

## AN INVESTIGATION OF BROWN IRON ORE SPOILS IN TENNESSEE

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**Abstract.** Many acres, concentrated primarily in the eastern United States, have been disturbed by iron ore mining in the past 250 years. Much of the disturbed soils research to date has been conducted on coal minesoils which is not usually applicable to iron ore spoils. The objective of this study was to compare properties of 140-170 year old brown iron ore spoils (minesoils) in Tennessee to those in adjacent undisturbed soils (native). Two minesoils and two native soils were described and sampled according to National Cooperative Soil Survey Standards. Variances of selected chemical properties were compared between sites using a grid sampling design and Hartley's test for homogeneity of variances. Differences in origin of overburden material and the degree of weathering prior to disturbance accounted for morphological and chemical differences between the minesoils. Minesoil 1 had developed a cambic horizon and minesoil 2 had not developed a diagnostic subsurface horizon. Bridging voids were observed in both minesoils but not in the native soils. Trace elements were highest in the surface horizons of both minesoils and native soils and the buried surface horizon in minesoil 1. Variations for total carbon, total aluminum, barium, manganese, phosphorus, titanium, and zirconium between 40-60cm were not consistently significantly different between minesoils and native pedons at a 0.05 alpha level.

Additional Key Words: Iron Ore Spoil, Minesoil, Minesoil Morphology, Bridging Voids, Minesoil Genesis

### Introduction

The current Soil Taxonomy system used for soil mapping usually does not adequately identify properties in minesoils (Thurman and Sencindiver 1986; Schafer et al. 1980; Schafer 1979). Characterization studies of minesoil properties are critical to develop appropriate criteria to better separate, classify, and manage minesoils. As a result, better decisions can be made for their profitable use under field crops, pasture, or wood-land.

The differences in characteristics of a disturbed soil from its premined condition depend on several factors including the type of equipment used for mining and reconstruction, the chemical composition of material exposed to/near the surface, the pre-weathered condition of the material prior to disturbance, site factors (i.e. slope, irregular topography, etc.), and the time since disturbance (Potter et al. 1988; Thurman and Sencindiver 1986; Haering et al. 1993; Bell et al. 1994). Properties altered by surface mining generally include soil horizonation,

soil structure (affecting macroporosity and permeability), bulk density, coarse fragment content, uniformity in color and chemical properties of parent material, and hydraulic conductivity (Haering et al. 1993; McSweeney and Jansen 1984; Ammons and Sencindiver 1990; Bell et al. 1994; Potter et al. 1988; Indorante and Jansen 1984). The rock type dominating the overburden and the degree of in situ weathering of that material before disturbance by mining strongly determines immediate properties such as pH, extractable bases, and weathering rates of minesoil material (Haering et al. 1993).

Much of the disturbed soils research to date has been conducted on coal minesoils which is not usually applicable to iron ore spoils. Iron ore spoils are not often associated with acidity problems, unlike coal minesoils which typically contain pyrite and sulfur compounds (Smith et al. 1971). Many acres, concentrated primarily in the eastern United States, have been disturbed by iron ore mining in the past 250 years. The Western Highland Rim physiographic region of Tennessee was a

large producer of iron ore during the 1800's (Burchard 1934; Safford 1856). Most of the Western Highland Rim's uppermost geology is of Mississippian age (Hershey and Maher 1963). Thin quaternary-aged loess, Upper Cretaceous gravel, sand, and clay non-uniformly overlie these geologic units (Burchard 1934; Springer and Elder 1980) (Fig. 1).

<b>LOESS (0-1 M.Y.B.P.)</b>
<b>CRETACEOUS (65-140 M.Y.B.P.)</b>
<b>MISSISSIPPIAN (330-365 M.Y.B.P.)</b> <b>St. Louis Limestone</b>
<b>Warsaw Limestone</b>
<b>Fort Payne Formation</b>
<b>Chattanooga Shale</b>

Figure 1. General geologic cross section of Tennessee's Western Highland Rim physiographic region.

The iron ore mined here is believed to have formed during the Tertiary period. Glauconitic sand beds, of Upper Cretaceous age, are postulated to have been the source of iron (Burchard 1934). Theoretically, iron moved readily through the sand layers, precipitated as iron oxides, and accumulated as ore at the interface of cherty portions of underlying limestone (Safford 1856; Killebrew 1874). The ore was deposited in irregular pockets, veins, or banks of variable size and was commonly located on ridge crests in zones of clay and cherty masses. This depositional pattern may reflect areas of the limestone that had formed sink holes or areas of preferential water flow. Depth to the ore deposits varied between 30 and 100ft parallel to the surface. This was shallow enough for the ore to be mined in shallow open mine pits. Soils disturbed during iron mining operations at that time were not reclaimed and offer an opportunity to study soil development from a known date of disturbance. The objective of this study was to compare properties of

140-170 year old iron ore minesoils to adjacent undisturbed soils.

## Materials and Methods

### Site selection and History

The study sites were located in Montgomery Bell State Park, in Dickson County Tennessee, near the former Laurel Furnace (Fig 2). The Laurel furnace was a steam cold-blast charcoal type furnace, operating between 1815 and the late 1850's (Smith et al. 1988). The spoils left from the mining operation at the Laurel furnace provided an ideal study site because they have not been influenced by intense anthropogenic activities or natural catastrophes since the mining ceased, and spoil piles were easily identified adjacent to excavated pits.

