Influences of Modern Pedogenesis on Paleoclimate Estimates from Pennsylvanian and
Permian Paleosols, Southeast Ohio

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This thesis titled
Influences of Modern Pedogenesis on Paleoclimate Estimates from Pennsylvanian and
Permian Paleosols, Southeast Ohio

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ABSTRACT

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Influences of Modern Pedogenesis on Paleoclimate Estimates from Pennsylvanian and Permian Paleosols, Southeast Ohio

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Exposed paleosols are subject to modern pedogenic processes which, over time, are expected to alter paleosol chemistry and subsequent paleoclimate estimates to better reflect the environment at the time of exposure rather than the time of formation.

Although paleosols are widely used in paleoclimatic reconstruction, current research typically does not address the degree of influence that modern weathering has on the bulk geochemistry of paleosols. Previously described Pennsylvanian and Permian paleoVertisols and paleoInceptisols with known durations of exposure were described and sampled from five roadcuts in southeastern, Ohio. Samples were collected at depths of 0, 25, 50, 100, and 150 cm from the outcrop surface, and then analyzed via XRF for major oxides (Ca, Fe, K, Mg, Na, Al, Si, Mn, P, and Ti). These data were used in molecular weathering ratios to characterize paleosol properties and calculate MAP and MAT.

Results indicate that although oxide geochemistry often differs between sampling depths, the differences do not occur in a pattern that supports that recent pedogenesis is a driving factor. Rather, this study may be capturing naturally occurring geochemical variations that are the result of small-scale differences in formational environment. Additionally, decade- level exposure time along these roadcuts may limit the extent of pedogenesis.

Ultimately, for geochemical studies on paleosols in outcrops located on young roadcuts in

temperate climates, current sampling techniques seem to be sufficient in mitigating the effects modern weathering. Recommendations from this study include sampling from 25-50cm beyond paleosol surface and taking multiple samples across an outcrop to account for lateral variation.

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CHAPTER 1: INTRODUCTION

Since soils form as a result of direct subaerial exposure, they provide a better reflection of climate during formation than subaqueous or marine sediment. As a result, paleosols are widely used in paleoenvironmental and paleoclimatic reconstructions (Kraus 1999). Various aspects of paleoclimate can be interpreted from paleosols using molecular weathering ratios, the relative concentrations of major oxides taken from near-surface samples (Sheldon et al. 2002). However, the methodologies in many papers do not define “near-surface” (Sheldon et al. 2002; Sheldon and Tabor 2009; Nordt and Driese 2010a; Nordt and Driese 2010b). This approach is problematic because, once exposed, paleosols are subject to modern weathering and pedogenesis. With time, near-surface paleosol samples are expected to better reflect modern environmental conditions than conditions at the time of formation. The influence of pedogenesis on paleoenvironmental proxies has been recently studied comparing outcrop to core (Clyde et al. 2016); however, this study did not address changes in geochemistry. Additionally, on the outcrop-scale that most paleosol sampling occurs, these pedogenic influences have not been evaluated.

This study examines previously described Pennsylvanian to Permian paleosols at five roadcuts in Athens and Meigs counties, Ohio (King 2008; Hembree and Nadon 2011; Catena and Hembree 2012; Dzenowski and Hembree 2012; Carnes 2017; Hembree and Bowen 2017). Paired Vertisol and Inceptisol samples were described in the upper and lower portion of each roadcut. Series of samples were taken from the surface of the outcrop to a maximum depth of 150 cm, and then analyzed for major oxide geochemistry

using X-ray fluorescence (XRF). Resulting weight percentages of major oxides were used in the calculation of molecular weathering ratios and climofunctions to estimate mean annual precipitation and temperature (Sheldon et al. 2002; Nordt and Driese 2010a; Nordt and Driese 2010b).

This study tested three main hypotheses: 1) the bulk geochemistry of a given horizon will differ based on depth from outcrop surface; 2) in a given horizon, paleoclimate estimates calculated from molecular weathering ratios will differ based on depth from outcrop surface; samples taken closer to an outcrop surface will possess a more modern climate signal compared to those deeper within the outcrop; 3) the degree of modern pedogenic alteration of paleosols geochemistry will vary between profiles based on paleosol type (Inceptisol vs. Vertisol), landscape position, and degree of lithification.

CHAPTER 2: PALEOSOLS AND PALEOCLIMATE

Impacts of Climate on Pedogenesis

Complex interactions between the climate, parent material, organisms, topography, and time of formation govern what soil may be present at a given location. Although the interplay between these factors leads to no factor acting independently, climate is often considered the most important (Retallack 2001). With the exception of Histosols and Entisols, the properties of all modern soil orders are associated with climate (Soil Survey Staff 1999). In well-drained soils, the soil climate reflects a muted view of the regional climate (Retallack 2001). Paleosols also reflect their formational environment; however, they are subject to diagenetic processes that can alter interpretations. If a paleosol experiences subsequent subaerial exposure, it may also be affected by pedogenic overprinting. Despite these caveats, paleosols are one of the best proxies for terrestrial paleoenvironmental and paleoclimatic reconstruction (Kraus 1999).

One aspect of climate is precipitation. Organic matter and clay content are strongly correlated with rainfall (Jenny 1941). Pedogenic clays formed in wetter climates tend to have a 1:1 layer structure rather than a 2:1 layer structure and are less rich in cations (Retallack 2001). As water is necessary for many hydrolytic chemical reactions, freely drained soils in humid climates experience chemical weathering beyond those in arid climates. Cations, especially alkali and alkaline earth metals, are preferentially leached in profiles exposed to high precipitation. The presence of these cations, as oxides or as carbonates, near the soil surface is a reliable indicator that a soil formed in arid conditions (Retallack 2001).

Table 1: Annual precipitation regimes, degree of seasonality, and interpreted soil moisture regimes modified from Cecil, 2013.

Number of wet months	Precipitation Regime	Degree of Seasonality	Interpreted soil moisture regime
0	Arid	Aseasonal	Aridic
1-2	Semiarid	Minimal	Aridic-Ustic
3-5	Dry subhumid	Seasonally wet	Ustic
6-7	Wet subhumid	Seasonally dry	Udic
9-11	Humid	Minimal	Aquic
12	Perhumid	Aseasonal	Peraquic

The seasonal availability of precipitation further influences pedogenesis. The degree of seasonality is a control on chemical weathering, affecting soil chemistry and mineralogy, as well as soil physical properties (Cecil and Dulong 2003). Seasonality also affects the presence or absence of plant available water in a profile, a control on plant ecology, soil organic matter, pH, and electroconductivity (Cecil 2013). The effects of seasonality on soil development are most evident in soils with high concentrations of 2:1 clays. Vertic properties such as slickensides, desiccation cracks, wedge-shaped peds, and gilgai microtopography, are generally considered evidence of seasonality (Soil Survey Staff 1999). Corresponding soil moisture regimes are interpreted to be udic to arid (Table 1). Other indicators of seasonality include concentrically banded argillans and concretions of iron and carbonates (Retallack 2001).

Soil temperature acts as a control on the rate of chemical weathering, and is also a limiting factor on biotic activity within a profile. Mean soil temperature is closely related to the mean annual air temperature, but it is also strongly influenced by the soil moisture content, cover type, and slope (Soil Survey Staff 1999). In arid conditions, or in soils with little to no cover, temperature fluctuations are the most severe. These changes occur

on a daily and annual basis in the upper horizons of all soils, but are muted with depth. At a depth of 50 cm, the soil temperature typically does not change in response to daily temperature fluctuations (Soil Survey Staff 1999). The extent of seasonal variations in soil temperature is also driven by latitude and climate. In tropical soils, seasonal changes in soil temperature are limited and primarily the result of changes in cloud cover and precipitation.

Use of Climofunctions in Interpreting Soil Properties

Bulk geochemistry can be used to infer soil-forming conditions through the calculation of molecular weathering ratios, which provide insight into the degree of soil development (Table 2A). Using elemental ratios is preferable to using single-element measurements due to small-scale variations in elemental abundance, sometimes attributed to textural heterogeneity (Sheldon and Tabor 2009). Weathering ratios used in this study were based on the weight percent of thirteen major oxides (Al_2O_3 , BaO , CaO , Cr_2O_3 , Fe_2O_3 , K_2O , MgO , MnO , Na_2O , P_2O_5 , SO_3 , SiO_2 , TiO_2) (Sheldon and Tabor 2009). All weathering ratios were calculated from the relative concentration of major oxides from near-surface samples.

The sum of bases to alumina ratio and the aluminum (Al) to silica (Si) ratio provide a proxy for hydrolysis, a measure of the displacement of cations by hydronium ions (Sheldon and Tabor 2009). In soils, the hydrolysis of aluminosilicate parent materials results in the formation of secondary clay minerals and cations in solution (Retallack 2001). The Al to Si ratio is also a measure of the “clayeyiness” of a soil, as Al increases relative to Si in profiles with silicate parent materials and secondary clay

mineral formation (Sheldon and Tabor 2009). This ratio informs on lessivage, the translocation of clay minerals within a profile, and can be applied to confirm field designations of argillic (Bt) horizons (Sheldon 2005; Sheldon and Tabor 2009). To determine the loss of base-forming cations through leaching, the ratio of a given oxide (CaO, MgO, Na₂O, K₂O) against titanium can be used (Sheldon and Tabor 2009). Base loss ratios are depth sensitive, as oxide geochemistry varies between horizons; therefore, in this study only horizons that have been field-designated as Bw or Bt were sampled. Studies have shown that in modern soils, alkaline earth elements are more susceptible to chemical weathering than alkali elements (Chadwick et al. 1999). To determine the accumulation of soluble salts (K and Na), the ratio of Na and K to Al can be used (Sheldon and Tabor 2009).

For paleoVertisols, additional molecular weathering ratios can be calculated (Table 2a). The presence of calcium carbonate in a soil system has a profound influence on many soil properties including the coefficient of linear extensibility (COLE), cation exchange capacity (CEC), clay content, and pH (Nordt and Driese 2010a). A strong relationship was found between percent CaO and Ca²⁺ in soils (Nordt and Driese 2010a). To reduce the influence of calcium carbonate, all horizons with CaO exceeding 2% were considered calcareous and were not sampled. In non-calcareous soils, evaluating base saturation at pH 8.2 gives a measure of soil acidity (Nordt and Driese 2010a). The CEC is a measure of exchangeable cations, or the total quantity of negatively charged exchange sites per unit volume of soil at pH 7.0 (Nordt and Driese 2010a). In Vertisols, CEC can also be used to describe clay mineralogy, with values exceeding 0.70 cmol/kg indicating

the presence of expandable clays (Nordt and Driese 2010a). Clay content strongly influences COLE values, as shrink-swell potential is controlled by the geometry of clay minerals (Nordt and Driese 2010a).

Paleosol geochemistry can also be used in climofunctions to reconstruct specific aspects of paleoclimate (Table 2b). One such climofunction is the chemical index of alteration excluding potassium (CIA-K) for paleoprecipitation. The CIA-K index reflects the preferential leaching of base oxides to aluminum oxide (Al_2O_3) with increasing rainfall (Sheldon et al. 2002). Ultimately, K_2O was excluded from the function to eliminate potential effects of diagenetic illitization and MgO was excluded because it presents differently in analysis than other base-forming oxides (Maynard 1992; Sheldon et al. 2002). As the CIA-K index was developed using Ultisols, Alfisols, Inceptisols, Mollisols, and Aridisols, there was some question into whether it is applicable to Vertisols (Sheldon et al. 2002; Nordt and Driese 2010b).

The Vertisol specific CALMAG weathering index was developed using the oxide geochemistry from 14 Pleistocene-age profiles meeting the criteria for a climosequence, MAP ranging from 267–1437cm (Table 2b) (Nordt and Driese 2010b). The weighted average of base-forming oxides was taken from samples of homogenized clay from the 25–100 cm depth interval to determine which oxides were the best predictors on precipitation. Topographic microhighs were excluded as microlows are more sensitive to changes in climate (Driese et al. 2005). Stepwise linear regression found that CaO and MgO were the best predictors, with CaO varying by 85% and MgO varying by 5% based on precipitation. Compared to the original CIA-K curve, the CALMAG weathering index

provided lower MAP estimates in arid climates and higher MAP estimates in humid climates (Sheldon et al. 2002; Nordt and Driese 2010b). The CALMAG weathering index was used in addition to the CIA-K index for paleoVertisol profiles in this study.

Mean annual paleotemperature (MAT) can be estimated using the weathering ratio of bases to alumina in Bw or Bt horizons in paleosols (Sheldon et al. 2002). This function was found to have a high significance in soils formed in temperatures between 2 and 20 °C, though it had a low R^2 value. MAT can also be estimated using the salinization ratio (Table 2b) (Sheldon and Tabor 2009).

Table 2a: Summary of molecular weathering ratios, modified from Sheldon and Tabor (2009) and Nordt and Driese (2010a)

Weathering Index	Formula	Explanation	Pedogenic Process
$\Sigma\text{Bases}/\text{Al}$	$\Sigma(\text{Ca}+\text{Mg}+\text{Na}+\text{K})/\text{Al}$	Hydrolysis of aluminosilicates results in clay minerals and cations in solution	Hydrolysis
CIA-K	$((100*(\text{Al}/\text{Al}+\text{Ca}+\text{Na}))$	Hydration of weathered feldspars to form secondary clay minerals	Hydration
Lessivage	$\text{Al}_2\text{O}_3/\text{SiO}_2$	Translocation of clays	Lessivage
Base Loss	$(\text{Ca}, \text{Mg}, \text{Na}, \text{K})/\text{Ti}$	Loss of a given base forming oxide vs titanium	Leaching
Salinization	$(\text{K} + \text{Na})/\text{Al}$	Accumulation of soluble salts	Salinization
Percent CaO	%CaO	Horizons with >2% CaO are considered calcareous	Calcification (Vertisols)
COLE	$\text{CaO} + \text{MgO}$	CaO and MgO are directly related to clay content	Shrink/Swell (Vertisols)
CEC	$(\text{CaO} + \text{MgO})/ \text{Al}_2\text{O}_3$	Cation exchange capacity	CEC (Vertisols)
Acidity	$\text{CaO} + \text{MgO}$	At pH 8.2, base saturation describes pH dependent acidity	pH (Vertisols)

Table 2b: Summary of climofunctions (Sheldon et al., 2002; Nordt and Driese, 2010b)

Climofunction	Formula	Climate Estimate
CIA-K	$14.265(\text{CIA-K})-37.632$	Mean annual precipitation
CALMAG	$\text{Al}_2\text{O}_3/(\text{Al}_2\text{O}_3+\text{CaO}+\text{MgO})*100$	Mean annual precipitation (Vertisols)
Salinization	$-18.516((\text{K} + \text{Na})/\text{Al}) + 17.298$	Mean annual temperature

Types of Evaluated Paleosols

Although they are commonly used for paleoenvironmental reconstructions, paleosols often do not provide information to the level of detail required by modern soil taxonomy. In addition to the absence of concrete climate data from the time of paleosol formation, factors such as diagenesis, the erosion of diagnostic horizons, and pedogenic overprinting make classifying paleosols into modern soil orders difficult (Mack et al. 1993). To address this, Mack et al. (1993) developed a classification scheme for paleosols based organic matter content, strength of horizonation, redox conditions, mineral alteration in situ, illuviation of insoluble minerals, accumulation of soluble minerals, and other surviving morphological features as applicable (Mack et al. 1993). To account for the recycling of modern soil order names in this classification system, the prefix paleo- was used to differentiate paleosols and modern soils at an order level. Subordinate modifiers were used to describe soils with secondary significant characteristics. Paleosols evaluated in this study include paleoVertisols and paleoInceptisols.

paleoVertisols

Shrink-swell processes control the formation of Vertisols. These processes occur when 2:1 expanding clays, such as smectite, are exposed to alternating periods of wetting and drying. Characteristic properties of modern Vertisols include slickensides, desiccation cracks, gilgai microtopography, and intense pedoturbation (Soil Survey Staff 1999). In modern soil taxonomy, this order includes mineral soils that contain a layer at least 25 cm thick within 100 cm of the soil surface that contains intersecting slickensides or dipping wedge-shaped peds; 30% or more clay in the fine-earth fraction from either

the surface to a depth of 18 cm or in all horizons from 18 cm to either a depth of 50 cm or a lithic contact, a duripan, or a petrocalcic horizon; and cracks that open periodically (Soil Survey Staff 1999). The diagnostic feature of paleoVertisols is secondary profile homogenization that resulted from pedoturbation. Evidence of shrink-swell in paleoVertisols includes desiccation cracks, wedge-shaped peds, hummock and swale structures, slickensides, and clastic dikes (Mack et al. 1993). Identifying 2:1 expanding clays in a paleosol strengthens the interpretation; however, their presence is not required as smectite and other 2:1 expanding clays are often diagenetically altered to illite or other clay minerals (Retallack 2001). Paleoprecipitation estimates focus on an annual mean and cannot predict the duration of wetness in the control section of a given profile; however, if a paleosol exhibits vertic properties, it is reasonable to assume that it formed under seasonally wet or seasonally dry conditions.

paleoInceptisols

Inceptisols are often thought of as weakly developed soils; however, they are developed beyond the extent of Entisols. At a minimum, Inceptisols require an epipedon, though if it is an ochric or anthrophic epipedon, a subsurface diagnostic horizon is also required (Soil Survey Staff 1999). A typical Inceptisol profile includes an ochric epipedon and a cambic (Bw) horizon; however, because the Inceptisol order acts as a catch-all for soils that do not quite meet the diagnostic requirements of other soil orders, many combinations of epipedons and diagnostic horizons are permitted (Soil Survey Staff, 1999). In this paper, the term paleoInceptisol will be used; however, Mack et al. (1993) grouped paleoInceptisols and paleoEntisols into the Protosol order. This order

includes paleosols with diagnostic horizons that are weakly developed to absent (Mack et al. 1993). Although a profile may contain features characteristic of other orders such as reduced iron, carbonate or gypsum deposits, or illuviated clays, in Protosols, these features are insufficiently developed for classification.

CHAPTER 3: GEOLOGIC SETTING

Pennsylvanian

During the Late Pennsylvanian, Ohio had a paleolatitude of 5–10° S (Opdyke and DiVenere 1994). Sedimentary strata from this time period in the study area are divided into the Allegheny, Conemaugh, and Monongahela groups (Fig. 1a). Sediment deposited during this period was a mix of marine, fluvial, and lacustrine, although the marine record is largely incomplete or absent above the Conemaugh Group (Figs. 1b–c) (Sturgeon 1958). Paleoclimate estimates for the time period indicate that climate was changing from ever-wet tropical conditions in the Allegheny Group toward a drier, seasonal climate through the Conemaugh and Monongahela groups (Fig. 2) (Joeckel 1995).

Conemaugh Group

Glenshaw Formation

Site 1 is located east of the U.S. Route 33/Stimson Avenue exit, east of Athens, Ohio (39.327°, -82.086°) (Fig. 3). Roadcut age is approximately 50 years. Paleosols excavated 25 to 50 cm into the outcrop at Site 1 were blocky, strongly horizonated mudstones, with overthickened B horizons containing angular blocky peds, slickensides on ped faces, and cutans (Dzenowski and Hembree 2012). Color ranged from dark red and reddish brown in the lower section and from grey-green to olive green in the upper portions, with a variegated gradational contact between unit (Hembree and Nadon 2011; Dzenowski and Hembree 2012). Desiccation cracks were prominent in the lower portion of the profile. Carbonate nodules were dispersed in lower portion of profile, and

Table 3: Summary of environmental interpretations by site

Site	1	2	3	4	5
Stratigraphy	Conemaugh Group Glenshaw Formation	Conemaugh Group Casselman Formation	Monongahela Group	Dunkard Group Waynesburg Formation	Dunkard Group Waynesburg Formation
Age	Late Pennsylvanian	Late Pennsylvanian	Late Pennsylvanian	Early Permian	Early Permian
Lithology	Red to reddish brown blocky mudstones, gleyed blocky mudstones in upper portion	Blocky claystones and mudstones, uniform red to variegated reds, greys, and olive greens	Grey blocky mudstones to red blocky mudstones	Reddish purple to blue- green and grey calcareous mudstones to reddish- brown blocky mudstones	Reddish brown to reddish grey platy to blocky mudstones and siltstones
Diagnostic Features	Angular peds, slickensides, cutans, desiccation cracks, dispersed carbonate nodules, concentrated Bk horizon	Wedge shaped peds, slickensides, cutans, dispersed carbonate nodules, thin concentrated Bk horizons, mottling	Angular blocky peds, rhizoliths, slickensides, Desiccation cracks, calcareous nodules, calcareous and silicious hardpans	Yellow to green mottling, with angular peds and large scale slickensides upsection	Slickensides, argillans, drab rhizohaloes, carbonate nodules
Interpreted Paleosols	Calcic paleoVertisols, gleyed paleoInceptisols	paleoAlfisols, paleoInceptisols, paleoVertisols	paleoVertisols, paleoInceptisols	Calcic paleoInceptisols, paleoVertisols	Calcic paleoVertisols, paleoVertisols, Inceptisols, Entisols, Histosol
Interpreted Environment	Distal alluvial floodplain	Well-drained, wooded distal floodplain with gilgai microtopography	Floodplain and interfluvial facies	Lower fluvial plain, with gilgai microtopography	Distal levee to proximal aggradational floodplain, distal floodplain
Interpreted Climate	Seasonally dry MAP 602-1217 mm/year	Seasonally dry, with periodic small-scale surface flooding	Seasonally dry to seasonally wet, with decreasing precipitation upsection	Seasonally dry 314-1198 mm/year (CIA- K) 282-960 mm/year (CALMAG)	Seasonally dry, with periodic flooding, decreasing upsection
References	Hembree and Nadon, 2011 Dzenowski and Hembree, 2012	Hembree and Nadon, 2011 Catena and Hembree, 2012	King, 2008	Hembree and Bowen, in press	Carnes and Hembree, 2016

Figure 1: Detailed sequence stratigraphy of the Conemaugh, Monongahela, and Dunkard groups, modified from Sturgeon (1958) and (Nadon and Hembree 2007).

Figure 2: Paleogeographic maps, created by Ron Blakey, Colorado Plateau Geosystems, showing the location of southeast Ohio in the Late Pennsylvanian and Middle Permian (Carnes 2017).

Figure 3: a) Location of sampling sites, southeast Ohio, b-f) Aerial photos of sampling sites with mapped modern soil series (Web Soil Survey).

concentrated into a Bk horizon in the upper portions of the profile. Clay chemistry was primarily kaolinite and illite, but also included illite/smectite and chlorite. Estimated paleoprecipitation from CIA-K ranged from 602 to 1217 mm/yr. (Hembree and Nadon 2011).

Paleosols at Site 1 were interpreted to be a stacked succession of profiles, and exhibited some overprinting (Dzenowski and Hembree 2012). The presence of vertic features including illuviated clay skins, slickensides, and desiccation cracks in conjunction with carbonate nodules support the classification of the lower paleosol as a calcic paleoVertisol. The well-developed nature of the profile and prominent vertic features suggests that this paleosol was formed on the distal portions of an alluvial floodplain in a seasonally wet climate (Table 3) (Aslan and Austin 1998; Hembree and Nadon 2011). The composite nature of the overall profile suggests that sedimentation and bioturbation rates remained consistent and that changes in climate resulted in the formation of a second profile in the upper portion (Dzenowski and Hembree 2012). This portion was classified as a vertic Gleysol and interpreted as a paleoInceptisol (Dzenowski and Hembree 2012).

