

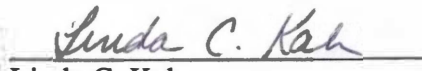
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I am submitting herewith a thesis written by Eric G. Ober entitled "The Paleohydrologic History of Coal Underclays Based on Pennsylvanian Paleosols in Eastern Tennessee." I have examined the final paper copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

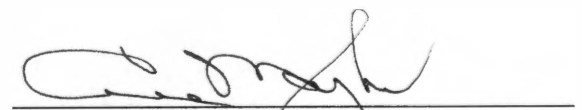

Steven G. Driese, Major Professor

We have read this thesis
and recommend its acceptance:


Claudia I. Mora


Linda C. Kah

Accepted for the Council:


Vice Provost and Dean of Graduate Studies

Thesis
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**THE PALEOHYDROLOGIC HISTORY OF COAL UNDERCLAYS BASED ON
PENNSYLVANIAN PALEOSOLS IN EASTERN TENNESSE**

A Thesis Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Eric G. Ober

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ABSTRACT

Carboniferous underclays have been interpreted as paleosols for over 150 years, but debate over their origin still persists. Underclays are common throughout Lower Pennsylvanian deposits on the Cumberland Plateau in eastern Tennessee. Through careful examination of the morphology, micromorphology and whole-rock geochemistry, it is possible to interpret the processes leading to underclay development and further our understanding of regional environmental change in the Pennsylvanian.

Underclays of the Lower Pennsylvanian Crooked Fork Group in eastern Tennessee contain morphological and geochemical features common to well-drained paleoVertisols, paleoAlfisols, and saturated paleoHistosols. Macromorphologic features such as pedogenic slickensides and angular blocky ped structure, in conjunction with micromorphologic features that include illuviated clay pore-fillings and sepic-plasmic microfabric, indicate a well-drained period early in paleosol development. Gley overprinting of vertic features, including drab, low-chroma paleosol colors, siderite-replaced rhizcretions, sphaerosiderite and pyrite nodules, extensive leaching and translocation of alkali and alkaline earth elements, and kaolinitization of smectites and hydroxyl-interlayer vermiculite (HIV) indicate a second stage of paleosol development during which the ancient soil was saturated and experienced moderate to low Eh and low pH conditions. Finally, burial and coalification of organic material and the stratigraphic juxtaposition of marine shales and sandstones on top of terrestrial deposits indicate a third stage of underclay development. This three-stage model of underclay genesis

appears to have been driven by high-order glacio-eustatic sea level fluctuations, as evidenced by stratigraphic relationships within the Crooked Fork Group.

Because Paleosols are the weathering products of rocks and unconsolidated sedimentary deposits, they can be used as proxies for determining paleoclimate. Previous studies proposed a shift in climate in North America at the Mississippian-Pennsylvanian boundary, from semi-arid to tropical or sub-tropical rainy. The chemical index of alteration without potash (CIA-K) was used as a proxy for paleo-mean annual precipitation (MAP). Using whole-rock geochemical data obtained through XRD analysis, an estimate of 1300 mm/yr of rainfall was obtained. This value is consistent with modern sub-tropical rainy environments and supports the hypothesis for climate change at the end of the Mississippian.

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1.0 INTRODUCTION

The idea that Carboniferous underclays are paleosols has persisted for over 150 years (Logan, 1842). It is still, however, not universally accepted and some researchers have gone as far as to state that underclays are unequivocally not paleosols (Schultz, 1958). The many definitions of underclays range from purely descriptive (Brownwell, 1978) to genetic (Bates and Jackson, 1984; Diessel, 1992). There are at least as many models for underclay genesis as there are definitions. These models fall into two categories, allochthonous and autochthonous. Allochthonous models assume that the mineralogy of underclays is inherited from lithologic and climatic change in the source area (Schultz, 1958), whereas allochthonous models hypothesize underclay properties are acquired at the site of deposition and may develop either synchronously with peat accumulation (Smith and O'Brien, 1965; Staub and Cohen, 1978; Moore, 1968) or prior to peat accumulation (Percival, 1986; Weller, 1930).

Underclays associated with three different coal seams within the Lower Pennsylvanian Crooked Fork Group of eastern Tennessee exhibit soil features common to modern, well-drained Vertisols and Alfisols, including pedogenic slickensides, angular blocky ped structures, root traces, and sepic-plasmic fabric, defined by segregations of clay minerals with preferred orientations and congruent extinction patterns (Brewer, 1964); and illuviated clay coatings on pore walls and peds, indicating that they are, indeed, paleosols. Gley overprinting, a feature characterized by drab (low chroma) soil colors, siderite precipitation within the soil matrix, and siderite replacement of calcite rhizcretions, indicate iron reduction in an anoxic environment and low Eh conditions

during paleosol saturation (Curtis and Coleman, 1986) coincident with sea level rise and development of a coal swamp.

Despite a complex pedogenic and diagenetic history, these underclays can provide valuable information about climate, particularly paleo-precipitation. Several methods have been devised to use paleosols to estimate paleo-precipitation. One method, ideally suited for use on paleosols formed well above the water table, relates the depth to the carbonate horizon to mean annual precipitation (MAP) (Caudill et al., 1996; Retallack, 1994). This method, however, has several drawbacks including erosional truncation and compaction of the paleosol, as well as the influence of differing paleoatmospheric levels of carbon dioxide on carbonate precipitation (Caudill et al., 1996). A second, and perhaps more generally applicable, method uses bulk geochemical measurements to estimate MAP (Sheldon et al., 2002).

This study will show that underclay paleosols provide evidence that soils formed during the Early Pennsylvanian in eastern Tennessee were initially well drained and subjected to seasonal shrink-swell processes. These paleosols were commonly overlain by coal swamps, or paleoHistosols, and were completely gleyed due to rising water-table associated with high-order transgressive/regressive cycles. The purpose of this paper is three fold; 1) to demonstrate that underclays are indeed paleosols, 2) to show that underclays had a complex pedogenic and diagenetic history controlled by sea-level change, and 3) to use geochemical techniques to calculate paleo-mean annual precipitation.

2.0 LOCATION AND METHODS

The Crooked Fork Group is exposed in roadcuts throughout the Cumberland Plateau in Tennessee. This study analyzed three underclays in outcrop and drill core. The Wartburg 1 paleosol crops out along US 27 in Wartburg, Tennessee (Fig. 1), and is overlain by the Poplar Creek Coal (Fig. 2). Additional samples of the Wartburg 1 paleosol were examined from drill core, provided by the Tennessee Division of Geology, from Petros, Tennessee, south of Wartburg, and Ivydel, Tennessee, near the Kentucky border (Fig. 1). The Wartburg 2 paleosol also crops out along US 27 approximately 2 km northwest of Wartburg. The third underclay, Rockwood 1, crops out along Interstate 40 at the Airport Road interchange near Rockwood, Tennessee (Fig. 1). All three underclays are 270-360 cm thick. Each underclay/coal couplet overlies deltaic sandstones and underlies marine shales or sandstone. The Rockwood 1 paleosol is the thickest and best developed of the paleosols examined in this study.

Paleosol macromorphology was described following the approach outlined by Retallack (1988). Colors were described using wetted samples and the Munsell Rock Color Chart. Two to three profiles per outcrop were described within both pseudoanticlines and pseudosynclines, where appropriate. Oriented samples were obtained from each horizon for petrographic analysis. Samples were collected every ten centimeters along each profile for bulk geochemical and density analysis. The bulk mineralogy of the paleosol samples was analyzed in hand-packed powder mounts. After oven drying at 60°C, pressed pellets were prepared from bulk, powdered paleosol samples and analyzed for selected major, minor and trace elements using a Philips

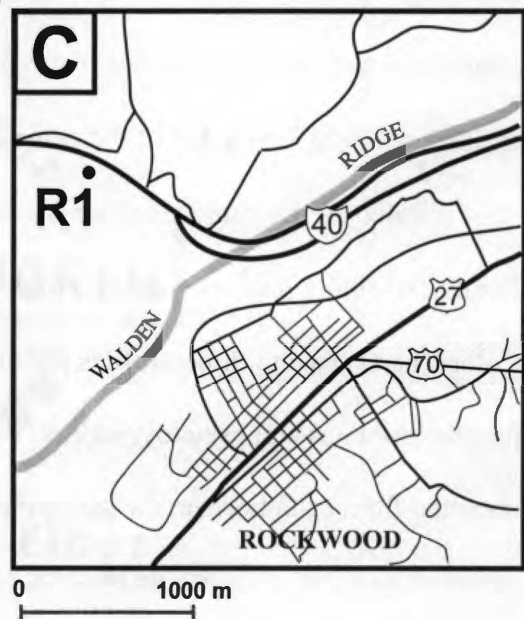
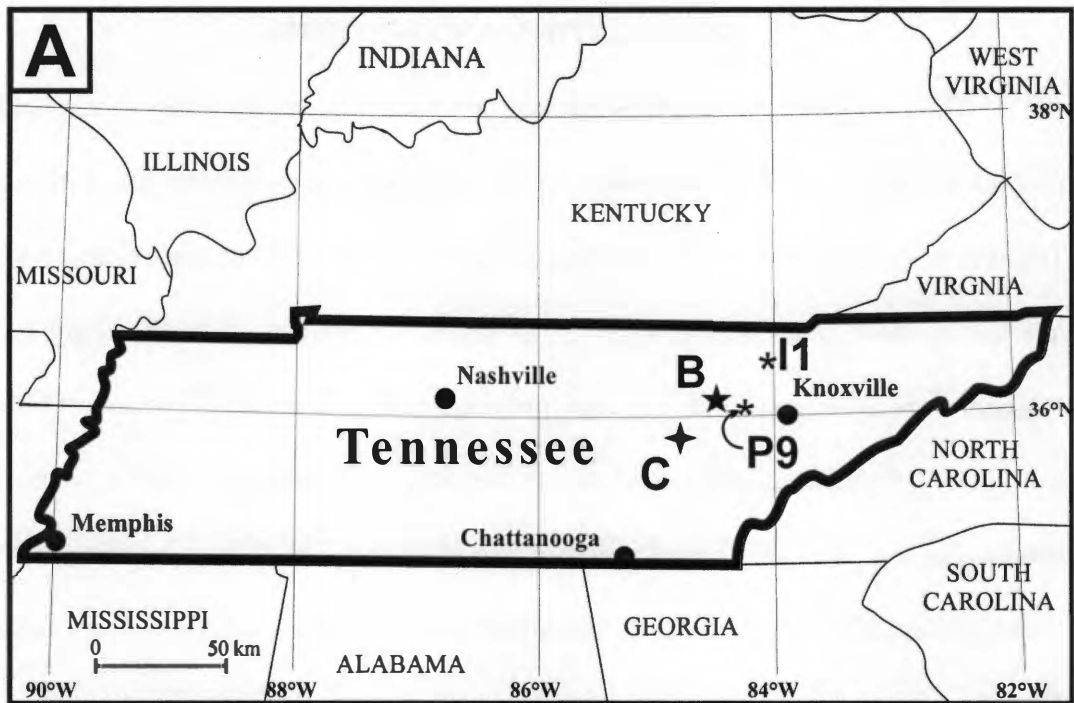


Figure 1: Locations of underclay outcrops and drill core locations in eastern Tennessee. (A) Locations of: I1) Ivydel 1 paleosol (N36° 28.134', W84° 10.716'); P9) Petros 9 paleosol (N36° 5.58', W84° 25.752'). (B) Locations of: W1) Wartburg 1 paleosol (N36° 6.391', W84° 35.714'); W2) Wartburg 2 paleosol (N36° 7.222', W84° 35.498'). C) Location of: R1) Rockwood 1 paleosol (N35° 53.769', W84° 42.168').

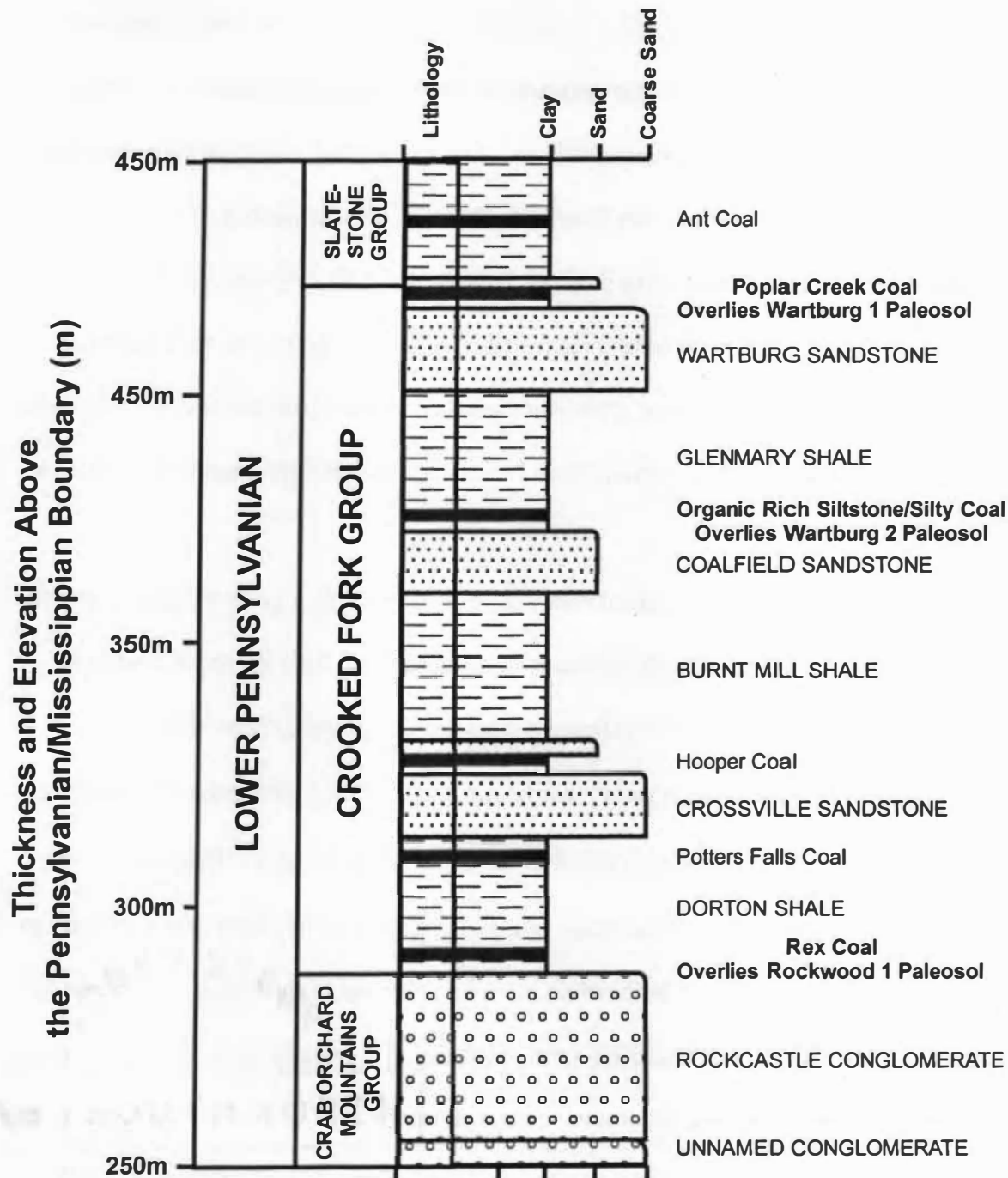


Figure 2: Generalized stratigraphic column for Lower Pennsylvanian rocks on the Cumberland Plateau. The paleosols discussed in this paper are in the Crooked Fork Group. (From Wilson et al., 1956)

MagixPRO wavelength-dispersive X-ray Fluorescence (XRF) Analyzer (Singer and Janitzky, 1986). The XRF analytical protocol employed appropriate clay soil and shale standards and reports major elements in oxide weight percent and trace elements in ppm (Appendix A). Bulk density was determined by paraffin coating of air-dried soil clods (Blake and Hartge, 1986). Clay mineral analysis of the $<0.7\ \mu\text{m}$ and $0.7\text{--}2.0\ \mu\text{m}$ size fractions was performed on samples taken near the top and bottom of each paleosol profile using elutriated mounts, glycolation and routine heat treatments using a Siemens D500 diffractometer. Thin sections were examined and described according to Brewer (1964).

Whole-rock XRF chemical data were evaluated using a mass-balance approach (Brimhall et al., 1988; 1991a,b; Driese et al., 2000; 2003). This approach evaluates chemical variations in a soil or paleosol resulting from closed-system effects of volumetric changes (strain, σ) and residual enrichment of the paleosol matrix, and open-system transport of material into or out of the soil (translocation, τ) (Brimhall, 1988; 1991a,b). Only element concentration and bulk density measurements are necessary to characterize these values. Choice of an immobile element is particularly important for translocation calculations, and zirconium or titanium is typically used. In clay-rich soils, however, small changes in zirconium occur with transport of detrital zircon and can result in large errors in the calculations; titanium is therefore preferred (Driese et al., 2000; 2003).

3.0 STRATIGRAPHY AND DEPOSITIONAL SETTING

During the Early Pennsylvanian, North America was moving north out of southern hemisphere tropical to sub-tropical arid and semi-arid zones into wet, equatorial regions (Cecil, 1990). Numerous rivers transported sediment to the northwest from the remnants of the Acadian highlands into a shallow epeiric sea, forming extensive delta systems (Cecil, 1990; Levin, 1991). Acadian highlands consisted of a low mountain range approximately 4000 km long with the southern end at a paleolatitude of approximately 15° South latitude and the northern end at the paleoequator (Levin, 1991).

Underclays examined in this study occur within the Lower Pennsylvanian Crooked Fork Group (Fig. 2). The predominantly siliciclastic Crooked Fork Group ranges from 77 to 268 m in thickness in Tennessee (Schnoebelen, 1983) and is composed of green and black shale, claystone, fine- to coarse-grained sandstone, conglomerate, and coal (Wilson et al., 1956; Schnoebelen, 1983). Included in this group are several gray-green to red underclays. These underclays are not fissile and have a hackly appearance common in paleosols.

The Crooked Fork Group thins from east to west, with fine-grained sediments increasing to the west. Immediately overlying the Crooked Fork Group is an unnamed marine shale of the Slatestone Group (Wilson et al., 1956). The Crooked Fork Group is underlain by coarse-sand-size to pebbly Lower Pennsylvanian Rockcastle Conglomerate of the Crab Orchard Mountains Group, which interfingers with deltaic and marine shales to the east (Wilson et al., 1956).

In Tennessee, the Crooked Fork Group is comprised of interbedded terrestrial and marine sediments deposited in delta environments (Schnoebelen, 1983). It is dominated by marine shales, but contains a moderate thickness of fluvial channel sandstones and at least five coal beds (Schnoebelen, 1983; Wilson et al., 1956). Other interpretations contend that the Crab Orchard and Crooked Fork Groups are actually barrier island sequences, with increasing deltaic deposits within the Crooked Fork Group and increasing in importance into the Slatestone Group (Milici et al., 1979).

4.0 OUTCROP DESCRIPTIONS

4.1 Wartburg 1

The Wartburg 1 outcrop is a horizontally stratified succession of sandstone, siltstone, shale and coal. Six lithofacies are identified in the outcrop (Fig. 3). Facies 1a, exposed at the base of the outcrop, is a dark greenish-gray (5GY 4/1), clay-rich, featureless siltstone containing quartz, with lesser amounts of detrital phyllosilicates, muscovite, and chlorite. Facies 1a grades into Facies 2a, the paleosol. Facies 2a is a slickensided, rooted claystone paleosol described in detail below. The Poplar Creek Coal is identified as Facies 3a. It is a black, vitreous, bituminous coal approximately 30 cm thick and is overlain by a fissile, indurated, 75 cm thick, organic-rich shale, designated as Facies 4a. Facies 5a shale has sharp top and bottom contacts, is somewhat less fissile than Facies 4a, and has thin (cm scale) interbeds and lenses of clay-rich siltstone and siderite. Facies 2a is also present as a 70 cm thick layer immediately underlying the thin Ant Coal. Facies 6a is a gray, silty shale interbedded with a very fissile, dark-gray shale.

The Wartburg 1 paleosol, shown in Figure 4A, is approximately 320 cm thick and contains nine morphological units equivalent to soil horizons (Table 1). There is little lateral variation within this paleosol, although lower horizons vary slightly in thickness and properties. The Wartburg 1 description is based on the best-exposed section of the paleosol. The morphological units, or horizons, are described below in descending order. A detailed summary can be found in Table 1. Horizon designations have been assigned using nomenclature adapted from Retallack (2001).

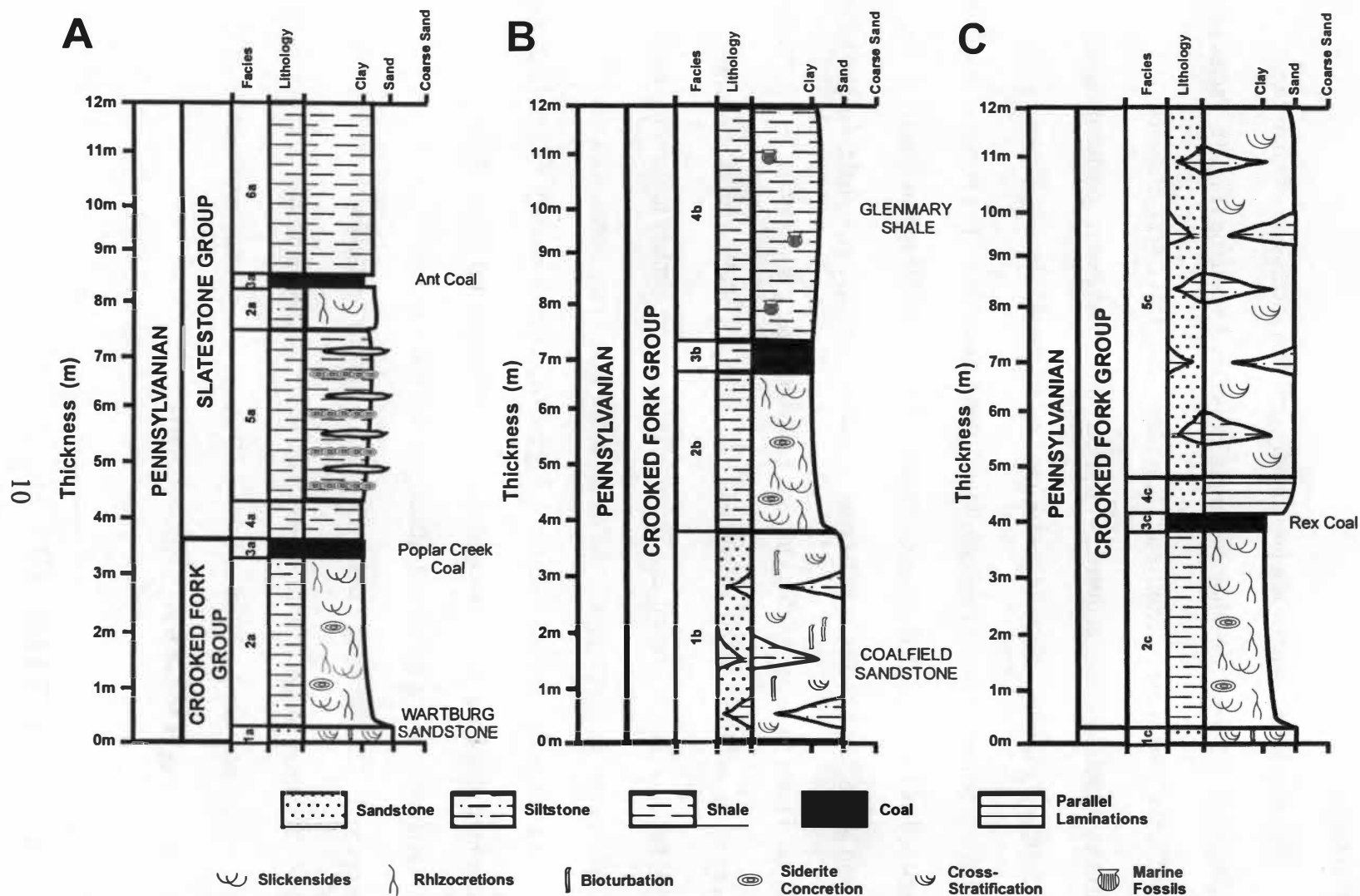


Figure 3: Local stratigraphy in outcrop at A: Wartburg 1, B: Wartburg 2, C: Rockwood 1. Wartburg 1 and Rockwood 1 adjacent strata inferred from Wilson et al. (1956)

Figure 4: Macroscale features of underclay paleosols exposed in outcrop on the Cumberland Plateau in eastern Tennessee. A) Schematic profile of the Wartburg 1 paleosol. Note the abundance of large siderite rhizcretions and slickensides. B1) Schematic profile of the Wartburg 2 paleosol, thinner northern section. Note the ubiquitous sphaerosiderite as well as the abundance of organic material and desiccation cracks at approximately 110cm depth. B2) Schematic profile of the Wartburg 3 paleosol, thicker southern section, that contains abundant slickensides, sphaerosiderite, and pyrite. Note the organic rich layer at approximately 100cm depth. C1) Schematic profile of the Rockwood paleosol, best exposed section. Note the abundance of slickensides, including a large master slickenside, and gley features. Also note the similarity to the pseudo-syncline shown in C3. C2) Schematic profile of the Rockwood paleosol at a pseudo-anticline. Note the abundance of clay and root traces as well as the presence of sphaerosiderite nodules. C3) Schematic profile of the Rockwood paleosol at a pseudo-syncline. Note the abundance of roots, sphaerosiderite and the presences of a master slickenside.

Key

	Sandstone		Parallel Laminations		Rhizcretions		Angular Blocky Peds
	Siltstone		Oxidized Mottling		Bioturbation		Organic Rich
	Silty Shale		Illuviated Clay		Desiccation Cracks		Sphaerosiderite
	Shale		Slickensides		Siderite Concretion		Framboidal Pyrite

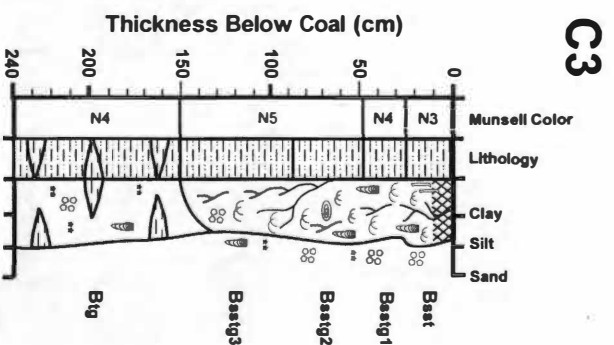
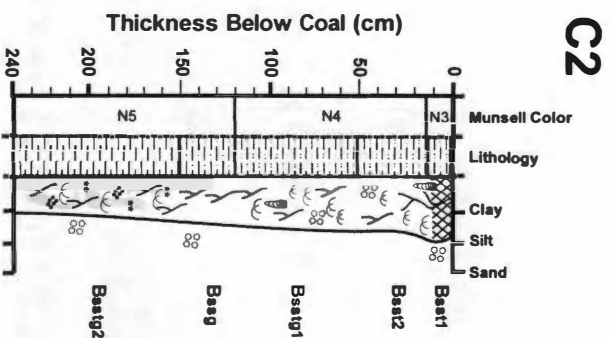
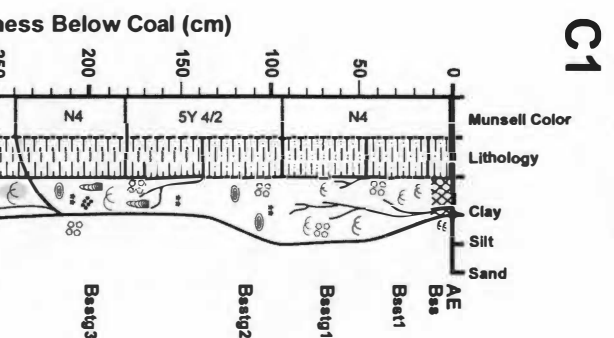
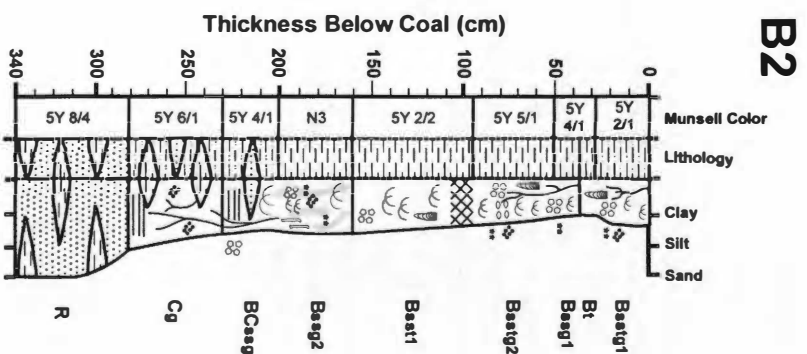
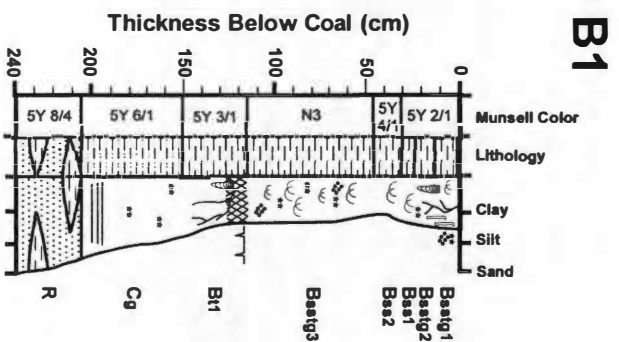
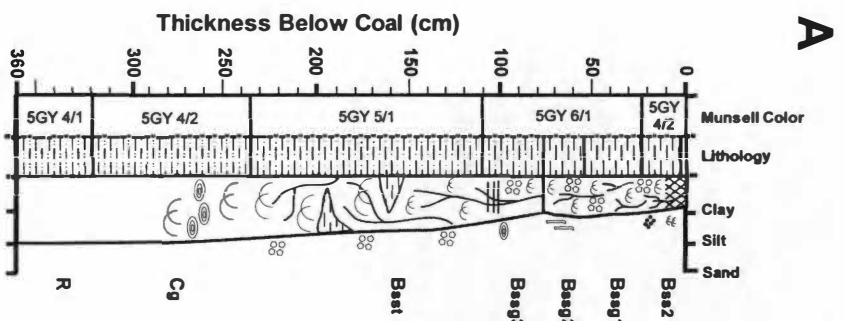


Table 1: Detailed descriptions of the two measured sections of the Wartburg 1 paleosol. Wartburg 1-1 is the easternmost section. Wartburg 1-2 is located 18.6 m west of Wartburg 1-1.