### Field Methods

Study sites were located within 800 meters northwest of the Laurel Furnace remnants. Two minesoil profiles and two soil profiles on adjacent undisturbed soils were described and sampled according to National Cooperative Soil Survey Standards (Soil Survey Staff 1993). Soil samples were taken from the entire thickness of each horizon. A grid design was also sampled for each profile to allow statistical analysis for selected chemical properties. The profile grid was 1 meter deep and 1 meter wide and was divided into 20 cm by 20 cm square sections (Fig. 3). Samples were taken and homogenized from the entire squares that were in columns 2 and 4 and row 3. The variance of selected chemical properties for each sampled column and row was compared between all profiles to determine if they were significantly different between the native pedons and spoils. Hartley's test for comparison of homogeneity of two independent variances was used (Snedecor 1956; Ott 1993). The test compares a calculated F value ( $F_c$ ) to a tabular F value ( $F_t$ ).  $F_c$  is determined by dividing the larger of the two variances by the smaller as shown by the following equation

$$F_c = \frac{s^2_{\max}}{s^2_{\min}}$$

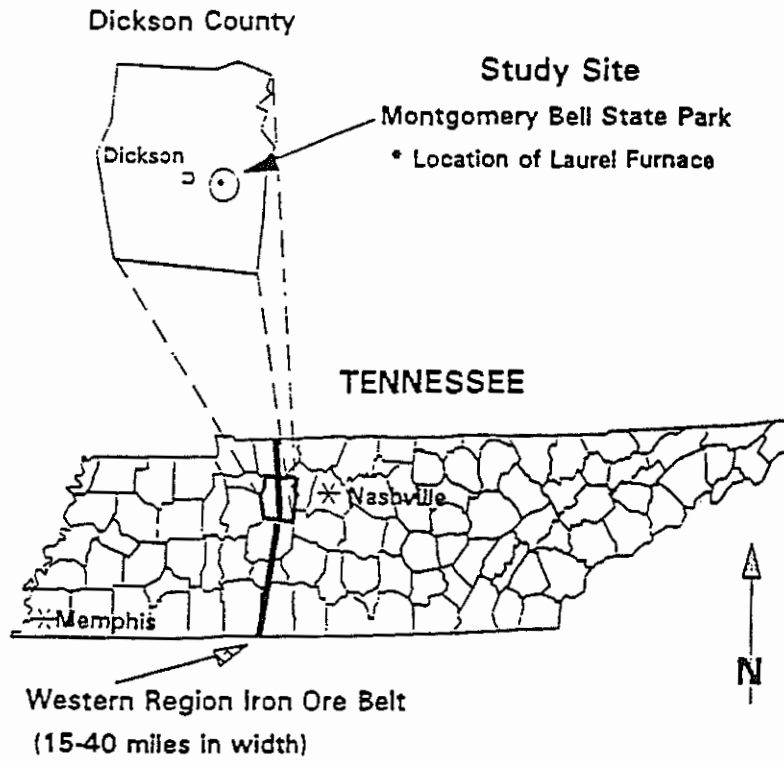


Figure 2. General location map of study area.

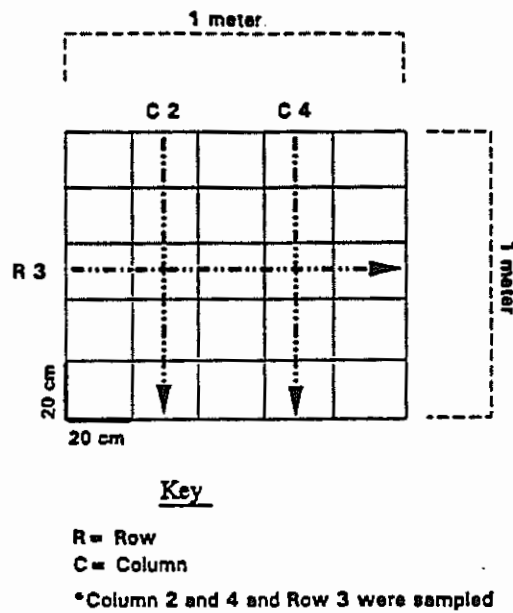


Figure 3. Grid outlay used for vertical and horizontal sampling for statistical analysis.

The null hypothesis states that  $\sigma_1^2 = \sigma_2^2$  if  $F_c$  is less than or equal to  $F_c$ . If  $F_c$  is greater (>) than  $F_c$ , then the compared variances are significantly different at that chosen alpha level. Note that the degrees of freedom (n=4) were the same for both compared variances and that a 95% confidence level was used for this study.

The undisturbed soils were referred to as native pedon 1 and 2, and the disturbed soils were referred to as spoil 1 and 2. Native pedon 1 developed on the shoulder of a convex side slope, and native pedon 2 developed on a nearly level portion of a ridgetop. Spoil 1 developed in overburden material on a ridgetop, and spoil 2 developed in overburden material in a drainage way.

#### Laboratory Methods

Horizon samples were air dried, sieved through a 2mm diameter limiting sieve, and homogenized thoroughly (Soil Survey Staff 1984). A sand sieving and sedimentation-pipette method was used to determine particle size distribution of clay, silt, and sand size fractions (Kilmer and Alexander 1949; Gee and Bauder 1986). Fine clay fractions were determined using a combination of the pipette method and centrifugation. Samples with > 0.5% organic carbon were pretreated with hydrogen peroxide (30%) to reduce potential interference of organic matter with sedimentation rates. Concentration of iron oxides, cation exchange capacity (CEC), exchangeable bases, total concentration of 24 elements, and pH were the selected chemical analyses. All procedures included two replications of each sample.

