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ENVIRONMENTAL SCIENCES DIVISION

CHARACTERISTICS OF SOILS AND SAPROLITE IN
SOLID WASTE STORAGE AREA 6

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Abstract

Solid Waste Storage Area 6 (SWSA-6) is one of the disposal sites for solid low-level radioactive waste at Oak Ridge National Laboratory. Soils and saprolites from the site were characterized to provide base line information to initiate assessment for remedial actions and closure plans. Physical, chemical, mineralogical, and engineering analyses were conducted on soil and saprolite samples.

High bulk density in the soil solum generally indicates low permeability, depending upon soil structure. The saprolite is more dense (1.9 to 2.0 g/ml) where less weathering has occurred as in profile 1. These bulk density values should be representative of saprolite at depths of 5 to 6 meters. Samples from the more oxidized and leached saprolite of soil profiles 3 and 4 have lower bulk densities (1.3 to 1.5 g/ml). These bulk density values are applicable to the upper 3 to 5 meters of saprolite. Surface and Bt horizons of the soil profiles have relatively high silt contents. This is primarily due to the presence of loess (wind blown silt) and the high silt content of the saprolite. The clay content generally increases with depth in the soil solum and clay-plugged upper saprolite but decreases after contact with harder saprolite. Moisture retention values generally decrease with depth, due to an increase in rock fragments.

Engineering properties of the soil solum are not too important because of the shallow depth. However, solum engineering properties are an indication of what saprolite fill properties will become as it weathers. Freshly removed saprolite has a unified soil classification of GC (clayey gravels) or GM (silty gravels), which indicates very high

gravel content with very few fines. Over time the gravel content will decrease and the fines will increase, with a resulting shift in plastic index to 15 or higher.

The presence of low pH values, low calcium carbonate equivalents (CCE), high concentrations of hydroxylamine-reducible manganese, and high concentrations of CBD-extractable manganese and iron are indicative of the highly weathered nature of the soils and saprolite at the site. High CCE values, and neutral to mildly alkaline pH values (pH 7-8) have been observed in the bedrock samples of HHMS core drillings. The soils and saprolites at SWSA-6 are generally low in organic carbon.

X-ray diffraction analyses of the clay size fraction of the soils and saprolite show high amounts of hydroxy-interlayered vermiculite. Large quantities of kaolinite have been found in the clay size fraction of samples from soil profiles 4 and 9. Gibbsite is present in the clay size fraction of only one horizon in soil profile 9. High concentrations of manganese and iron oxides along with poorly crystalline (neoformed) kaolinite are present in the clay size fraction of soils formed in the Maryville Limestone. Manganese and iron oxides are present in the soils and saprolites formed from the Nolichucky Shale, loess and alluvium. Micromorphological examinations indicate the presence of manganese and iron oxides in many different forms and associations. Manganese and iron oxides commonly occur as coatings on peds and saprolite surfaces. These oxides are generally associated with clay.

The results of physical, chemical, and mineralogical studies of SWSA-6 soils and saprolites will be incorporated with the results of other investigations, including geochemistry, geology, and hydrology for development of a comprehensive remedial action and closure plan.

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1. INTRODUCTION

Solid Waste Storage Area 6 (SWSA-6) is a low-level radioactive waste burial facility located on the Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee. Wastes composed of paper, filters, rags, gloves, tools and biological substances have been disposed in this low-level waste disposal site. Soils in SWSA-6 have been developed from the upper Maryville Limestone and lower Nolichucky Shale members of the Conasauga Group. The landforms on the site have been formed from episodic erosional geomorphic processes (Liezke and Lee, 1986). Drainageways are located in areas which favored surface waterflow. Drainageways tend to initially form in areas that either had a closer joint spacing or were more fractured, or in areas where the drainage network was inherited from an earlier erosion cycle. Because soil in the past has been removed by overland flow, depth to unoxidized and unleached rock is generally shallower in drainageway bottoms than on interfluves where more rainfall infiltrated and percolated downward, resulting in greater chemical weathering of rock and thicker saprolite.

An understanding of SWSA-6 soils, their role in the chemical environment of the solum and saprolite zone, and in surface and subsurface water movement is crucial in remedial action and closure of this and other burial grounds located on Conasauga Group residuum. Information regarding characteristics of soil and saprolite is revealed through physical, chemical, and mineralogic analyses. An understanding

of the various properties of soil and saprolite materials in disposal sites is important for development of a comprehensive management plan of the sites. This is especially true when an aspect such as hydrology of a disposal area is considered.

After entering the environment, radioactive contaminants leached from wastes will contact soil and geological materials. Characteristics of the soil and saprolite that change with increasing depth will influence the migration and interaction of radionuclides. Small differences among soils and wastes may greatly influence radionuclide migration. As a result of different speciations of various radionuclides, prediction of their behaviors in soils is difficult. Mechanisms of radionuclide interaction with soil materials are used as tools for predicting the amount of radionuclide movement in soils.

2. MATERIALS AND METHODS

2.1 Geology

Low-level radioactive Solid Waste Storage Area 6 (SWSA-6) is located in Melton Valley, northwest of White Oak Lake and southeast of Lagoon Road and Haw Ridge on the Oak Ridge Reservation in Tennessee (Fig.1). The study area encompasses 28 hectares and has been used as a solid waste disposal site for 20 years. The Oak Ridge Reservation occurs in the Valley and Ridge Province of East Tennessee. SWSA-6, which is located on the Copper Creek thrust block, is underlain by strata of the Middle to Late Cambrian Conasauga Group. The Conasauga Group in the Melton Valley area is approximately 550 m thick, and composed of silty limestones, calcareous shales, and alternating calcareous siltstones and mudstones. The uppermost Maryville Limestone and lowermost Nolichucky Shale are formations of the Conasauga Group that occur in SWSA-6. The greater portion of SWSA-6 is underlain by the Upper Member of the Maryville Limestone. This is composed of dark gray, green and maroon-colored calcareous shales interbedded with gray-blue silty limestones and mudstones. In the southern most part of SWSA-6, the Maryville Limestone is interbedded in a transitional zone with the Nolichucky Shale which contains oxidized claystones (Boegly, 1984).

2.2 Pedology

According to Boegly (1984) the soils in the SWSA-6 area are moist, strongly leached, acidic, low in organic matter, and have cation exchange capacities less than 10 meq/100g of soil. The carbonate cement



Figure 1. Location of Solid Waste Storage Area 6.

that is found throughout most of the group is leached out near the surface. The saprolite material still has bedding and rock structure present. A thin veneer of soil, usually less than 1m thick, overlies the saprolite. There are no distinct boundaries between the soil, saprolite and bedrock (Boegly, 1984).

The three types of parent material found in SWSA-6 are: 1) in situ regolith (residuum or saprolite), 2) transported sediments (colluvium and alluvium), and 3) ancient alluvium. Residuum from the upper member of the Maryville Limestone and the Nolichucky Shale beneath makes up the greatest portion of the parent material (Lietzke and Lee, 1986).

Throughout the area, thin limestone lenses have weathered to form thin seams of red and yellow clay. Silty limestone weathers to porous brown siltstone saprolite. Shales weather to saprolites with a brown or dull olive color. Weathering and differential water watermovement enhances the abundant joints in these siltstones and shales. Thicker and more numerous limestone lenses are found in the northernmost part of the site. At higher elevations in SWSA-6, resistant limestone lenses are found within a few feet of the surface. Boegly (1984) reports that the particle size data for near surface saprolite has a mean sand content of 36%, a silt content of 22% and a clay content of 42%. Due to the higher claystone content of the saprolite, the soils of SWSA-6 have a higher clay content in the subsoil. Small faults and folds are found throughout the srolite and bedrock beneath (Boegly, 1984).

The second most abundant parent material found at SWSA-6 is transported sediments (colluvium and alluvium). This parent material consists of sediments derived from both saprolite and in situ soils

(Lietzke and Lee, 1986).

The third parent material which exists in SWSA-6 is ancient alluvium (Lietzke and Lee, 1986). This material is found on a stable upland summit that represents the highest elevation in SWSA-6. According to Boegly (1984), the ancient alluvial deposits do not resemble the surrounding bedrock. The sediment probably originated from ancient Clinch River flooding events (Boegly, 1984). This deposit is generally 0.3 m thick, but in the southwestern corner of the site alluvium thickness is about 5 m. Highly weathered shale residuum lies beneath the alluvium.

2.3 Sampling - Field Methods

Soil and saprolite samples were taken from soil profiles 1, 3, 4, 9 and 10. Sampling was also completed on a shallow trench located approximately 100 m east of profile 9. A deep trench (trench 487) located approximately 150 m south of the entrance to the site was also sampled. All site locations are shown in Figure 2. Bulk soil and saprolite samples were taken from the various single and combined soil and saprolite horizons from the profiles and shallow trench. Core samples were taken from various single and combined soil and saprolite horizons using a sampling tube. Samples were stored in cylindrical containers. Large soil and saprolite clods taken from a depth of 3-6 m were retrieved from the deep trench. Core drillings were taken from depths of 0 to 12.4 m approximately 100 m northeast and east of profile 5 (Fig. 2). Thin section analyses were conducted on subsamples from the deep trench and bulk profile samples.

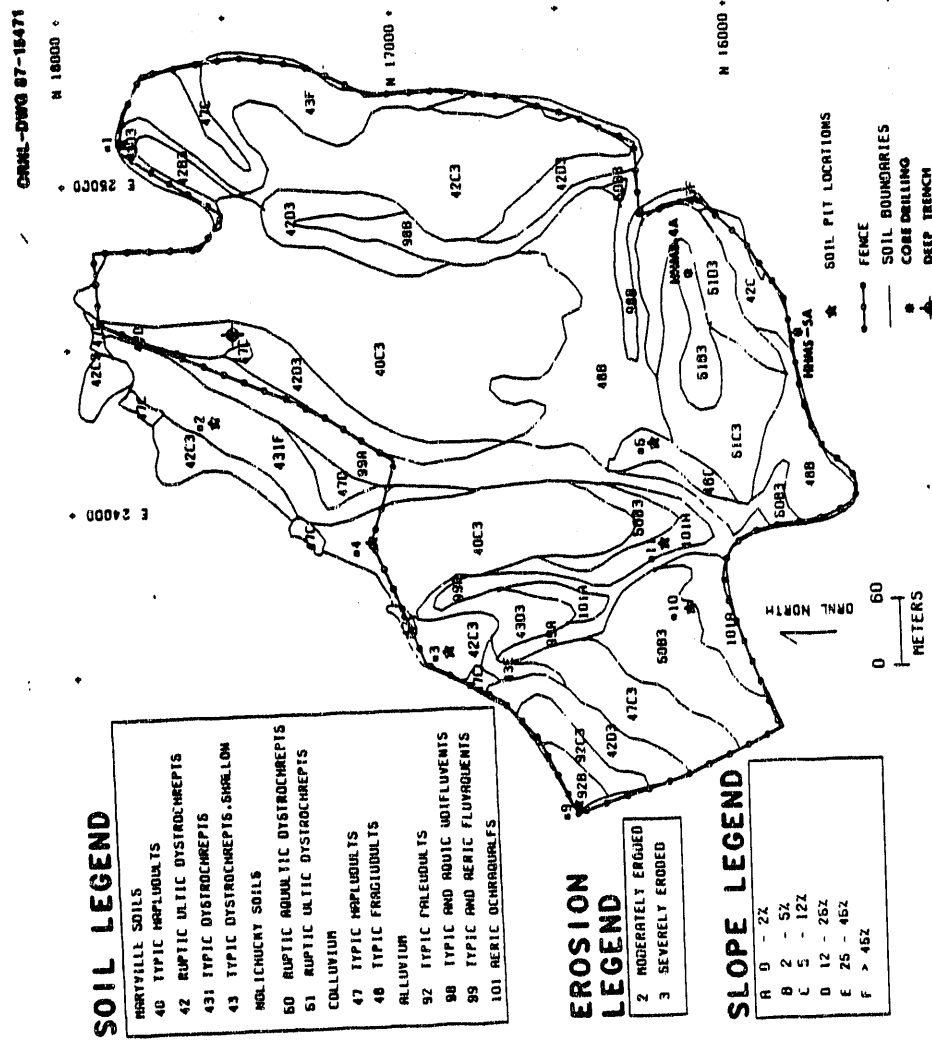


Figure 2. Soil map with locations of soil profiles, trenches and core drillings.

2.4 Sample Preparation

Bulk soil samples were air dried and ground to pass a 2 mm sieve. Coarse fragments and fine earth materials were stored in plastic bags in the Soil Sample Prep Building on the University of Tennessee, Knoxville campus. The core drillings that contained no bedrock were sieved in order to separate the fine earth and coarser fractions. Core drillings containing bedrock were not sieved.

2.5 Physical and Engineering Analysis

Physical and engineering analyses were conducted on soil and saprolite horizons. The pipette method was used to determine particle size distribution of the soil and saprolite (Soil Survey Staff, 1984). Liquid and plastic limits and flow index were determined using standard techniques (ASTM, 1980). Shrinkage limit was determined using the following equation: $SL = 2 + pi$, where SL is the shrinkage limit, and pi is the distance above or below the A-line that the plot of plasticity index and liquid limit rests on Casagrande's plasticity chart (Casagrande, 1932). Moisture retention was determined at 1/3 and 15 bars tension on a ceramic plate extractor (Richards, 1965). Moisture retention values were adjusted to account for coarse fragment content. Bulk densities were determined by the core method (Blake, 1965). Soil particle density was measured from five random core samples using the method of Blake (1965). These values were averaged and used to calculate total porosity.

2.6 Mineralogical Analysis

Qualitative mineralogy of soil and saprolite clay samples was

determined by x-ray diffraction and differential scanning calorimetry. Untreated clay samples were collected in conjunction with particle size determinations. Iron was removed from the clay fraction of selected samples using sodium citrate bicarbonate dithionite (CBD) followed by saturation of split samples with 1 N KCl and 1 N MgCl (Jackson, 1975). The untreated clay samples were oriented on ceramic tiles by suction through a Buchner funnel. Magnesium and potassium saturated clay samples were oriented on glass slides by the filter-membrane peel technique of Drever (1973). Before the clays were oriented on the slides, they were dispersed ultrasonically for 10 min. Air-dried magnesium-saturated samples were analyzed by x-ray diffraction at room temperature and after a 10% glycerol treatment. Air-dried potassium-saturated samples were analyzed at room temperature and following heat treatments at 105°C, 300°C, and 550°C.

Clay analysis by x-ray diffractions was conducted at the Oak Ridge National Laboratory. Diffractograms were made with a Philips model 3-202 diffractometer connected to a California Scientific computer system. The radiation was CuK α generated at 35 kV and 15 mA. Diffractograms were completed at a scan speed of 1 degree per minute stepped at intervals of 0.02 degrees. Diffractograms began and ended at 2 and 30 degrees 2 θ , respectively. Quantification of quartz, kaolinite, and gibbsite was achieved using differential scanning calorimetry (DSC).

2.7 Micromorphological Analysis

Petrographic analysis was conducted on 29 thin-section samples using a polarizing microscope. Descriptions, observations and

measurements of the optical properties of rock and soil forming minerals along with other crystalline and amorphous materials were by the methodology of Fitzpatrick (1984). A scanning electronmicroscope (SEM), Model ISI-40, was used to examine Cr horizon materials, especially manganese coatings (Jackson, 1975).

2.8 Chemical Analysis

Chemical analyses were conducted on representative samples from single and combined soil and saprolite horizons as well as core drillings. Soil pH was measured using a 1:1 (w/v) soil-to-solution ratio in water and 1 M KCl on the fine earth (<2 mm) of soil profiles. The same pH procedure was used on the fine earth (<2 mm) and the coarse fragment fractions (>2 mm) of the core drillings. The pH of one core drilling sample was measured in the supernatant portion of a 1:1 (w/v) soil/water paste (Peech, 1965). Organic carbon was determined by using a Leco CR12 Carbon Determinator. Calcium carbonate equivalent (CCE) was determined by acid titration (Sobek et al., 1978). Exchangeable bases were extracted with 1 M NH₄OAc. Exchangeable Al was extracted with 1 M KCl. Exchangeable bases and Al were determined by atomic absorption spectroscopy. Cation exchange capacity (CEC) was calculated as the sum of exchangeable bases plus KCl exchangeable Al (Soil Survey Staff, 1984). Exchangeable acidity was determined using a modified version of Thomas (1982). The following modifications were used: 50 ml of 1 M KCl were added to 2.5 g of soil and the mixture agitated on a mechanical shaker for 30 minutes. The extract was collected by gravity filtration

through Watman No. 42 filter paper. The remainder of the determination was unmodified.

Reducible manganese was extracted with hydroxylamine hydrochloride followed by determination using atomic absorption spectroscopy (Chao, 1972). Iron and magnesium were extracted using sodium citrate dithionite as described by Jackson (1975).

3. RESULTS AND DISCUSSION

3.1 Soil Morphology and Classification

Taxonomic classifications and mapping units for the five soils sampled are listed in Table 1. The soils are described in Lietzke and Lee (1986). Four of the profiles are illustrated in Figure 3. The soil in pit 1 is classified as a member of the loamy-skeletal, mixed, thermic, shallow Typic Dystrochrepts. The soil is formed in high silt content saprolite from the Maryville Limestone. Greater than 70% rock fragments by volume are present in soil 1. The saprolite (a slightly weathered siltstone facies of the Maryville Limestone) is present within 50 cm of the soil surface. Saprolite fragment interiors and surface coatings have olive-yellow to olive-brown colors. The saprolite is also coated with manganese oxides as illustrated in Figure 4. This soil probably formed during the late Pleistocene or early Holocene.

The soil in pit 3 is classified as a member of the clayey-skeletal, mixed, thermic, Ruptic-Ultic Dystrochrepts. The parent material is residuum from the Maryville Limestone. The saprolite is variegated, with olive colors. Siltstone and sandstone saprolite fragments are present throughout but greatly increase below a depth of 100 cm. The Ruptic-Ultic Dystrochrept has a moderately deep solum over weakly consolidated sedimentary rock. An intermittent, thin argillic horizon occurs where the depth to rock is greatest. The base saturation is less than 60% throughout the control section (approximately 25-100 cm) and the clay content is greater than 35%. Red and dark red iron oxides and black manganese oxides coat the saprolite joint and fracture faces.

The soil in pit 4 is classified as a member of the clayey, mixed,

Table 1. USDA soil classification, soil series and parent material of five soil profiles described at SWSA-6.

Pit	Soil No.	Classification	Parent Material
1	43	Typic Dystrochrepts; loamy-skeletal, mixed, thermic, shallow	Maryville Limestone
3	42	Ruptic-Ultic Dystrochrepts; clayey-skeletal, mixed, thermic	Maryville Limestone
4	40	Typic Halpudults; clayey, mixed, thermic	Maryville Limestone
9	92	Typic Paleudults; fine-loamy, siliceous, thermic	Old alluvium from local and distant sources
10	50	Ruptic-Aquultic Dystrochrepts; loamy-skeletal, mixed, thermic	Interbedded basal Nolichucky and uppermost Maryville

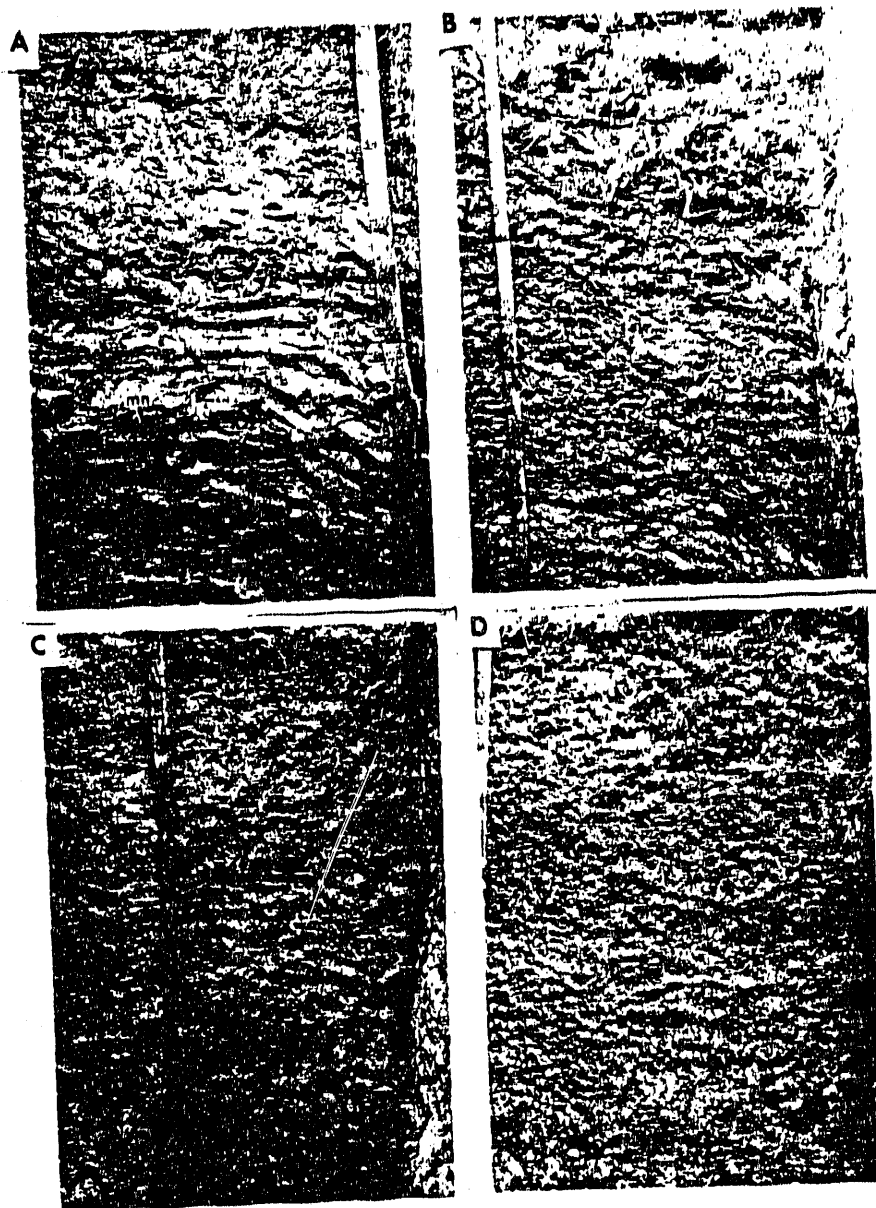


Figure 3. Photographs of soil profiles in SWSA-6 showing soil and saprolite development: A) Soil profile 1. Manganese coatings (mn) are present on the saprolite, B) Soil profile 3, C) Soil profile 4, D) Soil profile 9.