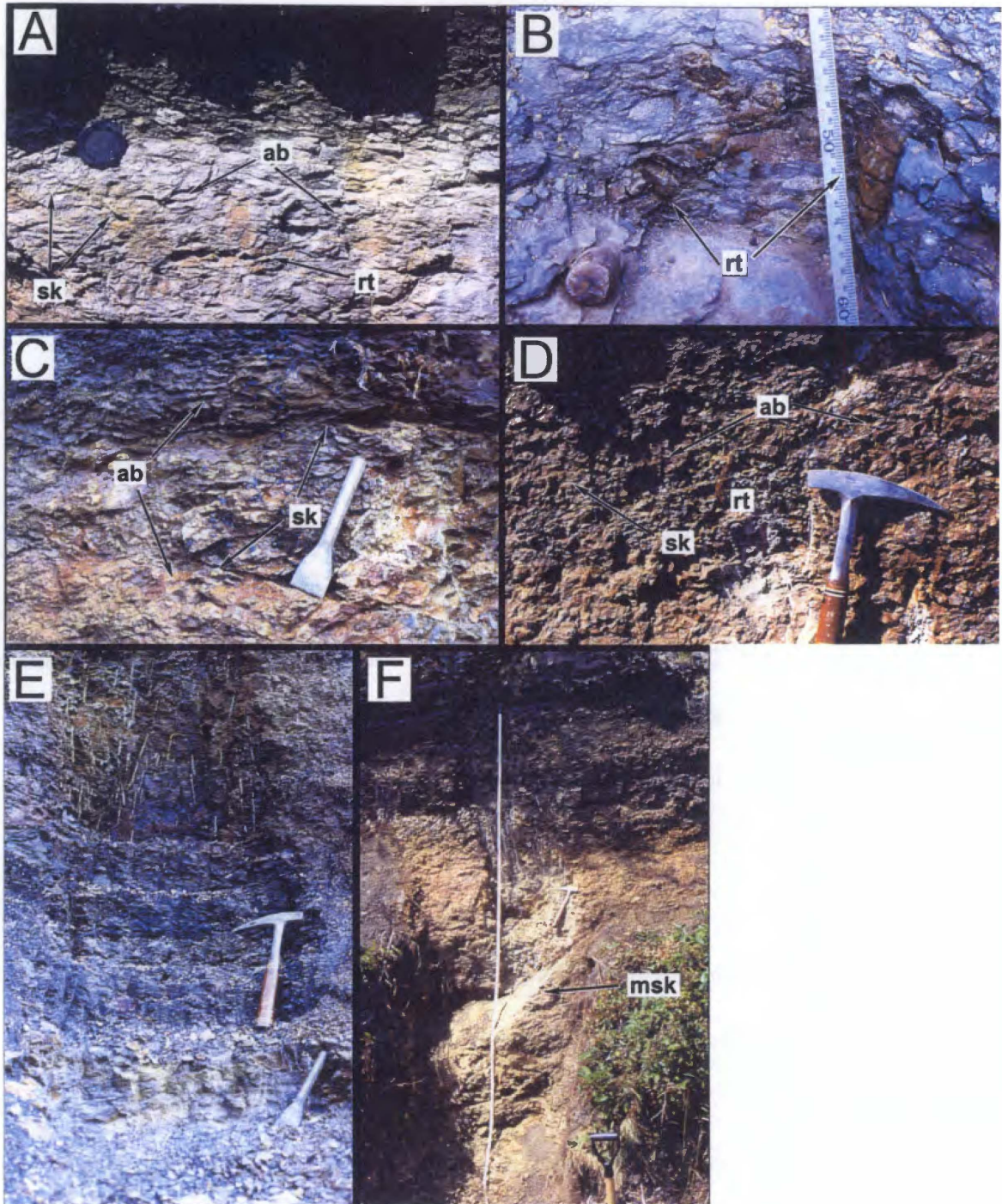
Paleosol	Wartburg 1					
Measured Section	1 (Well exposed)					
Unit #	Horizon	Color	Ped Structure	Matrix	Other Features	Micromorphology
1	B _{as1} 0-3cm	Dark Olive Gray (5Y 2/1)	Lenticular	Clay (<1% quartz silt), bimasepic fabric	Abrupt contact with coal (inherited coal clasts in paleosol matrix), root traces, slickensides	Inherited clasts of coal in paleosol matrix, macerated plant fossils
2	B _{as2} 3-24cm	Dusky Yellow Green (5GY 4/2)	Blocky	Clay (<1% quartz silt), bimasepic fabric	Gradational contact with overlying and underlying horizons, root traces, slickensides	Carbonized roots with preserved root hairs, framboidal pyrite near bottom, microslickensides, rhombohedral peds.
3	B _{ssg1} 24-55cm	Greenish Gray (5GY 6/1)	Angular blocky	Clay (<1% quartz silt), masepic fabric	Gradational contact with overlying horizon, sharp contact with underlying horizon, siderite rhizocretions, slickensides	carbonized roots, evidence of bioturbation, finely crystalline siderite rhizocretions
4	B _{ssg2} 55-77cm	Greenish Gray (5GY 6/1)	Angular blocky	Clay (<1% quartz silt), faint masepic fabric	Sharp upper contact, gradational lower contact, large siderite rhizocretions, few slickensides	Lenses of fine and coarse clay, burrows with meniscate back fill, collapsed root traces, large siderite concretions (1cm diameter)
5	B _{ssg3} 77-110cm	Greenish Gray (5GY 6/1)	Angular blocky	Silty clay (4-7% quartz silt), faint masepic fabric	Gradational upper and lower contacts, large siderite rhizocretions (1cm diameter), few slickensides	Coarse clay matrix, finely crystalline siderite around organic matter, carbonized roots, fine scale lamination
6	B _{ast} 110-235cm	Greenish Gray (5GY 5/1)	Angular blocky	Silty clay (4-7% quartz silt), faint masepic fabric	Gradational upper and lower contacts, very large siderite rhizocretions (5cm-10cm diameter), large asymmetrical slickensides, large mud lenses similar to B _{as2}	Fine clay matrix, rooting increases with depth, two generations of roots: one is carbonized and crosscuts illuviated clay filled roots
9	C _g 235-320cm	Dusky olive green (5GY 4/2)	-	Silty clay (10% quartz silt) faint lattisepic fabric	Very hard, laminated, layer of siderite concretions at 260 cm depth	Coarse silt, abundant siderite, rare muscovite and chlorite
10	R 320->360cm	Dark greenish gray (5GY 4/1)	-	Siltstone	Clay rich siltstone	Clay rich siltstone with 95% quartz, some phyllosilicates (muscovite, chlorite)

Table 1 (Continued)

Paleosol	Wartburg 1					
Measured Section	2 (Poorly exposed)					
Unit #	Horizon	Color	Ped Structure	Matrix	Other Features	Micromorphology
1	Bss10-5cm	Light olive gray (5Y 5/1)	Angular blocky	Clay (<1% quartz silt), strong bimasepic fabric	Gradational contact with coal (inherited coal clasts in paleosol matrix), root traces, slickensides	Inherited clasts of coal in paleosol matrix, macerated plant fossils
2	Bss2 5-22cm	Light olive gray (5Y 5/1)	Large angular blocky	Clay (<1% quartz silt), bimasepic fabric	Gradational contact with overlying and underlying horizons, root traces, slickensides	Carbonized roots, macerated plant fossils
3	Bssg1 22-50cm	Olive gray (5Y 4/1)	Large angular blocky	Clay (<1% quartz silt), strong bimasepic fabric	Gradational contact with adjacent horizons, siderite rhizcretions	Carbonized roots, large (1 cm diameter) siderite rhizcretions, framboidal pyrite
4	Bssg2 50-72cm	Light olive gray (5Y 6/1)	Large angular blocky	Clay (<1% quartz silt), bimasepic fabric	Gradational upper contact, sharp lower contact, siderite rhizcretions	Large siderite rhizcretions, less well developed bimasepic fabric than Bssg1, lenses of fine and coarse clay
5	Bssg3 72-120cm	Light olive gray (5Y 6/1)	Angular blocky	Silty clay (10-15% quartz silt), faint masepic fabric	Sharp upper contact, gradational lower contact, small root traces, large <i>Stigmara</i> rhizcretions, slickensides	Coarse clay matrix, finely crystalline siderite around organic matter, carbonized roots, fine scale lamination
7	Cg1 120-160cm	Grayish green (5G 5/1)	-	clayey silt (35% quartz silt and sand)	Gradational contact with adjacent horizons, abundant root siderite rhizcretions, relict cross bedding, large mud lenses similar to Bss2	Very coarse quartz silt/sandstone, abundant coarse phyllosilicates, fine crystalline siderite
8	Cg2 160-220cm	Grayish green (5G 5/1)	Lenticular	Silty clay (5-7% quartz silt), masepic fabric	Relict bedding, fissile, sandstone lenses	Fine clay matrix, small amount of quartz silt, some micas

The Wartburg 1 paleosol has a combination of vertic features and strong gley features. The overall color of the paleosol is greenish-gray (5GY 6/1), although some variation does exist. The top of the paleosol is in abrupt, wavy contact with the Poplar Creek Coal and change is gradual throughout the paleosol. Vertic features are strongest within the upper 24 cm. The upper two horizons, B_{ss1} and B_{ss2} are heavily slickensided and exhibit lenticular to blocky ped structures (Fig. 5A). Small root traces are abundant. Deeper in the paleosol, gley features become more apparent. From 24-110 cm below the coal, within horizons B_{ssg1}, B_{ssg2}, and B_{ssg3}, the amount of slickensides gradually decreases and the number and size of siderite rhizcretions increases. Additionally, the claystone becomes more indurated at 77 cm depth. This is most apparent in Wartburg 1-2 (profile 2, 18 m west of profile 1), where the B_{ssg3} horizon forms a hard layer that is resistant to weathering. Between 110 and 235 cm, the B_{sst} horizon, siderite rhizcretions reach their maximum size, from 5-10 cm diameter, some having features identifiable as *Stigmaria* (Fig. 5B). Lateral variation is greatest within this horizon. Large, soft, mud lenses interfinger with the dominant paleosol matrix, which is heavily overprinted by large, asymmetrical slickensides. In the Wartburg 1-2 section, this horizon is completely absent and is replaced by a fissile C_{g1} horizon, preserving original bedding, but containing abundant siderite rhizcretions. The lowermost horizon is a C_g horizon, from 235-320 cm below the coal. It is a very hard, laminated, silty-claystone with a layer of siderite concretions at 260 cm depth. The parent material, the R horizon, is a dark greenish-gray (5GY 4/1) featureless siltstone rich in clay that extends greater than 360cm below the coal.

Figure 5: Macromorphologic features in underclay paleosols. A) B_{s1} and B_{s2} horizons in the Wartburg 1 paleosol consisting of an olive gray shale showing wedge-shaped structural aggregates (ab, angular blocky peds) formed by the intersection of pedogenic slickensides (sk). B) Very large siderite rhizcretions (rt) composed of vertically stacked nodules in the Wartburg 1 paleosol at approximately 140cm below the coal. C) Angular blocky peds and slickensides near the top of the Wartburg 2 paleosol (B_{stg1}). D) Angular blocky peds, slickensides and cm scale siderite rhizcretions in the Rockwood 1 paleosol approximately 60cm below the coal in the B_{stg1} horizon. E) Lower 2/3 of the Wartburg 2 paleosol. Note the increasing ped size and more indurated appearance of the paleosol. F) Excavated section of the Rockwood 1 paleosol. Note the large master pedogenic slickenside exposed at 200 cm below the coal (msk)



4.2 Wartburg 2

The Wartburg 2 paleosol lies slightly lower in the Crooked Fork Group than the Wartburg 1 paleosol and overlies the Coalfield Sandstone. Four lithofacies can be identified on the second and third benches of the outcrop (Fig. 3). Facies 1b is a thinly cross-bedded quartz arenite with interbedded siltstones that has been identified as the Coalfield Sandstone (Schnoebelen, 1983). Locally, the Coalfield sandstone grades into a quartzwacke siltstone that underlies Facies 2b, the paleosol. Facies 3b is a silty smut, which is an organic-rich shale or poorly developed silty coal. The silty smut is 45% quartz sand and silt surrounded by organic matter. Some layers are sandier with quartz sand content reaching up to 75%, whereas others are nearly pure coal. Quartz grains are spherical and angular. The silty smut is overlain by Facies 4b, identified as the Glenmary Shale (Schnoebelen, 1983). The Glenmary Shale is thinly bedded, fissile, silty shale containing marine fossils.

The Wartburg 2 paleosol (Figs. 5B1 and B2) is approximately 280 cm thick and contains 11 distinct paleosol horizons (Table 2). Nearly constant seepage of groundwater from the overlying pyritic Glenmary shale has resulted in coating of ped and bedding plane surfaces with iron and manganese oxides and sulfates. The oxide coatings are easily distinguished from primary pedogenic features and, are not considered in this description. The diversity of paleosol horizons results from considerable lateral variation within the paleosol (Table 2; Fig. 4B1 and 4B2). Primary differences between the two measured sections can be attributed to variations in the thickness of the paleosol. Toward the west, at profile 1, the paleosol is 33 cm thinner than profile 2, just 11 m to the south.

Table 2: Detailed descriptions of the two measured sections of the Wartburg 2 paleosol. Wartburg 2-1 is the northernmost section. Wartburg 2-2 is located 20m south of the Wartburg 2-1 measured section.

Paleosol	Wartburg 2					
Measured Section	1 (Poorly developed)					
Unit #	Horizon	Color	Ped Structure	Matrix	Other Features	Micromorphology
1	Bsstg1 0-14cm	Olive Black (5Y 2/1)	Angular blocky	Silty clay (2-3% quartz silt), omnisepic fabric	Sharp contact with upper unit, gradational with bottom unit, slickensides	Reworked pedorelicts, burrows filled with quartz silt, illuviated clays, Fe-oxide pseudomorphs of pyrite and sphaerosiderite, root traces
2	Bsstg2 14-25cm	Olive Black (5Y 2/1)	Large angular blocky	Clay (< 1% quartz silt), omnisepic fabric	Gradational contact with adjacent horizons, slickensides	Abundant illuviated clay, root traces, micro-slickensides, sphaerosiderite
3	Bss1 25-32cm	Olive Black (5Y 2/1)	Angular blocky	Silty clay	Gradational top and bottom contacts, slickensides	-
4	Bss2 32-47cm	Olive Gray (5Y 4/1)	Small angular blocky	Clay	Gradational top and bottom contacts, slickensides	-
7	Bsstg3 47-115cm	Dark Gray (N3)	Angular blocky	Clay (< 1% quartz silt), omnisepic fabric	Gradational top and bottom contacts, slickensides	Evenly distributed framboidal pyrite, sphaerosiderite (two generations of growth, some engulfing pyrite), micro-slickensides
8	Bt1 115-150cm	Dark olive gray (5Y 3/1)	Blocky	Clay (< 1% quartz silt), bimasepic fabric	Gradational contact with adjacent horizons, root traces and organic matter, very few slickensides	Illuviated clays filling large root traces (multigenerational), desiccation cracks, carbonized organic matter
11	Cg 155-205cm	Light olive gray (5Y 6/1)	-	Clayey-sand (20% fine quartz sand and silt), silasepic fabric	Relict bedding, no ped structure	Weathered sphaerosiderites, relict bedding, coarse phyllosilicates
12	R 205-247cm	Grayish yellow (5Y 8/4)	-	Fine quartzarenite	Cross-bedded quartz sand with clay lenses	Fine quartz sand with quartz overgrowths, hematite cement and nodules.

Table 2 (Continued)

Paleosol	Wartburg 2					
Measured Section	1 (Well developed)					
Unit #	Horizon	Color	Ped Structure	Matrix	Other Features	Micromorphology
1	Bsstgl 0-29cm	Olive Black (5Y 2/1)	Angular blocky	Silty clay (2-3% quartz silt), omnisepic fabric	Sharp upper contact with, gradational with bottom unit, slickensides	Reworked pedorelicts, illuviated clays (multigenerational), framboidal pyrite and sphaerosiderite, root traces
5	Bt 29-37cm	Olive Gray (5Y 4/1)	-	Clay	Sharp contact with adjacent horizons, very soft, thickness varies	-
6	Bssgl 37-50cm	Olive Gray (5Y 4/1)	Angular blocky	Clay (< 1% quartz silt), masepic fabric	Sharp upper contact, gradational lower contact, siderite rhizocretions (1cm diameter), slickensides	Clays oriented with micro-slickensides, small orthogonal sphaerosiderite aggregates
7	Bsstg2 50-95cm	Gray (5Y 5/1)	Large angular blocky with small lenticular	Clay (< 1% quartz silt), bimasepic fabric	Gradational contacts with adjacent horizons, slickensided	Illuviated (multigenerational) clay infilling root macro-pores, sphaerosiderite, framboidal pyrite
8	Bsstl 95-160cm	Dark olive gray (5Y 2/2)	Angular blocky	Clay (< 1% quartz silt), bimasepic fabric	Gradational contact with upper horizon, sharp contact with bottom, slickensided	Illuviated clay skins, well preserved plant material, possible buried paleosol
9	Bssg2 160-200cm	Dark gray (N3)	Small Angular blocky	Clay (< 1% quartz silt), bimasepic fabric	Sharp upper contact, gradational lower contact, no visible roots, slickensides	Reticulate mottling, birefringent clays and organic matter filled burrows, coarse crystals of illite, framboidal pyrite, zoned siderites some with pyrite cores
10	BCssg 200-230cm	Olive gray (5Y 4/1)	Large angular blocky	Silty-sandy clay (up to 40% quartz silt), bimasepic fabric in clayey areas	Gradational upper contact, sharp lower contact, heavily slickensided, some siderite rhizocretions	Relict bedding, grainsize variation, lenses of quartz sand and silt, clay filled root casts, kaolinite cements
11	Cg 230-280cm	Light olive gray (5Y 6/1)	Angular blocky (poorly developed)	Sandy-silt (up to 40% quartz sand and silt)	Sharp top and bottom contacts, some siderite rhizocretions	Relict bedding, clay rich zones, some organic material and pyrite, coarse phyllosilicates, chlorite, tourmaline
12	R 280-336cm	Grayish yellow (5Y 8/4)	-	Fine quartzarenite	Cross-bedded quartz sand with clay lenses	Fine quartz sand with quartz overgrowths, hematite cement and nodules.

Even though there is marked lateral change, the degree of variability of horizonation is minor and the paleosol can be treated as a whole.

The Wartburg 2 paleosol has strong vertic features throughout. Like Wartburg 1, these features have been overprinted by gley processes. The top of the profile is in sharp contact with the silty smut. Unit 1, the B_{ssgl} horizon, contains more silt than any of the other well weathered horizons. Below 29 cm, silt content decreases and stays negligible throughout the paleosol to a depth of between 155 cm (profile 1) to 200 cm (profile 2). Although silt content changes little with depth, the ped size and hardness of the claystone increases (Fig. 5E). Organic matter, identified as black, fibrous material sometimes having relict cell structure in thin section, is abundant throughout the paleosol. However, small and large root traces and rhizocretions are rare. Only two horizons, one in profile 2 at approximately 40 cm depth and one in profile 1 at 115 cm, contain visible rhizocretions. At between 90 and 120 cm below the coal, layers of organic-rich material are apparent and, in profile 1, desiccation cracks, filled with vertically oriented illuviated clays are present. Slickensides and angular blocky ped structure are well developed throughout the paleosol (Fig. 5C and E), extending even into the lower BC_{ssg} horizon (Unit 10, Table 2). The parent material is a partially weathered silty, clay-rich unit at the top of the Coalfield Sandstone, which is unit 11. This horizon, the C_g horizon, is light olive gray (5Y 4/1), has little to no ped structure and contains large amounts of quartz sand and silt.

4.3 Rockwood 1

The Rockwood 1 paleosol lies at the base of the Crooked Fork Group and overlies a quartzwacke siltstone. It underlies a well-developed bituminous coal that is locally correlated with the Lower Pennsylvanian Rex Coal, although there is some doubt about this interpretation (B. Miller, pers. comm., 2002). Five lithofacies are identified in the outcrop (Fig. 3). Facies 1c is a silty sandstone that was only exposed through digging into the base of the outcrop. It is provisionally assigned to the Rockcastle Conglomerate of the Crab Orchard Mountains Group. On the eastern margin of the Cumberland Plateau, in the vicinity of the Rockwood 1 paleosol, the Rockcastle Conglomerate splits into a series of interbedded sandstone, siltstone and shale (Wilson et al., 1956). Immediately overlying Facies 1c is the underclay paleosol, designated as Facies 2c. Facies 2c is a slickensided, rooted, and gray-green to mottled red-brown claystone paleosol, between 240 and 340 cm thick, which is described in more detail below. The Rex Coal (Facies 3c) is a black, vitreous, bituminous coal that varies in thickness from 30 to 50 cm. Facies 4c is a silty finely-bedded sandstone with laminar beds. It is only 60 cm thick and is in sharp contact with a massive, medium-grained sandstone identified as Facies 5c. Facies 5c is at least 7 m thick, extending to the top of the outcrop. It is a medium-grained quartz arenite with large scale trough cross-stratification. Interbedded with the sandstone are lenses of dark, silty shale ranging from 20 to 30 cm in thickness.

The Rockwood 1 paleosol is approximately 350 cm thick and contains 12 morphological units that are equivalent to soil horizons (Table 3). Considerable lateral

Table 3: Detailed descriptions of the two measured sections of the Rockwood 1 paleosol. Rockwood 1-1 is the westernmost section.

Paleosol	Rockwood 1					
Measured Section	1 (Intermediate)					
Unit #	Horizon	Color	Ped Structure	Matrix	Other Features	Micromorphology
1	AE 0-2cm	Grayish Black (N2)	-	Silty clay matrix (5% quartz silt), masepic fabric	Sharp upper contact, Organic rich	Charcoal fragments, Micro-slickensides
2	Bss 2-12cm	Medium Dark Gray(N4)	Angular blocky	Silty clay matrix(5% quartz silt), lattisepic fabric	Gradational contacts, organic rich, small root traces and organic fragments, heavily slickensided	Fine organics with assimilated clay
3	Bsst1 12-33cm	Medium Dark Gray(N4)	Angular blocky	Coarse silty clay matrix (7% quartz silt), vomasepic fabric	Gradational contacts, organic rich, small root traces and organic fragments, slickensides	Reworked pedorelicts with silasepic fabric, illuviated clay filling of root traces, Iron oxide concretions
5	Bsstgl 33-94	Medium Dark Gray(N4)	Large angular blocky	Coarse silty clay matrix (10% quartz silt), lattisepic fabric	Gradational contacts, siderite rhizocretions (1 cm diameter), slickensides	Coarse clays, illuviated clay filling macro-pores.
8	Bsstg2 94-138	Light Olive Gray (5Y 4/2)	Large angular blocky	Silty clay matrix (5% quartz silt), bimasepic fabric	Gradational contacts, large siderite filled <i>Stigmara</i> casts, siderite concretions.	Fine clays, small amounts of illuviated clay skins, sphaerosiderite and blocky siderite nodules, rhombohedral peds
10	Btg 138-180cm	Dusky Yellow Green (5GY 4/2)	Blocky	Clay matrix (1% quartz silt), bimasepic fabric	Gradational contacts, siderite rhizocretions (1 cm diameter), very indurated	Fine clays, some illuviated clay fragments, sphaerosiderite concentrated around root traces
11	Bsstg3 180-239cm	Medium Dark Gray(N4)	Angular blocky	Clay matrix (<1% quartz silt), masepic fabric with lattisepic fabric matrix filling intra-ped macro-pores	Gradational upper contact, lower contact bounded by a master slickenside, no roots, some siderite concretions.	Fine clays, angular blocky peds, illuviated clays, abundant sphaerosiderites with framboidal pyrite cores.
12	Bsst2 239-340	Light Olive Gray (5Y 4/2) with large areas of Moderate Brown (5YR 4/4)	Very large angular blocky	Clay matrix (<1% quartz silt), omnisepic fabric	Upper contact bounded by a master slickenside, small root traces	Abundant illuviated clay "beds", deeper in horizon these beds are oxidized (red), fragments of parent material, siderite nodules roughly follow gley areas
13	CR	-	-	-	-	-

Table 3 (Continued): Rockwood 1-2 is located 27.5 m east of the Rockwood 1-1 profile.

Paleosol	Rockwood 1					
Measured Section	2 (Microhigh)					
Unit #	Horizon	Color	Ped Structure	Matrix	Other Features	Micromorphology
2	Bsst1 0-15cm	Dark Gray (N3)	Angular blocky	Silty clay matrix (15% quartz silt), silasepic to insepic fabric	Gradational contact bottom contact and sharp top contact, small root traces, large slickensides	Abundant organic matter including charcoal, illuviated clays, ped-like pedorelicts, organic filled root traces
4	Bsst2 15-52cm	Medium Dark Gray (N4)	Small angular blocky	Silty clay matrix (10% quartz silt), masepic fabric	Gradational top and bottom contact, small root traces, abundant slickensides	Large fragments of charcoal and other organic material, reworked illuviated clays, illuviated clay filling of macro-pores (multigenerational), carbonized root traces with preserved root hairs, coarse phyllosilicates
6	Bsstg1 52-120cm	Medium Dark Gray (N4)	Small angular blocky	Silty clay matrix (15% quartz silt), masepic fabric	Gradational top and bottom contact, small root traces, siderite rhizcretions (1cm diameter), abundant slickensides	Large calcite spar filling centers of siderite rhizcretions, abundant illuviated clay skins and filling macro-pores
8	Bssg 120-150cm	Medium Gray (N5)	Large blocky	Clayey silt matrix	Gradational top and bottom contacts, large siderite rhizcretions, minimal slickensides	-
9	Bsstg2 150 >240cm	Medium Gray (N5)	Large angular blocky	Clay matrix (<1% quartz silt), bimasepic fabric	Gradational upper contact, very large siderite rhizcretions, siderite concretions, oxidized mottling	Abundant sphaerosiderite with framboidal pyrite cores, rhombohedral peds and pedorelicts, reworked illuviated clays, illuviated clay filling macropores

Table 3 (Continued): Rockwood 1-3 is between the other two, 2 m west of Rockwood 1-2.

Paleosol	Rockwood 1					
Measured Section	3 (Microlow)					
Unit #	Horizon	Color	Ped Structure	Matrix	Other Features	Micromorphology
2	Bsst 0-26cm	Dark Gray (N3)	Small angular blocky	Silty clay matrix (15% quartz silt), insepic to masepic fabric	Sharp contact with coal, gradational bottom contact, small root traces, heavily slickensided	Abundant organic matter including charcoal, illuviated clays, compressed burrows, slickensides
4	Bsstgl 26-49cm	Medium Dark Gray (N4)	Small blocky	Silty clay matrix (10% quartz silt), vomasepic fabric	Gradational top and bottom contacts, small root traces, abundant slickensides	Organic matter, abundant illuviated clay skins and pore fillings (multigenerational), abundant roots with preserved root hairs, coarse phyllosilicates, pyritized organic matter.
5	Bsstg2 49-88cm	Medium Gray (N5)	Large angular blocky	Silty clay matrix (15% quartz silt), lattisepic fabric	Gradational top and bottom contacts, large siderite rhizocretions (1cm diameter), organic matter, slickensides	Organic matter, abundant illuviated clay skins and illuviated clay filling macro-pores (multigenerational), blocky siderite and sphaerosiderite, burrows
6	Bsstg3 88-150cm	Medium Gray (N5)	Large blocky	Silty clay matrix (10% quartz silt), bimasepic fabric	Gradational top and bottom contacts, large siderite rhizocretions (1cm diameter), contains a master slickenside, clay lenses with small blocky peds	Abundant illuviated clay skins and illuviated clay filling macro-pores (multigenerational), sphaerosiderite concentrated around root traces, large lithorelict (parent material)
7	Btg 150->240cm	Medium Dark Gray (N4)	Very large angular blocky peds	Silty clay matrix (15% quartz silt), vomasepic fabric	Gradational upper contact, clay lenses with lenticular peds, few slickensides, no large roots	Abundant illuviated clay skins and illuviated clay filling macro-pores, large euhedral sphaerosiderites

variation exists within the paleosol (Figs. 4C1, C2 and C3) and can be attributed to the presence of slickenside-bounded micro-high and micro-low vertic structures.

The Rockwood 1 paleosol has a combination of vertic features and strong gley features. The overall color of the paleosol is greenish-gray to gray (5Y 4/2 to N4), although at depth, the paleosol takes on a mottled appearance, having patches of red-brown coloration (5YR 4/4). Sphaerosiderite, pyrite, and siderite rhizcretions are ubiquitous throughout the paleosol. The top of the paleosol is in sharp contact with the Rex Coal, and change is gradual throughout most of the paleosol. Abundant vertic features occur in the Rockwood 1 paleosol, which exhibits evidence of having had gilgai micro-topography, including master slickensides bounding pseudoanticlines, called micro-highs, and pseudosynclines, called micro-lows (Fig. 6A and B) and angular blocky ped structure (Fig. 5E and 6F). Rhizcretions are common but there are few large, continuous rhizcretions; most are present as short segments, rarely exceeding 5 cm in length (Fig. 5E). The vast majority of root traces exist as small, carbonized root fragments disseminated throughout the paleosol.

Within a pseudoanticline, or micro-high (measured section Rockwood 1-2), the paleosol is characterized by thinning of the upper paleosol horizon and complete absence of others (Table 3 and Fig. 4C2), whereas within the pseudosyncline, or micro-low (measured section Rockwood 1-3) has more gradual changes in horizonation. The uppermost horizon, designated as Unit 1, only occurs in the westernmost measured section, Rockwood 1-1, and is an AE horizon. It is both depleted in sesquioxides (Fe_2O_3 and Al_2O_3) and rich in organic matter. This horizon is completely missing from the other two

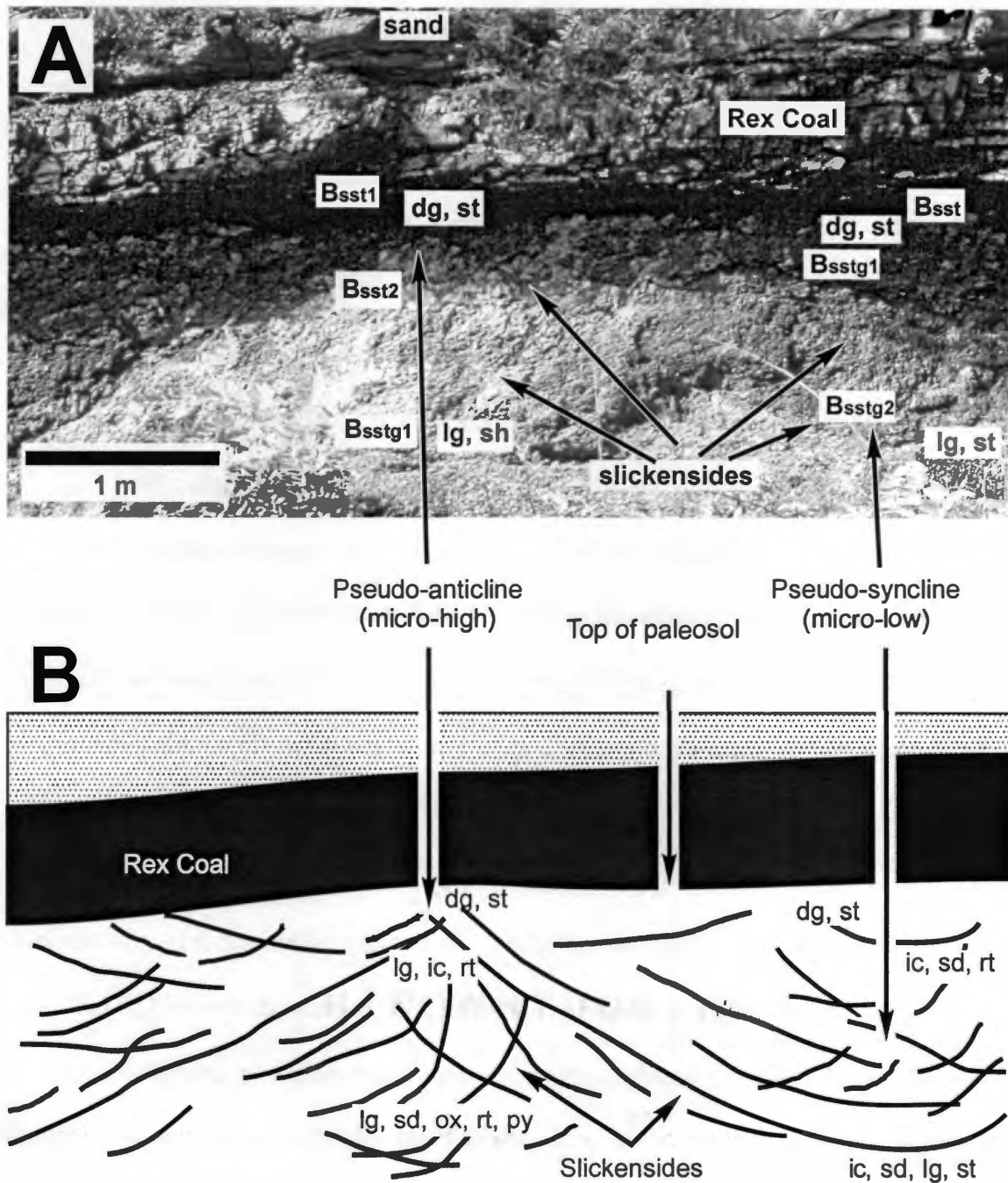


Figure 6: Macroscale features of the underclay paleosol along I-40 near Rockwood, Tennessee. Key: sand = sandstone; st = siltstone; ssh = silty shale; sh = shale; ox = oxidized mottling; ic = illuviated clay; rt = rhizocreations; sd = sphaerosiderite; py = pyrite. A) Photograph of the main outcrop of paleosol showing selected macromorphologic features and lateral variation of paleosol horization. B) Schematic tracing of photograph in A showing pedogenic slickensides, pseudo-anticlines and pseudo-synclines, paleosol color patterns (lg = light gray, dg = dark gray), and distribution of sphaerosiderite and pyrite.

measured sections. The uppermost horizon in the micro-high and the micro-low is designated as Unit 2. This horizon is a B_{sst1} horizon and is characterized by a silty clay matrix (up to 15% quartz silt) with a silasepic to insepic plasmic fabric forming angular blocky peds. There is abundant organic matter, small root traces and large slickensides. Unit 2 is thinner in the micro-high, only 15 cm thick as compared to 26 cm in the micro-low. Unit 5, designated as B_{sstg2} , is completely missing from the micro-high, but is present in both the micro-low and the western Rockwood 1-1 section.

Vertical change within the micro-low is gradual and slight. Slight color variations, abundance of organic matter, root traces, and silt content constitute most of the changes throughout the measured section. Overall the micro-low is relatively coarse-grained, containing between 10 to 15% quartz silt and has a fairly uniform distribution of siderite rhizocretions, some even reaching up to 1 cm in diameter. In contrast, the micro-high is silty only within the top 120 cm, where, with the exception of the missing Unit 5, a B_{sstg2} horizon, and the thinning of the upper-most horizon, it resembles the micro-low. Below 120 cm, the nature of the micro-high is considerably different from the micro-low. The matrix becomes much less silt-rich, containing <1% quartz silt. Below 150 cm depth, the micro-high has a mottled appearance with some red-brown coloration. The mottling is also present at the bottom of the Rockwood 1-1 measured section at a depth of below 260 cm. In the micro-low, this mottling does not appear above 240 cm.

5.0 DRILL CORE DESCRIPTIONS

Both the Ivydell 1 and the Petros 9 drill cores penetrate the Poplar Creek Coal and its associated underclay (Tennessee Division of Geology Files, 1953). The paleosol in each of these cores is therefore likely correlative with the paleosol found at the Wartburg 1 outcrop. Paleosols have a poor recovery potential in drill cores. Based on the observed thickness of the paleosols in outcrop, it is estimated that one third to two thirds of the paleosol sections were lost during drilling, and it is therefore impossible to determine accurate thicknesses from the core samples. These descriptions focus primarily on general characteristics of the paleosol, along with superjacent and subjacent strata.

5.1 Ivydell 1

The Ivydell 1 core consists of 274 m of section. The Poplar Creek Coal is located 70 m above the base of the core. The interval from 2 m below the coal to 3 m above the coal can be sub-divided into three lithofacies. Facies 1d is stratigraphically located within the Coalfield Sandstone and is a quartz arenite that becomes clay rich in the top 60 cm. This unit grades into Facies 2d, the underclay paleosol. It is characterized by large (1-2 cm diameter) siderite rhizocretions and carbonized root traces, along with slickenside surfaces. Only approximately 0.6 m of paleosol was preserved. The Poplar Creek Coal was removed for analysis. Overlying the coal, Facies 4d is a dark, fissile shale.

5.2 Petros 9

The bottom 14.3 m of the Petros 9 core can be sub-divided into four different lithofacies. The first lies stratigraphically within the Coalfield Sandstone and is 3.6 m thick. It is a fine-grained quartz sandstone with thin parallel laminations. Facies 1e grades into the overlying facies. Facies 2e is a quartzwacke sandstone or very sandy shale, 2.1 m in thickness. Like Facies 1e, it has fine parallel laminations. This unit is the parent material for the underclay paleosol. The underclay, Facies 3e, is a silty claystone containing large (2 cm diameter) siderite rhizcretions, smaller root traces, carbonized organic material, and slickensides. Only 0.6 m of paleosol survived the drilling process. Sixty cm of Poplar Creek Coal was removed for analysis; however, it is assumed that it is similar to the coal at Wartburg 1. Immediately overlying the coal is 8 m of dark, fissile shale, Facies 4e.