Iron oxides were extracted using a citrate-dithionite (cd) method described by Olsen and Ellis (1982). Exchangeable cations were extracted by saturation with ammonium acetate at pH7 combined with a NaCl vacuum extraction procedure (Jackson 1958; and Baker and Suhr 1982; Hammer and Lewis 1987). The extracts for both procedures were analyzed for Fe and bases using a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer. A direct displacement method and titration with 0.01 M HCl was used to determine CEC (Rhoades 1982) which

was measured with a Lab Conco distillation unit. A modification of Nadkarni's (1984) microwave oven acid digestion technique which uses HF and an aqua regia solution (mixture of HCl and HNO<sub>3</sub>) to digest inorganic matrices was used to solubilize the soil samples for elemental analysis (Gallagher 1993; Ammons et al. 1995). After the neutralization of the unreacted HF with boric acid, extracts were analyzed with a Thermo Jarrel Ash Model 61 Inductively Coupled Argon Plasma Spectrometer (ICAP-AES) for 24 elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sr, Ti, Zn, and Zr). A combination pH electrode and a 1:1 soil sample to water ratio was used to determine pH (McLean 1982).

For purposes of simplification, results graphed by depth were plotted by midpoint depth for each horizon so that the plot point value represents the value for the entire horizon.

#### Results and Discussion

Native pedon 1 formed in colluvial material over a residual paleosol, and native pedon 2 developed in loess over a residual paleosol. The horizonation sequence in both native pedons included argillic horizons (Table 1). Percent base saturation, pH, color, and clay content in both paleosols were similar, indicating that the paleosol in both native pedons formed in the same residual material (Tables 1 and 2). Fine clay to total clay ratios, free iron, and cation exchange capacity all reached maximums in the argillic horizons of both profiles (Fig 4).

Spoil 1 developed in backfill material which appeared to have been highly pre-weathered prior to deposition in a spoil. Properties in spoil 1 (2 - 140 cm) such as base saturation, CEC, pH, and matrix color greatly resembled those for the paleosols in native pedons 1 and 2 (Tables 1,2,3 and 4). This suggests that the buried paleosols in the native pedons are the dominant source of overburden material in which spoil 1 formed (Fig 5). Assuming this, the red color due to high iron content in spoil 1 reflect the development of the spoil material (paleosol

Table 1. Morphology of native pedons 1 and 2.

Horizon	Lower Depth	Color	Texture	Structure	Boundary	Cons.	Mn Concr. †	Mottles
<b>Native 1</b>	cm	moist				moist		
Oe	3-0							
A	16	10YR 4/4	SiL	2 mgr	cw	vfr	-----	-----
EB	35	7.5YR 5/6	SiL	1 mgr	cw	vfr	-----	-----
Bt1	60	5YR 5/6	gr. SiCL	1 msbk	cw	fr	c,f	c,d 7.5YR 5/6
Bt2	78	7.5YR 5/6	C	2 msbk	cw	fi	-----	f,p 10R 4/8
BC	94	10YR 6/6	vgr. C	1 fsbk	cw	vfr	-----	c,p 5YR 5/8
2Bt	116+	5YR 4/6	gr. C	2 msbk	-----	fi	-----	c,p 10YR 6/8
<b>Native 2</b>								
Oe	3-0	-----	-----	-----	-----	-----	-----	-----
A	21	10YR 4/4	SiL	2 mgr	cs	vfr	-----	-----
BE	32	7.5YR 4/6	SiL	1 msbk	cs	fr	-----	-----
Bt	58	7.5YR 4/4	SiCL	2 msbk	cw	fr	-----	-----
2Ab	95	10YR 5/4	vgr. SiL	1 mgr	cs	vfr	-----	-----
3Bt	108+	5YR 4/6	v.cob. C	2 msbk	-----	fi	-----	f,p 10YR 6/8

† Manganese concretions

Table 2. Chemical properties including exchangeable cations, base saturation, and pH, and total clay of native pedons 1 and 2.

Horizon	Lower Depth	NH <sub>4</sub> OAc Extractable Cations				Total Bases	NH <sub>4</sub> OAc CEC	Base Saturation	pH 1:1 H <sub>2</sub> O	Total Clay
		Ca	Na	K	Mg					
	cm	cmol <sub>c</sub> kg <sup>-1</sup>						%		%
<b>Native 1</b>										
A	16	0.92	0.04	0.22	0.42	1.60	6.10	19.6	4.7	19.2
EB	35	0.47	0.04	0.13	0.66	1.30	4.40	29.5	4.8	23.9
Bt1	60	1.39	0.04	0.12	1.53	3.08	9.19	33.5	4.7	38.5
Bt2	78	1.84	0.05	0.16	1.37	3.42	12.11	28.2	4.7	54.7
BC	94	1.85	0.05	0.14	1.09	3.13	8.83	35.4	4.6	45.5
2Bt	116+	2.13	0.05	0.20	1.51	3.89	13.23	29.4	4.6	67.0
<b>Native 2</b>										
A	21	0.55	0.08	0.20	0.45	1.28	6.30	20.3	4.5	16.0
BE	32	0.87	0.06	0.21	0.82	1.96	7.54	28.0	4.5	25.1
Bt	58	2.70	0.10	0.19	1.19	4.19	11.67	35.9	4.7	33.4
2Ab	95	0.88	0.10	0.18	0.46	1.61	7.21	22.3	4.7	24.0
3Bt	108+	1.91	0.05	0.25	1.04	3.25	11.24	28.9	4.7	54.1