Figure 4. Manganese coatings (mn) on the saprolite in soil profile 1.

thermic family of Typic Hapludults. This soil is formed in a thin layer of loess and old alluvium and the underlying saprolite from the Maryville Limestone. Soil profile 4 is a freely drained soil that is deep to hard rock. Bright hues of 5 YR are present between 46 to 84 cm, indicating high oxidation status in the soil solum. Hard manganese nodules (1-2 mm dia.) occur between 6 and 27 cm and a few black iron-manganese oxide nodules are between 27 and 70 cm. Red to dark red iron oxide and black manganese oxide coatings are present on faces of the saprolite. Rock fragments occupy less than 35% by volume of the soil solum.

The soil in pit 9 is classified as a member of the fine-silty, siliceous, thermic family of Typic Paleudults. The parent material is old alluvium from local and distant sources. Chert from the Knox formation and quartzite pebbles are present between 37 and 80 cm. Red clay plasma is present as coatings on the ped surfaces. A lithologic discontinuity is present in this soil profile at 53 cm where a layer of loess covers the highly weathered ancient alluvium. The presence of rounded quartz grains (Fig. 5) provides evidence of the alluvial nature of the parent material. Water flow zones are present below and within the 2Bt5 horizon. Surface residues are observed microscopically in these horizons (Fig. 6). These residues are the outer surfaces of aggregates from which one or more internal constituents have been removed. In this case clay and oxides have been removed.

The soil in pit 10 is classified as a member of the loamy-skeletal, mixed, thermic family of Ruptic-Aquultic Dystrocrepts. The parent material is interbedded basal Nolichucky shale and uppermost Maryville Limestone. Ped and fragment surfaces in the soil solum are coated with



Figure 5. A rounded quartz grain (q) and a disintegrated quartz grain (q) present in the alluvial soil of profile 9. The disintegrated quartz grain indicates a high degree of weathering.



Figure 6. Surface residue (r) is observed adjacent to a pore that contains an infilling of highly oriented clay (c) on the side and manganese and iron oxide (o) accumulation in the center. Small voids (v) are also present. This feature was observed in the BC horizon (190-230 cm) of soil profile 9.

different shades of brown and gray clay. Black manganese oxides coat brown colored shale fragments between depths of 84 to 120 cm. Glauconite pellets also occur within this zone. Steeply dipping rock structure is present in all horizons except the A and Bt horizon. The saprolite materials are quite hard below 120 cm.

The shallow trench exposed the basal old alluvium, the pebble zone beneath which represents an ancient river bed, and the underlying highly weathered Maryville saprolite beneath (Fig. 7).

3.2 Physical and Engineering Properties

3.2.1 Particle size distribution

Particle size distribution is reported in Table 2. High silt contents are predominant in the surface and in some Bt horizons of all soil profiles. This is due primarily to the presence of loess. Higher percentages of sand sized particles in C and Cr horizons are a result of disaggregation of larger shale fragments during sample preparation. The clay content generally increases with depth in the soil solum and clay plugged uppersaprolite but decreases after contact with harder saprolite. Fracture and joint spacing in harder saprolite are closer together which precludes migration of clay. However, most faces are coated with either iron or manganese compounds.

3.2.2 Bulk density

Bulk density values for the soil and saprolite horizons of the five soil profiles and shallow trench are shown in Table 3. High bulk



Figure 7. Soil profile in the Shallow Trench.

Table 2 Particle size (in mm) distribution, including rock fragments, and USDA soil textures of six soils at SWSA-6.

Pit Horizon	Depth (cm)	Particle size (in mm) distribution										Clay <0.002	Silt .05-.002	Sand 2-0.05	FSi .02-.002	Fragment >2mm	Texture with Modifier
		VCS 2-1	CS 1-.5	MS .5-2.5	FS .25-.1	VFS .1-.05	CSI .05-.02	FSi .02-.002	Sand 2-0.05	Silt .05-.002	Clay <0.002						
1	A-Bw	10.6	3.6	0.9	1.5	2.9	29.0	40.9	19.5	69.9	10.6	24.50	shaly silt loam				
	C-Cr1	19.0	8.6	1.3	1.3	2.7	12.2	28.1	32.9	40.3	26.8	71.12	ext. shaly loam				
	Cr2	16.8	9.6	1.3	1.6	0.3	5.2	24.7	29.6	29.9	40.5	85.99	ext. shaly clay				
	Cr3	28.0	16.5	4.6	5.9	3.6	8.3	12.2	58.6	20.5	20.9	78.27	ext. shaly sci**				
3	Cr4	26.0	11.7	2.9	4.0	4.6	12.6	19.4	49.2	32.0	18.8	94.00	ext. shaly loam				
	A-E	8.0	3.2	1.1	3.4	10.4	43.6	27.0	26.1	70.6	3.3	9.39	silt loam				
	BE	6.7	3.1	1.3	3.3	11.1	22.5	28.8	25.5	51.3	23.2	8.67	silt loam				
	BT-C	9.7	7.0	0.5	1.0	3.2	4.6	15.8	21.4	20.4	58.2	57.19	very shaly clay loam				
4	C1	11.5	4.5	0.9	2.4	8.5	17.4	17.4	27.8	34.8	37.4	67.00	ext. shaly clay loam				
	C2	6.1	2.1	0.4	1.6	13.8	16.1	13.9	24.0	30.0	46.0	66.76	ext. shaly clay loam				
	CrMin	23.8	9.1	1.2	3.8	6.5	10.9	17.5	44.4	28.4	27.2	78.93	ext. shaly clay loam				
	Cr	11.6	3.0	0.5	3.1	13.4	14.5	17.9	31.6	32.4	36.0	58.61	very shaly clay loam				
	A-E	3.5	1.7	0.3	0.5	2.1	54.4	30.8	8.1	85.2	6.7	10.45	silt				
	Bt1-Bt2	2.3	1.5	0.5	1.8	4.0	19.5	27.1	10.1	46.6	43.3	14.59	shaly clay loam				
	Bt3-CBt	12.3	6.7	1.7	3.9	9.8	2.9	23.9	34.4	26.8	38.8	25.52	very shaly clay				
	C1	1.3	1.1	0.2	0.5	1.9	10.8	25.3	5.0	36.1	58.9	46.69	very shaly clay				
	C2	0.8	0.5	0.3	0.9	5.0	17.3	23.1	7.5	37.4	55.1	37.75	very shaly clay				
	Cr1	13.0	9.7	1.2	2.0	3.4	14.4	18.5	29.3	35.7	35.0	86.14	ext. shaly clay loam				
9	Cr2	2.2	2.1	0.4	2.1	9.6	14.4	21.6	16.3	36.0	47.7	72.12	ext. shaly clay loam				
	Cr3	31.4	7.3	0.4	1.8	2.4	10.4	19.1	43.3	29.2	27.2	94.03	ext. shaly clay loam				
	Cr4	19.0	10.1	1.7	2.8	3.9	8.4	14.8	37.5	23.3	39.3	92.18	ext. shaly clay loam				
	Cr5	9.6	6.0	0.8	0.8	2.0	12.3	29.8	19.2	42.1	38.7	44.08	very shaly clay loam				
	Cr6	16.3	8.3	1.6	4.3	9.6	12.8	8.6	40.1	21.4	38.5	49.84	very shaly clay loam				
	Ap-E	2.6	1.6	2.4	8.4	7.5	38.9	34.9	22.5	73.8	3.7	4.44	silt loam				
	Bt1-Bt2	1.5	1.3	2.1	8.7	9.1	17.1	31.6	22.7	48.7	28.6	1.59	clay loam				
	2Bt3	1.7	1.5	1.9	8.6	9.2	26.8	30.6	22.9	47.4	29.7	17.42	gravelly clay loam				
	2Bt5	0.4	0.3	1.0	6.4	12.4	18.7	21.7	20.5	40.4	39.1	18.10	gravelly clay loam				
	10	Ap	2.8	2.9	1.0	2.2	2.5	21.2	34.5	11.4	55.7	32.9	12.73	silty clay loam			
Bt		5.2	4.2	1.7	3.1	3.8	6.1	31.2	18.0	37.3	44.7	16.30	shaly clay				
Btg		4.7	3.3	0.9	1.5	1.6	3.2	57.2	12.0	64.4	23.6	54.33	very shaly silt loam				
Cr		12.8	8.0	1.6	1.8	0.7	3.2	24.1	24.9	27.3	47.8	86.96	ext. shaly clay loam				
2Cr		6.2	4.5	2.2	4.8	2.9	4.5	25.3	20.6	29.8	49.6	75.71	ext. shaly clay loam				
3Cr		20.4	9.6	2.2	2.4	2.2	6.1	27.2	36.8	33.3	29.9	88.66	ext. shaly clay loam				
4Cr		7.3	5.0	3.2	10.4	7.0	3.9	18.3	32.8	22.2	45.0	67.85	ext. shaly clay				
5Cr		13.1	9.1	2.9	6.6	14.8	10.5	16.4	46.5	26.9	26.6	91.21	ext. shaly sci**				
ST APZ		0.5	0.5	0.9	6.3	9.2	15.1	19.0	17.4	34.1	48.5	1.22	clay				
PZ		5.2	6.7	29.7	28.5	2.1	2.2	1.1	72.2	3.3	24.5	43.52	v. gravelly clay loam				
BPZ	3.3	3.6	1.7	3.4	5.4	1.1	37.4	17.4	38.5	44.1	93.71	ext. shaly clay					

** sci = sandy clay loam.

* ext. = Extremely.

ST=shallow trench, APZ=above pebble zone, PZ=pebble zone, BPZ=below pebble zone.

density in the soil solum generally indicates low permeability, depending upon soil structure. The saprolite is more dense where less weathering has occurred as in profile 1. The saprolite horizons of profiles 3, 4 and 9 are highly weathered. These horizons exhibit lower bulk densities than the saprolitic material in profile 1 (Table 3). Saprolite bulk densities of soil profile 1 are indicative of deeper less oxidized and leached saprolite encountered in the bottoms and lower sidewalls of waste trenches in SWSA-6 at depths of 4 to 6 m.

3.2.3 Moisture retention

Moisture retention values for soil and saprolite horizons of the five soil profiles and shallow trench are shown in Table 3. The moisture retention values of samples from the surface horizons of the five soil profiles ranged from 12.4 to 17.9 percent. These horizons have high silt and organic carbon contents which are responsible for the high water retention values. High organic carbon contents are observed in the samples from the surface horizons of profiles 1 and 3 (Table 8).

Moisture retention of the soils in SWSA 6 generally decreases with depth, due to increased rock fragment content. Moisture retention values have been adjusted where more than 15% rock fragments are present.

3.2.4 Atterberg limits

Atterberg limits for the soils investigated are presented in Table 4. The liquid, plastic, and shrinkage limit values of samples from profiles 4 and 9 increase with depth. Additionally, in samples from profile 10 plasticity index, liquid and plastic limit values

Table 3. Water retention, bulk density, and total porosity of six soils at SWSA-6.

Pit	Horizon	Depth (cm)	Moisture		Retention* between 1/3-15 Bar	Corrected moisture for Rock Frag.	Rock Fragment	Bulk Density (g/cc)	Total Porosity (%)	
			1/3 Bar	15 Bar						
1	A-Bw	0 - 8	37.20	13.55	23.65	17.86	24.50	-	-	
	C-Cr	8 - 40	21.28	14.30	6.98	2.02	71.12	1.59	40.13	
	Cr2	40 - 110	19.18	15.16	4.02	0.56	85.99	1.91	28.08	
	Cr3	110 - 145	19.68	15.17	4.51	0.98	78.27	1.96	20.30	
	Cr4	145 - 205	18.10	11.86	6.24	0.37	94.00	-	-	
3	A-E	0 - 18	35.48	19.23	16.25	-	9.39	1.52	42.81	
	BE	18 - 25	24.33	15.63	8.70	-	8.67	-	-	
	Bt-C	25 - 105	35.41	23.74	11.67	5.00	57.19	-	-	
	C1	105 - 132	43.21	24.12	19.09	6.30	67.00	1.45	45.25	
	C2	132 - 150	45.52	26.96	18.56	6.17	66.76	-	-	
	CrMn	175 - 260	29.73	16.34	13.39	2.82	78.93	1.34	49.67	
	Cr	201 - 213	38.11	22.39	15.72	6.51	58.61	-	-	
4	A-E	0 - 27	24.02	11.67	12.35	-	10.45	1.42	44.76	
	Bt1-Bt2	27 - 70	30.77	23.44	7.33	-	14.59	1.42	46.71	
	Bt3-CBt	70 - 110	32.61	23.07	9.54	7.11	25.51	-	-	
	C1	110 - 170	43.50	31.95	11.55	6.16	46.69	1.45	45.74	
	C2	170 - 190	47.82	32.65	15.17	9.44	37.75	-	-	
	Cr1	190 - 230	33.15	22.29	10.86	1.51	86.14	-	-	
	Cr2	205 - 300	54.61	31.85	22.76	6.35	72.12	-	-	
	Cr3	230 - 300	29.41	19.33	10.08	0.60	94.03	1.44	54.50	
	Cr4	290 - 310	34.15	19.88	14.27	1.14	92.18	-	-	
	Cr5	310 - 366	35.81	19.49	16.32	9.13	44.08	-	-	
	Cr6	366 - 396	22.15	18.38	3.77	1.89	49.84	-	-	
	9	Ap-E	0 - 20	19.27	12.90	6.37	-	4.44	1.35	49.23
		Bt1-Bt2	20 - 53	18.68	15.90	2.78	-	1.59	1.55	42.02
2Bt3		53 - 80	19.41	11.43	7.98	6.59	17.42	1.36	48.70	
2Bt5		119 - 190	23.86	21.33	2.53	2.06	18.61	1.52	42.71	
10	Ap	0 - 14	19.25	17.30	1.93	-	12.73	-	-	
	Bt	14 - 23	20.81	18.99	1.82	1.52	16.30	-	-	
	Btg	23 - 50	25.76	23.10	2.66	1.21	54.33	-	-	
	Cr	50 - 74	24.17	21.26	2.91	0.38	86.96	-	-	
	2Cr	74 - 84	27.98	25.19	2.79	0.68	75.71	-	-	
	3Cr	84 - 120	21.63	19.06	2.57	0.30	88.66	-	-	
	4Cr	120 - 123	36.81	27.33	9.48	3.05	67.85	-	-	
	5Cr	123 - 150	23.60	17.31	6.29	0.55	91.21	-	-	
ST	APZ	100	27.32	22.67	4.67	-	1.22	-	-	
	PZ	200	14.93	11.67	3.26	1.84	43.52	-	-	
	BPZ	300	24.06	20.95	3.11	0.20	93.71	-	-	

ST=shallow trench, APZ=above pebble zone, PZ=pebble zone, BPZ=below pebble zone, *=used as an estimate of available water holding capacity.

increase with depth. The samples from the C-Cr1 horizon in profile 1 and the BE horizon in profile 3 have lower plasticity index and other values than their overlying surface horizons. The activity ratios are calculated by dividing the plasticity index by the percent clay. Generally, clays present in the soils at SWSA-6 are interpreted to be 1:1 or 2:1 non-swelling type clay minerals due to low activity ratios ($A < 1.15$).

Due to high percentage of organic carbon, liquid and plastic limits and clay activities are high in surface horizons of profiles 1 and 3. Clay activity ratio over 4 is determined in profile 3 where the organic carbon percentage is 4.1% (Table 8). Organic matter can assume the characteristics of shrink-swell clays at high water contents. High shrinkage limits in profile 1 and 3 are evidence of this. The liquid, plastic and shrinkage limits are low when small amounts of organics are present. Low quantities of organic carbon also cause a decrease in the plasticity index. In soil profiles where the organic carbon content of surface horizons is high (i.e., $> 1\%$) liquid, plastic and shrinkage limits and plasticity indexes are high. These values decrease in the E horizons and increase once again in the underlying Bt horizons (Table 4).

3.3 Mineralogical Properties

3.3.1 Clay size fraction

X-ray diffractograms of the clay size fraction of the soils at SWSA-6 are shown in Appendix B. Samples of the clay fraction from selected soil horizons were analyzed by X-ray diffraction to determine

their mineralogy (Table 5 and Appendix A). This information is useful for determining relative weathering intensity, soil forming processes and landform stability.

The minerals present in the clay size fraction include kaolinite, smectite, hydroxy interlayered vermiculite (HIV), vermiculite, chlorite, and illite. The other constituents of the clay size fraction of the soils in SWSA-6 are organics plus manganese and iron oxides. The clay minerals, organics and manganese and iron oxides are important for colloidal adsorption of radionuclides. The cation exchange capacity (CEC) of the clays in the soils of SWSA-6 vary with clay type.

The small traces of HIV present in some horizons are likely the result of illite weathering to vermiculite and its subsequent transformation to HIV in a freely drained and acidic soil environment. Based on qualitative estimates of HIV, a large amount of illite weathering appears to have occurred in the soils of profiles 4 and 9. Due to the small amount of illite present in the loess material, the clay fraction in the Ap and E horizons in profile 9 contains only small amounts of HIV and vermiculites.

Pedogenic chlorite is present in the soils and saprolite of profile 4, and the Bt1-Bt2 and 2Bt3 horizons of profile 9. Pedogenic chlorite is also observed in the shallow trench soils at a depth of 300 cm and in the clay fraction of soils in profile 10. Pedogenic chlorite is a transformation product of HIV in these soils.

Clay morphology is an important characteristic that affects micropore size and geometry, which in turn affects permeability. Kaolinite is present in both poorly crystalline (Neoformed) and highly

Table 5. Summation of mineralogical analyses from x-ray diffraction and differential scanning calorimetry determinations.

Pit	Horizon	Depth cm	-----Minerals present in clay fraction (<.002 mm)-----							
			Smectite	Vermiculite	HIV*	Chlorite**	Kaolinite	Illite	Oxides	Gibbsite
1	A-Bw	0-10	ND	H	Tr	ND	Tr	M	Tr	ND
	Cr4	145-205	ND	M	ND	ND	Tr	H	Tr	ND
3	A-E	0-18	ND	M	M	ND	Tr	M	Tr	ND
	Bt-C	84-105	ND	H	M	ND	Tr	M	Tr	ND
	C2	132-150	ND	H	L	ND	Tr	H	Tr	ND
	Cr	201-213	ND	M	Tr	ND	Tr	H	Tr	ND
4	A-E	0-27	ND	Tr	H	Tr	Tr	L	Tr	ND
	Bt1-Bt2	27-70	ND	L	H	Tr	Tr	L	Tr	ND
	Cr1	190-230	ND	M	M	ND	Tr	M	Tr	ND
	Cr4	290-310	ND	M	L	ND	Tr	H	Tr	ND
9	Ap-E	0-20	ND	L	H	Tr	Tr	L	Tr	ND
	Bt1-Bt2	20-53	ND	Tr	H	L	L	L	Tr	ND
	2Bt3	53-85	ND	Tr	H	L	L	L	Tr	ND
	2Bt5	119-190	ND	L	H	Tr	L	L	Tr	Tr
10	Ap	0-14	Tr	M	Tr	ND	Tr	M	Tr	ND
	Btg	23-50	Tr	H	Tr	ND	Tr	H	Tr	ND
	Cr	50-74	Tr	H	Tr	ND	Tr	H	Tr	ND
	5Cr	123-150	Tr	M	Tr	ND	Tr	H	Tr	ND
ST	APZ	100	ND	L	H	ND	L	M	Tr	ND
	PZ	200	ND	L	M	ND	L	M	Tr	ND
	BPZ	300	ND	L	M	ND	Tr	M	Tr	ND

Notes: ND=not detected, Tr=trace(<10%), L=low(10-20%), M=medium(20-30%), H=high(>30%).
 * HIV=hydroxy interlayered vermiculite. **Chlorite=pedogenic chlorite. ST=shallow trench,
 APZ=above pebble zone, PZ=pebble zone, BPZ=below pebble zone.

crystalline forms in the clay fraction of soils in SWSA-6. Poorly crystalline kaolinite affects micropore size. The poorly crystalline grains do not stack evenly and the clay particles are not evenly distributed. The geometry of the resultant larger micropore is less uniform when poorly crystalline kaolinite is present. In contrast, highly crystalline kaolinite tends to stack evenly resulting in smaller micropores with more even distribution of clay. The size and distribution of micropores has an indirect effect on radionuclide adsorption by clays.