6.0 MICROMORPHOLOGY

6.1 Paleosol Matrix

All three paleosols, in outcrop and the two cores, are dominated by sepic-plasmic matrix. Sepic-plasmic fabric can be sub-divided into specific categories based on clay orientation patterns and the density of the segregations. Five different categories of sepic-plasmic fabric are identified in the Lower Pennsylvanian underclay paleosols; masepic (one direction of preferred clay orientation), bimasepic (two directions), lattisepic (two directions, plasma separations are very short), omnisepic (two directions, affects all matrix clays), and Insepic (domains of clay orientation occur as isolated patches). In addition to sepic-plasmic fabric, some of the paleosol horizons with very high silt percentages, reaching up to 15%, have a silasepic fabric (silt size grains floating in a matrix with a flecked extinction pattern).

6.1.1 Wartburg 1 – The matrix of the Wartburg 1 paleosol is dominated by masepic and bimasepic plasmic fabrics. Whereas bimasepic fabrics dominate the upper horizons, usually less than 50 cm below the coal (Fig. 7A, B, and C), masepic plasmic fabric is more prevalent at depth. However, in silt-rich horizons, or horizons with silty lenses, such as Wartburg 1 Units 4, and 5 (Table 1), the masepic fabric is disturbed and weakly developed (Fig. 7E). Lattisepic fabric is common only in silt-rich horizons deep in the paleosol, Unit 9 (Table 1). Silt-size grains are scattered throughout the clay matrix, comprising between <1% to 35% of the paleosol material. These grains are primarily

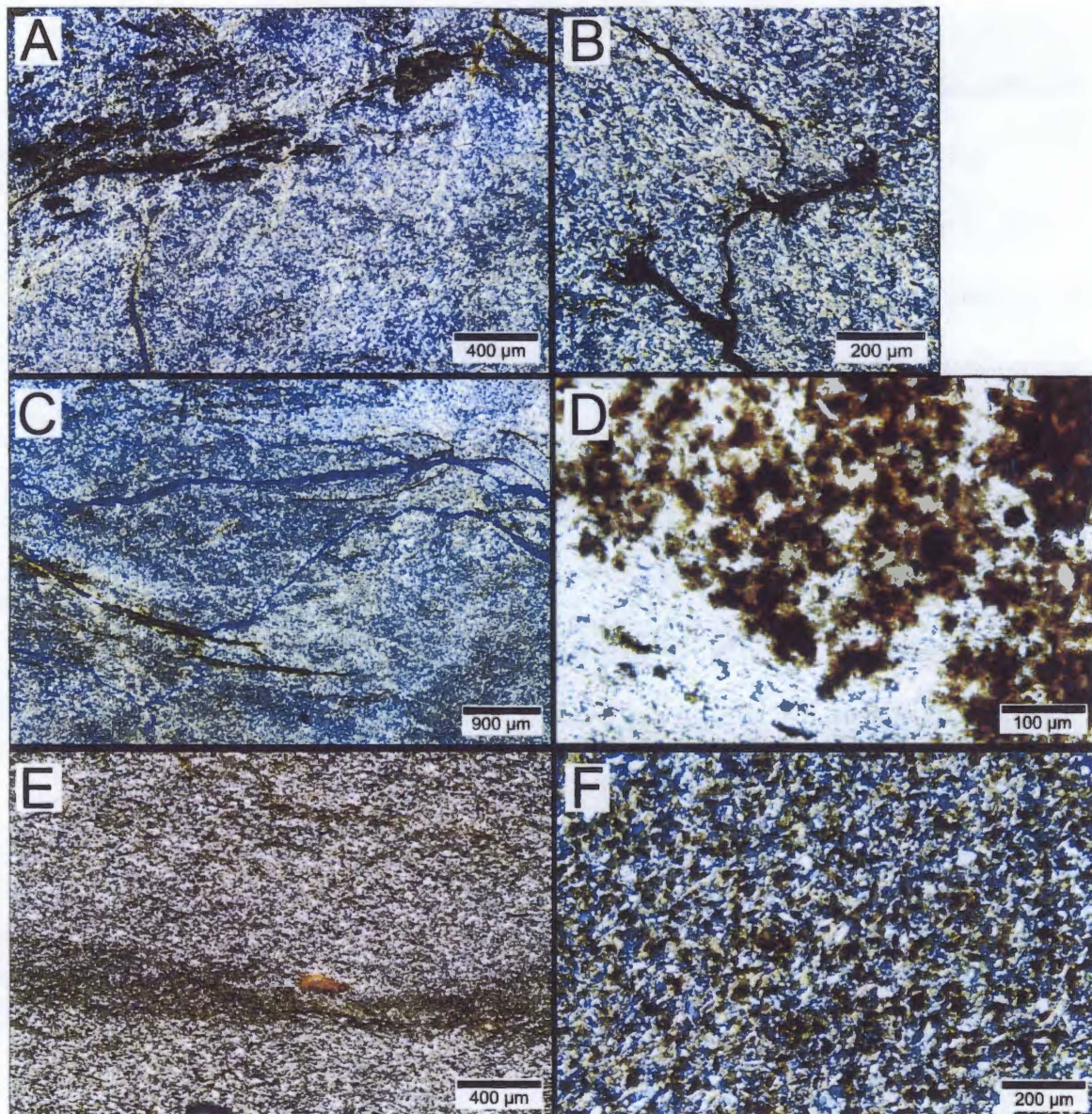


Figure 7: Micromorphology of the Wartburg 1 underclay paleosol. All photos under crossed polarized light, except for D. A) Organic-rich claystone, collected from 3 cm below the coal, with bimasepic plasmic fabric characterized by two preferred orientations of clays. B) Carbonized roots with preserved root hairs in a bimasepic plasmic fabric at 10 cm depth. C) Well developed bimasepic plasmic fabric in claystone at 30 cm depth below the coal. Thin layers of organic material are present. D) High magnification of a large siderite rhizocretion at 30 cm depth. The concretion is composed of numerous small blocky siderite crystals and nodules. E) Illuviated clay in a silty clay matrix 60 cm below the coal. F) Platy siderite crystals evenly distributed within the silty claystone at 280 cm below the coal.

angular to sub-angular, monocrystalline quartz grains although occasional grains of coarse phyllosilicates, including muscovite, chlorite, and illite, are present.

6.1.2 Wartburg 2 -- The matrix of the Wartburg 2 paleosol is dominated by omnisepic and bimasepic plasmic fabrics. Omnisepic fabric most commonly occurs in the uppermost paleosol horizons, at less than 115-37 cm below the coal (Fig. 8A). Omnisepic fabric is essentially an extreme development of bimasepic plasmic fabric in which the entire clay matrix is aligned within a preferred orientation pattern (Brewer, 1964). At greater depth, well-developed bimasepic and masepic plasmic fabrics are more common (Figs. 8B and 8C). Throughout most of the paleosol, silt content is less than 1%. Below 155-200 cm, however, silt and sand content increases to between 20% and 40% in the BC_{ssg} and C_g horizons, Units 10 and 11 (Table 2, Figs. 4B1 and B2).

As in the Wartburg 1 paleosol, the coarse fraction consists of angular to sub-angular monocrystalline quartz. The silt- and sand-size grains are not distributed throughout the paleosol and are present only in the BC and C horizons (Table 2). These horizons also contain coarse phyllosilicates, including chlorite, as well as some heavy minerals, including tourmaline.

6.1.3 Rockwood 1 -- The Rockwood 1 paleosol is dominated by bimasepic and masepic plasmic fabrics (Figs. 9B and E). In general, the degree of development of sepic-plasmic fabrics in this paleosol is less than that of the Wartburg 2 or even the Wartburg 1 paleosol. Other clay fabrics are also present within the Rockwood 1 paleosol, but to a

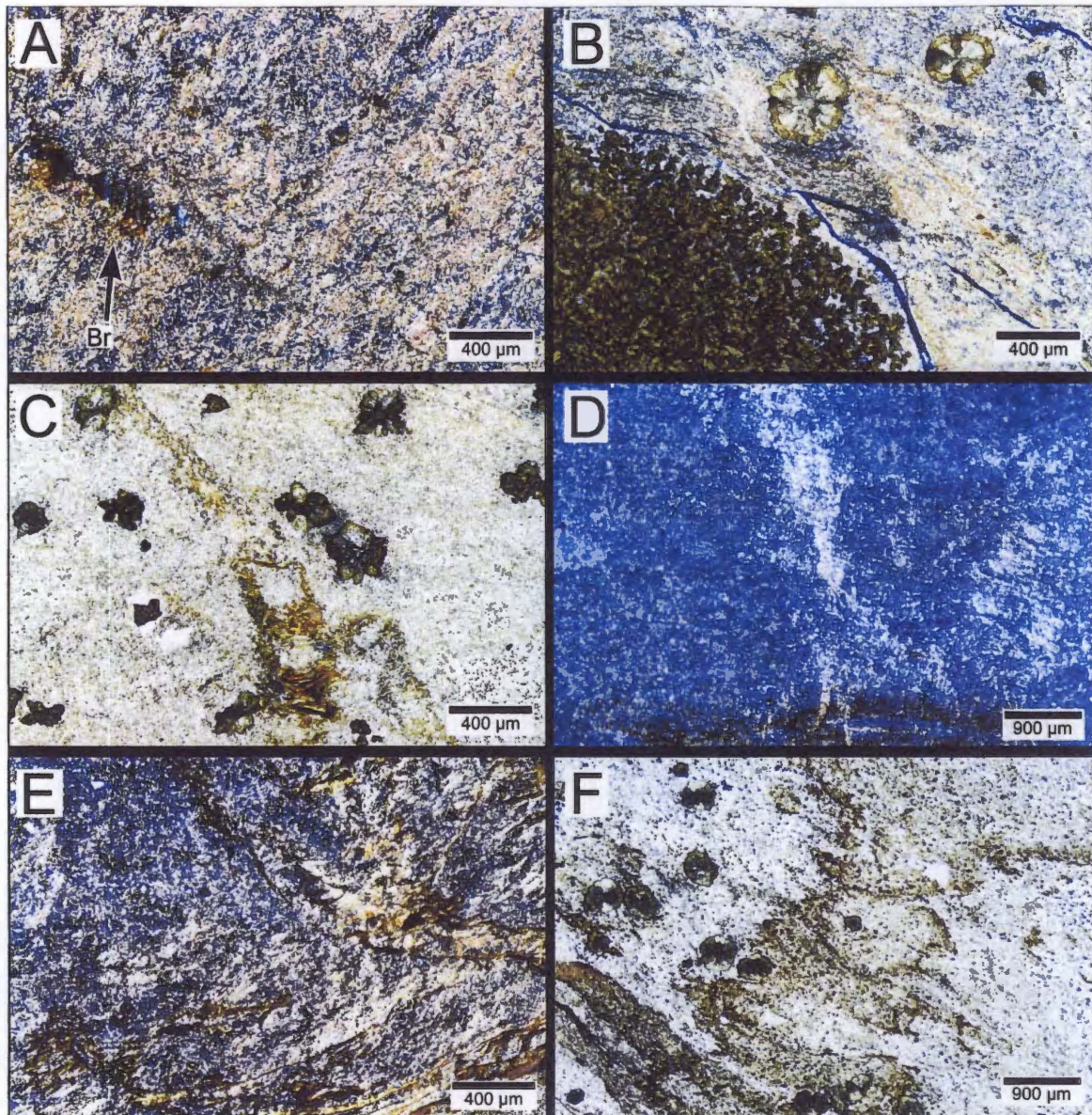
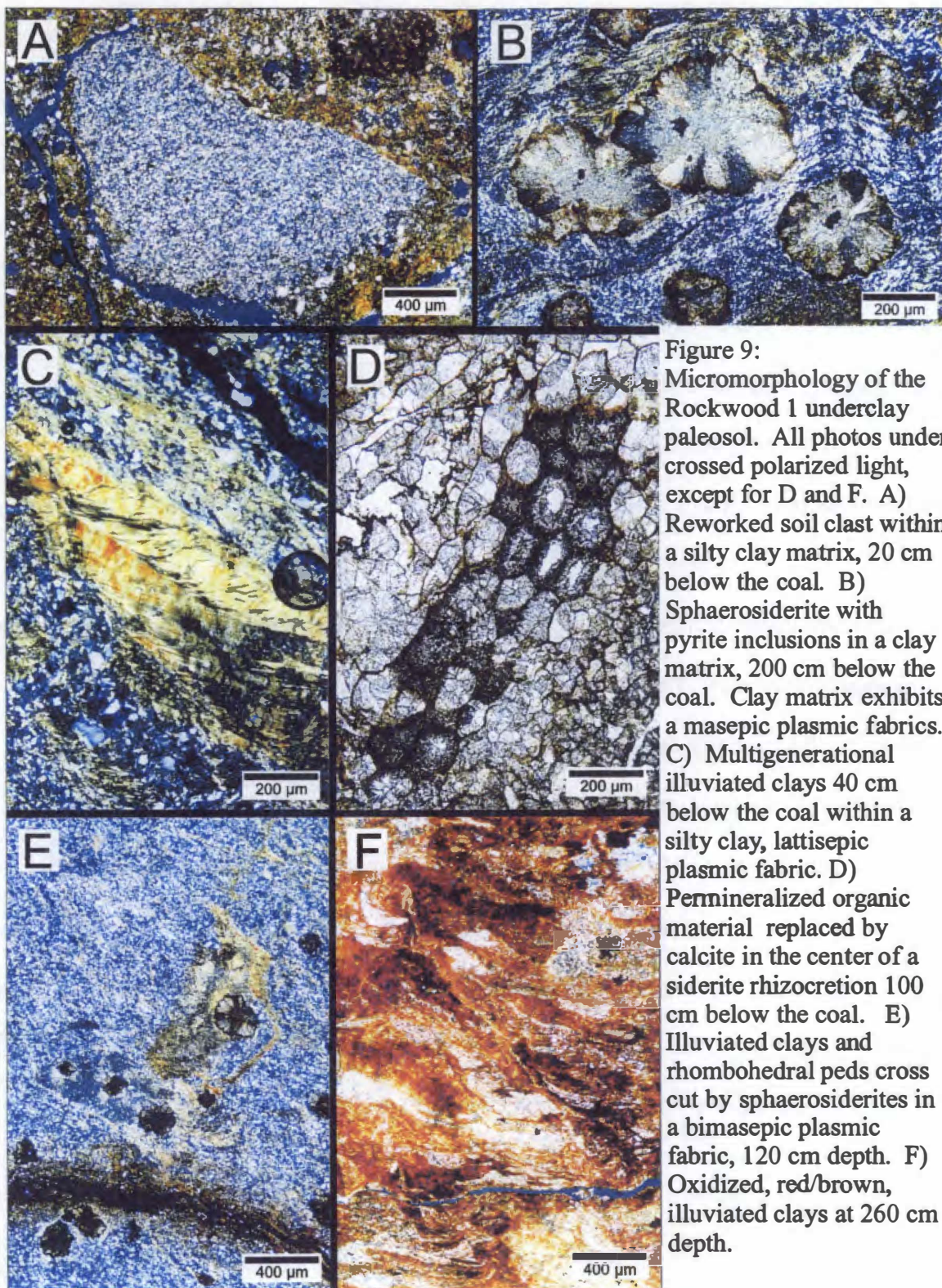


Figure 8: Micromorphology of the Wartburg 2 underclay paleosol. All photos under crossed polarized light except for C and F. A) Omniseptic plasmic fabric at a depth of 20 cm below the coal. Note the backfilled burrow on the left side of the photomicrograph (Br). B) Well-developed sphaerosiderites next to the tip of a large siderite rhizocretion in a well-developed masepic plasmic clay fabric 45 cm below the coal. Note the zonation within the larger sphaerosiderite nodules. C) Sphaerosiderites in a bimasepic plasmic fabric, 70 cm below the coal. Note the illuviated clay filled root channel running through the center of the photo. D) Vertically oriented birefringent clay filling a desiccation crack in the Wartburg 2 paleosol, 100 cm below the coal. E) Abundant, well preserved plant material and illuviated clays in a bimasepic plasmic fabric, 130 cm below the coal. F) Sphaerosiderites and pyrite nodules in an area of reticulate mottling, 180 cm below the coal.

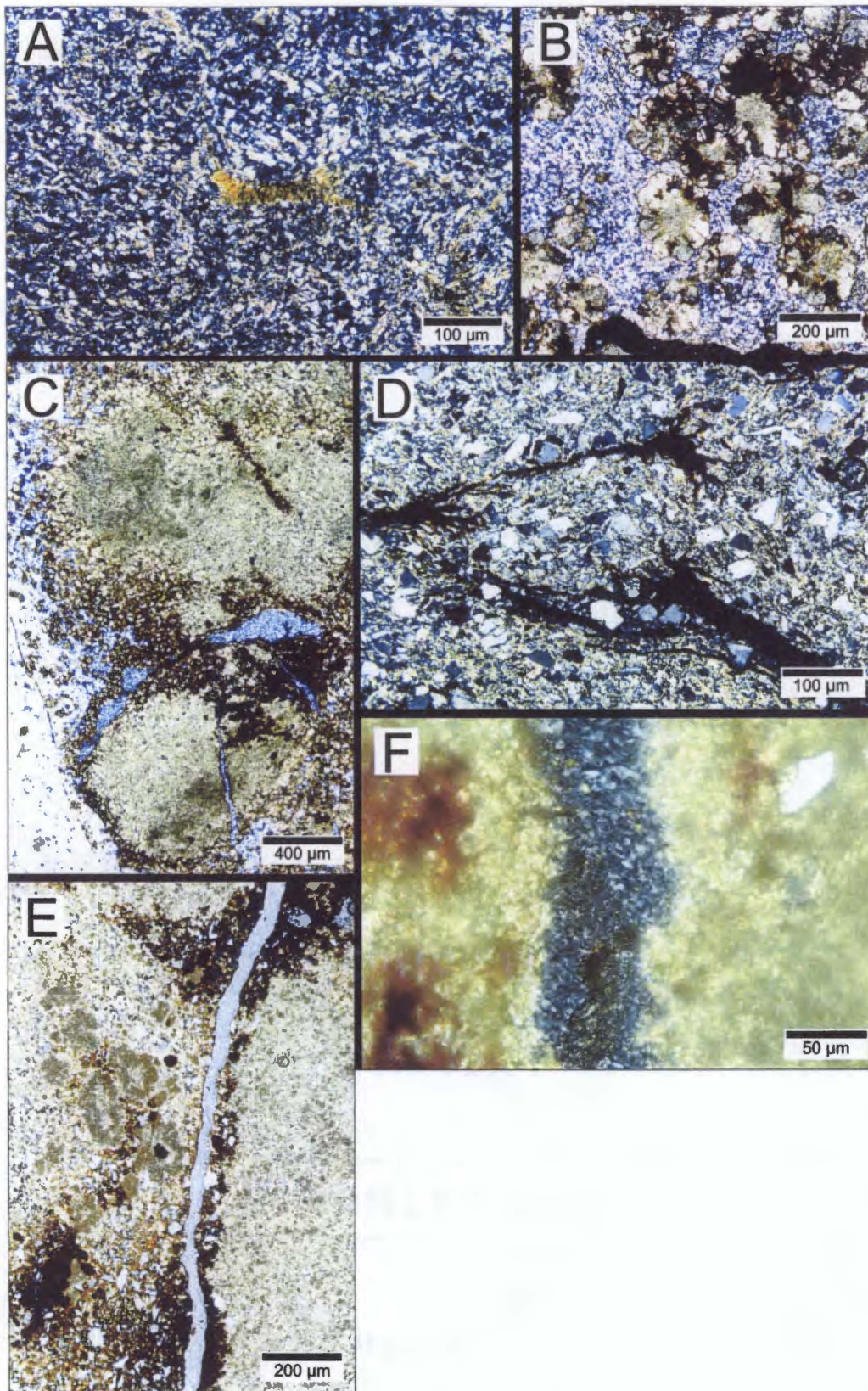


lesser degree. These include omnisepic, occurring only at the base of the Rockwood 1-1 measured section, lattisepic and insepic fabrics, present in silt-rich horizons within the upper third of the paleosol, and silasepic fabric, identified only in Unit 2, a B_{ss1} horizon with 15% quartz silt.

Quartz silt is very abundant in the Rockwood 1 paleosol, particularly in the micro-lows. It is exclusively composed of angular to subangular monocrystalline quartz and is fairly evenly distributed throughout the depth of the paleosol. Within micro-lows, quartz content ranges between 10% and 15% (Table 3); high silt contents are only attained within the upper 120 cm of the micro-high.

6.1.4 Ivydell 1 and Petros 9 -- Both the Ivydell 1 and Petros 9 paleosol cores have similar matrix characteristics. Very coarse clays are common, some as large as 10 μm in diameter. Additionally, Ivydell 1 and Petros 9 tend to contain large, coarse, monocrystalline quartz grains floating within the clay matrix. In general, silt content is low, but, can be up to 50% (Fig. 10D). Along with quartz grains, very rare, angular plagioclase grains are present. Dominant clay fabrics are bimasepic and masepic and tend to be moderately to well developed (Fig. 10B). Insepic plasmic fabric is present to a lesser degree (Fig. 10A). In some areas, the clay fabric has the clotted or mottled appearance common in heavily bioturbated soil (Fig. 10E).

Figure 10: Micromorphology of the Ivydell 1 (A, B, C) and the Petros 9 (D, E, F) paleosols. All photos are under crossed polarized light. Both the Ivydell and Petros cores contain paleosols which have a higher sand and silt content than their correlative paleosol at Wartburg 1. A) Illuviated clays in an insepic plasmic fabric. B) Sphaerosiderites in a masepic plasmic fabric. C) Kaolinite filling in the core of a siderite rhizocretion with blocky crystal morphology. D) Carbonized roots in a very sandy clay matrix. Note the preserved root hairs. E) Relict sphaerosiderites and large (20 μm) framboidal pyrites in a clay matrix. The matrix has a clotted or mottled appearance of heavily bioturbated/burrowed soil. F) Kaolinite in the core of a large siderite rhizocretion.



6.2 Pedological Features

6.2.1 Wartburg 1 -- Dense, dark gray, siderite rhizcretions ranging from 3-200 mm in diameter are common in morphological Units 3 through 9. Rhizcretions consist of homogeneous, dense, fine-grained siderite that becomes less dense at the rhizcretion margin (Fig. 7D). Individual siderite crystals have a blocky, euhedral morphology, are approximately 20 μm in diameter, and are non-interlocking. In Unit 9, a C_g horizon, individual, doubly terminated, scalenohedral siderite crystals are evenly distributed throughout the matrix (Fig. 7F). In addition to siderite, the Wartburg 1 paleosol contains framboidal pyrite in morphologic Unit 2.

The Wartburg 1 paleosol contains abundant organic material in the form of carbonized roots and macerated plant material. Finely macerated organic material is common throughout the paleosol, but is most abundant within the top 24 cm of the paleosol (Fig. 7A). Much of the organic material in Unit 1 appears to have been coalified, perhaps contemporaneously with the overlying coal. Well preserved, carbonized roots are abundant throughout the paleosol. Roots are generally several cm in length and are less than 1 mm in diameter (Fig. 7B and C). Many are remarkably well preserved, some having preserved root hairs (Fig. 7B).

Within morphologic Unit 4, there is a small amount of illuviated clay pore-fillings and reworked clay skins (Fig. 7E). These clay deposits are bright yellow and orange in color and have multigenerational banding.

6.2.2 Wartburg 2 -- The Wartburg 2 paleosol contains two different siderite morphologies, sphaerosiderite and euhedral siderite. Sphaerosiderite is the dominant siderite form (Fig. 8C and F). It is concentrated in discrete zones throughout the paleosol and is particularly abundant in morphologic Units 1, 2, 6, 7, 9 and 11. Sphaerosiderite nodules consist of a micritic core, sometimes containing framboidal pyrite, with bladed siderite, often zoned and radiating outward from the central core (Fig. 8C). Nodules are usually less than 100 μm in diameter but can be as large as 200 μm . The Wartburg 2 paleosol also contains some large siderite rhizocretions consisting of fine, blocky, euhedral crystals (Fig. 8B). Unlike Wartburg 1, however, they are not common and only occur in Unit 6. Framboidal pyrite is more abundant in the Wartburg 2 paleosol than the Wartburg 1 and it, or iron-oxide pseudomorphs after pyrite, can be found in Units 1, 7, 9, and 11.

Organic matter, within the Wartburg 2 paleosol, is concentrated between 95-160 cm below the coal. It is present as macerated, carbonized plant material as well as in well-preserved roots (Fig. 8E). Throughout the rest of the paleosol, small, carbonized roots are present, but few are more than a few cm in length and, with the exception of the large siderite rhizocretions, are seldom larger than 1 mm in diameter.

Although preserved root material is not as abundant as in the Wartburg 1 paleosol, there is an abundance of illuviated clay-filled root traces (Fig. 8C). Illuviated clay is also present as reworked clay skins and pore-fillings (Fig 8E). Additionally, in Wartburg 2, measured section 1, at a depth of 100-115 cm, there are vertically oriented birefringent

clays filling desiccation cracks. At a depth of 180 cm, the birefringent clay fabric shows evidence of reticulate mottling.

6.2.3 Rockwood 1 -- Like the Wartburg 2 paleosol, sphaerosiderite is the dominant siderite morphology. Sphaerosiderites, some with framboidal pyrite cores and some without, are present in morphologic Units 5, 6, 7, 8, 9, 10, and 11 (Fig. 9B and E). In many cases, particularly in Unit 7, they are quite large, up to 400 μm in diameter. Large siderite rhizocretions, approximately 1 cm in diameter, are also present in the Rockwood paleosol, but are not common. They occur in Units 5, 6, 8, 9, and 10. As in the Wartburg paleosols, these rhizocretions consist of small, blocky, euhedral siderite crystals. Some, however, contain calcite cores with large, up to 100 μm , interlocking crystals and permineralized organic matter (Fig. 9D). In addition to the mineral nodules, reworked soil clasts, or pedorelicts, are present in the top 20-30 cm of the paleosol (Fig. 9A).

Illuviated clay-pore fillings and reworked clay skins are pervasive throughout most of the paleosol, occurring in all of the morphologic units except Units 1 and 11. In nearly all cases, illuviated clays are multigenerational, showing color banding (Fig. 9C). Clays are commonly cross-cut by sphaerosiderite nodules and seem to drape around rhombohedral peds (Fig. 9E). Some of the paleosol horizons, such as the B_{sst2} horizon, designated Unit 12, consist of over 50% illuviated clays. Additionally, the illuviated clays in Unit 12, as well as some of the clay matrix, are red-brown in color rather than gray-green or yellow (Fig. 9F).

Organic material is present throughout the paleosol. It is primarily in the form of small, carbonized roots, charcoal, and coalified organic material. The charcoal and coal occur in the upper 15 cm of the paleosol. This zone, the AE, B_{ss} and B_{sst} horizons, morphologic Units 1 and 2, contain the highest concentration of organic material, up to 10%. Deeper in the paleosol, the organic material is less abundant and is primarily composed of small carbonized roots and macerated plant material.

6.2.4 Ivydell 1 and Petros 9 -- The Ivydell 1 and Petros 9 paleosols have similar pedological features to the Wartburg 1 and Wartburg 2 paleosols. These include reworked illuviated clay skins (Fig. 10A), sphaerosiderite nodules with micritic cores (Fig. 10B), large siderite rhizcretions composed of fine, blocky, euhedral crystals (Fig. 10C), well preserved, carbonized roots with preserved root hairs (Fig. 10D), and framboidal pyrite (Fig. 10E). There are, however, some striking differences that separate the Ivydell and Petros paleosols from the others. These differences are primarily in the realm of secondary mineral precipitation and dissolution. Many of the large rhizcretions, rather than consisting exclusively of siderite like the Wartburg paleosols, or containing primary calcite cores, like the Rockwood paleosol, have kaolinite filling voids in their cores (Fig. 10C and F). Other differences are in the morphology of the pyrite nodules. In the Wartburg and Rockwood paleosols, the framboidal pyrite nodules were rarely more than a few μm s in diameter. In the Petros 9 paleosol, they are as large as 20 μm in diameter (Fig. 10E). Additionally, some of the sphaerosiderites have been

partially or completely dissolved, leaving a spheroidal, iron-rich residue in their place (Fig. 10E).

7.0 MINERALOGY AND GEOCHEMISTRY

7.1 Mineralogy

In all three of the outcrop paleosols, the clay matrix is primarily composed of kaolinite and illite with reduced amounts of chlorite, illite/smectite (I/S) and hydroxyl interlayer vermiculite (HIV). There is considerable variation in the clay composition between the fine clay fraction ($< 0.7 \mu\text{m}$) and the coarse clay fraction ($0.7\text{-}2.0 \mu\text{m}$). Within the coarse fraction of all three outcrop paleosols, XRD analysis does not indicate the presence of I/S (Wartburg 1), or is present only in very small amounts (Wartburg 2 and Rockwood 1). Clay composition also varies with depth. Samples taken from near the top of the Wartburg 1 paleosol (10-60 cm below the coal) contain abundant kaolinite and illite with small amounts of chlorite (Fig. 11A). The top of the Wartburg 2 and Rockwood 1 paleosols contain HIV in addition to kaolinite, illite, and chlorite. At depth, HIV is absent in all of the paleosols and, with the exception of the Wartburg 1 paleosol, the other paleosols contain little or no chlorite at depth (150-240 cm below coal) (Table 4, Fig. 12B).

Three varieties of nodules are present within the paleosols; large siderite rhizocretions, sphaerosiderite nodules, and framboidal pyrite nodules. The siderite rhizocretions are 99% fine, blocky, euhedral siderite, with the remaining 1% consisting calcite spar within the core of the nodules. In some areas (Wartburg 1, Unit 9) large siderite nodules are conjoined to form a hard layer. Small sphaerosiderite nodules, less than $200 \mu\text{m}$ in diameter, are common throughout all of the paleosols, with the exception of Wartburg 1. Some of the sphaerosiderite nodules contain framboidal pyrite cores.

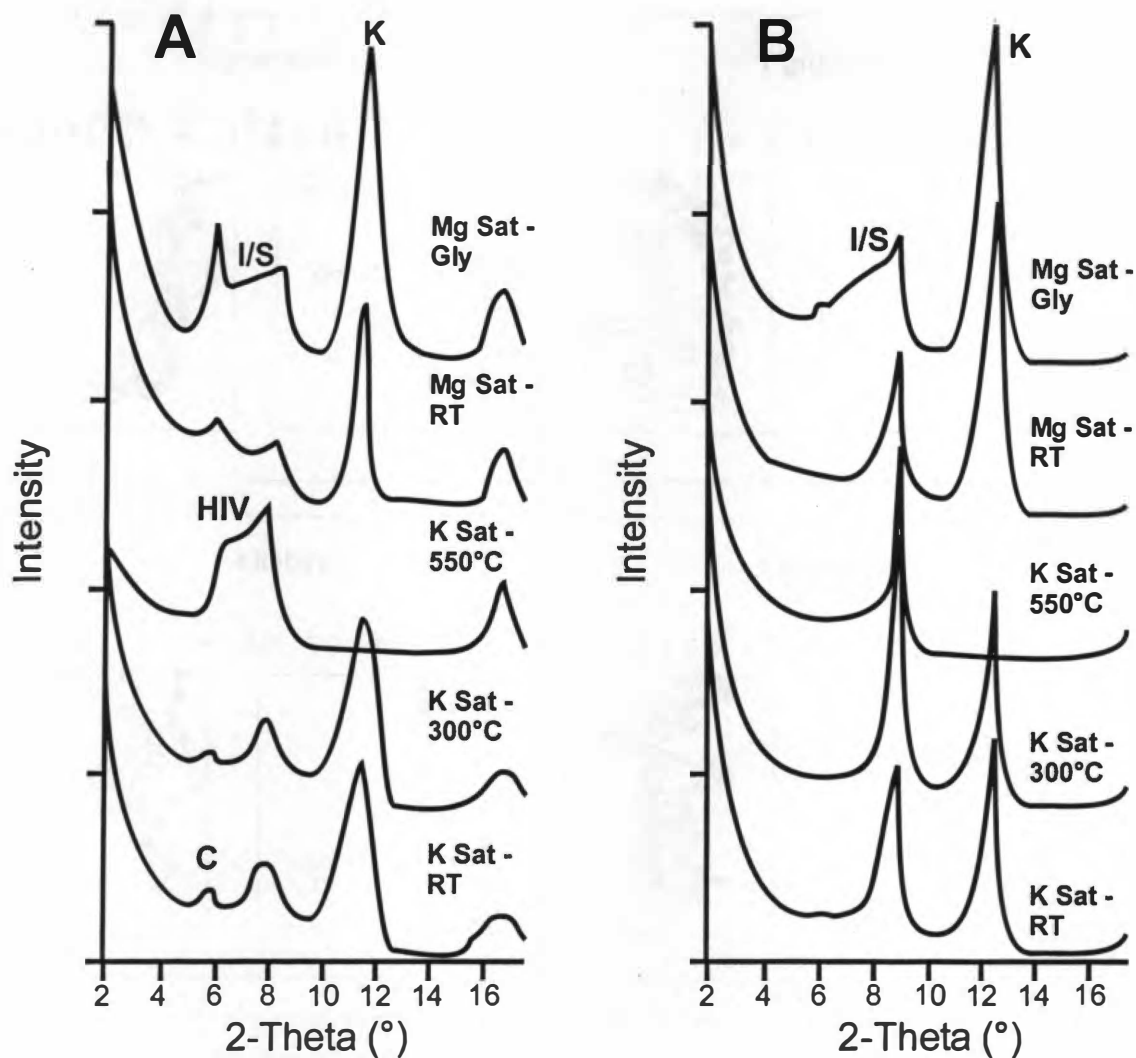


Figure 11: Smoothed X-ray diffraction patterns of the fine fraction ($< 0.7 \mu\text{m}$) of the Wartburg 2 underclay. A) Shallow depth (10-50 cm below the coal). B) Deep depth (150-190cm below the coal). Key: I = illite, S = smectite, C = chlorite, K = kaolinite, HIV = hydroxy-interlayer vermiculite.