Casselman Formation

Site 2 is east of U.S. Route 33, south of Athens, Ohio (39.301°, -82.102°) (Fig. 3). The roadcut age does not exceed 23 years. Paleosols identified at this site were interpreted as paleoAlfisols, paleoInceptisols, and paleoVertisols (Hembree and Nadon 2011; Catena and Hembree, 2012). Profiles range in color from uniform dark red, to variegated red grey and olive green, to purple and in texture from angular blocky

claystone to blocky mudstone. Gleyed and yellow mottles were observed. Carbonates ranged from dispersed nodules to thin concentrated layers. Vertic features such as slickensides, cutans, and wedge-shaped peds were observed in all profiles.

Identified landscapes at Site 2 include vegetated distal floodplain to alluvial swamp (Table 3) (Catena and Hembree 2012). Paleosols interpreted as Alfisols were thought to have formed on well-drained wooded areas with herbaceous groundcover on a distal floodplain, with compound stacking patterns, local gleization and coarse sandstone and rock fragments interpreted as evidence of flooding events (Hembree and Nadon 2011). The well-drained nature of the paleoVertisol profiles suggests that pedogenesis occurred in areas with locally elevated topography, whereas the gleyed matrix in paleoInceptisol profiles suggests that pedogenesis occurred in depressed waterlogged areas (Catena and Hembree 2012). This was attributed to the deposition of alluvial clays by small-scale regional flooding events and is common in modern Vertisols. The presence of this gilgai microtopography, in addition to illuviated clay skins, slickensides, and wedge-shaped peds, supports a seasonal climate (Driese et al. 2005; Catena and Hembree 2012).

Monongahela Group

Site 3 is located east of U.S. Route 50, northwest of Guysville, Ohio (39.303°, -81.938°) (Fig. 3). The roadcut is approximately 60 to 80 years old. Grey and red blocky mudstones, interpreted as paleosols due to the presence of angular blocky peds, rhizoliths, and horizonation, are present at Site 3 (King 2008). Gleyed beds were prevalent in the lower portion of the section, whereas red beds were more common in the

upper portions, suggesting improvement in drainage up section. Slickensides found along ped faces, and curvilinear fracture planes present in beds greater than 10 cm, suggest seasonality (King 2008). Calcareous nodules were present, and calcareous and siliceous cements were found at the base of thicker profiles. These cemented horizons were interpreted to be calcareous hardpans and non-calcareous fragipans, and suggest decreased precipitation up section (Soil Survey Staff 1999; King 2008). Paleosols were the dominant facies in the section, leading to the interpretation of floodplain and interfluvial facies associations (Table 3) (King 2008).

Permian

By the early Permian, Ohio was located between 15° N and S (Tabor and Poulson 2008). Strata of the Dunkard Group represent the youngest exposed Paleozoic strata in Ohio, West Virginia, and Pennsylvania (Fedorko and Skema 2013). Although there has been some controversy on the age of the Dunkard Group, recent studies suggest that the Waynesburg Formation contains the transition from the Gzhelian Stage (Late Pennsylvanian) to the Asselian (Early Permian) (Fig. 1a) (Martin 1998; Fedorko and Skema 2013). Located in the interior of continental Pangea, the Dunkard Basin was not subject to glacioeustatic sea level change as a control on paleosol formation (Cecil 2013). Additionally, although tectonic subsidence contributed to accommodation rates and basin architecture, minimal evidence of faulting and deformation further supports the importance on climate (Cecil 2013). Therefore, climate was the driving allogenic process in Ohio in the Permian. The Dunkard Group is comprised of interbedded black, gray, green, and red fissile shales, non-fissile claystones and mudstones, grey and green

siltstones, gray and green lithic and micaceous sandstones, and freshwater limestones, with thin to absent coal beds (Fig. 1d) (Fedorko and Skema 2013).

Dunkard Group

Site 4

Site 4 is located north of Ohio State Route 32, southwest of Coolsville, Ohio (39.213°, -81.826°) (Fig. 3). The roadcut is less than 23 years in age. Paleosols identified at Site 4 were interpreted as paleoInceptisols and paleoVertisols (Hembree and Bowen 2017). PaleoInceptisol profiles were characterized by weak horizonation and included reddish purple mudstones with yellow to green mottles, transitioning to blue-green to grey calcareous mudstones. In some profiles, relict bedding was preserved. PaleoVertisols ranged from dark red to reddish brown, calcareous, blocky to angular-blocky mudstones with large-scale slickensides, and yellow to green mottles.

The formational environment of Site 4 is interpreted as lower fluvial plain, with meandering to anastomosing streams, small lakes, and swamps (Table 3) (Martin 1998). Paleosols support this interpretation of a low-lying landscape with gilgai microrelief (Hembree and Bowen 2017). Paleosols lower in the section are heavily variegated, suggesting that glezation is the result of seasonal ponding. Up-section changes in color and chemistry reflect the shift to improved drainage from the Monongahela to the Dunkard group, and a decreasing influence of groundwater, though a seasonal perched water table may have been present. MAP estimates range from 314–1198 mm/year using CIA-K and from 282–960 mm/year using CALMAG (Hembree and Bowen 2017).

Site 5

Site 5 is located northeast of U.S. Route 33, northwest of Ravenswood, West Virginia in Meigs County, Ohio (38.964°, -81.823°) (Fig. 3). The roadcut does not exceed 21 years in age and includes strata from the Monongahela and Dunkard groups. This site is located on the southern, upper fluvial plain of the Dunkard Basin (Martin 1998). Site 5 was subdivided into three zones (Carnes 2017). Zone 1 was measured from the base of the roadcut to the top of the youngest sandstone bed at the base of the section. Paleosols, described at a depth of 50 cm, within this zone were thin (10–75cm), dark olive green to reddish brown platy mudstones and siltstones, and were bounded by fissile mudstones and fine-grained sandstones. Carbonate nodules were observed, as were few small-scale slickensides. Zone 2 contained the Waynesburg Coal and thick (190–210 cm), angular blocky mudstones, interpreted as paleosols, ranging from greyish brown to reddish grey in color. Drab rhizohaloes, small- to large-scale slickensides, argillans, and moderately well-developed carbonate nodules were identified (Carnes 2017). Paleosols in Zone 3 were thick, angular blocky to platy reddish brown to red mudstones. These paleosols had abundant slickensides and carbonate nodules, as well as reddish to grayish and grey green rhizohaloes.

The sections evaluated were interpreted to represent an aggradational floodplain in an anastomosing or meandering fluvial system (Table 3) (Carnes 2017). Zone 1 paleosols were classified as calcic Vertisols and Inceptisols. Profiles ranged from compound to composite, with sandstones representing frequently flooding events (Carnes 2017). Landscape interpretations ranged from distal levee to proximal floodplain. In Zone

2, paleosols were classified as Calcic Vertisols and Vertisols. Like Zone 1, Zone 2 paleosols were compound and composite; however, the blocky structure, increased prevalence of slickensides, and higher chromas indicated that paleosols formed under a more stable landscape such as a distal to proximal floodplain. Compound, cumulative, and composite calcic Vertisols and Entisols were found in Zone 3, which formed under long periods of landscape stability (Carnes 2017).

Modern Soil-Forming Conditions

From 1981 to 2010, annual precipitation in the study area averaged 100.00 cm/year (NCDC). Precipitation was well distributed throughout the year with the minimum monthly total of 6.58 cm in February and maximum monthly total of 11.25 cm in May (NCDC). Soils in this area meet the criteria for an udic, or seasonally dry, moisture regime, in which the soil moisture control section is not dry for a period exceeding 90 cumulative days and is not dry in all parts for less than 45 consecutive days in the growing season (Fig. 4) (Soil Survey Staff 1999). With 30-year averaged annual temperatures of 10.98° C, summer temperatures of 21.81° C and winter temperatures of -0.33° C, the climate in the study area meets the mesic temperature regime criteria (NCDC). Areas with mesic temperature regimes have a mean annual soil temperature between 8 and 15° C, with a difference between mean summer (June, July, August) and winter (December, January, February) temperatures exceeding 6° C at 50 cm (Soil Survey Staff 1999).

Despite being formed in close geographic association to the paleosols described above, differences in climate and landscape position between the Late Pennsylvanian,

Table 4: Modern soils exceeding 5 percent area of interest at selected sites (NRCS Web Soil Survey, Soil Survey Staff 1999, 2009, 2013, 2014)

Site	Soil Map Unit	Percent AOI	Soil Series	Order
1	Ud	57.5	Udorthents, loamy	Entisol
1	WmE	41.8	Westmoreland-Upshur complex, 25-40% slopes	Alfisol
2	WhC	77.7	Westmoreland-Guernsey silt loams, 8-15% slopes	Alfisol
2	WhE	18.6	Westmoreland-Guernsey silt loams, 25-40% slopes	Alfisol
3	BkF	100.0	Berks-Westmoreland silt loams, 40-70% slopes	Inceptisol
4	StF	99.2	Steinsburg sandy loam, 40-70% slopes	Inceptisol
5	UgD	73.4	Upshur-Gilpin silt loams, 15-25% slopes	Alfisol
5	UgE	26.6	Upshur-Gilpin complex, 25-50% slopes	Alfisol

Early Permian, and modern Ohio resulted in differences in classification at an order level.

Dominant modern soils at each site are classified as Entisols, Inceptisols, and Alfisols (Table 3) (NRCS Web Soil Survey). Of the three modern soil orders found in the study area, Alfisols exhibit the most profile development. Alfisols require an argillic horizon; however, unlike in Vertisols, the illuviated clays do not cause intersecting slickensides, wedge-shaped peds, or desiccation cracks (Soil Survey Staff 1999). Found at Sites 1, 2, and 5, these soils are deep and well-drained, and are located to large extent on forested hill summits, shoulders, and backslopes in the study area (Fig. 3) (Soil Survey Staff 1999, 2007, 2013, 2014). These soils are formed on residuum including interbedded sandstones, siltstones, clayey mudstones, weathered shales, and freshwater limestones. Inceptisols cover the majority of Sites 3 and 4 (Fig. 3). These are moderately deep, well-drained soils formed on upland residuum from fractured shales, weakly cemented sandstones, and conglomerate (Soil Survey Staff 1999, 2007, 2013, 2014). Profiles exhibit weak to

moderate development, with some illuviated clays indicated by a Bw horizon. Entisols are present at Site 1 (Fig. 3). These soils are very weakly developed in the subsurface. Udorthents in particular are often associated with upland road cuts where original soils have been covered with loamy fill (NRCS Web Soil Survey).

Figure 4: Constructed water balance curve for a soil with udic moisture regime and mesic temperature regime in Athens, Ohio (NCDC, NRCC).

CHAPTER 4: METHODS

Field Methods

Paleosols from the Pennsylvanian to Permian Conemaugh, Monongahela, and Dunkard groups were sampled at five sites in Athens and Meigs counties, southeast Ohio (Fig. 3A, Table 5). Selected profiles were located along road cuts with known ages, ranging from approximately 20 to 60 years. Selected paleosols were previously described in detail and were interpreted as paleoVertisols and paleoInceptisols (King 2008; Hembree and Nadon 2011; Catena and Hembree 2012; Dzenowski and Hembree 2012; Carnes 2017; Hembree and Bowen 2017). In this study, field descriptions were prepared for all sampled profiles and included Munsell color, texture, horizonation, presence of redoximorphic mottling, presence of carbonates, and any other diagnostic features in the manner described by the Schoeneberger et al. (2012).

At each outcrop, samples were taken from identified Bw and Bt horizons because certain weathering ratios are depth sensitive (Sheldon and Tabor 2009). Selected sampling sites were located at the top and base of each outcrop to account for weathering variations due to landscape position. When possible, paleoVertisol and paleoInceptisol profiles were sampled at each slope position, with paired samples taken approximately 7 m apart to account for lateral variation of the geochemistry (Fig. 5). Horizons containing significant amounts of carbonate were excluded from sampling, when possible.

At each of the 36 sampling locations, a series of 40 g samples was collected from depths of 0, 25, 50, 100, and 150 cm extending into the outcrop (Fig. 5). In order to avoid contamination from non-target depths and up-profile surface material, samples taken

from shallower depths (0–50 cm) were collected via excavation. An auger and a soil core were used to collect samples at 100 and 150 cm at sites 1 and 2. Due to increased lithification, sites 3, 4, and 5 were excavated in their entirety. The 100 and 150 cm depths for the lower paleoInceptisols at site 5 were excluded from sampling due to inaccessibility.

Table 5: Overview of paleosols sampled by site

Site	1	2	3	4	5
Stratigraphy	Conemaugh Group Glenshaw Formation	Conemaugh Group Casselman Formation	Monongahela Group	Dunkard Group Waynesburg Formation	Dunkard Group Waynesburg Formation
Roadcut Age	~50 years	<24 years	>57 years	<24 years	<22 years
Roadcut Location	39.327°, -82.086°	39.301°, -82.102°	39.303°, -81.938°	39.213°, -81.823°	38.964°, -81.823°
Paleosols Sampled (upper)	Inceptisols (gbm) above Vertisols (rbm)	Inceptisols (gbm) overlying Vertisols (rbm), abrupt contact	Inceptisols (rpm) above Vertisols (rbm)	Vertisols (rbm) above Inceptisols (rpm)	Inceptisols (rpm) overlying Vertisols (rbm), abrupt contact
Paleosols Sampled (lower)	Vertisols (rbm) above Inceptisols (gpm)	NA	Inceptisols (gpm) overlying Vertisols (gbm), diffuse contact	Vertisols (rbm) above Inceptisols (rbm to rpm)	Vertisols (rbm) above Inceptisols (gpm)
Method	Excavated to 50 cm, then cored to 150 cm	Excavated to 50 cm, then cored to 150 cm	Excavated to 150 cm	Excavated to 150 cm	Excavated to 150 cm, lower Inceptisols excavated to 50 cm

Figure 5: Sampling schematic for identified Bw and/or Bt horizons at study sites

Laboratory Methods

To determine bulk geochemistry, samples were shipped to an external lab, ALS Minerals (Reno, Nevada), where they were ground, homogenized and 0.7 g subsamples were taken for X-ray fluorescence (XRF) analysis. Analysis was conducted on an XRF spectrometer PANalytical, model Axios Fast. Samples were prepared for XRF analysis using the fusion bead method. Lithium metaborate flux was added to sample, and the sample was heated to 845 °C in a platinum crucible to facilitate oxidation (Watanabe 2015). Further, the crucible was heated to 1050 °C to facilitate fusion. After the sample has dissolved into the flux, a nonwetting agent was added and the melt was poured into a mold to cool into a lithium borate bead. XRF results were reported in weight percent for major oxides (Ca, Fe, K, Mg, Na, Al, O, Si, Mn, P, Ti). Detection limits and loss on ignition data are included in Table 6.

The major oxide geochemistry for each sample was used to calculate molecular weathering ratios and climofunctions (Table 2). Molecular weathering ratios included: sum of bases to alumina for hydrolysis, base to Ti ratio for leaching, lessivage for the downward translocation of clays, salinization ratio for salinization, and CIA-K for weathering of feldspar and subsequent hydration of clay minerals (Sheldon and Tabor 2009). The salinization ratio was also used to estimate the mean annual temperature (MAT) and the CIA-K ratio was used to estimate the mean annual paleoprecipitation (MAP) (Sheldon et al. 2002, Sheldon and Tabor 2009). For samples taken from paleoVertisol profiles, Vertisol specific functions were used to calculate the percent CaO, coefficient of linear extensibility (COLE), cation exchange capacity (CEC), and pH

(Nordt and Driese 2010a). Additionally, the CALMAG index was used to calculate MAP for paleoVertisol profiles, as other functions, including CIA-K, traditionally underestimate paleoprecipitation in this order (Nordt and Driese 2010b).

Table 6: XRF detection limits (wt. %) at 1000 °C, modified from Hembree and Blair (2016).

Analyte	Detection Limit	Analyte	Detection Limit
Al ₂ O ₃	0.01-100	Na ₂ O	0.01-10
BaO	0.01-66	P ₂ O ₅	0.01-46
CaO	0.01-60	SO ₃	0.01-34
Cr ₂ O ₃	0.01-10	SiO ₂	0.01-100
Fe ₂ O ₃	0.01-100	SrO	0.01-1.5
K ₂ O	0.01-15	TiO ₂	0.01-30
MgO	0.01-50	LOI	0.01-100
MnO	0.01-39		

Analyses and Comparisons

Changes in the weight percent of major oxides, molecular weathering ratios, MAP and MAT with increasing depth from the outcrop surface were compared. Each sample population consisted of values from a specific depth (0, 25, 50, 100, 150 cm) from all 36 sample series. Ten different paired comparisons were made between these populations for each metric (Ca, Na, Al, Base loss, CIA-K, etc.) to determine if there was a significant change in values with depth. Further comparisons evaluated differences based on slope position, the paleosol order, and degree of lithification (sites 1 and 2 versus sites 3, 4, and 5). Finally, MAP and MAT estimates from paleosol bulk geochemistry were compared qualitatively against current climate data.

Due to the low number of sampling sites and the inability to assume a normal distribution, non-parametric statistical analyses were used to describe the data collected in this study. The Spearman Rank correlation coefficient was used to determine whether there was a monotonic relationship between geochemistry and depth. It was calculated in R 3.2.1 using the `cor.test` function, with `type equals spearman`. Populations represented all of the values for each oxide, molecular weathering ratio, and climofunctions, and were also subdivided based on paleosol order, slope position, and degree of lithification. The Kruskal Wallis test was used to determine whether distributions varied between sample populations. It was calculated in R 3.2.1 by using the `kruskal.test` function with populations representing all of the values for each oxide, molecular weathering ratio, and climofunctions, and then into sub-populations based on paleosol order, slope position, and degree of lithification. The Wilcoxon Signed Rank test was used to determine whether population means varied between depths. It was calculated in R 3.2.1 using `wilcox.test`, `paired equals true`, using 10 paired comparisons per depth for each oxide weight percent, molecular weathering ratio, and paleoclimate estimate.

CHAPTER 5: RESULTS

Physical Properties by Site

Site 1

Lower Profiles

Sampling sites in the lower portion of Site 1 were located in west-facing vegetated trenches with deep modern soil development, including distinct horizonation above the paleoVertisol locations, and approximately 25° slopes. Overlying and underlying beds were exposed and described, and the previously interpreted paleosol horizons were excavated to 50 cm, and then cored to 150 cm. At this location paleoVertisol and paleoInceptisol profiles were not consecutive, with paleoInceptisols lower in the section (Table 5). The southern lower paleoInceptisol (1LI-1) was saturated at the time of sampling.

At the exposed surface, a greyish-green platy mudstone, interpreted as the lower paleoInceptisol, was located beneath a red variegated blocky to platy mudstone and located above a red platy mudstone (Figure 6). Transitions were abrupt. At 25 cm, grain size decreased and olive brown mottles and aggregate surface staining were present on a greyish green matrix, as were a few approximately 10 cm carbonate nodules. At 50 cm, matrix color was reddish brown with abundant yellow and greyish green mottles. The sample from 100 cm was an olive brown, loosely consolidated, clayey-mudstone with common fine yellow mottles. Lithification increased at 150 cm; the sample was a greyish green platy mudstone with common yellow mottles.

The dusky red blocky mudstone interpreted as the lower paleoVertisol was located beneath a finely laminated grey shale and above a greyish-green platy mudstone (Figure 6). Transitions were obscured by vegetation. Modern roots and fine yellow root traces were common in samples from the surface of the lower paleoVertisol. Matrix color at 0 cm ranged from greyish-green to dusky red with common fine greyish green mottles. At 25 cm, the sample was a dusky red blocky mudstone with abundant fine yellow root traces and common greyish green mottles. Few 5-8 cm carbonate nodules were observed likely transported from up section. At 50 cm, the matrix was reddish-brown, with abundant yellow to greyish-green rhizohaloes, common greyish-green mottles, and slickensides. A dusky red to olive brown blocky mudstone with common fine yellow root traces, and few weakly cemented 3-4 cm carbonates was present at 100 cm. By 150 cm, this had transitioned to a loosely indurated, dusky red to greyish green, blocky, claystone to mudstone with common fine brown mottles and yellow staining on aggregate faces.

Upper Profiles

Sampling sites in the upper portion of Site 1 were located on a west-facing, exposed surface between areas with extensive slump. Sites were not vegetated; however, dense grasses covered sections further up slope. Profile slopes ranged from 26° to 34°. Paleosols in the upper portion of Site 1 were excavated to a depth of 50 cm, and then cored to 150 cm.

The section containing the upper paleoVertisol was located on a bench capped by loosely consolidated sandstone that overlay a well-developed modern soil profile (Table 5) (Figure 7). The contact between the base of this soil and the upper paleoVertisol was

wavy and diffuse. A grey blocky mudstone was located beneath the upper paleoVertisol. The reddish-brown blocky mudstone interpreted as the upper paleoVertisol had few fine greyish-green mottles, few 5-8 cm carbonate mottles, and slickensides at the exposed surface. At 25 cm, the southern profile exhibited an abrupt change in matrix color to yellow, while the northern profile remained reddish-brown. Greyish-green fine mottles were common in both profiles, and root channels were observed. From 50 to 100 cm, the upper paleoVertisol profile remained a reddish-brown blocky mudstone with common fine greyish green and yellow mottles. At 150 cm, the sample changed to a reddish-brown to greyish-green platy mudstone, though slickensides and yellow mottles were still present.

Approximately 30 cm of lacustrine carbonate was weathering out above the greyish-green to blueish-grey platy to blocky mudstone interpreted as the upper paleoInceptisol profile. This profile was located above a reddish-brown blocky mudstone. At the exposed surface of the upper paleoInceptisol, large carbonate nodules formed a layer approximately 2.0-4.5 cm beneath the lower boundary of the lacustrine carbonate. Fine brown mottles were also common at 0 cm. At 25 cm, the sample included greyish-green platy to blocky mudstone with prominent brown surface staining and few to moderate discrete 5 cm carbonate nodules. By 50 cm, paleosol structure changed to platy to massive, and modern roots were observed in addition to the common 5 cm carbonate nodules. Carbonate frequency increased at 100 cm and evidence of root traces was observed; matrix color remained greyish-green and structure remained platy to massive. Samples at 150 cm were a uniform greyish-green platy mudstone.

Figure 6: Paleosol physical properties in the lower portion of Site 1, legend included as part of Figure 7.

Figure 7: Paleosol physical properties in the upper portion of Site 1.

Site 2

A single pair of paleoVertisols and paleoInceptisols was sampled at Site 2, as paleosols were not identified in the lower portions of the site (Table 5). Aspect was western; sampling sites at Site 2 included an unvegetated, exposed trench with very minimal modern soil development to an area vegetated with grasses, forbs, and shrubs and thick soil development. At Site 2, approximately 10 cm of sandstone cropped out above a black shale (Figure 8). This shale overlay a grayish-green blocky mudstone interpreted as a paleoInceptisol. An abrupt wavy contact delineated this mudstone from the dusky red to brown blocky mudstone, interpreted as a paleoVertisol, beneath it. A thin layer of micaceous sandstone was located below the paleoVertisol. Average slope varied from 44° in the paleoInceptisol profiles to 27° in the paleoVertisol profiles.