A sharp X-ray diffraction peak at 0.72 nm indicates crystalline kaolinite while broad 0.72 nm peak is typical of neoformed kaolinite (Appendix A). Highly crystalline kaolinite is present in the clay fractions of profiles 9 and 10. Soil profile 9 has old alluvium as parent material covered by a loess cap. The soil in profile 10 has interbedded Nolichucky Shale and upper Maryville Limestone as a parent material. Most of the highly crystalline kaolinite in saprolite is inherited from the Nolichucky Shale. Neoformed kaolinite (poorly crystalline) is present in the clay fractions of the soils throughout profiles 1, 3 and 4 (Appendix A). Soils containing neoformed kaolinite are present on the Maryville residuum.

Formation of gibbsite is used to estimate the relative age of a soil. Soil profile 9 represents the oldest soil in SWSA-6. Gibbsite, an aluminum hydroxide polymorph, is found in the clay fraction of the 2Bt5 horizon of profile 9 as indicated by differential scanning calorimetric analysis. The presence of gibbsite indicates that an advancement of weathering has occurred in profile 9.

Clay moves through larger cracks and voids of the saprolite and rock and coats these surfaces. Filling of host rock void spaces by clay minerals is the dominant cause of radionuclide and fluid flow retardation in the undisturbed zone (Lee and Tank, 1985). Clay is found as coatings and plugs associated with iron and manganese oxides and organic matter in larger saprolite voids and fractures. The clay coatings in the cracks and voids of the saprolite are likely deposited there by water movement within the soil profile or else are neoformed from solution.

3.3.2 Iron and manganese oxide coatings

Soil peds and weathered bedrock present in SWSA-6 contain iron and manganese oxide coatings that are in easily defined locations in the soil solum and underlying saprolite. These coatings have an extremely high adsorption capacity for a great number of radionuclides in low-level wastes.

Sodium citrate-bicarbonate-dithionite (CBD) extractable iron and manganese values are reported in Table 6. High iron values are found throughout all soils investigated. Lower iron values are present in the surface horizons of profiles 1 and 3. High manganese concentrations are present throughout most profiles.

Hydroxylamine reducible manganese (HA-Mn) concentrations are reported in Tables 6 and 7. In samples where low CBD-manganese concentrations are reported, low HA-Mn values also occur. Hydroxylamine reducible manganese decreases significantly in the presence of free carbonates. High concentrations of HA-Mn are present in highly

Table 6. The distribution of pH, ammonium acetate extractable bases, sodium dithionite extractable (CBD) iron and manganese, and hydroxylamine reducible (HA) manganese for five soil profiles at SWSA-6

Pit	Horizon	Depth (cm)	pH (1:1)		NH ₄ OAc		Fe	CBD	Mn	HA Mn
			Water	KCl	Ca	Mg				
-----ppm-----										
1	A-Bw	0 - 8	6.57	5.75	3507	226	826	399	297	
	C-Cr1	8 - 40	6.73	4.93	2261	171	1611	627	49	
	Cr2	40 - 110	4.82	3.48	1658	544	1927	229	7	
	Cr3	110 - 145	4.96	3.30	1924	343	1642	908	150	
	Cr4	145 - 205	5.00	3.38	2688	361	1305	1534	95	
3	A-E	0 - 18	6.45	5.79	2987	137	765	918	40	
	BE	18 - 25	6.11	5.18	1537	138	1550	752	4	
	Bt-C	25 - 105	5.38	4.31	2492	142	3626	207	2	
	C1	105 - 132	4.60	3.46	238	166	3326	100	12	
	C2	132 - 150	4.90	3.52	44	196	3886	1368	167	
	CrMn	175 - 260	5.02	3.48	77	159	2172	874	156	
	Cr	201 - 213	5.20	3.61	33	192	2723	161	48	
4	A-E	0 - 27	4.81	3.75	150	9	1255	620	39	
	Bt1-Bt2	27 - 70	5.09	3.59	157	129	2855	304	56	
	Bt3-Cbt	70 - 110	5.31	3.60	14	57	3580	114	13	
	C1	110 - 170	5.47	3.51	9	73	5467	117	17	
	C2	170 - 190	5.11	3.55	10	79	2315	126	211	
	Cr1	190 - 230	4.84	3.55	27	186	3480	988	125	
	Cr2	205 - 300	5.21	3.61	33	217	3264	2834	609	
	Cr3	230 - 300	4.84	3.55	11	327	1876	1820	209	
	Cr4	290 - 310	5.28	3.69	24	395	2850	1950	117	
	Cr5	305 - 366	5.11	3.51	34	477	1872	1628	182	
	Cr6	366 - 396	4.90	3.54	50	491	1443	2215	324	
9	Ap-E	0 - 20	5.91	5.55	1401	114	2683	13	29	
	Bt1-Bt2	20 - 53	4.49	3.79	270	3	1948	11	6	
	2Bt3	53 - 80	5.00	3.69	150	90	2203	182	1	
	2Bt5	119 - 190	4.90	3.48	61	40	2683	11	1	
10	Ap	0 - 14	4.68	3.55	912	325	2087	592	47	
	Bt	14 - 23	4.80	3.15	556	246	2652	1552	164	
	Btg	23 - 50	4.81	3.48	406	256	2642	521	45	
	Cr	50 - 74	4.81	3.42	722	629	2244	932	62	
	2Cr	74 - 84	5.05	3.45	600	488	4279	259	22	
	3Cr	84 - 120	6.50	5.09	3,488	1305	2539	103	208	
	4Cr	120 - 123	6.95	6.19	10,056	1468	2855	200	25	
	5Cr	123 - 150	7.25	6.25	17,643	1305	2297	165	224	
	APZ	100	4.88	3.55	29	118	4029	52	1	
	PZ	200	4.71	3.50	50	49	2127	155	1	
BPZ	300	4.59	3.48	32	255	3723	81	1		

Note: ST=shallow trench, APZ=above pebble zone, PZ=pebble zone, BPZ=below pebble zone.

Table 7. pH, Hydroxylamine reducible manganese and calcium carbonate equivalent (CCE) distributions for drill core samples from SWSA-6.

Sample	Depth m	pH				Hydroxylamine Reducible Mn (ppm)	CCE (%)
		>2mm (1:1 H ₂ O)	<2mm	>2mm (1:1 KCl)	<2mm		
HHMS-4B	0 -0.61	5.12	4.50	3.70	3.61	36.00	0.10
	0.61-1.22	4.80	4.74	3.51	3.48	184.00	0.61
	1.22-1.83	5.11	5.20	3.50	3.65	323.00	0.13
	1.88-2.44	5.25	4.89	3.47	3.45	308.00	0.07
	2.44-3.05	5.13	4.92	3.40	3.40	462.00	-0.03
	3.05-3.66	5.64	4.77	3.33	3.39	509.00	-0.40
	3.66-4.27	5.30	5.35	3.44	3.60	390.00	0.56
	4.27-4.88	5.74	5.45	3.80	3.87	512.00	0.62
	4.88-5.49	6.11	5.85	3.80	4.09	355.00	0.70
	6.91	7.60	-**	6.33	-**	87.00	26.17
	7.52	8.39	-	6.21	-	89.60	22.76
	8.13	8.10	-	6.73	-	91.80	28.92
	8.74	8.11	-	6.70	-	87.00	21.72
	9.35	8.30	-	6.48	-	72.80	17.10
	9.96	8.24	-	6.89	-	68.60	17.58
	10.57	8.30	-	6.69	-	70.00	16.96
	11.18	8.11	-	6.42	-	89.20	21.00
11.79	8.25	-	6.70	-	95.60	25.33	
12.40	8.11	-	6.70	-	88.00	27.66	
HHMS-5A	0-0.61	4.89	4.78	3.59	3.61	13.00	0.09
	0.61-1.22	4.82	4.73	3.38	3.49	47.30	-0.39
	1.22-1.83	5.10	5.21	3.61	3.65	261.00	0.15
	1.83-2.44	5.34	5.21	3.82	3.86	723.20	0.14
	2.44-3.05	5.69	5.80	4.24	4.08	308.00	0.65
	3.05-3.66	6.18	6.27	4.70	4.99	268.40	0.15
	6.71-7.32	-*	7.70	-*	-*	125.40	31.26
	7.32-7.93	8.21	-**	6.60	-**	92.80	22.50
	7.93-8.53	7.55	-	6.70	-	68.00	13.94
	8.53-9.14	7.65	-	6.49	-	88.20	23.83
	9.14-9.75	7.92	-	6.70	-	92.40	25.81
	10.36-10.97	7.67	-	6.09	-	94.80	28.43
	10.97-11.58	8.30	-	6.95	-	89.40	20.68
11.58-12.19	8.05	-	6.78	-	97.80	25.91	

* Insufficient sample, therefore the paste method was used.

**Samples beyond this point were of bedrock and no soil.

weathered zones in the soil, saprolite, and deep core drillings at SWSA-6.

The diffractograms of the clay size fraction which received CBD treatments have no 0.78 nm or 0.48 nm peaks. The X-ray diffraction peaks at 0.78 nm and 0.48 nm are indicative of manganese oxides (D. A. Lietzke, Personal Comm.). The 0.78 nm peak is not present in X-ray diffractograms from the surface horizons of profiles 1, 3 and 4. The absence of this peak suggests that these horizons developed in a different parent material than the underlying horizons or that intense weathering processes caused the translocation of Mn oxides from these surface horizons. The upper horizons in these three profiles contain large quantities of silt that probably resulted from loess deposition. The soils in profile 9 and the shallow trench contain small concentrations of HA-Mn and CBD extractable manganese (Table 6). This suggests that these soils, which formed from old alluvium and loess, either contained small quantities of naturally occurring manganese when they were deposited or pedogenic processes have removed the majority of these materials.

Iron oxides are present throughout the five soil profiles and the shallow trench. An iron oxide X-ray diffraction peak at 0.41 nm was observed in the untreated clay size fraction of most samples (Appendix A). This X-ray peak disappeared after CBD treatment. A large concentration of CBD-extractable iron is present in the soils of all profiles and the shallow trench (Table 6).

3.3.3 Microscopic observations of manganese and iron oxides

Manganese and iron oxides are present microscopically throughout these soils (Appendix B). These oxides are in many different forms and have many different associations. Microscopically, manganese and iron oxides are observed as (1) nodules and concretions, (2) granular segregated bodies, (3) crystalline forms, (4) neo and quasi forms, (5) tubular bodies, (6) dendritic growths, (7) botryoidal forms, and (8) as impregnations (Fig. 8). Manganese and iron oxides are abundant in highly oriented clay coatings around pores and on rock fragments (Fig. 9). The microscopic observations of manganese and iron oxide and clay coatings on rock, saprolite and ped faces indicate movement of these constituents within the soil and saprolite profile. This movement is primarily due to water.

3.4 Soil Chemical Properties

3.4.1 Organic matter content

The organic carbon contents decrease with depth in the soils in all profiles and the shallow trench (Table 8). The surface horizons of profiles 1 and 3 contain large quantities of organic carbon. Organic materials illuviate with clay minerals. These clay minerals and organic particles are translocated (illuviated) through the soil into saprolite. The accumulation of clay minerals and organic particles at 120 cm (profile 10) is a result of less permeable saprolite which begins at this depth.

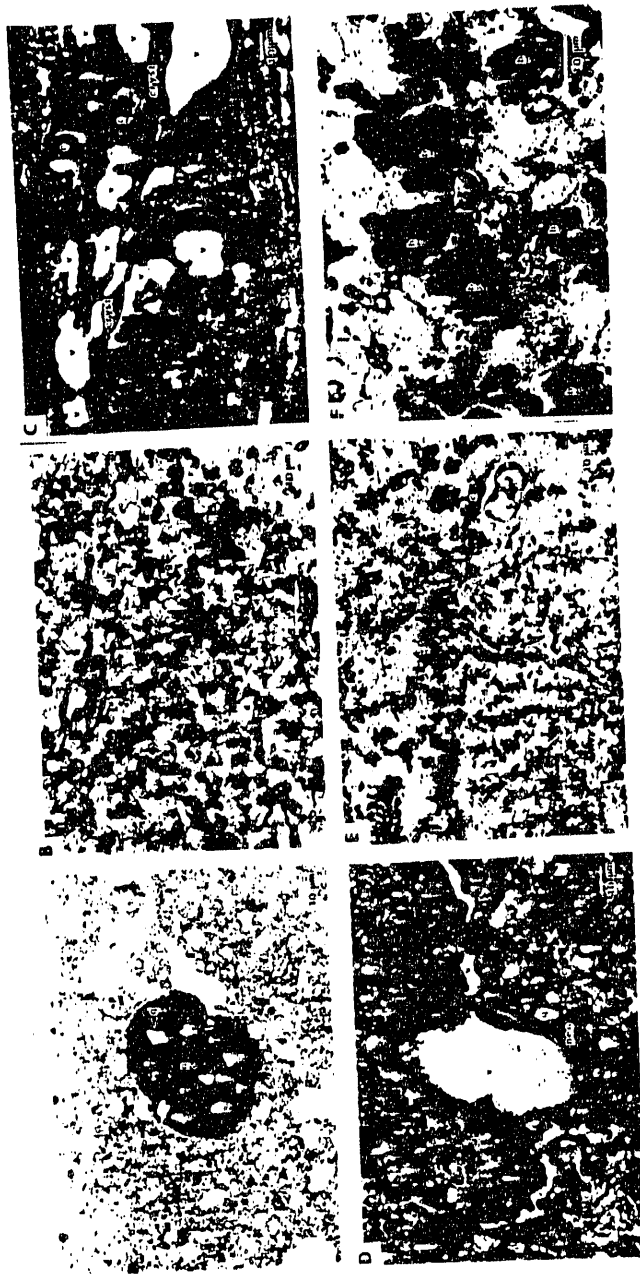


Figure 8. Various forms of manganese and iron oxides and their associations : A) Manganese and iron oxide nodule (n) with quartz grain (q) inclusions. The nodule is present in the E horizon of soil profile 9 (20 cm). B) Granular segregation (g) of manganese and iron oxide. Exfoliating mica grains (m) are also present. These features were found between 3.66 and 4.27 meters in the deep trench. C) Crystalline manganese and iron oxides (cryst) are present with highly oriented clays (c) enclosed within voids (v). These features occurred in the Cr2 horizon of soil profile 4 (290-300 cm). D) A complex neocutan (neo) consisting of manganese and iron oxides and clay (c) coating a void (v) located in the Cr2 horizon of soil profile 1 (110-140 cm). Quartz grains (q) are also present. E) Granular segregation occurring in dendritic growth lines (d) found in the deep trench between 3.66 and 4.27 meters. Clay coatings (c) are also present. F) Botryoidal segregation (b) of manganese and iron oxides found at 3.66 to 4.27 meters in the deep trench. Clay coatings (c) are also present.

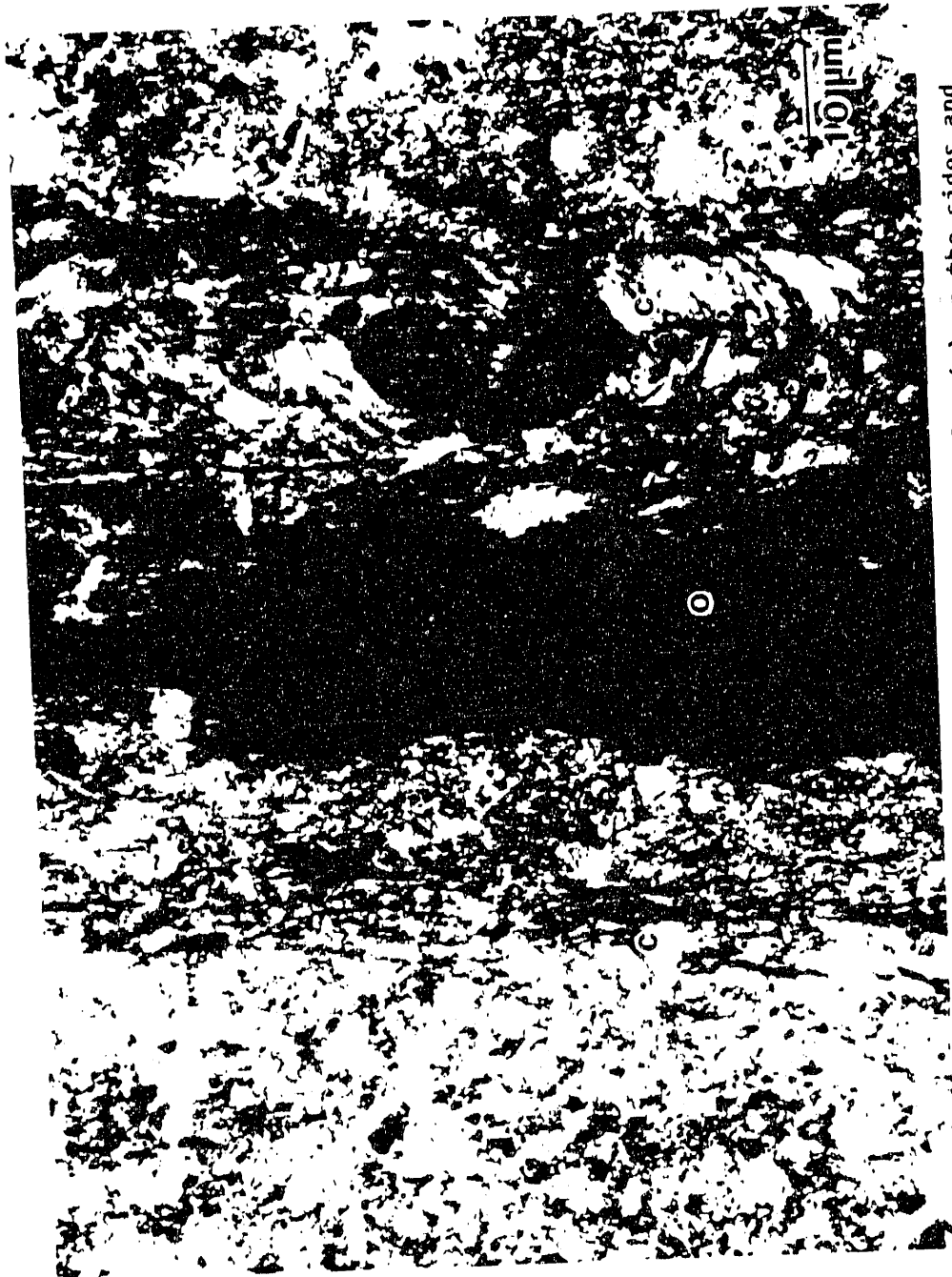


Figure 9. Pore with infillings of highly oriented clay (c) on the sides and manganese and iron oxides (o) in the center. These features were found in the 2BC horizon (190-230 cm) of soil profile 9.

Table 8. Organic carbon distributions in six soils at SWSA-6.

Pit	Horizon	Depth	Carbon
		(cm)	(%)
1	A-Bw	0 - 8	4.33
	C-Cr1	8 - 40	0.59
	Cr2	40 - 110	0.24
	Cr3	110 - 145	0.12
	Cr4	145 - 205	0.12
3	A-E	0 - 18	4.10
	BE	18 - 25	0.65
	Bt-C	84 - 105	0.61
	C1	105 - 132	0.17
	C2	132 - 150	0.13
	CrMn	175 - 260	0.05
	Cr	201 - 213	0.11
4	A-E	0 - 27	0.74
	Bt1-Bt2	27 - 70	0.28
	Bt3-CBt	70 - 110	0.40
	C1	110 - 170	0.10
	C2	170 - 190	0.09
	Cr1	190 - 230	0.08
	Cr2	205 - 300	0.05
	Cr3	230 - 300	0.01
	Cr4	290 - 310	0.03
	Cr5	310 - 366	0.02
	Cr6	366 - 396	<0.01
9	Ap-E	0 - 20	1.80
	Bt1-Bt2	20 - 53	0.48
	2Bt3	53 - 80	0.09
	2Bt5	119 - 190	0.09
10	Ap	0 - 14	0.73
	Bt	14 - 23	0.45
	Btg	23 - 50	0.39
	Cr	50 - 74	0.12
	2Cr	74 - 84	0.14
	3Cr	84 - 120	0.44
	4Cr	120 - 123	0.72
5Cr	123 - 150	0.47	
ST	APZ	100 cm	0.17
	PZ	200 cm	0.08
	BP	300 cm	0.06

ST = shallow trench, APZ = above pebble zone, PZ = pebble zone, BPZ = below pebble zone

3.4.2 Hydrogen ion activities

The hydrogen ion activities (pH) of the soil and saprolite samples from the various soil profile horizons, core drillings and shallow trench ranged from 4.5 to 7.3 (Tables 6 and 7). Higher pH values are observed in the A and B horizons of profiles 1 and 3 and the lower saprolite (5Cr) of profile 10. Soil pH values range from 6.1 to 7.3 in these horizons. The higher pH values in the surface horizons of profiles 1 and 3 are due to past surface applications of lime. The pH of the lower saprolite horizon (5Cr) in profile 10 is high due to the presence of free carbonate. Free carbonates occur naturally in the saprolite and soil of profile 10. The carbonate bedrock of core HHMS-4B (below 7.52 m) has pH values ≥ 8.1 . The pH values of the carbonate bedrock of core HHMS-5A (below 7.32 m) range from 7.6 to 8.3.

Values for KCl extractable aluminum and total acidity for the soil and saprolite in the five soil profiles and the shallow trench are shown in Table 8. The values for extractable Al and total acidity generally increase with depth in all soils. The samples in profile 9 have low concentrations of extractable aluminum and total acidity due to the presence of free carbonate in the saprolite.

