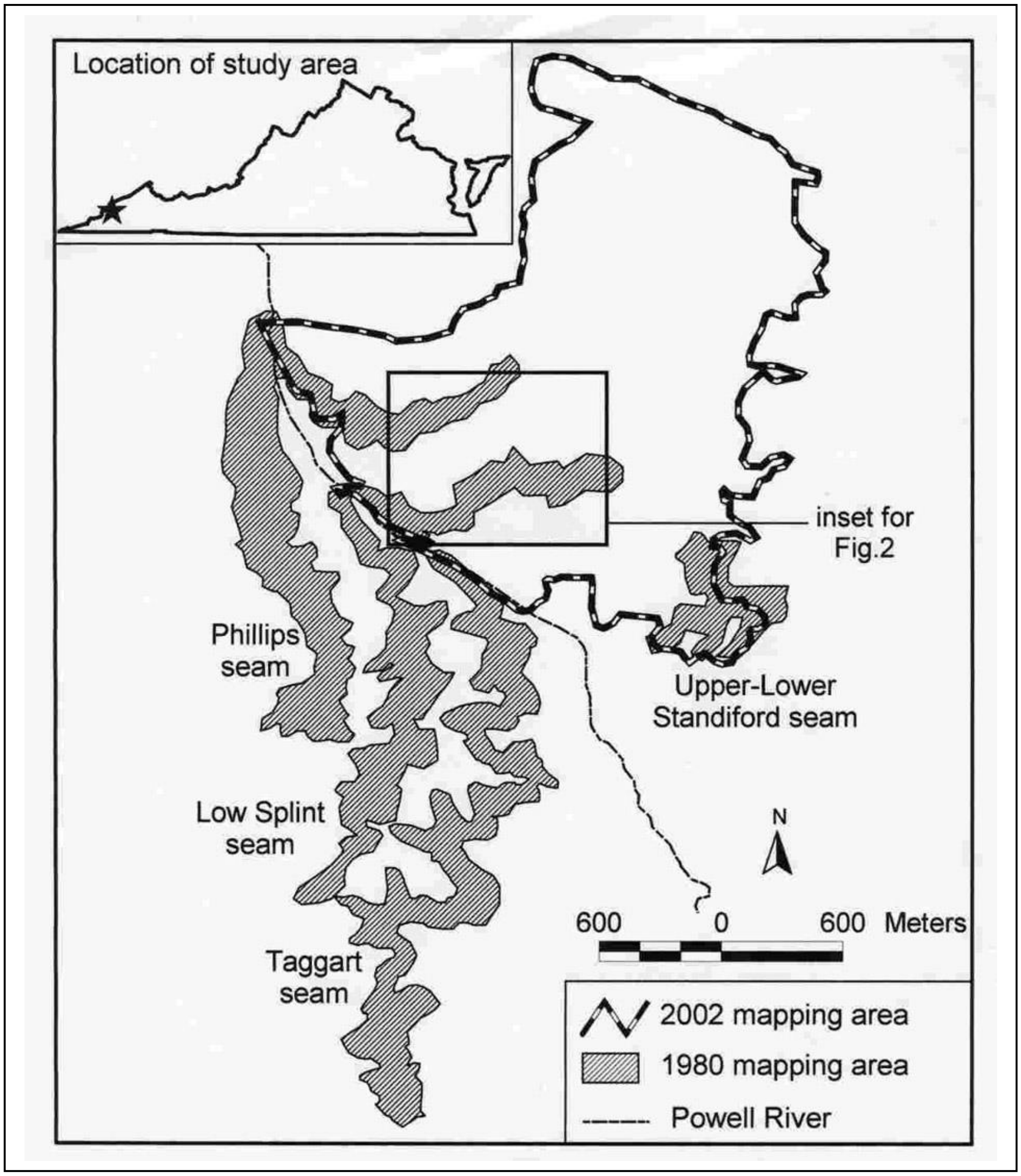

Figure 1. Mine soil study area utilized in 1980 and 2002 at the head of the Powell River in Wise County, Virginia. The older (1980) mapping study was confined to lands directly affected by mining (highwall/bench/outslopes) and therefore did not develop mapping unit concepts for the relatively undisturbed forested sideslopes

occurring between the four mined bench levels shown. The 2002 mapping area outlined above was extensively re-mined in the 1980's and 1990's, which resulted in drastic disturbance of the vast majority of the landscape, including a significant portion (see inset) of the area mapped in 1980.

surface stoniness, particle-size family, and depth to consolidated rock. In the adapted criteria (Table 1), particle-size family and depth to consolidated rock were retained. However, mine soil pH was so variable across the mapped area that it was found to be difficult to apply as a detailed mapping criterion, and was eliminated. The first SCS slope class (0-15%) was divided into two (0-8% and 8-15%) classes because the original range was so wide that it allowed areas with very different management needs to be grouped into one unit. A "rough undulating" slope category (0 to 15%) was also added to cover areas where the surface was very uneven. In the SCS mapping criteria, rock type was not a defined criterion. However, rock type was used in our adapted 1980 mapping criteria because it clearly influences mine soil properties in this area (Daniels and Amos, 1981; Haering et al., 1993). For the 1980 mapping, four rock type classes were established: sandstone (>66%); siltstone (>66%); sandstone (>50%) mixed with siltstone; and siltstone (>50%) mixed with sandstone. Rock color, however, was not used as a mapping criterion.