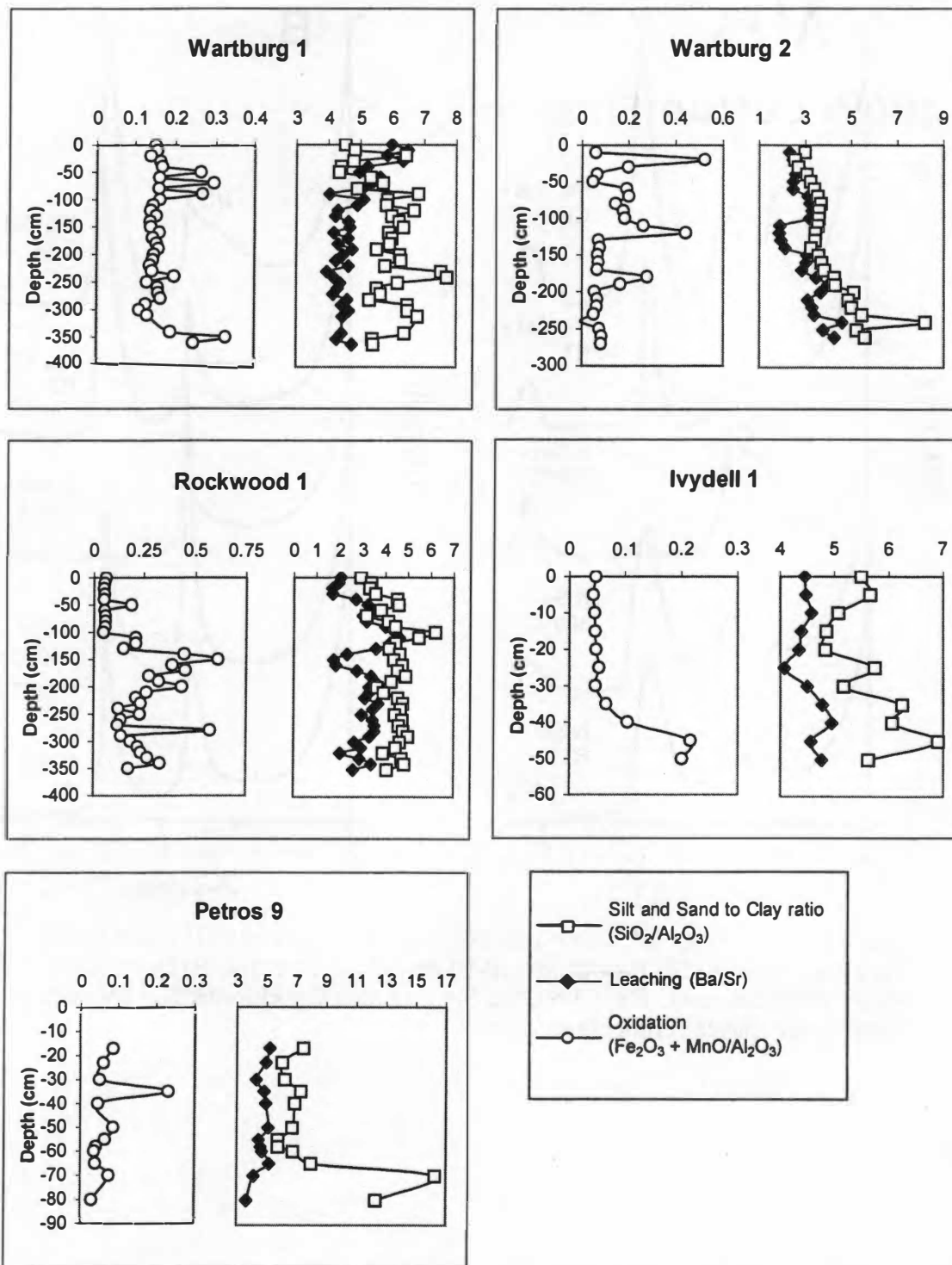


Figure 12: Whole-rock XRF data, expressed as molecular ratios (see Retallack 2001), for paleosols in outcrop and drill core.

Table 4: Clay-mineral species distribution within the three paleosols sampled in outcrop. Key: + = abundant, - = low abundance, 0 = not present, HIV = Hydroxy Interlayer Vermiculite, I/S = Illite/Smectite.

Paleosol	Wartburg 1		Wartburg 2		Rockwood 1	
Size Fraction	Coarse (0.7-2.0 μ m)	Fine (< 0.7 μ m)	Coarse (0.7-2.0 μ m)	Fine (< 0.7 μ m)	Coarse (0.7-2.0 μ m)	Fine (< 0.7 μ m)
Clay Species	Samples taken near the top of the paleosol					
Kaolinite	+	+	+	+	+	+
Illite	+	+	+	+	+	+
Chlorite	+	+	+	+	+	+
HIV	0	0	+	+	+	+
I/S	0	-	0	+	0	+
Clay Species	Samples taken near the bottom of the paleosol					
Kaolinite	+	+	+	+	+	+
Illite	+	+	+	+	+	+
Chlorite	+	+	0	0	-	0
HIV	0	0	0	0	0	0
I/S	0	+	-	+	-	+

Framboidal pyrite nodules are less common in the paleosols. They are small (< 20 μ m) and are often associated with sphaerosiderite nodules, having been engulfed by them.

7.2 Geochemistry

Whole-rock geochemical analysis was performed at 10 cm intervals at each paleosol outcrop and in each paleosol core. Molecular ratios represent common weathering reactions in soils and paleosols and can be used to qualitatively assess the degree to which these reactions have taken place (Retallack, 2001). Molecular ratio calculations based on common pedogenic reactions (see Retallack, 2001) show an overall lack of oxidation within these paleosols (Fig. 12). Oxidation ratios, in most cases, range

between 0.05-0.15 with the exception of the Wartburg 2 and Rockwood 1 paleosols. These paleosols have unusually high oxidation ratios, up to 0.5 in Wartburg 2 and 0.6 in Rockwood 1. There does not appear to be any relationship between oxidation ratio and depth within the Wartburg 1 paleosol, although high oxidation values correspond roughly to horizons with high siderite and pyrite concentrations. In contrast, the Rockwood 1 paleosol has a major inflection in the oxidation ratio at 150 cm depth (Fig. 12). Above 150 cm, the oxidation ratio is low, approximately 0.5. At depths greater than 150 cm, the ratio ranges between 0.25 and 0.5. Ba/Sr ratios in the paleosols suggest relatively extensive leaching, having values < 5 and < 4 in some paleosols. Wartburg 2, Rockwood 1 and Ivydell 1 are increasingly leached at shallow depths. In the Wartburg 1 and Rockwood 1 paleosols, as well as the Petros 9, clay content remains relatively constant with depth. High silt and sand to clay ratios below 70 cm depth in the Petros 9 were obtained from the parent material. The Wartburg 2 and Ivyell 1 paleosols have a marked increase in silt and sand content with depth (Fig. 12).

Mass-balance calculations of elements predominantly controlled by detrital influx show an overall loss of SiO_2 and Zr within the Wartburg 2 paleosol. A major inflection occurs between 100 and 200 cm below the silty smut in both of the Wartburg 2 measured sections. Below that depth, there is little or no apparent loss or gain of elements predominantly controlled by detrital influx, after the inflection, up to 50% of quartz and 25% of zircon are lost (Fig. 13). Similar transport calculations of alkali and alkaline earth metals indicate removal of these elements in each of the paleosols, particularly in the Rockwood 1 paleosol (Fig. 14). Ba and Na appear to be more resistant to transport

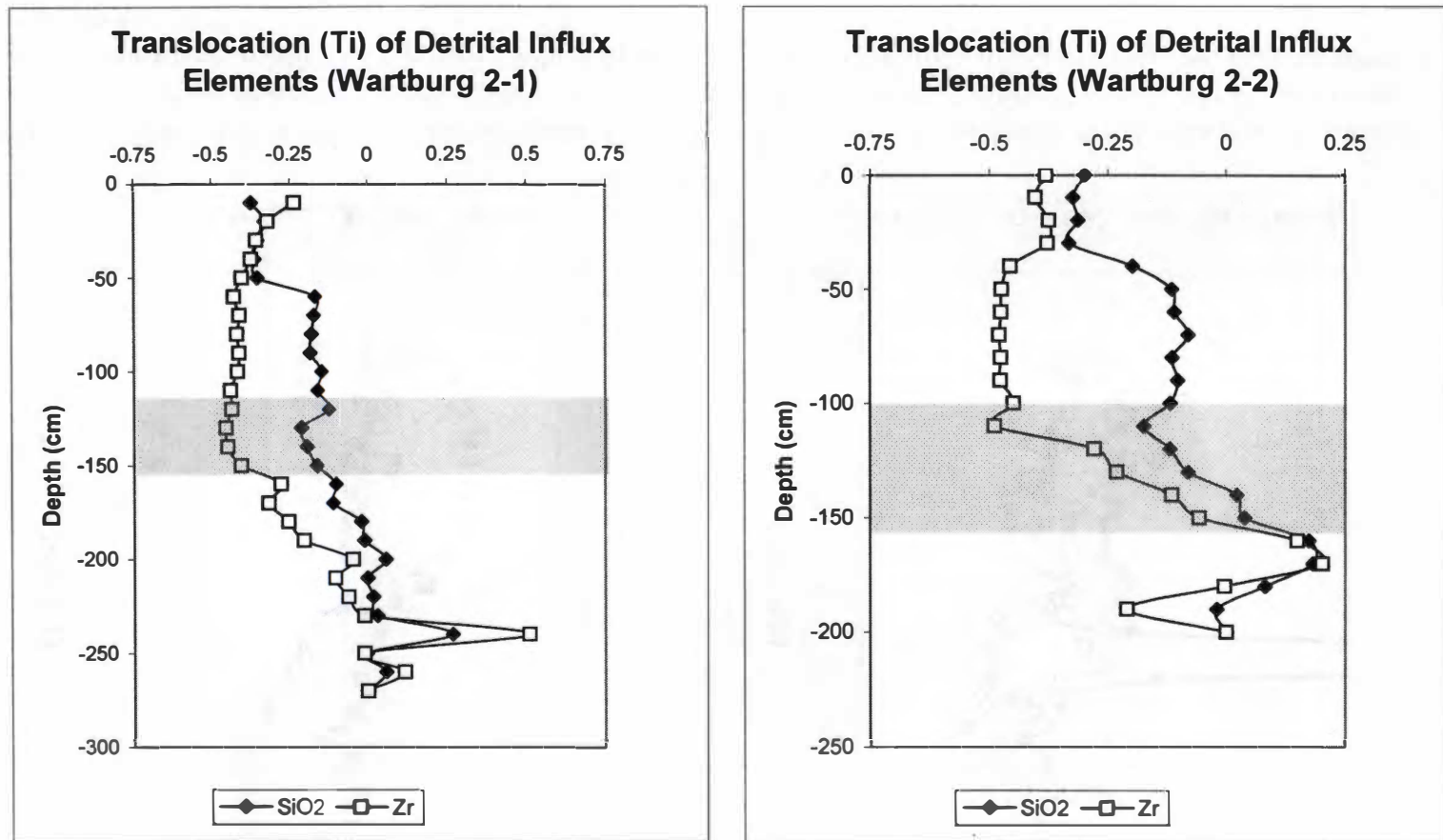


Figure 13: Transport functions (τ ; translocation) for detrital influx elements in the Wartburg 2 paleosol, assuming Ti is the immobile element. Negative values represent net loss of constituent relative to parent material with -1 equivalent to 100% loss; positive values represent net gain of constituent relative to parent material with +1 equivalent to 100%. The shaded area represents morphologic Unit 8. A) Wartburg 2 paleosol, measured section 1. B) Wartburg 2 paleosol, measured section 2.

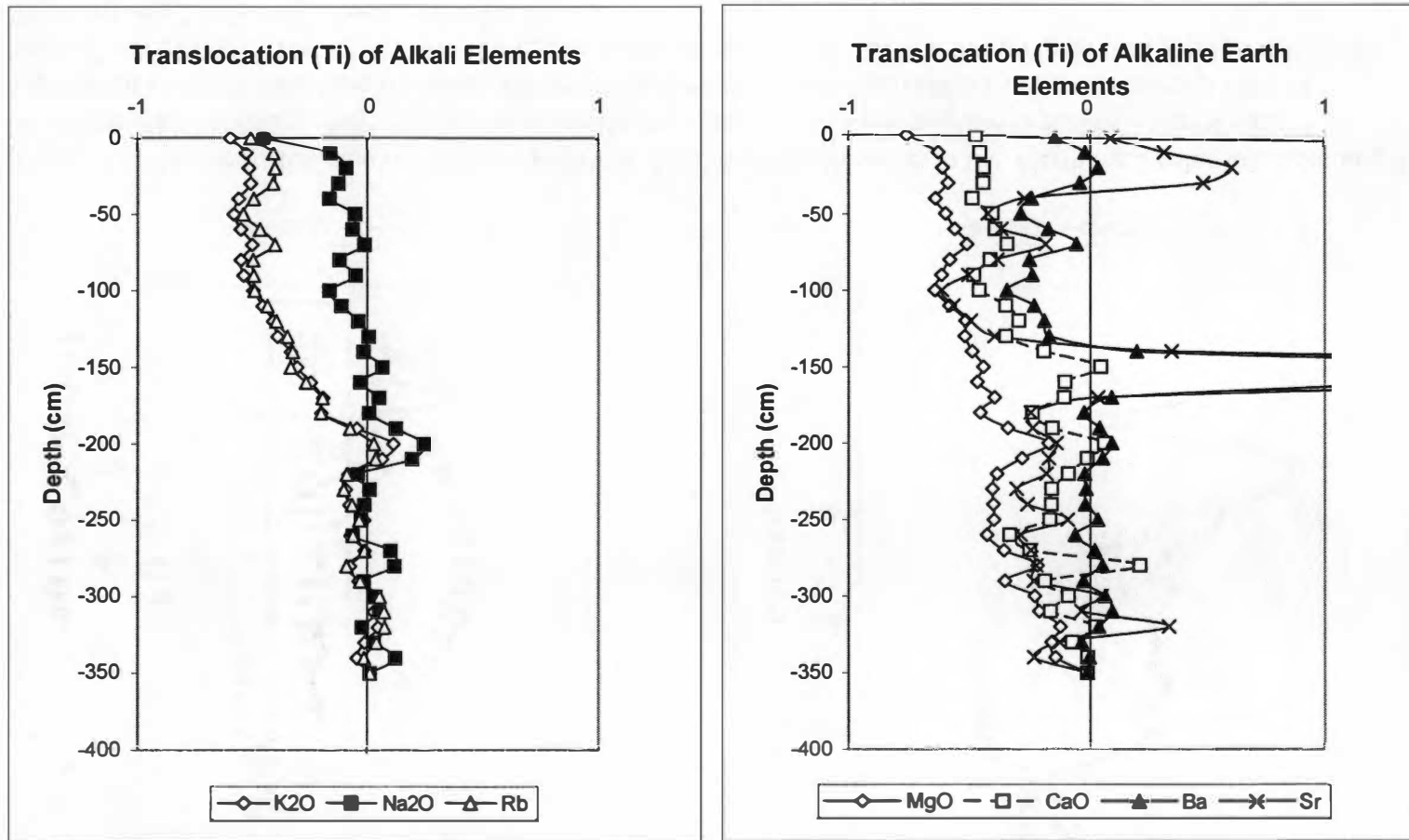


Figure 14: Transport functions (τ ; translocation) for alkali and alkaline earth elements in the Rockwood 1 paleosol, assuming Ti is the immobile element. Negative values represent net loss of constituent relative to parent material with -1 equivalent to 100% loss; positive values represent net gain of constituent relative to parent material with +1 equivalent to 100%.

than the other alkali and alkaline earths. These elements, Na in particular, are easily transported and the apparent resistance to transport within these paleosols remains unexplained.

Fe_2O_3 and Al_2O_3 concentrations vary with depth in each of the outcrop paleosols as shown in Figure 15, but lack consistency among paleosols. Al_2O_3 tends to increase in concentration as depth decreases in the Wartburg 1, Wartburg 2 and Rockwood 1 paleosols. The Fe_2O_3 concentration, however, does not follow the same pattern. Iron concentration in the Wartburg 1 paleosol is relatively constant throughout. Wartburg 2 iron concentration increases overall as depth decreases and has three exceptionally high concentrations at 20 cm, 120 cm, and 180 cm depth. The Rockwood 1 paleosol has high iron concentrations below 150 cm depth and relatively low concentrations above -150 cm.

As will be discussed in detail later, the chemical index of alteration without potash (CIA-K) can be used as a proxy for paleo-mean-annual-precipitation (MAP). CIA-K is a measure of the degree of weathering within a soil, or paleosol, profile (Nesbitt and Young, 1982). CIA-K values in each of the paleosols have a generally increasing trend with depth and range between 85-95.5% (Fig. 16).

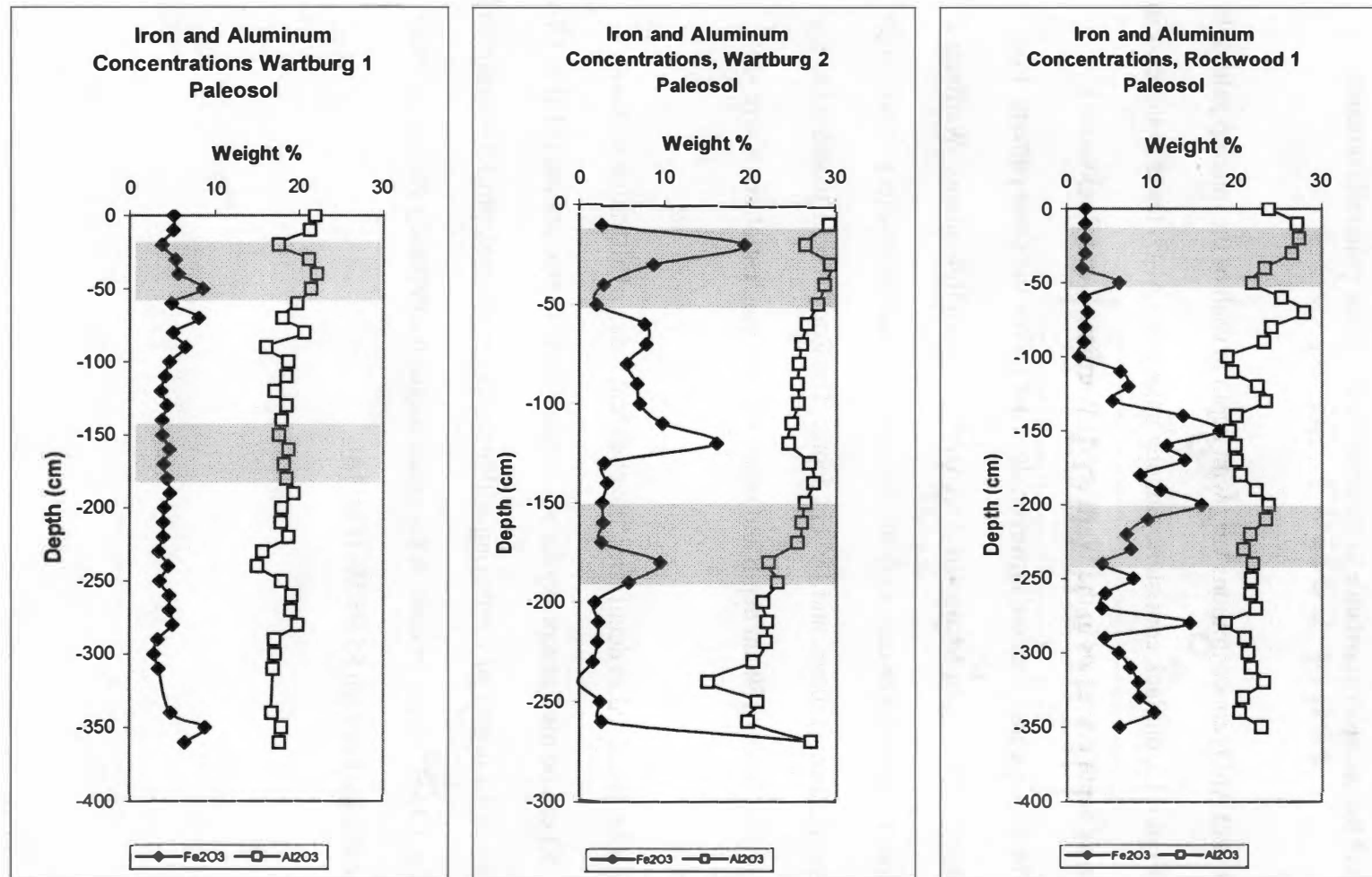


Figure 15: Iron and Aluminum oxide concentration in the three paleosols that were studied in outcrop. Shaded areas indicate the zones from which samples were taken for clay mineral analysis.

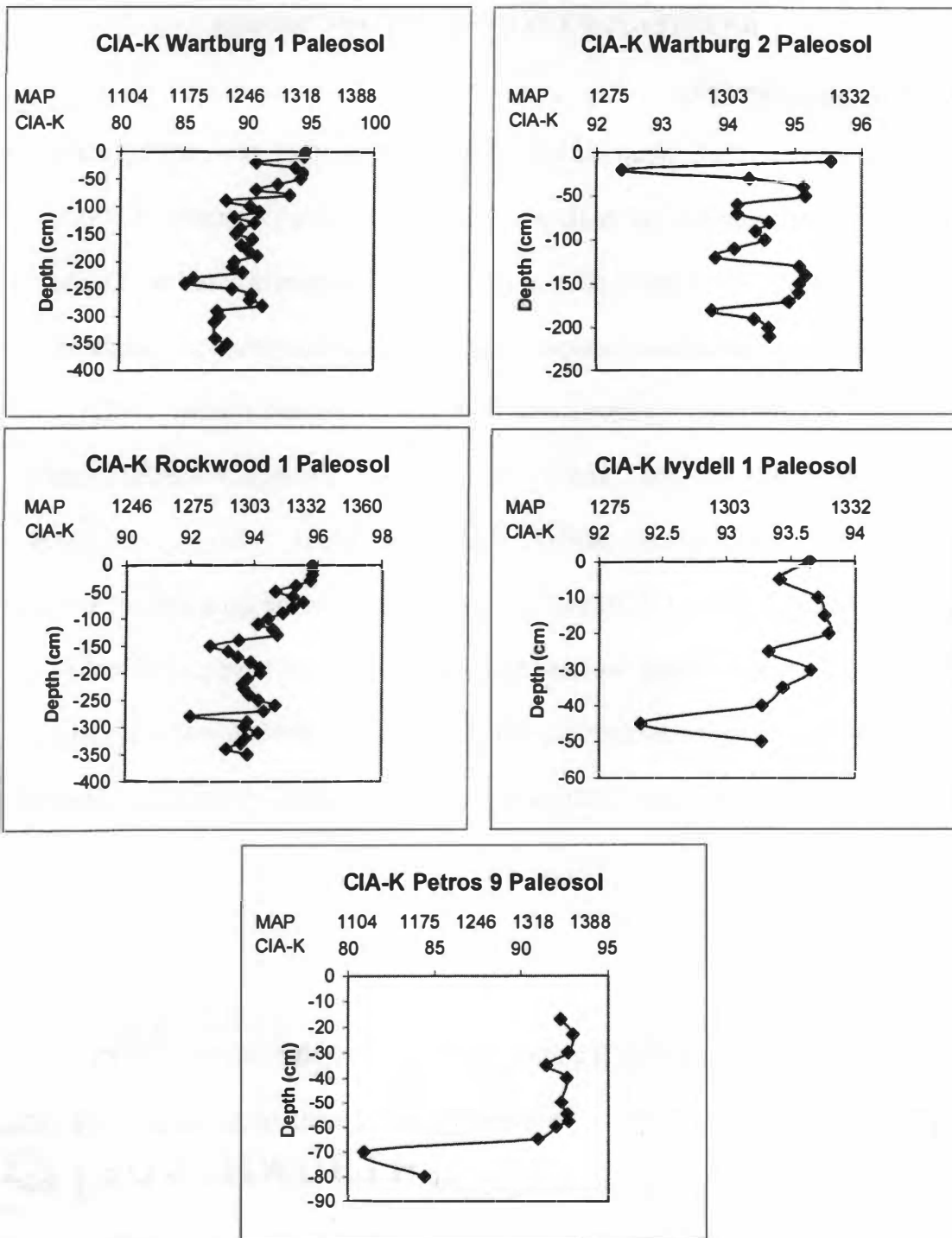


Figure 16: Geochemical calculations of CIA-K (chemical index of alteration without potash) with depth in each of the paleosols. Mean annual precipitation (MAP) values obtained from these calculations are approximately 1300 mm/yr.

8.0 INTERPRETATIONS AND DISCUSSION

8.1 Local Paleogeography

The Crooked Fork Group is a siliciclastic sequence that represents deposition within deltaic and intertidal and shallow subtidal environments (Schnoebelen, 1983; Milici et al., 1979). This interpretation of the paleoenvironment is based on: 1) other workers paleoenvironment interpretations, cited above; 2) superjacent and subjacent strata within the study area; 3) known coal-forming environments (Diessel, 1992; Bhattachayra and Walker, 1992), and; 4) the tendency for Vertisols to form in areas of very low relief (Coulombe et al., 1996a,b; Wilding and Tessier, 1988). It is suggested here that the Wartburg 1 and Wartburg 2 paleosols formed on the delta plain of a river-dominated delta system. Small rises and falls in sea-level could have produced the lithologic succession shown by the units immediately above and below the paleosols, thereby flooding them, creating a coal swamp, and introducing a reducing geochemical environment.

8.2 Underclays

The genesis of underclays is a topic of debate and until recently, few researchers accepted a pedogenic model. There are many different definitions for underclays, some are descriptive, such as, “an argillaceous, gray, non-bedded stratum found directly under a coal” (Brownwell, p. 138, 1978), whereas others are genetic, such as, “a layer of clay lying immediately beneath a coal bed. It represents the old soil in which the plants grew from which the coal was formed, and it commonly contains fossil roots” (Bates and

Jackson, 1984). Although the second definition recognizes underclays as paleosols, it does not adequately address the problem of underclay genesis.

There are numerous models of underclay development. Most models can be divided into two classes, allochthonous and autochthonous. The first group of models, allochthonous models, suggests that underclay properties, particularly mineralogy, are inherited from either the lithologic characteristics of the parent material or more frequently from climatic change in the source area (Grim and Allen, 1938; Schultz, 1958). The second group of models is more generally accepted. Autochthonous models suggest that underclay properties are acquired at the site of deposition, either during or after sedimentation. Most researchers who recognize underclays as paleosols propose autochthonous models (Gardner et al., 1988).

Autochthonous models can be sub-divided into three broad categories. The first suggests that physical and chemical differences in regional water chemistry, such as variations in water salinity or alkalinity, are controls on illitization and alteration of illite to chlorite, or the differential flocculation of kaolinite and illite, and thus account for variations in clay content in underclays (Williams et al., 1968). Other models suggest a pedogenic origin for underclays.

A second group suggests that underclay development occurs after peat accumulation wherein soil conditions are so acidic that intense, organic-acid leaching occurs in the underlying rock or sediment (Staub and Cohen, 1978). Other similar models propose that pedogenesis occurs nearly synchronously with peat accumulation. Changes in the rate of bacterial decomposition of organic material results in small

changes in water pH and leaching, thus influencing either peat accumulation or underclay development (Smith and O'Brien, 1965; Moore, 1968). These models assume the pedogenic environment to be acidic and reducing, based on the abundance of organic matter.

A third group of models suggests that underclay development occurred above a paleowater table after peat accumulation in a poorly to well-drained, oxidizing soil environment (Weller, 1930; Percival, 1986). A variation on this model suggests that underclay paleosols were initially well drained, above a paleowater table and, as sea-level rose, resulting from either climate change or tectonism within the basin, the water table rose, saturating the paleosol, allowing peat accumulation. But, even though the paleosol was initially well drained, most of the paleosol characteristics and mineralogy are the result of pedogenic processes after the formation of a coal swamp (Gardner et al., 1988).

8.3 PaleoVertisols and PaleoAlfisols

In the previous sections, the need to demonstrate that Lower Pennsylvanian underclays on the Cumberland Plateau were paleosols was addressed.

8.3.1 Soil Definition -- Soil can be defined in many different ways. Merriam-Webster's Collegiate Dictionary (2000) alone contains five definitions pertaining to the traditional definition of soil; soil is the natural medium for the growth of land plants (Soil Survey Staff, 1998). By this definition, it is hard to dispute that underclays were once soils. They contain fossilized plant material including roots. For the sake of completeness,

however, a more rigorous definition is needed. The USDA, Soil Survey Staff (1998) defines soils as, “a natural body comprised of ... minerals and organic matter, liquid, and gases that occurs on the land surface, occupies space, and is characterized by ... horizons, or layers, ... distinguishable from the initial material ... or the ability to support rooted plants in a natural environment.” It is possible to go a step further and define individual soil types.

The underclays studied for this project appear to have characteristics found in two common types of soil, Vertisols and Alfisols. Vertisols are soils that typically form in areas of low relief, have a high clay content ($> 23\%$), and in an environment with seasonal variability in precipitation or seasonal soil-moisture deficits (Coulombe et al., 1996a,b; Wilding and Tessier, 1988; Soil Survey Staff, 1998). They contain abundant pedogenic slickensides, sepic-plasmic clay fabric, and are thicker than 50 cm (Mora and Driese, 1999; Soil Survey Staff, 1998). Many Alfisols contain vertic features, such as slickensides and sepic-plasmic fabric (Soil Survey Staff, 1998). These features, however, are accessory. Alfisols are base-rich, forested soils with an ochric epipedon or A horizon (light-colored surface horizon) overlying clay rich subsurface horizons (B_t) with abundant translocated (illuviated) clays rich in exchangeable base cations (Soil Survey Staff, 1998; Retallack, 2001). This study, of course, is concerned with sedimentary rocks that are over 300 million years old, not modern soils. Fortunately, when a soil is buried, many of the pedologic features developed before burial are preserved (Retallack, 2001; Caudill et al., 1996; Driese and Mora, 1993).

8.3.2 Underclays as Paleosols -- Underclays can be interpreted as paleosols if they meet two criteria; 1) they exhibit pedogenic structures such as pedogenic slickensides, gilgai micro-topography, structural aggregates called peds, and soil micro-textures such as sepic-plasmic fabric, 2) they contain fossilized organic material and show evidence of rooting. Based on the simplest definition of a soil, the second criterion would be sufficient to classify underclays as paleosols. The first criterion, however, is necessary to show that these underclays initially developed as either paleoVertisols or vertic paleoAlfisols.

Both the traditional definition for a soil and the definition adopted by the Soil Survey Staff (1998) place emphasis on plant colonization as a criterion for soil classification. Evidence for plant colonization of all of the lower Pennsylvanian underclays in this study is abundant and is found in three forms; macerated organic material, branching carbonized roots, and large iron-carbonate rhizocretions. Organic material is abundant in all of the paleosols, both in outcrop and in core and is present as macerated organic material, charcoal, and carbonized roots. With the exception of the Wartburg 2-1 measured section, there is an abundance of organic matter at the top surface of the paleosols (Fig. 4, Fig. 7A). Additionally, the Wartburg 2 paleosol has a second concentration of organic material between 95 cm and 165 cm (Table 2, Fig. 9E). Shrink-swell processes and pedoturbation in Vertisols tend to break decomposing organic material into small fragments (Wilding and Tessier, 1988; Coulombe et al., 1996a, b). The presence of macerated organic material, is therefore a potential indicator of vertic properties. In addition to fragments of organic material, the Crooked Fork Group

underclays also contain abundant branching roots (Figs. 7B and C, Fig. 10D). Retallack (1988) has pointed out that even when no other pedologic evidence exists, the presence of roots indicates that the rock unit was once subaerally exposed and subject to soil-forming processes.

Additional evidence of plant colonization comes in the form of iron-carbonate, or siderite rhizcretions. In Vertisols, it is common for decaying plant roots to become replaced by micritic calcite (Driese and Mora, 1993; Caudill et al., 1996). Rhizcretions typically consist of a series of short segments, stacked to form downward branching root casts. They are composed of dense, micritic carbonate and may contain central tubules of sparry calcite or clay (Klappa, 1980). Some carbonate rhizcretions contain permineralized plant material, preserving the original cell structure of the root. The Crooked Fork Group underclays all contain at least some rhizcretions (Figs. 5B and D). They are, however, not calcite or dolomite, as is most common, but siderite. The siderite rhizcretions range in size from 0.5 to 5 mm in diameter and have a dense, microsparitic to micritic composition. No tubules have been observed in the rhizcretions, but some do contain permineralized plant material. Siderite rhizcretions are coarser in texture than their more typical calcite counterparts. This may be due to recrystallization and replacement of calcite by siderite, as evidenced by calcite-replaced organic material in the core of some of the rhizcretions (Fig. 9D).

Soils that develop in environments in which precipitation is seasonally variable, and that contain over 30% expandable clays, develop distinctive macro-morphologic and micro-morphologic features including pedogenic slickensides, gilgai micro-topography,

and sepic-plasmic clay micro-fabric (Driese et al., 2000, 2003; Caudill et al., 1996; Soil Survey Staff, 1998). Pedogenic slickensides form in clay-rich soils when the shear strength of the soil is exceeded by swelling pressure, caused by expansion of clays, and where vertical movement is confined (Coulombe et al., 1996a,b; Wilding and Tessier, 1988; Mora and Driese, 1999). Pedogenic slickensides can be distinguished from tectonic slickensides by their generally random orientation. The surface expression of clay expansion is in the form of gilgai micro-topography, a series of low-relief hummocks and swales. In the subsurface, this structure is expressed as pseudoanticlines and pseudosynclines (Mora and Driese, 1999), often bounded by master slickensides. Although only one of the Crooked Fork Group paleosols exhibits evidence of gilgai topography (Rockwood 1) (Fig. 6), all three outcrops exhibit some degree of slickenside development (Fig. 5). The Ivydell 1 and Petros 9 cores also contain pedogenic slickenside surfaces, characterized by smooth, polished, striated failure planes. Intersecting slickenside surfaces resulted in the development of subangular to angular blocky aggregates of clay, silt and sand bounded by oriented clay minerals with bright interference colors, interpreted as “peds” (Fig. 5).

