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Spatial Variability and Mineralogy of Selected Mine Spoils from Western North Dakota

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Introduction

Lignite coal mining in western North Dakota has created large acreages of disturbed land, portions of which have not been reclaimed because they were mined before the current stringent regulations were enacted. Regulations now require that spoil materials be reshaped and covered with 5 feet of soil material, if available, and revegetated. Prior to these regulations, soil materials were not stockpiled, and the mine operators were only required to level off the spoil piles. As a result, many of these areas are sparsely vegetated due to the high salt content of the spoil materials. Revegetation of such areas depends primarily on the physical and chemical properties of the reshaped spoil materials and is affected by spatial variability of these properties. In addition, reliable estimates of expected variability in reshaped spoils are needed to determine the optimum depth of soil replacement for reclamation under current regulations.

This study was conducted to determine the variability of reshaped spoil materials by characterizing samples collected within plant rooting zones for several chemical and physical parameters, and to determine the sampling intensity needed to describe this variability. With the exception of a recent study by Klages and Hopper (1982), clay mineralogy data for mine spoils in the Northern Great Plains are lacking. Therefore, the clay mineral composition of selected spoil materials and surrounding unmined soils was determined.

Methods and Materials

Field

The spoil variability and clay mineralogy studies were conducted on a 400-acre area in the North American Coal Corporation Indianhead Mine near Zap. The climate of the area is semiarid, with annual precipitation commonly ranging from 12 to 16 inches and temperature extremes from -35 to 100°F (Ries et al., 1977).

The spoil variability study utilized only samples collected from reshaped spoil materials which had no soil material on the surface. The area is located on the Fort Union geologic group which is composed of soft shales, sandstone and lignite. An overburden depth of 50 feet and a coal seam thickness of 5 to 20 feet are common. Much of the surface is covered with glacial till, outwash, and loess which serve as parent materials for most of the soils (Power et al., 1978). During the mining operation, overburden materials in the study area were side cast into piles by dragline and reshaped to approximate original contour by bulldozer three years prior to sampling. Vegetation consisted of sparse clumps of sweetclover.

Spoil variability samples were systematically collected from four 400 square foot plots according to the method described by Petersen and Calvin (1965). Plots 1 through 4 were located on summit, shoulder, backslope, and footslope positions, respectively, along a 420-foot slope which had a vertical fall of 53 feet. It was hypothesized that the variability of the spoil materials would change with slope position due to spoil placement and regrading techniques. Samples were collected to a depth of 48 inches in 6-inch increments at 23 points located 5 feet apart, yielding a total of 184 samples per plot. All mine spoil samples were collected with a truck-mounted Giddings probe using a 2-inch diameter tube.

The clay mineralogy study used materials from three different sources. Samples were collected from the reshaped spoil materials in an area adjacent to the variability study site and from spoil materials at another nearby location which had been topsoiled to a depth of at least 36 inches. Additional samples were collected from three unmined soils located around the perimeter of the study area. From the reshaped untopsoiled spoil, a total of 15 samples were collected at five points along an 800-foot transect at depths identical to the topsoiled site; there was no soil material within the sampling depths because it was placed in the bottom of the trench during mining operations. On the topsoiled spoil, samples were systematically collected (Petersen and Calvin, 1965) from a 900-square foot plot to a depth of 36 inches in 12-inch increments at 14 points located 10 feet apart, yielding a total of 42 samples. From the unmined soils, samples were collected by hand from exposed profiles to a depth of 36 inches. Three to five samples were obtained from each A- and B- horizon depending on the thickness, then composited to form single samples. The soils sampled were Belfield silt loam (Glossic Natriborolls, fine, montmorillonitic), Flaxton sandy loam (Pachic Argiborolls, fine loamy, mixed), and Rhoades silt loam (Leptic Natriborolls, fine, montmorillonitic).

All samples collected in the two studies were sealed in plastic bags, transported to the laboratory, air-dried, and passed through a 2 mm sieve.

Laboratory

Three parameters commonly used to characterize mine spoils were selected as indicators of spoil variability. These included electrical conductivity (EC), pH, and particle-size analysis. Electrical conductivity was determined using a YSI model 31 conductivity bridge and saturated paste extracts from 200-gram spoil samples. A Corning model 12 pH meter was used to measure the pH of 20-gram samples mixed with 20 milliliters of water. Particle-size analysis was determined by the pipette method of Day (1965).

