Evaluation of Bentonite for the Control of Acid Drainage from Surface Mined Lands

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As part of the acid mine drainage abatement program of the West Virginia Surface Mining Reclamation Task Force, we at the Northeastern Forest Experiment Station were requested to evaluate the effectiveness of bentonite in retarding water flow through potentially toxic materials. Sealing with bentonite is one of three procedures currently being evaluated to retard the downward flow of water through restored surface mines containing toxic substrata. The other two procedures -- PVC covering (Foree 1982; Caruccio and Geidel 1983) and segregation of toxic strata within a densely packed clay seal (Acid Mine Drainage Technical Advisory Committee 1983)--both have distinct disadvantages: high cost, drought potential for surface vegetation, erosion potential, and unknown longevity of the PVC liner. Bentonite, on the other hand, should not deplete moisture for surface vegetation, would not provide a surface conducive to erosion, could last indefinitely, and could be obtained in effective quantities at a cost substantially lower than that for PVC liner. Additionally, the cost of incorporating the bentonite is substantially less than the cost of installing PVC liner.

Bentonite (sometimes used incorrectly as a synonym for the term montmorillonite) refers to the altered deposit of volcanic ash usually found in prehistoric lakes or estuaries (Borchardt 1977). Bentonite is a montmorillonitic clay, though the name bentonite is now applied to the entire family of clays that have montmorillonite as their chief constituent.

The key to the expansion and water-sealing action of bentonite lies in its structure (Weaver 1946). The clay flake is composed of minute crystalline sheets, and when completely dispersed in water, a cubic inch of dry bentonite subdivides into nearly 10 billion flakes having a combined surface area of nearly an acre. The thin sheets are parallel, and a single layer of tightly held water molecules is present on the basal plane of each sheet. When wetted, more water molecules force their way between the sheets spreading them apart, and a hull of water many times thicker than the sheet is held by electrostatic attraction.

The first serious consideration given to the use of bentonite in water impedance work was in the 1930's, and much of the original work was done by Powell (1940). He proposed two broad classifications under which bentonite is used to impede the flow of water. Under the first classification, grouting, a bentonite solution is injected under pressure into a porous strata to fill the voids. This is done to impede the flow of water in underground channels and porous strata. The second classification, placement, is the direct application of bentonite either in pure layer, a bentonite-soil mixture, or by sprinkling on the water surface. The placement methods are used to control and impede the passage of surface waters. This is the method under study to seal restored surface mines once the toxic substrata are in place.

To stop seepage with a bentonite-soil mixture consider: type of soil, particle size of both soil and bentonite, percentage of bentonite mixed with the soil, thickness of bentonite-soil layer, means of confinement, and hydrostatic head (Ferris 1943). Ferris found that soils with a high clay content are not suitable for sealing with bentonite because the essential dense layer will not form when in contact with water. When rocks are present in the bentonite-soil mixture, even in small quantities, water passes along their surface and washes the bentonite away causing seepage, particularly when adjacent rocks form a chain through the layer. Fine sandy soils or sandy loams that form a dense blanket are most effectively sealed. Ferris found that the bentonite-soil mixture should be finer than the mean grain size of the soil. This prevents the expansion of the individual bentonite particles from decreasing the density and causing new voids.

If soil and bentonite are to be used as a mixture, the bentonite must be spread evenly over the surface and incorporated with 3 or 4 inches of soil with a harrow or by hand raking (Cahn 1937). This blanket is then covered with several inches of soil. Only meager data as to the life of a bentonite seal under various weathering conditions are available, but it is believed that the seal, if undisturbed, will last indefinitely (Weaver 1946).

Experimental Methods and Data Interpretation

A suitable site for the study plots was furnished by the Mashuda Mining Company on the Jack Maxon property near Morgantown, West Virginia. Nine plots of near uniform composition and physical arrangement were selected in 1983 for evaluation of bentonite application.

The plots were arranged in a 3 x 3 Latin square design (Figure 1) and were established on a slope of approximately 5 percent. Three plots were control (no bentonite application), three contained 1 pound of bentonite per square foot, and three contained 2 pounds of bentonite per square foot.