The fresh surface of the paleoInceptisol was a dusky grayish-green blocky mudstone, with common, fine brown mottles, brown staining on ped faces, and common 1.5-2.0 cm carbonate nodules. Carbonate frequency decreased to few at 25 cm. At 50 cm, there was a strongly lithified grayish-green platy to blocky mudstone with common olive brown to reddish-brown fine mottles, common 2-3 cm carbonate nodules, and thick, oxidized rhizohaloes. Samples from 100 cm were grayish-green, blocky to platy mudstone, with few reddish-brown mottles, and common 1-2 cm carbonate nodules. At 150 cm, samples were from an olive brown, platy mudstone with common reddish-brown mottles and 1-2 cm carbonates.

The paleoVertisol was a strongly aggregated, reddish-brown to dusky red blocky mudstone with common grayish-green mottles at 0 cm. At 25 cm, mottle color changed to

brown, and few pale green root traces were observed. Slickensides were present in the red to reddish-brown blocky mudstone at 50 cm. Greyish-green fine mottles were also common. Samples from 100 cm were dusky red, with common grayish-green mottles. Iron concretions were observed at the southern paleoVertisol. At 150 cm, the blocky mudstone was reddish brown, with slickensides, few, fine olive brown mottles, and yellow staining on aggregate faces. Grain size decreased, as did aggregate strength.

Figure 8: Paleosol physical properties at Site 2, legend included in as part of Figure 7.

*Site 3**Lower*

The outcrops at Site 3 had a southwestern aspect. Paleosols in the lower portion were exposed, located on an unvegetated face beneath of vegetated sandstone ledge. In some areas, thick slump from overlying sections, including sandstone fragments, were present. Soil development was minimal. A grayish-green platy to blocky mudstone, interpreted as the paleoInceptisol, was located below the sandstone bed (Figure 9). A diffuse contact separated the base of the paleoInceptisol from a grayish-green blocky mudstone with wedge shaped peds, interpreted as the paleoVertisol (Table 5). Cover extended from the base of the paleoVertisol to the bottom of the outcrop. The Fishpot Limestone is located below the paleoVertisol, but it was not exposed at this site (King, 2008). Slopes ranged from 31° to 43° in the paleoInceptisol profiles and were approximately 43° in the paleoVertisol profiles.

At a fresh surface, the paleoInceptisol was a grayish-green micaceous blocky-to-platy mudstone with modern roots. At 25 cm, the paleoInceptisol was grayish-green, platy to blocky, with common brown surface staining and clay skins on aggregate faces. Aggregate size increased at 50 cm; the paleosol was a greyish-green, platy to blocky, micaceous mudstone with yellow surface staining. The 100 cm sample contained a greyish-green blocky mudstone with few 10 cm carbonate nodules. Grain size decreased at 100 cm. At 150 cm, the sample was a greyish-green, platy-to-massive, sandy mudstone. Samples were strongly lithified and contained few mm-scale carbonate nodules and few, fine olive brown mottles.

The paleoVertisol was a greyish-green, angular blocky, micaceous, sandy mudstone at 0 cm. Aggregates were strongly lithified and wedge shaped. Modern roots were present. At 25 cm, the sample was similar, but contained olive brown staining on ped surfaces. At 50 cm, the paleoVertisol was a greyish-green to dark grey blocky mudstone with large aggregates and olive brown surface staining. Samples from 100 cm were strongly lithified, and contained common, olive brown, fine mottles in addition to the staining on ped faces. At 150 cm, the paleoVertisol was a dusky red, strongly lithified, blocky to massive mudstone with yellow staining on ped surfaces.

Upper

In the upper portion of Site 3, a sandstone bed crops out, exposing vegetation-free trenches between ridges composed of up section slump. Slump ridges had minimal soil development; paleosols were exposed at the surface of the trenches. In this section, a sandstone bed overlay a grey platy mudstone, which abruptly transitioned to a dusky red-to-brown, platy mudstone that was interpreted as the paleoInceptisol (Table 5) (Figure 10). The paleoInceptisol overlay a grey platy mudstone, a red blocky mudstone, and a calcareous red blocky mudstone. This calcareous horizon abruptly transitioned into a second dusky red blocky mudstone that was interpreted as the paleoVertisol. A grey platy mudstone was located beneath the paleoVertisol. Slope was approximately 26° in the paleoInceptisol and approximately 31° in the paleoVertisol.

At 0 cm, the paleoInceptisol was a dusky red to brown, platy to subangular blocky mudstone with few blueish grey mottles and yellow surface staining. The 25 cm samples were a reddish-brown, platy mudstone with common greyish-green mottles and common

yellow surface staining. Samples from 50 cm strongly resembled samples from 25 cm. Grain size increased by 100 cm, and visible micas were present. Color varied from variegated yellow, reddish-brown, and greyish-green in the southern profile to blueish grey with yellow mottles in the northern profile. At 150 cm, the paleoInceptisol sample was composed of a greyish-green, platy, sandy mudstone with common yellow brown mottles and surface staining.

The paleoVertisol was a dusky red blocky mudstone at 0 cm. Cutans were present on ped faces, as was brown surface staining. Free carbonates were also present. A reddish-brown to dusky red blocky mudstone as present at 25 cm. Samples from this depth contained common, moderate olive brown mottles and root traces, brown staining on ped faces, slickensides, and few mm-scale carbonate nodules. The 50 cm sample contained common 3-5 cm carbonate nodules, free carbonates, greyish green root traces, and slickensides in a dusky red sandy mudstone matrix. At 100 cm, the sample was a strongly lithified, reddish-brown, blocky mudstone with yellow staining on aggregate surfaces, common blueish grey mottles, and common mm-scale carbonates. At 150 cm, the sample was a strongly lithified, dusky red, blocky sandy mudstone with common dark grey to blueish grey mottles and common mm-scale carbonates.

Figure 9: Paleosol physical properties in the lower portion of Site 3, legend included in as part of Figure 7.

Figure 10: Paleosol physical properties in the upper portion of Site 3, legend included in as part of Figure 7.

*Site 4**Lower*

Site 4 was west-facing. In the lower portion of Site 4, paleoVertisol and paleoInceptisol profiles were not consecutive, with the paleoInceptisols lower in the section (Table 5). PaleoVertisol samples were collected from an unvegetated portion of the slope with alternating ridges and trenches. Ridges had exposed blocky mudstone at the surface. Depressions contained debris from up section that was cleared prior to sampling. The slope in this portion of the outcrop was approximately 33°. PaleoInceptisol samples were collected from an unvegetated portion of the slope containing alternating ridges and trenches. Trenches had minimal soil development and contained moderate up slope-derived fill that was cleared prior to sampling. The slope was approximately 40°. Iron concretions were common at the surface of the lower paleoInceptisols. The surface of the eastern paleoInceptisol was wet when sampled.

An olive brown to reddish-brown, blocky mudstone overlay the reddish-brown, blocky mudstone that was interpreted as the paleoVertisol (Figure 11). An abrupt, wavy transition delineated the base of the paleoVertisol from the top of the underlying greyish-green, platy mudstone. At 0 cm, the paleoVertisol was a reddish-brown, blocky mudstone with common olive brown mottles and yellow staining on aggregate surfaces. Small, mm-scale, carbonate nodules were frequent and few 5 to 8 cm carbonate nodules were also present. The sample from 25 cm contained a dusky red to reddish-brown, blocky mudstone with common yellow staining on aggregate surfaces, common mm-scale carbonates, and common slickensides. The sample from 50 cm resembled the sample

from 25 cm; however, it had an increase in clay content and was strongly aggregated. Changes were minimal to 100 cm. At 150 cm, the paleoVertisol was a dusky red, blocky, clayey mudstone with common, fine olive brown mottles, common mm-scale carbonate nodules, and slickensides.

An intercalated sandstone and siltstone bed containing thick, well-developed nodular iron concretions gradually transitioned into the red, platy to blocky mudstone interpreted as the paleoInceptisol. The transition between the paleoInceptisol and the underlying grey platy mudstone was abrupt. At the fresh surface, the paleoInceptisol was a reddish-brown to dusky red, platy mudstone, variegated with olive brown. Few slickensides were present, and iron concretions were common. The western sample from 25 cm contained a strongly lithified, dusky red, platy to blocky mudstone with frequent olive brown mottles and metallic slickensides. In contrast, the eastern 25 cm sample contained interlayered olive brown and blueish grey, platy mudstones. At 50 cm, samples contained strongly lithified, dusky red to olive brown, blocky mudstones with common dark grey mottles, common mm-scale carbonates, and few slickensides. The sample from 100 cm contained a reddish-brown to olive brown, very strongly lithified, platy mudstone with metallic slickensides. This sample was collected above a layer containing in situ 5 to 8 cm iron concretions. The strongly lithified, greyish-green to olive platy mudstone collected at 150 cm contained few mm-scale carbonate nodules and few slickensides. A carbonate film was present on ped surfaces.

Upper

In the upper portion of Site 4, sampling sites for the upper paleoVertisol were located on a vegetated slope, ranging from 27 to 43°. Approximately 4 to 8 cm of slumped material from up section was cleared prior to sampling. Modern soil development was minimal. Sampling sites for the upper paleoInceptisol were collected in an unvegetated trench containing minimal up section slump, and very minimal modern soil development. Slopes were approximately 23°.

An intercalated shale and sandstone layer was located above the reddish-brown, blocky mudstone interpreted as the upper paleoVertisol (Table 5, Figure 12). The underlying layer was a grey, platy mudstone that graded into sandstone. Transitions between beds were abrupt. At the surface, the paleoVertisol was a reddish-brown, subangular blocky mudstone containing few greyish-green mottles, few dispersed mm-scale carbonate nodules, and few slickensides. At 25 cm, the samples were reddish-brown with few greyish-green mottles, and sparsely dispersed mm-scale carbonate nodules. Aggregate strength increased to 50 cm. Aggregates at 100 cm were strongly lithified and subangular blocky to rounded in shape. Samples from this depth contained common, mm-scale carbonate nodules and common, greyish-green, fine mottles. An increase in aggregate size was observed at 150 cm. Cutans were present on ped faces, as were large, greater than 10 cm, slickensides. Moderate-to-coarse greyish-green mottles were common in a reddish-brown matrix, and mm-scale carbonates were common.

Approximately 95 cm of sandstone overlay the reddish-brown, platy mudstone that was interpreted as the paleoInceptisol. A silty shale layer beneath the paleoInceptisol

graded into a sandstone layer. Transitions were abrupt. At the surface, the paleoInceptisol was an olive brown to reddish-brown, platy mudstone with brown staining on aggregate surfaces and common modern roots. At 25 cm, color varied from dusky red to olive brown, with common greyish-green mottles, and yellow staining on ped faces.

Aggregates were strongly lithified at 25 cm. At 50 cm, samples were olive brown to reddish-brown, with yellow staining and contained slickensides. The sample from 100 cm contained a brown, platy to blocky mudstone that was interlayered with a blueish-grey, platy mudstone. The sample was strongly lithified, and slickensides and yellow staining was present on aggregate surfaces. The 150 cm sample was a variegated, brown to blueish-grey, platy to massive mudstone containing cutans and orangish-yellow staining on ped faces.

Figure 11: Paleosol physical properties in the lower portion of Site 4, legend included in as part of Figure 7.

Figure 12: Paleosol physical properties in the upper portion of Site 4, legend included in as part of Figure 7.

*Site 5**Lower*

. PaleoVertisol samples from the lower portion of Site 5 were collected from an unvegetated face with narrowly spaced ridges and trenches. Up section detritus and modern soil development were minimal to absent. Slopes were approximately 23°. PaleoInceptisol samples were collected from an unvegetated face located beneath a series of outcropping sandstone beds. The sampling area had moderate up section cover, minimal soil development, and large carbonate nodules were common on the surface. Slope was approximately 34°.

Approximately 10 cm of grey coal to coaly, platy mudstone was above the greyish-green, blocky mudstone that was interpreted as the upper paleoVertisol (Table 5, Figure 13). Beneath, an abrupt contact separated the paleoVertisol from a covered sandstone bed. At a fresh surface, the paleoVertisol was a dusky red, blocky mudstone with common, fine greyish-green mottles, yellow staining on ped surfaces, few mm-scale carbonate nodules, and exposed slickensides. At 25 cm, the sample was grayish-green with olive brown and reddish brown mottles, and had an increase in carbonate frequency. By 50 cm, matrix color transitioned to olive brown and mottle colors ranged from brown to yellow. At 100 cm, the sample contained greenish-grey, blocky to platy mudstone with common reddish brown, dusky red, and yellow mottles and common mm-scale carbonates. Soil structure at 150 cm ranged from blocky, to platy, to massive, and the color was greenish grey with common yellow surface staining. Carbonate nodules remained common, and size increased from 0.2 to 0.5 cm.

A micaceous sandstone bed cropped out above a grey, platy mudstone in the lower portion of Site 5. A wavy, diffuse boundary separated this mudstone from the red, platy mudstone that was interpreted to be the lower paleoInceptisol. A second wavy, diffuse boundary separates the paleoInceptisol with the underlying grey platy mudstone. At 0 cm, the paleoInceptisol was a greenish-grey to reddish-brown platy mudstone with few 3-5 cm carbonate nodules. Samples from 25 cm contained a greyish-green to olive brown, platy mudstone with brown surface staining. The 50 cm sample was a strongly lithified, blueish-grey to dark grey, platy mudstone with common yellow surface staining. The 100 and 150 cm depths were excluded from sampling because sampling sites were determined to be too lithified to core efficiently and the outcrop was too unstable to excavate safely.

Upper

Samples from the upper portion of Site 5 were collected from a moderately sloping, approximately 24°, unvegetated face with elevated lobes and depressed troughs located beneath a vegetated sandstone bed. Detritus from up section was minimal on the lobes. Modern soil development was not observed between the sandstone bed and the underlying dusky red platy mudstone, interpreted as the upper paleoInceptisol. An abrupt transition delineated the boundary between the upper paleoInceptisol from the underlying reddish-brown blocky mudstone interpreted as the upper paleoVertisol (Table 5) (Figure 14). A finely laminated, grey, micaceous sandstone bed was located below the paleoVertisol.

At the surface, the paleoInceptisol was a dusky red, platy, fine mudstone with few fine olive brown mottles. At 25 cm, the matrix color transitioned to reddish-brown with common, olive brown and brown, fine mottles. Mottles were not observed at 50 cm; however, yellow surface staining was frequent. Modern roots were present in this sample. Samples from 100 cm included reddish-brown, platy to blocky mudstone with yellow staining on ped surfaces and common, olive brown, moderate mottles. The 150 cm sample was a variegated reddish-brown to olive brown, platy to massive mudstone with common yellow staining on aggregate surfaces.

PaleoVertisol samples from 0 cm contained a reddish-brown, blocky mudstone with common, olive brown, fine mottles and root traces and common mm-scale carbonate nodules. At 25 cm, carbonate frequency decreased and slickensides were observed. By 50 cm, carbonate nodule size increased to 3 to 5 cm and brown staining was observed on aggregate faces. The sample from 100 cm contained common, yellowish-green rhizohaloes, 2-3 mm in diameter, outlined in yellow. Matrix color was reddish-brown, and few olive brown mottles were also present. Carbonate nodules, 2 to 3 cm in diameter, were common, and slickensides were frequent. At 150 cm, aggregate size increased. The sample was a reddish-brown, blocky mudstone that contained few, faint yellow mottles, brown surface staining, and common, mm-scale carbonate nodules.

Figure 13: Paleosol physical properties in the lower portion of Site 5, legend included in as part of Figure 7.

Figure 14: Paleosol physical properties in the upper portion of Site 5, legend included in as part of Figure 7.

Geochemical Properties by Site

A table containing oxide weight percent, molecular weathering ratios, and climofunctions by site is included as Appendix A.

Site 1

Lower

In lower paleoVertisol samples from Site 1, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (16.52 at 100 cm to 18.78 at 150 cm), CaO (5.32 at 100 cm to 0.93 percent at 150 cm), Fe_2O_3 (6.98 at 0 cm to 8.90 at 50 cm), K_2O (4.12 at 0 cm to 3.86 at 100 cm), MgO (1.92 at 25 cm to 2.02 at 150 cm), Na_2O (0.23 at 25 cm to 0.15 at 100 cm), P_2O_5 (0.20 at 0 cm and 25 cm to 0.24 at 100 cm), SiO_2 (54.22 at 100 cm to 59.36 at 150 cm), and TiO_2 (0.87 at 100 cm to 0.99 at 150 cm). These variations did not, however, change consistently with depth. As a result of the changes in oxide concentrations, all calculated molecular weathering ratios exhibited variability. A summary of resulting MAP and MAT estimates for all paleosols at Site 1 is included in Table 7.

In the lower paleoInceptisol samples from Site 1, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (20.55 at 50 cm to 22.28 at 150 cm), CaO (0.82 at 50 cm to 0.49 at 100 cm), Fe_2O_3 (6.24 at 25 cm to 11.00 at 50 cm), K_2O (3.33 at 50 cm to 3.48 at 150 cm), MgO (2.18 at 50 cm to 1.95 at 150 cm), MnO (0.04 at 25 cm and 100 cm to 0.09 at 150 cm), Na_2O (0.23 at 25 cm to 0.20 at 50 cm), and P_2O_5 (0.12 at 0 cm to 0.06 at 150 cm). These variations did not change consistently with

depth. The sum of bases to aluminum, CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, and the K/Ti ratio also exhibited variability.

Table 7: Summary of MAP and MAT estimates by paleosol at Site 1 (Sheldon 2006; Nordt and Driese 2010b)

Site 1	Lower paleoVertisol	Lower paleoInceptisol	Upper paleoVertisol	Upper paleoInceptisol
MAP min (mm) CIA-K	817 at 100 cm	1273 at 25 cm	504 at 100 cm	689 at 100 cm
MAP max (mm) CIA-K	1339 at 150 cm	1313 at 100 cm	774 at 0 cm	1235 at 25 cm
S.E. (mm) CIA-K	172	172	172	172
MAP min (mm) CALMAG	1137 at 100 cm		833 at 100 cm	
MAP max (mm) CALMAG	1526 at 150 cm		1080 at 0 cm	
S.E. (mm) CALMAG	108		108	
MAT min (°C)	12.39 at 0 cm	13.75 at 50 cm	13.36 at 0 cm	13.52 at 0 cm
MAT max (°C)	12.90 at 150 cm	13.87 at 150 cm	13.54 at 25 cm	13.65 at 25cm
S.E. (°C)	4.0	4.0	4.0	4.0

Upper

In the upper paleoVertisol samples from Site 1, weight percents of oxides that varied by more than one standard deviation included: Al₂O₃ (14.92 at 100 cm to 16.41 at 150 cm), CaO (5.76 at 0 cm to 9.39 at 25 cm), Fe₂O₃ (8.35 at 0 cm to 6.25 at 25 cm), K₂O (2.70 at 100 cm to 3.00 at 0 cm), MgO (2.17 at 25 cm to 2.40 at 150 cm), Na₂O (0.11 at 25 cm to 0.16 at 150 cm), SiO₂ (49.18 at 100 cm to 54.16 at 150 cm), and TiO₂

(0.80 at 100 cm to 0.88 at 150 cm). These variations did not change consistently with depth. The sum of bases to aluminum, CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, and the Na/Ti ratio also exhibited variability; as did all Vertisol specific molecular weathering ratios except the COLE.

In the upper paleoInceptisol samples from Site 1, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (19.80 at 25 cm to 16.63 at 100 cm), CaO (1.15 at 25 cm to 8.67 at 100 cm), Fe_2O_3 (5.27 at 50 cm to 4.69 at 100 cm), K_2O (3.37 at 50 cm to 2.84 at 100 cm), MgO (2.38 at 0 cm to 1.99 at 100 cm), MnO (0.03 at 25 cm to 0.15 at 100 cm) Na_2O (0.23 at 25 cm to 0.15 at 100 cm), P_2O_5 (0.29 at 0 cm to 0.20 at 50 cm), SiO_2 (60.80 at 25 cm to 52.13 at 100 cm), and TiO_2 (1.03 at 50 cm to 0.85 at 100 cm). These variations did not change consistently with depth. The sum of bases to aluminum, CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, Na/Ti, and the K/Ti ratio also exhibited variability.

Site 2

In the paleoVertisol samples from Site 2, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (18.03 at 0 cm to 15.25 at 100 cm), CaO (5.01 at 0 cm to 9.05 at 150 cm), Fe_2O_3 (10.63 at 50 cm to 8.39 at 100 cm), K_2O (2.48 at 50 cm to 2.11 at 100 cm), MgO (1.46 at 0 cm to 4.34 at 100 cm), MnO (0.06 at 0 to 50 cm to 0.21 at 100 cm), Na_2O (0.12 at 0 to 100 cm to 0.10 at 150 cm), SO_3 (0.02 at 0 cm to 0.07 at 100 cm), SiO_2 (51.26 at 0 cm to 43.92 at 100 cm), and TiO_2 (0.91 at 0 cm to 0.77 at 100 cm). These variations did not change consistently with depth. All molecular weathering ratios, except CIA-K, also varied more than one standard deviation

from the mean; as did all Vertisol specific molecular weathering ratios. Resulting MAP and MAT values for Site 2 are included in Table 8.

Table 8: Summary of MAP and MAT estimates by paleosol at Site 2 (Sheldon 2006; Nordt and Driese 2010b)

Site 2	PaleoVertisol	PaleoInceptisol
MAP min (mm) CIA-K	548 at 100 cm	267 at 50 cm
MAP max (mm) CIA-K	879 at 0 cm	400 at 100 cm
S.E. (mm) CIA-K	172	172
MAP min (mm) CALMAG	778 at 100 cm	
MAP max (mm) CALMAG	1234 at 0 cm	
S.E. (mm) CALMAG	108	
MAT min (°C)	14.22 at 150 cm	12.73 at 25 cm
MAT max (°C)	14.37 at 0 cm	13.29 at 150 cm
S.E. (°C)	4.0	4.0

In the paleoInceptisol samples from Site 2, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (10.91 at 50 cm to 12.97 at 150 cm), CaO (22.00 at 50 cm to 15.85 at 100 cm), Fe_2O_3 (4.19 at 50 cm to 4.69 at 150 cm), K_2O (2.54 at 25 cm to 2.25 at 50 cm), MgO (1.63 at 50 cm to 2.02 at 150 cm), MnO (0.12 at 0 and 50 cm to 0.07 at 150 cm), P_2O_5 (0.22 at 25 cm to 0.18 at 150 cm), SiO_2 (37.04 at 50 cm to 43.62 at 100 cm), and TiO_2 (0.55 at 50 cm to 0.66 at 150 cm). These variations did

not change consistently with depth. The sum of bases to aluminum, CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, the Na/Ti ratio, and the K/Ti ratio also exhibited variability.

Site 3

Lower

In lower paleoVertisol samples from Site 3, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (6.46 at 50 cm to 16.00 at 100 cm), CaO (0.63 at 0 cm to 0.37 at 150 cm), Fe_2O_3 (10.33 at 0 cm to 6.98 at 50 cm); K_2O (2.61 at 25 cm to 2.32 at 50 cm), MgO (2.02 at 0 cm to 1.53 at 50 cm), Na_2O (0.55 at 100 cm to 0.68 at 150 cm), SiO_2 (60.96 at 0 cm to 64.90 at 50 cm), and TiO_2 (0.92 at 0 cm to 1.00 at 100 cm). These variations did not change consistently with depth. All calculated molecular weathering ratios exhibited variability except Al/Si and the COLE. Resulting MAP and MAT estimates for all paleosols at Site 3 is included in Table 9.