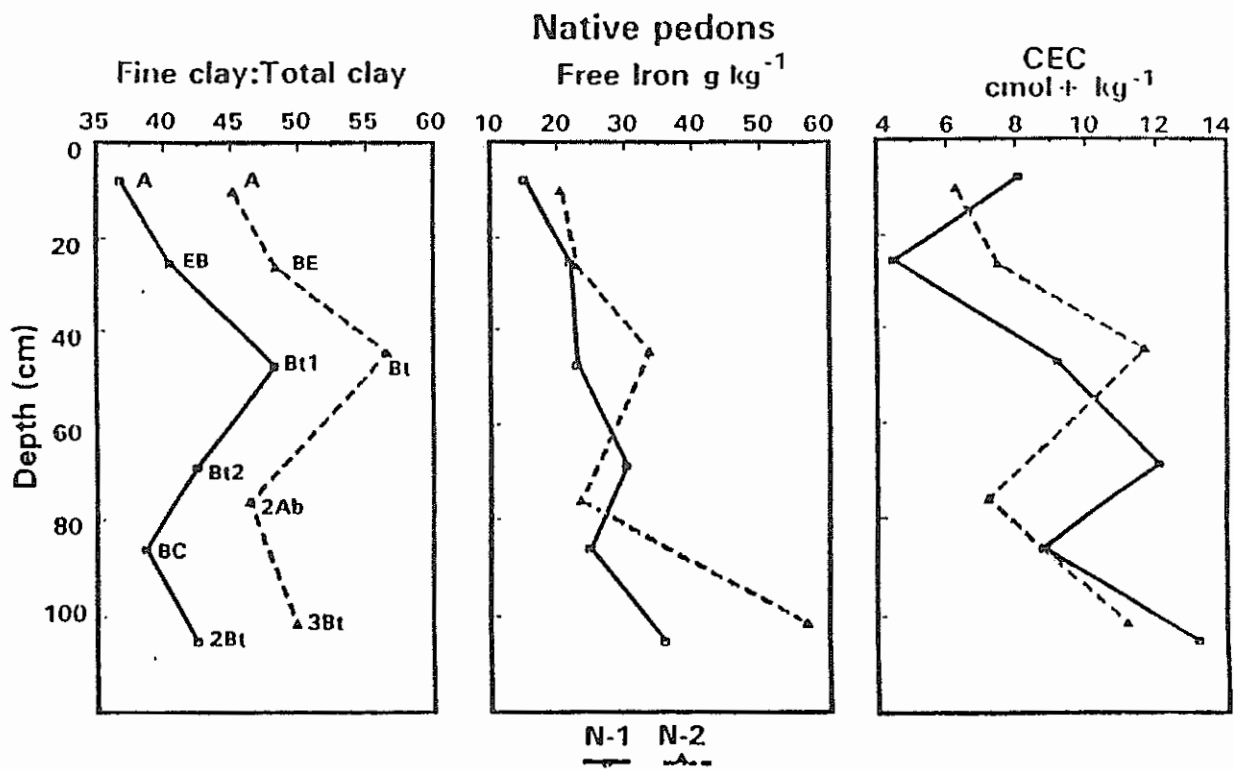


Figure 4. Fine clay to total clay ratio, free iron, and cation exchange capacity distribution by depth in native pedons 1 and 2.

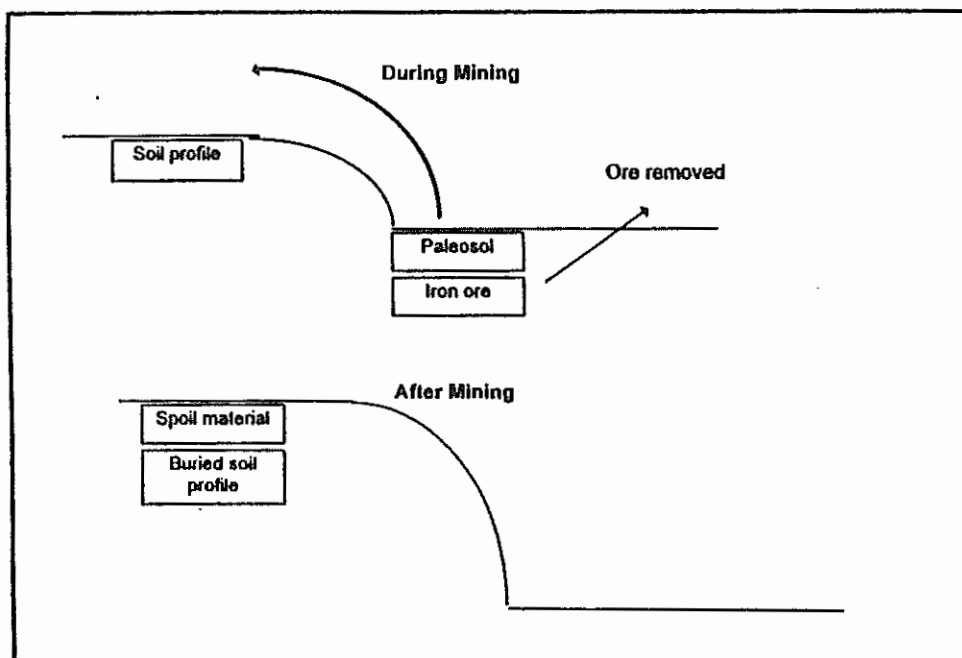


Figure 5. Hypothesized origin of spoil material for spoil 1.

Table 3. Morphology of spoils 1 and 2.

Horizon	Lower Depth	Color	Texture	Structure	Bridging Voids	Boundary	Cons.	Mn Concr. †	Mottles
<b>Spoil 1</b>									
Oe	3-0	moist					moist		
A	2	7.5YR 3/1	CL	2 myr		as	vfr		
Bw1	30	5YR 4/6	SiC	2 myr*	few	cs	l	c,f	c,d 7.5YR 4/4
Bw2	70	2.5YR 4/8	vgr. SiC	2 myr*	common	gs	l		m,d 7.5YR 4/4
C	140	2.5YR 3/6	SiCL	2 myr*	common	gw	l		c,d 7.5YR 4/6
2Ab	160+	7.5YR 4/4	SiCL	2 myr*			fr		
<b>Spoil 2</b>									
Oe	2-0								
A	6	10YR 3/4	gr. CL	2 myr		cw	vfr		
C1	41	7.5YR 5/6	ex.cob. C	0 m	few	cs	fr	c,f	m,p 2.5YR 4/8
C2	93	7.5YR 4/4** 2.5YR 4/8	vgr. C	0 m	few	cw	fr	c,f	c,d 7.5YR 5/8 c,d 7.5YR 3/2
C3(L)»	108	10YR 4/6	vgr. C	0 m		cs	fr	c,f	c,p 7.5YR 6/8
C3(R)»	108+	7.5YR 5/6	ex.gr. C	0 m			fr		f,p 2.5YR 4/6

† Manganese concretions

\*Material did not fit morphology structures in Soil Survey. To avoid confusion of field descriptions, the Taxonomy structure the material resembled most was selected.