Between 1977 and 1994, the Low Splint and the Taggart-Taggart Marker seams were re-mined using second-cut contour mining techniques. The area was reclaimed in accordance with SMCRA to approximate original contour insofar as possible, but due to shortage of overburden, extensive gently rolling areas were produced that strongly resemble those in a mountaintop removal/valley fill landscape. The final surface layer consisted of "topsoil substitute" overburden that would provide suitable growth media for plants based on soil test data. To this end, attempts were made to bury any acid-producing materials.

During the fall of 2001, USDA-NRCS mapped approximately 450 ha of the re-mined area for this research project (Fig 2). A detailed (Order 1) working scale of 1:6000 was employed to allow for (1) detailed interpretive value and (2) direct comparison with the 1980 map described above. The initial mapping legend was based on the legend used in Buchanan County, VA, which was concurrently being mapped by NRCS, and is similar in geology and mined landforms to the Powell River Education Center area. Established mine soil series concepts were used, along with slope and stoniness phases, to establish a mapping legend. Since much of the area that was mapped in 1980 is currently under active mining permit, the portion of the site mapped in 2002 was not identical to that mapped in 1980, although relatively large portions of the mapped areas overlapped (Figs 1 and 2.) After field delineation was complete, 20 soil pits were dug in the mapped area at locations chosen cooperatively with NRCS personnel to represent the dominant soils. Pits were excavated by backhoe, described, in Table 1 and the 2002 mapping legend in Table 5.

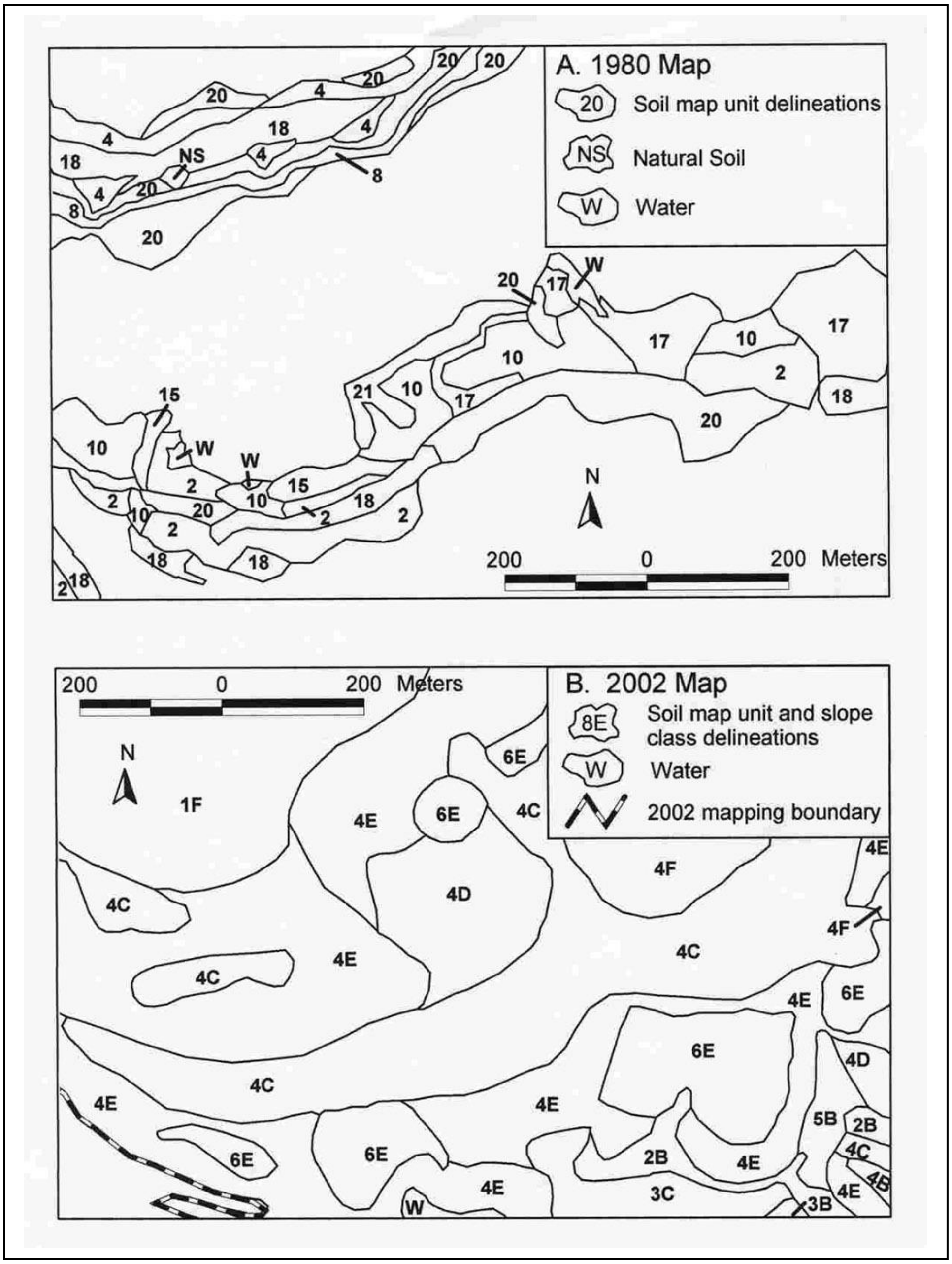

Figure 2. Detailed Order 1 soil surveys of the map inset area shown in Fig.1, mapped utilizing different criteria and methods in 1980 and 2002. The 1980

mine soil landscape (top) clearly reflects the dominant narrow highwall/bench landforms typical of pre-SMCRA mining techniques. The post-SMCRA (bottom) landscape is comprised almost entirely of mine soils with less than 10% natural soil remaining. Description of the 1980 mapping criteria is given

Table 1. Mine soil class criteria used for design of 1980 mapping units. Particle size family was also used as a criterion, but is not included here since all mapping units were loamy-skeletal. A total of 22 discrete mapping units were delineated based on various combinations of the four criteria given below.