3.4.3 Cation exchange capacity and exchangeable and extractable bases

Cation exchange capacity (CEC) values vary throughout all soils investigated (Table 9). These values reported for saprolite may be high due to the presence of free carbonates. The values only express the CEC of the fines (<2 mm) produced by laboratory manipulation and not the solid saprolite in the field state. Rock and/or saprolite fragments

Table 9. Exchangeable bases, extractable Al, total acidity and summation cation exchange capacity on five soil profiles and a shallow trench at SWSA-6.

Pit	Horizon	Depth cm	Exchangeable bases				Extractable Al (KCl)	Total acidity	CEC summation
			Ca	Mg	K	Na			
							-----meq/100g-----		
1	A-Bw	0 - 8	23.19	1.04	0.71	0.08	13.81	0.00	25.02
	C-Cr1	8 - 40	1.09	0.69	0.52	0.04	0.10	0.00	2.34
	Cr2	40 - 110	0.96	2.37	0.63	0.06	2.83	2.06	6.08
	Cr3	110 - 145	1.16	2.17	0.30	0.17	1.67	2.79	6.59
	Cr4	145 - 205	0.56	0.85	0.28	1.33	0.64	0.00	3.02
3	A-E	0 - 18	9.10	0.66	1.26	0.10	7.35	-0.39	11.12
	BE	18 - 25	1.71	0.32	0.91	0.03	0.10	-0.30	2.97
	Bt-C	84 - 105	2.46	0.66	-	0.06	0.10	-0.39	-
	C1	105 - 132	1.05	0.90	0.87	0.07	10.59	8.5	11.39
	C2	132 - 150	0.225	-	0.60	0.22	8.45	9.05	-
	CrMn	175 - 260	0.12	0.86	0.31	-	8.20	7.2	-
	Cr	201 - 213	0.225	1.12	0.25	1.43	8.10	5.75	8.77
4	A-E	0 - 27	0.60	0.07	0.16	0.05	8.86	1.50	2.38
	Bt1-Bt2	27 - 70	4.70	0.60	0.27	0.03	2.08	5.83	11.43
	Bt3-Cbt	70 - 110	0.078	0.30	0.22	0.02	6.76	8.47	9.14
	C1	110 - 170	0.05	0.26	0.18	0.07	8.85	11.50	12.07
	C2	170 - 190	0.06	-	-	0.04	11.67	9.63	-
	Cr1	190 - 230	0.07	0.74	0.22	0.07	9.49	8.35	9.45
	Cr2	205 - 300	0.09	0.22	0.22	0.11	9.79	7.18	8.39
	Cr3	230 - 300	0.07	1.18	0.25	0.61	9.21	7.96	9.52
	Cr4	290 - 310	0.10	1.34	0.22	0.02	8.25	7.67	9.35
	Cr5	310 - 366	0.12	1.57	0.26	0.07	9.19	7.61	9.63
	Cr5	366 - 396	0.23	2.17	0.28	0.06	6.60	5.79	8.53
9	Ap-E	0 - 20	-	0.35	0.27	0.03	0.03	0.39	-
	Bt1-Bt2	20 - 53	1.16	0.15	0.35	0.03	0.03	2.10	3.79
	2Bt3	53 - 80	0.02	0.13	0.21	0.03	0.03	6.84	7.23
	2Bt5	119 - 190	0.01	0.13	0.20	0.03	0.03	6.56	6.93
10	Ap	0 - 14	1.06	1.55	0.41	0.03	10.31	5.83	8.88
	Bt	14 - 23	3.72	1.40	0.37	0.04	6.74	6.53	11.56
	Btg	23 - 50	2.90	1.51	0.47	0.05	7.97	8.55	13.48
	Cr	50 - 74	0.67	2.29	0.36	-	9.24	8.16	-
	2Cr	74 - 84	0.62	2.35	0.21	0.11	9.50	7.81	11.10
	3Cr	84 - 120	2.18	6.25	0.25	0.08	0.10	0.39	9.25
	4Cr	120 - 123	-	7.87	0.23	0.12	0.04	0.39	-
	5Cr	123 - 150	-	6.26	0.15	0.16	0.04	0.00	-
ST	APZ	100 cm	0.10	0.39	0.28	0.10	-	4.79	5.66
	PZ	200 cm	0.16	0.17	0.37	0.23	5.07	4.74	5.46
	BPZ	300 cm	0.08	0.28	0.41	0.07	15.12	12.16	12.99

ST = shallow trench, APZ = above pebble zone, PZ = pebble zone, BPZ = below pebble zone.

(>2 mm) comprise a large volume of the lower horizons in the soils at SWSA-6.

Total exchangeable bases for the soil and saprolite are reported in Table 9. Calcium values are high in surface horizons of profiles 1, 3, and 9. This is probably due to surface additions of lime. The calcium values of samples from the 3Cr, 4Cr, and 5Cr horizons of profile 10 were extremely high due to the presence of free carbonates. The calcium, magnesium, potassium and sodium values varied throughout all soils. The Cr horizons in profile 3 and the Cr4 horizon of profile 1 contained higher concentrations of sodium than found in any of the other soil horizons analyzed.

Ammonium acetate extractable base concentrations are shown in Table 6. High calcium values were observed throughout profile 1. Samples from profile 3 have high calcium concentrations in the upper one meter of soil. Calcium levels were also high in samples from the Ap-E and Bt1-Bt2 horizons of profile 9. The decrease with depth is related to the lithologic discontinuity present at 53 cm. The old alluvium at this depth is highly leached and therefore virtually free of carbonates. Extremely low calcium values were found in samples from the shallow trench. Samples from profile 10 contained extremely high calcium values especially in the saprolite horizons which contain free carbonate. Ammonium acetate extractable magnesium values varied randomly throughout all samples. High magnesium values were observed in the samples from the free carbonate saprolite horizons in profile 10. This suggests the presence of Mg-calcite or dolomite in the bedrock.

Calcium carbonate equivalent (CCE) values for the core drilling

samples are reported in Table 6. CCE values decreased sharply in highly weathered portions of the soil where pH values were low. These values increased at the weathering front between leached and unleached bedrock.

4. SUMMARY

The soil map of SWSA-6 shows the location and extent of each major kind of soil. Within each geologic formation, soils were identified according to morphologic characteristics. Weathering groups of soils were related to past geomorphic processes that shaped the present day landforms. Depth to unleached saprolite or to rock may not coincide with the formation of the soil solum, since deeper saprolite weathering can be active, while geomorphic processes are differentially stripping off surface horizons. During the past history of the site, the Clinch River flowed over part of the site. Evidence for this is the presence of well-rounded quartzites from the Unaka Mountains as well as local subrounded chert from the Knox Group. As the Clinch continued to down cut, erosion processes stripped off most of the alluvium, leaving a small uneroded and loess-covered remnant in the northwest corner. When the soil survey was made in 1985, the site was thought to be underlain by the upper Maryville Limestone. Further investigations have shown that the lower Nolichucky Shale and the transition zone between the two formations occupy the southern third of the site (Lietzke, personal communication).

Average soil solum thickness on the site, except for the No. 40 and 92 soils, is thin (less than 1 meter). Soil solums have a relatively high silt and clay content, and contain organic carbon. They have good sorption properties for radionuclides, but their thinness makes them relatively unimportant for remedial action and closure. In fact, during clearing activities, most of the soil solum in areas that have been

heavily trenched was pushed off into drainageways or buried under leached and unleached saprolite removed from trenches.

Of importance for remedial action and future development of burial grounds in the Conasauga Group are the properties of the oxidized and leached saprolite. It is in this material that most low-level wastes have been buried. In-place properties of saprolite are much different from disturbed properties. In-place saprolite has fairly low permeability on a soil scale, but high permeability on a geologic scale. When this saprolite is removed, it readily parts into individual fragments bounded by joints and fractures. The chemical properties of in-place saprolite are largely controlled by the iron-manganese-clay complex that coats most fracture and joint surfaces, with minimal effects from clay minerals within fragments. The data contained in Tables 2 through 9 were obtained from disturbed, crushed, and otherwise manipulated samples, and is more applicable to properties of disturbed saprolite. Important physical, chemical, and sorption properties of undisturbed saprolite must be obtained from in-place observations with minimal disturbance. The methodology to accomplish this is either not available, not fully developed, or extremely expensive.

Leached saprolite varies greatly in physical and chemical properties depending on how weathered it is. The saprolite beneath the No. 43 soils is not highly weathered. Coarse fragment content is high and there is relatively low clay content. The leached saprolite beneath Soils 40 and 42 is more highly weathered. Fragment content is lower and the clay content is higher. The leached saprolite beneath the No. 51 soils should have similar properties as that beneath the No. 40 and 42

soils.

Engineering properties of the soil solum are not too important because of the shallow depth. However, solum engineering properties are an indication of what saprolite fill properties will become as it weathers. Freshly removed saprolite has a unified soil classification of GC, GM or GP, which indicates very high gravel content with very few fines. Over time the gravel content will decrease and the fines will increase, with a resulting shift to the ML, CL, ML-CL classifications and a plastic index of 15 or higher.

Water flow pathways in both leached saprolite and unleached saprolite are highly variable and irregular. Water that infiltrates the soil solum starts to become channelized in the lower solum. Tree stem flow directs water beneath the tree directly into tree roots and tree root voids. The influence of trees and tree roots on subsurface water flow pathways remains for long periods after tree removal. Water flow zones in leached and unleached saprolite have different chemical properties than the disturbed bulk chemical properties. Saturated water flow in these flow zones can carry radionuclides for long distances with minimal interaction with sidewalls. Most contaminated water flow from trench bottoms and lower sidewalls probably occurs in established flow zones, although some water will be transmitted for short distances as saturated flow through smaller fracture and joint planar pores before it assumes a condition of unsaturated flow. Unsaturated flow is slower and allows more time for contaminants to come into contact with pore sidewalls. Keeping water from ponding in trench bottoms is crucial to preventing or slowing movement of nuclides. Chemical and clay doping of

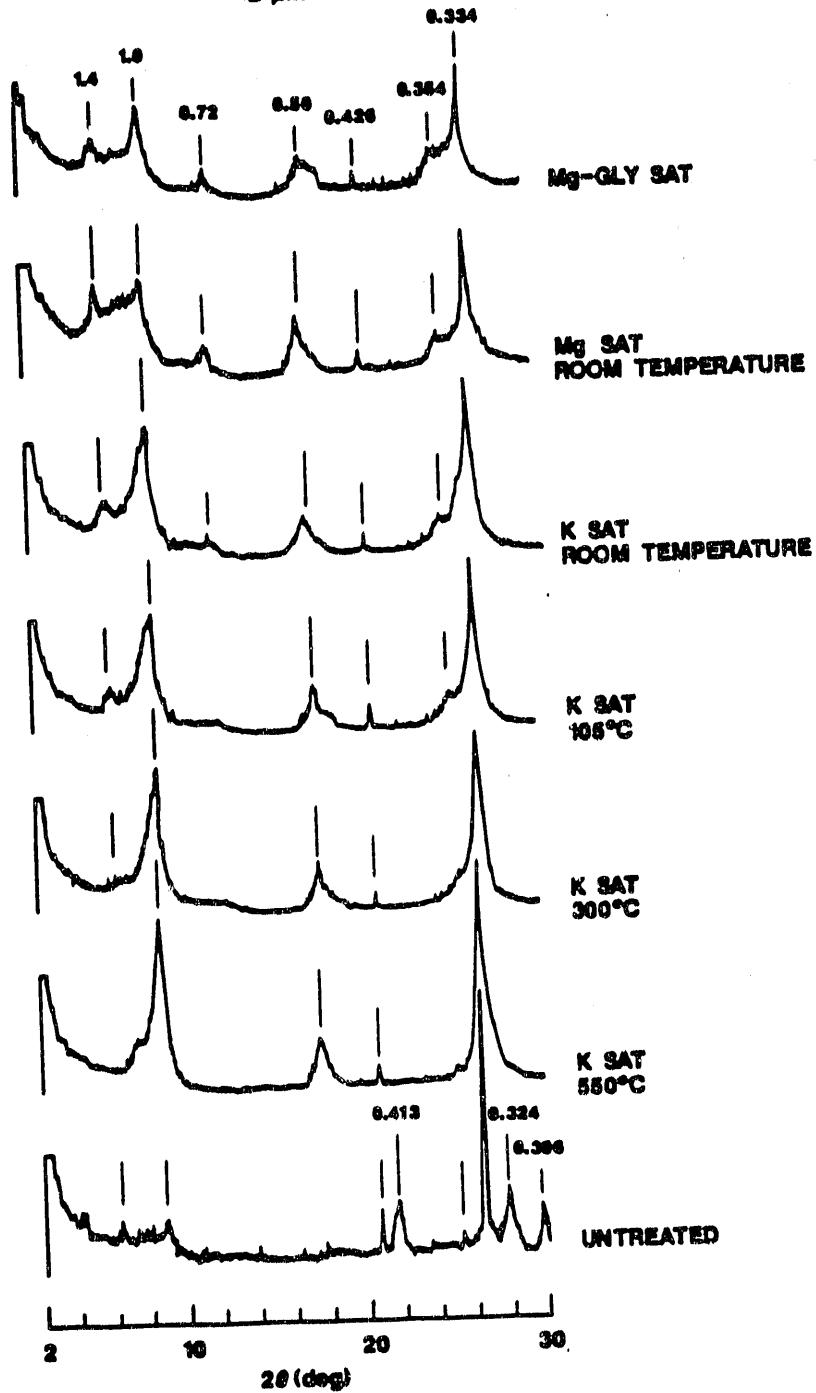
trench bottoms can be utilized to retain certain very mobile nuclides. The study of the chemical environment of existing filled trench bottoms is needed to determine the redox potential and how far nuclides have already moved under fluctuating perched water tables.

Remedial action for the closure of SWSA-6 will require a plan to provide for periodic maintenance for a considerable time. Irregular settlement of trench fill as decay of organic fill occurs and soil collapses into voids will necessitate the addition of fill to depressions. Fill will have to be obtained either on-site or from suitable off-site soil. Liming, fertilization and reseedling will have to be done with each reshaping. Vegetation will have to be selected for its shallow rooting characteristics. As the fill stabilizes and regrading disturbances become less frequent, woody plants will begin to invade the site, some with deep rooting characteristics.

5. REFERENCES

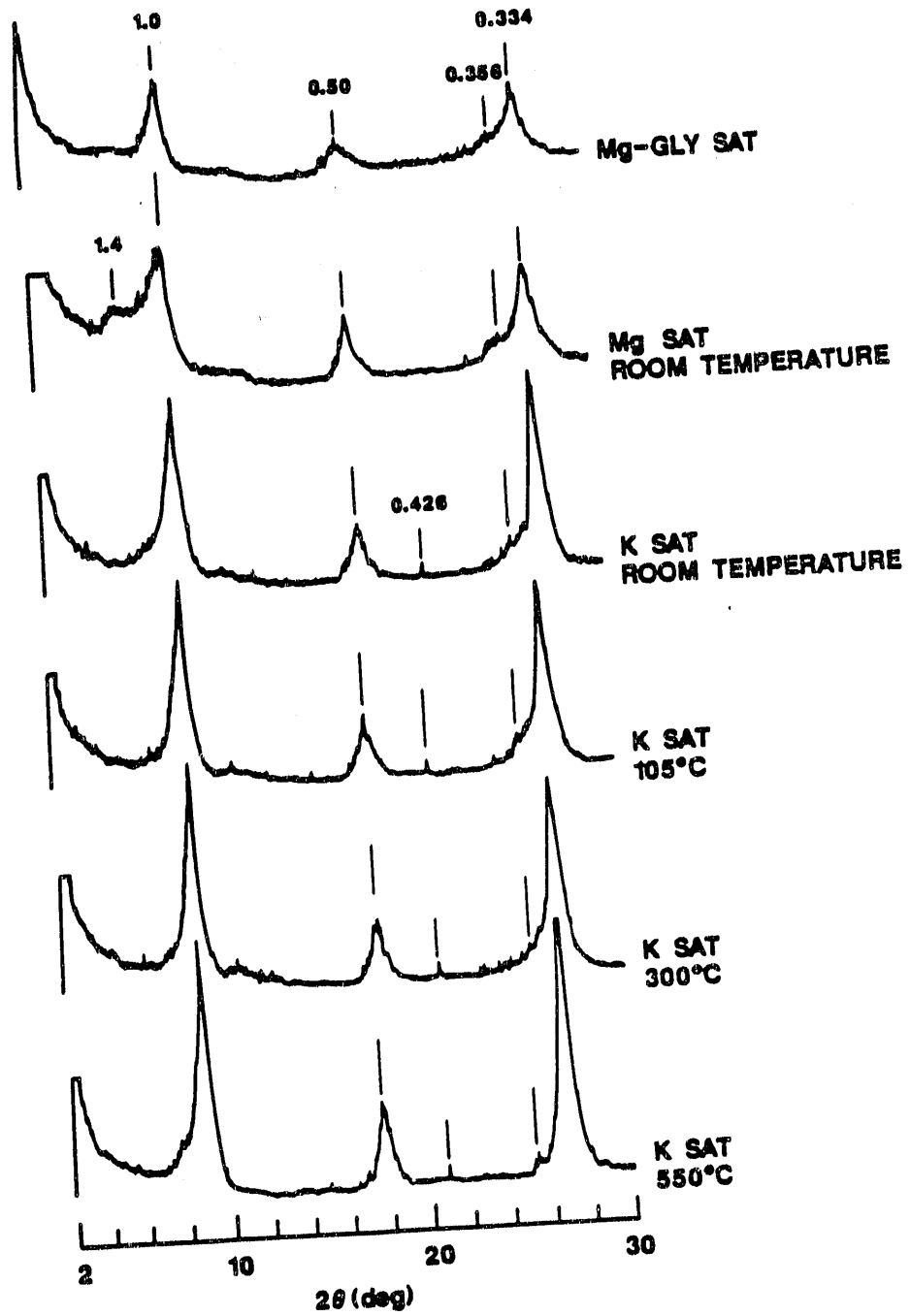
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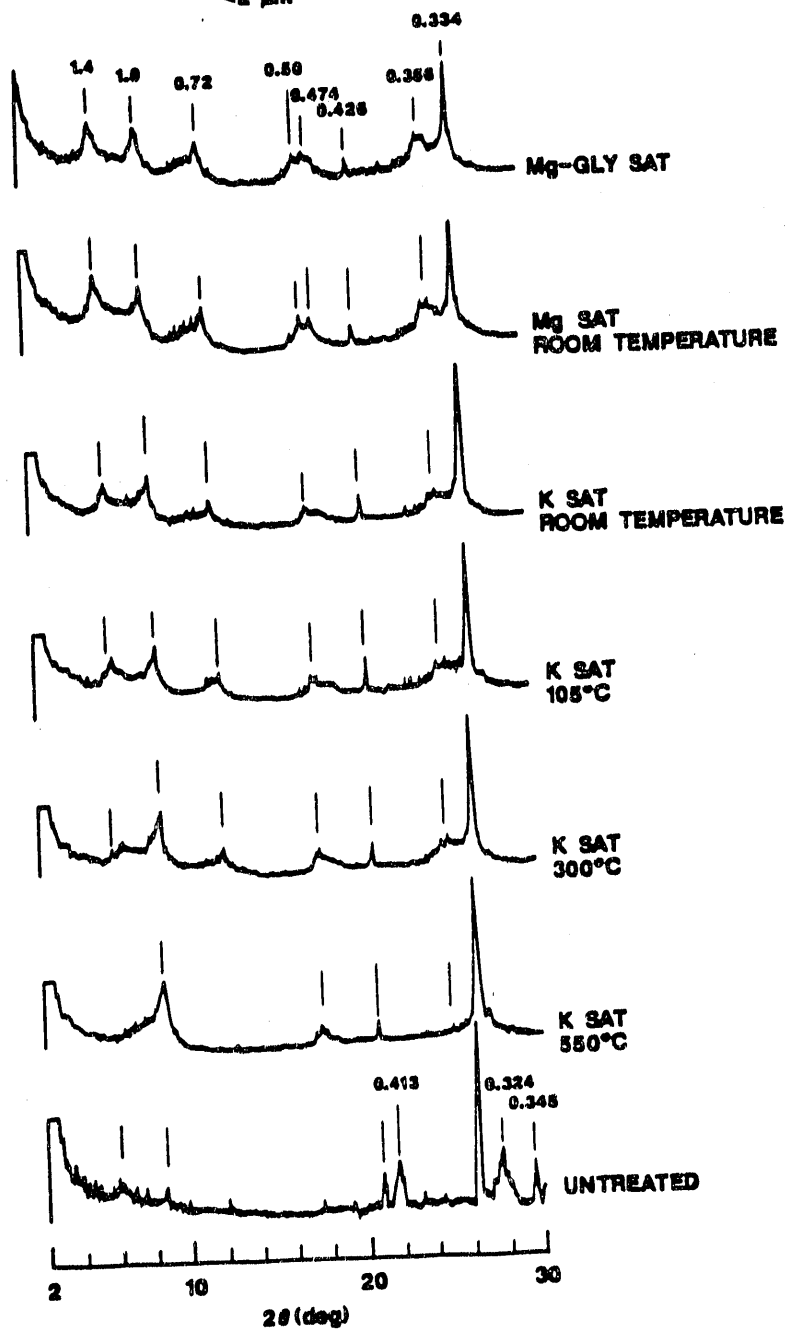
APPENDIX A. X-Ray Diffratograms of Clay Fraction from
Selected Soil Horizons.