\*\*Mottled matrix color

»Material contrasted in horizon between left and right portion of the profile

Table 4. Chemical properties including exchangeable cations, base saturation, and pH, and total clay of spoils 1 and 2.

Horizon	Lower Depth	NH <sub>4</sub> OAc Extractable Cations				Total Bases	NH <sub>4</sub> OAc CEC	Base Saturation	pH 1:1 H <sub>2</sub> O	Total Clay
		Ca	Na	K	Mg					
		cmol <sub>c</sub> kg <sup>-1</sup>								
cm						%		%		
<b>Spoil 1</b>										
A	2	19.71	0.27	0.46	4.19	24.64	32.54	75.7	5.1	29.5
Bw1	30	0.43	0.04	0.22	0.67	1.36	12.48	10.9	4.3	45.3
Bw2	70	1.63	0.22	0.22	1.95	4.02	11.92	33.7	4.7	42.8
C	140	1.67	0.06	0.24	1.44	3.42	12.50	27.4	4.7	35.6
2Ab	160+	0.97	0.08	0.19	1.04	2.29	10.83	21.1	4.9	30.7
<b>Spoil 2</b>										
A	6	23.32	0.12	0.64	5.61	29.69	30.67	96.2	6.2	36.3
C1	41	5.73	0.07	0.53	3.30	9.63	14.22	67.7	5.7	53.5
C2	93	1.32	0.05	0.24	0.98	2.58	9.62	26.8	4.6	45.3
C3(R)	108	2.68	0.05	0.14	1.71	4.58	12.05	38.0	4.7	59.2
C3(L)	108+	1.64	0.04	0.19	1.35	3.22	10.54	30.6	4.5	49.8

material) prior to deposition in a spoil. Differences in clay content in spoil 1 compared to the paleosol material indicates that mixing with loess material had occurred during placement of the overburden material. Spoil 2 developed in backfill material that was less pre-weathered and originated from limestone material originally underlying the iron ore before mining occurred. It was abundant with cherty coarse fragments. Coarse fragments in the upper portion of spoil 2 appeared less weathered than fragments at lower depths, reversing the weathering sequence expected from pedogenic processes. This suggests that during the mining process the material was removed and backfilled from higher depths to lower depths, so that material originally at a lower depth (less weathered) was deposited at the upper portion of the spoil.

Bridging voids (packing voids), averaging 1 cm in diameter, were observed between rock fragments and soil material in the subsoil of both spoils. The voids were not present in either native pedon. Both spoils

had a higher occurrence of color mottling not associated with anaerobic conditions than the native soils (Table 3). Presumably, these mottles resulted from contrasting materials mixed together during the spoil construction. Moderate medium granular structure was observed in the surface horizon of both spoils. Differences in thickness of the surface horizon between spoil 1 and 2 were a result of differences in landscape position. Spoil 1 was positioned at the shoulder of a hollow more susceptible to surface erosion than the more stable position of spoil 2 (in a drainageway).

Subsoil structure observed in spoil 1 was better described by the "man-made" structure termed "fritted" proposed by McSweeney and Jansen (1984) than the morphology structures outlined in Soil Taxonomy. Massive structure was observed throughout the subsoil of spoil 2. Subsoil horizonation differed between the spoils. A cambic horizon had developed in spoil 1 noted by change in color and fine clay movement (Table 4 and Fig. 6). Diagnostic subsurface horizons did