Criterion	Classes			
Slope, %	0-8	8-15	15-30	30-70
Depth to rock, cm	0-60	60-120	> 120	N/A
Distance between stones on surface, m	≥ 30	30-10	10-1	< 1
Rock fragment type	Sandstone (> 66%)	Siltstone (> 66%)	Sandstone (> 50%) and siltstone	Siltstone (> 50%) and sandstone

and sampled between February and May of 2002. Data from soil descriptions and subsequent soil sample analyses were used to develop the final mapping legend.

In both 1980 and 2002, large samples (3 to 10 kg) of each horizon were taken for analysis. The soil was air-dried, gently crushed, and sieved through a 2 mm (10 mesh) sieve. In 1980, large samples (3 to 10 kg) of each horizon were sieved in the field to determine the approximate weight percentage of rock fragments ≥75 mm. Mass content of fragments <75 mm was also determined in the lab. In 2002, total rock fragment content and relative percentages of gravels, cobbles, stones and boulders were visually estimated in the field (Soil Survey Staff, 1993). Field rock fragment volume estimates were converted to weight estimates using Method 3B1 (USDA-NRCS, 1996). Percent of small gravel (≤20 mm) content was also quantified in the laboratory by sieving. However, very large (approximately 60 kg) samples are required to accurately measure the percentage of rock fragments between 25 and 75 mm, and visual estimates are recommended for determining percentage of rock fragments >75 mm (Soil Survey Staff, 1993; USDA-NRCS, 1996). Therefore, we did not attempt to statistically compare the values for 1980 vs. 2002 whole soil rock fragment contents due to differences in their determination, and due to the uncertainties in accurate estimation.

Particle-size analysis of soil samples taken in both 1980 and 2002 was performed by the pipette method using air-dry samples using Method 3A1 (USDA-NRCS, 1996). Organic material was removed from A horizons by pretreatment with H_20_2 prior to particle-size analysis. Soil pH was determined in a 1:1 water slurry (Thomas, 1996). Weighted average for whole profile pH, and percent sand, silt, and clay in the assumed particle-size control section (25-100 cm) was calculated. The particle-size control section for Inceptisols and Entisols was chosen because it is used for established mine soil series in southwest Virginia. For the purposes of this study, densic materials were included in the analyses of the 25 to 100 cm section, but four shallow (depth to rock ≤50 cm) mine soils described in 1980 were excluded from statistical comparisons. Soil property comparison parameters were weighted by horizon thickness. The mean weighted averages of various parameters were compared using both a Mann-Whitney test and an approximate 2-sample t-test for different sampling years, and a paired t-test for depth contrasts within the same year (Minitab, 2000). The Mann-Whitney non-parametric contrast compares median values of test parameters, and was used initially for comparing data from sampling years due to small and unequal sample sizes (n=20 to 26). The approximate 2-sample t-test was also used to compare parameter means, and we found the results were identical to the results of the non-parametric test at $p \leq 0.05$.

Results and Discussion

Mine Soils and Mapping Concepts – 2002

The four established mine soil series currently being used to map Southwest Virginia mine soils are Sewell, Fiveblock, Kaymine, and Cedarcreek (Soil Survey Division, 2003). All these series are classified as Typic Udorthents (Table 2). In all series, the percentage of rock fragments range from 15 to 80% by volume, but average 35% or more in the particle-size control section (25-100 cm).

Most of these soils have red, brown, yellow, or gray lithochromic color variegations in at least some horizons. Lithochromic color variegations are caused by contrasting rock fragment colors in the soil

Table 2. Summary of taxonomic classes and properties of established and proposed mine soil series formed in overburden from Central Appalachian coal mining.

Series	Taxonomic class	Soil pH	Clay in control section	Rock fragment type	Drainage class
			------ % ------		
Sewell	Loamy-skeletal, mixed, semiactive, acid, mesic Typic Udorthents	3.5 –5.5	< 18	≥ 65% gray sandstone	Somewhat excessively drained
Fiveblock	Loamy-skeletal, mixed, semiactive, nonacid, mesic Typic Udorthents	5.6 – 7.8	< 18	≥ 65% gray sandstone	Somewhat excessively drained
Cedarcreek	Loamy-skeletal, mixed, active, acid, mesic Typic Udorthents	3.5 – 5.5	> 18	No rock type predominates	Well drained
Kaymine	Loamy-skeletal, mixed, active, nonacid, mesic Typic Udorthents	5.6 – 7.8	> 18	No rock type predominates	Well drained
Proposed Series I	Loamy-skeletal, mixed, semiactive, nonacid, mesic Typic Udorthents	5.6 – 7.8	< 18	No rock type predominates	Well drained
Proposed Series II	Loamy-skeletal, mixed, semiactive, nonacid, mesic Typic Epiaquents	5.6 – 7.8	< 18	No rock type predominates	Poorly to very poorly drained

profile rather than by redoximorphic processes (USDA-NRCS, 2002). All series are typically mapped on both pre- and post-SMCRA mined lands, on slopes ranging from nearly level (<5%) to very steep (<5% to >75%; see Fig. 3). None of the established soils include densic materials (highly compacted; bulk density $\geq$ 1.80 Mg m^{-3}) or the depth to the contact with these materials (Soil Survey Staff, 1999). It is logical to expect that topsoil substitutes emplaced by post-SMCRA reclamation activities would be compacted during grading. Daniels and Amos (1981) also observed highly compacted subsoil layers in pre-SMCRA mine soils which appeared to be primarily related to traffic by rubber tired mining equipment such as loaders and haulers. However, densic materials were not defined or added to *Soil Taxonomy* until after many mine soil series were established.

