2016/2017 Research Report

Long-Term Effects of Rock Type, Amendments and Weathering on Mine Soil Properties and TDS Potentials

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Executive Summary

In the early 1980s, the USDI Office of Surface Mining (OSM) and the Powell River Project (PRP) cooperatively funded the construction and establishment of the Controlled Overburden Placement (COP) experiment. This research project is the longest running of its kind in the world and has generated over 50 journal and proceedings articles to date. Results from these plots have largely underpinned regional protocols for topsoil substitute selection since the mid-1980s. Our current research program is designed to complete the determination of long-term (30+ years) effects of overburden rock type and surface treatments on important mine soil morphological, physical, and chemical properties. In parallel, we also plan to measure the net TDS elution potential from a set of archived fresh spoil samples taken in 1982 from the initial phase of the experiment vs. weathered rock fragments extracted at varying depths from the current plots. Once this study is completed, we will combine our findings to predict the ability of selected overburden materials to weather and transform into mine soils suitable for the support of native hardwoods and hayland/pasture vegetation, and to estimate their rate(s) of transformation.

During the 2016-2017 project year, we completed the detailed morphological description of soil profiles from selected treatments in the COP Rock Mix and Surface Amendment experiments. Bulk soil/rock samples (n = 370) were taken from all morphological horizons and then incrementally with depth. To date, we have fully processed all samples to separate out the rock fragment components and we have completed most chemical and physical analyses. In this report, we focus on the morphological properties of these soils as described in September 2016. The morphology of these 30+ year-old mine soils is striking. Profound physical x chemical weathering of the rock spoils was noted, particularly in the higher siltstone spoils. Well aggregated ^A horizons have formed to depths > 10 cm and most subsoils contained moderately well-developed cambic ^Bw horizons. The long-term influence of sawdust and biosolids additions in the surface treatment experiment is still apparent in darker overall colors and stronger aggregation than noted in the untreated control plots. Perhaps most surprising is the apparent development of compacted subsoil layers in the lower B and C horizons. Since all vehicle traffic has been excluded, we can only hypothesize that these layers are being formed by net physical illuviation and sorting of finer textured soil sized materials downward.

In the coming project year (2017/2018), we propose to complete all remaining analyses (primarily texture and bulk density) and develop a new column leaching protocol to evaluate differences in TDS leaching potentials of the original archived 1982 vs. 2016 rock samples extracted from the plots. If funds are available for a final third year (2018/2019), we will complete lab analyses on C forms (humus vs. coal vs. carbonate) in samples from 1982, 2008, and 2016 to quantify C-sequestration rates, along with describing, sampling and analyzing a set of local native soil profiles for comparison.

Introduction and Background

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 contained a number of contentious provisions including return to original contour (AOC), long-term liability bonding periods, and return to "equal or better" post-mining land use conditions. However, one of the more important provisions was SMCRA's allowance for use of pre-selected overburden materials as topsoil substitutes when (A) the native A+E horizon materials are less than 6 inches thick, and (B) the physical and chemical properties of the proposed substitute spoil materials are deemed suitable for such use. Since native topsoil layers throughout the Appalachian coalfields are usually less than six inches thick, and removing them from steep slopes is difficult and expensive, the vast majority of coal mined lands in the region have employed topsoil substitutes.