**PROFILE 1
A (0-10 cm)**<2 μ m

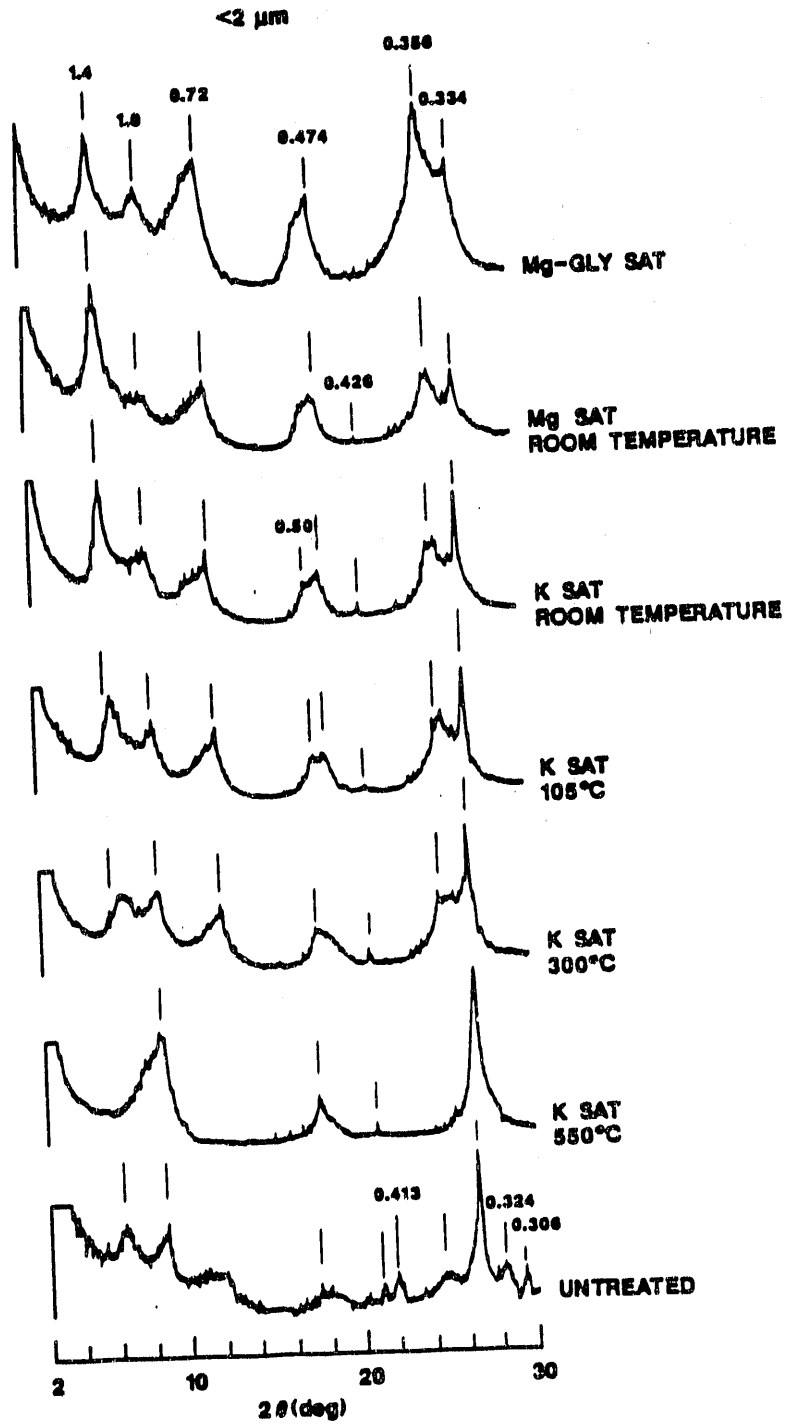
PROFILE 1
Cr3 (145-205 cm)

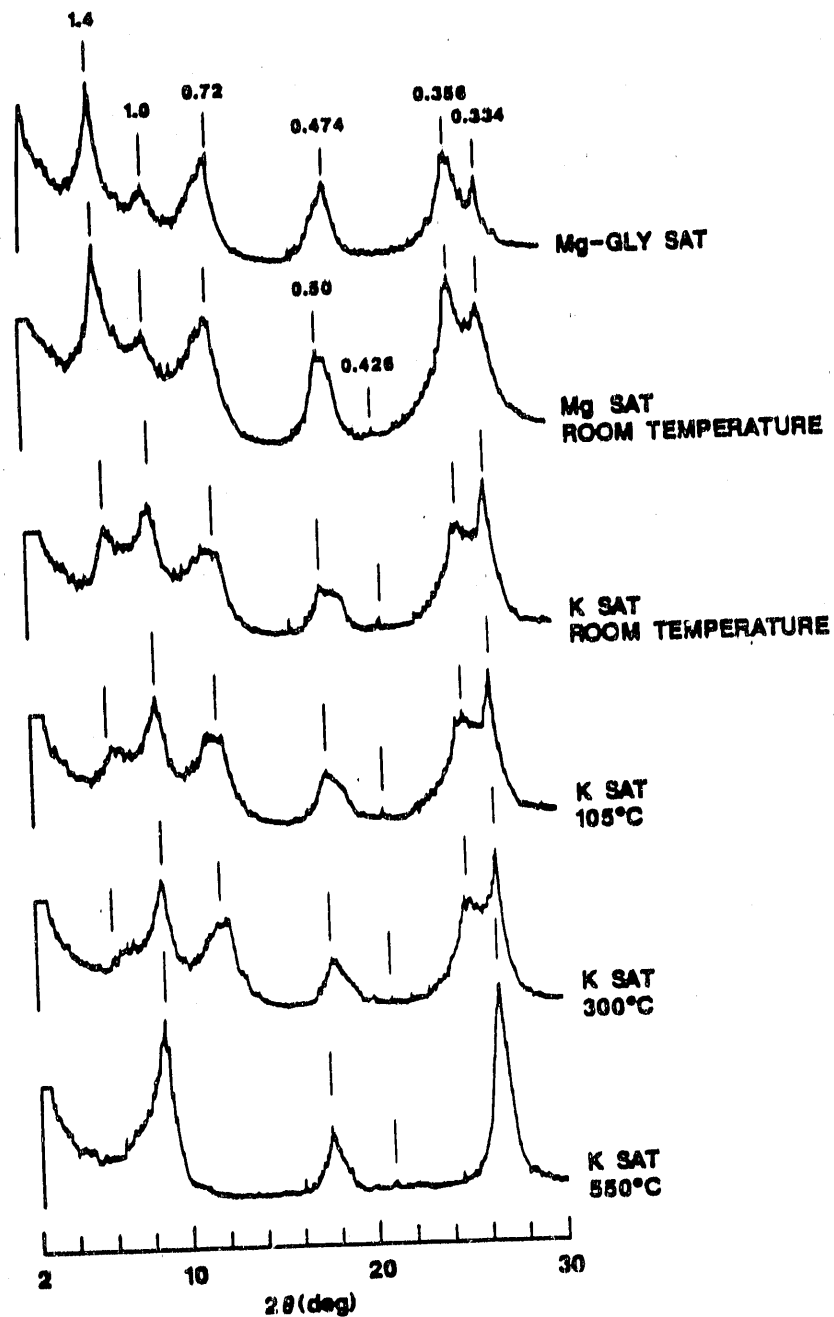
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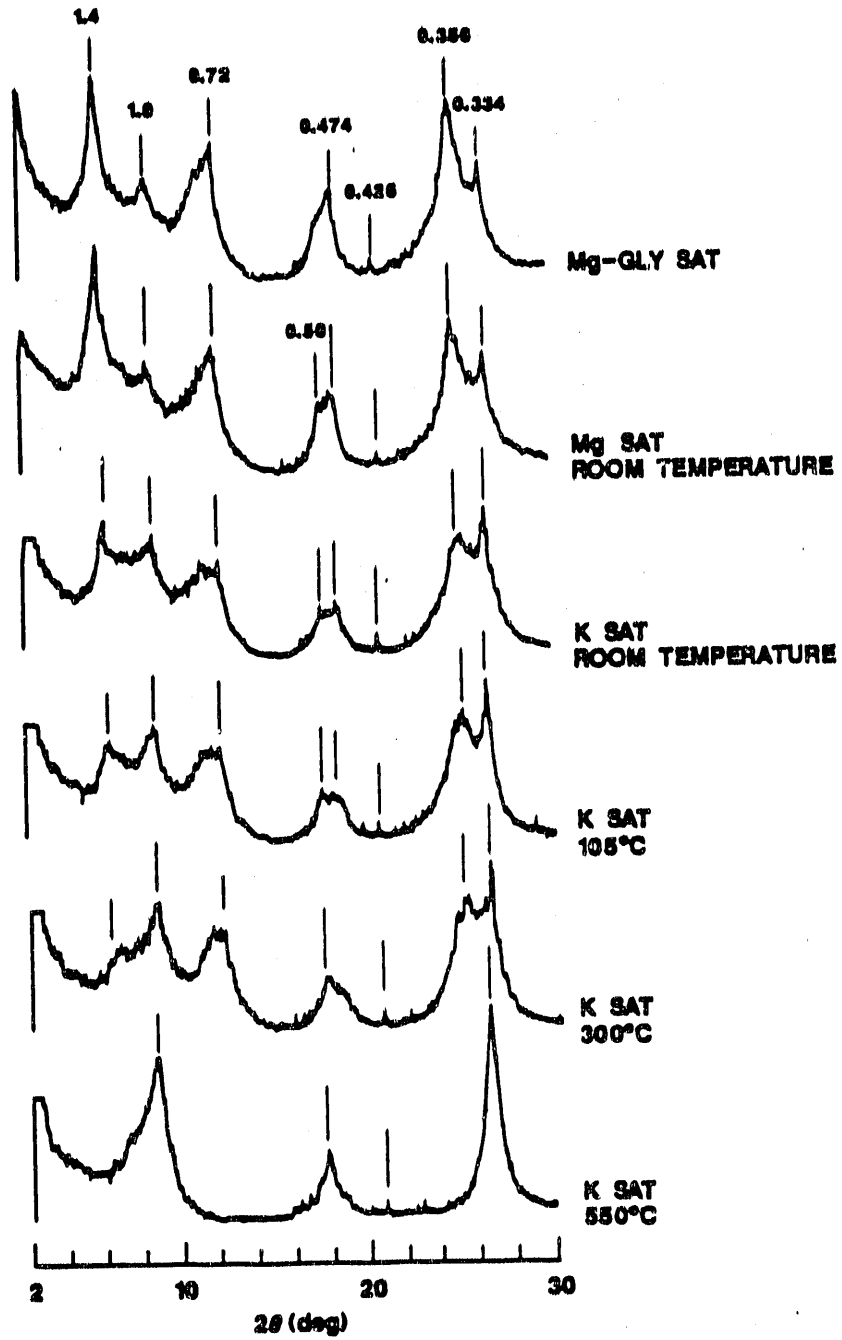


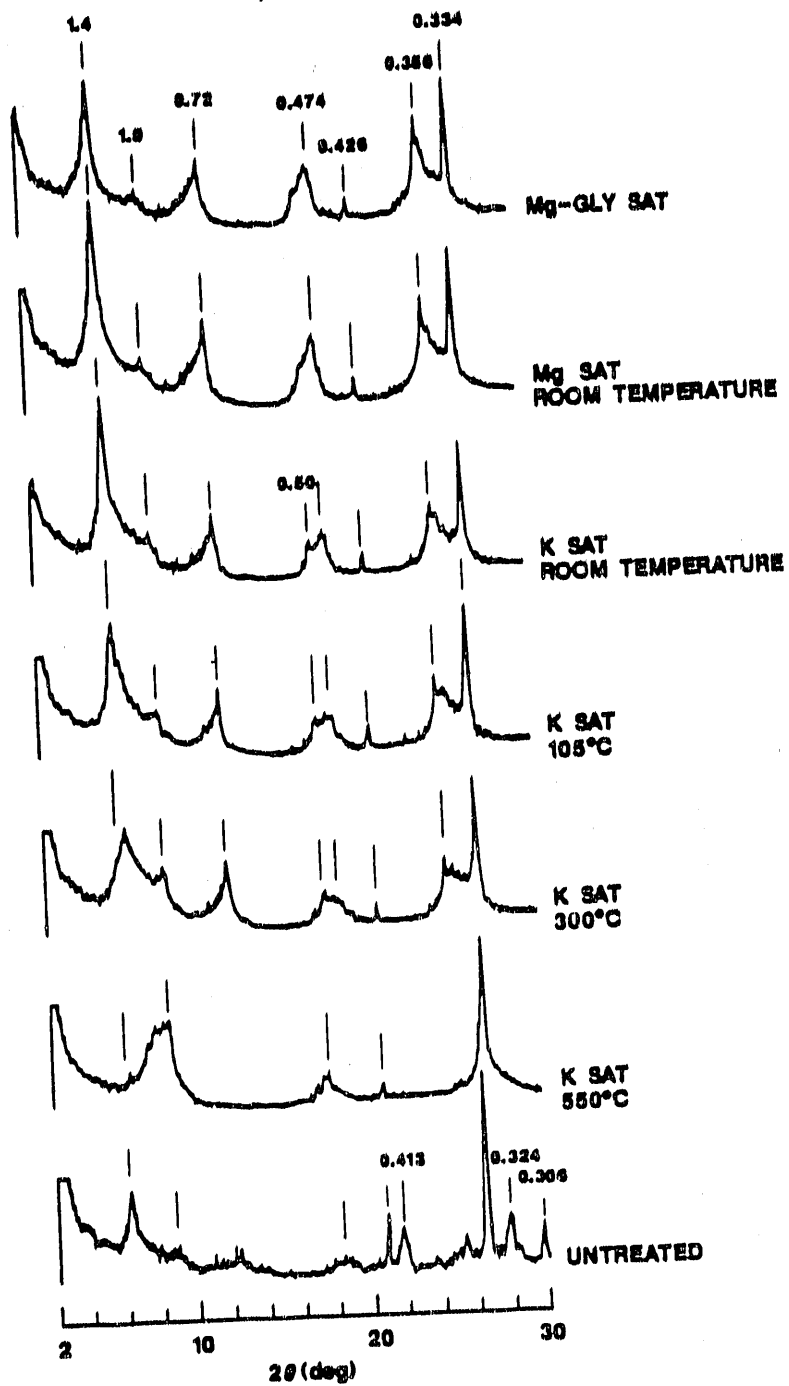
**PROFILE 3
Ap (0-10 cm)**<2 μ m

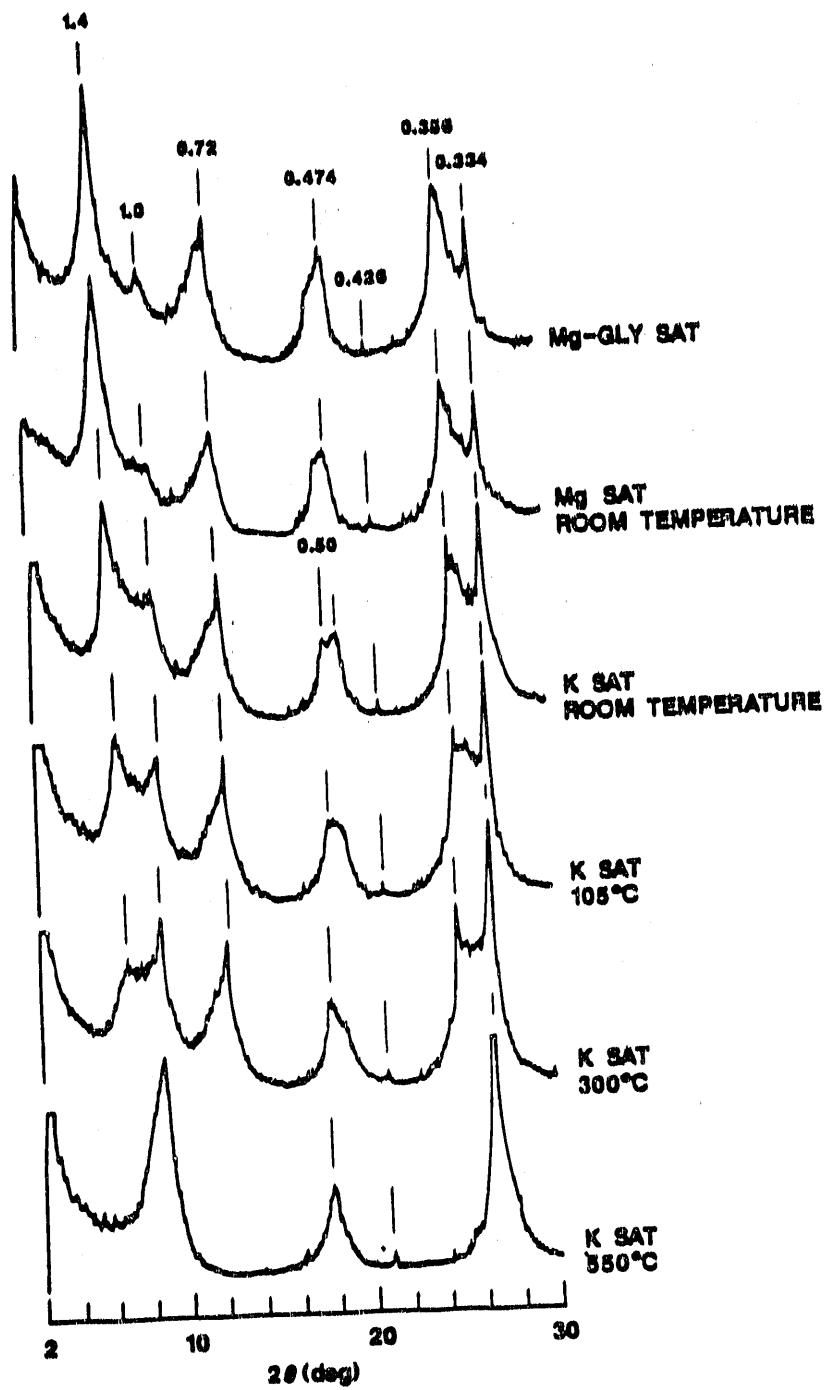
PROFILE 3
C/Bt (84-105 cm)