Analysis of the spoil variability data generally followed the procedure of Cassel and Bauer (1975). The minimum number of samples required to estimate a given parameter was determined by the equation $N = t_{\alpha}^2 s^2/D^2$ (Petersen and Calvin, 1965), where t_{α} is the Student's t value at a given probability level (α) with n-1 degrees of freedom (df), s is the standard deviation, and D is the acceptable error chosen for a given parameter. The t value calculated for this study using the 95 percent probability level and 22 df equalled 2.074. The D value, arbitrarily selected, was 10 percent of the mean.

Clay-size fractions were collected for x-ray diffraction analysis by standard sedimentation procedures (Rutledge et al., 1967) after dispersing 30-gram samples in 0.5 N Na_2CO_3 and distilled water using an ultrasonic probe for 10 minutes at 100 watts. After collection, the clay fractions were saturated with 1 N $MgCl_2$ washed with methanol, freeze-dried, and stored. Additional sample preparation followed procedures described by Rhoton et al. (1979). Peak areas for the various mineral species were delineated on the basis of symmetry and average baseline heights. Photocopies of various peaks were cut out and weighed. Relative percentages of clay minerals in each sample were determined by a modification of the method of Johns et al. (1954). Modifications were similar to those described by Wall and Wilding (1976) and Klages and Hopper (1982).

RESULTS AND DISCUSSION

Mean values calculated for EC and pH measurements (Table 1) from the spoil variability study represent an average of the 23 samples collected at each depth. Electrical conductivity was greatest in plots 2 and 3, respectively, and generally appeared to decrease with depth except for plot 4. Some of the differences among sampling depths were significant at the 5 percent level; however, in most cases the absolute differences are minimal. Based on the N values determined for EC, the spoil materials were most variable in plot 1 and at the lower sampling depths in plot 2. The highest pH measurements were recorded in plots 2 and 4, but absolute differences among depths and plots are negligible. The N values of pH indicate that the spoil materials are quite homogeneous.

Most of the variations in sand, silt, and clay contents (Table 2) among sampling depths were not significant at the 5 percent level. Samples obtained below 24 inches in plot 2 and from plot 3 contained greater amounts of sand and correspondingly smaller amounts of silt and clay than other plots. The N values determined for sand indicate that the spoil materials were most variable in plot 1 and

Table 1. Mean, standard deviation (SD), and number of samples (N) required to estimate electrical conductivity (EC) and pH at different depths and slope positions on reshaped spoil.

Depth	EC (mho/cm)			pH		
(in)	Mean	SD	N	Mean	SD	N
	Plot 1					
0-6	3.9ab*	1.14	38	8.1ab	.21	1
6-12	4.0a	1.41	53	8.1ab	.29	1
12-18	4.0a	1.49	60	8.0b	.48	2
18-24	4.0a	1.46	57	8.1ab	.26	1
24-30	4.0a	1.31	46	8.0b	.30	1
30-36	4.0a	1.62	71	8.0b	.36	1
36-42	3.3b	1.46	84	8.2a	.36	1
42-48	3.4ab	1.39	72	8.1ab	.29	1
	Plot 2					
0-6	5.7a	.85	10	7.9c	.10	1
6-12	5.0b	.36	2	8.0c	.09	1
12-18	5.2ab	.44	3	7.9c	.11	1
18-24	5.3ab	.55	5	8.0c	.15	1
24-30	4.5c	1.15	28	8.1b	.30	1
30-36	4.2c	1.55	59	8.3a	.35	1
36-42	3.6d	1.04	36	8.3a	.22	1
42-48	3.7d	1.19	44	8.4a	.27	1
	Plot 3					
0-6	4.7a	.94	17	8.0b	.13	1
6-12	4.7a	1.17	27	8.1a	.09	1
12-18	4.7a	1.02	20	8.1a	.17	1
18-24	4.7a	1.00	19	8.1a	.14	1
24-30	4.5ab	1.06	24	8.1a	.13	1
30-36	4.8a	1.34	34	8.1a	.13	1
36-42	4.2ab	.80	16	8.1a	.14	1
42-48	4.1b	.83	18	8.1a	.16	1
	Plot 4					
0-6	3.6ab	1.20	48	8.1a	.16	1
6-12	3.7ab	.58	11	8.2a	.11	1
12-18	4.0a	.89	26	8.2a	.13	1
18-24	3.6ab	.61	12	8.2a	.11	1
24-30	3.8ab	.52	8	8.2a	.11	1
30-36	3.9ab	.93	24	8.2a	.12	1
36-42	3.4b	.49	9	8.2a	.11	1
42-48	3.8ab	.79	19	8.0b	.47	1

*Mean values followed by the same letter are not significantly different at the 5 percent level according to Duncan's Multiple Range Test.