In the lower paleoInceptisol samples from Site 3, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (16.35 at 0 cm to 18.00 at 150 cm), BaO (0.06 at 50 cm to 0.12 at 150 cm), CaO (1.98 at 100 cm to 0.37 at 150 cm), Fe_2O_3 (7.53 at 100 cm to 5.16 at 150 cm), K_2O (2.80 at 50 cm to 2.48 at 150 cm), MgO (1.93 at 0 cm to 1.31 at 150 cm), MnO (0.06 at 100 cm to 0.02 at 150 cm), P_2O_5 (0.12 at 0 cm to 0.06 at 150 cm), Na_2O (0.71 at 0 cm to 0.50 at 150 cm), SO_3 (0.07 at 0 cm to 0.33 at 150 cm), SrO (0.03 at 0 cm to 0.11 150 cm), SiO_2 (64.62 at 0 cm to 60.17 at 100 cm), and TiO_2 (0.92 at 100 cm to 1.01 at 150 cm). These variations did not change consistently with depth. All molecular weathering ratios except Al/Si exhibited variability.

Table 9: Summary of MAP and MAT estimates by paleosol at Site 3 (Sheldon 2006; Nordt and Driese 2010b)

Site 3	Lower paleoVertisol	Lower paleoInceptisol	Upper paleoVertisol	Upper paleoInceptisol
MAP min (mm) CIA-K	1292 at 0 cm	1089 at 100 cm	65 at 0 cm	1005 at 0 cm
MAP max (mm) CIA-K	1334 at 100 cm	1281 at 150 cm	344 at 50 cm	1047 at 100 cm
S.E. (mm) CIA-K	172	172	172	172
MAP min (mm) CALMAG	1515 at 0 cm		315 at 0 cm	
MAP max (mm) CALMAG	1586 at 100 cm		695 at 50 cm	
S.E. (mm) CALMAG	108		108	
MAT min (°C)	12.81 at 25 cm	12.75 at 0 cm	11.24 at 150 cm	12.68 at 100 cm
MAT max (°C)	13.39 at 50 cm	13.70 at 150 cm	11.90 at 25 cm	12.79 at 0cm
S.E. (°C)	4.0	4.0	4.0	4.0

Upper

In the upper paleoVertisol samples from Site 3, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (9.87 at 0 cm to 11.37 at 50 cm), BaO (0.03 at 0 and 100 cm to 0.05 at 50 cm), CaO (18.57 at 0 cm to 9.96 at 50 cm), Fe_2O_3 (4.67 at 0 cm to 5.19 at 50 cm), K_2O (2.05 at 0 cm to 2.31 at 50 cm), MgO (1.47 at 50 cm to 1.38 at 150 cm), MnO (0.17 at 0 cm to 0.06 at 150 cm), Na_2O (0.41 at 0 cm to 0.69 at 150 cm), SO_3 (0.09 at 0 cm to 0.04 at 50, 100, and 150 cm), SiO_2 (44.19 at 0 cm to 57.19 at 50 cm), and TiO_2 (0.57 at 0 cm to 0.71 at 50 cm). These variations did not change consistently with depth. The sum of bases to aluminum, CIA-K, the Ca/Ti ratio,

the Mg/Ti ratio, the Na/Ti ratio, and K/Ti ratio also exhibited variability; as did all Vertisol specific molecular weathering ratios except the COLE.

In the upper paleoInceptisol samples from Site 3, weight percents of oxides that varied by more than one standard deviation included: Al_2O_3 (18.52 at 100 cm to 18.95 at 150 cm), CaO (3.55 at 0 cm to 2.90 at 100 cm), Fe_2O_3 (7.86 at 50 cm to 6.02 at 150 cm), K_2O (3.90 at 50 cm to 3.74 at 100 cm), MgO (2.44 at 25 cm to 2.31 at 100 cm), Na_2O (0.23 at 25 cm to 0.35 at 100 cm), and SiO_2 (53.79 at 25 cm to 56.15 at 150 cm). These variations did not change consistently with depth. The sum of bases to aluminum, CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, Na/Ti, and the K/Ti ratio also exhibited variability.

Site 4

Lower

In lower paleoVertisol samples from Site 4, weight percentages of oxides that varied by more than one standard deviation included: Al_2O_3 (21.11 at 50 cm to 22.17 at 150 cm), CaO (0.36 at 0 cm to 0.62 at 25 cm), Fe_2O_3 (8.91 at 0 cm to 12.26 at 50 cm), K_2O (3.67 at 50 cm to 2.80 at 150 cm), MgO (2.25 at 50 cm to 2.41 at 150 cm), Na_2O (0.26 at 25 and 150 cm to 0.21 at 100 cm), SiO_2 (52.65 at 0 cm to 49.58 at 100 cm), and TiO_2 (0.95 at 0 cm to 0.88 at 100 cm). All calculated molecular weathering ratios exhibited variability except Mg/Ti, (K+Na)/Al, and the COLE. Oxide weight percentages from Site 4 for SO_3 were not provided. Resulting MAP and MAT estimates for all paleosols at Site 4 is included in Table 10.

In the lower paleoInceptisol samples from Site 4, weight percentages of oxides that varied by more than one standard deviation included: Al_2O_3 (19.48 at 50 cm to 21.64

at 150 cm), CaO (0.50 at 25 cm to 3.07 at 100 cm), Fe₂O₃ (7.09 at 50 cm to 10.97 at 150 cm), K₂O (3.97 at 25 cm to 3.50 at 100 cm), MgO (2.12 at 100 cm to 2.33 at 150 cm), MnO (0.02 at 25 cm to 0.05 at 100 cm), P₂O₅ (0.10 at 0 cm and 25 cm to 0.22 at 100 cm), Na₂O (0.19 at 0 cm and 100 cm to 0.29 at 50 cm), SiO₂ (55.59 at 50 cm to 49.54 at 100 cm), and TiO₂ (0.94 at 50 cm to 0.82 at 150 cm). All molecular weathering ratios except (K+Na)/Al exhibited variability. Although variations exist, they did not change consistently with depth.

Table 10: Summary of MAP and MAT estimates by paleosol at Site 4 (Sheldon 2006; Nordt and Driese 2010b)

Site 4	Lower paleoVertisol	Lower paleoInceptisol	Upper paleoVertisol	Upper paleoInceptisol
MAP min (mm) CIA-K	1387 at 25 cm	1059 at 100 cm	686 at 100 cm	1235 at 50 cm
MAP max (mm) CIA-K	1427 at 0 cm	1306 at 25 cm	1051 at 25 cm	1303 at 150 cm
S.E. (mm) CIA-K	172	172	172	172
MAP min (mm) CALMAG	1559 at 25 cm		1032 at 100 cm	
MAP max (mm) CALMAG	1578 at 0 cm		1334 at 25 cm	
S.E. (mm) CALMAG	108		108	
MAT min (°C)	13.46 at 25 cm	12.87 at 50 cm	13.45 at 150 cm	13.33 at 50 cm
MAT max (°C)	13.63 at 100 cm	13.50 at 150 cm	13.57 at 100 cm	13.55 at 150 cm
S.E. (°C)	4.0	4.0	4.0	4.0

Upper

In the upper paleoVertisol samples from Site 4, weight percentages of oxides that varied by more than one standard deviation included (20.14 at 25 cm to 18.18 at 100 cm), CaO (3.47 at 25 cm to 7.83 at 100 cm), Fe₂O₃ (10.60 at 50 cm to 7.99 at 150 cm), K₂O (3.53 at 25 cm to 3.13 at 100 cm), (2.10 at 50 cm and 100 cm to 2.49 at 150 cm), MnO (0.07 at 25 cm to 0.16 at 150 cm), Na₂O (0.17 at 100 cm to 0.23 at 150 cm), SiO₂ (48.26 at 25 cm to 43.66 at 100 cm), and TiO₂ (0.85 at 25 cm to 0.75 at 100 cm). The sum of bases to aluminum, CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, the Na/Ti ratio, and K/Ti ratio also exhibited variability; as did all Vertisol specific molecular weathering ratios except the COLE. Although variations existed, they did not change consistently with depth.

In the upper paleoInceptisol samples from Site 4, weight percentages of oxides that varied by more than one standard deviation included: Al₂O₃ (20.49 at 50 cm to 21.75 at 150 cm), CaO (1.08 at 50 cm to 0.57 at 150 cm), Fe₂O₃ (8.81 at 50 cm to 11.71 at 150 cm), K₂O (3.57 at 50 cm to 3.75 at 150 cm), MgO (2.38 at 0 cm to 2.32 at 50 cm and 100 cm), Na₂O (0.32 at 50 cm to 0.22 at 150 cm), SiO₂ (53.33 at 50 cm to 50.02 at 100 cm and 150 cm), and TiO₂ (0.94 at 50 cm to 0.85 at 150 cm). The sum of bases to aluminum, CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, Na/Ti, and the K/Ti ratio also exhibited variability. Although variations existed, they did not change consistently with depth.

*Site 5**Lower*

In lower paleoVertisol samples from Site 5, weight percentages of oxides that varied by more than one standard deviation included: Al_2O_3 (21.05 at 25 cm to 22.10 at 150 cm), CaO (0.47 at 25 cm to 0.57 at 100 cm), Fe_2O_3 (12.09 at 25 cm to 6.04 at 150 cm), K_2O (3.50 at 0 cm and 100 cm to 3.33 at 25 cm), MgO (1.85 at 0 cm and 150 cm to 1.78 at 25 cm), Na_2O (0.16 at 50 cm to 0.44 at 150 cm), P_2O_5 (0.10 at 25 cm to 0.17 at 100 cm), SiO_2 (49.55 at 0 cm to 55.21 at 150 cm), and TiO_2 (0.81 at 0 cm to 0.97 at 150 cm). All calculated molecular weathering ratios exhibited variability except the sum of bases to aluminum, the ratios of Al/Si and $(\text{K}+\text{Na})/\text{Al}$, and the COLE. Although variations existed, they did not change consistently with depth. Resulting MAP and MAT estimates for all paleosols at Site 5 are included in Table 11.

In the lower paleoInceptisol samples from Site 5, weight percentages of oxides that varied by more than one standard deviation included: CaO (0.31 at 0 cm to 2.51 at 50 cm), Fe_2O_3 (9.28 at 25 cm to 10.99 at 50 cm); K_2O (3.85 at 0 cm to 3.37 at 50 cm), MgO (2.40 at 0 cm to 2.25 at 50 cm), P_2O_5 (0.05 at 0 cm to 0.15 at 50 cm), SiO_2 (52.28 at 25 cm to 48.55 at 50 cm), and TiO_2 (0.93 at 25 cm to 0.83 at 50 cm). All molecular weathering ratios except Al/Si exhibited variability. Although variations exist, they did not change consistently with depth.

Upper

In the upper paleoVertisol samples from Site 5, weight percentages of oxides that varied by more than one standard deviation included: Al_2O_3 (18.79 at 25 cm to 19.59 at

150 cm), CaO (3.17 at 0 cm to 2.77 at 100 cm), Fe₂O₃ (9.92 at 25 cm to 6.96 at 150 cm), K₂O (3.78 at 25 cm to 3.92 at 100 cm), MgO (1.96 at 50 cm to 1.89 at 100 cm), Na₂O (0.10 at 50 cm to 0.32 at 150 cm), SiO₂ (49.43 at 25 cm to 52.26 at 150 cm), and TiO₂ (0.79 at 0 cm to 0.88 at 150 cm). As a result, the CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, the Na/Ti ratio, and K/Ti ratio also exhibited variability; as did all Vertisol specific molecular weathering ratios except the COLE. Although variations existed, they did not change consistently with depth.

Table 11: Summary of MAP and MAT estimates by paleosol at Site 5 (Sheldon 2006; Nordt and Driese 2010b)

Site 5	Lower paleoVertisol	Lower paleoInceptisol	Upper paleoVertisol	Upper paleoInceptisol
MAP min (mm) CIA-K	1382 at 150 cm	1098 at 50 cm	1060 at 0 cm	1287 at 150 cm
MAP max (mm) CIA-K	1411 at 50 cm	1329 at 0 cm	1107 at 100 cm	1315 at 0 cm
S.E. (mm) CIA-K	172	172	172	172
MAP min (mm) CALMAG	1607 at 50 cm		1355 at 0 cm	
MAP max (mm) CALMAG	1614 at 25 cm		1396 at 100 cm	
S.E. (mm) CALMAG	108		108	
MAT min (°C)	13.60 at 150 cm	13.38 at 25 cm	12.87 at 25 cm	13.59 at 0cm
MAT max (°C)	13.87 at 50 cm	13.46 at 0 cm	13.12 at 50 cm	13.69 at 100 cm
S.E. (°C)	4.0	4.0	4.0	4.0

In the upper paleoInceptisol samples from Site 5, weight percentages of oxides that varied by more than one standard deviation included: Al_2O_3 (21.91 at 50 cm to 22.43 at 100 cm), CaO (0.45 at 0 cm to 0.56 at 150 cm), Fe_2O_3 (11.19 at 0 cm to 5.34 at 150 cm), K_2O (3.74 at 0 cm to 3.42 at 150 cm), MgO (2.13 at 0 cm to 1.79 at 150 cm), P_2O_5 (0.11 at 25 cm to 0.16 at 100 cm), and SiO_2 (49.50 at 0 cm to 55.65 at 150 cm). As a result, the CIA-K, the Ca/Ti ratio, the Mg/Ti ratio, Na/Ti, the K/Ti, and (K+Na)/Al ratio also exhibited variability. Although variations existed, they did not change consistently with depth.

Comparisons

Overall

At each depth, oxide weight percent, molecular weathering ratios, and MAP and MAT estimates varied extensively; however, a trend with depth was not confirmed (Appendix 2; Figures 15–18). The Spearman Rank Correlation Coefficient did not indicate a monotonic relationship existed between geochemistry and depth for any oxide weight percent, molecular weathering ratio, or paleoclimate estimate ($\alpha=0.05$) (Table 12). Results of the Kruskal-Wallis test did not indicate varying distributions between sample populations ($\alpha=0.05$) for any oxide weight percent, molecular weathering ratio, or climate estimate (Table 13). Differences in overall population means with depth were found using the Wilcoxon Signed Rank test ($\alpha=0.05$); however, these differences did not occur in a pattern that indicated they were a function of depth (Table 14).

Upper v. Lower

This section is a comparison of the upper and lower paleosol sample geochemistry, with the samples from Site 2 counting as upper, to determine if slope position had an effect on the weathering profile. The Spearman Rank Correlation Coefficient did not indicate a monotonic relationship between geochemistry and depth for any oxide weight percent, molecular weathering ratio, or climate estimate in the upper or lower paleosol samples ($\alpha=0.05$) (Table 12). The Kruskal-Wallis test did not indicate varying distributions between sample populations ($\alpha=0.05$) for any oxide weight percent, molecular weathering ratio, or climate estimate (Table 13). Differences in upper and lower paleosol population means with depth were found using the Wilcoxon Signed Rank

test ($\alpha=0.05$); however, these differences did not occur in a pattern that indicates they are a function of depth (Appendix C).

Lithified v. Unconsolidated

This section includes a comparison of the sample geochemistry between Sites 1 and 2, and Sites 3-5 to determine if the degree of lithification affected the weathering profile. A monotonic relationship between geochemistry and depth was detected using the Spearman Rank Correlation Coefficient for the percent by weight of Cr_2O_3 in Sites 3, 4, and 5 ($\alpha=0.05$). Monotonic relationships were not found for other oxide weight percents, molecular weathering ratios, or climate estimates (Table 12). The Kruskal-Wallis test did not indicate varying distributions between sample populations ($\alpha=0.05$) for any oxide weight percent, molecular weathering ratio, or climate estimate (Table 13). Differences in population means with depth were found in lithified and unconsolidated paleosols using the Wilcoxon Signed Rank test ($\alpha=0.05$); however, these differences did not occur in a pattern that indicates they are a function of depth (Appendix C).

PaleoVertisols v. PaleoInceptisols

This section includes a comparison of the sample geochemistry between paleoVertisols and paleoInceptisol to determine if properties related to paleosol order affected the weathering profile. A monotonic relationship between geochemistry and depth was detected using the Spearman Rank Correlation Coefficient for the ratio of $(\text{K}+\text{Na})/\text{Al}$ in the paleoInceptisols ($\alpha=0.05$). Monotonic relationships were not found for other oxide weight percents, molecular weathering ratios, or climate estimates (Table 12). The Kruskal-Wallis test did not indicate varying distributions between sample

populations ($\alpha=0.05$) for any oxide weight percent, molecular weathering ratio, or climate estimate (Table 13). Differences in paleoVertisol and paleoInceptisol population means with depth were found using the Wilcoxon Signed Rank test ($\alpha=0.05$); however, these differences did not occur in a pattern that indicates they are a function of depth (Appendix C).

Figure 15: Molecular weathering ratio vs. depth (cm) for a) CIA-K, b) $\sum \text{bases}/\text{Ti}$, c) Al/Si, d) Ca/Ti

Figure 16: Molecular weathering ratio vs. depth (cm) for a) $(K+Na)/Al$, b) K/Ti , c) Mg/Ti , d) Na/Ti

Figure 17: Vertisol-specific molecular weathering ratio vs. depth (cm) for a) CEC, b) COLE, c) Percent CaO, d) pH

Figure 18: Paleoclimate vs. depth (cm) for a) MAP-CIA-K(mm), b) MAP-CALMAG(mm), c) MAT(°C)

Table 12: Spearman Rank Correlation Coefficient Results

		Overall	Upper	Lower	Sites 1,2	Sites 3-5	Vertisols	Inceptisols
Oxide (wt%)	Al ₂ O ₃	0.896	0.897	0.894	0.911	0.947	0.761	0.762
	BaO	0.586	0.894	0.242	0.786	0.424	0.794	0.202
	CaO	0.982	0.860	0.914	0.855	0.835	0.662	0.803
	Cr ₂ O ₃	0.431	0.664	0.472	0.699	0.036	0.944	0.323
	Fe ₂ O ₃	0.105	0.260	0.248	0.503	0.125	0.455	0.152
	K ₂ O	0.411	0.719	0.477	0.566	0.571	0.746	0.387
	MgO	0.653	0.277	0.162	0.193	0.276	0.344	0.307
	MnO	0.812	0.967	0.782	0.254	0.342	0.793	0.818
	Na ₂ O	0.658	0.219	0.757	0.725	0.486	0.543	0.962
	P ₂ O ₅	0.177	0.695	0.180	0.824	0.087	0.508	0.176
	SO ₃	0.134	0.177	0.501	0.251	0.076	0.987	0.102
	SiO ₂	0.633	0.482	0.867	0.826	0.439	0.555	0.878
	SrO	0.145	0.991	0.088	0.757	0.137	0.575	0.071
	TiO ₂	0.891	0.756	0.987	0.738	0.639	0.666	0.975
Molecular Weathering Ratio	Σbases/Al	0.573	0.502	0.924	0.848	0.503	0.425	0.960
	CIA-K	0.609	0.630	0.982	0.736	0.713	0.973	0.555
	Al/Si	0.884	0.819	0.959	0.969	0.682	0.784	0.743
	Ca/Ti	0.601	0.459	0.909	0.955	0.509	0.376	0.890
	Mg/Ti	0.847	0.735	0.445	0.336	0.231	0.849	0.351
	Na/Ti	0.737	0.456	0.732	0.821	0.578	0.679	0.925
	K/Ti	0.302	0.301	0.600	0.536	0.420	0.520	0.398
	(K +Na)/Al	0.590	0.858	0.250	0.494	0.912	0.911	0.047
	%CaO	0.585	0.683	0.683	0.599	0.414	NA	NA
	COLE	0.569	0.689	0.662	0.671	0.388	NA	NA
	CEC	0.417	0.452	0.706	0.604	0.328	NA	NA
	pH	0.952	0.549	0.515	0.579	0.650	NA	NA
Climofunction	MAP (CIA-K)	0.342	0.260	0.922	0.731	0.367	0.574	0.554
	MAP (CALMAG)	0.585	0.160	0.581	0.455	0.870	NA	NA
	MAT	0.585	0.859	0.246	0.491	0.907	0.923	0.049

Table 13: Kruskal-Wallis Results

		Overall	Upper	Lower	Sites 1,2	Sites 3-5	Vertisols	Inceptisols
Oxide (wt%)	Al ₂ O ₃	0.769	0.936	0.793	0.847	0.984	0.586	0.833
	BaO	0.943	0.880	0.856	0.966	0.981	0.927	0.817
	CaO	0.714	0.912	0.697	0.894	0.902	0.833	0.603
	Cr ₂ O ₃	0.923	0.981	0.961	0.970	0.330	0.996	0.854
	Fe ₂ O ₃	0.427	0.760	0.716	0.751	0.506	0.736	0.468
	K ₂ O	0.801	0.978	0.964	0.979	0.903	0.948	0.780
	MgO	0.797	0.782	0.711	0.562	0.778	0.772	0.692
	MnO	0.812	0.707	0.889	0.761	0.708	0.972	0.409
	Na ₂ O	0.937	0.882	0.977	0.816	0.995	0.922	0.955
	P ₂ O ₅	0.559	0.982	0.426	0.972	0.322	0.978	0.472
	SO ₃	0.641	0.961	0.155	0.728	0.855	0.616	0.822
	SiO ₂	0.882	0.828	0.964	0.737	0.966	0.987	0.846
	SrO	0.778	0.968	0.284	0.927	0.652	0.954	0.748
	TiO ₂	0.736	0.861	0.904	0.719	0.954	0.980	0.553
Molecular Weathering Ratio	Σbases/Al	0.840	0.897	0.786	0.873	0.990	0.759	0.858
	CIA-K	0.771	0.897	0.842	0.876	0.930	0.818	0.848
	Al/Si	0.997	0.999	0.993	0.984	0.996	0.997	0.997
	Ca/Ti	0.698	0.902	0.701	0.883	0.914	0.834	0.593
	Mg/Ti	0.948	0.967	0.899	0.861	0.899	0.964	0.958
	Na/Ti	0.980	0.889	0.987	0.951	0.986	0.992	0.975
	K/Ti	0.933	0.933	0.993	0.995	0.886	0.974	0.973
	(K +Na)/Al	0.944	0.984	0.881	0.966	0.995	0.418	0.999
	%CaO	0.848	0.580	0.928	0.600	0.973	NA	NA
	COLE	0.800	0.526	0.955	0.728	0.964	NA	NA
	CEC	0.771	0.610	0.918	0.711	0.964	NA	NA
	pH	0.804	0.531	0.955	0.727	0.962	NA	NA
Climofunction	MAP (CIA-K)	0.740	0.692	0.840	0.850	0.900	0.618	0.848
	MAP (CALMAG)	0.713	0.272	0.902	0.587	0.974	NA	NA
	MAT	0.938	0.998	0.863	0.933	0.996	0.999	0.465