The four established mine soil series are differentiated by reaction class, particle-size class, and rock color and type (Table 2 and Fig. 3). Sewell and Fiveblock soils both contain <18% clay in the particle-size control section, but have different reaction classes and different dominant rock types. Family-level reaction class is measured between 25 and 50 cm or the top of the root limiting layer if present at < 50 cm (Soil Survey Staff, 1999). Sewell soils form in acid (pH $\leq$ 5.5), brown, oxidized sandstone, and thus have a lower pH than Fiveblock soils, which form primarily in moderately acidic to alkaline (pH 5.6 to 7.8) gray, unoxidized sandstone overburden. Cedarcreek (acid) and Kaymine (non-acid) soils both have > 18% clay in the particle-size control sections and form in mixed overburden (not more than 65% of any rock type), but are differentiated by reaction class.

None of the 20 soil profiles sampled on the Powell River Project area in 2002 contained more than 18% clay in the particle-size control section (Table 3). Mean clay content in the 20 pedons was about 10%, which meant that none of the pedons were classified as either Kaymine or Cedarcreek series. Soils fitting the criteria for the Sewell series were described in earlier work on the Powell River Project (Haering et al., 1993), but that series was not identified at that time. We were able to identify one of the 20 pedons we described and sampled as Sewell, and one as a possible Sewell taxajunct (Table 4). A taxajunct resembles and fits the use and management criteria for an established soil series and only differs by taxonomic criteria (Soil Survey Staff, 1993). In the Sewell taxajunct, the dominant rock fragment type included brown siltstone as well as brown sandstone, and the soil was well drained. We were also able to classify three of the pedons as Fiveblock, and four as a probable new series that had higher pH in the control section than allowed for Fiveblock.

Figure 3. Active mining at Powell River Project area in early 1980's. Older pre-SMCRA highwalls can be seen in background. Deeper unoxidized strata generate the gray spoils seen in the middle of the picture while pre-weathered oxidized strata generate the brown spoils with more acidic reaction and lower rock fragment content. This area also corresponds to the inset area shown in Figs. 1 and 2.

Table 3. Weighted average soil pH in whole profile, and sand, silt, clay, and weight percent rock fragments in particle size control section (25-100 cm, or 25 cm to bedrock, if less than 100 cm deep for the 1980 and 2002 mine soil pedons. Four shallow or very shallow (<50 cm) soils sampled in 1980 were excluded. Rock fragment percentages were not compared statistically because of differences in methods of measurement between the two sampling years

Year	Pedons	Soil pH	Sand	Silt	Clay	Rock Fragments
			----------------------------	%	------------------------------	
2002	20	6.91a†	59a	31a	10a	85
1980	26	5.46b	53a	33a	14b	45

†Mean values followed by the same letter in columns are not significantly different ($\alpha = 0.05$)

Table 4. Closest-fit series level classification of mine soil pedons examined in 2002 and 1980.

	Soil Series†						
Year	Sewell	Fiveblock	Kaymine	Cedarcreek	Proposed Series I	Proposed Series II	Other
	number of pedons						
2002	2	7	0	0	7	4	0
1980	5	4	2	2	7	1	9††

† Includes taxajuncts
†† Three of these nine pedons had mixed rock type and an acid (pH 3.5-5.5) reaction; one pedon was tentatively classified as Itmann series (loamy-skeletal, mixed, acid, mesic Typic Udorthent formed in coal processing wastes); one was somewhat poorly drained; two were shallow; one was very shallow; and one was both very shallow and poorly drained.

We found seven pedons that were well drained and non-acid (pH >5.5), coarse-textured (<18% clay in the particle-size control section), and contained <65% either gray or brown sandstone rock fragments in the particle-size control section. These pedons did not fit within the property ranges of any of the established series concepts currently being used in Virginia by USDA-NRCS. The Fiveblock and Sewell series were originally set up for use on mountaintop removal mines where selective overburden placement was practiced (Soil Survey Division, 2003), and may not be completely applicable to mine soils constructed in other mining situations, such as those found in post-SMCRA deep cut contour mining in southwestern Virginia. Thus, an unnamed well drained series with mixed rock type, < 18% clay, and non-acid reaction was used in our final mapping legend (Table 5) and identified as "Proposed Series I" in map units 4B, 4C, 4D, 4E, and 4F. A description of a typical pedon of Proposed Series I is presented in Table 6 and Fig. 4. Proposed Series I is similar in classification and properties (Table 2) to the Fiveblock and Sewell series, except for parent material and drainage class. It would be similar in use and management to those series even though its properties fall outside of their currently established ranges of properties. Alternatively, the new soils could be identified as a taxajunct to Fiveblock or Sewell, or the series ranges of those series could be expanded.