In 1982, the USDI Office of Surface Mining and the Powell River Project (PRP) co-funded the installation of the Controlled Overburden Placement (COP) experiment to objectively assess the viability of the topsoil substitute concept and to determine whether or not organic amendments would be beneficial. In one component of the COP experiment we are directly comparing five mixes of sandstone:siltstone (SS:SiS) overburden while in a separate experiment we are following the effects of topsoil return, sawdust addition and four incremental loading rates of biosolids. All treatments are replicated four times and the plots are split between herbaceous (dominantly tall fescue) and forest (red oak following pine) vegetation. We intensively monitored those two side-by-side experiments through the mid 2000's and our results can be reviewed at the PRP web site and at http://landrehab.org. The original installation and early results are summarized by Roberts et al. (1988 a,b,c) and Haering et al. (1993) reported on the initial development of soil morphology as observed from soil pits. Most recently, Nash (2012) sampled the surface and subsoil layers in both experiments and reported on long-term changes in chemical and physical properties along with an initial attempt to quantify actual rates of C-sequestration. In summary, we have found that (A) properly selected and placed spoil materials provided an outstanding soil medium for tall fescue production and allowed vigorous invasion of native herbaceous species; (B) higher pH spoils such as the siltstone strata employed were deleterious to pine tree growth; and (C) higher rates of biosolids amendments drove high fescue production while suppressing the pines. The COP experiment remains the longest intact and continuously monitored study of mine soil genesis in the world. Follow-up studies by various PRP researchers at other sites in the 1990's and 2000's also characterized the wider effects of biosolids applications and the nature of inherent variability in mine soil properties in the Research & Education Center area (Haering et al., 2004).

Over the past several decades, the concept of topsoil substitution has been directly and indirectly criticized from a number of perspectives. First of all, advocates of the return of Appalachian mined lands to native forest covers have pointed to the lack of topsoil salvage and the inclusion of higher pH unweathered spoils as directly inhibiting effective reforestation. Secondly, the fact that relatively unweathered spoils (such as those employed in the COP study) release significant total dissolved solids (TDS) loads to drainage waters over time has been implicated as a component of mining related surface water degradation under both low and moderate pH conditions. Finally, the ability of these mine soils to accumulate organic matter, maintain a stable and viable microbial biomass and available nutrient pools, and overall productivity potentials beyond the requisite five-year performance liability period is also questioned by many.

Progress to Date and Future Research Plans

This program was originally proposed and funded by PRP in 2016/2017 as a one-year intensive project with the expectation that further funding for this fiscal year (2017/2018) would not be available. During the 2016-2017 project year, we completed the detailed morphological description of soil profiles from three selected treatments in the rock mix experiment and five treatments from the surface amendment experiment. Bulk soil/rock samples were taken from all morphological horizons and then every 10 cm with depth. To date, we have completed basic chemical analyses on these samples and initiated physical property analyses. Our interpretations of overall morphology and mine soil weathering processes are summarized in this report. Our 2018 report will focus on changes in chemical and physical properties of these soils once all lab analyses are completed.

In the current project year (2017/2018), we also plan to develop a new column leaching protocol to evaluate differences in TDS leaching potentials of the original samples archived in 1982 vs. 2016 rock samples extracted from the plots. If funds are available for a final third year (2018/2019), we will complete further more detailed lab analyses on C forms (humus vs. coal vs. carbonates) in samples from 1982, 2008 and 2016 to quantify organic matter accumulation (C-sequestration) rates. We will then combine data sets from all 35+ years of the experiment to produce a model of long-term soil development. Finally, we will combine our findings to predict the ability of selected overburden materials to weather and transform into mine soils suitable for the support of native hardwoods and hayland/pasture vegetation, and to estimate their rate(s) of transformation.

Thus, by a combination of direct and differential analyses, we are currently working to meet the following objectives:

Research Objectives

1. To determine the long-term (30+ years) effects of overburden rock type and surface treatments on important mine soil morphological, physical, and chemical properties.

2. To measure the net TDS elution potential of a range of fresh, partially weathered and well-weathered topsoil substitute materials.

3. To estimate the actual rate of organic matter accumulation (C-sequestration) in these mine soils and to compare the properties of these now relatively well-developed mine soils to local native soils.

4. To predict the ability of selected overburden materials to weather and transform into mine soils suitable for the support of native hardwoods and hayland/pasture vegetation, and to estimate their rate(s) of transformation.

Methods and Procedures

This project is focused on the analysis of a combination of current and past data sets and mine soil samples from the Controlled Overburden Placement (COP) experiment established in 1982. For the results reported here, we excavated, sampled and described three pedons in late September 2016 from each of the pure SS, 1:1 SS:SiS, and pure SiS treatments in the Rock Mix experiment along with three pedons each from the control (2:1 SS:SiS), topsoil, 50 T/Ac sawdust, and 25 T/Ac + 50 T/Ac biosolids plots in the Surface Treatment experiment.