Table 14: Overall Wilcoxon Signed Rank Results

		Overall									
depth (cm)		0-25	0-50	0-100	0-150	25-50	25-100	25-150	50-100	50-150	100-150
Oxide (wt%)	Al ₂ O ₃	0.660	0.154	0.723	0.138	0.354	0.858	0.067	0.959	0.030	0.002
	BaO	0.634	0.917	0.667	0.179	0.709	0.587	0.277	0.417	0.672	0.037
	CaO	0.310	0.195	0.554	0.452	0.151	0.630	0.590	0.701	0.231	0.008
	Cr ₂ O ₃	1.000	1.000	0.789	0.174	1.000	0.789	0.357	1.000	0.346	0.850
	Fe ₂ O ₃	0.566	0.935	0.417	0.118	0.182	0.651	0.473	0.084	0.094	0.973
	K ₂ O	0.594	0.174	0.163	0.452	0.280	0.235	0.694	0.544	0.899	0.158
	MgO	0.253	0.376	0.060	0.809	0.661	0.177	0.453	0.285	0.513	0.305
	MnO	0.684	0.939	0.872	0.423	0.630	0.604	0.590	0.494	0.638	0.077
	Na ₂ O	0.535	0.176	0.492	0.310	0.309	0.443	0.241	0.717	0.074	0.091
	P ₂ O ₅	0.739	0.073	0.286	0.131	0.043	0.130	0.092	0.523	0.768	0.837
	SO ₃	0.147	0.740	0.153	0.266	0.136	0.586	0.913	0.004	0.061	0.913
	SiO ₂	0.162	0.286	0.624	0.221	0.138	0.326	0.580	0.427	0.185	0.018
	SrO	0.969	0.628	0.248	0.358	0.527	0.121	0.443	0.585	0.569	0.806
	TiO ₂	0.141	0.893	0.483	0.334	0.548	0.362	0.574	0.178	0.438	0.016
Molecular Weathering Ratio	Σ bases/Al	0.182	0.311	0.858	0.238	0.375	0.939	0.338	0.698	0.238	0.010
	CIA-K	0.529	0.215	0.417	0.467	0.338	0.589	0.554	0.577	0.263	0.008
	Al/Si	0.184	0.464	0.549	0.830	0.911	0.694	0.688	0.696	0.761	0.734
	Ca/Ti	0.276	0.272	0.673	0.437	0.315	0.723	0.554	0.723	0.256	0.007
	Mg/Ti	0.003	0.233	0.094	0.158	0.891	0.626	0.673	0.946	0.630	0.604
	Na/Ti	0.930	0.287	0.775	0.280	0.896	0.701	0.231	0.891	0.108	0.142
	K/Ti	0.264	0.077	0.037	0.023	0.413	0.432	0.075	0.689	0.048	0.844
	(K +Na)/Al	0.687	0.399	0.338	0.339	0.628	0.564	0.239	0.445	0.350	0.910
	%CaO	0.671	0.523	0.523	0.468	0.865	0.865	0.551	0.640	0.212	0.027
	COLE	0.523	0.663	0.670	0.459	0.850	0.865	0.542	0.616	0.163	0.029
	CEC	0.610	0.580	0.580	0.580	0.966	0.832	0.551	0.393	0.442	0.027
	pH	0.687	0.766	0.932	0.246	0.899	0.832	0.433	0.610	0.284	0.067
Climofun ction	MAP (CIA-K)	0.610	0.149	0.272	0.609	0.219	0.480	0.672	0.577	0.249	0.007
	MAP (CALMAG)	0.927	0.459	0.329	0.712	0.966	0.832	0.495	0.551	0.304	0.034
	MAT	0.783	0.248	0.185	0.293	0.851	0.675	0.338	0.285	0.330	0.824

CHAPTER 6: DISCUSSION

Sampling Depth and Bulk Geochemistry

In this study, few relationships between bulk geochemistry and depth were observed. A monotonic relationship between Cr_2O_3 and depth was detected at Sites 3, 4, and 5 ($\alpha=0.05$). The distribution of chromium and other heavy metals is controlled by transport processes and biologically mediated reactions (Tokunaga et al. 2001). Sites 3, 4, and 5 were strongly lithified, some with free carbonates forming within the macropores, which could have restricted transport within the soil body. However, across all sites, chromium values were essentially homogeneous, ranging from <0.01 to 0.02 percent, meaning that any minute change in concentration could provide a signal (Appendix A). A monotonic relationship between the salinization ratio and depth was also found in the paleoInceptisols ($\alpha=0.05$). This ratio has been noted to be unreliable, however, due to differences in diagenetic processes that affect components Na and K (Retallack 1991; Sheldon and Tabor 2009). The salinization ratio is used to calculate MAT, which also exhibits a monotonic relationship with depth (Table 12). Across all sites, MAT ranges from 11.867 to 14.671 °C in the Pennsylvanian and Permian, compared to the modern 30-year average MAT of 10.98 °C; however, the high standard error (± 4.0 °C) supports that there is no significant difference in values (Sheldon 2006; NCDC 2017). The Wilcoxon signed rank test found differences in population means in multiple oxides, molecular weathering ratios, and climofunctions in all compared groups. Although these variations occurred, they were inconsistent with depth, and not arranged in a pattern that suggested modern weathering was the cause (Appendix B). One explanation for the observed deviations in these values is local variation in soil properties.

Causes of Observed Geochemical Variation

Local Variation in Soil Properties

Many aspects of soil formation contribute to the presence of physical and chemical variability within a soil body. Lithic parent material may not have a uniform geochemistry, and primary mineralogy informs on the development of secondary clay minerals such as kaolinite (Retallack 2001; Graham and O'Geen 2010). Sedimentary rocks are less susceptible to alteration from weathering than other rock types, particularly sedimentary rocks formed from previously weathered materials (Tuttle and Briet 2009). However, rocks deposited under reducing conditions weather more extensively than those deposited under oxidizing conditions (Chigara and Oyama 1999). Therefore, many studies have been conducted that characterize weathering processes in exposed, organic rich shales. Many of these studies focus on the loss of organic matter and change in composition of organic carbon with depth, although loss of pyrite and carbonate has also been observed (Leythaeuster 1973; Clayton and Swetland 1978; Littke et al. 1991). Tuttle and Briet (2009) evaluated changes in chemistry and mineralogy along a 40-year-old roadcut through a black shale containing distinct weathering zones ranging from unaltered shale to soil. Indicators of limited weathering included dissolution of calcite and chlorite, and the formation of gypsum, jarosite, and effervescent salts. Strongly weathered samples lost feldspars, chlorite, goethite, gypsum, jarosite, and effervescent salts, while retaining quartz, illite, and illite-smectite, and exhibited an increase in permeability. Some oxide concentrations, including SiO_2 , Al_2O_3 , and MgO , experienced minimal variation across the weathering zones, whereas Na_2O and K_2O were depleted

(Tuttle and Briet 2009). B horizons do not tend to be enriched in organic carbon; however, we expect that a similar pattern of weathering would occur in paleosols. Support for this can be found in Petsch et al. (2000), which documented a similar loss in organic carbon and pyrite in the upper 2–3 m in both highly weathered and recently exposed shales. Petsch et al. (2000) also found that rates of weathering were dominated by factors beyond chemical reactivity, such as hydrology and erosion rate.

Variability in textural class can also lead to local-level differences in rates of soil development. Tazikeh et al. (2017) classified soils formed in an aridic climate from sandstones, siltstones, mudstones, shales, marles, and limestones and compared physiochemical and morphological characteristics. Soils that formed from coarse-grained parent materials were classified as Entisols and lacked a genetic B horizon, whereas soils that formed on fine-grained parent materials were classified as Aridisols and contained illuviated calcic and/or gypsic horizons. Those soils that formed on claystones exhibited vertic properties and were classified as Vertisols. Soils in Tazikeh et al. (2017)'s study were formed under a MAP of 255 mm and MAT of 13 °C, compared to the CIA-K calculated MAP ranging from 65 mm at Site 3 to 1427 mm at Site 4 and calculated MATs ranging from 11.24 °C at Site 4 to 14.37 °C at Site 2 (Tables 8–10). We expect that the increase in precipitation would result in deeper profile development due to hydrologically mediated reactions. This expectation is confirmed in Clyde et al. (2013) that evaluated weathering depth in sediment cores, and found that the sampling location that exhibited the greatest weathering effects was located under coarse-grained sandstone, allowing for enhanced penetration of meteoric water.

Another factor that can influence soil chemistry, and subsequently soil development, is the composition and distribution of vegetation. Plants, through above ground inputs as well as root exudates, provide a source of soil organic matter, which contributes to cation exchange capacity and provides aggregate stability (Retallack 2001). Kooch et al. (2017) evaluated variations of litter quality, soil physio-chemical properties, and macrofauna activity in a broad-leaf mixed deciduous forest. Soil properties that varied based on vegetation type included soil bulk density, sand content, and silt content, and pH, as well as soil productivity by providing a source of N, P, K, Ca, and Mg (Kooch 2017). Beyond composition altering soil chemistry, leaf litter thickness also contributes to lateral variation by increasing soil moisture and dampening changes in soil temperature (Fekete et al. 2016). Plant rooting activities also contribute to soil formation in several ways including: mixing as a result of root expansion during growth, infilling of root channels with overlying material, altering small-scale hydrology through water uptake, and formation of pit/mound microtopography during uprooting (Schaetzl et al. 1989).

Vegetation also impacts biological activity within the soil, including the density of annelids and nematodes, as well as microbial respiration rates (Kooch 2017). Microorganisms promote the biogenic concentration of minerals or mineral phases within the soil (Timofeeva and Golov 2010). Burrowing soil macrofauna mix and alter soil texture, decrease bulk density and increase infiltration, porosity, and permeability (Platt et al. 2016). The effect that small soil organisms have on soil properties was explored by Hale et al. (2005) as they examined how invasive earthworms altered the soil in a temperate deciduous forest in Minnesota. Although decreased bulk density is associated

with burrowing activity, in this study, processes related to feeding led to compaction of mineral and organic material within the gut, leading to an increase in bulk density in the upper mineral horizons (Hale et al. 2005). This increase was thought to result in an increase in surface runoff, although typically infiltration rates increase with earthworm activity. Other findings included a decrease in soil organic matter content, homogenization of upper soil horizons, and decrease in availabilities of nitrate, ammonium, and phosphate (Hale et al. 2005). Burrowing activities of larger soil fauna, such as badgers and foxes, cause a secondary loss of horizonation throughout the soil profile as these organisms excavate materials from deeper horizons into the topsoil, decreasing pH and enriching it with K, Ca, and Mg. Conversely, organic material from surface horizons is translocated deeper into the profile, which alters C and N availability around burrow openings (Kurek et al. 2014). In addition to altering soil properties, organisms can alter small-scale surface topography by creating mounds and depressions related to burrowing activities (Kurek et al. 2014). Some soil arthropods, such as ants and termites, can produce large nest mounds which have been found to alter plant productivity and species composition (Ciska and Olff 2011). Overall, biological activities result in an increase in landscape heterogeneity.

Additionally, microtopography, such as the gilgai microhighs and microlows in Vertisols, contributes to lateral variability on a scale of 2 to 5 m (Miller et al. 2010). Microhighs are typically drier than microlows and exhibit 4-5 times greater surface crack area, whereas microlows exhibit higher root density and greater COLE (Kishne et al. 2009). Despite differences in COLE, clay content does not vary consistently between

microhighs and microlows (Khitrov 2016). Vertical cracks common in Vertisol provide a source of surface material to deep in the soil profile. Interestingly, the location of cracks typically remain clustered, driven by a heterogeneous distribution of rain and surface hydrology, which leads to small-scale differences in input (Kishne et al. 2009). These factors include differences in oxide mobility, oxidation potentials, and leaching depths (Driese et al. 2000). Microlows are subject to translocation of exchangeable bases, Na, K, Ca, and Mg, and the subsequent formation of zones of precipitated pedogenic calcite and gypsum (Driese et al. 2000). Microhighs are enriched in S, Na, and redox-sensitive trace elements (Driese et al. 2000). Leaching depths reported by Driese et al. (2000) were 60 cm in the microhigh and 120 cm in the microlow. Inceptisols exhibit comparably minor pedogenesis and retain more properties of the parent material. In this study, many of the profiles classified as paleoInceptisols were interpreted to have formed on vertic parent materials and maintain some properties, such as slickensides, that are characteristic of Vertisols (Catena and Hembree 2012; Dzenowski and Hembree 2012; Hembree and Bowen 2017). Although vertic properties were present in the soils interpreted as paleoInceptisols, they were not sufficiently developed to be interpreted as paleoVertisols in their own right.

Deep Weathering Profile

A second possible explanation for the lack of weathering signal found in this study is that the modern weathering profile extends beyond 150 cm. This is suggested by preliminary results from the core-outcrop comparison study of Clyde et al. (2016). This project is affiliated with the 2011 Bighorn Basin Coring Project. The purpose of the

project was to attain high-resolution records, beyond stratigraphic resolution of outcrop sampling, by eliminating biases of surface weathering, incomplete exposures, and imprecise measuring of surface sections (Clyde et al. 2013). Initial visual core descriptions found evidence of oxidation, hydration, and fracturing extending 20-30 m below the outcrop surface, suggesting that outcrop level sampling procedures were insufficient to reach fresh material (Clyde et al. 2013). Clyde et al. (2016) were able to correlate the 900 m of vertical core taken from three sites to equivalent beds in outcrops within approximately 1.5 km, and evaluated various isotopic geochemical and magnetic proxies as well as color to better understand the effects of recent weathering (Maxbauer et al. 2016). The authors found that certain proxies, such as carbon isotopes in pedogenic carbonate, carbon isotopes inorganic matter, and percent organic carbon, were resistant to surficial weathering (Clyde et al. 2016). Variability in proxies, including oxygen isotopes from pedogenic carbonate and color, was attributed to surface weathering (Clyde et al. 2016). These studies did not consider bulk geochemical proxies. Based on relative location of cores and outcrops, it is possible that these differences can be attributed to lateral variation both on a local scale and a landscape scale rather than surficial weathering.

The order level differences between the modern soils mapped on the study outcrops and the paleosols suggests that the weathering profile does not extend past 150 cm. Modern soils mapped at Sites 1, 2, and 5 are predominantly Alfisols (Figure 3, Table 4). Although they are clay rich, differences in clay mineralogy result in the formation of a soil that is quite distinct from their paleoVertisol parent material. In Vertisols, a function

has been developed relating the CEC to clay mineralogy (Nordt and Driese 2010a). In this study, the majority of paleoVertisol samples had CEC values exceeding the 0.70 cmol/kg threshold that suggests expandable clays (Figure 17a). CEC of the Alfisols forming at these sites was not calculated; however, high soil fertility is a hallmark of the Alfisol soil order (Soil Survey Staff 1999). The primary difference between Alfisols and Vertisols is physical rather than geochemical, as Alfisols lack intersecting slickensides, wedge shaped peds, and vertical cracks that characterize Vertisols, and also and maintain horizonation (Soil Survey Staff 1999).

Modern, poorly developed Entisols and Inceptisols are present at Sites 1, 3, and 4; however, the presence of these soils is likely a function of the young roadcut ages rather than similar environmental conditions to those in the Pennsylvanian and Permian (Soil Survey Staff OSD, NRCS Web Soil Survey). The Udorthents present at Site 1, for example, are associated with cut and fill construction practices, forming on a separate parent material with distinct original geochemistry (NRCS Web Soil Survey). For recent Entisols and Inceptisols that formed on paleosols as a parent material, differences in landscape position are sufficient to lead to distinct features. Being located on a hillslope improves drainage, which means that these soils are forming under primarily oxidizing conditions. The paleoInceptisols in this study are primarily drab, suggesting they were formed in reducing conditions which is consistent with interpreted environmental conditions ranging from proximal to distal floodplain (Table 3).

Outcrop Age

A third potential explanation to the lack of depth-related change in bulk geochemistry is that the 20-60 year-old roadcuts sampled in this study were too young for a modern climate signal to form. This is supported by the study of Hinojosa et al. (2016) on a recent climosequence with approximate profile ages of decades to 5,000 years. The soil profile in the decades-age soil contained only a thin AC horizon slightly enriched in organic matter, with poor structure (Hinojosa et al., 2016). The first evidence of any type of B horizon occurred in soils formed in approximately 3,100 BC. Although this study focuses on soils forming on beach dunes under very different conditions than soils forming in Ohio, it supports that 20-60 years is not sufficient time for extensive pedogenesis. In oxidizing conditions, expected features of pedogenesis include translocated clays, reddening in color, and accumulations of major and trace elements (Ufnar 2017). Yellowish-orange cutans were present on aggregate surfaces at many sampling sites, suggesting that these paleosols are subject to pedogenesis.

Fischer et al. (2007) examined the effect that exposure has on organic carbon content in exposed roofing slates. These tiles, only 5 mm thick, had exposure times ranging from 90 to 100 years and experienced OC loss ranging from 0.007 percent/year for slates with moderate initial carbon content to 0.15 percent/year in slates with high initial carbon content (Fischer et al. 2007). Weathering was observed to occur from exposed edges of the roofing slates inwards towards the covered portions. Although the decadal exposure time in Fischer et al. (2007)'s study is similar to exposure time in this study, the mm sampling scale is unrealistic for outcrop level paleosol studies, when

individual aggregates can be larger than 5 mm. Indeed, the restriction of weathering rinds to the exterior of aggregate surfaces could explain why a weathering signal was not observed, as they compose a minute portion of the sample. Future repeated sampling of paleosol outcrops with longer exposure times, such as those in the western U.S., could better resolve the effect of time.

With time comes an additional question of repeated overprinting, where signal is not just altered by modern exposure but also by all previous potential exposures since the first instance of pedogenesis. However, in a study of a recent chronosequence in an alluvial setting, Ulfar (2007) found that illuvial clay accumulation rates in the lower portion of stacked profiles functionally ceases once the profile is buried, and that pedogenesis occurs in the upper portion as new Bt horizons form. Although this paper focuses only on illuviation rates determined from optically stimulated luminescence, it is possible that other pedogenic processes that operate in the B-horizon would behave similarly. This is supported by Catena and Hembree (2012)'s study, where an oxidized paleoVertisol was interpreted to have served as parent material for a gleyed paleoInceptisol. Although the upper portion of these soils took on properties characteristic of reducing conditions, below a certain depth, the soil retained its original properties.

Significance to Paleosol Studies

Many paleosol studies with a paleoclimate focus do not clearly explain outcrop sampling depth, discussing a vertical depth but not a horizontal depth (Driese and Ober 2005; Kahmann et al. 2008; Nordt and Driese 2010b; Hembree and Nadon 2011;

Hembree and Bowen 2017). Some papers discuss modern soil pit dimensions, but do not discuss analogous paleosol sampling strategies (Driese et al. 2005; Nordt and Driese 2010a). Others mention trenching to reduce or remove upslope slump and vegetative cover, but do not go into detail (King 2008; Catena and Hembree 2012). Rosenau et al. (2016) describe outcrop sampling methods excellently, collecting samples from sites that had been picked back to the lowest position of unaltered parent material as determined by sedimentary structures or change in grain size. The position they describe corresponds with the 0 cm sampling surface in this study, and although the description is clear, it does not account for the influences of recent pedogenesis within the paleosol. The intent of this study was to characterize the effects that modern weathering has on paleogeochemistry, and then develop a more standardized sampling depth for outcrop scale paleosol studies.

A recommended sampling depth was not apparent from the results of this study, however. The Wilcoxon Signed Rank test identified differences in geochemistry at many depths ($p=0.05$), with the most frequent differences occurring between samples from 100 and 150 cm (Appendix C). However, because differences between shallower depths and 150 cm were not observed, we cannot say that the weathering profile extends between 100 and 150 cm. We would recommend sampling from between 25 and 50 cm in outcrop-level paleosol studies in similar environments. This depth corresponds with outcrop sampling procedures in several recent studies: Carnes (2017) trenched to 50 cm, Dzenowski and Hembree (2012) excavated 25-50 cm of weathered sediment to sample fresh rock, Hembree and Blair (2016) sampled from 50-100 cm deep trenches. Other

studies sampled from beyond this depth, for example: Trendell et al. (2013) sampled from a 1 m deep trench, while Rosenau et al. (2016) and Clyde et al. (2016) compared paleosols in outcrop against those in core.

Much of the change in geochemistry observed can be attributed to small-scale lateral changes in the soil. Many previous studies considered lateral variability in paleosols, taking samples from multiple profiles along transects ranging in length from 24.2 m to 220 m (Driese and Ober 2005; Dzenowski and Hembree 2012; Catena and Hembree 2012; Carnes 2017, Hembree and Bowen 2017). Catena and Hembree (2012) found paleosol profiles that were not laterally continuous across 220 m, rather occurring as lenses. Identified variations within a single profile included the occurrence and prevalence of carbonates, mottles as well as the preservation of A and C horizons (Catena and Hembree 2012). Hembree and Bowen (2017) were able to capture variation both vertically within each 32 m section and laterally between three sections along a 70 m outcrop. This variation was attributed to channel migration, and was most prevalent in areas distal to the paleochannel, and evidence of ponding adjacent to well-drained paleosols was present (Hembree and Bowen 2017). On a smaller scale Dzenowski and Hembree (2012) observed changes in horizonation and soil development in paleosol profiles within sections spaced 14.8 and 9.4 m apart. Differences in rhizolith abundance and distribution between the three sections demonstrated variation in vegetation concentration and type over short distances (Dzenowski and Hembree 2012). Paleosols in Driese and Ober (2005)'s study exhibited substantial lateral variability which was attributed to differences in drainage conditions associated with gilgai microrelief in

modern Vertisols. To account for this small scale variation, we also recommend using mean values determined from samples taken from multiple locations along an outcrop prior to making interpretations when conducting this scale of paleosol research.

CHAPTER 7: CONCLUSIONS

To evaluate the influence of pedogenesis on bulk geochemical paleoenvironmental proxies, this study addressed three main hypotheses: 1) the bulk geochemistry within a single horizon will differ based on depth from outcrop surface; 2) paleoclimate estimates calculated from molecular weathering ratios will differ based on depth from outcrop surface, with those near the surface having a more modern climate signal and; 3) the degree of pedogenesis will differ based on paleosol type (paleoInceptisol vs. paleoVertisol), landscape position, and degree of lithification. Although physical properties, oxide geochemistry and paleoenvironmental proxies varied extensively between sampling depths, a trend with depth was not consistently observed. Additionally, sample distributions did not vary between any compared groups.

Although differences in oxide geochemistry between depths were observed in this study, the pattern suggests that they are the result of local variations in soil conditions at the time of formation rather than the result of recent pedogenesis. These variations range in scale from sub-meter processes such as plant community composition and distribution, bioturbation from burrowing fauna, biogenic mineral formation, or differences in drainage conditions resulting from microrelief to outcrop-level processes such as channel migration in meandering fluvial systems or slope aspect. Evaluating these small-scale variations is important, as they provide a more holistic approach to paleoenvironmental reconstructions. Replicate sampling within identified horizons along transects can be used to recognize lateral variation.

Another possible explanation is that the weathering profile extended beyond 150 cm into the outcrop, and all geochemical signals observed were the result of recent pedogenesis. Order level differences between soils forming at these sites versus the interpreted paleosol classifications do not support this explanation. One way to test this in future studies would be to collect control samples from the soils forming on the outcrop, and then comparing soil geochemistry against paleosol geochemistry.

A more likely explanation is that exposure time on the 20-60 year old roadcuts was not sufficient for a modern weathering signal to form. Limited features of pedogenesis, including the presence of yellowish-orange clay skins on aggregate surfaces were observed; however, it is possible that they were not developed enough to significantly alter geochemistry. It is possible that modern climate signals would be more pronounced on older outcrops. The effect of exposure time on paleosol geochemistry could be resolved by future studies on outcrops with longer, known, exposure times.