Table 5. Mine soil mapping legend used in 2002.

Map Unit	Map Unit Type	Description	Slope
			----%---
1F	Complex	(Proposed series I)-Sewell-Rock outcrop	55-150
2B	Complex	(Proposed Series I)-(Proposed series II)	0-8
3B	Consociation	Fiveblock	0-8
3C	Consociation	Fiveblock	8-15
4B	Complex	(Proposed series I)-Sewell	0-8
4C	Complex	(Proposed series I)-Sewell	8-15
4D	Complex	(Proposed series I)-Sewell	15-35
4E	Complex	(Proposed series I)-Sewell	35-55
4F	Complex	(Proposed series I)-Sewell	55-80
5B	Consociation	Sewell	0-8
6E	Complex	Gilpin-Shelocta*	35-55
W	--	Water (pond)	--

*Natural soils mapped in undisturbed areas.

All established mine soil series currently being used in the eastern U.S. are well drained or somewhat excessively drained. A somewhat poorly drained mine soil series has been recently proposed for adoption in Buchanan County, VA (Haering et al., 2002), and significant areas of poorly to very poorly drained mine soils have been documented in the Powell River Project watershed (Atkinson et al., 1998). Although areas of poorly drained mine soils of up to 2 ha have been previously mapped with spot symbols (Ammons and Sencindiver, 1990), researchers working on prime farmland soils have noted that poorly drained mine soils series should be established (Indorante et al., 1992). Current regulatory concern over accurate wetland identification and jurisdictional designation require that these areas be accurately delineated on soil maps wherever possible.

While determining pit locations in the 2002 mapping project, we intentionally located several pits in areas where wetland vegetation indicated that impeded drainage was present, and we described two poorly drained and two very poorly drained pedons. The two poorly drained soils were described in areas where it appeared (from observation of landscape position and redoximorphic features within the profile) that water was removed so slowly that the soils either

Table 6. Typical pedon of proposed series I, described in 2002. Seven pedons of this series were described and sampled in 2002, and seven were described and sampled in 1980.

Horizon	Depth	Description
	---cm---	
A	0-6	Brown (10YR 4/3) very gravelly sandy loam; weak fine granular structure, friable; 55% rock fragments by volume (mostly gravel sized; approximately 50% gray sandstone, 40% brown sandstone, 10% gray siltstone), many fine and very fine roots; neutral (pH 6.7); clear smooth boundary.
AC	6-20	Dark grayish brown (10YR 4/2) extremely cobbly loam, with few brownish yellow (10YR 6/8) and yellowish brown (10YR 7/8) lithochromic color variegations; mainly weak fine subangular blocky structure with small areas of structureless massive; friable; 70% rock fragments by volume (mostly cobbles with some stones and gravels: 35% brown sandstone, 35% gray sandstone; 20% gray siltstone/shale; and 10% carboliths); common fine and very fine roots; slightly alkaline (pH 7.5); clear wavy boundary.
C	20-120+	Very dark grayish brown (10YR 3/2) extremely stony sandy loam with common brownish yellow (10YR 6/8), yellowish brown (10YR 7/8), and strong brown lithochromic color variegations; structureless massive, firm with pockets of loose friable and very firm material; 75% rock fragments by volume (mostly stones in upper part of horizon, boulders in lower part: 40% brown sandstone, 30% gray sandstone, 15% gray siltstone/shale; 15% carboliths); few fine and very fine roots along rock faces in upper part of horizon; slightly alkaline (pH 7.5).
		Notes: This pedon was located on a reclaimed steep shoulder/backslope area. Slope was 30%. Vegetation was mainly grasses such as tall fescue (*Festuca arundinacea* Schreb.) and forbs such as sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don] with scattered small black locust *(Robinia pseudoacacia* L.), and butterfly bush (*Buddleja japonica L.*) The soil was judged to be well to somewhat excessively drained because of the lack of redoximorphic features.

Table 7. Typical pedon of proposed series II, described in 2002. Three pedons of this series, and one pedon of an acid taxajunct, were described and sampled in 2002, and one was described and sampled in 1980.

Horizon	Depth	Description
	---cm---	
Ag	0-20	Dark gray (10YR 4/1) very gravelly sandy loam, with 8% reddish brown (10YR 4/4) and 6% yellowish brown (10YR 5/8) Fe concentrations as pore linings, and common light olive brown (2.5Y 5/4) lithochromic color variegations; moderate medium subangular blocky structure; friable; 40% rock fragments by volume (mainly gravel-sized: 60% gray sandstone; 20% gray siltstone/shale; 15% brown sandstone; 5% carboliths); many medium, fine, and very fine roots; slightly acid (pH 6.2); gradual wavy boundary.
AC	20-55	Gray (10YR 4/2) very gravelly loam, with 6% strong brown (7.5YR 5/8) Fe concentrations and 4% dark gray (2.5Y 4/1) Fe depletions as pore linings, and common brownish yellow (10YR 6/6) lithochromic color variegations; weak coarse subangular blocky structure; mostly firm with some friable areas; 60% rock fragments by volume (mostly gravels and cobbles: 60% gray sandstone; 20% gray siltstone/shale; 15% brown sandstone; 5% carboliths); many medium, fine and very fine roots; neutral (pH 7.3); gradual wavy boundary.
Cd	55-140+	Gray (10YR 4/2) very gravelly loam, with 5% strong brown (7.5 YR 5/6 and 5/8) Fe concentrations and 3% dark gray (2.5Y 4/1) depletions as pore linings, and common brownish yellow (10YR 6/8) lithochromic color variegations; structureless massive; very firm; 60% rock fragments by volume (mostly gravels and cobbles: 60% gray sandstone; 20% gray siltstone/shale; 15% brown sandstone; 5% carboliths); few fine and very fine roots in upper part of horizon; neutral (pH 7.3).
		Notes: This pedon was in a nearly level (< 2% slope) micro-depressional landform in a reclaimed pasture area. Vegetation included rushes (*Juncus sp*.) and sedges (*Carex* sp.) The pit was located in a ponded area and required pumping so that it could be described. The soil was judged to be very poorly drained because of reduced matrix colors in all horizons, evidence of long-term ponding, and redox concentrations in a reduced matrix within 15 cm. of the surface. Meets hydric soil field indicators F3, F8, F9 (USDA-NRCS, 2002)