Figure 1. Soil observation and sampling pit being excavated by Dan Early in a pure siltstone (SiS) plot in the Rock Mix Experiment in September 2016. Excavator traffic was limited to the alleyways between plots and the soil pit face was aligned to allow for optimal photography.

At each pit location we carefully described mine soil morphology, rooting features, and spoil packing/settling patterns using standard soil survey protocols. We took photographs and at a later date, we will superimpose a grid to allow better volumetric quantification of rock amount/size, coarse rooting and other important features. We then incrementally sampled the mine soils with depth by both morphological horizon (e.g. A-Bw-C) and in 10 cm increments from 50 cm and then again from 50 to 75 cm and 75 to 100 cm to allow quantification of changes in physical and chemical properties with depth. Finally, representative rock fragments were sampled from the upper 0-20 cm, 50-70 cm and from the lowest portion (~1.5 m) of each pit for future TDS studies. A total of 370 separate samples were collected for laboratory analysis. These samples were air-dried in our greenhouse at Virginia Tech and then rock fragments (> 2 mm) were separated away from soil fines for each bulk sample. This was an extremely laborious process and took approximately three months to complete. The fine earth fraction (< 2 mm) was then transported to our laboratories where the following analyses are being conducted:

- pH and total titratable/exchangeable acidity
- Saturated paste electrical conductance and soluble salts species (cations + anions)
- Total organic carbon and Walkley-Black organic matter
- Total-N
- Exchangeable cations
- Dilute acid extractable nutrients and metals
- Extractable Fe- and Mn-oxides
- Calcium carbonate equivalence
- % Rock fragments
- Particle size analysis
- Bulk density on intact clods (taken from cohesive subsoil layers from pits)
- Moisture desorption/water holding capacity on < 2mm fractions

Vegetation was also surveyed on the plots by Sara Klopf in September of 2016.

Over the past project year, we completed approximately 2/3 of the laboratory analyses listed above, primarily for chemical parameters. All lab analyses will be completed in 2017/2018. Over the coming year, we will also utilize archived rock fragments from the original 1982 sampling along with the current (Fall 2016) rock fragment samples to make up a set of TDS leaching columns. These will be run via the technique developed in our lab under the combined PRP/ARIES/OSM funded TDS prediction project. This will allow determination of the extent to which TDS elution potentials for the two dominant spoil types have (a) changed over thirty years and (b) vary between near-surface and deeper weathering zones in the current day mine soils.

Results and Discussion

In this report, we focus on the morphological properties of these soils as described in September 2016. The morphology of these 30+ year-old mine soils was striking and varied widely among rock types and surface treatments as discussed in more detail below. This soil pit sampling was the first since 1989 (Haering et al., 1993), and significant changes in overall horizon development and associated pedogenesis were obvious in all profiles. In particular, overall ^A horizons were deeper and more distinct. Similarly, the subsoils had differentiated into moderately well-developed ^Bw horizons in all pedons while only certain treatments (e.g. sawdust) contained ^Bw horizons in 1989. Representative profile descriptions (Tables 1 – 5) for five pedons from September 2016 along with images (Figures 2 – 6) of each are provided below along with summary commentary in their captions.

Table 1. Soil profile description for Plot 2 (1:1 SS:SiS) in Controlled Overburden Placement Experiment. Described and sampled in late September, 2016.

Described and Sampled by: D. Johnson, J. Buckwalter, K. Haering; Parent Material: 1:1 Sandstone:Siltstone.

Vegetation: Mostly multiflora rose (*Rosa multiflora*) and *Solidago altissima* var. altissima. Also native ferns, red maple (*Acer rubrum*) and elm (Ulmus sp) seedlings, *Erigeron sp., Carex* sp, tall fescue (*Schedonorus arundinaceus*), broomsedge (*Andropogon virginicus*). Northern red oak (*Quercus rubra*) in overstory.