Results from this study did not identify a specific sampling depth beyond which bulk geochemistry is no longer affected by modern weathering. This suggests that current outcrop level sampling techniques are sufficient. We recommend sampling from 25-50 cm beyond the fresh surface, which can be recognized by the presence of sedimentary structures and a change in texture. A second recommendation addresses lateral variation. We recommend sampling multiple locations along an outcrop to account the effect of small-scale changes in parent material geochemistry, grain size, drainage, vegetation distribution and type, soil faunal activities, and microrelief.

REFERENCES

- Aslan, A., Austin, W., 1998, Holocene flood-plain soil formation in the southern lower Mississippi Valley: implications for interpreting alluvial paleosols: *Geological Society of America Bulletin*, v. 110, p. 433-449.
- Carnes, J., 2017, Response of soils and soil ecosystems to the Pennsylvanian-Permian climate transition in the upper fluvial plain of the Dunkard Basin, Southeastern Ohio, USA [M.S. Thesis]: Ohio University, Athens, Ohio, 146 p.
- Catena, A. and Hembree, D., 2012, Recognizing vertical and lateral variability in terrestrial landscapes: a case study from the paleosols of the Late Pennsylvanian Casselman Formation (Conemaugh Group) Southeast Ohio, USA: *Geosciences*, v. 2, p. 178-202.
- Cecil, C., 2013, An overview and interpretation of autocyclic and allocyclic processes and the accumulation of strata during the Pennsylvanian-Permian transition in the central Appalachian Basin, USA: *International Journal of Coal Geology*, v. 119, p. 21-31.
- Cecil, C. and Dulong, F., 2003, Precipitation models for sediment supply in warm climates: SEPM Special Publication No. 77, p. 21-28.
- Chadwick, O., Derry, L., Vitousek, P., Huebert., B., and Hedin, L., 1999, Changing sources of nutrients during four million years of ecosystem development: *Nature*, v. 397, p. 491-497.
- Chigara, M., and Oyama, T., Mechanism and effect of chemical weathering on sedimentary rocks: *Engineering Geology*, v. 55, p. 3-14.
- Clayton, J., and Swetland, P., 1978, Subaerial weathering of sedimentary organic matter: *Geochimica et Cosmochimica*, v. 42, p. 305-312.
- Clyde, W., Gingerich, P., Wing, S., Rohl, U., Westerhold, T., Bowen, G., Johnson, K., Baczynski, A., Diefendorf, A., McNerney, F., Schnurrenberger, D., Noren, A., Brady, K., and the BBC Science Team, 2013, Bighorn basin coring project (BBCP): an IODP-style continental coring project investigating Early Paleogene hyperthermals: *Scientific Drilling*, v. 16, p. 21-31.
- Clyde, W., Maxbauer, D., and Bowen, G., 2016, Using core-outcrop comparisons to understand the effects of recent surficial weathering on paleoenvironmental proxies in continental settings: *Geological Society of America Abstracts with Programs*, v. 48.
- Driese, S., Mora, C., Stiles, C., Joeckel, R., and Nordt, L., 2000, Mass-balance reconstruction of a modern Vertisol: implications for interpreting the geochemistry and burial alteration of paleo-Vertisols: *Geoderma*, v. 95, p. 179-204.
- Driese, S., Nordt., L., Lynn, W., Stiles, C., and Mora, C., 2005, Distinguishing climate in the soil record using chemical trends in a Vertisol climosequence from the Texas coast prairie,

- and application to interpreting Paleozoic paleosols in the Appalachian Basin, U.S.A.: *Journal of Sedimentary Research*, v. 75, p. 339-349.
- Driese, S and Ober, E., 2005, Paleopedologic and paleohydrologic records of precipitation seasonality from Early Pennsylvanian: "underclay" paleosols, U.S.A.: *Journal of Sedimentary Research*, v. 75, p. 997-1010.
- Dzenowski, N. and Hembree, D., 2012, Examining local climate variability in the Late Pennsylvanian through paleosols: an example from the Lower Conemaugh Group of southeastern Ohio, USA: *Geosciences*, v.2, p 260-276.
- Fedorko, N., Skema, V., 2013, A review of the stratigraphy and stratigraphic nomenclature of the Dunkard Group in West Virginia and Pennsylvania, USA: *International Journal of Coal Geology*, v. 119, p. 2-20.
- Fekete, I., Varga, C., Biro, B., Toth, J., Varbiro, G., Lajtha, K., Szabo, G., and Kotroczo, Z., 2016, The effects of litter production and litter depth on soil microclimate in a Central European deciduous forest: *Plant and Soil*, v. 398, p. 291-300.
- Fischer, C., Karius, V., and Thiel, V., 2007, Organic matter in black slate shows oxidative degradation within only a few decades: *Journal of Sedimentary Research*, v. 77, p, 355-365.
- Graham, R., and O'Geen, A., 2010, Soil mineralogy trends in California landscapes: *Geoderma*, v. 154, p. 418-437.
- Hale, C., Frelich, L., Reich, P., and Pastor, J., 2005, Effects of European earthworm invasion on soil characteristics in northern hardwood forests of Minnesota, USA: *Ecosystems*, v. 8, p. 911-927.
- Hembree, D. and Blair, M., 2016, A paleopedological and ichnological approach to interpreting spatial and temporal variability in Early Permian fluvial deposits of the lower Dunkard Group, West Virginia, U.S.A., *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 454, p. 246-266.
- Hembree, D. and Bowen, J., 2017, Paleosols and ichnofossils of the Upper Pennsylvanian-Lower Permian Monongahela and Dunkard Groups (Ohio, USA): a multi-proxy approach to unraveling complex variability in ancient terrestrial landscapes: *PALAIOS*, v. 32, p. 295-320.
- Hembree, D. and Nadon, G., 2011, A paleopedologic and ichnologic perspective of the terrestrial Pennsylvanian landscape in the distal Appalachian Basin, U.S.A.: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 312, p. 138-166.
- Hinojosa, C., Nooren, K., Solleiro-Rebolleno, E., Sedov, S., Salazar, O., 2016, Soil development on a beach ridge chronosequence in the Gulf of Mexico coastal plain and its relation to the ancient land use: *Quaternary International*, v. 418, p. 180-194.
- Jenny, H., 1941, *Factors in Soil Formation*, McGraw-Hill, New York. 191 p.

- Joeckel, R., 1995, Paleosols below the Ames Marine Unit (Upper Pennsylvanian Conemaugh Group) in the Appalachian Basin, U.S.A.; variability on an ancient depositional landscape: *Journal of Sedimentary Research*, v. 65, p.393-407.
- King, M.R., 2008, Fluvial architecture of the interval spanning the Pittsburgh and Fishpot Limestones (Late Pennsylvanian), southeastern Ohio [M.S. Thesis]: Ohio University, Athens, Ohio, 144 p.
- Khitrov, N., 2016, Properties and regimes of Vertisols with gilgai microtopography (a review): *Eurasian Soil Sciences*, v. 49, p. 257-271.
- Kishne, A., Morgan, C., and Miller, W., 2009, Vertisol crack extent associated with gilgai and soil moisture in the Texas Gulf Coast prairie: *Soil Science Society of America Journal*, v. 73, p. 1221-1230.
- Kooch, Y., Samadzadeh, B., Hosseini, S., 2017, The effects of broad-leaved tree species on litter quality and soil properties in a plain forest stand: *Catena*, v. 150, p. 223-229.
- Kraus, M., 1999, Paleosols in clastic sedimentary rocks: their geologic applications: *Earth-Science Reviews*, v. 47, p. 41-70.
- Kurek, P., Kapusta, P., Holeksa, J., 2014, Burrowing by badgers (*Meles meles*) and foxes (*Vulpes vulpes*) changes soil conditions and vegetation in a European temperate forest: *Ecological Research*, v. 29, p. 1-11.
- Leythauser, D., 1973, Effects of weathering on organic matter in shales: *Geochemica et Cosmochimica*, v. 37, p. 120-133.
- Littke, R., Klussman, U., Krooss, B., Leythauser, D., 1991, Quantification of loss of calcite, pyrite and organic matter during weathering of Toarcian black shales and effects on kerogen and bitumen characteristics: *Geochimica et Cosmochimica*, c. 55, p. 3369-3378.
- Mack, G., James, W. and Monger, H., 1993, Classification of paleosols: *Geological Society of America Bulletin*, v. 105, p. 129-136.
- Maxbauer, D., Feinberg, J., Fox, D., Clyde, W., 2016, Magnetic minerals as recorders of weathering, diagenesis, and paleoclimate: a core-outcrop comparison of Paleocene-Eocene paleosols in the Bighorn Basin, WY, USA: *Earth and Planetary Science Letters*, v. 452, p. 15-26.
- Martin, W., 1998, Geology of the Dunkard Group (Upper Pennsylvanian-Lower Permian) in Ohio, West Virginia, and Pennsylvania: Ohio Department of Natural Resources, Division of Geological Survey Bulletin, v. 73, p. 1-49.
- Maynard, J., 1992, Chemistry of modern soils as a guide to interpreting Precambrian paleosols: *Journal of Geology*, v. 100, p. 279-289.
- Miller, W., Kishne, A., and Morgan, C., 2010, Vertisol morphology, classification, and seasonal cracking patterns in the Texas Gulf Coast prairie: *Soil Survey Horizons*, v. 51, p. 10-16.

- Nadon, G. and Hembree, D., 2007. Variations in Sequence, Fluvial, and Pedogenic Architecture in the Distal Appalachian Foreland Basin, SE Ohio. SEPM Great Lakes Section Field Conference, Athens, Ohio.
- National Climate Data Center, National Centers for Environmental Information, Data Tools: 1981-2010 Normals: Athens, Ohio. Available Online, Accessed 2/8/2017.
- Nordt, L. and Driese, S., 2010a, A modern soil characterization approach to reconstructing physical and chemical properties of paleo-Vertisols: *American Journal of Science*, c. 310, p. 37-64.
- Nordt, L. and Driese, S., 2010b, New weathering index improves paleorainfall estimates from Vertisols: *Geology*, v. 38, p. 407-410.
- Northeast Regional Climate Center, Cornell University: Monthly Average Potential Evapotranspiration (PET) Estimates, Charleston, West Virginia. Available Online, Accessed 2/22/2017.
- Opdyke, N., DiVenere, C., 1994, Paleomagnetism and Carboniferous climate: *United States Geological Survey Bulletin*, v. 2110, p. 8-10.
- Petsch, S., Berner, R., and Eglinton, T., 2000, A field study of the chemical weathering of ancient sedimentary organic matter: *Organic Geochemistry*, v. 31, p. 475-487,
- Platt, B., Kolb, D., Kunhardt, C., Milo, S., and New, L., 2016, Burrowing through the literature: the impact of soil-disturbing vertebrates on physical and chemical properties of soil: *Soil Science*, v. 181, p. 175-191.
- Retallack, G., 1988, Field recognition of paleosols: *Geologic Society of America Special Paper* 216, p. 1-20.
- Retallack, G., 1991, Untangling the effects of burial alteration and ancient soil formation: *Annual Review of Earth and Planetary Sciences*, v. 19, 24 p.
- Retallack, G., 2001, *Soils of the Past: An Introduction to Paleopedology*, Blackwell Science, Oxford, 404 p.
- Schaetzl, R., Johnson, D., Burns, S., Small, T., 1989, Trees uprooting: review of terminology, process, and environmental implications: *Canadian Journal of Forest Research*, v. 19, p. 1-11.
- Schoeneberger, P., Wysocki, D., Benham, E., and Soil Survey Staff, 2012, *Field book for describing and sampling soils*, Version 3.0, Natural Resources Conservation Service, Nation Soil Survey Center, Lincoln, Nebraska.
- Sheldon, N., 2005, Do red beds indicate paleoclimatic conditions?: A Permian case study: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 228, p. 305-319.

- Sheldon, N., Retallack, G., and Tanaka, S., 2002, Geochemical climofunctions from North America soils and application to paleosols across the Eocene-Oligocene boundary in Oregon: *Journal of Geology*, v. 112, p. 487-494.
- Sheldon, N. and Tabor, N., 2009, Quantitative paleoenvironmental and paleoclimate reconstruction using paleosols: *Earth Science Reviews*, v. 95, p. 1-52.
- Soil Survey Staff, 1999, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions: Berks Series. Available online. Accessed 2/3/2017.
- Soil Survey Staff, 2007, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions: Westmoreland Series. Available online. Accessed 2/3/2017.
- Soil Survey Staff, 2013, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions: Westmoreland Series. Available online. Accessed 2/3/2017.
- Soil Survey Staff, 2014, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions: Upshur Soil Series. Available online. Accessed 2/3/2017.
- Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online. Accessed 2/2/2017.
- Soil Survey Staff, 1999, Soil Taxonomy: U.S. Department of Agriculture Handbook 436, Second Edition: Washington, D.C., U.S. Government Printing Office, 886 p.
- Sturgeon, M., 1958, The geology and mineral resources of Athens County, Ohio: Department of Natural Resources Geological Survey Bulletin 57, 600 p.
- Tabor, N., and Poulson, C., 2008, Palaeoclimate across the late Pennsylvanian-Early Permian tropical palaeolatitudes: a review of climate indicators, their distribution, and relation to palaeophysiographic climate factors: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 268, p. 293-310.
- Tazikeh, H., Arash, A., Farhad, K., and Mojtaba, B., 2017, Soil-parent material relationship in a mountainous arid area of Kopet Dag basin, North East Iran: *Catena*, v. 152, p. 252-267.
- Timofeeva, Y. and V. Golov, 2010, Accumulation of microelements in iron nodules in concretions in soils: a review: *Eurasian Soil Science*, v. 43, p. 401-407.
- Tokunaga, T., Wan, J., Firestone, M., Hazen, T., Schwartz, E., Sutton, S., Newville, M., Olson, K., Lanzirotti, A., and Rao, W., 2001, Distribution of chromium contamination and microbial activity in soil aggregates: *Environmental Science Technology*, v. 35, 37 p.
- Trendell, A., Nordt, L., Atchley, S., Leblanc, S., Dworkin, S., 2013, Determining floodplain plant distributions and populations using paleopedology and fossil root traces: Upper Triassic

- Sonsela Member of the Chinle Formation at Petrified Forest National Park, Arizona: *Palaos*, v. 28, p. 471-490.
- Tuttle, M., and Breit, G., 2009, Weathering of the New Albany Shale, Kentucky, USA: I. weathering zones defined by mineralogy and major-element composition: *Applied Geochemistry*, v. 24, p. 1549-1564.
- Ufnar, D., 2007, Clay coatings from a modern soil chronosequence: a tool for estimating the relative age of well-drained paleosols: *Geoderma*, v. 141, p. 181-200.
- Veen, G., and Olff, H., 2011, Interactive effects of soil-dwelling ants, ant mounds and simulated grazing on local plant community composition: *Basic and Applied Ecology*, v. 12, p. 703-712.
- Watanabe, M., 2015, Sample preparation for X-ray fluorescence analysis IV. Fusion bead method – part 1 basic principles: *Rigaku Journal*, v. 31, pg. 12-17.

APPENDIX A: OXIDE WEIGHT PERCENT, MOLECULAR WEATHERING
RATIOS, AND PALEOCLIMATE ESTIMATES BY SITE

Site 1		Inceptisol 1-base					Inceptisol 2-base				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	20.460	21.800	21.820	22.650	22.600	21.960	21.400	19.280	21.500	21.950
	BaO	0.050	0.060	0.060	0.060	0.060	0.060	0.050	0.040	0.050	0.050
	CaO	0.840	0.790	0.770	0.500	0.720	0.450	0.540	0.870	0.480	0.360
	Cr ₂ O ₃	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
	Fe ₂ O ₃	9.610	5.920	6.110	6.870	6.590	5.850	6.550	15.880	6.700	6.030
	K ₂ O	3.290	3.500	3.450	3.490	3.580	3.480	3.400	3.210	3.440	3.380
	MgO	2.060	2.180	2.100	1.930	1.740	2.100	2.070	2.250	2.100	2.160
	MnO	0.120	0.030	0.050	0.030	0.130	0.040	0.040	0.040	0.040	0.040
	Na ₂ O	0.190	0.210	0.200	0.200	0.200	0.230	0.250	0.200	0.230	0.230
	P ₂ O ₅	0.150	0.060	0.070	0.050	0.060	0.080	0.140	0.140	0.100	0.060
	SO ₃	0.290	0.590	0.420	0.960	0.250	0.480	1.000	0.060	0.600	0.510
	SiO ₂	54.070	57.630	57.510	55.040	55.640	57.760	56.960	49.480	57.520	57.000
	SrO	0.020	0.020	0.020	0.020	0.030	0.020	0.020	0.020	0.020	0.020
	TiO ₂	1.000	1.050	1.040	0.970	1.000	1.040	0.990	0.890	1.010	0.990
Molecular Weathering Ratio	$\Sigma \text{bases}/\text{Al}$	0.519	0.508	0.494	0.437	0.439	0.468	0.482	0.574	0.478	0.463
	CIA-K	91.750	92.444	92.658	94.817	93.242	94.833	93.888	90.983	94.501	95.506
	Al/Si	0.223	0.223	0.224	0.243	0.239	0.224	0.221	0.230	0.220	0.227
	Ca/Ti	1.196	1.072	1.054	0.734	1.025	0.616	0.777	1.392	0.677	0.518
	Mg/Ti	4.082	4.114	4.001	3.942	3.448	4.001	4.143	5.009	4.120	4.323
	Na/Ti	0.245	0.258	0.248	0.266	0.258	0.285	0.325	0.290	0.293	0.299
	K/Ti	2.790	2.826	2.813	3.051	3.035	2.837	2.912	3.058	2.888	2.895
	(K +Na)/Al	0.189	0.190	0.186	0.181	0.186	0.189	0.191	0.197	0.191	0.184
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	1271.179	1281.086	1284.135	1314.936	1292.462	1315.160	1301.684	1260.241	1310.426	1324.759
	MAP (CALMAG)										
	MAT	13.792	13.787	13.850	13.941	13.854	13.803	13.758	13.645	13.766	13.893

Site 1		Inceptisol 1- top Sampling depth (cm)					Inceptisol 2- top Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	18.820	18.720	18.650	18.320	18.460	20.200	20.870	20.600	14.930	18.740
	BaO	0.060	0.060	0.060	0.050	0.060	0.060	0.060	0.060	0.040	0.050
	CaO	1.220	1.600	1.780	2.590	1.940	1.360	0.690	0.780	14.750	4.610
	Cr ₂ O ₃	0.020	0.020	0.020	0.020	0.020	0.020	0.030	0.020	0.040	0.020
	Fe ₂ O ₃	5.280	5.410	5.420	5.270	5.790	5.210	4.650	5.110	4.100	4.730
	K ₂ O	3.250	3.240	3.220	3.200	3.220	3.420	3.380	3.520	2.480	3.120
	MgO	2.410	2.340	2.360	2.280	2.400	2.350	2.250	2.330	1.690	2.170
	MnO	0.040	0.040	0.050	0.050	0.040	0.030	0.020	0.030	0.240	0.080
	Na ₂ O	0.270	0.210	0.220	0.200	0.230	0.180	0.170	0.180	0.100	0.150
	P ₂ O ₅	0.200	0.150	0.170	0.160	0.150	0.370	0.280	0.230	0.330	0.380
	SO ₃	0.410	0.500	0.570	0.980	1.820	0.110	0.100	0.480	1.380	0.430
	SiO ₂	60.790	60.940	60.530	59.590	59.870	59.590	60.660	60.530	44.660	56.820
	SiO	0.010	0.010	0.020	0.020	0.020	0.020	0.010	0.010	0.020	0.020
	TiO ₂	0.970	0.970	1.020	0.950	0.960	1.020	1.040	1.040	0.750	0.930
Molecular Weathering Ratio	Σbases/Al	0.652	0.677	0.700	0.779	0.729	0.615	0.522	0.554	2.273	0.934
	CIA-K	87.607	85.190	83.827	78.432	82.538	87.946	93.152	92.318	35.622	68.473
	Al/Si	0.182	0.181	0.182	0.181	0.182	0.200	0.203	0.201	0.197	0.194
	Ca/Ti	1.791	2.349	2.485	3.883	2.878	1.899	0.945	1.068	28.010	7.060
	Mg/Ti	4.923	4.780	4.584	4.755	4.953	4.565	4.287	4.439	4.465	4.623
	Na/Ti	0.359	0.279	0.278	0.271	0.309	0.227	0.211	0.223	0.172	0.208
	K/Ti	2.841	2.832	2.677	2.856	2.844	2.843	2.756	2.870	2.804	2.844
	(K +Na)/Al	0.211	0.206	0.206	0.207	0.209	0.198	0.189	0.199	0.191	0.193
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	1212.084	1177.601	1158.162	1081.195	1139.770	1216.912	1291.186	1279.280	470.523	939.142
	MAP (CALMAG)										
	MAT	13.400	13.488	13.478	13.465	13.423	13.633	13.804	13.607	13.765	13.718

Site 1		Vertisol 1-base					Vertisol 2-base				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	18.000	17.380	17.170	15.030	18.280	17.140	17.380	16.740	18.000	19.270
	BaO	0.050	0.050	0.050	0.040	0.050	0.050	0.050	0.050	0.050	0.050
	CaO	2.720	2.950	2.920	9.730	1.240	3.830	3.480	4.370	0.910	0.620
	Cr ₂ O ₃	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
	Fe ₂ O ₃	6.170	8.430	8.970	7.310	7.370	7.780	7.960	8.830	8.030	7.600
	K ₂ O	4.200	4.040	3.990	3.500	4.170	4.030	4.080	3.870	4.220	3.610
	MgO	2.020	1.910	1.920	1.740	2.090	1.920	1.920	1.940	2.250	1.940
	MnO	0.040	0.040	0.040	0.080	0.020	0.050	0.040	0.050	0.020	0.060
	Na ₂ O	0.130	0.120	0.120	0.090	0.150	0.120	0.120	0.110	0.140	0.150
	P ₂ O ₅	0.190	0.190	0.190	0.180	0.240	0.200	0.200	0.230	0.300	0.220
	SO ₃	0.420	0.350	0.040	0.160	0.260	0.140	0.100	0.050	0.080	0.130
	SiO ₂	58.740	56.190	55.900	48.930	60.210	55.210	56.030	54.220	59.510	58.510
	SnO	0.040	0.030	0.030	0.030	0.030	0.040	0.030	0.030	0.020	0.040
	TiO ₂	0.950	0.920	0.910	0.790	0.960	0.910	0.920	0.880	0.950	1.020
Molecular Weathering Ratio	Σbases/Al	0.823	0.850	0.855	1.732	0.673	0.956	0.909	1.029	0.675	0.529
	CIA-K	77.723	75.760	75.718	45.728	87.964	70.533	72.706	67.320	90.521	93.344
	Al/Si	0.181	0.182	0.181	0.181	0.179	0.183	0.183	0.182	0.178	0.194
	Ca/Ti	4.078	4.567	4.570	17.541	1.840	5.994	5.387	7.073	1.364	0.866
	Mg/Ti	4.213	4.114	4.181	4.364	4.314	4.181	4.135	4.368	4.693	3.769
	Na/Ti	0.176	0.168	0.170	0.147	0.201	0.170	0.168	0.161	0.190	0.190
	K/Ti	3.749	3.723	3.718	3.756	3.683	3.755	3.760	3.729	3.766	3.001
	(K +Na)/Al	0.264	0.263	0.263	0.262	0.260	0.266	0.265	0.261	0.267	0.216
	%CaO	3.572	3.980	3.964	13.579	1.619	5.204	4.690	5.969	1.200	0.833
	COLE	0.170	0.171	0.171	0.281	0.147	0.186	0.180	0.196	0.145	0.133
	CEC	39.418	39.188	39.143	31.943	40.616	38.343	38.722	37.702	40.652	41.431
	pH	7.320	7.332	7.329	8.005	7.069	7.461	7.412	7.533	7.046	6.875
Climofunction	MAP (CIA-K)	1098.359	1061.767	1060.980	501.968	1289.249	964.329	1004.842	904.454	1336.920	1389.539
	MAP (CALMAG)	1360.242	1337.366	1334.247	851.108	1483.558	1263.224	1295.333	1212.055	1494.351	1567.115
	MAT	12.402	12.429	12.428	12.449	12.476	12.373	12.383	12.465	12.363	13.306