stayed wet at shallow depths periodically throughout the growing season, or stayed wet for long periods in other parts of the year (Soil Survey Staff, 1993). Vegetation on these poorly drained soils included common hydrophytic rushes (*Juncus* sp.) and/or sedges (*Carex* sp.) and the soils met hydric soil field indicators F3 and F8 (USDA-NRCS, 2002). The two very poorly drained mine soils were described as such because there was evidence that water remained at or very near the ground surface throughout most of the growing season. The vegetation on these very poorly drained soils was also dominantly hydrophytic, and there was a complete absence of previously seeded facultative upland grasses such as tall fescue (*Festuca arundinacea* Schreb.). The very poorly drained soils met hydric soil indicators F3, F8, and F9. Both poorly and very poorly drained soils were located in minor (<1 m local relief) depressions formed during the final grading process, and were found in direct association with well-drained mine soils. Three of the four poorly to very poorly drained pedons we described were non-acid, but one poorly drained pedon with 60% gray sandstone had an average pH of 4.8, indicating that rock color was not always an accurate predictor of pH. The lower pH in this pedon was likely a result of the inclusion of small amounts of acid-producing materials with the gray sandstone overburden.

The poorly and very poorly drained mine soils are identified on the mapping legend (Table 5) as "Proposed Series II" in map unit 2B, and a typical very poorly drained pedon is described in Table 7. Proposed Series II was classified as a Typic Epiaquent, with mixed rock type, <18% clay in the particle-size control sections, and a non-acid reaction class (Table 2). The acid pedon we described would fall outside of the Proposed Series II range, but would be similar in use and management due to impeded drainage. Proposed Series II would be strongly dissimilar in use and management to the previously established and better drained mine soil series because of the poor drainage and long-term ponding.

The presence or absence of densic materials in mine soils is not addressed in the current mine series concepts being applied in the Appalachians. Research on reclaimed mine soils in Illinois, however, has shown that the presence of a compacted layer may be the factor that is most limiting to use and management (Indorante et al., 1994). We found densic materials within 70 cm in 11 of the 20 pedons described as part of the 2002 mapping. These were produced by compaction during grading of the land surface, and appeared to be more common in relatively level areas. Five of the 20 pedons contained a densic contact, including some of the poorly drained pedons, while the others contained readily identifiable densic materials in some part of the soil profile. A densic contact (Cd horizon) was described where densic materials were continuous around the pit face, the horizon was very firm or extremely firm in consistence, and fine roots (if any) were only found along rock fragment faces. In some cases, the densic contact was underlain by loose, friable material with large bridging voids, indicating that the compaction process was limited to a certain depth below the surface.

We did not propose a new series for mine soils with a densic contact because they occurred across both the proposed and established series that we observed in 2002, and they were present in only about 50% of observed pedons. It is likely that compacted (densic), non-compacted, and deep-ripped soils will occur in close association and could fit within the same series range of properties once the distribution of the densic materials are properly specified. Soils with densic contact < 50 cm deep are placed into a shallow family because the densic contact is a root-limiting layer and limits soil depth class (Soil Survey Staff, 1999). After further investigation, it is likely that many new series will be established that are analogues of the current series, but with shallow densic contacts. The presence or absence of a densic contact is very important in mine soil management, and therefore needs to be recognized at the phase or family level when classifying mine soils. At the phase level, soil differences that affect use and management of a given series such as surface texture or flooding potential are accounted for. Mine soils series that contain shallow densic contacts but are later mechanically ripped could be handled as “ripped” phases.

Although NRCS mapped this area at a relatively large scale (1:6,000), the mapping legend (Table 5) was relatively simple because only established mine soil series concepts were used, along with slope and stoniness phases, to establish mapping units. Data distributions from the 20 profiles suggest that these mine soil properties were highly variable over short distances on the same landform. For example, we observed a pH range of 3.7 to 8.4 in two profiles 50 m apart. Rock color was equally variable, although particle-size distribution appeared to be less variable than rock color or pH. This high degree of close-spaced variability was recognized by designing certain map units as complexes of soils and miscellaneous land types (e.g. rock outcrop, water, etc.). Map units were developed by taking the composition of soil series and phases into account. Soil reaction (pH), particle-size, rock content and color, drainage class, as described and observed from the 20 soil profiles were used to separate series and phases. The mapped area included map unit consociations of Fiveblock (3B and 3C) and Sewell series (5B), dominated by a single soil and similar soils. The dominant map unit in the area was a complex of Proposed Series I (see Fig. 4) and Sewell (units 4B, 4C, 4D, 4E, and 4F), since these areas contained dissimilar acid and non-acid mine soils. Rock outcrop is a miscellaneous land type that limits the use of soil in the mapping unit. Map unit 1F was a complex of Proposed Series I, Sewell, and rock outcrop, and was used to describe an area with a partially exposed highwall. Map unit 6E (Gilpin-Shelocta complex) was used to map small areas of remaining natural soils. The Gilpin series (moderately deep) and Shelocta series (deep and very deep), both fine-loamy Typic Hapludults, are identified as a complex because they occur together in such an intricate pattern on the landscape that separating the two soils is impractical at the scale of mapping.