Horizon	Depth	Description
	--cm--	
O	3-0	Partially decomposed mixed leaf litter.
^A	0-9	Very dark grayish brown (10YR 3/2) gravelly loam; moderate granular structure; friable; many (5) coarse, common (4) very fine and (3) fine roots; 15% rock fragments by volume (15% gravel); low relative bulk density; no packing voids; clear smooth boundary.
^Bw	9-30	Dark yellowish brown (10YR 3/6) stony loam, with common (10%) dark yellowish brown (10YR 4/6) lithochromic color variegations; weak subangular blocky structure; friable; many (6) fine and common (3) coarse roots; 20% rock fragments by volume (20% stones); medium relative bulk density; no packing voids; clear wavy boundary.
^C1	30-84	Dark yellowish brown (10YR 4/4) extremely stony loam, with common (19%) dark gray (10YR 4/1) lithochromic color variegations; structureless massive structure; friable; common (2) very fine and (1) fine roots; 65% rock fragments by volume (50% stones, 15% gravel); high relative bulk density; no packing voids; clear irregular boundary.
^C2	84-125+	Dark gray (10YR 4/1) very stony clay loam, with many (25%) dark yellowish brown (10YR 3/6) lithochromic color variegations; structureless massive structure; firm; few (0.8) coarse roots; 50% rock fragments by volume (40% stones, 10% gravels); medium relative bulk density; no packing voids.
Remarks:		Lower ^Bw and ^C1 are quite compact due to "settling" and possibly migration of fines downward over time.

Figure 2. Soil profile from Plot #2, 1:1 Sandstone:Siltstone (SS:SiS) mine soil after 34 years of development. Note well-developed ^A horizon due to organic matter incorporation over time and ^Bw horizon delineated based on > 50% by volume of weak to moderate structural development. The lower portion of the ^Bw and the C1 were quite compact and root limiting, even though the spoils were loosely end-dumped and excluded from traffic.

Table 2. Soil profile description for Plot 15 (SiS) in Controlled Overburden Placement Experiment. Described and sampled in late September, 2016.

Described and Sampled by: D. Johnson, J. Buckwalter; Parent Material: 100% Siltstone

Vegetation: (~75% cover), *lespedeza cuneata*, Allegheny blackberry, tall fescue, some *Acer rubrum* seedlings. Willows (*Salix sp*.) and Northern red oak (*Quercus rubra*) in overstory. Large Autumn olive over pit

Horizon	Depth	Description
	--cm--	
O	3-0	Partially decomposed mixed leaf litter.
^A	0-12	Very dark grayish brown (10YR 3/2) gravelly silt loam; moderate granular structure; friable; many (7) very fine and common (3) fine and (1) coarse roots; 22% rock fragments by volume (20% gravels, 2% stones); low relative bulk density; no packing voids; clear smooth boundary.
^Bw	12-32	Very dark grayish brown (10YR 3/2) gravelly loam; weak subangular blocky structure; friable; common (3) fine, (2) very fine, and (1) coarse roots; 32% rock fragments by volume (30% gravels, 2% stones); medium relative bulk density; few packing voids; gradual wavy boundary.
^BC	32-58	Dark grayish brown (10YR 4/2) very gravelly loam; weak subangular blocky structure; friable; common (3) very fine and few (0.5) coarse roots; 45% rock fragments by volume (30% gravels, 10% cobbles, 5% stones); medium relative bulk density; few packing voids; gradual smooth boundary.
^CB	58-86	Dark gray (10YR 4/1) extremely cobbly loam; weak subangular blocky structure; friable; common (2) very fine and very few (0.1) coarse roots; 75% rock fragments by volume (35% gravels, 25% cobbles, 10% stones, 5% boulders); medium relative bulk density; few packing voids; gradual wavy boundary.
^C	86-125+	Dark grayish brown (10YR 4/2) very gravelly clay loam; structureless massive structure; very friable; few (0.5) coarse and (0.5) fine roots; 75% rock fragments by volume (35% gravels, 25% cobbles, 10% stones, 5% boulders); medium relative bulk density; common packing voids.
Remarks:		Plot 15 siltstone is much coarser/rockier than plot 14 and plot 9 siltstone. B horizons in siltstone plots are less developed than other rock mixes overall.