On the micro-scale, shrinking and swelling of clays imparts a distinctive sepic-plasmic fabric (Mettleton and Sleeman, 1985; Wilding and Tessier, 1988). Shrink-swell cycles result in preferential alignment of birefringent clay minerals aligned in up to two planes (Brewer, 1964). The Crooked Fork underclay paleosols exhibit some degree of clay orientation at all depths (Figs. 7, 9, 10 and 11), and in some cases have a very well

developed sepic-plasmic fabric in which the entire clay matrix is preferentially aligned (Fig. 9A).

Based on the abundance of rooting in the Lower Pennsylvanian Underclays, and the presence of pedogenic structures, it can be unequivocally stated that the Crooked Fork Group underclays are paleosols. The abundance of features common to modern Vertisols and vertic Alfisols suggests that at least at the start of their development, these underclays were Vertisols or Alfisols.

8.3.3 Siderite --Siderite is a common precipitate in wetland soils and can be found as blocky crystals, concretions, or spherules (Ludvigson et al., 1998; Curtis and Coleman, 1986). One variety, common in the Lower Pennsylvanian underclay paleosols of the Crooked Fork Group is sphaerosiderite. Sphaerosiderite is a millimeter-scale morphologically distinct, spherulitic form of siderite often forming in siliciclastic mudstones as an early diagenetic or pedogenic product (Baker et al., 1995, Ludvigson et al., 1998). It also forms in reducing Holocene wetland soils (Landuydt, 1990). Sphaerosiderite nodules in wetland soils most commonly form by geomicrobiological processes along the edges of plant roots (Landuydt, 1990; Ludvigson et al., 1998). It has also been found forming aggregates within the soil or paleosol groundmass (Landuydt, 1990). Three requirements are necessary for siderite precipitation in a soil: 1) the soil environment must be saturated and anoxic (Ludvigson et al., 1998; Baker, 1995), 2) the soil Eh must be low, ranging between 0.1 V and -0.6 V, with moderately high to low pH,

4.5 to 10.5 (Krauskopf, 1972; Ludvigson, 1998), and, 3) if the pH is high, the soil or groundwater iron content must be high (Krauskopf, 1972; Pye et al., 1990).

8.4 Three-Stage Model of Underclay Genesis

Lower Pennsylvanian underclays of the Crooked Fork Group contain a complex suite of pedogenic features. These features include some that are exclusively developed in moderate to well-drained paleoVertisols and paleoAlfisols and others that are typical of wetland soils, or Histosols. When both of these suites of features are considered, along with the repetitive stratigraphic succession of terrestrial and near shore facies to marine facies, it becomes apparent that these underclay paleosols experienced a complex pedologic and diagenetic history of soil development. I propose that the Lower Pennsylvanian underclay paleosols of the Crooked Fork Group in Eastern Tennessee went through a three-stage development process driven by sea-level change as a result of either tectonic subsidence (Gardner et al., 1988) or glacial-eustatic forcing (Cecil, 1990; Chesnut, 1989; Heckel, 1986; Fischer, 1986) (Fig. 17).

8.4.1 Stage 1 -- The Crooked Fork Group paleosols contain a suite of pedogenic structures and features indicating that they initially developed in a well-drained environment above the paleo-watertable (Fig. 17-I). These features are primarily vertic, however, there are indicators that these were not pure paleoVertisols, but rather vertic paleoAlfisols.

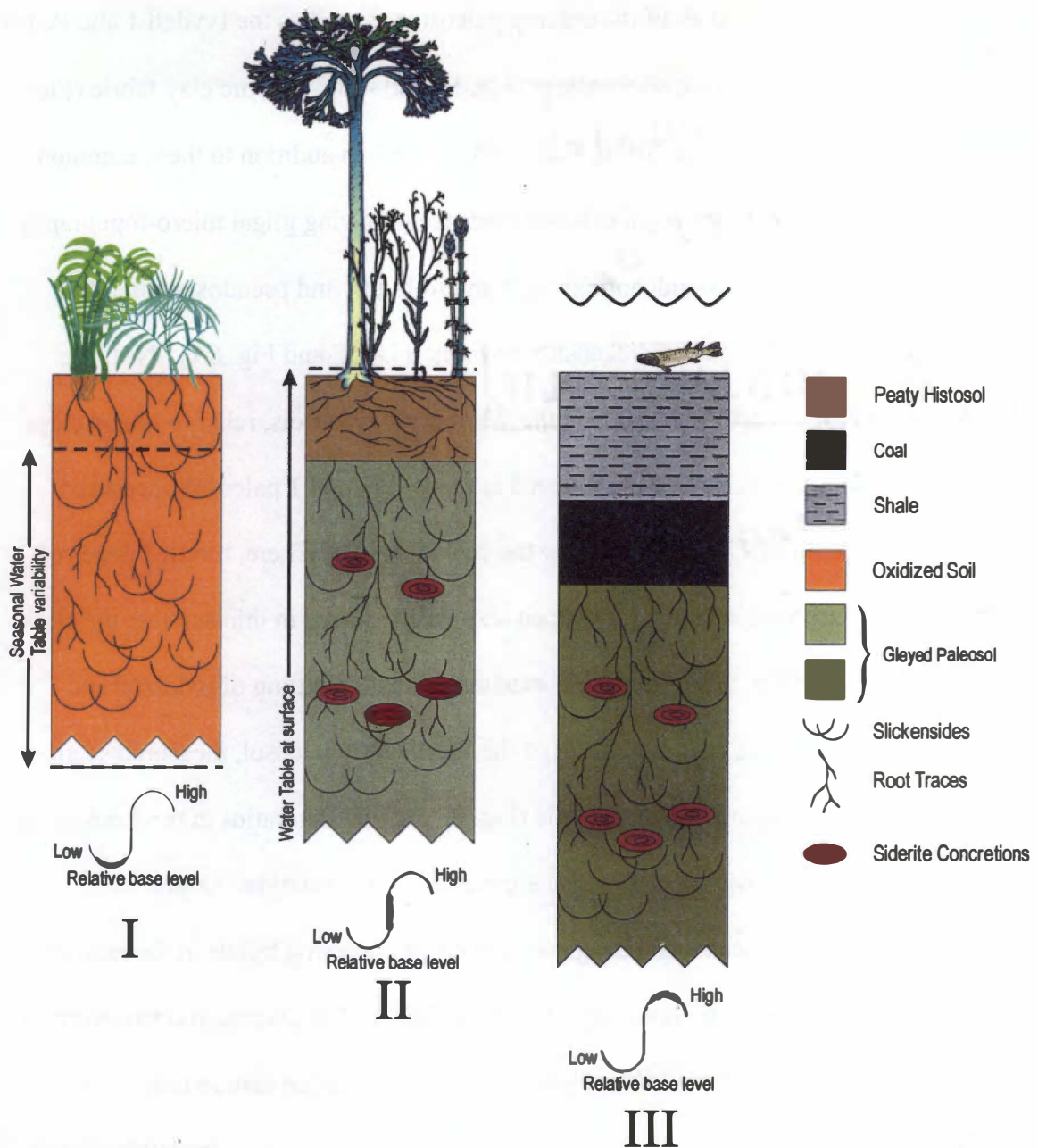


Figure 17: Three-stage genesis of Lower Pennsylvanian underclay paleosols of the Crooked Fork Group in Eastern Tennessee, proposed in this study. Stage I: Sea-level low-stand, lowered water tables, well-drained paleoVertisol or vertic paleoAlfisol. Stage II: Sea-level rise, rising water table, saturation of the paleosol forming a coal swamp. Low Eh/pH, iron reduction and precipitation of siderite and pyrite. Stage III: Sea-level highstand. Flooding and burial of the paleosol, deposition of marine sediment, coalification and decomposition of organic matter, continued reduction of the paleosol.

Vertic features common to all of the outcrop paleosols as well as the Ivydell 1 and Petros 9 drill core include pedogenic slickensides (Fig. 5), and sepic-plasmic clay fabric (Figs. 7A, B, C, Figs. 9A, B, E, Figs. 9B, E, Figs. 10A, and B). In addition to these common features, the Rockwood 1 paleosol exhibits evidence of having gilgai micro-topography in the form of subsurface pseudoanticlines, or micro-highs, and pseudosynclines, or micro-lows bounded by master slickenside surfaces (Fig. 5F and Fig. 6A). Near the bottom of the Rockwood 1 paleosol and the Wartburg 2 paleosols, relict oxidized clays are present. They are especially pronounced in the Rockwood 1 paleosol, measured section 1, at a depth of 250-350 cm below the coal (Fig. 4B). There, mottled zones of red/brown clay are visible in hand specimen and, when viewed in thin section, the clays appear red in color (Fig. 9F). To a lesser extent, reticulate mottling of oxidized and reduced zones are visible in thin sections of the Wartburg 2 paleosol, measured section 2, at a depth of 180 cm below the coaly shale (Fig. 9F). Oxidation ratios in the Rockwood 1 paleosol (i.e., $(\text{Fe}_2\text{O}_3 + \text{MnO})/\text{Al}_2\text{O}_3$) also support this interpretation. Degree of oxidation in a soil or paleosol can be approximated by observing trends in the ratio of total iron plus manganese to aluminum (Retallack, 2001). The average oxidation ratio for Rockwood 1 paleosols below -150 cm is 0.28. In contrast, the oxidation ratio at shallow depths, above -150 cm, is only 0.11, indicating that the upper paleosol horizons are less oxidized than deeper horizons.

Many vertic features are the direct result of the abundance of expandable clays in paleoVertisols and Vertisols (Soil Survey Staff, 1998). Indeed, smectite dominates the mineralogy of almost all soils that are classified as Vertisols (Soil Survey Staff, 1998).

With respect to clay stability, smectite is relatively unstable and, in even a moderately acidic environment, is rapidly transformed into pedogenic chlorites and ultimately kaolinite (Borchardt, 1989). The presence of residual smectite within the fine, pedogenic, fraction of all of the outcrop paleosols further supports the hypothesis that these were once vertic soils (Table 4).

One property of these paleosols which is an indicator of having been a well drained soil but not necessarily of a paleoVertisol, is the presence of illuviated clays. Illuviated clays are the result of removal of clay from the A and particularly E horizons of Alfisols, among other soil types, by water percolating through the soil. The clays are then transported and deposited in macro-pores deeper in the soil profile (FitzPatrick, 1993). Illuviated clays are abundant in the Rockwood 1 and Wartburg 2 paleosols (Fig. 9C, Fig 10C and F) and are present, but somewhat less abundant in the paleosols underlying the Poplar Creek Coal (Wartburg 1, Ivydell 1, and Petros 9) (Fig. 7E and Fig. 10A).

8.4.2 Stage 2 -- Throughout the Crooked Fork Group, it is apparent that a series of small marine transgressions and regressions occurred. The Crooked Fork Group can be subdivided into three major shallowing upward packages, the top of each is capped with an underclay paleosol and coal (Wilson et al., 1956) (Fig. 2). Marine facies typically overlie the coal (Fig. 3). Stage 2 would have developed as sea level began to rise at the end of the regression, resulting in a corresponding rise in water table and saturation of the paleosol (Fig. 17-II).

Gley is a soil feature that is characterized by blue-gray or green-gray coloration and mottling containing abundant iron-manganese and iron-carbonate nodules as a result of water logging and burial of the soil (Retallack, 2001). All of the Crooked Fork Group paleosols have gley features and, thus must have been waterlogged late in their history. Saturated soils are typically, but not necessarily, reducing soils. Several factors are necessary to produce reducing soil conditions: 1) the soil must be saturated to exclude oxygen from the atmosphere; 2) the soil must contain abundant organic material that can be oxidized and decomposed; 3) a microbial population must exist to decompose the organic material, and; 4) groundwater flow has to be minimal (Vepraskas and Faulkner, 2001). Reducing soil conditions lead to the precipitation of siderite and pyrite, both containing reduced forms of iron (Kraus, 1997; 1998). Abundant siderite and pyrite nodules are present in the Crooked Fork Group paleosols, indicating a reducing soil environment (Figs. 6B, Figs. 8D, F, Figs. 9 B, C, F, Figs. 9 B, E, Figs. 10B, C, E, F).

Another indicator of acidic conditions and intense weathering is the presence of abundant kaolinite (Moore and Reynolds, 1997, Krauskopf, 1979). Kaolinite is a well known constituent of underclay matrix (Gardner, 1988; Schultz, 1958) and can be identified both petrographically and through XRD analysis. These clays, identified by very low birefringence and a “book-like” structure, are abundant in the paleosol matrix (Table 4) and are visible in thin section as clay pore-fillings in siderite rhizocretions in the Ivydell 1 and Petros 9 paleosols. XRD analysis reveals that kaolinite is present in abundance in all of the underclay paleosols (Fig. 12, Table 4). It can be produced by intense acid leaching of the paleosol through weathering reactions involving smectite,

chlorite and HIV (Barnhisel and Bertsch, 1989). In humid-tropical environments, chlorite, present in small amounts in the underclay paleosols, is weathered to kaolinite through the following reaction: chlorite $\rightarrow$ HIV $\rightarrow$ smectite (nontronite) $\rightarrow$ kaolinite (Barnhisel and Bertsch, 1989). Pedogenic chlorite can itself only be produced in old acidic soils by the weathering of vermiculite and smectite (Barnhisel and Bertsch, 1989). As discussed previously, pedogenic smectite would have been produced during Stage I. It is likely that a large proportion of the kaolinite in the underclay paleosols was produced by acid leaching of smectites produced in Stage I during coal swamp formation.

8.4.3 Stage 3 -- Continued rise in sea-level completely submerged the Crooked Fork Group paleosols and resulted in burial of the paleosol and coalification of organic material (Fig. 17-III). All of the paleosols are overlain by marine shales or sandstones (Wilson et al, 1956; Schnoebelen, 1983) (Fig. 3), supporting this conclusion. Marine inundation would have resulted in continued gleying of the paleosol (Kraus, 1998) and precipitation of secondary siderite (Baker, 1995).

8.5 Pennsylvanian Climate

8.5.1 Models for Pennsylvanian Climate -- Several researchers have studied the problem of climate in the Carboniferous. Most have focused on using Pennsylvanian and Mississippian stratigraphic relationships in cyclothem as a record of sea-level change (Heckel, 1986; Fischer, 1986; Cecil, 1990). Both Heckel (1986) and Fischer (1986) suggested that climate change in the Carboniferous was controlled by orbital forcing

resulting in glacio-eustatic changes in sea level. Cecil (1990) proposed that major shifts in climate were not confined to high latitudes. By studying the stratigraphic changes in climate-sensitive lithologies in low paleolatitude rocks of the Mississippian and Pennsylvanian, Cecil (1990) proposed a model of climate change, governed by plate tectonics and glacio-eustatic sea level change, in which paleoprecipitation in the Late Mississippian was generally low but highly variable, ranging from semi-arid to wet-dry tropical, and in the Early Pennsylvanian, a shift toward a wet-dry to tropical rainy climate occurred.

8.5.2 Paleosols and Climate -- Soils are the weathering products of the parent material on which they form, whether it is rock or unconsolidated sediment. Their composition, both chemical and physical, is a function of the original composition of the parent material and climatic processes including: temperature, atmospheric composition, and precipitation. Because their composition is in large part dependent upon the climate in which they form, paleosols can be used as paleoclimate proxies. In recent years, more emphasis has been placed on using paleosols to determine paleoclimate. Some researchers have used stable carbon isotopes in pedogenic carbonate to estimate paleoatmospheric $p(\text{CO}_2)$ (Cerling, 1991; Mora and Driese, 1999; Ekart and Cerling, 1997; Mora et al., 1991, 1996). Other research has focused on using paleosols to determine paleo-mean annual precipitation (Retallack, 1994; Caudill et al., 1996; Sheldon et al., 2002).

Climatic influence on soil structure and chemistry make it possible to use geochemical and physical properties of paleosols to estimate paleo-mean annual

precipitation (MAP). One method involves measuring the depth to the carbonate horizon to estimate MAP. A data base, compiled by Retallack (1994), empirically relates the depth to carbonate horizon in modern soils to MAP with the intent to use this relationship to estimate MAP in paleosols. Retallack (1994) assumed that all of the soils were situated on freely drained, low-lying terrains. The carbonate horizon was defined as the horizon which had the highest abundance of carbonate nodules. Horizons containing “veins” and “cements” were ignored, and massive carbonate horizons or layers were not included because of the ancient age and development that they indicate. The depth to the carbonate horizon was found to be proportional to MAP, i.e. higher MAP is associated with a deeper carbonate horizon. Using this technique in paleosols poses several problems: 1) erosional truncation of the paleosol would lead to underestimation of MAP, 2) a fluctuating water table may produce nodular carbonate horizons, and, 3) transportation of carbonate nodules along slickensides in paleoVertisols may produce a “false” carbonate horizon. Additionally, this technique only works if the paleosol *has* a carbonate horizon. A second, and perhaps more generally applicable method, uses bulk geochemical characteristics to estimate MAP. This method, pioneered by Sheldon et al. (2002), relates the chemical index of alteration without potash (CIA-K) to MAP. CIA-K is a measurement of the degree of rock weathering, specifically the breakdown of feldspars and micas to accessory minerals and clays (Nesbitt and Young, 1982; Maynard, 1992). It is calculated by taking the molecular ratio of Al_2O_3 to the sum of $\text{Al}_2\text{O}_3 + \text{CaO} + \text{Na}_2\text{O}$, and multiplying it by 100. K_2O is taken out of the equation because it is altered during burial diagenesis as smectites are converted to illite by potassium-metasomatism

(Maynard, 1992). Sheldon et al. (2002) compiled geochemical measurements of 127 modern Alfisols, Mollisols, and Ultisols and related the CIA-K to modern MAP at each site. They obtained the following empirical formula:

$$\text{MAP} = 14.3(\text{CIA-K}) - 37.632$$

$$R^2 = 0.73$$

Because this method is not dependent on the presence of a carbonate horizon and is insensitive to depth within the paleosol, it is more generally applicable than using the depth to carbonate horizon. It does, however, have a few shortcomings. First, because it is a measure of degree of weathering, it only estimates the MAP at the final stage of paleosol development. In addition, if the soil contains large amounts of pedogenic carbonates, MAP estimates will be unrealistically low. Third, CIA-K as a proxy for MAP was developed for use in well drained soils in which chemical alteration was the result of rainwater percolating through the soil. Its applicability to saturated soils and paleosols may be limited. The final problem is that the CIA-K index has not been adequately tested on vertic soils.

In order to validate this method in paleoVertisols, MAP was estimated using bulk geochemical data from modern east Texas Vertisols (Stiles, 2000). If modern, carbonate-poor upper horizons or leached zones of Vertisols are used, then there is a nearly 1:1 relationship between estimated MAP and measured MAP with an $R^2 = 0.83$ (Fig. 18). Based on these data, it is reasonable to estimate paleoMAP using CIA-K on paleoVertisols.

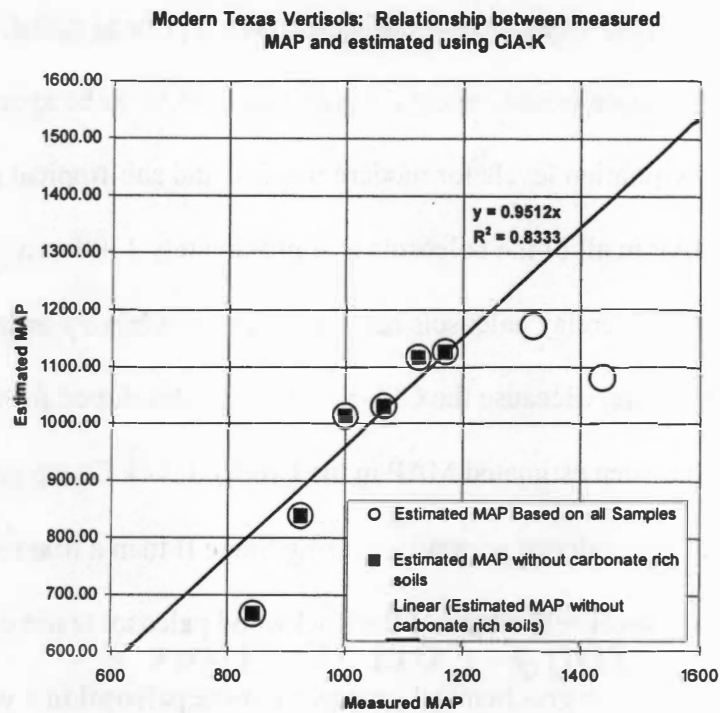


Figure 18: Relationship between the estimated mean annual precipitation (MAP), calculated using CIA-K, and measured precipitation from modern east Texas Vertisols.

8.5.3 Paleo-MAP in the Pennsylvanian -- Using bulk geochemistry and CIA-K, it is possible to estimate MAP of a paleosol during the period prior to burial. Based on Cecil's (1990) model, one would expect estimated paleoMAP to be approximately 1300 mm/yr (typical precipitation levels for modern tropical and sub-tropical climates). Estimated paleoMAP in all of the paleosols is approximately 1300 mm/yr (Fig. 17). The geochemistry of the underclay paleosols has, however, been largely influenced by pore water in a saturated state. Because the CIA-K index was developed for well drained soils, similarities between estimated MAP in the Crooked Fork Group paleosols may be more related to geochemistry of pore water during Stage II than a true measure of paleo-MAP. Furthermore, because the base of the Rockwood paleosol is not completely gleyed, it may preserve the geochemical properties of the paleosol in a well drained state and the use of CIA-K as a proxy for MAP may be justified. MAP estimates from the oxidized base of the Rockwood 1 paleosol yield an estimate of 1310 mm/yr. This is typical of tropical and sub-tropical MAP in modern climates and supports Cecil's (1990) climate model for the early Pennsylvanian.

9.0 CONCLUSIONS

Lower Pennsylvanian underclays from the Crooked Fork Group in Eastern Tennessee formed by pedogenic processes that occurred both before and during peat accumulation and have undergone a complex paleohydrologic and diagenetic history governed by glacio-eustatic sea level change. Their genesis occurred in a river-dominated deltaic environment through a three-stage process (Fig. 17).

Stage 1: During sea level lowstands, the paleosols were well-drained paleoVertisols or vertic paleoAlfisols. Soil conditions were oxidizing, imparting the red-brown color now seen at depth. Highly expandable clays, such as smectite, resulted in the development of pedogenic slickensides, gilgai micro-topography, and sepic-plasmic fabrics.

Stage 2: Rising sea level resulted in a rise in local water tables, saturating the paleosols, producing a reducing, anoxic soil environment. A peat swamp developed on top of the old paleoVertisol and iron reduction resulted in gleying of the paleosol and precipitation of sphaerosiderite and pyrite nodules along with siderite concretions and siderite replacement of calcite rhizoliths. Extensive acid leaching resulted in kaolinite production.

Stage 3: Continued rising sea level eventually flooded the paleosol, burying it, resulting in coalification of organic matter, including the peat, and continued reduction of the paleosol.

Mean annual precipitation estimates, made through bulk geochemical analysis, support Cecil's (1990) model for a tropical to sub-tropical wet humid environment during

the Lower Pennsylvanian period, although limitations in the CIA-K index make further study of well drained paleosols necessary.

10.0 SUGGESTIONS FOR FURTHER RESEARCH

This research is just one step in understanding the complex history and development of Lower Pennsylvanian underclay paleosols and much work still need to be done. Future research should focus in four areas.

1) Stable isotopic analysis of sphaerosiderites may elucidate the paleohydrology and paleoclimate during the paleosols formation. Previous research has shown that $\delta^{18}\text{O}$ values from sphaerosiderite nodules can be used to determine estimates of paleotemperature and paleoprecipitation as well as ancient groundwater sources (Ludvigson et al., 1998, Ufnar et al., 2001). Additional research demonstrates the use of $\delta^{13}\text{C}$ from sphaerosiderite nodules to determine the origin of siderite in sedimentary deposits (Baker et al., 1995).

2) Examination of other Lower Pennsylvanian and Upper Mississippian underclay paleosols from Eastern Tennessee would provide a broader understanding of underclay genesis and geochemical analysis of paleosols from both sides of the Mississippian/Pennsylvanian boundary would further our understanding of climate change in the Carboniferous.

3) This research postulates that Lower Pennsylvanian underclay paleosols were paleoVertisols or paleoAlfisols early in their history and became saturated and reduced as sea level rose. This hypothesis is based primarily on a combination of soil properties, both morphologic and geochemical, that are typically not found together in combination with stratigraphic relationships between rock units. One area of future research should focus on finding and studying modern analogs.

Modern Vertisols are common along the Texas Gulf coast (Soil Survey Staff, 1998; Stiles, 2001) and may be becoming saturated as a result of Holocene rises in sea level. Studying these modern analogs could help further our understanding of Pennsylvanian underclay geochemical alteration and genesis.

4) All of the paleosols in this study were overlain by well developed coals. The exception was the Wartburg 2 paleosol, which was overlain by a carbonaceous shale or silty smut. Unlike the other underclay paleosols, Wartburg 2 is interpreted to be a compound paleosol implying a nearby source of additional sediment influx. Could there be a relationship between paleosol development and the coal and organic rich deposits overlying them?

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APPENDICES

Appendix A

Raw bulk geochemical data and bulk density measurements. Geochemical data are expressed as weight % for major elements and oxides and in ppm for trace elements and oxides.

Field Site Wartburg 1-1 N36°06.393'
Run Date 7/25/02 W084°35.720'
Operator Mary Bryan
Calibration Soil&Sed Cal
Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	Sr (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	WB1-1-00B	93.38	21.917	955	0.47	36	5.137	4.299	1.8	0.246	0.059	208	551	58.449	102	0.948	162	79	0.017	40	11	103	183	5
10	WB1-1-10B	94.981	21.311	945	0.457	44	5.084	4.395	1.712	0.26	0.057	208	-86	60.536	93	0.968	173	101	0.021	41	11	105	161	6
20	WB1-1-20B	94.787	17.58	758	0.449	43	3.766	3.269	1.512	0.608	0.058	141	-89	68.478	83	0.915	199	114	0.02	43	11	102	116	6
30	WB1-1-30B	94.635	21.178	1022	0.458	61	5.312	4.549	1.83	0.358	0.08	202	-119	59.69	103	0.984	177	114	0.028	45	13	107	169	6
40	WB1-1-40B	93.805	22.132	998	0.481	71	5.671	4.883	1.758	0.276	0.086	227	-112	57.333	122	0.963	152	123	0.05	44	14	103	177	5
50	WB1-1-50B	93.207	21.43	950	0.497	62	8.547	4.621	1.682	0.261	0.09	213	209	54.819	122	0.937	144	165	0.105	45	21	105	152	3
60	WB1-1-60B	94.482	19.758	976	0.465	48	4.88	4.198	1.852	0.482	0.064	189	-93	61.868	111	0.895	168	109	0.038	41	12	101	162	6
70	WB1-1-70B	93.924	17.998	822	0.534	48	8.035	3.562	1.543	0.537	0.091	157	127	60.469	98	0.849	174	115	0.123	41	18	101	121	4
80	WB1-1-80B	93.504	20.611	943	0.474	50	5.036	4.511	1.739	0.379	0.064	201	-116	59.52	119	0.951	161	98	0.041	41	15	97	174	5
90	WB1-1-90B	94.042	16.089	640	0.507	47	6.455	2.995	1.423	0.735	0.079	129	-23	64.597	101	0.902	232	98	0.111	39	15	103	99	7
100	WB1-1-100B	95.558	18.682	927	0.456	51	4.638	3.854	1.645	0.732	0.085	164	-145	64.374	116	0.909	198	97	0.031	41	11	103	132	6
110	WB1-1-110B	93.6	18.503	815	0.481	52	4.127	3.734	1.584	0.816	0.085	160	-122	63.358	108	0.964	214	100	0.026	41	13	98	136	6
120	WB1-1-120B	95.121	17.079	674	0.467	47	3.649	3.22	1.472	0.774	0.087	138	-130	67.249	100	0.971	257	83	0.026	42	12	101	122	6
130	WB1-1-130B	95.278	18.494	695	0.483	39	4.342	3.441	1.531	0.642	0.083	147	-78	65.124	105	0.955	273	100	0.024	45	9	108	114	9
140	WB1-1-140B	94.677	17.915	747	0.485	58	3.781	3.433	1.519	0.747	0.087	142	-102	65.512	103	1.013	265	98	0.025	43	12	104	123	7
150	WB1-1-150B	94.766	17.603	761	0.494	51	3.765	3.456	1.503	0.766	0.09	145	-67	65.858	104	1.037	264	126	0.027	43	13	109	119	8
160	WB1-1-160B	98.179	18.737	765	0.509	54	4.599	3.732	1.839	0.651	0.1	159	-46	64.949	117	1.058	260	98	0.036	47	11	111	120	6
170	WB1-1-170B	94.16	18.176	825	0.528	49	3.994	3.692	1.62	0.71	0.116	152	-91	64.091	114	1.025	245	114	0.037	45	12	106	118	7
180	WB1-1-180B	95.013	18.5	763	0.514	48	4.333	3.858	1.593	0.873	0.113	154	-93	64.45	113	0.98	231	105	0.038	43	11	108	125	7
190	WB1-1-190B	94.744	19.33	849	0.518	51	4.658	3.924	1.708	0.627	0.108	169	-117	62.664	114	0.991	218	130	0.049	46	12	105	130	7
200	WB1-1-200B	95.328	17.906	741	0.522	50	4.012	3.484	1.55	0.771	0.121	147	-99	65.776	108	0.985	255	108	0.041	45	11	107	126	8
210	WB1-1-210B	95.121	17.835	698	0.533	43	3.915	3.336	1.54	0.771	0.121	141	-111	65.908	105	0.971	268	103	0.039	44	10	108	111	7
220	WB1-1-220B	94.252	18.717	834	0.532	49	3.908	3.795	1.613	0.727	0.116	160	-123	63.641	115	0.997	225	119	0.039	43	13	107	127	7
230	WB1-1-230B	95.382	15.642	604	0.555	43	3.39	2.86	1.388	0.981	0.141	118	-116	69.3	97	0.965	303	82	0.041	40	10	107	95	9
240	WB1-1-240B	94.634	15.012	602	0.6	44	4.457	2.764	1.382	0.925	0.156	109	-23	68.183	92	0.928	303	91	0.078	42	13	103	83	9
250	WB1-1-250B	93.958	17.865	733	0.551	47	3.52	3.454	1.564	0.759	0.132	140	-105	64.942	107	0.975	256	98	0.041	42	14	101	130	8
260	WB1-1-260B	93.57	19.105	774	0.551	53	4.588	3.673	1.857	0.635	0.126	150	-79	61.962	115	1.04	282	117	0.041	46	13	103	138	8
270	WB1-1-270B	94.624	19.012	775	0.542	54	4.589	3.771	1.83	0.657	0.125	157	-55	63.04	119	1.04	268	118	0.044	45	13	110	123	8
280	WB1-1-280B	94.619	19.833	842	0.517	53	4.967	3.99	1.657	0.595	0.108	173	-117	61.729	117	1	211	117	0.033	44	12	107	135	6
290	WB1-1-290B	92.991	17.041	742	0.549	48	3.261	3.397	1.508	0.851	0.128	133	-88	65.035	107	1.013	266	106	0.043	41	17	102	128	8
300	WB1-1-300B	92.651	17.109	728	0.538	44	2.858	3.352	1.515	0.842	0.125	130	-34	65.36	100	0.955	253	90	0.037	39	17	99	130	9
310	WB1-1-310B	94.942	16.876	648	0.526	39	3.37	3.099	1.462	0.889	0.119	124	-32	67.556	93	0.865	257	100	0.03	37	12	101	107	9
340	WB1-1-340B	91.995	16.719	687	0.565	52	4.771	3.207	1.592	0.824	0.126	129	1064	62.897	99	0.963	266	105	0.064	40	16	101	113	9
350	WB1-1-350B	91.519	17.884	743	0.696	64	8.793	3.48	1.809	0.648	0.164	143	636	56.658	111	1.001	242	149	0.147	49	23	110	118	5
360	WB1-1-360B	88.688	17.632	817	0.699	57	6.425	3.555	1.946	0.682	0.158	134	788	58.169	110	1.022	230	106	0.142	43	28	109	126	6
STANDARDS																								
	NIST 97B	83.588	35.608	214	0.435	22	1.292	0.479	0.117	0.092	0.072	35	287	42.777	93	2.546	500	75	0.003	39	2	203	183	15
	NIST 2711	91.877	12.075	867	3.613	131	4.057	2.947	1.778	1.538	0.18	108	434	64.884	231	0.492	265	331	0.079	1	10	71	103	7
	GSD-9	91.716	10.666	367	4.733	46	4.864	1.925	2.452	1.455	0.152	81	109	64.369	164	0.882	370	71	0.073	27	11	86	89	9
	NBS-2704	91.395	12.132	404	3.507	112	5.852	2.467	2.055	0.756	0.221	101	3801	63.055	134	0.751	295	434	0.071	29	14	87	79	6