Almost all mine soils studied in 2002 were identified in the same taxonomic class at the family level (e.g. coarse-loamy Typic Udorthents). Mine soils were described and identified with Bw horizons, particularly in instances where the overburden was pre-weathered and the resultant mine soils were somewhat finer in texture (higher in silt). Those soils containing Bw horizons thick enough to qualify as cambic were then classified as Typic Dystrudepts. Further detail on cambic horizon formation and other aspects of pedogenesis in these soils is given by Haering et al. (2004) and in our companion paper in these proceedings.

<u>Mine Soils and Mapping Concepts – 1980</u>

Established mine soil series concepts were not available for use when the research area was first mapped in 1980, so we had to develop site-specific mine soil mapping classes from the criteria described in Table 2. The 1980 mapping was intended to be an Order 1 inventory of the mine soils on four bench levels that could be used to aid locating areas for intensive research on successful revegetation and post-mining land use. Due to the detailed scale utilized (1:4800), and the very complex nature of the landscape mapped (see Fig. 5), many small (< 1 ha) delineations were made, and numerous spot symbols for wetlands, tension cracks, and low pH areas (hotspots) were utilized throughout the mapped section (Fig. 2). This combination of scale and local complexity of the highwall/bench/outslope landscape resulted in the development of over 40 field mapping units. These 40 field units were compiled and correlated to 22 by combining units with similar composition of stoniness, depth, and rock-type-criteria. However, no units were combined to permit a range of more than two classes within one criterion.

Figure 4. Profile of proposed series 1 described in 2002. This pedon is < 18% clay and formed from mixed spoil types.

Figure 5. Mined landscape at Powell River Project area. Older pre-SMCRA

benches can be seen on the ridge in the background. The area in the left center corresponds to the detailed mapping area shown in Figure 2.

The mine soil mapping areas depicted in Figs. 2 and 5 are identical in map coverage, but obviously changed greatly in overall landform type due to re-mining between 1980 and 2002. The 1:4800 1980 mine soil map clearly indicates two narrow linear bench features separated by unmined (unmapped) natural ground. Since the mapping units were based upon a combination of rock type, stoniness, depth and slope criteria, rather than soil series, numerous map unit delineations were identified. In contrast, the 2002 soil map legend was based upon conventional USDA-NRCS Soil Survey map unit criteria and series concepts, and therefore contained fewer delineations per area mapped even though it was mapped at a similar working scale (1:6000). The comparison shown in Fig. 2 also clearly indicates the effects of re-mining over time as the vast majority of the landscape area shown in 2002 is comprised of mine soils while less than half of the 1980 landscape was mined lands.

In general, the profiles sampled in 1980 were significantly lower in pH and higher in clay (α = 0.05), and appeared to be lower in rock fragments than the profiles sampled in 2002 (Table 3). However, we were not able to rigorously quantify differences in rock fragment content because of the different rock fragment measurement methods used in 1980 and 2002. The lower pH and higher clay content of the 1980 mine soils was a result of their containing a higher percentage of brown, pre-weathered, oxidized overburden than the 2002 soils.

While much of the central Appalachian coalfields landscape has been subjected to re-mining in the past twenty years, mine soil landscapes similar to those that we described in 1980 still commonly occur throughout the region, and modern soil mapping and classification efforts must necessarily deal with both pre- and post-SMCRA landforms and associated mine soils. Although the original 1980 study area could obviously not be remapped in 2002 because it had been re-mined, descriptions and data from the 30 profiles characterized in 1980 were used to determine probable mine soil series classifications for individual pedons. We were able to assign tentative series designations to most of the pedons, even though the 1980 pedons generally had much more varied morphology and properties than the 2002 pedons, and the series were much more difficult to identify.

Five of the 1980 pedons were identified as Sewell series and four met the requirements for

Fiveblock series. We were also able to identify two pedons each as being Cedarcreek and Kaymine series. Seven of the 1980 pedons contained < 18% clay, mixed rock type, and non acid reaction, and fit the concept of our Proposed Series I. Three pedons had < 18% clay, mixed rock type, and an acid reaction. These would either be identified as another new proposed series (which would be similar to Proposed Series I, but with an acid reaction), or treated as Sewell taxajuncts. One pedon formed primarily in carbolithic material (oxidized coal), and was identified as the Itmann series, a loamy-skeletal, mixed, acid, mesic Typic Udorthent that is formed in coal processing wastes.

Four of the profiles on the middle portions of benches were shallow or very shallow to rock. It appears that shallow mine soils are relatively common on older pre-SMCRA (highwall/bench/outslope) landscapes. However, all current series concepts are deep (> 100 cm) soils. These shallow soils should be identified as new series and mapped in consociations or complex map units because they are dissimilar to deeper soils and have use limitations. There were also four somewhat poorly to poorly drained pedons described, all with acid reaction, located on benches. These soils with impeded drainage would limit building construction, but that is an unlikely land use on these older mined areas.