Figure 3. Soil profile from Plot #15, Siltstone mine soil after 34 years of development. This pedon was considerably higher in rock fragments than the other two pure SiS profiles, but still exhibits significant physical weathering effects relative to its original rock content (>80%) in 1982. Subsoil compaction was not as notable in this particular profile.

Table 3. Soil profile description for Plot 25 (112 Mg/ha sawdust over 2:1 SS:SiS) in the Controlled Overburden Placement Experiment. Described and sampled in late September, 2016.

Described and Sampled by: D. Johnson, J. Buckwalter; Parent Material: 2:1 Sandstone:siltstone amended with 112 Mg/ha sawdust.

Vegetation: Little veg (<40% cover). Allegheny blackberry, some *Lespedeza cuneata*, native ferns. Lots of Autumn olive in overstory, plus *Quercus rubra*.

Horizon	Depth	Description
	--cm--	
O	2-0	Partially decomposed mixed leaf litter.
^A	0-12	Very dark brown (10YR 2/2) loam; moderate granular structure; friable; many (6) very fine and (6) fine and common (3) very coarse roots; 10% rock fragments by volume (10% gravels); low relative bulk density; no packing voids; clear smooth boundary.
^BA	12-25	Dark yellowish brown (10YR 3/4) gravelly loam; weak subangular blocky structure; very friable; common (7) fine roots; 15% rock fragments by volume (15% gravels); low relative bulk density; no packing voids; clear smooth boundary.
^Bw	25-50	Dark yellowish brown (10YR 3/6) very gravelly loam; moderate subangular blocky structure; friable; common (2) fine roots; 35% rock fragments by volume (20% cobbles, 15% gravels); medium relative bulk density; no packing voids; gradual wavy boundary.
^BC	50-90	Dark brown (10YR 3/3) very gravelly sandy loam; weak subangular blocky structure; very friable; common (2) fine roots and few (0.5) coarse roots; 35% rock fragments by volume (20% gravels, 10% cobbles, 5% stones); medium relative bulk density; no packing voids; gradual smooth boundary.
^C	90-125+	Dark yellowish brown (10YR 3/4) very gravelly sandy loam; structureless massive structure; friable; common (2) fine roots; 35% rock fragments by volume (20% gravels, 10% cobbles, 5% stones); medium relative bulk density; no packing voids.
Remarks:		Much lower rock content than most other profiles with only moderate subsoil compaction. Significant rooting throughout profile.

Figure 4. Soil profile from Plot #25; 112 Mg/ha sawdust added to 2:1 SS:SiS. Rock content was lower in this soil and subsoil compaction was not as notable in this particular profile, but the subsoil ^Bw was considerably more compact than observed in 1989 by Haering et al. (1993).

Table 4. Soil profile description for Plot 31 (112 Mg/ha biosolids over 2:1 SS:SiS) in the Controlled Overburden Placement Experiment. Described and sampled in late September, 2016.

Described and Sampled by: D. Johnson, J. Buckwalter; Parent Material: 2:1 Sandstone:siltstone amended with 112 Mg/ha sewage sludge biosolids.

Vegetation: Very little herbaceous veg (20% cover). Allegheny blackberry, native ferns (2 species), poison ivy, *Lespedeza cuneata*. Mostly autumn olive in overstory.