Field Site Wartburg 1-2 N36°06.391'
Run Date 11/20/02 W084°35.720'
Operator Bill Dean
Calibration Soil&Sed Cal
Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	Sr (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	WB1-2-008	91.845	21.809	908	0.431	45	4.361	4.181	1.87	0.26	0.081	183	82	58.078	90	0.957	165	90	0.02	39	39	101	165	6
10	WB1-2-108	94.133	21.528	1005	0.427	49	5.009	4.534	1.807	0.326	0.06	206	-30	59.257	96	0.989	167	106	0.025	42	21	106	149	6
20	WB1-2-208	95.022	19.84	869	0.422	44	4.522	4.011	1.689	0.494	0.061	175	-36	62.855	96	0.928	175	103	0.027	40	19	107	138	7
30	WB1-2-308	94.485	20.128	926	0.424	51	4.829	4.084	1.717	0.495	0.061	182	79	61.578	101	0.931	174	107	0.025	44	12	105	142	6
40	WB1-2-408	93.747	21.535	974	0.441	62	5.278	4.567	1.759	0.4	0.065	210	15	56.502	118	0.989	165	163	0.026	43	15	107	160	5
50	WB1-2-508	92.61	22.799	990	0.456	60	5.306	4.85	1.735	0.313	0.072	225	2	55.858	135	0.989	153	123	0.029	41	18	107	173	6
60	WB1-2-608	93.358	21.685	947	0.445	45	4.843	4.438	1.693	0.398	0.069	202	6	58.612	122	0.948	171	98	0.034	41	24	101	164	7
70	WB1-2-708	95.606	17.522	783	0.455	56	5.318	3.393	1.498	0.836	0.078	145	-3	65.32	103	0.943	221	114	0.073	41	19	109	130	6
80	WB1-2-808	97.645	14.459	561	0.443	38	3.172	2.613	1.212	0.984	0.075	106	-15	73.652	85	0.865	266	89	0.029	35	23	105	101	9
90	WB1-2-908	95.515	19.563	859	0.451	61	4.731	3.932	1.639	0.66	0.064	172	-3	63.261	111	0.979	207	100	0.032	42	14	106	154	6
100	WB1-2-1008	97.714	13.593	496	0.463	41	2.951	2.301	1.122	1.088	0.065	93	-20	75.129	81	0.818	272	78	0.026	34	19	96	86	9
110	WB1-2-1108	99.611	11.417	422	0.516	39	2.564	1.864	0.931	1.23	0.14	73	138	79.936	76	0.832	398	82	0.033	36	27	105	65	11
120	WB1-2-1208	97.502	12.509	481	0.523	38	2.79	2.129	1.03	1.159	0.139	84	-16	76.251	79	0.814	288	118	0.027	34	28	96	81	8
130	WB1-2-1308	95.564	16.535	701	0.482	47	3.765	3.179	1.403	0.97	0.102	130	2	67.947	99	0.989	273	98	0.028	40	28	110	107	8
STANDARDS																								
	GSD-9	92.905	10.607	379	4.864	45	4.869	1.967	2.457	1.485	0.158	80	151	65.375	163	0.9	370	72	0.077	27	10	95	73	10
	NBS2704	91.186	11.961	405	3.532	115	5.89	2.468	2.031	0.759	0.222	99	3129	63.012	131	0.753	288	441	0.075	28	13	91	77	7

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Wartburg 1-1 paleosol bulk density

Sample Name	Depth (cm)	wt. in air (g)	wt. in air w/par (g)	wt. in water w/par (g)	Bulk density (g/cm ³)	Bulk Porosity (%)	Pp1/Pw
0	0	8.58	9.14	5	2.1569832	16.60441	1.064538
20	20	23.75	25.13	14.24	2.2476341	15.18362	1.050394
40	40	25.5	26.75	14.51	2.0882821	21.19766	1.130558
60	60	48.16	47.79	28.06	2.2952486	13.38684	1.028603
80	80	27.73	28.74	16.69	2.2605978	14.69442	1.04437
100	100	25.5	26.41	15.55	2.3085327	12.96103	1.023571
120	120	21.84	22.86	13.16	2.2645161	14.54656	1.042563
140	140	13.58	14.09	8.35	2.3424184	11.60685	1.00789
160	160	20.89	21.56	12.77	2.3153941	12.62664	1.019654
180	180	24.75	25.77	15.02	2.2893114	13.61089	1.031271
200	200	35.23	36.54	21.42	2.295945	13.36057	1.028291
220	220	16.5	17.32	10.13	2.3312402	12.02867	1.012723
240	240	28.85	30	17.93	2.3777473	10.27369	0.992915
260	260	36.19	37.51	22.16	2.3215253	12.39527	1.016961
280	280	17.83	18.79	10.83	2.2924286	13.49326	1.029869
300	300	29.09	30.2	18.01	2.3629061	10.83373	0.999151
310	310	29	30	17.92	2.3555957	11.1096	1.002252
340	340	22.55	23.47	14	2.3738842	10.42701	0.994614
360	360	11.07	11.72	6.85	2.3609005	10.90942	1

Wartburg 1-2 paleosol bulk density

Sample Name	Depth (cm)	wt. in air (g)	wt. in air w/par (g)	wt. in water w/par (g)	Bulk density (g/cm ³)	Bulk Porosity (%)	Pp1/Pw
0	0	16.11	17	9.8	2.29778	13.291272	2.14066
20	20	13	13.54	7.82	2.25869	14.766519	2.3783
40	40	38.2	39.11	23.03	2.26632	14.478676	2.33194
60	60	11.23	11.67	6.78	2.26107	14.676459	2.36379
80	80	13.85	14.24	8.48	2.32123	12.406451	1.99818
100	100	28.16	29.19	17.61	2.40227	9.3481177	1.50561
120	120	17.25	18.17	10.97	2.47213	6.7118337	1.06102
130	130	14.25	15.09	9.09	2.48547	6.2088635	1

Field Site Wartburg 2-1 N36°07.227'
Run Date 11/27/02 W084°36.501'
Operator Bill Dean
Calibration Soil&Sed Cal
Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	Sr (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	WB2-1-00B	87.083	29.425	394	0.44	34	2.615	1.581	0.827	0.285	0.087	85	435	50.308	105	1.34	229	74	0.012	34	9	130	111	8
10	WB2-1-10B	89.826	28.186	478	0.465	39	3.046	2.304	0.985	0.318	0.075	117	284	52.773	98	1.456	240	133	0.049	43	10	135	101	8
20	WB2-1-20B	90.231	27.67	478	0.498	26	2.532	2.573	1.054	0.314	0.088	133	250	53.852	97	1.464	253	147	0.036	44	7	129	113	8
30	WB2-1-30B	87.914	28.39	494	0.495	53	2.549	2.118	1.117	0.308	0.073	112	689	51.196	97	1.431	246	164	0.02	40	16	133	111	9
40	WB2-1-40B	90.835	27.897	522	0.454	20	2.11	3.308	0.993	0.27	0.075	167	298	54.266	118	1.265	190	212	0.013	39	7	116	125	7
50	WB2-1-50B	93.536	25.029	469	0.688	30	8.914	3.068	1.077	0.266	0.082	149	7959	52.202	88	1.102	160	69	0.16	38	25	114	108	4
60	WB2-1-60B	92.4	25.062	469	0.556	18	5.777	3.302	1.027	0.25	0.088	159	7563	54.261	85	1.139	165	64	0.08	36	17	117	87	8
70	WB2-1-70B	92.036	24.922	456	0.629	23	7.355	3.1	1.045	0.261	0.077	149	9682	52.39	87	1.065	153	61	0.104	35	25	113	93	7
80	WB2-1-80B	93.001	26.371	524	0.577	26	4.68	3.42	1.079	0.259	0.077	170	1082	55.06	108	1.162	168	73	0.074	39	10	118	107	7
90	WB2-1-90B	92.656	26.359	533	0.517	31	3.298	3.497	1.05	0.253	0.096	173	432	56.183	174	1.17	169	50	0.046	39	8	113	129	6
100	WB2-1-100B	92.12	25.969	528	0.483	36	2.291	3.502	1.083	0.264	0.077	178	360	57.069	131	1.21	184	56	0.017	38	5	120	111	9
110	WB2-1-110B	91.45	26.72	459	0.475	29	2.601	2.877	1.098	0.272	0.085	149	1228	55.807	101	1.263	178	93	0.02	36	8	125	108	7
120	WB2-1-120B	92.326	24.099	371	0.475	46	2.096	1.967	1.029	0.284	0.083	102	155	60.86	75	1.291	257	172	0.017	48	9	127	82	9
130	WB2-1-130B	92.497	22.951	415	0.456	36	1.759	2.099	1.011	0.296	0.057	117	82	62.446	67	1.269	269	123	0.014	47	13	123	91	9
140	WB2-1-140B	94.496	21.795	424	0.457	22	1.708	2.824	0.857	0.25	0.058	143	-3	65.416	86	1.196	292	60	0.013	44	4	119	72	10
150	WB2-1-150B	94.793	22.045	434	0.462	25	2.08	2.759	0.859	0.239	0.061	145	-7	64.971	86	1.168	304	64	0.018	45	6	112	99	11
160	WB2-1-160B	95.467	19.182	426	0.412	22	1.256	2.67	0.687	0.22	0.059	125	-2	69.736	58	1.11	352	61	0.008	43	6	109	70	10
170	WB2-1-170B	95.055	19.355	433	0.409	20	1.184	2.688	0.679	0.23	0.062	122	-9	69.22	61	1.084	363	57	0.007	42	5	113	60	12
180	WB2-1-180B	91.787	22.013	453	0.403	22	1.943	3.003	0.716	0.234	0.089	142	-5	62.076	91	1.183	258	32	0.022	45	5	118	80	9
200	WB2-1-200B	92.364	20.622	464	0.397	19	1.459	2.959	0.688	0.227	0.078	136	-33	64.568	95	1.206	333	26	0.009	55	12	119	72	10
220	WB2-1-220B	84.889	8.775	358	0.416	34	39.881	1.009	0.345	0.127	0.274	42	492	33.054	54	0.528	297	96	0.31	40	82	107	92	0
STANDARDS																								
	GSD-9	92.843	10.648	395	4.863	46	4.886	1.981	2.449	1.477	0.157	80	196	65.25	163	0.903	369	71	0.077	26	9	95	69	10
	NBS2704	91.278	11.968	413	3.53	118	5.951	2.474	2.031	0.759	0.223	100	3045	63.009	132	0.754	290	446	0.073	28	16	85	83	6
	GSD-9	92.458	10.589	394	4.848	45	4.892	1.967	2.443	1.467	0.156	80	197	64.968	163	0.899	369	71	0.077	27	9	95	55	10
	NBS2704	90.973	11.983	414	3.525	117	5.954	2.461	2.026	0.76	0.223	99	3029	62.744	132	0.752	288	444	0.072	27	16	84	76	7

Wartburg 2-1 paleosol bulk density

Sample Name	Depth (cm)	wt. in air (g)	wt. in water w/par (g)	wt. in water w/par (g)	Bulk density (p, g/cm3)	Bulk Porosity (%)	Pp1/Pw
0	0	29.46	30.67	17.52	2.220803	16.20366	1.157053
20	20	23.59	24.79	14.62	2.3668896	10.68341	1.085541
40	40	10.79	11.5	6.6	2.3176611	12.54109	1.108598
60	60	26.81	27.89	16.6	2.3632713	10.81995	1.087203
80	80	32.9	33.99	20.08	2.3096724	12.84255	1.112433
100	100	46.64	49.79	29.79	2.3223342	12.36475	1.106367
120	120	46.19	47.87	28.1	2.29801	13.28264	1.118078
140	140	52.79	54.47	32.44	2.3346929	11.89838	1.100511
160	160	12.74	13.64	7.55	2.2092486	16.63213	1.162999
200	180	23.32	24.41	13.69	2.1794393	17.75701	1.178906
220	220	53.1	54.93	34.5	2.5693548	-3.043214	1

Wartburg 2-2 paleosol bulk density

Sample Name	Depth (cm)	wt. in air (g)	wt. in water w/par (g)	wt. in water w/par (g)	Bulk density (p, g/cm3)	Bulk Porosity (%)	Pp1/Pw
10	10	31.23	32	19.17	2.3306	12.052943	0
30	30	31.22	32.22	18.92	2.28439	13.796595	0
50	50	9.57	10.03	5.97	2.3925	9.7169811	0
70	70	16.07	16.65	9.82	2.35171	11.256328	0
90	90	17.94	18.54	11.18	2.38846	9.8693759	0
110	110	17.88	18.23	11.34	2.48055	7.1490393	0
130	130	13.55	14.27	8.16	2.26252	14.621766	0
150	150	34.13	35.51	20.72	2.2906	13.562112	0
170	170	15.57	16.15	8.61	2.35117	11.276434	0
190	190	31.71	32.69	20.04	2.4455	7.7169326	0
210	210	31.81	32.62	19.55	2.33515	11.880944	0
230	230	58.09	59.25	35.59	2.3236	12.316981	0
250	250	36.39	37.23	22.35	2.33269	11.973875	0
270	270	17	17.64	10.44	2.33232	11.988035	0

Field Site Wartburg 2-2 N36°07.222'
Run Date 12/6/02 W084°36.498'
Operator Bill Dean
Calibration Soil&Sed Cal
Field Collection Eric Ober

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Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	S* (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	WB2-2-00B	88.059	29.143	379	0.465	84	2.655	1.539	1.051	0.315	0.082	76	415	51.178	105	1.432	278	213	0.015	38	13	136	98	8
10	WB2-2-10B	91.32	28.371	344	0.918	54	19.268	1.329	1.223	0.306	0.116	66	415	39.8	89	1.035	179	128	0.998	37	45	123	109	2
20	WB2-2-20B	90.3	29.261	417	0.68	50	8.718	1.807	1.188	0.318	0.088	95	337	46.64	98	1.265	207	162	0.167	41	24	125	116	4
30	WB2-2-30B	89.269	28.647	442	0.532	37	2.862	2.316	1.081	0.305	0.077	126	444	51.82	109	1.424	227	168	0.02	38	10	132	100	9
40	WB2-2-40B	89.018	27.834	476	0.513	30	2.026	2.564	1.03	0.296	0.084	130	476	53.02	123	1.439	219	164	0.019	39	15	133	117	8
50	WB2-2-50B	94.343	26.602	474	0.655	20	7.682	3.009	1.08	0.28	0.105	145	2805	53.255	122	1.126	164	96	0.138	36	22	117	105	6
60	WB2-2-60B	94.781	25.941	498	0.636	40	7.839	3.228	1.121	0.277	0.081	160	269	54.215	102	1.152	173	69	0.132	35	15	117	117	4
70	WB2-2-70B	93.854	25.623	476	0.558	34	5.591	3.376	1.085	0.269	0.07	165	2234	55.64	95	1.194	177	99	0.092	35	15	120	106	6
80	WB2-2-80B	93.173	25.477	491	0.579	30	6.791	3.286	1.115	0.276	0.072	165	476	54.118	95	1.167	175	68	0.116	36	12	118	96	6
90	WB2-2-90B	93.535	25.572	507	0.575	37	7.064	3.36	1.114	0.26	0.073	167	307	54.1	102	1.116	166	53	0.118	37	13	110	116	6
100	WB2-2-100B	93.221	24.764	518	0.613	40	9.727	3.3	1.181	0.268	0.114	162	608	51.801	174	1.084	155	71	0.19	39	19	115	104	3
110	WB2-2-110B	96.79	24.44	469	0.658	38	16.039	3.01	1.178	0.251	0.115	148	831	49.516	160	0.993	143	74	0.373	39	28	116	114	2
120	WB2-2-120B	90.481	26.847	514	0.527	29	2.933	3.271	1.153	0.265	0.093	173	53	54.029	169	1.206	168	48	0.015	37	4	119	107	7
130	WB2-2-130B	89.079	27.347	425	0.536	40	3.241	2.831	1.189	0.251	0.078	152	82	52.312	128	1.143	161	56	0.016	40	6	112	106	5
140	WB2-2-140B	90.758	26.333	485	0.513	41	2.703	2.963	1.081	0.265	0.07	161	39	55.514	101	1.167	177	62	0.015	43	5	118	89	7
150	WB2-2-150B	91.545	25.923	446	0.511	64	2.807	2.945	1.066	0.256	0.071	160	85	56.701	94	1.107	203	63	0.02	45	4	113	99	6
160	WB2-2-160B	91.946	25.469	531	0.524	76	2.6	3.199	1.026	0.252	0.09	170	248	57.464	119	1.134	197	44	0.02	54	6	111	115	6
170	WB2-2-170B	94.705	22.081	431	0.596	21	9.48	2.964	0.997	0.234	0.072	142	17946	55.284	79	0.992	188	57	0.091	40	25	108	86	6
180	WB2-2-180B	94.348	23.099	456	0.541	25	5.812	3.069	0.956	0.236	0.06	153	7582	58.588	73	1.041	210	59	0.063	40	14	112	88	8
190	WB2-2-190B	93.544	21.418	472	0.457	27	1.795	2.97	0.862	0.237	0.071	142	5	64.517	82	1.074	260	67	0.013	49	3	112	72	10
200	WB2-2-200B	93.187	21.887	482	0.471	33	2.21	3.224	0.941	0.235	0.086	154	365	62.841	99	1.105	252	48	0.012	63	7	106	101	8
210	WB2-2-210B	94.177	21.733	481	0.442	28	2.121	3.139	0.897	0.248	0.079	150	36	64.259	93	1.111	265	40	0.011	67	5	114	92	10
220	WB2-2-220B	93.273	20.28	463	0.457	30	1.581	3.1	0.857	0.24	0.075	149	47	85.316	87	1.115	280	43	0.012	72	15	112	64	10
230	WB2-2-230B	92.592	15.03	418	0.421	22	-0.166	2.465	0.758	0.219	0.064	102	248	72.629	58	1.009	386	63	0.008	54	37	108	44	13
250	WB2-2-250B	93.546	20.756	503	0.427	40	2.416	3.212	1.12	0.258	0.069	149	800	63.906	85	1.127	283	241	0.015	60	9	113	89	9
260	WB2-2-260B	93.13	19.856	494	0.417	34	2.561	3.002	1.081	0.243	0.065	133	810	64.811	74	1.078	305	125	0.013	56	7	112	81	10
270	WB2-2-270B	93.18	19.873	499	0.427	35	2.538	3.153	1.107	0.233	0.065	144	1405	64.334	80	1.131	287	301	0.017	55	14	115	82	9
280	WB2-2-280B	102.343	4.981	109	0.389	16	0.48	0.452	0.272	0.128	0.047	21	51	95.086	26	0.432	311	10	0.006	15	21	87	17	11
STANDARDS																								
	NBS2704	91.329	12.057	411	3.562	116	5.818	2.496	2.04	0.767	0.224	100	3032	63.056	132	0.78	290	444	0.073	27	15	89	79	8
	GSD-9	91.895	10.569	406	4.845	47	4.729	1.966	2.438	1.464	0.157	79	142	64.407	162	0.896	366	70	0.076	26	11	88	77	10
	NBS2704	90.99	12.012	410	3.54	113	5.83	2.485	2.034	0.768	0.224	100	3026	62.796	132	0.755	290	443	0.073	27	15	89	83	6
	GSD-9	92.361	10.833	406	4.878	46	4.772	1.963	2.456	1.476	0.158	80	145	64.878	164	0.905	370	72	0.075	26	11	88	71	9

Field Site Rockwood 1-1 N35°53.769'
 Run Date 12/20/02 W084°42.168'
 Operator Bill Dean
 Calibration Soil&Sed Cal
 Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	Sr (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	RW1-1-00B	71.78	23.82	545	0.429	34	2.238	1.858	0.485	0.157	0.088	112	3723	40.924	169	1.281	257	42	0.003	41	8	132	338	7
10	RW1-1-10B	88.37	27.125	610	0.435	37	2.206	2.132	0.704	0.238	0.112	132	564	53.952	199	1.232	296	77	0.011	43	6	126	138	10
20	RW1-1-20B	88.06	27.379	625	0.434	48	2.155	2.126	0.716	0.25	0.134	130	381	53.451	235	1.198	300	85	0.008	43	8	122	140	10
30	RW1-1-30B	89.447	26.507	578	0.432	47	2.187	2.153	0.755	0.24	0.134	128	257	55.644	217	1.193	328	81	0.008	44	9	117	126	11
40	RW1-1-40B	92.383	23.329	481	0.417	32	1.856	2.028	0.896	0.241	0.094	115	189	62.293	113	1.255	405	70	0.005	43	9	124	93	12
50	RW1-1-50B	91.829	21.873	420	0.45	31	6.157	1.793	0.72	0.254	0.078	97	186	59.05	83	1.165	384	108	0.132	41	19	123	83	11
60	RW1-1-60B	89.076	25.287	499	0.47	38	2.086	1.988	0.804	0.257	0.081	115	180	56.755	93	1.192	353	102	0.01	43	11	122	92	11
70	RW1-1-70B	87.677	27.927	545	0.486	39	2.47	2.088	0.858	0.26	0.089	124	260	52.167	115	1.141	284	120	0.012	39	14	115	117	8
80	RW1-1-80B	89.738	24.081	449	0.451	29	2.121	1.954	0.764	0.24	0.078	108	140	58.698	90	1.185	369	101	0.01	42	10	115	100	12
90	RW1-1-90B	91.248	23.221	496	0.434	27	2.019	2.181	0.764	0.282	0.073	118	104	60.821	79	1.29	353	98	0.008	41	8	127	82	12
100	RW1-1-100B	94.307	18.908	388	0.411	22	1.41	2.163	0.645	0.225	0.052	108	28	69.179	56	1.171	402	50	0.005	36	10	112	81	13
110	RW1-1-110B	93.529	19.46	428	0.488	27	6.286	2.202	0.708	0.225	0.07	113	16	62.818	59	1.102	322	78	0.08	34	17	120	88	10
120	RW1-1-120B	93.69	22.433	441	0.492	29	7.213	2.332	0.801	0.238	0.08	118	17	58.83	67	1.075	285	80	0.086	33	17	118	102	7
130	RW1-1-130B	92.154	23.449	478	0.481	32	5.365	2.556	0.84	0.264	0.071	135	-28	57.813	85	1.138	264	61	0.049	34	12	119	92	7
140	RW1-1-140B	93.845	19.975	827	0.547	27	13.645	2.56	0.817	0.236	0.137	128	-20	54.598	172	1.04	237	67	0.137	34	25	120	121	5
150	RW1-1-150B	92.375	19.162	1450	0.631	27	17.974	2.389	0.797	0.229	0.351	113	-59	49.447	529	0.931	200	71	0.174	32	34	117	186	3
160	RW1-1-160B	93.324	19.656	1247	0.591	31	11.729	2.833	0.831	0.227	0.278	136	34	55.582	430	1.015	210	61	0.154	33	22	117	154	6
170	RW1-1-170B	93.196	19.992	527	0.555	37	13.853	2.866	0.889	0.232	0.117	141	148	53.48	122	0.957	189	67	0.123	28	32	109	121	6
180	RW1-1-180B	94.212	20.471	513	0.514	30	8.619	3.085	0.87	0.242	0.091	152	87	59.052	97	1.04	216	42	0.085	31	20	115	99	6
190	RW1-1-190B	95.804	22.293	508	0.53	26	11.035	3.433	0.978	0.251	0.087	164	245	55.975	91	0.966	164	51	0.103	28	28	112	113	5
200	RW1-1-200B	97.149	23.74	466	0.582	21	15.844	3.512	1.078	0.244	0.099	160	375	50.89	90	0.846	126	58	0.155	25	40	110	114	3
210	RW1-1-210B	94.276	23.445	508	0.613	26	9.466	3.79	1.054	0.264	0.141	162	147	54.316	98	0.955	145	56	0.086	30	21	110	120	4
220	RW1-1-220B	93.11	21.597	503	0.602	30	7.017	3.469	0.98	0.225	0.159	170	73	57.87	103	1.017	196	46	0.052	35	16	105	123	6
230	RW1-1-230B	93.16	20.79	504	0.554	24	7.542	3.416	0.927	0.236	0.133	167	51	58.367	87	1.013	197	45	0.046	33	18	112	117	7
240	RW1-1-240B	92.994	21.898	520	0.573	39	4.124	3.596	0.965	0.239	0.153	180	22	60.213	98	1.049	201	50	0.046	35	12	107	109	7
250	RW1-1-250B	92.843	21.711	521	0.541	74	7.786	3.668	0.923	0.224	0.201	177	1107	56.508	112	0.998	170	78	0.029	39	24	112	120	4
260	RW1-1-260B	93.477	21.665	508	0.463	38	4.508	3.688	0.941	0.231	0.111	184	388	60.603	94	1.069	198	55	0.025	38	11	113	101	7
270	RW1-1-270B	93.308	22.22	531	0.502	79	4.127	3.789	1.018	0.262	0.122	187	228	60.057	96	1.03	184	65	0.019	36	16	112	104	6
280	RW1-1-280B	92.903	18.687	465	0.685	36	14.419	3.01	1.052	0.226	0.17	146	287	52.577	84	0.875	162	119	1.045	37	42	109	84	2
290	RW1-1-290B	93.749	20.889	509	0.546	44	4.45	3.701	1.027	0.235	0.136	184	177	61.548	98	1.034	194	63	0.025	39	17	107	118	6
300	RW1-1-300B	92.694	21.317	524	0.577	41	6.098	3.787	1.156	0.233	0.158	189	108	58.209	126	0.975	172	81	0.032	55	18	108	108	6
310	RW1-1-310B	92.838	21.648	536	0.528	32	7.414	3.718	1.179	0.236	0.118	192	33	58.848	116	0.972	168	84	0.031	55	17	110	102	3
320	RW1-1-320B	92.037	23.133	511	0.649	34	8.363	3.803	1.316	0.22	0.193	193	290	53.12	160	0.976	154	100	0.085	88	21	110	121	5
330	RW1-1-330B	93.376	20.657	465	0.573	30	8.493	3.503	1.231	0.226	0.129	162	46	57.377	103	0.952	167	119	0.091	95	23	103	112	4
340	RW1-1-340B	95.318	20.336	473	0.603	35	10.236	3.333	1.236	0.243	0.141	170	81	57.976	89	0.938	172	148	0.128	83	23	110	91	6
350	RW1-1-350B	91.081	22.85	487	0.625	46	6.15	3.666	1.48	0.227	0.179	181	45	54.744	119	0.974	173	131	0.039	45	20	103	120	6
STANDARDS																								
	GSD-9	93.617	10.751	412	4.903	46	5.006	1.99	2.478	1.502	0.158	81	139	65.685	165	0.913	376	72	0.077	27	12	90	77	9
	NBS2704	91.805	12.148	421	3.565	116	5.919	2.493	2.043	0.774	0.226	100	3018	63.328	133	0.76	292	450	0.074	27	15	91	70	7
	GSD-9	94.224	10.799	404	4.932	49	5.004	2.005	2.496	1.508	0.159	81	134	66.172	166	0.918	377	72	0.079	27	11	93	81	9
	NBS2704	91.428	12.101	424	3.554	114	5.667	2.484	2.036	0.770	0.225	99.000	3000	63.088	131	0.758	287	441	0.074	27.000	15.000	92.000	75.000	6.000
	GSD-9	94.537	10.644	410	4.95	48	5.01	2.017	2.5	1.509	0.16	83	132	66.397	167	0.921	380	73	0.079	28	12	94	81	8
	NBS2704	91.568	12.104	414	3.556	115	5.909	2.488	2.034	0.77	0.224	100	3007	63.173	133	0.759	291	447	0.075	27	15	92	78	6

Field Site Rockwood 1-2 Microhigh N35°53.762'
Run Date 12/22/02 W084°42.158'
Operator Bill Dean
Calibration Soil&Sed Cal
Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	S* (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	RW1-2-00B	85.628	28.594	685	0.448	48	2.128	2.023	0.607	0.231	0.173	124	888	52.133	389	1.211	289	77	0.007	45	9	125	109	10
10	RW1-2-10B	88.808	27.349	627	0.432	54	1.842	2.14	0.703	0.237	0.107	129	416	54.568	161	1.218	316	96	0.01	43	10	123	96	9
20	RW1-2-20B	89.318	26.939	589	0.436	25	2.033	2.207	0.715	0.266	0.132	129	317	55.168	228	1.217	322	64	0.008	45	7	124	110	11
30	RW1-2-30B	88.882	25.832	603	0.431	45	1.971	2.125	0.712	0.242	0.118	125	293	56.003	200	1.241	330	85	0.008	46	13	124	130	11
40	RW1-2-40B	89.711	26.438	634	0.432	49	1.862	2.118	0.719	0.246	0.138	125	273	56.308	242	1.239	325	92	0.008	46	11	124	131	11
50	RW1-2-50B	93.275	21.057	431	0.409	23	1.555	1.888	0.629	0.238	0.071	106	175	66.001	78	1.263	445	51	0.005	42	12	125	101	12
60	RW1-2-60B	91.979	23.275	438	0.408	22	1.806	2.066	0.703	0.239	0.069	112	167	62	74	1.254	392	55	0.008	40	7	126	93	12
70	RW1-2-70B	91.946	23.788	465	0.406	24	2.068	2.236	0.733	0.244	0.066	121	133	61.001	70	1.247	372	58	0.008	41	8	117	103	10
80	RW1-2-80B	92.336	23.505	471	0.41	24	2.68	2.218	0.709	0.254	0.085	121	202	61.103	91	1.185	354	61	0.025	40	7	122	98	10
90	RW1-2-90B	91.249	22.868	468	0.409	24	1.948	2.24	0.698	0.235	0.095	123	109	61.431	110	1.165	355	54	0.008	38	7	113	90	11
100	RW1-2-100B	91.505	20.666	398	0.466	43	14.291	1.844	0.673	0.229	0.105	100	355	51.824	92	0.986	294	104	0.271	38	33	114	112	7
110	RW1-2-110B	83.955	12.02	258	0.617	39	42.593	0.906	0.588	0.16	0.145	51	136	25.093	110	0.524	173	164	1.176	41	92	113	127	-4
120	RW1-2-120B	91.984	22.998	474	0.406	36	3.968	2.345	0.674	0.233	0.095	129	371	59.901	114	1.139	345	60	0.007	37	11	120	78	10
130	RW1-2-130B	91.213	20.685	1153	0.478	41	9.574	2.329	0.891	0.212	0.275	110	570	55.622	432	0.977	288	115	0.067	44	22	114	135	7
140	RW1-2-140B	92.563	20.14	450	0.424	33	5.453	2.544	0.685	0.245	0.067	122	421	61.734	85	1.051	338	73	0.023	38	16	116	76	9
150	RW1-2-150B	92.029	18.097	411	0.422	40	8.441	2.202	0.604	0.203	0.084	110	773	60.722	65	1.018	345	109	0.026	36	26	115	70	9
160	RW1-2-160B	93.297	17.718	1038	0.642	33	17.85	2.247	0.832	0.224	0.284	107	0	52.125	391	0.932	204	78	0.223	37	39	117	156	4
170	RW1-2-170B	87.845	13.529	419	0.662	27	31.871	1.818	1.005	0.201	0.197	91	-40	36.94	117	0.681	150	92	0.619	28	68	112	137	-1
180	RW1-2-180B	91.528	16.985	520	0.809	29	19.006	2.406	0.924	0.201	0.255	118	76	49.561	138	0.873	188	82	0.382	34	40	114	115	3
190	RW1-2-190B	94.672	18.205	588	0.726	25	20.285	2.567	0.901	0.219	0.226	123	295	50.246	171	0.855	179	70	0.269	32	43	111	101	3
200	RW1-2-200B	92.226	19.532	1049	1.344	35	10.634	2.869	0.844	0.215	0.806	136	315	54.628	388	0.969	208	68	0.133	51	28	104	132	6
210	RW1-2-210B	93.199	17.774	426	0.596	23	15.989	2.711	0.896	0.209	0.118	131	418	53.596	78	0.89	193	64	0.257	30	40	105	99	2
220	RW1-2-220B	93.546	20.194	501	0.515	41	10.714	3.19	0.883	0.223	0.137	153	729	56.405	95	0.961	192	86	0.115	32	25	107	116	5
STANDARDS																								
	GSD-9	94.284	10.832	406	4.936	48	4.968	2.006	2.493	1.509	0.16	82	132	66.21	166	0.919	378	73	0.079	27	11	93	79	10
	NBS2704	90.606	11.994	418	3.531	115	5.862	2.474	2.02	0.765	0.224	98	2981	62.441	131	0.753	286	442	0.073	27	14	90	79	6
	GSD-9	94.687	10.836	419	4.962	47	5.018	2.011	2.515	1.502	0.16	83	134	66.531	167	0.92	383	74	0.079	27	12	93	76	9
	NBS2704	91.211	12.037	417	3.548	115	5.89	2.477	2.039	0.77	0.224	100	2996	62.925	133	0.758	292	446	0.073	27	15	91	62	7