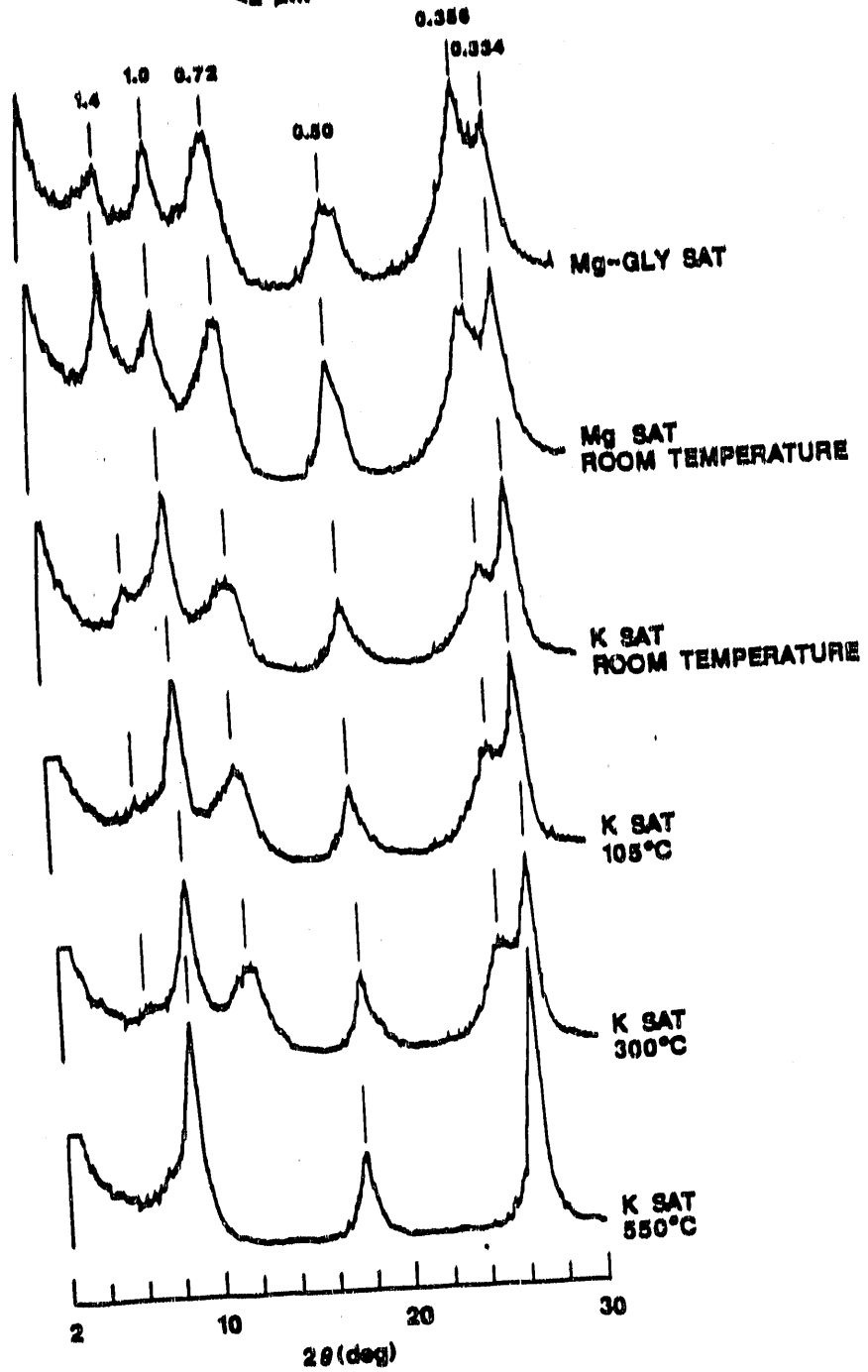


**PROFILE 3
C (132-150 cm)**<2 μm 

**PROFILE 3
Cr (201-213 cm)**<2 μm 

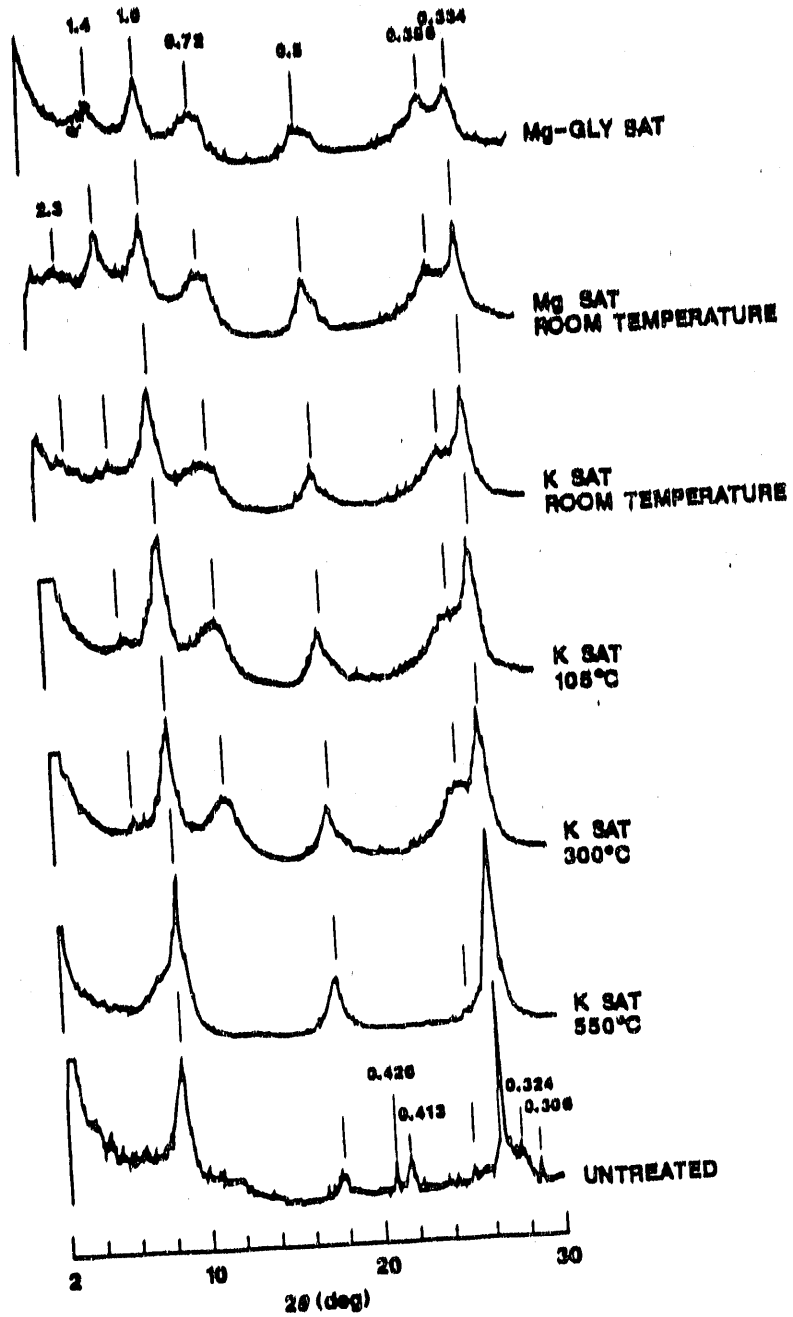
**PROFILE 4
A AND E (0-27 cm)**<2 μm 

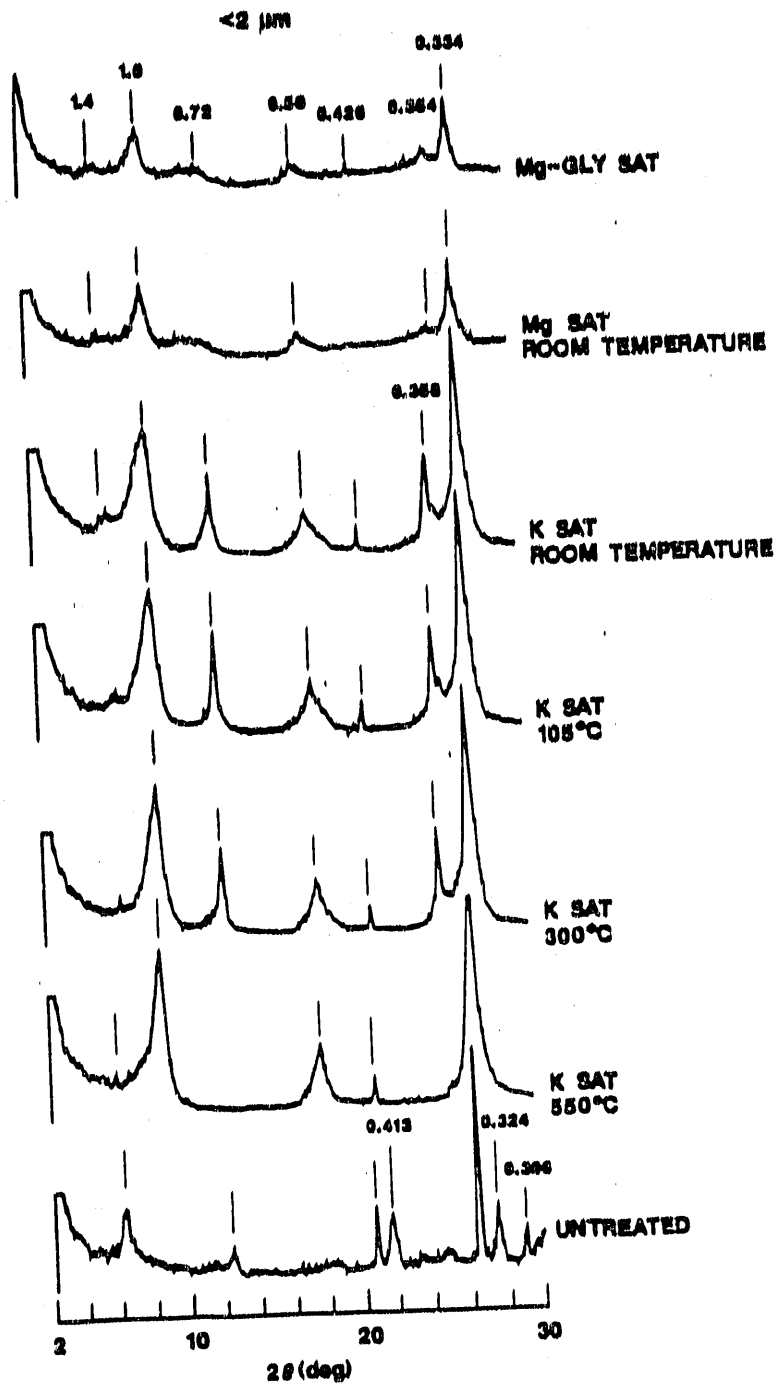
PROFILE 4
Btl-Bt2 (27-70 cm)<2 μm 

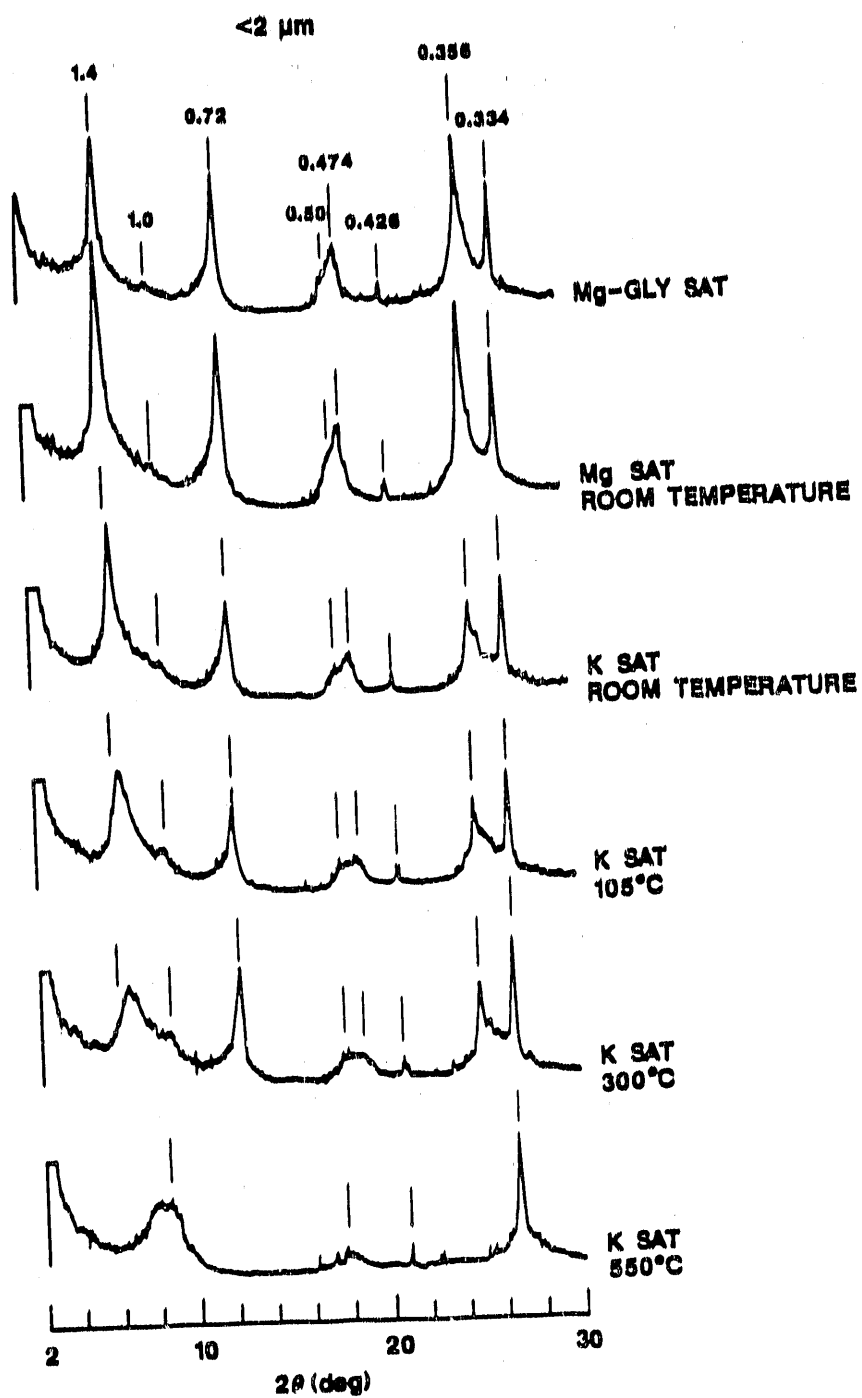
PROFILE 4
CrI (190-230 cm)<2 μm 

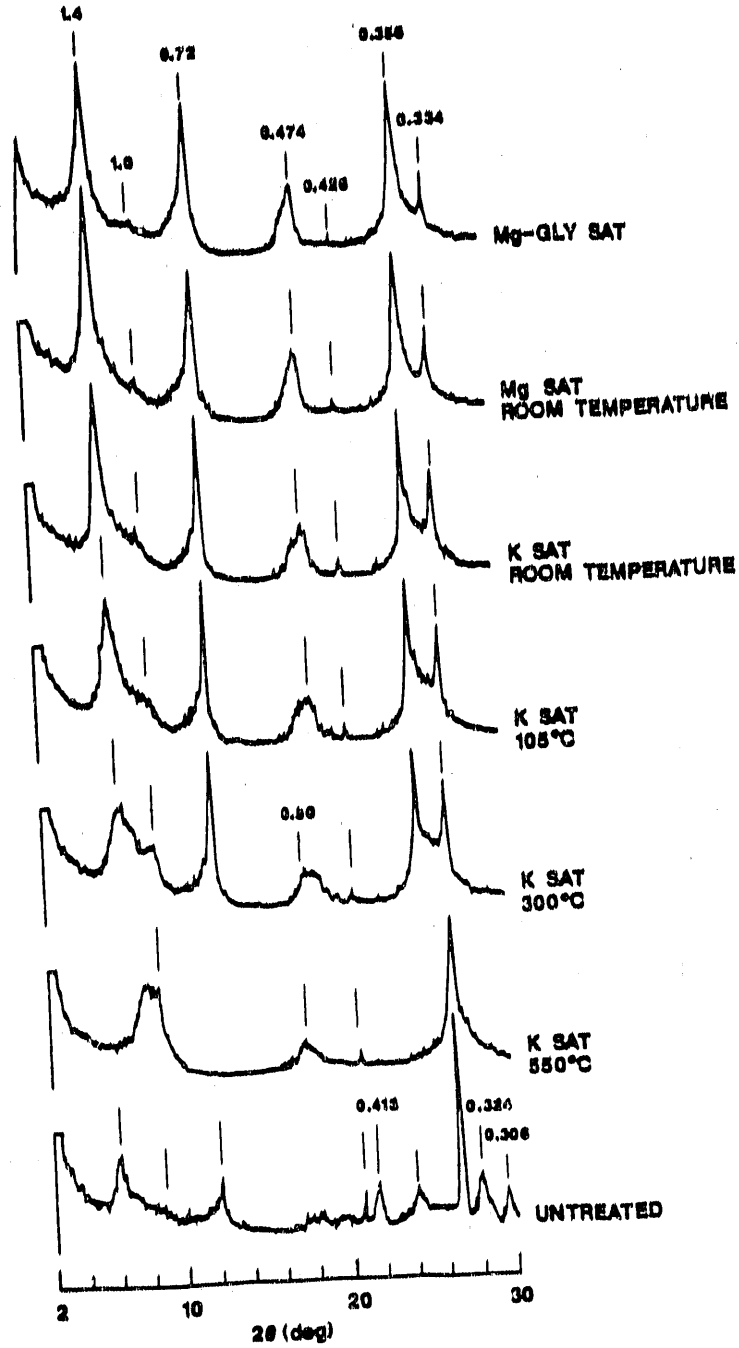
PROFILE 4
Cr2 (290-310 cm)