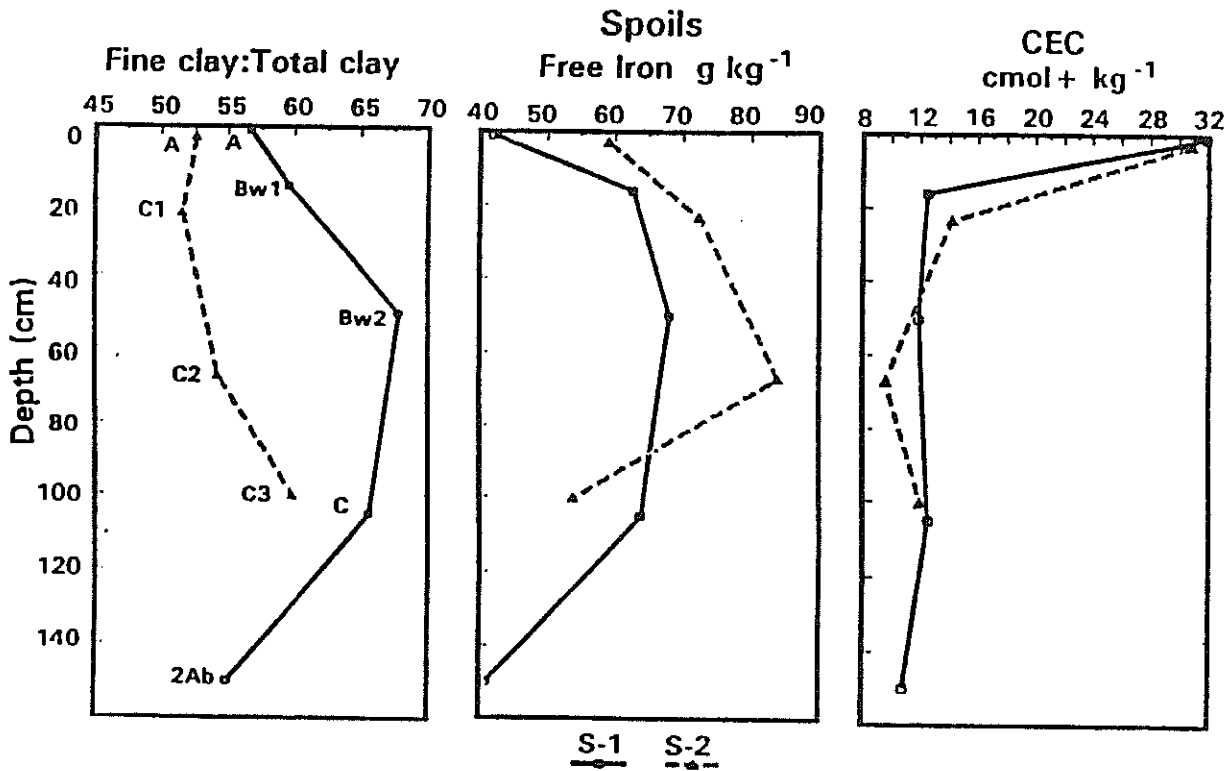


Figure 6. Fine clay to total clay ratio, free iron, and cation exchange capacity distribution by depth in spoils 1 and 2.



not develop in spoil 2. Differences in soil structure and preweathered condition of parent material most likely accounts for the difference in subsoil development between them.

Total iron and free iron concentrations in both spoil profile's were approximately double that of the native pedons (Figs. 4 and 6; Table 5a and b). An "enrichment" of iron oxides was expected in the spoils due to their parent material source having been associated with the origin and mining of the iron ore. Total barium (Ba) was highest in the surface horizons of both native pedons and spoils except for the buried horizon in spoil 1 (Table 5a and b). Total barium almost doubled in the buried A horizon (from the overlying horizon) in spoil 1 but not in the buried A horizon of native pedon 2. Total manganese (Mn) concentrations were significantly highest ( $\alpha$  0.05) in the surface horizons of all four pedons and generally decreased with depth. In spoil 1, total manganese significantly increased in the buried A horizon from overlying horizons. Trace element concentrations in the buried A horizon in native pedon 2 did not tend to increase such as those in the buried A horizon of spoil 1. Lower clay content, lower total carbon content, differences in parent material, and higher coarse fragment contents in the buried horizon in native pedon 2 presumably reduced its ability to retain trace elements compared to the buried horizon in spoil 1. Total copper (Cu) was significantly higher in the surface horizon compared to subsurface horizons in native pedon 1 and both spoils. Distribution of sulfur by depth differed between the native pedons and the spoils. Total sulfur (S) was significantly highest in the surface horizons of the spoils.

Hartley's test indicated if variations of a selected element in row 3 (40 - 60cm) were significantly different between any two sites. Total carbon, total aluminum, barium, manganese, phosphorus, titanium, and zirconium were the elements compared between sites (Table 6). Variation of manganese and zirconium were not significantly different ( $\alpha$  0.05)

between any two sites. Variances of total carbon, total aluminum, barium, phosphorus, and titanium were not consistently significantly different between the native pedons and the spoils.

### Conclusions

1. The buried paleosols in the native pedons are the primary origin of overburden material in which spoil 1 formed. Mixing of this material with loess had occurred. Less pre-weathered cherty limestone material originally below the iron ore was the source of overburden material for spoil 2.
2. The differences in origin of overburden material and the degree of weathering prior to placement in a spoil accounted for morphologic differences such as subsoil development, color, carbon content, rock fragment content, and iron oxide concentration between spoil 1 and 2.
3. A cambic horizon developed in spoil 1. A diagnostic subsurface horizon did not develop in spoil 2. The "fritted" structure with a loose (noncoherent) consistence observed in spoil 1, not present in spoil 2, accelerated the rate of fine clay and free iron movement to the degree of forming a weakly developed cambic horizon within 140-170 years. The massive structure throughout spoil 2 did not allow as much water through the profile, limiting profile development.
4. Bridging voids, averaging about 1 cm in diameter, were observed in both soils (minesoils) but not in the native soils.
5. Moderate medium granular structure formed in the surface horizons of both spoils as well as the native pedons.
6. The association of the spoil material with the iron ore during the mining process enriched the spoil materials with iron oxides.
7. In general, trace elements were highest in the surface horizons of both minesoils and native soils and

Table 5a and b. Total elemental concentrations determined using an acid digestion technique for native pedons 1 and 2 and spoils 1 and 2.

Horizon	Lower Depth	Al	Fe	K	Ba	Ca	Co	Cr	Cu
	cm	g kg <sup>-1</sup>			mg kg <sup>-1</sup>				
<b>Native 1</b>									
A	16	27.2	17.7	9.3	420	4,510	50	30	70
EB	35	33.8	22.3	9.6	370	1,250	10	40	<2
Bt1	60	51.2	36.5	9.4	320	2,030	<3	70	<2
Bt2	78	61.4	38.9	10.4	280	1,190	20	70	10
BC	94	44.5	29.9	9.9	220	1,520	10	50	10
2Bt	116+	71.6	43.1	12.0	240	1,150	<3	80	<2
LSD <sup>05</sup>		2.6	2.2	1.5	90	750	30	10	5

<b>Native 2</b>									
A	21	29.6	23.3	11.2	500	1,240	30	30	20
BE	32	42.2	25.3	13.4	460	930	20	30	20
Bt	58	49.7	37.5	11.8	390	1,200	20	40	20
2Ab	95	32.8	29.4	8.9	290	890	20	30	10
3Bt	108+	71.1	59.1	11.9	260	1,000	10	80	5
LSD <sup>05</sup>		1.1	1.6	0.6	170	360	10	10	20

\*LSD= Least Significant Difference calculated using PC SAS (SAS Institute Inc., 1988). If the difference between horizon values is greater than the LSD, the values are significantly different at an alpha level of 0.05.