Field Site Rockwood 1-3 Microrlow N35°53.765'
Run Date 12/3/02 W084°42.159'
Operator Bill Dean
Calibration Soil&Sed Cal
Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	Sr (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	RW1-3-00B	87.86	27.369	678	0.448	57	1.825	2.06	0.677	0.233	0.143	125	607	53.533	283	1.222	286	104	0.01	42	12	123	109	9
10	RW1-3-10B	88.81	28.034	637	0.439	42	2.226	2.175	0.738	0.251	0.11	134	485	53.402	183	1.207	299	88	0.009	45	8	119	137	9
20	RW1-3-20B	87.582	28.434	800	0.467	36	2.362	1.978	0.662	0.227	0.278	125	408	51.672	686	1.222	258	82	0.007	53	7	122	188	10
30	RW1-3-30B	87.838	28.103	702	0.452	37	2.751	2.111	0.741	0.247	0.201	135	427	51.737	434	1.241	259	103	0.007	51	12	125	171	9
40	RW1-3-40B	90.245	28.293	523	0.417	28	2.011	2.211	0.758	0.253	0.076	128	199	56.774	90	1.277	346	74	0.006	46	6	125	100	12
50	RW1-3-50B	91.135	25.202	489	0.416	27	2.123	2.193	0.789	0.266	0.072	124	188	58.594	82	1.332	355	70	0.005	44	6	128	89	12
60	RW1-3-60B	92.886	23.171	454	0.408	26	1.783	2.282	0.731	0.25	0.067	125	60	62.841	77	1.205	359	62	0.006	39	9	121	84	11
70	RW1-3-70B	91.195	23.733	474	0.408	26	1.91	2.246	0.73	0.241	0.078	121	119	60.504	81	1.189	358	66	0.007	38	7	115	91	11
80	RW1-3-80B	92.453	19.801	435	0.408	23	1.513	2.038	0.64	0.228	0.072	110	110	66.417	70	1.189	378	52	0.007	38	8	120	89	11
90	RW1-3-90B	91.701	23.791	491	0.469	33	5.137	2.274	0.745	0.252	0.112	122	149	57.599	101	1.117	320	100	0.045	39	14	118	101	10
100	RW1-3-100B	90.878	25.832	543	0.443	43	4.089	2.435	0.782	0.239	0.149	136	452	55.576	200	1.109	287	86	0.022	41	11	112	121	8
110	RW1-3-110B	91.644	24.543	496	0.432	40	5.674	2.394	0.754	0.241	0.123	128	439	56.161	156	1.076	301	93	0.051	39	14	117	118	8
120	RW1-3-120B	93.538	22.154	476	0.419	39	5.125	2.69	0.741	0.235	0.081	133	377	60.789	86	1.103	311	71	0.027	37	13	116	74	9
130	RW1-3-130B	93.399	22.269	479	0.402	25	2.453	2.605	0.68	0.226	0.066	140	277	63.365	112	1.14	328	42	0.006	38	8	118	89	10
140	RW1-3-140B	90.361	18.154	1397	0.519	43	13.986	1.983	0.573	0.192	0.394	97	1297	53.133	530	0.929	300	90	0.086	40	34	109	182	7
150	RW1-3-150B	90.819	22.226	1439	0.507	92	8.376	2.656	0.752	0.229	0.412	129	863	54.209	693	1.022	244	102	0.037	55	24	109	187	6
160	RW1-3-160B	91.075	17.207	391	0.528	85	17.544	1.911	0.89	0.199	0.133	94	537	51.632	89	0.885	295	124	0.155	35	43	114	91	3
170	RW1-3-170B	92.036	21.212	455	0.412	38	4.394	2.402	0.67	0.216	0.148	120	823	61.31	136	1.043	341	45	0.007	38	11	113	92	9
180	RW1-3-180B	92.8	18.81	398	0.422	44	6.328	2.182	0.638	0.199	0.118	109	782	62.857	116	1.008	369	72	0.023	39	19	114	72	9
190	RW1-3-190B	92.967	18.047	401	0.436	30	6.678	2.223	0.671	0.196	0.093	112	585	63.354	99	1.021	371	79	0.054	39	22	114	74	11
200	RW1-3-200B	92.923	18.014	398	0.424	29	6.151	2.194	0.656	0.229	0.093	110	608	63.915	90	1.015	377	88	0.038	37	22	115	72	10
210	RW1-3-210B	90.251	18.859	443	0.449	28	7.934	2.331	0.71	0.197	0.1	119	655	58.419	103	0.981	286	133	0.065	36	30	112	97	8
220	RW1-3-220B	89.936	15.886	409	0.814	24	17.359	2.564	0.868	0.196	0.136	125	408	50.92	78	0.859	179	85	0.369	33	83	105	107	3
STANDARDS																								
	NBS2704	91.371	12.016	400	3.545	114	5.914	2.469	2.028	0.75	0.223	99	3054	63.121	133	0.754	290	442	0.075	27	14	90	77	7
	GSD-9	93.093	10.639	402	4.883	46	4.897	1.976	2.456	1.479	0.158	80	167	65.473	164	0.904	370	72	0.077	27	9	96	73	10
	NBS2704	91.216	12.075	415	3.549	114	5.88	2.481	2.037	0.769	0.224	99	2993	62.898	132	0.758	290	445	0.074	27	15	91	70	6
	GSD-9	94.72	10.85	406	4.951	48	4.997	2.016	2.513	1.508	0.16	82	130	66.572	167	0.925	381	74	0.079	28	11	94	70	9

Rockwood 1-1 paleosol bulk density

Sample Name	Depth (cm)	wt. in air		wt. in water		Bulk density (p, g/cm ³)	Porosity (%)	Pp1/Pw
		(g)	w/par (g)	(g)	w/par (g)			
RW1-1-00	0	10.35	11.12	5.93	2.10746806	20.47298	0.88421	
RW1-1-10	10	15.14	15.93	8.94	2.19774194	17.06834	0.94379	
RW1-1-20	20	12.58	13.35	7.45	2.20701754	16.71632	0.93982	
RW1-1-30	30	11.84	12.8	7.05	2.22463466	16.05152	0.93238	
RW1-1-40	40	12.63	13.45	7.66	2.28712274	13.69348	0.9069	
RW1-1-50	50	15.06	16	9.28	2.3449827	11.51009	0.88453	
RW1-1-60	60	10.17	10.84	6.15	2.27688587	14.08054	0.91099	
RW1-1-70	70	31.55	32.6	18.93	2.25	15.09434	0.92187	
RW1-1-80	80	24.63	25.69	15.06	2.31630094	12.59242	0.89548	
RW1-1-90	90	11.22	12.03	8.85	2.31075515	12.80169	0.89763	
RW1-1-100	100	23.82	24.91	14.69	2.34808324	11.39309	0.88336	
RW1-1-110	110	13.16	13.89	8.13	2.35487197	11.14445	0.88089	
RW1-1-120	120	21.3	22.23	13.08	2.33211679	11.99559	0.88941	
RW1-1-130	130	18.72	19.55	11.61	2.36962025	10.58037	0.87533	
RW1-1-140	140	18.47	17.35	11.02	2.71981651	-2.83459	0.76282	
RW1-1-150	150	51.36	53.28	32.52	2.45350318	7.414974	0.8454	
RW1-1-160	160	28.45	39.67	18.17	2.49075875	6.009104	0.83276	
RW1-1-170	170	35.2	36.67	22	2.4	9.433962	0.86425	
RW1-1-180	180	34.85	35.82	21.74	2.41556933	8.846441	0.85868	
RW1-1-190	190	41.91	45.41	27.71	2.65626781	-0.23651	0.78067	
RW1-1-200	200	41.23	42.44	26.31	2.48708434	6.148515	0.83399	
RW1-1-210	210	23.36	24.32	14.65	2.41377727	8.914065	0.85932	
RW1-1-220	220	28	29.01	17.18	2.32902033	12.11244	0.89059	
RW1-1-230	230	34.17	35.21	20.86	2.31051841	12.81063	0.89772	
RW1-1-240	240	41.08	42.19	25.33	2.34742857	11.41779	0.8836	
RW1-1-250	250	46.07	47.99	27.67	2.25342391	14.96514	0.92047	
RW1-1-260	260	33.87	35.07	20.83	2.30234139	13.11919	0.90091	
RW1-1-270	270	56.46	58.1	34.13	2.27558337	14.12855	0.9115	
RW1-1-280	280	46	48.82	28.9	2.42105263	8.639523	0.85673	
RW1-1-290	290	56.36	59.71	34.07	2.2758393	14.12682	0.91148	
RW1-1-300	300	38.41	40.9	23.01	2.24474026	15.29282	0.92403	
RW1-1-310	310	98.44	103.43	59.11	2.25263158	14.99503	0.92079	
RW1-1-320	320	24.34	25.15	14.84	2.25835052	14.77923	0.91846	
RW1-1-330	330	91.18	93.32	55.14	2.27697003	14.0766	0.91095	
RW1-1-340	340	8	8.71	4.91	2.33009709	12.07181	0.89018	
RW1-1-350	350	15.81	16	8.95	2.07419825	21.72837	1	

Rockwood 1-2 paleosol bulk density

Sample Name	Depth (cm)	wt. in air		wt. in water		Bulk density (p, g/cm ³)	Porosity (%)	Pp1/Pw
		(g)	w/par (g)	(g)	w/par (g)			
RW1-2-00	0	82.4	30.14	16.92	1.10174881	58.42457	1.88264	
RW1-2-10	10	23.45	24.09	13.72	2.16906475	18.1485	0.95626	
RW1-2-20	20	15.24	15.66	8.87	2.15321821	18.74648	0.9633	
RW1-2-30	30	16.74	17.5	9.51	2.08381743	21.36538	0.99538	
RW1-2-40	40	40.26	42.32	24.91	2.36052117	10.92373	0.8787	
RW1-2-50	50	21.9	22.59	13.22	2.27073733	14.3118	0.91345	
RW1-2-60	60	17.27	17.67	10.35	2.24809827	15.24157	0.92347	
RW1-2-70	70	13.16	13.59	7.94	2.26995552	14.37666	0.91416	
RW1-2-80	80	21.54	22.26	12.98	2.26471963	14.53888	0.91587	
RW1-2-90	90	14.14	14.49	9.26	2.80778689	1.592948	0.79539	
RW1-2-100	100	14.21	14.72	8.83	2.37713755	10.2967	0.87256	
RW1-2-110	110	33.7	34.72	20.56	2.30821918	12.89739	0.89861	
RW1-2-120	120	27.78	28.63	17.16	2.35423729	11.16066	0.88105	
RW1-2-130	130	12.74	13.36	7.72	2.28409875	13.80892	0.90812	
RW1-2-140	140	44.59	46	26.51	2.21983496	16.24019	0.93448	
RW1-2-150	150	69.56	70.8	41.19	2.20669722	16.72841	0.93996	
RW1-2-160	160	11.74	12.59	7.3	2.37972973	10.19888	0.87161	
RW1-2-170	170	22.65	23.12	14.2	2.41242604	8.965055	0.8598	
RW1-2-180	180	114.7	116.22	77.74	2.79455727	-5.45499	0.74223	
RW1-2-190	190	57.82	59.17	37.29	2.53472988	4.349824	0.81831	
RW1-2-200	200	25.3	26.4	16.02	2.45366379	7.408913	0.84535	
RW1-2-210	210	21.26	21.95	12.96	2.3053012	13.0075	0.89975	
RW1-2-220	220	58.4	60.5	36.5	2.4	9.433962	0.88425	

Rockwood 1-3 paleosol bulk density

Sample Name	Depth (cm)	wt. in air		wt. in water		Bulk density (p, g/cm ³)	Porosity (%)	Pp1/Pw
		(g)	w/par (g)	(g)	w/par (g)			
RW1-3-00	0	14	14.36	8.1	2.13559322	19.41158	1.12381	
RW1-3-10	10	13.14	13.61	7.76	2.19814126	17.05127	1.09183	
RW1-3-20	20	14.3	15.29	8.13	2.06569951	21.28681	1.15058	
RW1-3-30	30	13.84	14.51	8.24	2.22428571	16.06469	1.079	
RW1-3-40	40	22.48	23.14	13.61	2.28094701	13.92653	1.05219	
RW1-3-50	50	12.14	12.61	7.37	2.29058604	13.56355	1.04778	
RW1-3-60	60	24.07	24.59	14.78	2.33186222	12.0052	1.02922	
RW1-3-70	70	26.81	27.32	16.44	2.3268081	12.19592	1.03146	
RW1-3-80	80	14.36	15.02	8.77	2.31198569	12.75526	1.03807	
RW1-3-90	90	17.91	18.63	11.15	2.38446746	10.0201	1.00651	
RW1-3-100	100	18.84	19.59	11.47	2.30067843	13.18195	1.04317	
RW1-3-110	110	29.8	30.8	18	2.27288136	14.23089	1.05593	
RW1-3-120	120	24.11	25	14.5	2.25796046	14.79394	1.06291	
RW1-3-130	130	36.51	37.87	20.59	2.06400754	22.11292	1.16279	
RW1-3-140	140	18.12	18.87	10.74	2.2097561	16.61298	1.08609	
RW1-3-150	150	17.35	18.28	10.21	2.18697479	17.47265	1.09741	
RW1-3-160	160	26.66	28.05	16.21	2.29607656	13.3556	1.04526	
RW1-3-170	170	14.83	15.63	8.68	2.1702439	18.104	1.10587	
RW1-3-180	180	18.49	19.38	11	2.22176235	16.15991	1.08022	
RW1-3-190	190	8.78	9.45	5.17	2.18891967	17.39926	1.09643	
RW1-3-200	200	42.11	43.73	24.7	2.17685238	17.85463	1.10251	
RW1-3-210	210	21.9	23	13.14	2.25	15.09434	1.06667	
RW1-3-220	220	20.62	21.51	12.83	2.38228498	10.10245	1.00744	

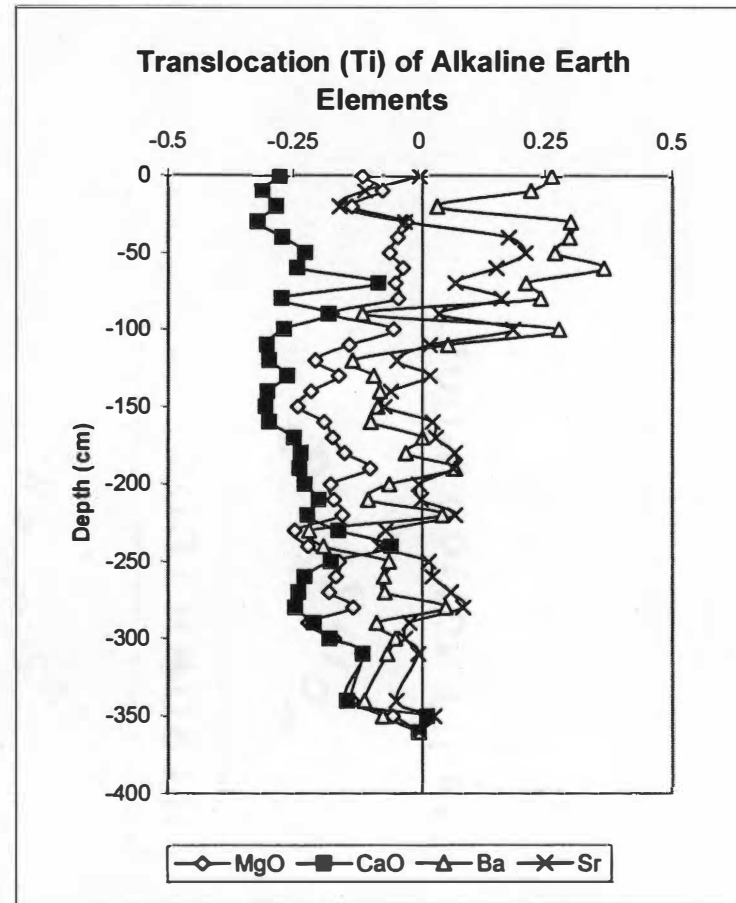
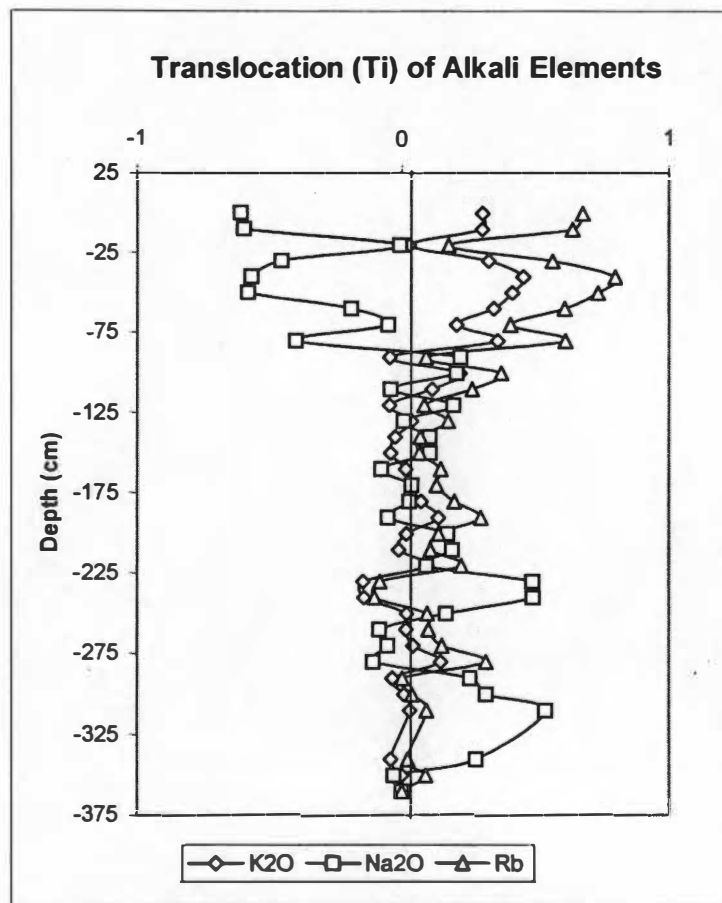
Field Site Iydeli 1 N36°28.134'
Run Date 11/22/02 W084°10.716'
Operator Bill Dean
Calibration Soil&Sed Cal
Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	S* (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
0	ID1-00B	95.311	20.852	579	0.413	20	1.534	3.313	0.765	0.395	0.055	142	80	66.841	83	1.191	291	39	0.003	37	5	112	102	10
5	ID1-05B	94.016	20.002	561	0.42	15	1.336	3.085	0.708	0.393	0.056	133	14	66.876	80	1.198	278	53	0.003	35	11	117	88	10
10	ID1-10B	94.866	21.83	574	0.416	15	1.543	3.205	0.773	0.431	0.053	141	17	65.243	80	1.228	285	39	0.005	36	1	120	95	10
15	ID1-15B	92.836	21.99	578	0.419	17	1.6	3.235	0.777	0.428	0.054	145	-31	62.933	84	1.262	268	34	0.003	36	9	115	114	10
20	ID1-20B	94.279	22.395	579	0.418	16	1.677	3.312	0.794	0.439	0.054	149	-30	63.788	85	1.26	270	39	0.003	36	5	116	110	10
25	ID1-25B	93.533	19.562	562	0.436	20	1.63	3.174	0.767	0.368	0.055	139	450	66.172	88	1.18	280	40	0.004	37	11	116	92	10
30	ID1-30B	93.834	21.227	585	0.418	20	1.548	3.344	0.784	0.412	0.056	145	203	64.667	83	1.212	278	40	0.004	36	6	119	102	10
35	ID1-35B	95.121	18.618	539	0.407	20	1.913	3.055	0.705	0.345	0.052	129	1242	68.586	72	1.178	292	30	0.008	36	8	117	78	10
40	ID1-40B	93.574	18.457	543	0.414	24	2.985	3.237	0.853	0.351	0.056	136	166	65.914	70	1.153	287	48	0.019	39	26	117	87	9
45	ID1-45B	92.077	15.986	494	0.424	42	5.047	2.824	0.918	0.338	0.058	111	223	65.099	69	1.061	277	97	0.158	41	47	112	94	8
50	ID1-50B	93.908	18.93	552	0.418	33	5.854	3.291	1.083	0.368	0.068	141	109	62.652	74	1.051	218	100	0.045	42	18	113	102	7
60	ID1-60B	92.792	14.677	464	0.546	28	8.494	2.525	0.742	0.434	0.09	104	75	64.081	67	0.973	268	75	0.095	43	31	107	82	7
STANDARDS																								
	NBS2704	91.454	11.986	419	3.531	115	5.896	2.478	2.034	0.789	0.225	100	3059	63.21	132	0.756	289	446	0.073	27	15	90	74	7
	GSD-9	92.413	10.54	401	4.847	44	4.854	1.97	2.437	1.476	0.157	80	144	65.009	163	0.899	370	72	0.076	26	10	96	78	9

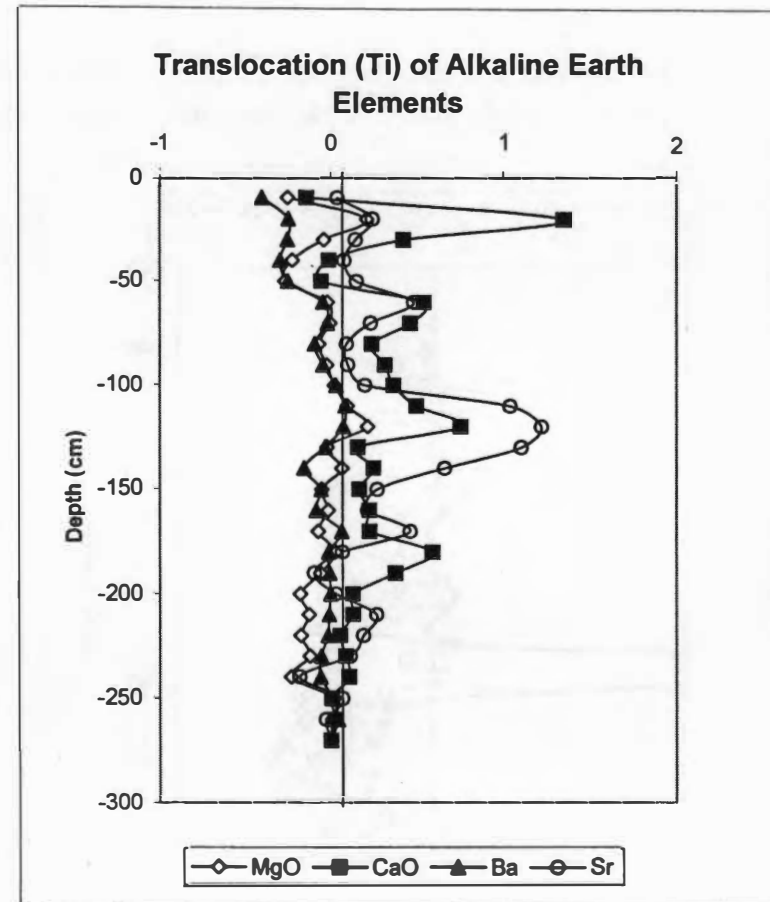
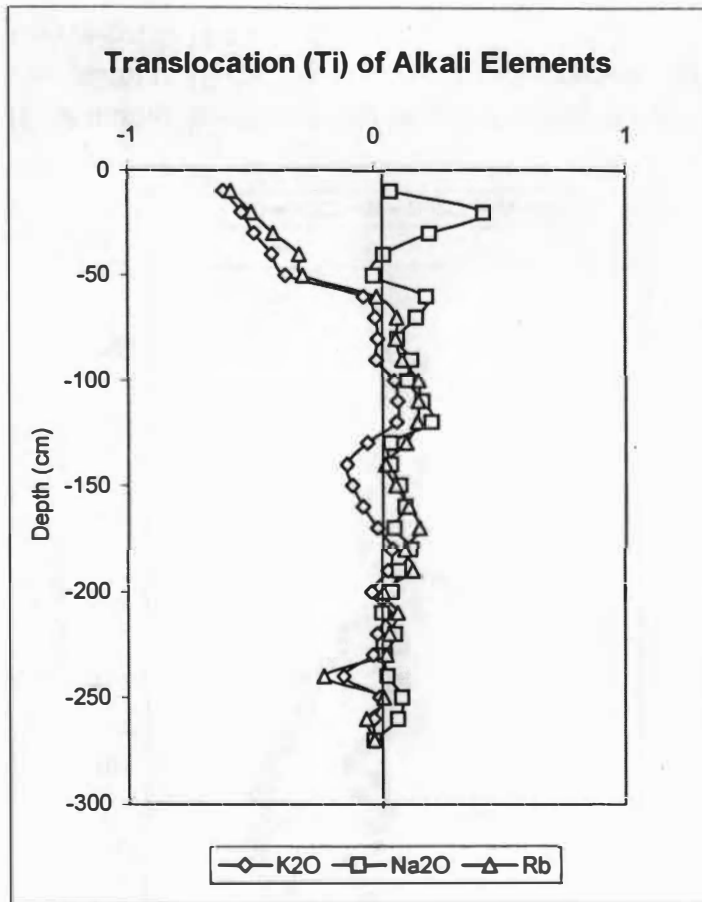
Field Site Petros 9 Core N36°05.58'
Run Date 11/22/02 W084°25.752'
Operator Bill Dean
Calibration Soil&Sed Cal
Field Collection Eric Ober

Depth (cm)	Sample Name	Sum of Conc. (%)	Al2O3 (%)	Ba (ppm)	CaO (%)	Cu (ppm)	Fe2O3 (%)	K2O (%)	MgO (%)	Na2O (%)	P2O5 (%)	Rb (ppm)	S* (ppm)	SiO2 (%)	Sr (ppm)	TiO2 (%)	Zr (ppm)	Zn (ppm)	MnO (%)	Y (ppm)	Co (ppm)	Cr (ppm)	V (ppm)	Hf (ppm)
17	PT9-1-17B	95.239	16.251	497	0.41	20	2.181	2.665	0.638	0.375	0.053	122	70	71.55	61	0.976	244	60	0.007	28	23	104	97	9
23	PT9-1-23B	94.879	19.149	560	0.414	27	1.817	2.967	0.728	0.422	0.055	136	645	68.087	72	1.036	243	48	0.007	30	13	110	101	9
30	PT9-1-30B	94.899	18.833	552	0.432	21	1.484	2.879	0.732	0.423	0.055	126	694	68.848	82	1.004	247	68	0.003	30	12	110	100	9
35	PT9-1-35B	92.408	15.356	516	0.452	26	5.454	2.908	0.703	0.373	0.061	122	112	65.965	68	0.951	231	92	0.043	39	41	102	90	7
40	PT9-1-40B	96.188	17.637	527	0.407	21	1.267	2.945	0.708	0.404	0.056	125	34	71.689	68	0.94	239	67	0.003	29	14	101	104	8
50	PT9-1-50B	94.161	17.378	528	0.419	26	2.317	2.931	0.692	0.416	0.056	125	38	68.847	66	0.96	232	56	0.013	32	22	102	83	8
55	PT9-1-55B	93.628	19.512	539	0.419	25	1.956	3.123	0.771	0.477	0.063	136	2	66.181	77	0.984	250	53	0.007	39	14	108	93	9
58	PT9-1-58B	95.31	20.033	546	0.415	26	1.287	3.08	0.774	0.495	0.06	129	41	68.069	76	0.956	232	57	0.004	35	11	107	80	8
60	PT9-1-60B	93.176	17.377	514	0.409	30	0.979	2.891	0.693	0.465	0.059	119	-30	69.253	70	0.923	233	41	0.003	34	25	104	79	10
65	PT9-1-65B	96.187	15.771	502	0.403	25	0.956	2.631	0.649	0.507	0.054	105	40	74.246	62	0.84	218	54	0.005	29	17	102	81	8
70	PT9-1-70B	97.801	8.746	291	0.424	18	0.978	1.627	0.673	0.782	0.051	57	55	83.813	45	0.594	189	91	0.019	22	45	92	35	8
80	PT9-1-80B	97.335	11.179	337	0.404	21	0.501	1.977	0.669	0.808	0.061	69	45	80.92	59	0.695	201	151	0.009	28	55	94	45	8
STANDARDS																								
	NBS2704	91.858	12.037	403	3.553	115	5.912	2.468	2.038	0.791	0.226	100	3064	63.506	133	0.758	291	445	0.073	27	15	91	71	7
	GSD-9	91.678	10.458	403	4.818	43	4.821	1.949	2.427	1.463	0.156	79	148	64.472	162	0.89	365	71	0.075	27	10	94	74	10

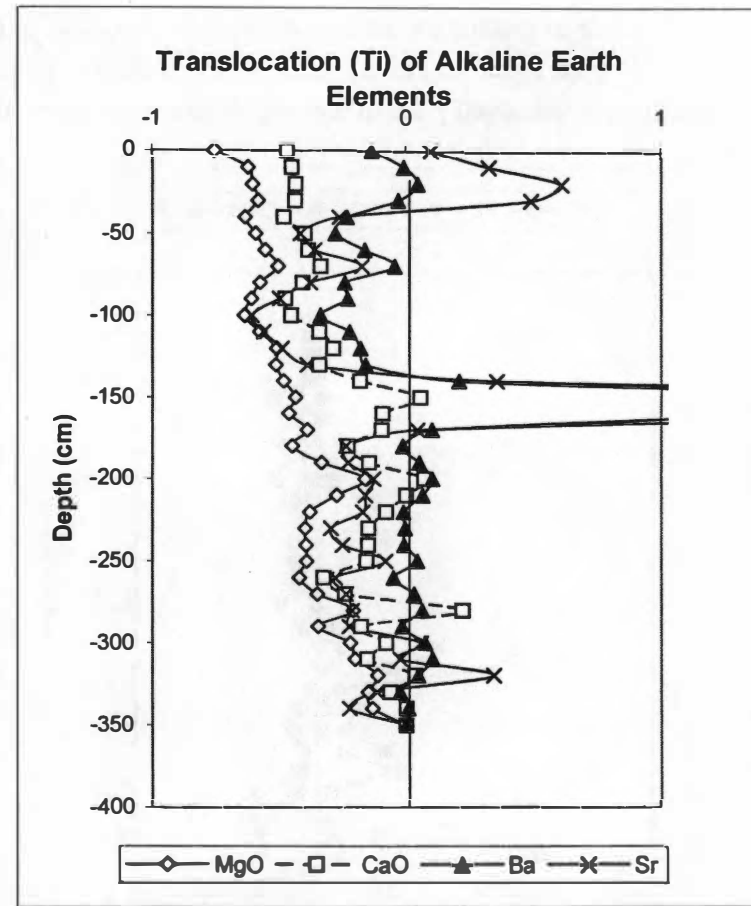
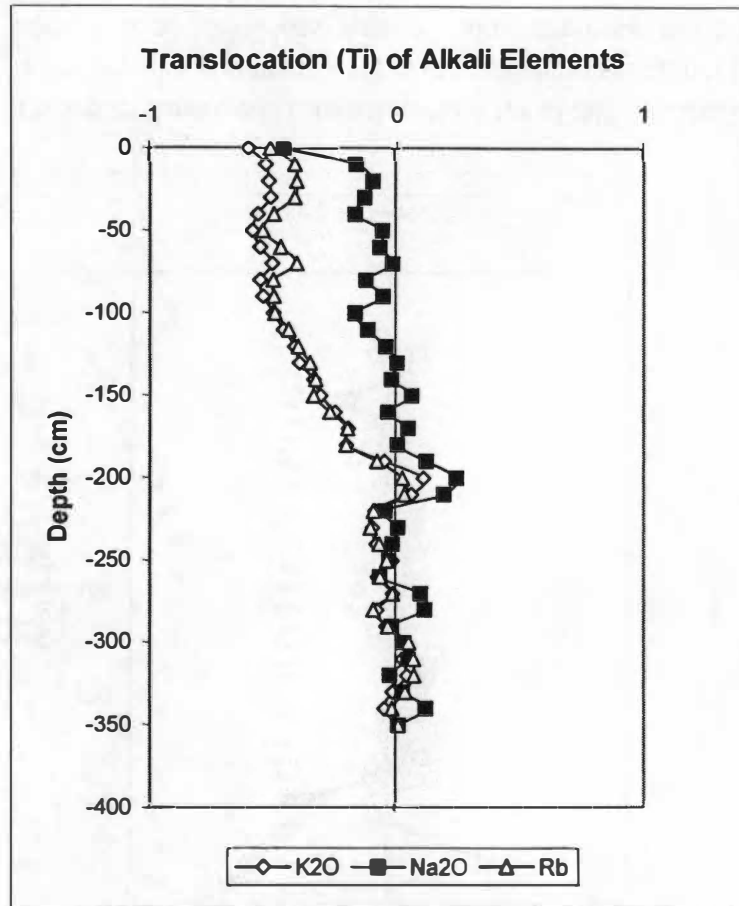
Appendix B



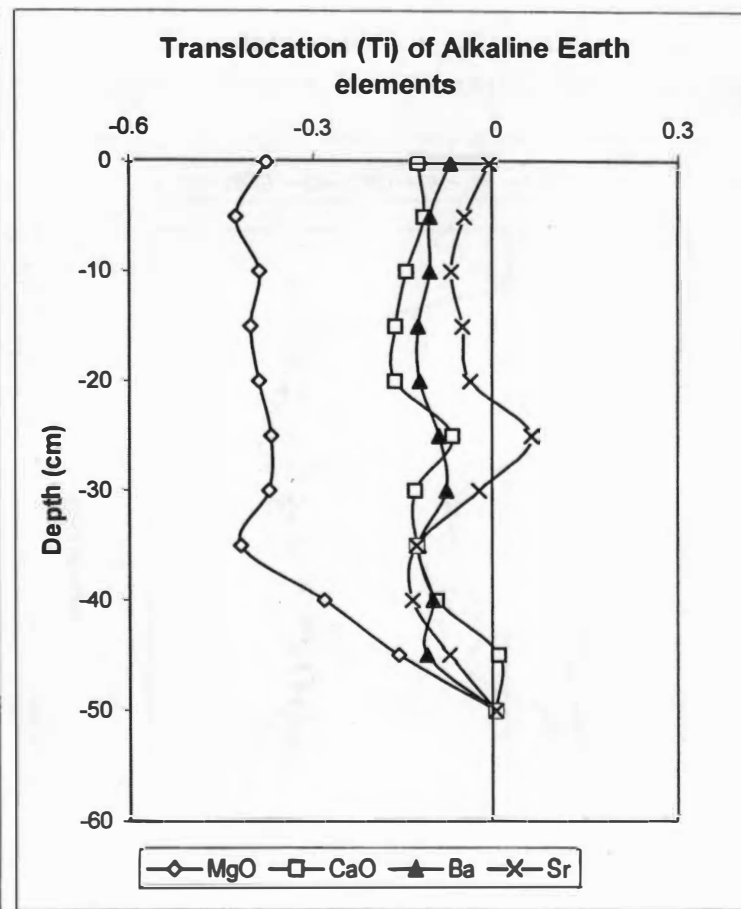
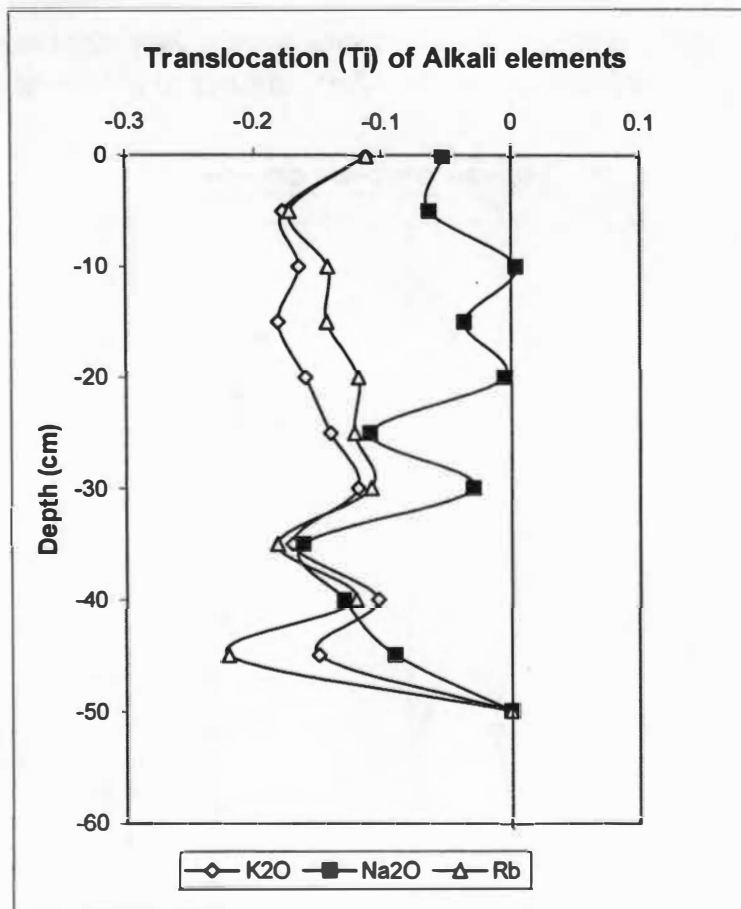
Transport functions (τ ; translocation) for alkali and alkaline earth elements in the Wartburg 1 paleosol, assuming Ti is the immobile element. Negative values represent net loss of constituent relative to parent material with -1 equivalent to 100% loss; positive values represent net gain of constituent relative to parent material with +1 equivalent to 100%.