Each plot was underlain with a sheet of 20-mil PVC plastic liner turned up at the edges to hydrologically isolate each plot and intercept all downward percolating water. Eighteen inches of coarse, toxic coal waste was placed over the plastic in each plot, and this was covered with 18 inches of "topsoil" composed of intermixed A, B, and C horizon material containing neutral rock. The "topsoil" layer was applied in two increments to those plots treated with bentonite. First, 6 inches of topsoil were applied and smoothed; then the bentonite was spread and incorporated to a depth of 3 or 4 inches with a garden tiller; and finally another 12 inches of "topsoil" were added (Figure 2). The topsoil on all plots was smoothed and then compacted as usual.

Each plot measured approximately 16, x 161 for a total surface area of about 256 square feet. The plots are separated by plank divides and plastic sheeting. The bottom and sides of each plot are lined with 20 mil PVC plastic. Plastic sheeting was rolled up on the sides and over the top of the divides to prevent water from flowing into and over the plots. Water that penetrates and passes through the bentonite layer into the toxic material is drained to drums where it is measured.

Surface runoff is monitored by flumes equipped with automatic stage recorders. Water failing to penetrate the bentonite layer is intercepted by a thin sand collecting zone placed along the lower edge of the plots just above the bentonite layer. Water retained by the bentonite layer and water penetrating through the toxic material is drained from the plots through 1 1/411 plastic pipes leading from the lower edge of each plot to 55-gallon barrels equipped with stage recorders. Runoff is monitored continuously except in the winter months. Samples of runoff collected in the 55 gallon barrels are analyzed for pH, common ions, and selected trace elements. Surface runoff is not chemically evaluated.

Soil moisture is monitored by taking a core from a random location in each plot. It is determined by weighing the samples before and after drying overnight at 105^0C. Subsamples are taken about 4 inches above and 8 to 10 inches below the bentonite/topsoil layer and sealed in plastic containers. Except during winter months, moisture readings will be taken every 3 months for at least 1 year. Sample holes are refilled with bentonite-soil plugs after each set of readings to prevent breaks in the bentonite seal. New cores are taken for each set of readings.

A recording tipping bucket has been installed at the plot site to monitor rainfall. Samples of the topsoil and toxic material were analyzed in the laboratory (Table 1) for pH (1:2 soil:water extract), P, K, Ca, and Mg by emission spectrophotometer (Flannery and Markus 1971). Exchangeable acidity and exchangeable aluminum in both the toxic and nontoxic minesoils were determined by the Yuan procedure (Yuan 1959). Specific conductance and textural analysis were also determined on both materials.

Results

Data were collected at the site from September 1 through November 30, 1983. Drains were disconnected at the end of November and will not be reconnected until March 1984. Freezing and thawing during the winter months interfere with the study and render data collected during those months questionable.

Preliminary data indicate that the bentonite, at least in the quantities selected for evaluation, may not be effective as a sealant (Table 2). Initial results were encouraging in that drainage from the bottom of the soil profile was largely limited to the plots containing no bentonite. However, subsequent evaluations at the end of October and November showed no appreciable differences in drainage between bentonite and control plots. This implies that the reduced drainage observed earlier on the bentonite plots may be due to absorption of water by the bentonite. No appreciable differences were noted in the chemical composition of waters from control and bentonite plots.