Site 1		Vertisol 1- top					Vertisol 2- top				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	16.040	16.080	15.700	14.680	16.100	16.420	14.860	15.200	15.150	16.720
	BaO	0.040	0.040	0.040	0.040	0.040	0.040	0.030	0.040	0.030	0.040
	CaO	5.140	5.680	6.850	10.700	6.040	6.370	13.050	9.680	8.480	6.480
	Cr ₂ O ₃	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
	Fe ₂ O ₃	8.550	8.590	8.720	7.100	8.330	8.150	3.910	7.770	8.730	4.470
	K ₂ O	3.010	3.090	2.990	2.710	3.040	2.980	2.380	2.640	2.680	2.720
	MgO	2.470	2.440	2.440	2.320	2.630	2.160	1.900	2.060	2.030	2.170
	MnO	0.040	0.050	0.060	0.080	0.050	0.050	0.110	0.070	0.080	0.050
	Na ₂ O	0.150	0.120	0.130	0.120	0.190	0.110	0.100	0.100	0.110	0.120
	P ₂ O ₅	0.140	0.140	0.140	0.120	0.130	0.140	0.120	0.130	0.130	0.140
	SO ₃	0.070	0.050	0.060	0.050	0.060	0.060	0.200	0.040	0.050	0.110
	SiO ₂	53.900	52.810	51.080	48.470	53.130	53.080	48.000	49.360	49.880	55.190
	SrO	0.030	0.030	0.030	0.030	0.030	0.020	0.020	0.020	0.020	0.020
	TiO ₂	0.860	0.880	0.820	0.780	0.850	0.860	0.780	0.800	0.810	0.900
Molecular Weathering Ratio	Σbases/Al	1.191	1.246	1.406	1.938	1.319	1.246	2.104	1.699	1.560	1.221
	CIA-K	62.578	60.441	55.344	42.760	58.772	58.263	38.347	46.111	49.271	58.260
	Al/Si	0.175	0.179	0.181	0.178	0.179	0.182	0.182	0.181	0.179	0.179
	Ca/Ti	8.512	9.193	11.897	19.537	10.120	10.549	23.828	17.233	14.910	10.254
	Mg/Ti	5.691	5.494	5.896	5.893	6.131	4.977	4.826	5.102	4.966	4.777
	Na/Ti	0.225	0.176	0.204	0.198	0.288	0.165	0.165	0.161	0.175	0.172
	K/Ti	2.968	2.977	3.092	2.946	3.032	2.938	2.587	2.798	2.805	2.562
	(K +Na)/Al	0.218	0.220	0.220	0.213	0.224	0.207	0.184	0.199	0.203	0.188
	%CaO	7.002	7.786	9.478	14.823	8.183	8.672	18.026	13.427	11.828	8.717
	COLE	0.221	0.229	0.249	0.311	0.240	0.234	0.340	0.288	0.267	0.236
	CEC	36.026	35.583	34.268	29.850	35.016	35.485	28.250	31.690	32.872	35.527
	pH	7.702	7.751	7.857	8.124	7.809	7.779	8.228	8.033	7.942	7.791
Climofunction	MAP (CIA-K)	816.060	776.226	681.215	446.644	745.111	735.630	364.397	509.111	568.003	735.571
	MAP (CALMAG)	1103.090	1071.866	989.702	766.688	1039.004	1057.466	695.275	844.408	903.847	1059.576
	MAT	13.252	13.219	13.229	13.349	13.154	13.457	13.883	13.617	13.532	13.819

Site 2		Inceptisol 1					Inceptisol 2				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	10.840	11.660	10.500	13.600	15.140	11.630	12.300	11.320	12.020	10.800
	BaO	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
	CaO	22.000	20.300	23.900	13.950	10.650	18.600	16.750	20.100	17.750	21.600
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.020	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	4.390	3.860	3.600	4.820	5.300	4.500	4.720	4.770	4.490	4.070
	K ₂ O	2.200	2.380	2.080	2.350	2.630	2.500	2.690	2.420	2.490	2.260
	MgO	1.590	1.690	1.570	2.140	2.380	1.760	1.880	1.680	1.800	1.660
	MnO	0.120	0.100	0.130	0.050	0.030	0.110	0.100	0.110	0.110	0.110
	Na ₂ O	0.100	0.100	0.080	0.080	0.090	0.160	0.160	0.110	0.130	0.110
	P ₂ O ₅	0.170	0.190	0.170	0.140	0.150	0.220	0.240	0.210	0.230	0.200
	SO ₃	0.180	0.270	0.120	0.060	0.050	0.050	0.050	0.050	0.040	0.040
	SiO ₂	36.190	39.100	35.120	45.540	49.400	41.130	43.320	38.950	41.690	37.300
	SrO	0.040	0.030	0.040	0.030	0.020	0.040	0.040	0.030	0.040	0.030
	TiO ₂	0.540	0.580	0.530	0.680	0.770	0.590	0.610	0.570	0.610	0.550
Molecular Weathering Ratio	Σ bases/Al	2.388	2.099	2.631	1.362	1.040	1.979	1.746	2.148	1.844	2.373
	CIA-K	32.908	36.369	30.452	49.222	58.501	38.269	42.109	35.902	40.201	33.221
	Al/Si	0.300	0.298	0.299	0.299	0.306	0.283	0.284	0.291	0.288	0.290
	Ca/Ti	40.741	35.000	45.094	20.515	13.831	31.525	27.459	35.263	29.098	39.273
	Mg/Ti	2.944	2.914	2.962	3.147	3.091	2.983	3.082	2.947	2.951	3.018
	Na/Ti	0.185	0.172	0.151	0.118	0.117	0.271	0.262	0.193	0.213	0.200
	K/Ti	4.074	4.103	3.925	3.456	3.416	4.237	4.410	4.246	4.082	4.109
	(K + Na)/Al	0.212	0.213	0.206	0.179	0.180	0.229	0.232	0.223	0.218	0.219
	%CaO										
	COLE										
Climofunction	MAP (CIA-K)	431.805	481.176	396.772	664.518	796.882	508.278	563.051	474.515	535.831	436.259
	MAP (CALMAG)										
	MAT	13.369	13.360	13.489	13.990	13.971	13.063	13.008	13.160	13.262	13.235

Site 2		Vertisol 1					Vertisol 2				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	16.780	16.210	16.740	17.530	16.630	19.270	18.780	18.940	12.970	14.760
	BaO	0.030	0.020	0.030	0.030	0.030	0.040	0.040	0.040	0.050	0.040
	CaO	8.290	9.300	7.230	5.690	7.500	1.720	2.580	3.110	12.150	10.600
	Cr ₂ O ₃	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.010	0.020
	Fe ₂ O ₃	8.120	8.720	10.380	9.860	9.970	12.550	11.050	10.880	6.910	9.200
	K ₂ O	2.280	2.200	2.370	2.490	2.410	2.620	2.640	2.580	1.720	2.100
	MgO	1.600	1.600	1.710	1.640	2.060	1.320	1.360	1.510	7.030	2.760
	MnO	0.080	0.080	0.060	0.050	0.080	0.030	0.040	0.050	0.370	0.160
	Na ₂ O	0.100	0.100	0.100	0.110	0.110	0.140	0.130	0.130	0.120	0.090
	P ₂ O ₅	0.090	0.080	0.100	0.090	0.090	0.070	0.070	0.080	0.050	0.070
	SO ₃	0.030	0.040	0.030	0.030	0.040	0.010	0.010	0.020	0.110	0.050
	SiO ₂	49.470	47.250	48.860	51.290	48.260	53.050	53.110	52.180	36.550	44.160
	SrO	0.010	0.010	0.020	0.010	0.020	0.010	0.010	0.010	0.020	0.020
	TiO ₂	0.860	0.820	0.860	0.900	0.850	0.950	0.960	0.940	0.640	0.760
Molecular Weathering Ratio	Σbases/Al	0.731	0.814	0.682	0.566	0.726	0.301	0.357	0.387	1.621	1.054
	CIA-K	66.667	63.296	69.547	75.139	68.606	91.197	87.389	85.392	51.387	57.996
	Al/Si	0.339	0.343	0.343	0.342	0.345	0.363	0.354	0.363	0.355	0.334
	Ca/Ti	9.640	11.341	8.407	6.322	8.824	1.811	2.688	3.309	18.984	13.947
	Mg/Ti	1.860	1.951	1.988	1.822	2.424	1.389	1.417	1.606	10.984	3.632
	Na/Ti	0.116	0.122	0.116	0.122	0.129	0.147	0.135	0.138	0.188	0.118
	K/Ti	2.651	2.683	2.756	2.767	2.835	2.758	2.750	2.745	2.688	2.763
	(K +Na)/Al	0.142	0.142	0.148	0.148	0.152	0.143	0.147	0.143	0.142	0.148
	%CaO	9.446	10.758	8.169	6.341	8.516	1.874	2.841	3.437	15.438	12.501
	COLE	0.168	0.178	0.160	0.145	0.165	0.105	0.113	0.120	0.254	0.200
	CEC	39.165	38.484	39.619	40.570	39.284	42.706	42.279	41.999	31.869	36.575
	pH	7.305	7.390	7.217	7.044	7.276	6.278	6.504	6.642	7.882	7.567
Climofunction	MAP (CIA-K)	892.267	829.430	945.959	1050.197	928.409	1349.519	1278.540	1241.311	607.448	730.647
	MAP (CALMAG)	991.790	920.913	1043.291	1164.183	1004.959	1524.022	1439.720	1388.260	479.563	755.183
	MAT	14.672	14.671	14.566	14.552	14.492	14.646	14.567	14.649	14.671	14.551

Site 3		Inceptisol 1-base					Inceptisol 2-base				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	16.560	17.460	18.820	17.640	18.620	16.140	16.150	15.700	16.200	17.370
	BaO	0.080	0.070	0.060	0.090	0.100	0.070	0.070	0.060	0.090	0.140
	CaO	0.440	0.420	0.410	0.840	0.310	0.360	0.380	0.400	3.120	0.420
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.020	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	7.090	6.430	6.280	8.160	5.390	7.820	7.550	7.920	6.890	4.930
	K ₂ O	2.630	2.780	3.030	2.630	2.900	2.650	2.660	2.570	2.530	2.060
	MgO	1.880	1.700	1.840	1.620	1.460	1.940	1.920	1.940	1.620	1.150
	MnO	0.020	0.040	0.030	0.080	0.020	0.040	0.050	0.050	0.040	0.010
	Na ₂ O	0.710	0.660	0.610	0.510	0.570	0.700	0.680	0.680	0.580	0.420
	P ₂ O ₅	0.050	0.080	0.130	0.080	0.080	0.030	0.040	0.040	0.140	0.190
	SO ₃	0.080	0.110	0.130	0.210	0.200	0.060	0.050	0.050	0.200	0.460
	SiO ₂	64.490	63.740	61.420	60.490	63.990	64.750	65.150	64.890	59.840	65.020
	SrO	0.030	0.050	0.080	0.050	0.060	0.020	0.020	0.010	0.070	0.160
	TiO ₂	0.990	1.020	1.000	0.930	1.020	0.970	0.970	0.950	0.910	1.000
Molecular Weathering Ratio	Σbases/Al	0.578	0.525	0.514	0.528	0.448	0.594	0.591	0.607	0.831	0.380
	CIA-K	89.378	90.423	91.497	88.173	92.539	89.936	89.924	89.480	70.970	92.273
	Al/Si	0.151	0.161	0.181	0.172	0.171	0.147	0.146	0.143	0.160	0.157
	Ca/Ti	0.633	0.586	0.584	1.286	0.433	0.529	0.558	0.600	4.883	0.598
	Mg/Ti	3.763	3.302	3.646	3.451	2.836	3.963	3.922	4.046	3.527	2.279
	Na/Ti	0.924	0.834	0.786	0.707	0.720	0.930	0.903	0.922	0.821	0.541
	K/Ti	2.252	2.311	2.569	2.398	2.411	2.316	2.325	2.294	2.357	1.747
	(K +Na)/Al	0.242	0.235	0.228	0.209	0.219	0.249	0.248	0.248	0.228	0.168
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	1237.352	1252.246	1267.577	1220.152	1282.434	1245.308	1245.141	1238.796	974.750	1278.646
	MAP (CALMAG)										
	MAT	12.809	12.956	13.084	13.429	13.244	12.686	12.715	12.698	13.078	14.185

Site 3		Inceptisol 1- top					Inceptisol 2- top				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	18.520	18.380	18.300	18.350	19.080	18.680	18.890	19.060	18.690	18.810
	BaO	0.060	0.050	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
	CaO	3.730	3.410	3.250	2.920	3.250	3.370	3.260	3.140	2.870	2.960
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	7.570	8.740	8.600	8.340	6.100	7.490	6.930	7.110	5.820	5.930
	K ₂ O	3.800	3.780	3.830	3.700	3.840	3.820	3.910	3.960	3.770	3.860
	MgO	2.400	2.400	2.330	2.170	2.290	2.410	2.470	2.470	2.440	2.410
	MnO	0.050	0.050	0.040	0.060	0.040	0.040	0.040	0.040	0.040	0.040
	Na ₂ O	0.240	0.230	0.240	0.300	0.250	0.250	0.230	0.230	0.400	0.330
	P ₂ O ₅	0.240	0.240	0.250	0.240	0.220	0.230	0.220	0.230	0.200	0.210
	SO ₃	0.030	0.030	0.020	0.020	0.030	0.020	0.030	0.030	0.030	0.070
	SiO ₂	54.270	53.080	53.850	55.110	56.000	54.280	54.490	54.630	56.440	56.300
	SrO	0.030	0.020	0.020	0.020	0.020	0.020	0.030	0.030	0.030	0.030
	TiO ₂	0.910	0.870	0.890	0.920	0.930	0.910	0.920	0.920	0.940	0.930
Molecular Weathering Ratio	Σbases/Al	0.937	0.911	0.893	0.834	0.853	0.898	0.889	0.872	0.863	0.861
	CIA-K	72.072	73.643	74.379	75.976	75.118	74.073	74.974	75.794	76.081	76.048
	Al/Si	0.201	0.204	0.200	0.196	0.201	0.203	0.204	0.206	0.195	0.197
	Ca/Ti	5.838	5.582	5.201	4.520	4.977	5.274	5.047	4.861	4.348	4.533
	Mg/Ti	5.226	5.466	5.187	4.674	4.879	5.247	5.320	5.320	5.143	5.135
	Na/Ti	0.340	0.341	0.347	0.420	0.346	0.354	0.322	0.322	0.548	0.457
	K/Ti	3.541	3.684	3.649	3.410	3.501	3.559	3.603	3.650	3.401	3.519
	(K +Na)/Al	0.243	0.243	0.248	0.245	0.239	0.243	0.244	0.245	0.254	0.251
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	990.481	1012.890	1023.386	1046.163	1033.922	1019.021	1031.871	1043.563	1047.659	1047.188
	MAP (CALMAG)										
	MAT	12.791	12.795	12.704	12.759	12.865	12.792	12.779	12.767	12.604	12.651

Site 3		Vertisol 1-base					Vertisol 2-base				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	16.560	16.350	16.640	16.420	17.240	15.960	15.920	16.270	15.570	15.510
	BaO	0.100	0.090	0.080	0.070	0.090	0.060	0.070	0.080	0.070	0.060
	CaO	0.840	0.650	0.540	0.490	0.430	0.420	0.420	0.430	0.380	0.300
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	11.490	6.500	4.470	6.960	8.720	9.160	9.110	9.490	8.010	8.490
	K ₂ O	2.500	2.620	1.930	2.150	2.620	2.610	2.590	2.700	2.660	2.380
	MgO	2.060	1.510	1.060	1.320	1.840	1.980	1.980	2.000	1.760	1.680
	MnO	0.050	0.050	0.010	0.030	0.050	0.050	0.050	0.070	0.040	0.020
	Na ₂ O	0.550	0.610	0.500	0.370	0.650	0.720	0.720	0.680	0.730	0.700
	P ₂ O ₅	0.100	0.170	0.130	0.200	0.180	0.040	0.030	0.030	0.060	0.070
	SO ₃	0.180	0.280	0.200	0.420	0.330	0.070	0.070	0.080	0.130	0.060
	SiO ₂	58.660	64.930	67.260	63.790	60.520	63.250	63.690	62.530	65.350	64.510
	SrO	0.100	0.170	0.130	0.180	0.160	0.010	0.010	0.020	0.040	0.050
	TiO ₂	0.900	0.940	1.000	1.040	0.970	0.940	0.940	0.960	0.960	0.950
Molecular Weathering Ratio	Σbases/Al	0.625	0.541	0.395	0.436	0.542	0.613	0.613	0.607	0.592	0.549
	CIA-K	87.195	88.210	90.218	91.632	90.304	89.122	89.098	89.541	89.166	90.138
	Al/Si	0.166	0.148	0.146	0.152	0.168	0.149	0.147	0.153	0.140	0.142
	Ca/Ti	1.329	0.985	0.769	0.671	0.631	0.636	0.636	0.638	0.564	0.450
	Mg/Ti	4.535	3.183	2.100	2.515	3.759	4.174	4.174	4.128	3.633	3.504
	Na/Ti	0.788	0.836	0.644	0.458	0.864	0.987	0.987	0.913	0.980	0.950
	K/Ti	2.355	2.363	1.636	1.753	2.290	2.354	2.336	2.385	2.349	2.124
	(K +Na)/Al	0.218	0.235	0.175	0.179	0.227	0.251	0.250	0.248	0.262	0.240
	%CaO	1.127	0.835	0.691	0.643	0.571	0.544	0.542	0.559	0.485	0.389
	COLE	0.139	0.123	0.111	0.116	0.127	0.130	0.130	0.131	0.124	0.121
	CEC	40.662	41.491	42.194	41.887	41.414	41.033	41.026	41.055	41.291	41.464
	pH	6.971	6.711	6.440	6.565	6.784	6.836	6.836	6.846	6.736	6.675
Climofunction	MAP (CIA-K)	1274.908	1293.840	1331.255	1357.617	1332.867	1310.833	1310.380	1318.647	1311.658	1329.771
	MAP (CALMAG)	1495.065	1568.422	1634.165	1607.918	1569.201	1536.599	1535.951	1538.351	1559.024	1576.332
	MAT	13.261	12.950	14.058	13.987	13.104	12.646	12.660	12.699	12.446	12.848

Site 3		Vertisol 1- top					Vertisol 2- top				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	6.240	7.030	10.130	9.720	9.680	13.490	14.080	12.600	10.920	11.140
	BaO	0.020	0.030	0.040	0.030	0.030	0.040	0.050	0.050	0.030	0.040
	CaO	30.200	25.300	11.300	11.800	11.600	6.930	5.760	8.620	10.700	9.050
	Cr ₂ O ₃	0.005	0.005	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	2.930	3.520	4.430	4.420	4.880	6.400	6.690	5.950	5.260	5.330
	K ₂ O	1.210	1.400	2.030	1.940	1.910	2.890	2.980	2.580	2.270	2.290
	MgO	1.020	1.040	1.300	1.180	1.140	1.730	1.840	1.640	1.440	1.420
	MnO	0.300	0.260	0.070	0.080	0.070	0.040	0.040	0.060	0.080	0.050
	Na ₂ O	0.330	0.420	0.730	0.700	0.730	0.480	0.440	0.530	0.590	0.650
	P ₂ O ₅	0.140	0.170	0.260	0.250	0.260	0.300	0.280	0.300	0.270	0.270
	SO ₃	0.140	0.100	0.050	0.040	0.040	0.030	0.020	0.030	0.040	0.030
	SiO ₂	30.740	36.590	57.080	55.800	56.110	57.630	57.970	57.300	55.530	58.190
	SrO	0.040	0.040	0.040	0.030	0.030	0.030	0.030	0.040	0.030	0.030
	TiO ₂	0.390	0.450	0.690	0.660	0.670	0.750	0.760	0.730	0.680	0.700
Molecular Weathering Ratio	Σ bases/Al	9.510	7.231	2.688	2.849	2.814	1.549	1.355	1.864	2.429	2.118
	CIA-K	10.115	13.087	31.780	30.069	30.277	50.188	55.705	43.234	34.839	38.865
	Al/Si	0.120	0.113	0.105	0.103	0.102	0.138	0.143	0.130	0.116	0.113
	Ca/Ti	110.285	80.073	23.324	25.463	24.658	13.160	10.794	16.817	22.410	18.413
	Mg/Ti	5.182	4.579	3.733	3.542	3.371	4.570	4.797	4.451	4.196	4.019
	Na/Ti	1.090	1.203	1.363	1.367	1.404	0.825	0.746	0.936	1.118	1.197
	K/Ti	2.631	2.638	2.494	2.492	2.417	3.267	3.325	2.997	2.830	2.774
	(K +Na)/Al	0.297	0.314	0.335	0.335	0.338	0.290	0.280	0.291	0.314	0.318
	%CaO	45.425	37.258	14.850	15.757	15.451	9.158	7.638	11.319	14.272	11.912
	COLE	0.608	0.526	0.297	0.303	0.298	0.234	0.217	0.260	0.290	0.262
	CEC	-31.572	-12.743	24.701	23.376	23.684	33.678	35.187	31.096	26.650	29.239
	pH	8.838	8.692	8.071	8.093	8.076	7.776	7.675	7.911	8.044	7.921
Climofunction	MAP (CIA-K)	-161.855	-106.467	241.975	210.092	213.971	585.096	687.934	455.473	298.994	374.046
	MAP (CALMAG)	-57.835	42.206	575.417	535.772	543.857	946.088	1037.794	814.830	638.679	733.874
	MAT	11.801	11.487	11.087	11.104	11.047	11.921	12.104	11.913	11.486	11.401