Table 2. Mean, standard deviation (SD), and number of samples (N) required to estimate percent sand, silt, and clay at different depths and slope positions on reshaped spoil.

Depth (in)	Sand			Silt			Clay		
	Mean	SD	N	Mean	SD	N	Mean	SD	N
					Plot 1				
0-6	31.8ab*	5.29	12	32.0ab	3.14	4	36.2ab	4.28	6
6-12	30.3ab	9.91	46	33.4a	7.21	20	36.3ab	4.55	7
12-18	32.1ab	7.57	24	33.1ab	5.72	13	34.8b	3.56	5
18-24	31.9ab	7.14	22	32.5ab	5.50	12	35.6ab	4.27	6
24-30	32.9ab	11.05	49	30.7ab	5.86	16	36.4ab	7.95	21
30-36	34.5a	9.50	33	29.7b	6.60	21	35.8ab	5.10	9
36-42	36.1a	11.69	45	29.5b	8.47	36	34.6b	5.76	12
42-48	27.5b	7.28	30	33.8a	6.52	16	38.7a	4.62	6
					Plot 2				
0-6	29.3b	1.76	2	33.4a	3.10	4	37.4a	2.30	2
6-12	29.7b	2.14	2	33.2a	2.47	2	37.2a	2.34	2
12-18	29.0b	1.87	2	32.9a	2.72	3	38.0a	2.38	2
18-24	31.7b	9.15	36	31.9ab	7.10	21	37.1a	3.60	4
24-30	39.6a	14.93	61	27.1bc	9.87	57	33.2b	5.95	14
30-36	42.2a	20.70	104	24.4c	13.70	136	33.5b	8.50	28
36-42	41.4a	20.62	107	26.5bc	14.40	127	32.1b	6.95	20
42-48	45.8a	17.92	66	23.0c	13.40	146	31.4b	5.53	13
					Plot 3				
0-6	35.3b	3.82	5	29.5a	3.20	5	35.2ab	3.59	5
6-12	35.9ab	6.94	16	28.9a	5.18	14	35.2ab	3.09	3
12-18	39.5a	10.18	29	26.8a	6.96	29	33.7b	3.72	5
18-24	35.8ab	6.58	15	29.3a	5.60	16	34.9ab	2.39	2
24-30	33.8b	6.76	17	30.0a	5.68	15	36.4a	2.26	2
30-36	34.9b	5.03	9	29.4a	3.89	8	35.7ab	2.23	2
36-42	34.7b	7.54	20	29.7a	5.15	13	35.6ab	3.30	4
42-48	34.4b	7.57	21	29.1a	5.67	16	36.4a	4.54	7
					Plot 4				
0-6	28.1b	2.74	4	36.0a	3.53	4	35.9a	3.57	4
6-12	31.5ab	4.08	7	32.7b	3.70	6	35.7a	2.73	3
12-18	31.3ab	4.36	8	32.2b	3.07	4	36.6a	2.90	3
18-24	29.8ab	7.60	28	31.9b	2.95	4	38.3a	7.09	15
24-30	32.6a	7.37	22	31.6b	5.23	12	35.8a	3.58	14
30-36	32.9a	8.90	32	30.3b	5.48	14	37.1a	6.86	15
36-42	31.4ab	6.25	17	32.9b	4.57	8	35.7a	3.52	4
42-48	29.9ab	6.04	18	32.8b	3.90	6	37.2a	4.47	6

*Mean values followed by the same letter are not significantly different at the 5 percent level according to Duncan's Multiple Range Test.

below 18 inches in plot 2. Spoil variability in terms of finer particle sizes is much less, excluding silt contents below 24 inches in plot 2.