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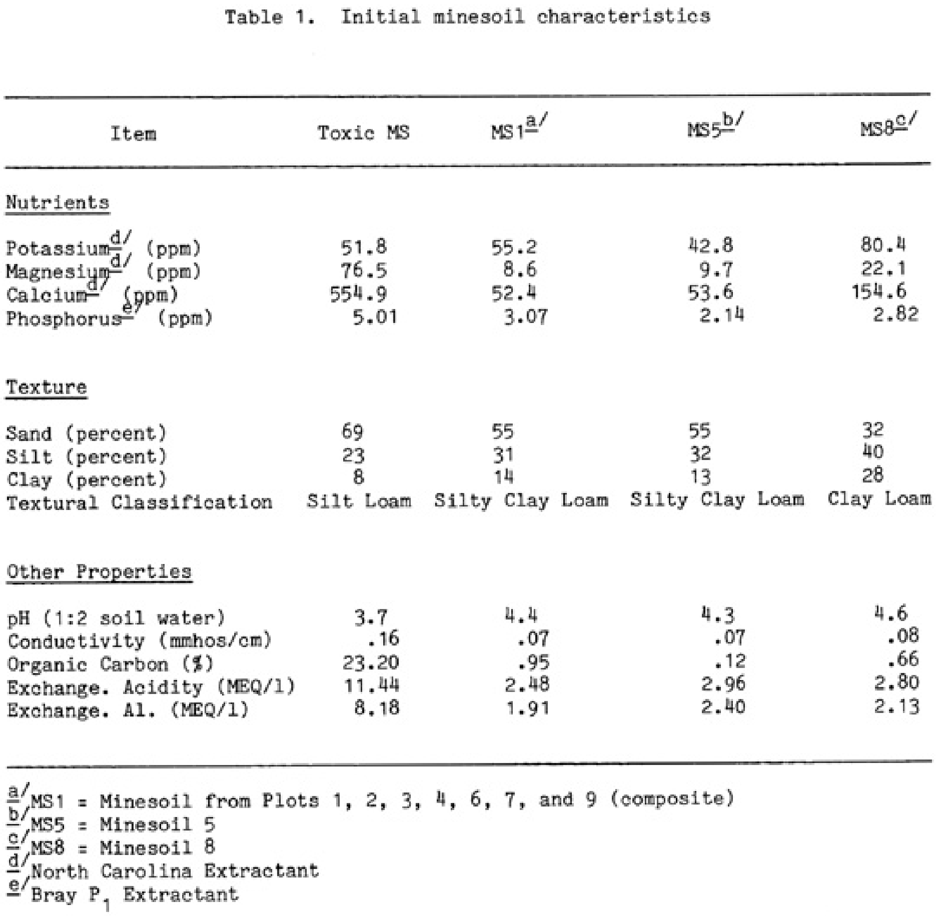


Table 1. Initial minesoil characteristics

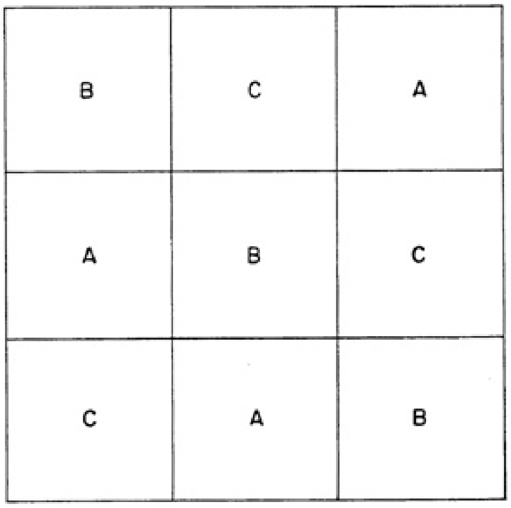
Item	Toxic MS	MS1[a]	MS5[b]	MS8[c]
Nutrients				
Potassium[d] (ppm)	51.8	55.2	42.8	80.4
Magnesium[d] (ppm)	76.5	8.6	9.7	22.1
Calcium[d] (ppm)	554.9	52.4	53.6	154.6
Phosphorus[e] (ppm)	5.01	3.07	2.14	2.82
Texture				
Sand (percent)	69	55	55	32
Silt (percent)	23	31	32	40
Clay (percent)	8	14	13	28
Textural Classification	Silt Loam	Silty Clay Loam	Silty Clay Loam	Clay Loam
Other Properties				
pH (1:2 soil water)	3.7	4.4	4.3	4.6
Conductivity (mmhos/cm)	.16	.07	.07	.08
Organic Carbon (%)	23.20	.95	.12	.66
Exchange. Acidity (MEQ/l)	11.44	2.48	2.96	2.80
Exchange. Al. (MEQ/l)	8.18	1.91	2.40	2.13

[a] MS1 = Minesoil from Plots 1, 2, 3, 4, 6, 7, and 9 (composite)
[b] MS5 = Minesoil 5
[c] MS8 = Minesoil 8
[d] North Carolina Extractant
[e] Bray P_1 Extractant