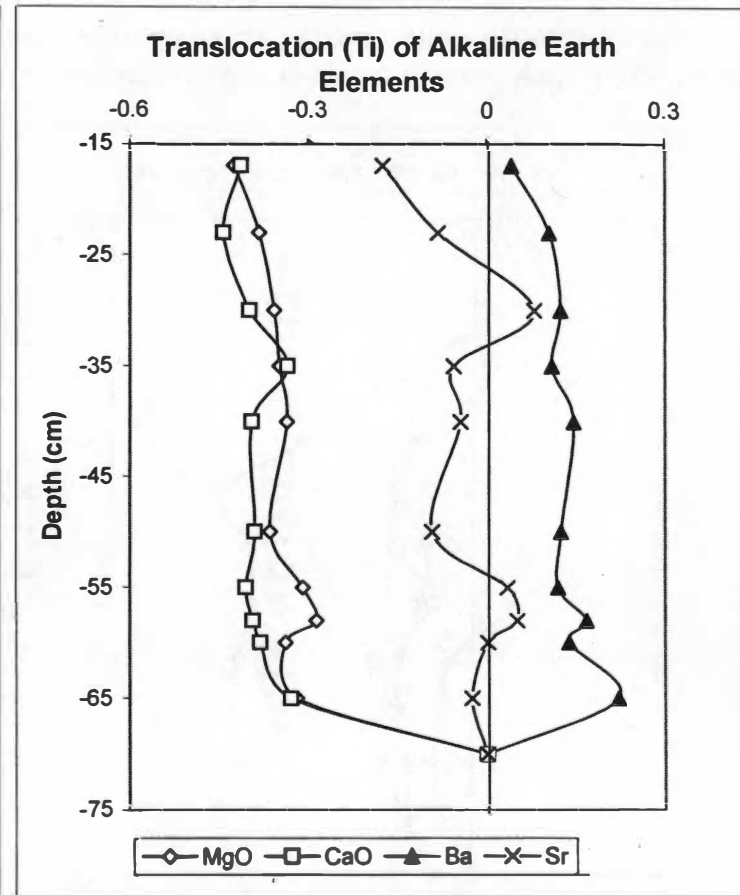
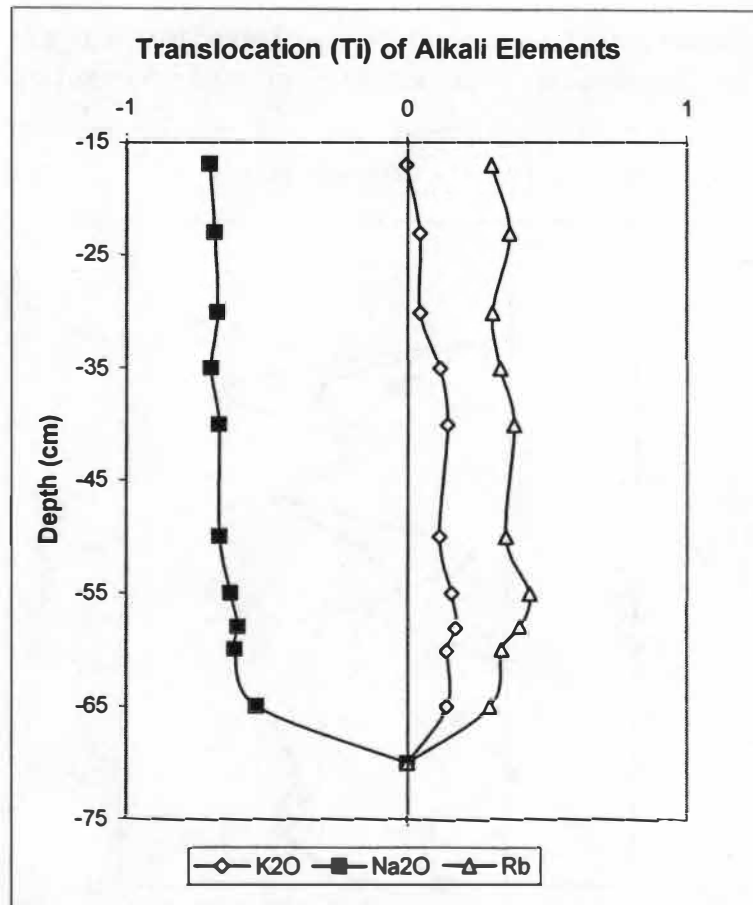
Transport functions (τ ; translocation) for alkali and alkaline earth elements in the Wartburg 2 paleosol, assuming Ti is the immobile element. Negative values represent net loss of constituent relative to parent material with -1 equivalent to 100% loss; positive values represent net gain of constituent relative to parent material with +1 equivalent to 100%.



is the immobile element. Negative values represent net loss of constituent relative to parent material with -1 equivalent to 100% loss; positive values represent net gain of constituent relative to parent material with +1 equivalent to 100%.

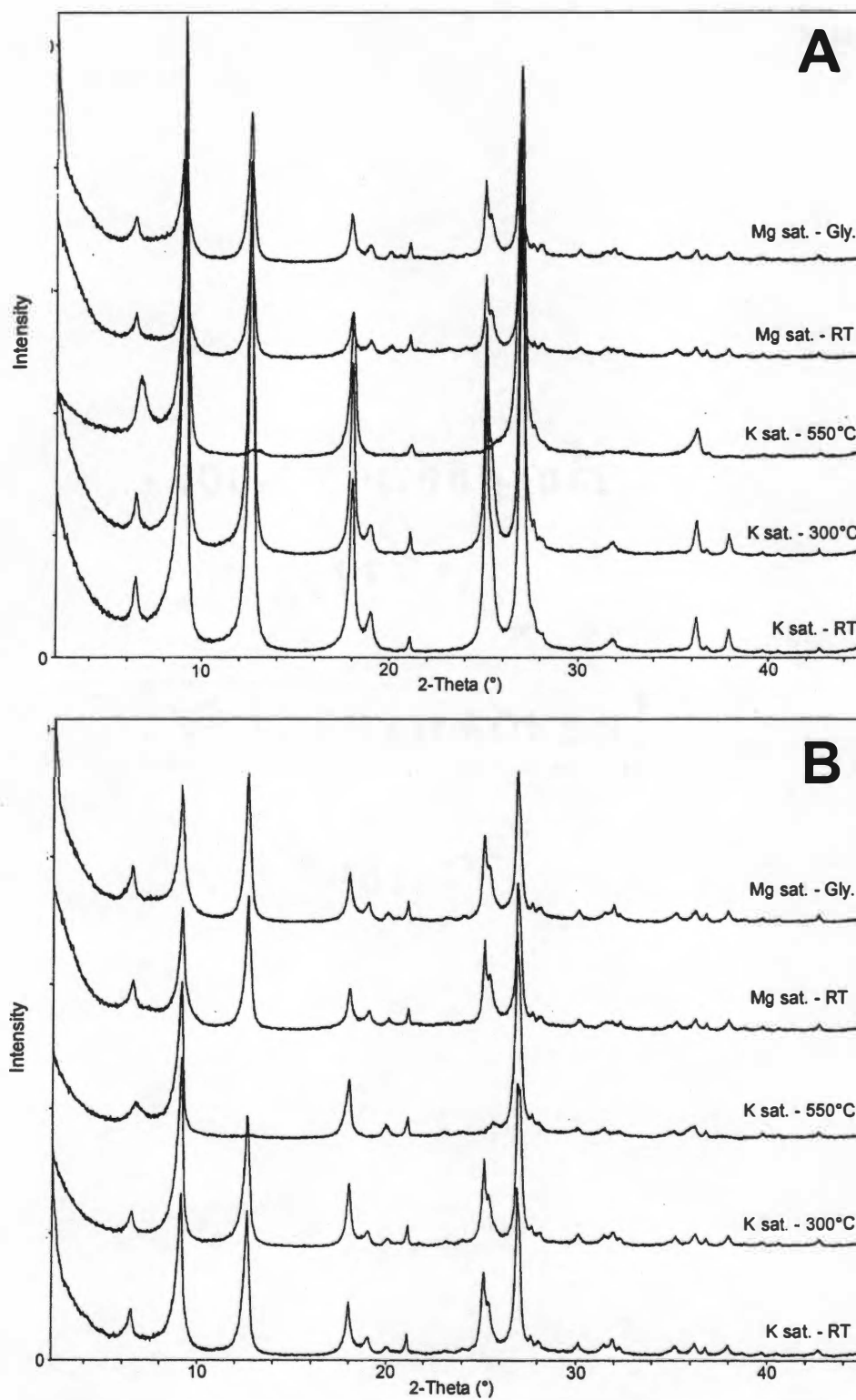


the immobile element. Negative values represent net loss of constituent relative to parent material with -1 equivalent to 100% loss; positive values represent net gain of constituent relative to parent material with +1 equivalent to 100%.

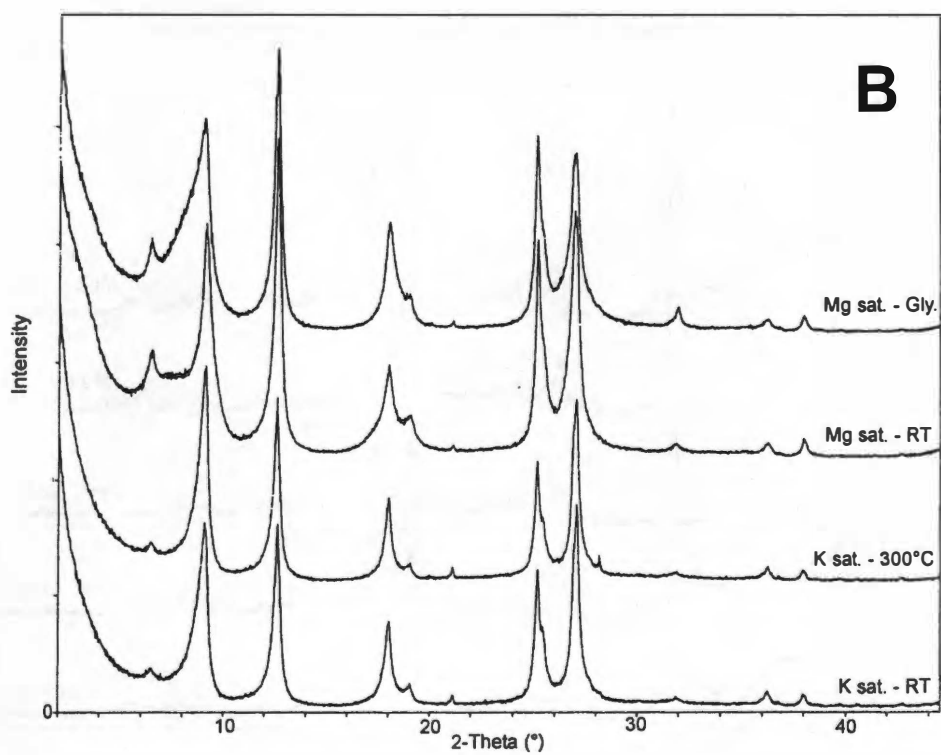
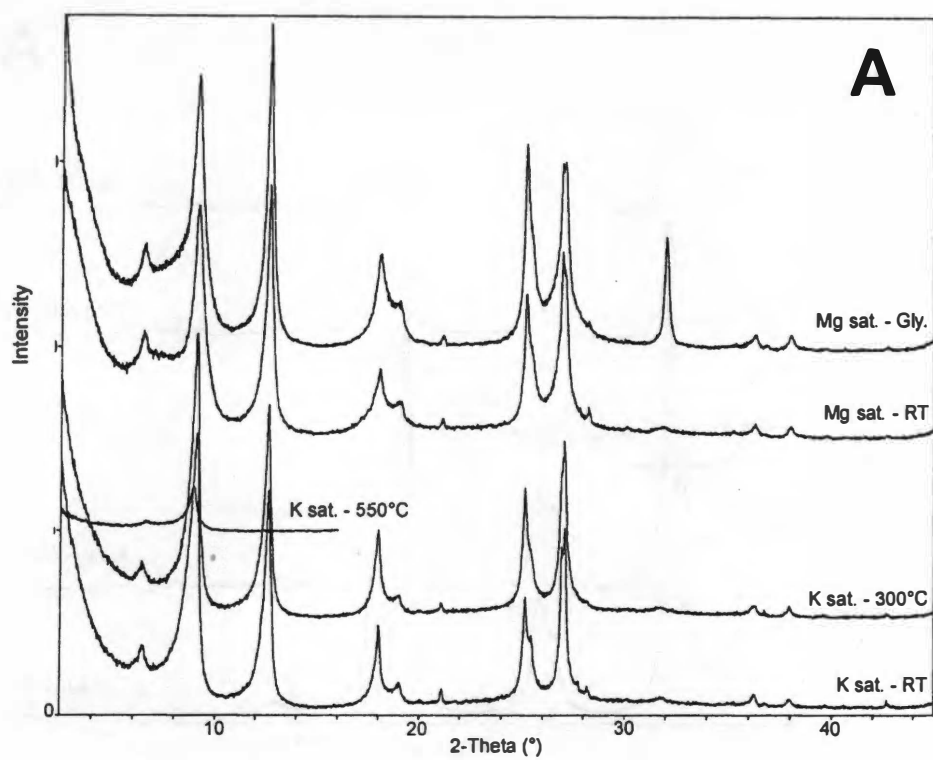


the immobile element. Negative values represent net loss of constituent relative to parent material with -1 equivalent to 100% loss; positive values represent net gain of constituent relative to parent material with +1 equivalent to 100%.

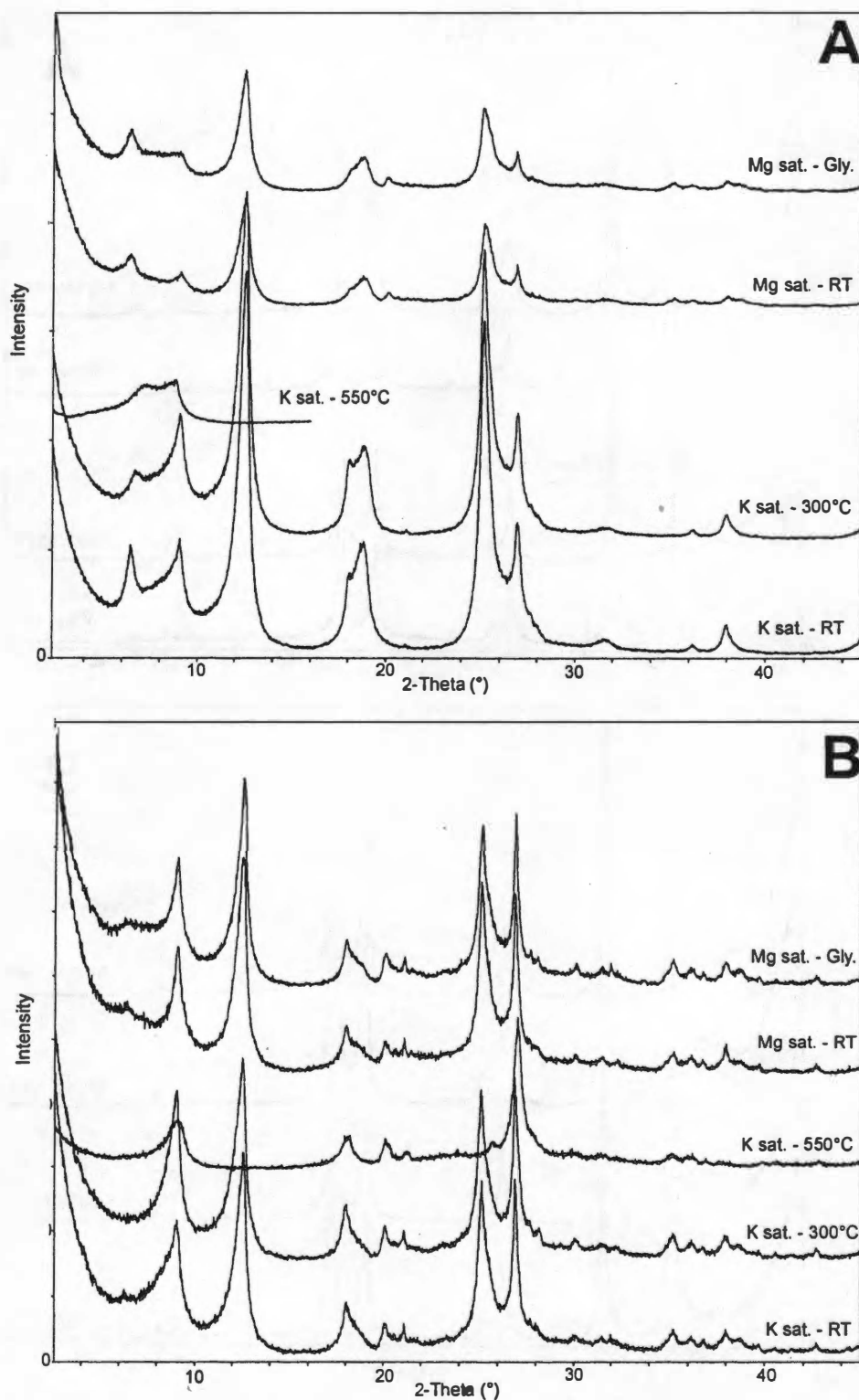
Appendix C



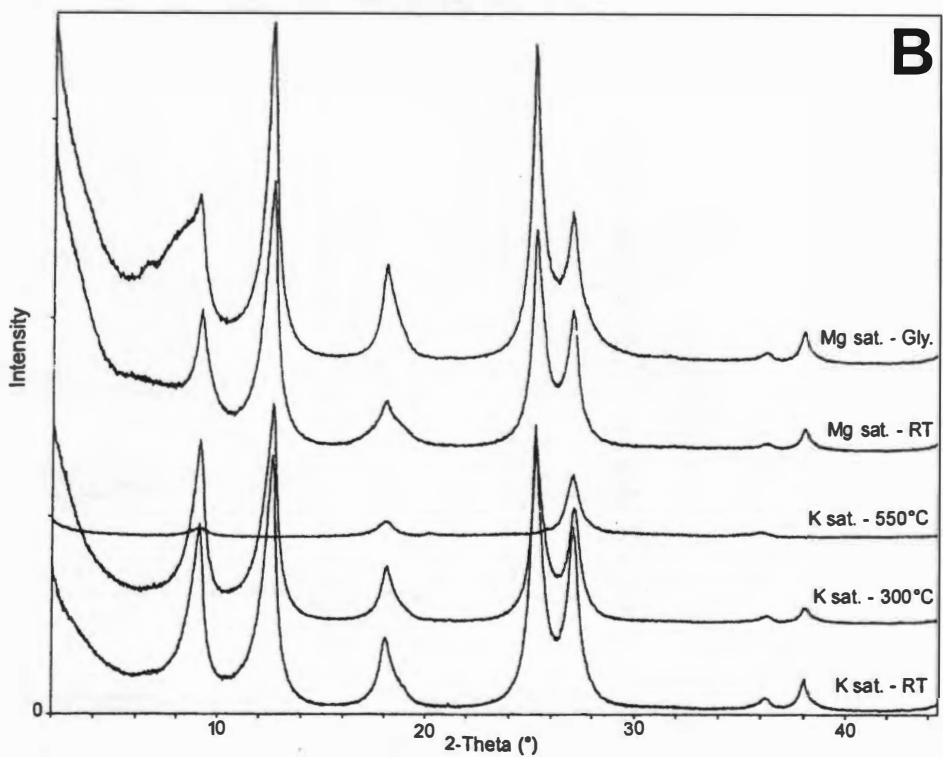
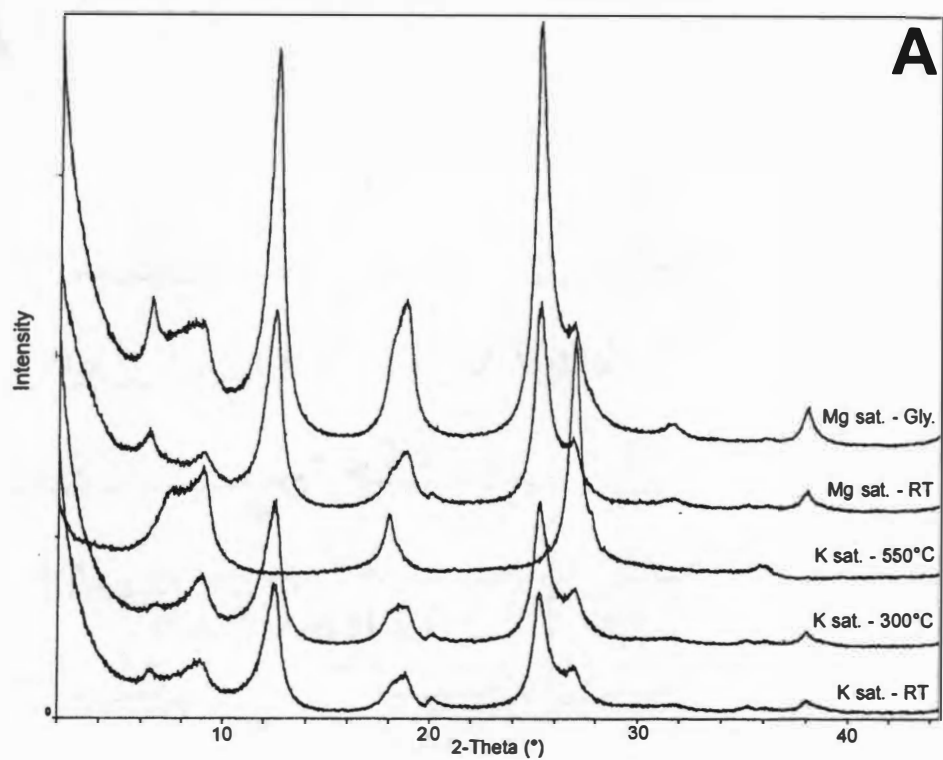
X-ray diffraction patterns for the coarse clay fraction (0.7-2.0 μm) of the Wartburg 1-1 paleosol clay analysis. A) Sample taken from a depth of 20 - 60 cm. B) Sample taken from a depth of 140 - 180 cm.



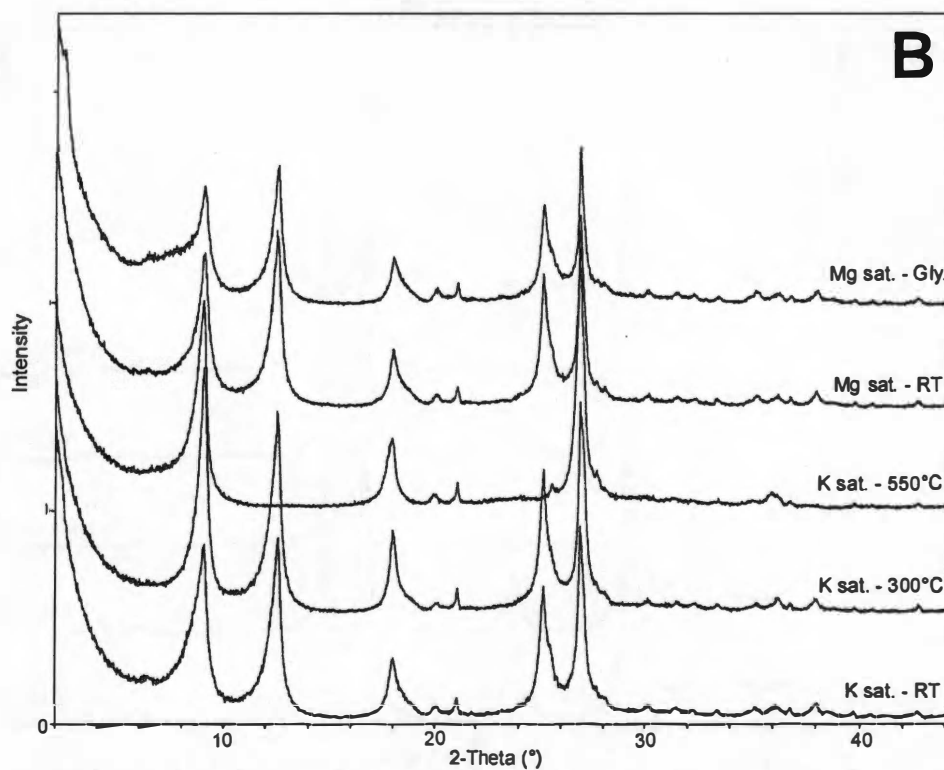
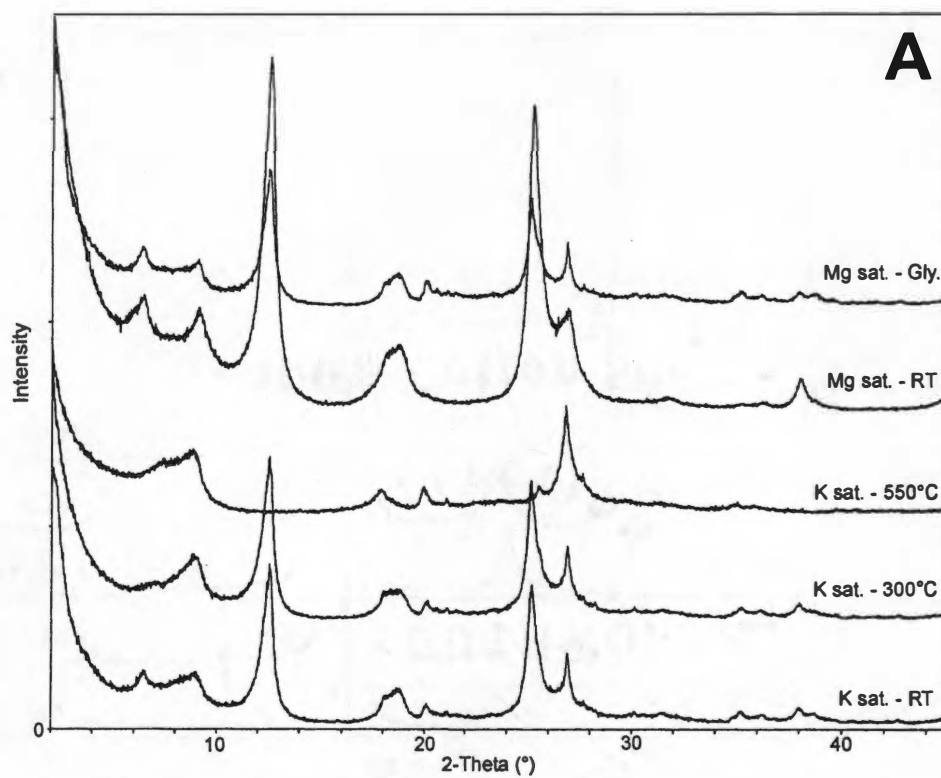
X-ray diffraction patterns for the fine clay fraction ($< 0.7 \mu\text{m}$) of the Wartburg 1-1 paleosol clay analysis. A) Sample taken from a depth of 20 - 60 cm. B) Sample taken from a depth of 140 - 180 cm.



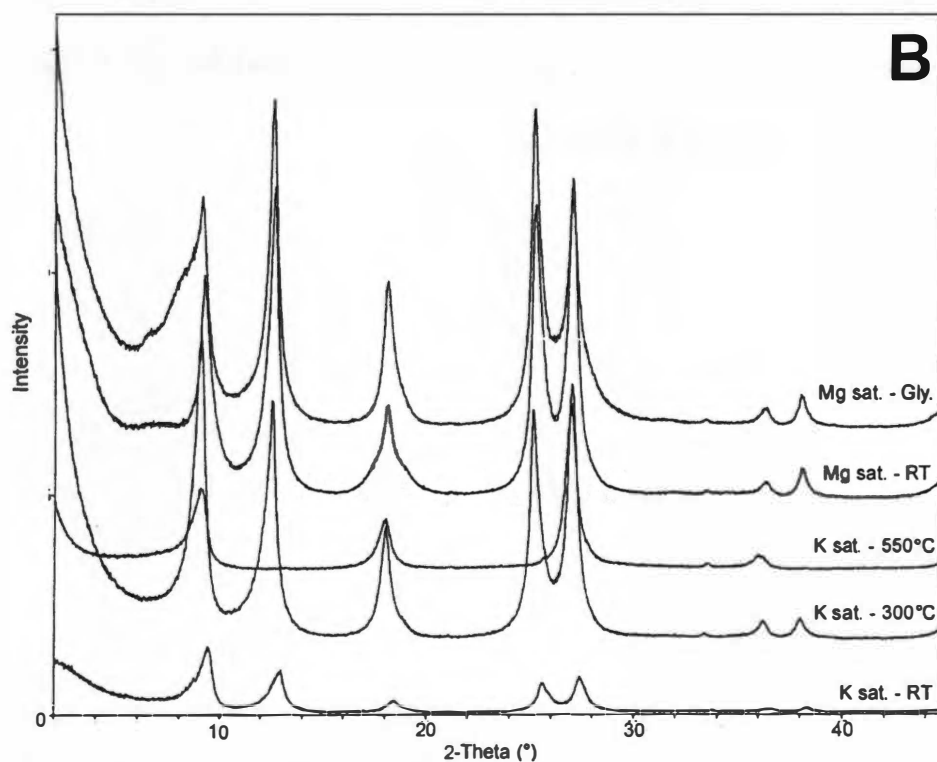
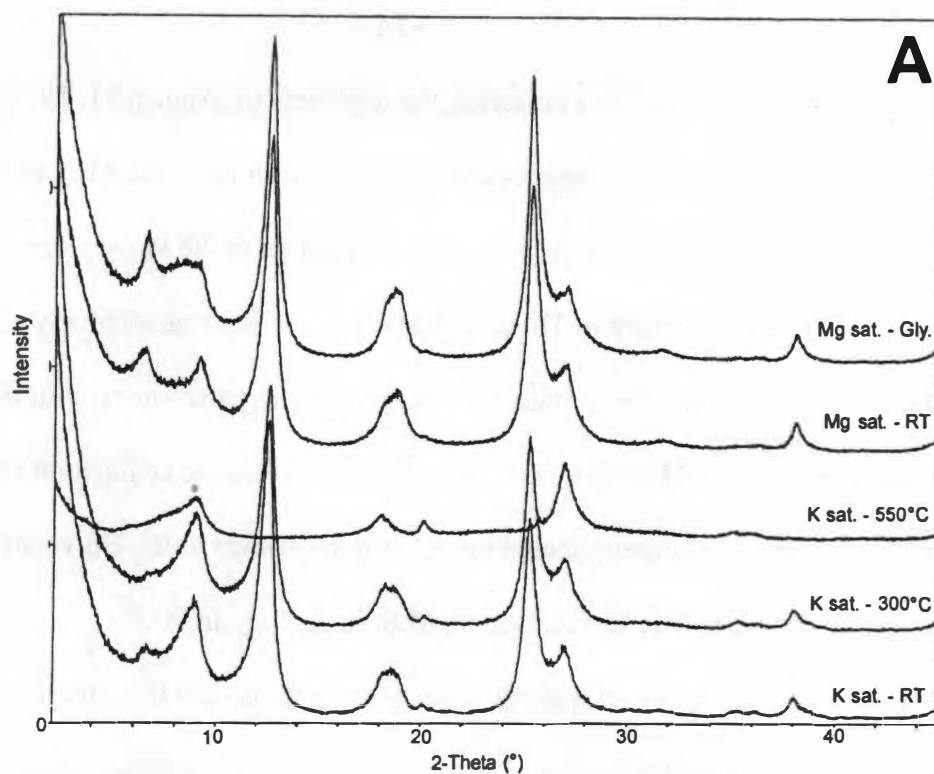
X-ray diffraction patterns for the coarse clay fraction (0.7-2.0 μm) of the Wartburg 2-2 paleosol clay analysis. A) Sample taken from a depth of 10 - 50 cm. B) Sample taken from a depth of 150 - 190 cm.



X-ray diffraction patterns for the fine clay fraction ($< 0.7 \mu\text{m}$) of the Wartburg 2-2 paleosol clay analysis. A) Sample taken from a depth of 10 - 50 cm. B) Sample taken from a depth of 150 - 190 cm.



X-ray diffraction patterns for the coarse clay fraction (0.7-2.0 μm) of the Rockwood 1-1 paleosol clay analysis. A) Sample taken from a depth of 10 - 50 cm. B) Sample taken from a depth of 200 - 240 cm.



X-ray diffraction patterns for the fine clay fraction ($< 0.7 \mu\text{m}$) of the Rockwood 1-1 paleosol clay analysis. A) Sample taken from a depth of 10 - 50 cm. B) Sample taken from a depth of 200 - 240 cm.

VITA

Eric G. Ober was born in Pittsburgh, Pennsylvania on August 31, 1973. He was raised in Pittsburgh and attended grade-school and high-school in the Mt. Lebanon School District. After completing high-school, he went on to the Pennsylvania State University where he was active in Theta Xi Fraternity and became a Nittany Lions fan. In 1995, he graduated from Penn State, receiving a B.S. in geosciences. Out of college, Eric worked in the oil field services industry as a marine seismic acquisition specialist for Schlumberger, Ltd. He further pursued his interest in geology at the University of Tennessee, Knoxville, where he received an M.S. in geology in 2003.

Eric is a member of the Geologic Society of America and the American Association of Petroleum Geologists. He served as the AAPG chapter treasurer while at Tennessee. Eric continues to have an interest in sedimentary geology and plans to return to the oil and gas industry in Pittsburgh.