The data were further analyzed to determine if differences existed among the plots due to slope position (Table 3). Each plot was considered a different treatment and compared with others using the 184 replications per plot and the parameters previously discussed. Electrical conductivity and sand and silt contents in plots 1 and 4 were significantly different (5 percent level) from plots 2 and 3. Some significant differences in pH and clay contents were also identified among plots. These data indicate that spoil materials can vary with slope position; however, it is not known if these data would be more variable than similar data collected from plots located along the same contour.

Table 3. Statistical comparison of overall mean values computed for each parameter and plot on reshaped spoil.

Parameter	Mean			
	Plot 1	Plot 2	Plot 3	Plot 4
EC (mho/cm)	3.83b*	4.65a	4.56a	3.72b
pH	8.06b	8.11ab	8.06b	8.15a
Sand (%)	32.13b	36.07a	35.54a	30.95b
Silt (%)	31.83a	28.81b	29.09b	32.54a
Clay (%)	36.04ab	34.97c	35.38bc	36.54a

*Mean values followed by the same letter are not significantly different at the 5 percent level according to Duncan's Multiple Range Test.

Clay mineralogy of the undisturbed soils, topsoiled spoil plot, and the regraded, untopsoiled spoil transect is shown in Table 4. The mineralogy values from all unmined soils were averaged for comparison with the topsoiled mine spoils, assuming that the "topsoil" consisted of mixtures of A- and B-horizon materials from different soils. All the unmined soils were predominantly smectitic, regardless of horizon. Smectite concentrations were greatest in Belfield, Rhoades, and Flaxton, respectively. After averaging, the mineralogy of the undisturbed soils was dominated by smectite (70 percent) and illite (14 percent), with smaller amounts of chlorite (8 percent), quartz (6 percent), and vermiculite (2 percent). The mineralogy of the topsoiled spoils is similar; average compositions of the three sampling depths are smectite (73 percent), illite (14 percent), chlorite (5 percent), quartz (5 percent), and vermiculite (3 percent). Average values for samples collected along the transect from the reshaped spoil indicate a higher content of smectite (83 percent) than for the unmined soils and topsoiled spoils. Illite contents (7 percent) were lower, but the other minerals were present in similar amounts.

SUMMARY AND CONCLUSIONS

The variability of reshaped mine spoils was measured by collecting spoil samples from four plots located at summit, shoulder, backslope and footslope positions along a slope created by regrading operations. The minimum number of samples required to obtain an acceptable estimate of EC, pH and particle-size were used as indicators of spoil variability. Based on EC and percent sand data, the spoil materials were most variable at the summit and shoulder positions, and the number of samples required varied considerably depending on the sensitivity of the parameter. The results reported here represent only one given set of conditions; the number of samples required could be reduced considerably by increasing the acceptable error. Therefore, the objectives of any studies conducted on similar materials should be clearly defined before a sampling scheme is selected.

Clay mineralogy was determined for reshaped mine spoils, topsoiled mine spoils, and unmined soils in the vicinity of the mine. The mineralogy of the soils and topsoiled spoils was very similar; each was dominated by smectite and illite. The reshaped spoils contained approximately 10-13 percent more smectite and about 7 percent less illite. Other minerals were present in comparable amounts. The effect of greater amounts of smectite in the reshaped spoils on reclamation efforts is not known, but spoil materials containing 83 percent smectite would probably not behave drastically different from those containing 70 percent smectite.

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Table 4. Clay mineralogy of selected spoil materials and surrounding unmined soils.

Material	Site	Depth (in)	Smectite	Chlorite	Vermiculite	Illite	Quartz
			%				
Unmined soil	Belfield-A hor.	0-17	75	7	1	12	5
	Belfield-B hor.	17-36	76	9	—	12	3
	Rhoades-A hor.	0-10	67	14	—	13	6
	Rhoades-B hor.	10-36	69	9	1	15	6
	Flaxton-A hor.	0-20	53	5	9	25	8
	Flaxton-B hor.	20-36	77	5	3	10	5
		Mean	70	8	2	14	6
Mine spoil	Topsoiled	0-12	74	5	3	13	5
		12-24	72	5	4	14	5
		24-36	72	6	3	14	5
		Mean	73	5	3	14	5
Mine spoil	Reshaped (no topsoil)	0-12	84	4	2	7	3
		12-24	84	2	5	6	3
		24-36	82	5	3	7	3
		Mean	83	4	3	7	3

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