<2 μm

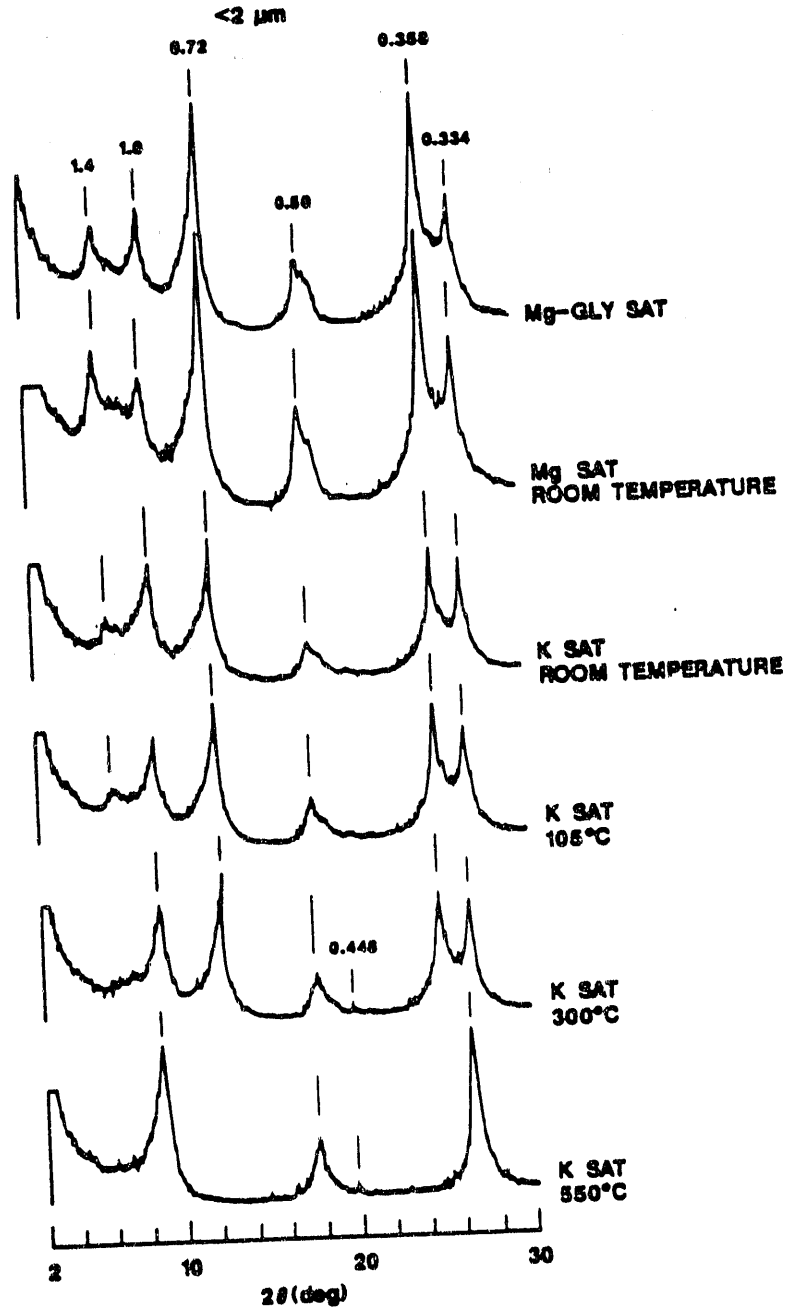


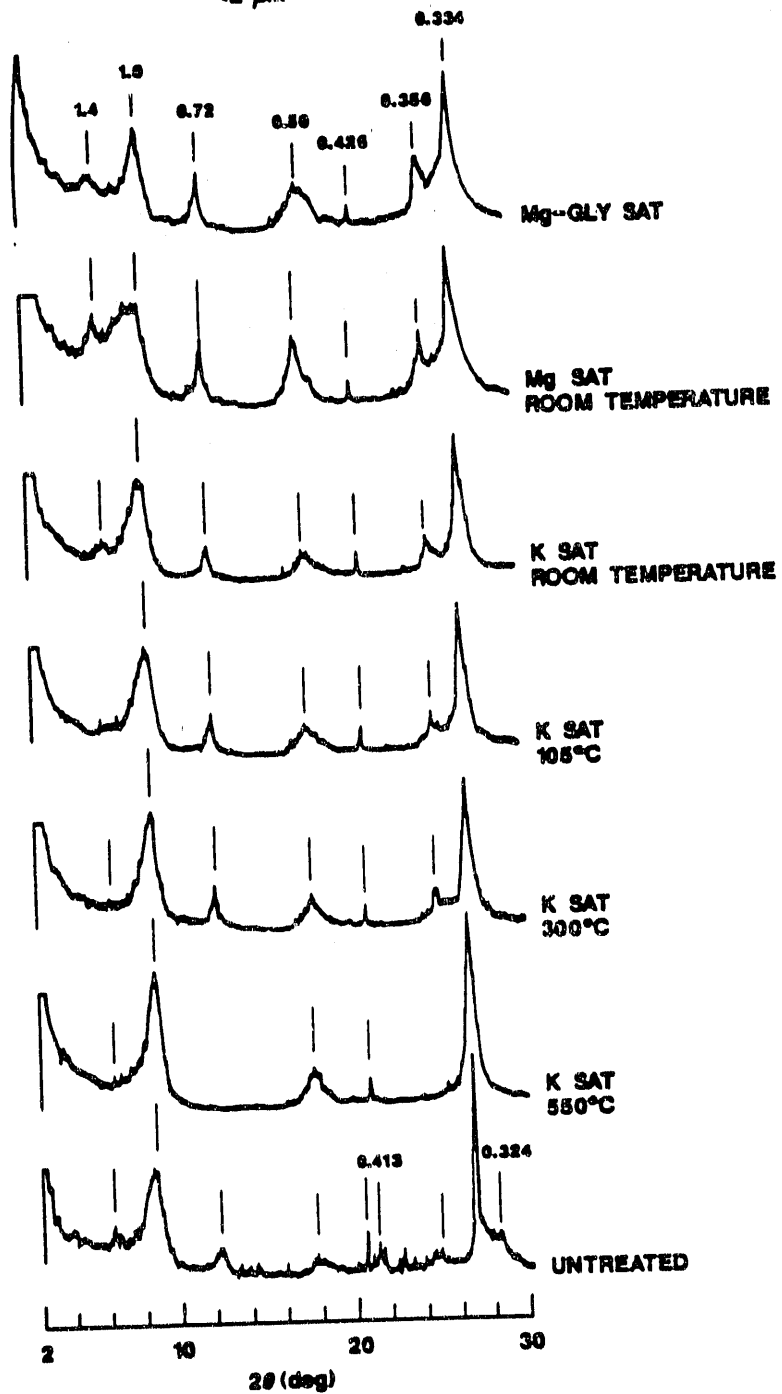
**PROFILE 9
Ap AND E (0-20 cm)**

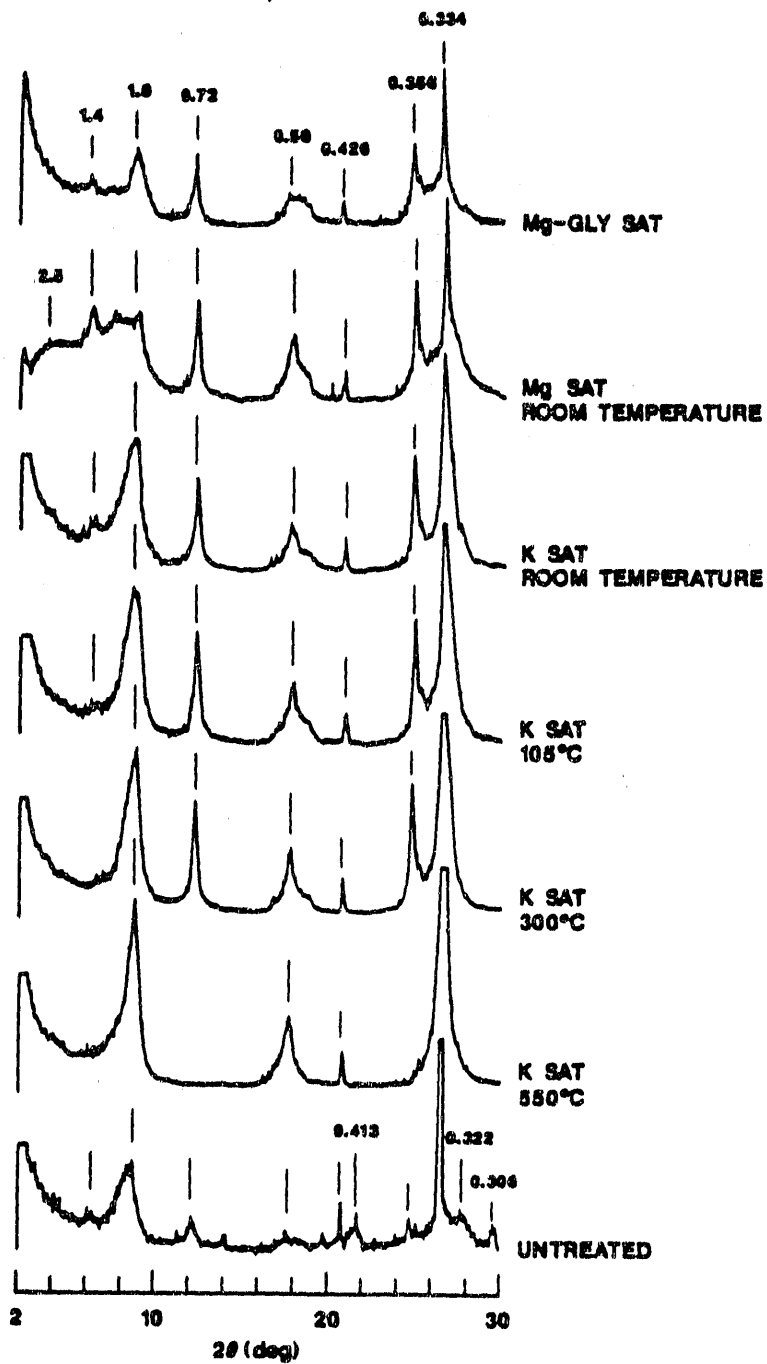
**PROFILE 9
Bt1 AND Bt2 (20-53 cm)**

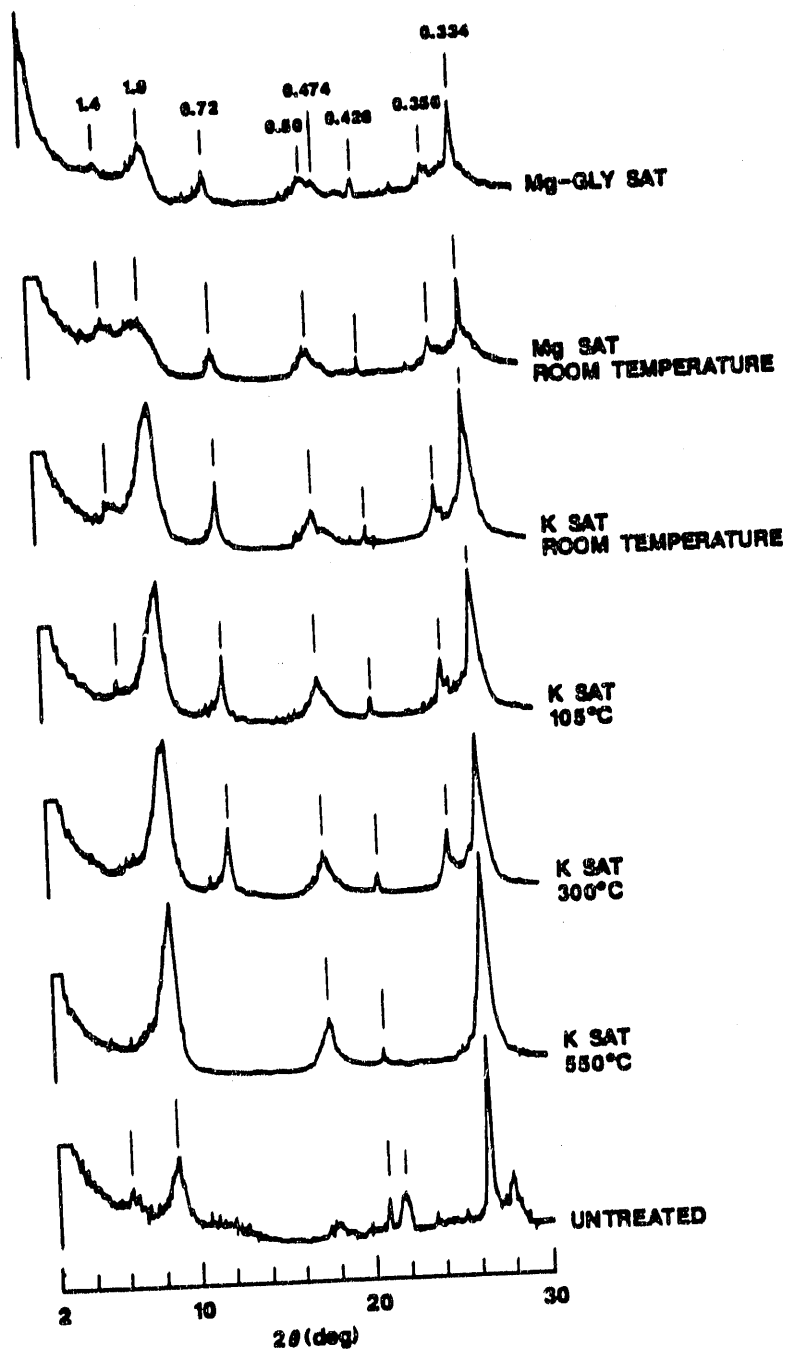
**PROFILE 9
2Bt3 (53-80 cm)**<2 μm 

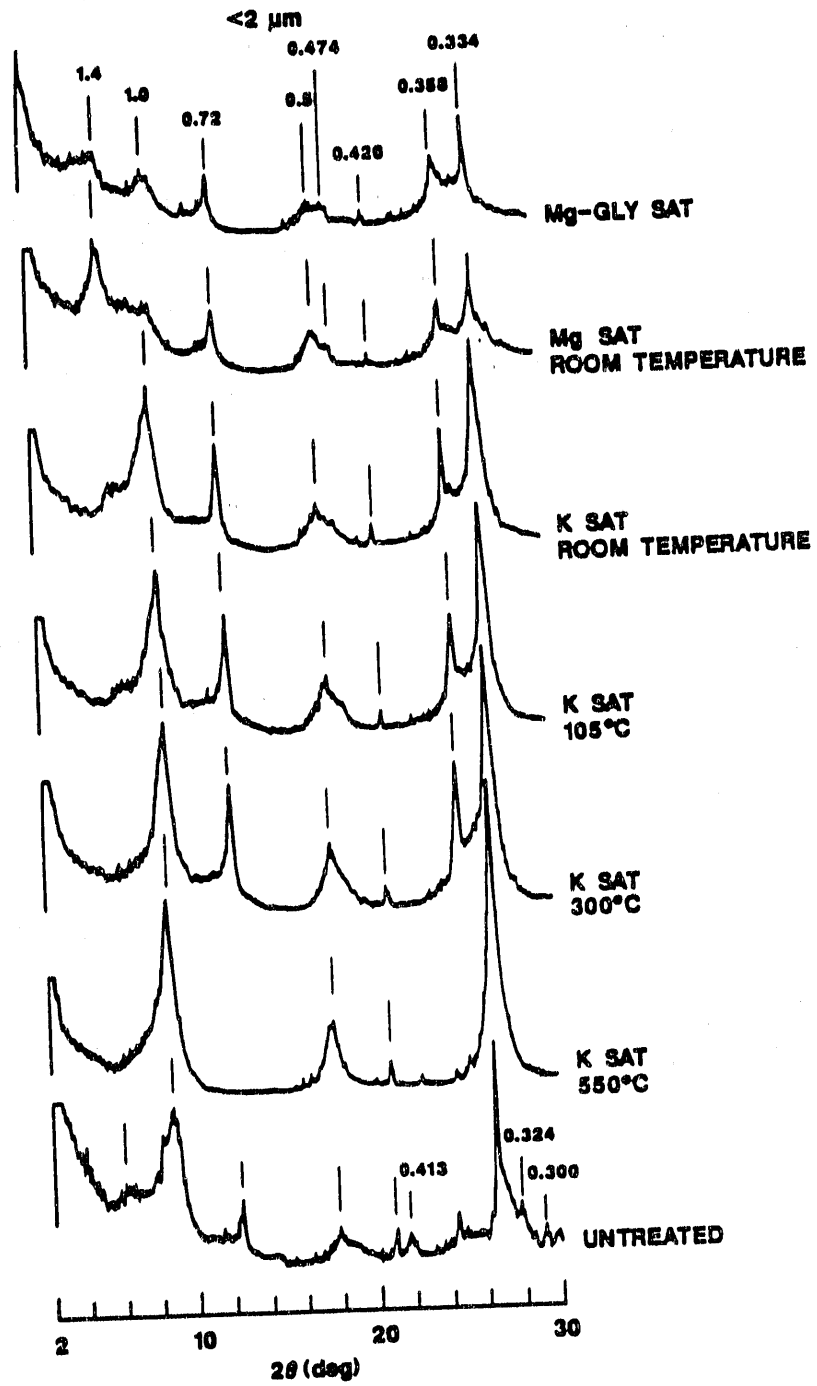
PROFILE 9
2Bt5 (119-19C cm)

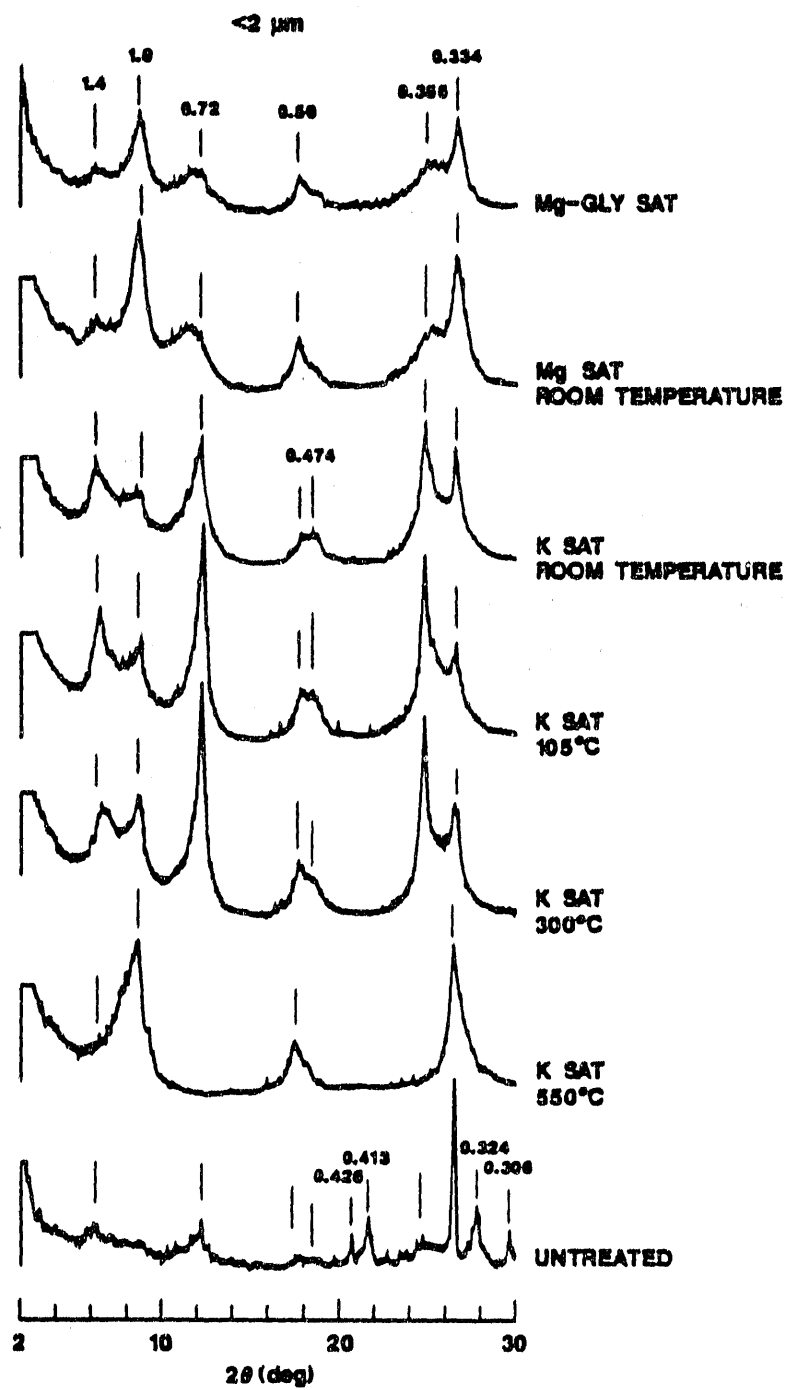


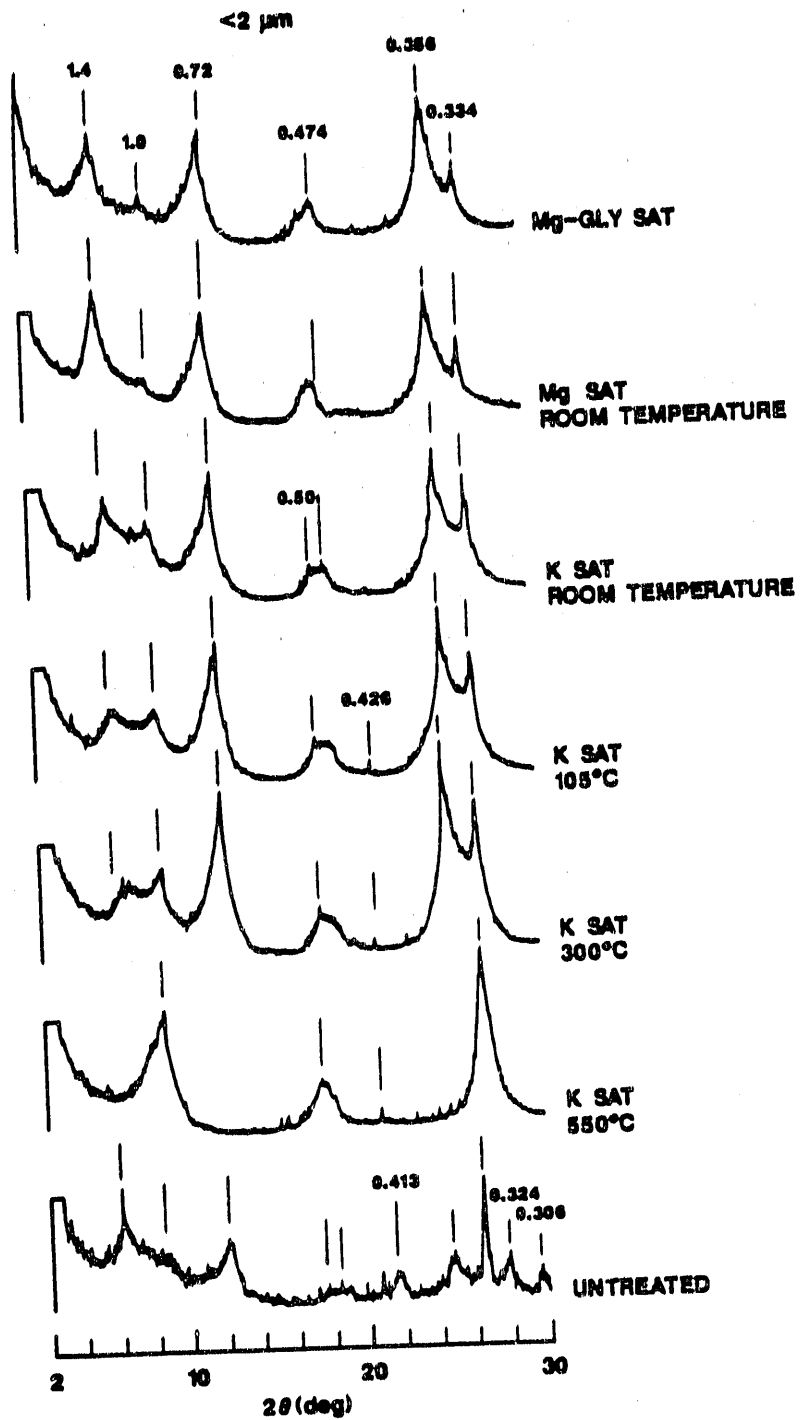
**PROFILE 10
Ap (0-14 cm)**<2 μm 

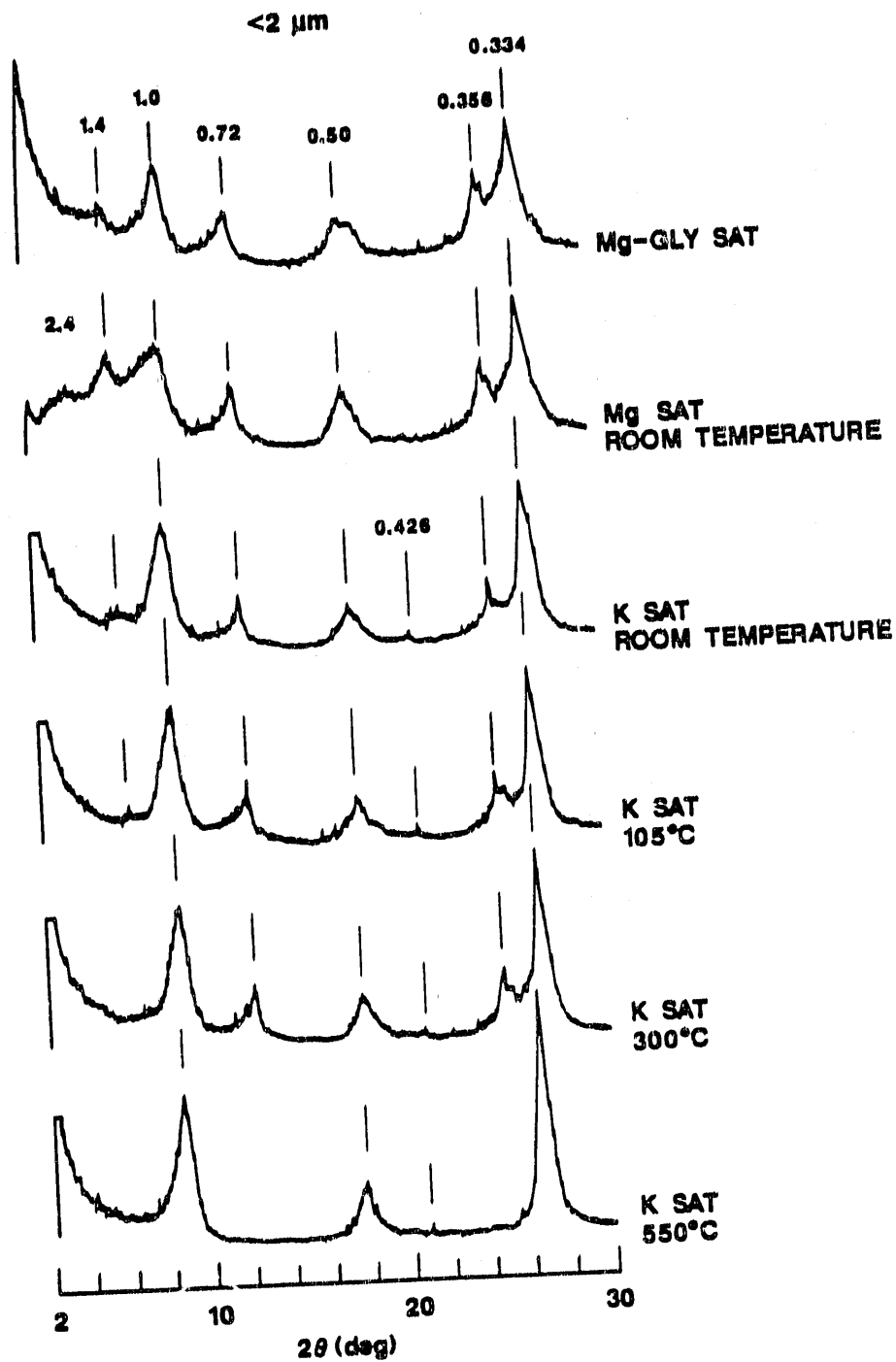
**PROFILE 10
Btg (23-50 cm)**<2 μm 

PROFILE 10
Cri (50-74 cm)<2 μ m

**PROFILE 10
Cr5 (123-150 cm)**

**SHALLOW TRENCH
ABOVE PEBBLE ZONE (100 CM)**

**SHALLOW TRENCH
PEBBLE ZONE (200 cm)**

**SHALLOW TRENCH
BELOW PEBBLE ZONE (300 cm)**

Appendix B. Thin Section Discriptions.