Horizon	Depth	Description
	--cm--	
O	5-0	Partially decomposed mixed leaf litter.
^A	0-10	Very dark grayish brown (10YR 3/2) very gravelly silt loam; moderate granular structure; friable; many (5) very fine, common (3) fine and (1) coarse, and few (0.5) very coarse roots; 45% rock fragments by volume (25% gravels, 10% cobbles, 10% stones); low relative bulk density; no packing voids; clear smooth boundary.
^Bw	10-29	Very dark grayish brown (10YR 3/2) extremely gravelly sandy loam, with many (35%) dark yellowish brown (10YR 4/6) lithochromic color variegations; weak subangular blocky structure; friable; common (2) fine and (1) very fine and few (0.2) coarse roots; 65% rock fragments by volume (35% gravels, 20% cobbles, 10% stones); medium relative bulk density; few packing voids; gradual wavy boundary.
^C1	29-75	Brown (10YR 4/3) extremely gravelly sandy loam, with many (40%) yellowish brown (10YR 5/6) lithochromic color variegations; structureless massive; friable; few (0.8) medium and (0.2) very fine roots; 70% rock fragments by volume (40% gravels, 20% stones, 10% cobbles); high relative bulk density; no packing voids; clear irregular boundary.
^C2	75-125+	Yellowish brown (10YR 5/6) very cobbly sandy loam, with common (15%) brown (10YR 4/3) lithochromic color variegations; structureless massive; very friable; common (1) medium roots; 50% rock fragments by volume (30% gravels , 20% cobbles); medium relative bulk density; few packing voids.
Remarks:		Several large stones across top of pit face.