Table 2. Amount of overall precipitation and drainage from study plots

Item	September	October	November	Total
	inches			
Precipitation	2.53	3.30	3.71	9.54
DRAINAGE FROM CONTROL PLOTS				
Plot 2	.016	.300+	.300+	
Plot 4	.029	.300+	.300+	
Plot 9	.031	.300+	.300+	
Average	.024			
DRAINAGE FROM 1 lb/sq ft BENTONITE PLOTS				
Intercepted by Bentonite				
Plot 3	.052	.010	.005	.067
Plot 5	.000	.010	.002	.013
Plot 7	.072	.083	.103	.259
Average	.041	.034	.037	.113
Passing through Bentonite				
Plot 3	.000	.103	.300+	
Plot 5	.031	.300+	.300+	
Plot 7	.000	.300+	.300+	
Average	.010			
DRAINAGE FROM 2 lb/sq ft BENTONITE PLOTS				
Intercepted by Bentonite				
Plot 1	.008	.013	.010	.031
Plot 6	.008	.005	.005	.018
Plot 8	.000	.000	.000	.000
Average	.005	.006	.005	.016
Passing through Bentonite				
Plot 1	.020	.026	.155	
Plot 6	.000	.300+	.300+	
Plot 8	.000	.103	.300+	
Average	.007			

Figure 1.--Plot arrangement.



B	C	A
A	B	C
C	A	B

TREATMENT A - NO BENTONITE (CONTROL)
TREATMENT B - ONE POUND PER SQUARE FOOT
TREATMENT C - TWO POUNDS PER SQUARE FOOT

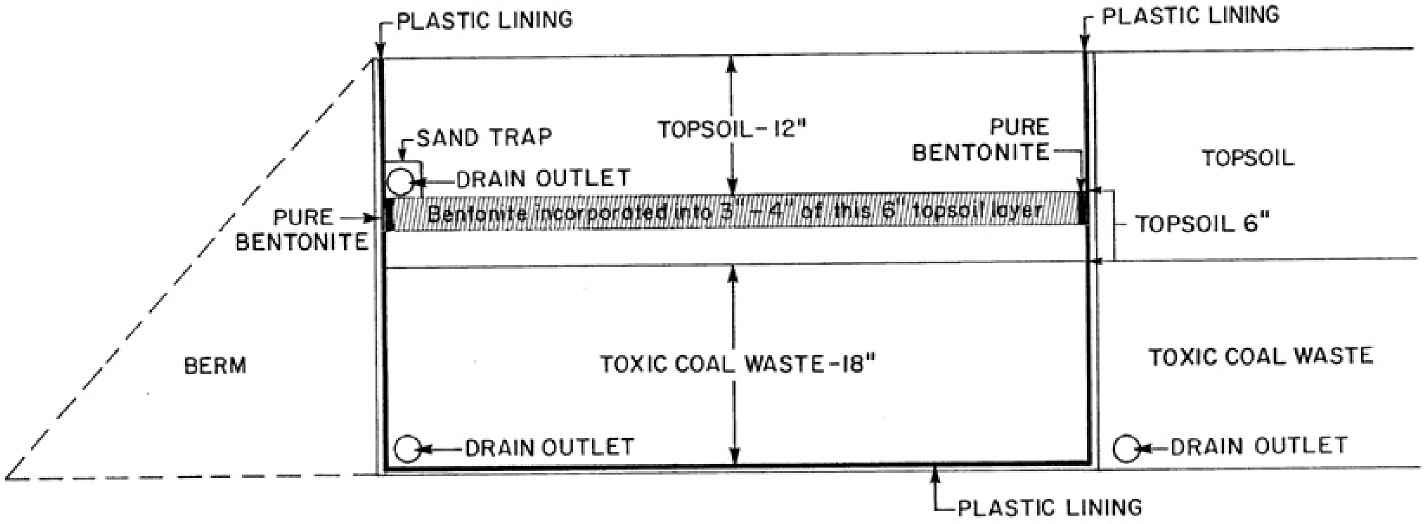


Figure 2.--Profile description.