Thin Section Descriptions

Sample #: 1

Pit: 1

Horizon and depth: Bw, cambic, 10-55 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage area 6 (SWSA-6)

Structure and pores: Alveolar with many irregular pores distributed around rock fragments.

Passages: Abundant rounded to sub-rounded

Fecal material: None visible

Organic matter: Rare

Particle size distribution: Extremely shaly loam.

Fine material: Very frequent yellowish-orange, forming a matrix and coatings.

Silt: Abundant quartz and occasional feldspar

Sand: Very fine occasional quartz

Rock fragments: Dominant striated sedimentary rock fragments with some glauconite present in weathered areas.

Coatings: Clay coatings, manganese and iron oxide coatings and compound coatings of their combinations are found in rock fragments.

Surface residues: None

Secondary crystalline material: None

Segregation and concretions: Frequent, dark brown to black, well rounded to irregular manganese and iron oxide concretion and segregated bodies. They take form as solid concretion, concretions with enclosed quartz grains, infillings in rock fragments, coatings on rock fragments, coatings in pores and compound coating occurring alone with highly oriented clays in pores.

Weathering features: Highly weathered rock fragments with rounded edges, fine material removal from rock fragment, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: A low amount of weathering has occurred and not much leaching has taken place. Weathering of sedimentary rock fragments in the horizon has occurred.

Thin Section Descriptions

Sample #: 10

Pit: 1

Horizon and depth: Cr1, saprolite; 55-110 cm, oriented parallel to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage area 6, (SWSA-6)

Structure and pores: Massive with occasional irregular pores migrating parallel to the saprolite grain.

Passages: Occasional

Fecal material: None

Organic matter: None visible

Particle size distribution: Extremely shaly clay

Fine material: Very abundant reddish brown forming a matrix and clay coatings.

Matrix: Very abundant reddish-brown moderately anisotropic around pores.

Silt: Frequent quartz, rare feldspar, occasional mica, occasional glauconite.

Rock fragments: Rare

Coatings: Frequent clay coatings and an occasional occurrence of manganese and iron oxide coating are found predominantly in the pores.

Surface residues: Lighter colored areas are found adjacent to the pores that migrate perpendicular to the saprolite grains.

Secondary Crystalline material: None visible

Segregation and concretions: Segregations and concretions of manganese and iron oxide are found throughout.

Weathering features: Contorted and exfoliated mica grains, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Saprolite originating from weathering of sedimentary rock.

Thin Section Descriptions

Sample #: 11

Pit: 1

Horizon and depth: Cr2, saprolite, 110-145 cm, oriented parallel to the strike

Location: Oak Ridge, Tennessee, Solid Waste Storage area 6 (SWSA-6)

Structure and pores: Massive with dendritic pores that run parallel to the saprolite grain.

Passages: Rare

Faecal material: None

Organic matter: None visible

Particle size distribution: Extremely shaly sandy clay

Fine material: Very frequent pale brown forming a matrix and abundant orange to orange-red in pores.

Matrix: Very frequent pale brown, weakly anisotropic with frequent embedded silt grains.

Silt: Frequent quartz, occasional heavy minerals, rare feldspar and occasional mica.

Sand: Frequent quartz

Rock fragments: None

Coatings: Compound coatings of highly oriented clays, iron oxide, manganese and silt sized heavy minerals are present in pores.

Surface residues: None

Secondary Crystalline material: None visible

Segregation and concretions: Occasional black manganese concretions are found around pores and in the S-matrix.

Weathering features: Exfoliated and contorted mica grains, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Saprolite originating from weathering of shale and siltstone.

Thin Section Descriptions

Sample #: 12

Pit: 1

Horizon and depth: Cr3, saprolite, 145-205 cm, oriented parallel to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage area 6 (SWSA-6)

Structure and pores: Massive with dendritic pores that predominantly migrate parallel to the saprolite grain.

Passages: Occasional

Fecal material: None

Organic matter: None

Particle size distribution: Extremely shaly loam

Fine material: Very abundant highly oriented orange clay coatings are found in pores and on mineral grains.

Matrix: Rare orange, moderately anisotropic with embedded quartz and mica.

Silt: Abundant quartz, very frequent mica and rare feldspar

Sand: Very fine occasional glauconite

Rock fragments: None

Coatings: Occasional, highly oriented clay coating on mineral grains. Dominant clay coatings are found in pores passages and around micaceous bands.

Surface residues: Lighter colored areas are found around the larger passages and pores.

Secondary crystalline material: None

Segregation and concretions: Round and irregular brown to black manganese and iron oxide concretion are observed throughout the thin section. They are primarily positions around pores passages and mica bands. Manganese and iron oxide segregation and coating are prominent and associated with the sides of the pores and the clay on them. Neomangan are present on the shale saprolite fragment.
Weathering features: Micas were exfoliated and contorted, oxidation of manganese.

Microorganisms: None visible

Genesis: Sedimentary siltstone and shale are weathered to form saprolite.

Thin Section Descriptions

Sample #: 13

Pit: 3

Horizon and depth: C/Bt, illuvial clay and parent material 84-110 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Angular blocky with irregular dendritic pores.

Passages: Occasional

Fecal material: None present

Organic matter: None

Particle size distribution: Very shaly clay

Fine material: Abundant reddish-orange, red and brown forming a matrix and coatings

Matrix: Abundant reddish-orange, red and brown anisotropic zones and random anisotropic flecks. Distinct flecks were found in the rock fragments in the lower relief areas. An area of green anisotropic clay is found adjacent to a rock fragment.

Silt: Rare quartz, rare mica, and rare feldspar

Sand: Very fine rare glauconite

Rock fragments: Very frequent shale

Coatings: Dominant highly oriented clay coatings are found between rock fragments in pores and on mineral grains. Manganese and iron oxide coatings are found associated with the clay coatings.

Surface residues: None

Secondary crystalline material: None

Segregation and concretions: Dark brown to black manganese and iron oxide concretions occur in rounded to irregular forms. Granular segregations of manganese and iron oxide are observed around the concretions.

Weathering features: Micaceous are contorted and exfoliated, quartz grains are pitted, rock fragments are broken and exhibited rounded edges.

Microorganisms: None visible

Genesis: Deposition of clay in the form of clay coatings, weathering of rock fragments.

Thin Section Descriptions

Sample #: 14 and 15

Pit: 3

Horizon and depth: Cr, saprolite, 201-213 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Massive with occasional irregular pores

Passages: Occasionally

Fecal material: None

Organic matter: Rare

Particle size distribution: Very shaly clay loam

Fine material: Dominant orange and brown forming a matrix and clay embedded silt grains.

Matrix: Dominant orange and brown moderately anisotropic with embedded silt grains.

Silt: Abundant quartz, occasional feldspar and occasional highly oriented biotite and rare glauconite.

Rock fragments: Rare

Coatings: Very abundant highly oriented orange-red clay coatings are found around pores. Manganese and iron oxide coatings are found in association with the clay coatings

Surface residues: Lighter colored areas are found adjacent to areas of high clay content and manganese segregation.

Secondary Crystalline material: None visible

Segregation and concretions: Manganese and iron segregation are associated with clay coatings. Manganese and iron oxide granular segregation in dendritic growth bands and concretions are present.

Weathering features: Rare

Microorganisms: None visible

Genesis: Saprolite weathered from sedimentary rock

Thin Section Descriptions

Sample #: 16 and 17

Pit: 4

Horizon and depth: Cr2, saprolite, 290-300 cm, oriented parallel to the strike

Location: Oak Ridge, Tennessee, Solid Waste Storage area 6 (SWSA-6)

Structure and pores: Massive with occasional dendritic pores migrating parallel to the saprolite grain.

Passages: Occasional

Fecal material: None

Organic matter: Rare, plant tissue

Particle size distribution: Extremely shaly clay loam

Fine material: Dominant orange to orange-red and golden highly oriented clay are found as coating. Occasional golden and brown unoriented clay are found in inclusions.

Matrix: Dominant orange to orange-red and golden highly oriented clay are coating pores and occasional golden and brown unoriented clays are found within inclusions with embedded silt grains.

Silt: Frequent quartz, rare feldspars and occasional mica

Sand: Mica, occasional glauconite

Rock fragments: None

Coatings: Highly oriented clay is coating pores. Manganese and iron oxide coatings are found associated with the clay and iron coatings. Compound coatings of highly oriented clay and manganese and iron oxides are observed pores.

Surface residues: Lighter colored areas are found adjacent to pores and manganese oxide segregated areas.

Secondary Crystalline material: Crystalline manganese oxide

Segregation and concretions: Granular manganese and iron oxide segregation occur in the anisotropic areas. Neomangans are present adjacent to fractures and plane pores. Manganese and iron oxide concretions and highly crystalline manganese oxide are present in passages. Tubular shaped manganese oxides are present.

Weathering features: Micaceous were exfoliated and contorted, oxidation of manganese and iron.

Microorganisms: Bug in a pore

Genesis: Saprolite weathered from sedimentary rock

Thin Section Descriptions

Sample #: 18, 19, 20, 21, and 22

Pit: 4

Horizon and depth: Cr2, saprolite; 290-310 cm, oriented perpendicular to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Massive with frequent dendritic pores migrating parallel to the saprolite grain.

Passages: Occasional

Fecal material: None

Organic matter: Rare

Particle size distribution: Extremely shaly clay loam

Fine material: Abundant orange-red forming coatings and bridges

Matrix: Abundant orange-red moderated to highly anisotropic with embedded silt grains.

Silt: Abundant quartz, abundant mica, rare feldspar and rare heavy minerals

Sand: Occasional mica

Rock fragments: Rare

Coatings: Orange-red highly oriented clays coat pores and passages along with manganese oxide. Together they form compound coatings.

Surface residues: Occasional light colored area around pores and segregated areas.

Secondary crystalline material: Manganese oxide

Segregation and concretions: Manganese and iron oxide are found as coatings on pores. Concretions and granular segregation of manganese and iron oxide are found in fine grained area and dark bands. Neomangans occur in the saprolitic shale.

Weathering features: Contorted and exfolated mica

Microorganisms: Rare

Genesis: Saprolite weathered from shale and siltstone

Thin Section Descriptions

Sample #: 23

Pit: 9

Horizon and depth: E, elluvial, 20 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA)-6

Structure and pores: Granular with frequent pores

Passages: Frequent

Fecal material: None

Organic matter: Occasional, plant tissue (roots) with iron oxide coatings

Particle size distribution: Silt

Fine material: Rare golden, forming coatings and rare matrix areas in the matrix.

Matrix: Rare golden, moderately anisotropic with rare random domains.

Silt: Dominant quartz, rare feldspar, occasional mica

Sand: Very fine quartz

Rock fragments: Rare

Coatings: Rare oriented clay coatings in pores

Surface residues: None

Secondary Crystalline material: None

Segregation and concretions: Very frequent, well rounded to irregular and tubular shaped manganese and iron oxide concretions

Weathering features: Quartz grains are pitted and mica grains are exfolated and contorted, oxidation of manganese and iron.

Microorganisms: Rare

Genesis: Loess (wind blown silt)

Thin Section Descriptions

Sample #: 24

Pit: 9

Horizon and depth: 2Bt3, argillic, 70 cm, below loess zone

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Subangular blocky with frequent pores

Passages: Frequent

Fecal material: None

Organic matter: Rare, roots

Particle size distribution: Cobbly clay loam

Fine material: Very abundant orange, orange-red highly oriented forming a matrix and clay coatings.

Matrix: Very abundant orange, orange-red highly oriented moderately anisotropic with very frequent random domains and embedded silt and very fine sand grains.

Silt: Dominant quartz, rare feldspar, occasional mica and occasional heavy mineral

Sand: Quartz, feldspar

Rock fragments: None

Coatings: High oriented clay coatings were found around pores along with manganese and iron oxide coatings forming compound coatings.

Surface residues: None

Secondary Crystalline material: None

Segregation and concretions: Orange to black colored manganese and iron oxide are found in segregated areas. Concretions dominantly contain quartz grains.

Weathering features: Exfoliated and contorted mica grains, oxidation of manganese and iron.

Microorganisms: None

Genesis: Ancient alluvium and illuvial zone for clays

Thin Section Descriptions

Sample #: 25

Pit: 9

Horizon and depth: 2Bt5, argillic, 130 cm (above a highly mottled zone)

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Subangular blocky structure with occasional pores

Passages: Occasional

Fecal material: None

Organic matter: Rare, roots

Particle size distribution: Cobbly clay loam

Fine material: Dominant light orange-red and red forming a matrix and clay coatings.

Matrix: Dominant light orange, orange-red and rare brown and red highly anisotropic with abundant random domains and embedded silt and very fine sand grains.

Silt: Abundant quartz, occasional feldspar, rare mica, and frequent heavy mineral.

Sand: occasional quartz, siliceous oolitic fragment and polycrystalline quartz grains are discovered.

Rock fragments: None

Coatings: Very frequent highly oriented clay coatings are found around pores. Manganese and iron oxide coating are found associated with them. Together they form compound coatings.

Surface residues: None

Secondary Crystalline material: None visible

Segregation and concretions: Manganese and iron segregation are found in flow zones. Segregations and concretions were dark red and black in color.

Weathering features: Pitted quartz grains and contorted and exfolated mica grains are present. Oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Ancient alluvial with illuvial clays present

Thin Section Descriptions

Sample #: 26

Pit: 9

Horizon and depth: 2Bt5, argillic, 160 cm (bottom of highly mottled zone)

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6(SWSA-6)

Structure and pores: Subangular blocky with occasional small dendritic pores

Passages: Rare

Fecal material: None

Organic matter: Rare, roots

Particle size distribution: Cobbly clay loam

Fine material: Dominant, orange, orange-red and red forming a matrix and crescentic clay coatings.

Matrix: Dominant, orange, orange-red and red with very abundant oriented domains and embedded silt and very fine sand.

Silt: Very frequent quartz, frequent biotite, occasional feldspar

Sand: Frequent quartz, occasional biotite

Rock fragments: None

Coatings: Thick, highly oriented, very abundant clay coatings manganese and iron oxide coatings are associated with clay coatings in pores.

Surface residues: None

Secondary Crystalline material: Goethite

Segregation and concretions: Manganese and iron oxide segregation is abundant. Manganese and iron oxide concretions are also present.

Weathering features: Rounded pitted quartz grains, exfoliated and contorted biotite, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Ancient alluvium with illuvial clays

Thin Section Descriptions

Sample #: 27

Pit: 9

Horizon and depth: BC, 190-230 cm, oriented perpendicular to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Subangular blocky with very frequent pores

Passages: Rare

Fecal material: None

Organic matter: None

Particle size distribution: Cobbley clay loam

Fine material: very abundant yellow, golden orange, orange-red, red and green frequent area forming a matrix and coatings.

Matrix: Very abundant, yellow golden orange, orange-red, red and green frequent areas around pores and embedded silt and very fine sand.

Silt: Abundant quartz, occasional biotite, heavy mineral feldspar

Sand: Very fine occasional quartz, rare mica

Rock fragments: Frequent

Coatings: Abundant highly oriented clay coatings are found in pores and on rock fragments. Iron and manganese oxides are associated with the clay coatings thus, forming compound coatings.

Surface residues: Lighter areas are observed around pores

Secondary crystalline material: Iron oxide (goethite)

Segregation and concretions: Occasionally bright and dark red and black segregation and concretions are observed around the pores and rock fragments.

Weathering features: Pitted quartz grains exfoliated and contorted mica, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Aciient alluivum

Thin Section Descriptions

Sample #: 28, 29, 30

Pit: Deep trench

Horizon and depth: 244-305 cm, oriented parallel to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Occasional

Passages: None

Fecal material: None

Organic matter: None

Particle size distribution: Extremely shaly loam

Fine material: Abundant orange forming a matrix and coatings

Matrix: Abundant orange moderately anisotropic with domain in siltstone.

Silt: Abundant quartz, rare feldspar, occasional mica

Sand: Very fine rare glauconite pellets

Rock fragments: Very abundant

Coatings: Occasional highly oriented clay coatings are found on pore and rock fragments. Manganese and iron oxide are associated with them. Together they form compound coatings.

Surface residues: Areas are present where fine material have been removed and deposited in adjacent zones.

Secondary crystalline material: Red crystalline mineral, (iron oxide)

Segregation and concretions: Brown, red and black segregations in areas with brown and black concretions were observed. They were associated with rock fragment and clay around pores. Neomangans are found in the saprolitic shale.

Weathering features: Oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Saprolite weathered from siltstone and shale

Erratic: Striated areas of high oriented micaceous minerals

Thin Section Descriptions

Sample #: 31, 32, and 33

Pit: Deep trench

Horizon and depth: 366-427 cm, oriented parallel to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Massive with very abundant irregular pores in the saprolitic shale the pores are dendritic and migrate parallel to the grain. In the saprolitic siltstone the pores migrate perpendicular to the grain, but parallel to each other.

Passages: Occasional

Fecal material: None

Organic matter: None

Particle size distribution: Extremely shaly loam

Fine material: Occasional orange, orange-red highly oriented forming a matrix and coatings.

Matrix: Occasional orange, orange-red highly oriented and moderately anisotropic with occasional oriented domains and embedded silt grains.

Silt: Occasional quartz, rare mica abundantly oriented in lines, rare feldspar.

Sand: Frequent glauconite

Rock fragments: Rare

Coatings: Highly oriented orange, orange-red clay coatings are found in the pores. Manganese and iron oxide coating are also present. Compound coatings are developed from their combination.

Surface residues: None

Secondary crystalline material: None

Segregation and concretions: Manganese and iron segregation are observed in and around pores. Manganese and iron granular segregation occur in an accumulation zone. Small concretions of manganese and iron are distributed throughout the thin section.

Weathering features: Pitted quartz grains, exfoliated and contorted mica grains, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Saprolite weathered from siltstone and shale

Thin Section Descriptions

Sample #: 34, 35

Pit: Deep trench

Horizon and depth: 417-488 cm, oriented parallel to the strike

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Massive with occasional pores in saprolitic shales which have pores that migrate parallel to the grain.

Passages: Rare

Fecal material: None

Organic matter: None

Particle size distribution: Extremely shaly clay loam

Fine material: Very abundant orange, orange red highly moderately oriented forming a matrix and coatings.

Matrix: Very abundant orange, orange-red moderately anisotropic with occasional random and swirled domains and embedded silt grains.

Silt: Very abundant quartz, occasional feldspar, occasional oriented mica.

Sand: Very fine, very frequent glauconite
Rock fragments: Dominant

Coatings: Frequent highly oriented clay coatings are found in and around the pores. Manganese and iron oxide are associated with them. Together they form compound coatings.

Surface residues: None
Secondary crystalline material: None

Segregation and concretions: occasional black neomangans are present in the saprolitic shale. Occasional red, brown and black manganese and iron granular segregations are found throughout the slide.

Weathering features: Pitted quartz grains contorted and exfoliated mica grains, oxidation of manganese and iron

Microorganisms: None visible

Genesis: Saprolite is formed from weathered siltstone with sorted grains and shale.

Erratic: Striated layering of mica grain that are highly weathered

Thin Section Descriptions

Sample #: 36

Pit: 3

Horizon and depth: Cr, saprolite, 160 cm (Manganese accumulation zone).

Location: Oak Ridge, Tennessee, Solid Waste Storage Area-6 (SWSA-6)

Structure and pores: Massive with very abundant dendritic and crazy plane pores.

Passages: Frequent

Fecal material: None

Organic matter: Rare, plant roots coated with iron oxide

Particle size distribution: Extremely shaly clay loam

Fine material: Abundant orange highly oriented form a matrix and clay coatings.

Matrix: Abundant orange highly oriented, low anisotropic with occasional domains and embedded silt grains.

Silt: Frequent quartz pockets in shale. In weathered areas quartz is oriented in a circle. Occasional mica, rare glauconite pellets.

Sand: Very fine quartz

Rock fragments: Abundant

Coatings: Highly oriented clays are found around pores and rock fragment along with manganese and iron oxides. They form compound coatings.

Surface residues: None

Secondary crystalline material: None visible

Segregation and concretions: Brown to black segregations and concretions of manganese and iron oxide are found in highly weathered zones and in pores.

Weathering features: Zones where fine material has been leached out are present. Mica is exfoliated and contorted, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: The saprolite is formed from weathered sandstone and shale.

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Thin Section Descriptions

Sample #: 36

Pit: 3

Horizon and depth: Cr, saprolite, 160 cm (Manganese accumulation zone).

Location: Oak Ridge, Tennessee, Solid Waste Storage Area-6 (SWSA-6)

Structure and pores: Massive with very abundant dendritic and crazy plane pores.

Passages: Frequent

Fecal material: None

Organic matter: Rare, plant roots coated with iron oxide

Particle size distribution: Extremely shaly clay loam

Fine material: Abundant orange highly oriented form a matrix and clay coatings.

Matrix: Abundant orange highly oriented, low anisotropic with occasional domains and embedded silt grains.

Silt: Frequent quartz pockets in shale. In weathered areas quartz is oriented in a circle. Occasional mica, rare glauconite pellets.

Sand: Very fine quartz

Rock fragments: Abundant

Coatings: Highly oriented clays are found around pores and rock fragment along with manganese and iron oxides. They form compound coatings.

Surface residues: None

Secondary crystalline material: None visible

Segregation and concretions: Brown to black segregations and concretions of manganese and iron oxide are found in highly weathered zones and in pores.

Weathering features: Zones where fine material has been leached out are present. Mica is exfoliated and contorted, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: The saprolite is formed from weathered sandstone and shale.

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