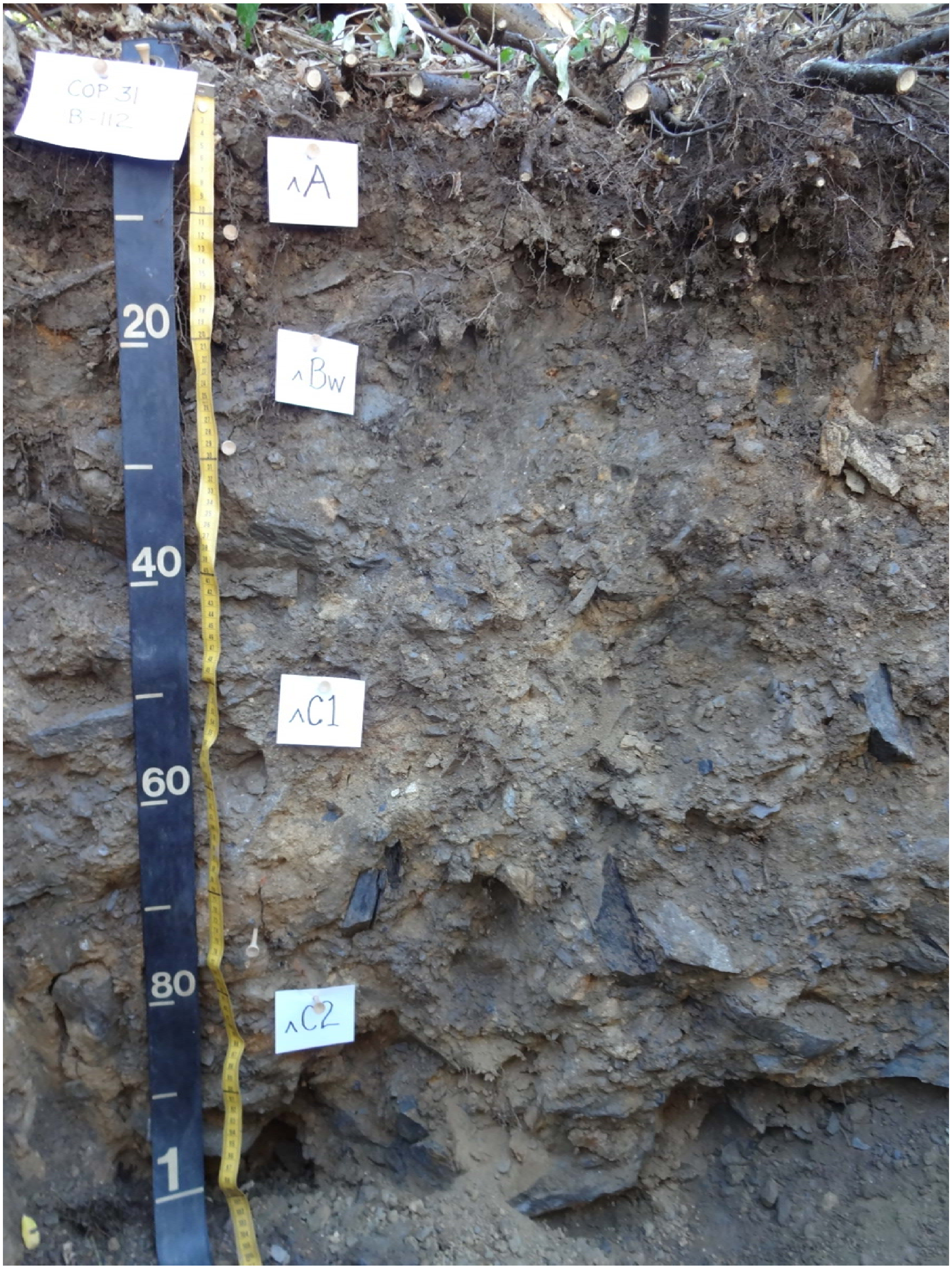

Figure 5. Soil profile from Plot #31, 112 Mg/ha biosolids added to 2:1 SS:SiS. Both ^C horizons were quite compact and root limiting. Note the dark, thick and well-aggregated ^A horizon with heavy rooting concentration.

Table 5. Soil profile description for Plot 46 (30 cm topsoil 2:1 SS:SiS) in the Controlled Overburden Placement Experiment. Described and sampled in late September, 2016.

Described and Sampled by: D. Johnson, J. Buckwalter; Parent Material: 2:1 Sandstone:siltstone amended with 30cm of topsoil

Vegetation: *Solidago altissima var altissima, Lespedeza cuneata,* Allegheny blackberry, some poison ivy and *Clematis virginiana*. Northern red oak (*Quercus rubra*) in overstory a little away from plot.

Horizon	Depth	Description
	--cm--	
O	7-0	Partially decomposed mixed leaf litter.
^A1	0-7	Brown (10YR 4/3) gravelly loam; moderate granular structure; friable; many (5) very fine, common (1) medium, and few (0.5) very coarse roots; 20% rock fragments by volume (20% gravels); low relative bulk density; no packing voids; clear wavy boundary.
^A2	7-15	Yellowish brown (10YR 5/4) very gravelly sandy loam, with many (40%) brown (10YR 4/3) and few (1%) yellowish brown (10YR 5/8) lithochromic color variegations; moderate subangular blocky structure; friable; common (4) very fine and few (0.3) medium and (0.1) very coarse roots; 44% rock fragments by volume (34% gravels, 5% cobbles, 5% stones); low relative bulk density; no packing voids; clear wavy boundary.
^Bw	15-40	Brown (10YR 4/3) extremely gravelly sandy loam, with common (10%) brown (10YR 4/3) lithochromic color variegations; weak subangular blocky structure; friable; common (1) very fine and few (0.1) coarse roots; 75% rock fragments by volume (50% gravels, 20% cobbles, 5% stones); high relative bulk density; few packing voids; clear irregular boundary.
^BC	40-74	Very dark grayish brown (10YR 3/2) extremely gravelly sandy loam, with few (1%) yellowish brown (10YR 5/8) and (1%) dark grayish brown (10YR 4/2) lithochromic color variegations; weak subangular blocky structure; friable; few (0.5) very fine and (0.1) coarse roots; 76% rock fragments by volume (40% gravels, 20% cobbles, 15% stones, 1% boulders); medium relative bulk density; common packing voids; clear irregular boundary.
^C	74-125+	Brown (10YR 4/3) extremely gravelly sandy loam, with common (5%) very dark grayish brown (10YR 3/2) lithochromic color variegations; structureless massive; very friable; many (4) very fine roots; 60% rock fragments by volume (35% gravels, 20% cobbles, 5% boulders); medium relative bulk density; few packing voids.
Remarks:		Large flat stone covering 1/2 of pit face at surface. ^A2 horizon shows signs of physical mixing. 1% carboliths in ^Bw horizon.