Horizon	Lower Depth	Mg	Mn	Na	Ni	P	S	Sr	Ti	Zn	Zr
	cm	mg kg <sup>-1</sup>									
<b>Native 1</b>											
A	16	1,270	1,560	5,560	30	250	870	60	1,580	80	80
EB	35	1,480	600	1,910	30	190	120	30	2,340	40	100
Bt1	60	2,700	140	1,060	60	220	270	50	1,920	210	80
Bt2	78	3,060	160	620	50	230	270	60	2,020	200	80
BC	94	2,810	110	380	60	80	650	60	1,520	130	60
2Bt	116+	3,930	80	260	60	300	470	50	2,050	220	80
LSD <sup>15</sup>		170	50	1,400	20	60	280	30	200	70	10
<b>Native 2</b>											
A	21	1,310	1,230	3,200	20	70	120	60	2,180	50	100
BE	32	1,940	620	2,840	20	50	100	50	2,600	160	110
Bt	58	2,880	510	2,040	20	<5	100	50	2,770	60	110
2Ab	95	1,870	480	1,440	20	<5	40	40	2,130	60	90
3Bt	108+	3,340	90	270	40	90	100	70	2,480	120	80
LSD <sup>05</sup>		200	20	870	20	30	100	20	90	160	5

Table 5a and b. Total elemental concentrations determined using an acid digestion technique for native pedons 1 and 2 and spoils 1 and 2.

Horizon	Lower Depth	Al	Fe	K	Ba	Ca	Co	Cr	Cu
	cm								
<b>Spoil 1</b>									
A	2	30.9	41.2	4.9	280	5,790	30	40	40
Bw1	30	66.3	68.4	8.8	250	750	10	60	5
Bw2	70	62.1	68.5	4.9	280	1,040	10	50	10
C	140	58.4	75.6	6.8	260	780	20	40	10
2Ab	160+	51.1	44.7	12.0	450	870	20	30	10
LSD <sub>05</sub> *		16.5	12.4	0.6	170	520	20	10	30
<b>Spoil 2</b>									
A	6	39.4	61.1	8.6	280	8,670	<3	60	30
C1	41	73.0	76.9	13.1	230	2,100	<3	100	<2
C2	93	72.0	94.0	9.0	280	810	20	60	<2
C3(L)	108+	92.6	65.9	11.6	360	1,200	10	120	10
C3(R)	108+	73.1	53.0	14.8	280	970	20	110	10
LSD <sub>05</sub> *		2.0	1.6	0.7	10	140	5	10	10

\*LSD= Least Significant Difference calculated using PC SAS (SAS Institute Inc., 1988). If the difference between horizon values is greater than the LSD, the values are significantly different at an alpha level of 0.05.

Horizon	Lower Depth	Mg	Mn	Na	Ni	P	S	Sr	Ti	Zn	Zr
	cm										
<b>Spoil 1</b>											
A	2	1,580	820	1,980	20	520	770	70	1,330	140	50
Bw1	30	2,400	380	990	40	110	150	40	2,660	150	90
Bw2	70	2,280	310	870	40	130	110	30	2,820	120	90
C	140	2,180	490	750	40	60	80	40	2,820	90	80
2Ab	160+	2,330	780	2,380	30	30	10	50	2,720	50	100
LSD <sub>05</sub>		230	120	1,090	20	140	70	30	170	60	10
<b>Spoil 2</b>											
A	6	2,930	1,510	3,890	40	700	1,130	60	980	240	40
C1	41	4,290	790	400	60	580	30	70	2,610	290	70
C2	93	2,180	630	1,040	30	180	110	60	2,690	160	80
C3(L)	108+	3,580	180	360	70	750	180	150	2,650	280	100
C3(R)	108+	4,290	690	320	80	530	50	70	1,900	380	80
LSD <sub>05</sub>		70	100	90	20	100	90	5	970	70	10

Table 6. List of calculated F values, using Hartley's test of homogeneity of variances, between all sites.

Between Sites	% total carbon	Al	Ba	Mn	P	Ti	Zr
				$F_c$			
N1/N2	3.0	16.8*	1.8	2.8	3.2	8.8*	2.0
N1/S1	9.0*	27.1*	17.9*	3.7	1.2	1.5	4.4
N1/S2	1.6	1.4	7.5*	5.7	3.3	1.7	1.0
N2/S1	2.9	1.6	9.9*	1.3	3.7	5.5	2.2
N2/S2	4.8	19.0*	4.2	2.0	10.6*	5.3	2.0
S1/S2	14.0*	30.0*	2.4	1.5	2.9	1.0	4.4

\*Calculated F value exceeded tabular F value at a 95% confidence level ( $F_{\alpha=0.05, df 4,4} = 6.4$ ) indicating a significant difference between the variations for the two sites for that elemental concentration.

the buried surface horizon in minesoil 1. Of the trace elements, total barium and manganese best identified the buried A horizons.

8. Variations for seven selected chemical analyses at a depth of 40-60cm were not consistently significantly different between spoils and native pedons at a 0.05 alpha level.