Fifteen out of the 30 pedons described in 1980 contained densic materials (≥ 1.8 g/cc bulk density) and a densic contact within 70 cm of the soil surface. Densic contacts occurred across all series and in about half of the described pedons. These compacted soils were most often located in the middle of benches, but were observed to occur in all positions on the bench itself as a result of equipment traffic. Plant rooting was either completely limited by these compacted layers, or was confined to rock fragment faces.

Weak Bw horizons have been described in some older Appalachian mine soil pedons, usually because they contain more evident soil structure (Haering et al., 1993; 2004). Some Bw horizons have also met the color, thickness and depth requirement for cambic horizons (Ciolkosz et al., 1985), and the soils are therefore identified as Inceptisols. Currently, however, there are no established mine soil series that are Inceptisols, so these soils would be treated as non-limiting taxajuncts to existing mine soil series. Distinct Bw horizons with moderate structure were described in six of the pedons described in 1980, although these were ignored in our tentative classifications. Although these horizons contained structure which was more evident and stronger in grade than that in the adjoining A and C horizons, none of them met the increased clay requirement, only two of them met both the depth and relative color difference requirement for cambic horizons. Mine soils often form subsoil horizons in layers of different spoil types, so these relative color differences my have resulted from different parent materials rather than from soil development.

Conclusions

The mine soil series concepts currently being used in Virginia adequately described mine soil particle-size class, soil texture, and pH of the mine soil profiles characterized in both the 2002 and 1980 mapping projects. Soil pH was so variable within short distances, however, that it was not used as a mapping criteria in 1980, and it was necessary to use complexes of soils with different pH values in most of the 2002 mapping units. We observed soils with drainage class and rock type/color properties that were well outside of the range of established mine soil series. One type of mine soil that was common in both mapped areas contained <18% clay, was non-acid, well-drained, and had mixed rock type, and therefore did not fit in the range of any established mine soils. We therefore proposed a new series to cover these soils, although they would not differ in use and management from the established Fiveblock series, and could have been identified as taxajuncts.

In mine soils constructed both before and after SMCRA, we found poorly and very poorly drained mine soils that would not be covered under any of the currently established mine soil series and associated interpretive frameworks. These soils are currently mapped with spot symbols, or listed as map unit inclusions due to their small extent. Most of these soils occurred in a complex with well drained mine soils in micro-depressions on nearly levels created during grading in the post-SMCRA mine soils, and on benches in the pre-SMCRA areas. However, occasionally these areas do exceed several contiguous ha in size, and are too large to be spot symbols or map unit inclusions. We have therefore proposed another new series that would include these poorly and very poorly drained soils. Contrasting drainage class is a soil series criterion and soil use and management is greatly affected by drainage class, as is hydric soil identification (USDA-NRCS, 2002).

Half the mine soils in both the 2002 and 1980 mapping projects contained densic materials in their C horizons. We did not propose a new series to cover mine soils with densic contact, since densic materials were found across all of the established and proposed series we used to classify these mine soils. However, since a densic contact affects soil depth and post-mining land use considerably, we feel that the presence or absence of densic materials should be addressed at the series level in the future classification of these soils. Remediated (ripped) areas could be identified at the phase level for mapping purposes.

Mine soils constructed before SMCRA in this study were generally finer-textured (> 14% clay) and lower in pH (< 5.5) than post-SMCRA mine soils. This is likely a result of the fact that the pre-SMCRA mine soils formed primarily in oxidized, pre-weathered overburden. The larger percentage of unoxidized, unweathered, overburden parent material in the post-SMCRA soils is a result of improvements in mining efficiency that allows mine operators to take wider and deeper cuts into harder, unweathered overburden strata.

The current surface coal-mined landscape of the central Appalachians contains a complex mixture of landforms similar to those mapped by this project in 1980 and 2002. The older, pre-SMCRA landscapes are particularly complex due to their combination of narrow bench and highwall landscapes with intervening undisturbed forested sideslopes. When mapped at an Order 1 level of detail, such as in this study, this inherent landform variability can be accounted for and delineated utilizing current USDA-NRCS Soil Survey procedures, or via site-specific application of the older USDA-SCS criteria that were commonly used before the mid-1980's. The mine soils found on these older (pre-1980) landscapes are likely to be much more variable in important properties such as depth to rock, densic contact, spoil type, and reaction class than those produced by more modern mining methods. The larger scale of disturbance associated with post-SMCRA mining often entails the simultaneous removal of multiple seams and occasionally entire ridge systems, resulting in much more uniform post mining landscapes with respect to surface contours. However, our detailed pedon analysis in 2002 still revealed significant close-spaced variability in fundamental soil properties such as occurrence of densic contacts and poor internal drainage important to effective land use interpretations.

Overall, the use of large map scales ($\leq$ 1:12,000) is essential to delineate and accurately portray the local complexity of these lands, particularly those created before the passage of SMCRA in 1977. On these older mined lands, the narrow and sinuous nature of the characteristic highwall/bench/outslope landscape, coupled with the frequent inclusion of relatively narrow

(< 150 m; see Fig. 2a) strips of undisturbed lands between mining benches, is very difficult or impossible to delineate at conventional soil mapping scales (e.g. 1:24,000).

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