Figure 6. Soil profile from Plot #46, 30 cm topsoil over 2:1 SS:SiS. The ^Bw horizon was quite compact and root limiting. The ^A1 and ^A2 horizon still showed dominant yellowish brown coloration of the original mixed A-B-C horizon materials that were added as “topsoil” in 1982. The ^Bw horizon was quite dense and root limiting.

Overall, profound physical x chemical weathering of the rock spoils was noted in all treatments relative to observations made in the late 1980s, particularly in the higher siltstone spoils. Well aggregated ^A horizons have formed to depths > 10 cm (Tables 6 and 7) in most treatments and all pedons contained moderately well-developed cambic ^Bw horizons, with many containing deeper transitional BC horizons. In 1989, only certain treatments (e.g. sawdust) contained cambic horizons and most profiles were described with simpler A-AC-C horizon morphology.

Table 6. Controlled Overburden Placement Rock Mix soil profiles in 2016 (mean of 3 pits/treatment).

Treatment	Depth of A	Depth to bottom of Bw
Sandstone (SS)	9b*	41a
1:1 SS:SiS	10ab	38a
Siltstone (SiS)	12a	36a

*Column means followed by different letters are significantly different ($p \leq 0.05$, Fisher's LSD).

Table 7. Controlled Overburden Placement Surface Amendment soil profiles 2016 (mean of 3 pits/treatment).

Treatment	Depth of A	Depth to bottom of Bw
Control (2:1 SS:SiS)	8c*	39a
Topsoil (30 cm)	17a	48a
Sawdust (112 Mg/ha)	12b	45a
Biosolids (56 Mg/ha)	10bc	43a
Biosolids (112 Mg/ha)	10bc	45a

*Column means followed by different letters are significantly different ($p \leq 0.05$, Fisher's LSD).

The long-term influence of sawdust and biosolids additions in the surface treatment experiment is still apparent in darker overall colors and stronger aggregation than noted in the untreated control plots. In 1989, average A horizon depth across most treatments was 7 cm while most treatments supported ^A horizons $\geq$ 10 cm in thickness in 2016.

Perhaps our most surprising observation in this study is the apparent development of compacted subsoil layers in the lower B and C horizons. Since all vehicle traffic has been excluded, we can only hypothesize that these layers are being formed by net physical illuviation and sorting of finer textured soil sized materials downward over extended periods of time in these mine soils. These compacted layers were definitely not observed in our last soil pit studies in 1989, and we had previously attributed (e.g. Haering et al., 2004) similar layers to relict effects of compaction from rubber-tired haulers and excessive final dozer grading. While we still believe those mechanisms are major reasons for root-limiting compaction in Appalachian mine soils, these results indicate that natural pedogenic processes may be active in forming these limiting layers as well.

Summary and Conclusions

Once we have completed all final physical and chemical analyses on the primary horizon and depth increment samples, we will statistically evaluate them to reconfirm the extent of chemical and physical weathering in these materials over the past 34 years. However, our detailed morphological studies clearly indicate that significant pedogenesis has occurred over a relatively short period in these mine soils, resulting in well-developed profiles, including readily discernible cambic (^Bw) subsoil horizons. Thus, while the vast majority of these soils were classified as Entisols by U.S. Soil Taxonomy in the 1980s, they would now all be classified as Inceptisols.

The long-term influence of varying surface treatments (topsoil, sawdust and biosolids) is still readily apparent in the surface ^A horizons of these mine soils, but does not appear to have consistently affected subsoil morphology. The overall influence of those treatments on bulk soil chemical and physical properties remains to be determined over the coming year.

The finding that significant compact and root-limiting subsoil layers appear to be forming in these mine soils via combined pedogenic processes is an important and novel finding. To our knowledge, this has not been reported in the scientific literature to date and may be important for developing management practices (e.g. ripping for forest establishment) on older mined lands, even where rough grading and other practices to limit compaction were followed.

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