### Literature Cited

- Ammons, J.T. and J.C. Sencindiver. 1990. Minesoil mapping at the family level using a proposed classification system. *J. of Soil and Water Cons.* 45:566-571. <https://doi.org/10.2136/sssaj1987.03615995005100030047x>
- Ammons, J.T., M.E. Essington, R.J. Lewis, A.O. Gallagher, and G.M. Lessman. 1995. An application of a modified microwave total dissolution technique for soils. *Commun. Soil Sci. Plant Anal.* 26:831-842. <https://doi.org/10.1080/00103629509369338>
- Baker, D.E., and N.H. Suhr. 1982. Atomic absorption and flame emission spectrometry. p 13-27. In A.L. Page (ed.). *Methods of soil analysis. Part 2.* 2nd ed. Agronomy Monogr. 9. ASA. Madison, WI.
- Bell, J.C., R.L. Cunningham, and C.T. Anthony. 1994. Morphological characteristics of reconstructed prime farmland soils in Western Pennsylvania. *J. Environ. Qual.* 23:515-520. <https://doi.org/10.2134/jeq1994.00472425002300030016x>
- Burchard, E.F. 1934. Brown iron ore of the Western Highland Rim, Tennessee. US Geological Survey Bull. 39. Division of Geology. Nashville, TN.
- Gallagher, A.O. 1993. A modified method of total elemental analysis for determining background metals in Tennessee. M.S. thesis. University of Tennessee.
- Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. p. 383-411. In A. Klute (ed.). *Methods of soil analysis. Part 2.* 2nd ed. Agron. Monogr. 9. ASA, Madison, WI.
- Haering, K.C., W.L. Daniels, and J.A. Roberts. 1993. Changes in mine soil properties resulting from overburden weathering. *J. Environ. Qual.* 22:194-200. <https://doi.org/10.2134/jeq1993.00472425002200010026x>
- Hammer, R.D., and R.J. Lewis. 1987. Extraction time requirements for determination of exchangeable bases with a mechanical vacuum extractor. *Soil Sci. Soc. Am. J.* 51: 828-831. <https://doi.org/10.2136/sssaj1987.03615995005100030047x>
- Hershey, R.E. and S.W. Maher. 1963. Limestone and dolomite resource of Tennessee. Division of Geology. 65 Nashville, TN.
- Indorante, S.J. and I.J. Jansen. 1984. Perceiving and defining soils on disturbed land. *Soil Sci. Soc. Am. J.* 48:1334-1337. <https://doi.org/10.2136/sssaj1984.03615995004800060027x>
- Jackson, M.L. 1958. *Soil chemistry: A first course.* 6th ed. Madison, WI.
- Killebrew, J.B. 1874. *Tennessee: Its agricultural and mineral wealth.* Trave and Howell printers. Nashville, TN.
- Kilmer, V.J. and L.T. Alexander. 1949. Methods of making mechanical analysis of soils. *Soil Science.* 68:15-24. <https://doi.org/10.1097/00010694-194907000-00003>
- McLean, E.O. 1982. Soil pH and lime requirement. p. 199-224. In A.L. Page, et al. (ed.) *Methods of soil analysis. Part 2.* 2nd ed. Agron. Monogr. 9, ASA, Madison, WI.
- McSweeney, K. and I.J. Jansen. 1984. Soil structure and associated rooting behavior in minesoils. *Soil Sci. Soc. Am. J.* 48:607-612. <https://doi.org/10.2136/sssaj1984.03615995004800030028x>
- Nadkarni, R.A. 1984. Applications of microwave oven sample dissolution. *Analysis-Analytical Chemistry.* 56: 2233-2237. <https://doi.org/10.1021/ac00276a056>
- Olsen, R.V., and R. Ellis. 1982. Free iron oxides. p 301-312. In A.L. Page et al. (ed.). *Methods of soil analysis. Part 2.* 2nd ed.

Agron. Monogr. 9. ASA. Madison, WI.

Ott, R.L. 1993. An introduction to statistical methods and data analysis. Duxbury Press. Belmont, CA. pp. 785-788.

Potter, K.N., F.S. Carter, and E.C. Doll. 1988. Physical properties of constructed and undisturbed soils. Soil Sci. Soc. Am. J. 52:1435-1438.

<https://doi.org/10.2136/sssaj1988.03615995005200050043x>

Rhoades, J.D. 1982. Cation exchange capacity. p. 149-157. In A.L. Page (ed.). Methods of soil analysis. Part 2. 2nd ed. Agronomy Monogr. 9. ASA. Madison, WI.

Safford, J.P. 1856. A geological reconnaissance of the state of Tennessee. 1st biennial report. G.C. Torbett. Nashville, TN.

Schafer, W.M. 1979. Variability of minesoils and natural soils in Southeastern Montana. Soil Sci. Soc. Am. J. 43:1207-1212.

<https://doi.org/10.2136/sssaj1979.03615995004300060031x>

Schafer, W.M., G.A. Nielson, and W.D. Nettleton. 1980. Minesoil genesis and morphology in a spoil chronosequence in Montana. Soil Sci. Soc. Am. J. 44:802-807.

<https://doi.org/10.2136/sssaj1980.03615995004400040029x>

Smith, D., C. Stripling, and J. Brannon. 1988. Tennessee's western highland rim iron industry a cultural survey. Dept. of Cons. Division of Archaeology. Series no. 8. TN.

Smith, R.M., E. Tryon, and E. Tyner. 1971. Soil development on mine spoil. West Virginia University. Agri. Exper. Stat. Morgantown.

Snedecor, G.W. 1956. Statistical methods applied to experiments in agriculture and biology. 5th ed. Iowa State Univ. Press. Ames. IA. p. 96.

Soil Survey Staff. 1984. Soil survey investigations report no. 1. USDA-SCS. U.S. Gov. Print Office, Washington, D.C.

Soil Survey Staff. 1993. Soil survey manual. USDA Handb. 18. U.S. Gov. Print Office, Washington, D.C.

Springer, M.E. and J.A. Elder. 1980. Soils of Tennessee. University of Tennessee Agri. Exper. Stat. Bull. 596. Knoxville, TN.

Thurman, N.C. and J.C. Sencindiver. 1986. Properties, classification, and interpretations of minesoils at two sites in West Virginia. Soil Sci. Soc. Am. J. 50:181-185.

<https://doi.org/10.2136/sssaj1986.03615995005000010034x>