Site 4		Inceptisol 1-base					Inceptisol 2-base				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	18.500	18.430	18.820	17.570	21.450	20.950	21.800	20.140	21.490	21.830
	BaO	0.040	0.040	0.050	0.040	0.060	0.060	0.060	0.050	0.060	0.060
	CaO	0.580	0.520	0.540	5.580	1.220	1.190	0.480	1.640	0.550	0.600
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	7.700	7.560	8.250	8.660	10.980	10.860	9.320	5.930	11.220	10.960
	K ₂ O	4.160	4.160	4.210	3.260	3.770	3.660	3.780	3.520	3.740	3.760
	MgO	1.960	1.920	2.020	1.960	2.320	2.290	2.390	2.370	2.280	2.330
	MnO	0.010	0.010	0.010	0.070	0.030	0.050	0.030	0.070	0.020	0.020
	Na ₂ O	0.170	0.170	0.170	0.150	0.220	0.210	0.230	0.410	0.230	0.220
	P ₂ O ₅	0.076	0.043	0.137	0.259	0.237	0.127	0.147	0.176	0.176	0.129
	SO ₃										
	SiO ₂	57.050	57.430	55.700	48.470	49.570	50.070	52.670	55.480	50.600	50.270
	SrO	0.030	0.030	0.030	0.030	0.030	0.020	0.030	0.020	0.030	0.030
	TiO ₂	0.920	0.940	0.900	0.840	0.820	0.860	0.890	0.970	0.850	0.820
Molecular Weathering Ratio	Σbases/Al	0.583	0.574	0.581	1.074	0.584	0.585	0.522	0.668	0.521	0.523
	CIA-K	93.273	93.767	93.718	62.836	89.263	89.305	94.573	84.635	93.973	93.760
	Al/Si	0.191	0.189	0.199	0.214	0.255	0.247	0.244	0.214	0.250	0.256
	Ca/Ti	0.898	0.788	0.855	9.461	2.119	1.971	0.768	2.408	0.922	1.042
	Mg/Ti	4.221	4.047	4.447	4.623	5.606	5.276	5.321	4.841	5.315	5.630
	Na/Ti	0.238	0.233	0.243	0.230	0.346	0.315	0.333	0.545	0.349	0.346
	K/Ti	3.834	3.752	3.966	3.291	3.898	3.608	3.601	3.077	3.731	3.888
	(K +Na)/Al	0.259	0.259	0.257	0.215	0.207	0.206	0.205	0.223	0.206	0.203
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	1292.913	1299.956	1299.261	858.718	1235.710	1236.299	1311.447	1169.692	1302.890	1299.858
	MAP (CALMAG)										
	MAT	12.512	12.493	12.540	13.319	13.463	13.491	13.502	13.175	13.484	13.539

Site 4		Inceptisol 1- top					Inceptisol 2- top				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	21.700	20.970	20.830	21.960	21.660	21.800	21.650	21.390	22.070	22.670
	BaO	0.050	0.050	0.050	0.050	0.060	0.050	0.060	0.060	0.050	0.060
	CaO	0.260	0.770	0.510	0.630	0.540	0.460	0.470	0.480	0.390	0.320
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	8.160	8.740	11.740	11.400	12.460	9.660	10.620	12.780	11.600	7.410
	K ₂ O	3.770	3.620	3.620	3.730	3.730	3.760	3.770	3.720	3.680	3.860
	MgO	2.470	2.300	2.270	2.350	2.320	2.330	2.330	2.230	2.290	2.490
	MnO	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
	Na ₂ O	0.250	0.260	0.230	0.220	0.210	0.250	0.250	0.230	0.200	0.300
	P ₂ O ₅	0.040	0.125	0.180	0.264	0.198	0.119	0.180	0.186	0.095	0.091
	SO ₃										
	SiO ₂	53.580	52.820	51.170	49.430	49.760	51.710	50.890	49.170	49.730	53.300
	SrO	0.010	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.010
	TiO ₂	0.960	0.940	0.910	0.890	0.880	0.930	0.930	0.900	0.860	0.970
Molecular Weathering Ratio	Σbases/Al	0.517	0.551	0.526	0.523	0.519	0.514	0.519	0.510	0.490	0.510
	CIA-K	96.086	91.983	94.102	93.577	94.226	94.587	94.476	94.474	95.508	95.471
	Al/Si	0.239	0.234	0.240	0.262	0.257	0.248	0.251	0.256	0.262	0.251
	Ca/Ti	0.386	1.167	0.798	1.008	0.874	0.704	0.720	0.760	0.646	0.470
	Mg/Ti	5.098	4.848	4.943	5.232	5.224	4.964	4.964	4.909	5.276	5.086
	Na/Ti	0.336	0.356	0.326	0.319	0.308	0.346	0.346	0.329	0.300	0.399
	K/Ti	3.330	3.265	3.373	3.553	3.594	3.428	3.437	3.505	3.628	3.374
	(K +Na)/Al	0.207	0.207	0.206	0.200	0.202	0.206	0.207	0.206	0.195	0.206
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	1333.033	1274.507	1304.730	1297.243	1306.504	1311.650	1310.074	1310.045	1324.786	1324.269
	MAP (CALMAG)										
	MAT	13.465	13.461	13.479	13.589	13.551	13.492	13.456	13.485	13.680	13.483

Site 4		Vertisol 1-base					Vertisol 2-base				
		Sampling depth (cm)					Sampling depth (mm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	17.200	18.630	16.070	14.290	15.710	15.340	14.110	14.490	15.100	15.990
	BaO	0.050	0.050	0.040	0.040	0.050	0.040	0.040	0.040	0.040	0.040
	CaO	9.500	6.460	11.670	15.260	9.830	8.310	11.860	12.170	8.590	6.820
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	9.280	8.920	8.410	7.090	8.570	8.600	8.160	7.900	8.110	7.720
	K ₂ O	3.000	3.280	2.840	2.570	2.820	2.820	2.510	2.600	2.770	2.940
	MgO	2.010	2.110	1.960	1.910	2.480	3.030	2.610	2.450	2.650	2.660
	MnO	0.170	0.110	0.160	0.230	0.280	0.280	0.300	0.260	0.210	0.150
	Na ₂ O	0.150	0.180	0.160	0.140	0.150	0.170	0.130	0.140	0.150	0.150
	P ₂ O ₅	0.077	0.087	0.093	0.106	0.120	0.162	0.151	0.157	0.198	0.201
	SO ₃										
	SiO ₂	41.640	45.620	40.540	37.590	42.370	44.440	41.020	42.270	45.590	47.920
	SrO	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.030	0.030	0.030
	TiO ₂	0.700	0.760	0.680	0.630	0.690	0.720	0.680	0.720	0.760	0.800
Molecular Weathering Ratio	Σbases/Al	1.503	1.123	1.836	2.490	1.747	1.702	2.204	2.165	1.693	1.411
	ClA-K	49.541	60.741	42.796	33.811	46.440	49.922	39.318	39.325	48.766	55.838
	Al/Si	0.243	0.241	0.234	0.224	0.219	0.203	0.203	0.202	0.195	0.197
	Ca/Ti	19.329	12.106	24.442	34.498	20.290	16.438	24.840	24.073	16.097	12.141
	Mg/Ti	5.689	5.501	5.711	6.007	7.122	8.338	7.605	6.742	6.909	6.588
	Na/Ti	0.276	0.305	0.303	0.286	0.280	0.304	0.246	0.251	0.254	0.242
	K/Ti	3.634	3.659	3.541	3.459	3.465	3.321	3.130	3.062	3.090	3.116
	(K +Na)/Al	0.203	0.206	0.208	0.211	0.210	0.217	0.208	0.210	0.215	0.214
	%CaO	14.288	9.479	17.541	23.227	14.656	11.682	16.672	16.742	11.980	9.484
	COLE	0.283	0.235	0.319	0.378	0.300	0.287	0.337	0.339	0.283	0.254
	CEC	33.338	36.479	30.639	25.300	31.393	31.822	27.626	27.966	31.874	34.187
	pH	8.016	7.781	8.153	8.344	8.083	8.032	8.217	8.222	8.014	7.880
Climofun ction	MAP (ClA-K)	573.040	781.815	447.309	279.831	515.235	580.138	382.491	382.618	558.593	690.424
	MAP (CALMAG)	923.545	1118.298	791.905	594.842	836.362	868.790	684.410	693.634	864.956	988.672
	MAT	13.537	13.475	13.453	13.395	13.410	13.276	13.452	13.408	13.319	13.327

Site 4		Vertisol 1- top					Vertisol 2- top				
		Sampling depth (mm)					Sampling depth (mm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	15.630	15.870	15.710	15.320	15.580	14.430	15.220	15.400	15.570	15.340
	BaO	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
	CaO	7.090	5.940	6.120	7.240	6.560	9.580	7.720	6.650	6.600	7.130
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	7.860	8.150	8.060	7.760	8.020	7.450	7.770	7.990	8.160	7.900
	K ₂ O	3.540	3.640	3.640	3.550	3.600	3.380	3.560	3.600	3.630	3.580
	MgO	2.260	2.290	2.290	2.270	2.300	2.130	2.250	2.260	2.300	2.260
	MnO	0.090	0.060	0.060	0.090	0.070	0.180	0.110	0.080	0.070	0.080
	Na ₂ O	0.150	0.150	0.140	0.140	0.150	0.140	0.140	0.140	0.150	0.140
	P ₂ O ₅	0.286	0.291	0.294	0.293	0.321	0.306	0.311	0.316	0.316	0.306
	SO ₃										
	SiO ₂	48.160	49.030	48.880	47.990	49.240	45.450	47.990	48.670	49.270	47.990
	SrO	0.020	0.020	0.020	0.020	0.030	0.020	0.020	0.020	0.030	0.020
	TiO ₂	0.760	0.780	0.780	0.760	0.770	0.710	0.760	0.770	0.780	0.770
Molecular Weathering Ratio	Σbases/Al	1.451	1.309	1.342	1.500	1.405	1.850	1.564	1.424	1.413	1.485
	CIA-K	54.333	58.960	58.041	53.355	56.137	44.984	51.617	55.554	55.974	53.761
	Al/Si	0.191	0.191	0.189	0.188	0.186	0.187	0.187	0.186	0.186	0.188
	Ca/Ti	13.286	10.846	11.175	13.568	12.134	19.217	14.467	12.300	12.051	13.188
	Mg/Ti	5.892	5.817	5.817	5.918	5.918	5.944	5.866	5.816	5.843	5.816
	Na/Ti	0.254	0.248	0.231	0.237	0.251	0.254	0.237	0.234	0.248	0.234
	K/Ti	3.949	3.957	3.957	3.960	3.964	4.036	3.972	3.964	3.946	3.942
	(K +Na)/Al	0.261	0.264	0.265	0.266	0.266	0.269	0.268	0.268	0.268	0.268
	%CaO	10.198	8.545	8.815	10.444	9.354	13.998	11.068	9.566	9.393	10.291
	COLE	0.249	0.230	0.233	0.252	0.241	0.288	0.259	0.241	0.242	0.249
	CEC	34.235	35.424	35.166	33.877	34.657	31.036	33.368	34.515	34.613	34.011
	pH	7.856	7.756	7.773	7.870	7.814	8.033	7.907	7.817	7.818	7.859
Climofunction	MAP (CIA-K)	662.362	748.622	731.480	644.132	695.991	488.107	611.749	685.126	692.961	651.713
	MAP (CALMAG)	983.915	1058.351	1042.060	964.163	1010.641	816.750	935.148	1001.576	1007.940	971.659
	MAT	12.467	12.413	12.383	12.376	12.374	12.308	12.330	12.336	12.332	12.343

Site 5		Inceptisol 1-base					Inceptisol 2-base				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	22.060	19.950	17.000			22.050	22.760	22.270		
	BaO	0.060	0.060	0.040			0.060	0.070	0.070		
	CaO	0.300	0.860	4.480			0.320	0.470	0.540		
	Cr ₂ O ₃	0.010	0.010	0.010			0.010	0.010	0.010		
	Fe ₂ O ₃	9.190	9.100	11.290			11.150	9.450	10.680		
	K ₂ O	3.810	3.580	2.860			3.890	3.900	3.870		
	MgO	2.450	2.210	2.110			2.340	2.350	2.380		
	MnO	0.050	0.110	0.330			0.040	0.120	0.050		
	Na ₂ O	0.270	0.330	0.330			0.220	0.240	0.240		
	P ₂ O ₅	0.037	0.205	0.244			0.072	0.079	0.061		
	SO ₃										
	SiO ₂	52.900	53.730	46.780			49.350	50.820	50.320		
	SrO	0.020	0.020	0.020			0.030	0.030	0.030		
	TiO ₂	0.960	0.960	0.780			0.880	0.900	0.880		
Molecular Weathering Ratio	Σbases/Al	0.513	0.580	1.007			0.502	0.502	0.520		
	CIA-K	95.707	90.450	66.179			95.896	94.796	94.178		
	Al/Si	0.246	0.219	0.214			0.263	0.264	0.261		
	Ca/Ti	0.445	1.276	8.180			0.518	0.744	0.874		
	Mg/Ti	5.057	4.561	5.360			5.269	5.174	5.359		
	Na/Ti	0.362	0.443	0.545			0.322	0.344	0.351		
	K/Ti	3.365	3.162	3.109			3.748	3.674	3.729		
	(K + Na)/Al	0.207	0.221	0.214			0.207	0.203	0.206		
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	1327.623	1252.634	906.407			1330.322	1314.640	1305.824		
	MAP (CALMAG)										
	MAT	13.464	13.198	13.335			13.458	13.543	13.487		

Site 5		Inceptisol 1- top					Inceptisol 2- top				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	22.310	21.270	21.540	22.430	22.290	21.410	20.820	21.360	21.750	21.910
	BaO	0.060	0.060	0.060	0.060	0.060	0.060	0.050	0.060	0.060	0.060
	CaO	0.570	0.530	0.560	0.530	0.560	0.510	0.400	0.520	0.610	0.490
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	11.230	10.900	9.620	8.660	5.340	11.900	13.280	9.870	9.650	6.730
	K ₂ O	3.580	3.360	3.420	3.520	3.420	3.420	3.300	3.430	3.470	3.400
	MgO	1.920	1.790	1.800	1.900	1.790	1.770	1.770	1.870	1.750	1.910
	MnO	0.030	0.050	0.040	0.030	0.020	0.040	0.030	0.040	0.060	0.030
	Na ₂ O	0.270	0.280	0.290	0.340	0.420	0.270	0.330	0.033	0.350	0.460
	P ₂ O ₅	0.156	0.135	0.156	0.162	0.143	0.101	0.074	0.140	0.181	0.143
	SO ₃										
	SiO ₂	49.650	50.260	51.030	51.920	55.650	49.440	49.130	51.380	50.950	54.770
	SrO	0.020	0.010	0.010	0.020	0.010	0.010	0.020	0.020	0.020	0.020
	TiO ₂	0.820	0.860	0.900	0.900	0.980	0.800	0.820	0.900	0.860	0.960
Molecular Weathering Ratio	Σbases/Al	0.458	0.451	0.453	0.452	0.446	0.446	0.448	0.442	0.454	0.464
	CIA-K	93.777	93.724	93.509	93.642	92.879	93.980	94.250	95.529	92.811	93.006
	Al/Si	0.265	0.249	0.249	0.255	0.236	0.255	0.250	0.245	0.252	0.236
	Ca/Ti	0.990	0.878	0.886	0.839	0.814	0.908	0.695	0.823	1.010	0.727
	Mg/Ti	4.639	4.124	3.963	4.183	3.619	4.384	4.277	4.117	4.032	3.942
	Na/Ti	0.424	0.420	0.415	0.487	0.552	0.435	0.519	0.047	0.524	0.617
	K/Ti	3.702	3.313	3.222	3.316	2.959	3.625	3.412	3.231	3.421	3.003
	(K +Na)/Al	0.194	0.193	0.194	0.195	0.197	0.194	0.198	0.176	0.199	0.203
	%CaO										
	COLE										
	CEC										
	pH										
Climofunction	MAP (CIA-K)	1300.096	1299.346	1296.274	1298.172	1287.281	1302.995	1306.849	1325.089	1286.312	1289.100
	MAP (CALMAG)										
	MAT	13.713	13.731	13.706	13.691	13.649	13.713	13.639	14.033	13.610	13.548

Site 5		Vertisol 1-base					Vertisol 2-base				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	16.530	16.760	17.010	17.320	17.270	15.600	16.360	16.590	16.920	16.960
	BaO	0.050	0.050	0.050	0.050	0.050	0.040	0.040	0.050	0.050	0.050
	CaO	5.820	5.670	5.560	4.930	5.060	8.390	6.680	6.280	6.010	5.420
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	6.690	6.560	6.680	6.340	7.190	6.340	6.460	6.340	6.230	6.380
	K ₂ O	4.190	4.250	4.270	4.360	4.270	4.030	4.210	4.210	4.290	4.280
	MgO	2.020	2.030	2.040	2.030	1.990	2.090	2.190	2.150	2.120	2.110
	MnO	0.060	0.060	0.050	0.040	0.050	0.090	0.070	0.070	0.060	0.060
	Na ₂ O	0.160	0.160	0.170	0.160	0.170	0.130	0.140	0.150	0.140	0.140
	P ₂ O ₅	0.434	0.444	0.444	0.427	0.450	0.431	0.419	0.406	0.406	0.435
	SO ₃										
	SiO ₂	49.410	49.740	50.060	50.670	49.750	47.040	48.890	49.160	50.000	49.980
	SrO	0.030	0.030	0.020	0.020	0.020	0.030	0.030	0.030	0.030	0.030
	TiO ₂	0.780	0.780	0.800	0.820	0.800	0.740	0.780	0.780	0.800	0.800
Molecular Weathering Ratio	Σbases/Al	1.240	1.212	1.186	1.102	1.108	1.610	1.374	1.306	1.251	1.182
	CIA-K	60.384	61.320	62.084	65.244	64.562	50.213	56.933	58.716	60.262	62.711
	Al/Si	0.197	0.199	0.200	0.201	0.205	0.195	0.197	0.199	0.199	0.200
	Ca/Ti	10.627	10.353	9.898	8.563	9.008	16.148	12.197	11.467	10.699	9.649
	Mg/Ti	5.131	5.157	5.053	4.905	4.929	5.596	5.563	5.462	5.251	5.226
	Na/Ti	0.264	0.264	0.274	0.251	0.274	0.226	0.231	0.248	0.226	0.226
	K/Ti	4.555	4.620	4.526	4.508	4.526	4.617	4.576	4.576	4.547	4.536
	(K + Na)/Al	0.290	0.290	0.288	0.288	0.284	0.293	0.293	0.290	0.288	0.287
	%CaO	8.359	8.109	7.906	7.008	7.250	12.104	9.535	8.978	8.512	7.736
	COLE	0.222	0.220	0.218	0.207	0.208	0.267	0.240	0.233	0.227	0.217
	CEC	36.213	36.441	36.637	37.323	37.239	33.199	35.133	35.665	36.103	36.653
	pH	7.707	7.693	7.684	7.614	7.622	7.942	7.811	7.770	7.740	7.679
Climofun ction	MAP (CIA-K)	775.164	792.609	806.845	865.747	853.042	585.564	710.839	744.071	772.892	818.542
	MAP (CALMAG)	1103.247	1118.920	1132.493	1182.778	1175.451	921.424	1035.498	1068.705	1096.794	1135.545
	MAT	11.923	11.925	11.963	11.972	12.043	11.867	11.880	11.937	11.965	11.989

Site 5		Vertisol 1- top					Vertisol 2- top				
		Sampling depth (cm)					Sampling depth (cm)				
		0	25	50	100	150	0	25	50	100	150
Oxide (Weight %)	Al ₂ O ₃	15.990	15.240	12.100	15.940	14.820	16.010	15.850	16.010	14.950	15.210
	BaO	0.030	0.040	0.040	0.030	0.020	0.030	0.030	0.030	0.030	0.030
	CaO	5.740	7.380	17.250	5.750	8.620	5.770	5.740	5.660	8.320	7.640
	Cr ₂ O ₃	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Fe ₂ O ₃	7.490	7.550	6.160	7.250	7.500	7.560	7.640	8.260	7.800	8.250
	K ₂ O	2.910	2.700	2.060	2.920	2.680	2.940	2.890	2.950	2.730	2.800
	MgO	2.140	2.020	1.750	2.120	2.000	2.020	2.000	1.970	1.840	1.870
	MnO	0.060	0.070	0.220	0.060	0.090	0.060	0.060	0.070	0.100	0.100
	Na ₂ O	0.220	0.230	0.180	0.230	0.220	0.220	0.220	0.230	0.210	0.220
	P ₂ O ₅	0.268	0.264	0.218	0.260	0.250	0.260	0.258	0.267	0.253	0.262
	SO ₃										
	SiO ₂	49.200	47.960	38.030	49.800	45.970	49.760	49.630	49.570	46.070	46.560
	SrO	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.020	0.020
	TiO ₂	0.780	0.760	0.570	0.780	0.740	0.780	0.780	0.800	0.740	0.740
Molecular Weathering Ratio	Σbases/Al	1.211	1.432	3.167	1.214	1.619	1.196	1.198	1.177	1.544	1.447
	CIA-K	59.691	52.486	27.652	59.539	48.033	59.600	59.479	60.010	49.142	51.625
	Al/Si	0.192	0.187	0.188	0.189	0.190	0.190	0.188	0.190	0.191	0.193
	Ca/Ti	10.481	13.830	43.101	10.499	16.590	10.536	10.481	10.076	16.013	14.704
	Mg/Ti	5.436	5.266	6.083	5.385	5.355	5.131	5.080	4.879	4.927	5.007
	Na/Ti	0.363	0.390	0.407	0.380	0.383	0.363	0.363	0.370	0.366	0.383
	K/Ti	3.163	3.012	3.064	3.174	3.071	3.196	3.141	3.127	3.128	3.208
	(K +Na)/Al	0.220	0.217	0.209	0.222	0.220	0.221	0.220	0.223	0.221	0.223
	%CaO	8.352	10.770	26.105	8.314	12.751	8.343	8.332	8.193	12.348	11.310
	COLE	0.223	0.248	0.407	0.223	0.268	0.221	0.220	0.218	0.260	0.249
	CEC	35.869	34.028	19.737	35.861	32.525	36.007	35.981	36.174	33.146	33.958
	pH	7.716	7.852	8.425	7.714	7.950	7.702	7.696	7.684	7.909	7.856
Climofun ction	MAP (CIA-K)	762.243	627.947	165.028	759.400	544.927	760.543	758.295	768.186	565.602	611.895
	MAP (CALMAG)	1084.154	967.591	446.994	1083.220	886.000	1090.532	1088.729	1100.862	915.118	960.296
	MAT	13.232	13.288	13.433	13.187	13.222	13.199	13.221	13.168	13.210	13.168

APPENDIX B: OXIDE WEIGHT PERCENT VS. DEPTH

a) Al_2O_3 , b) BaO , c) CaO , d) Cr_2O_3

e) Fe_2O_3 , f) K_2O , g) MgO , h) MnO

i) Na_2O , j) P_2O_5 , k) SO_3 , l) SiO_2

APPENDIX C: WILCOXAN SIGNED RANK RESULTS

		Upper									
depth (cm)		0-25	0-50	0-100	0-150	25-50	25-100	25-150	50-100	50-150	100-150
Oxide (wt%)	Al ₂ O ₃	0.881	0.147	0.622	0.841	0.765	0.927	0.701	0.970	0.674	0.126
	BaO	0.777	0.098	0.396	0.890	0.057	0.511	0.943	0.065	0.134	0.319
	CaO	0.430	0.452	0.674	0.622	0.546	0.825	0.729	0.681	0.528	0.162
	Cr ₂ O ₃	1.000	1.000	0.789	0.371	1.000	0.789	0.789	1.000	1.000	1.000
	Fe ₂ O ₃	0.380	0.701	0.794	0.312	0.430	0.526	0.391	0.033	0.044	0.911
	K ₂ O	1.000	0.490	0.161	0.490	0.948	0.576	0.867	0.341	0.616	0.235
	MgO	0.605	0.550	0.455	0.629	0.868	0.955	0.235	0.640	0.227	0.225
	MnO	0.666	0.801	0.507	0.889	0.917	0.602	0.834	0.163	0.916	0.034
	Na ₂ O	0.752	0.133	0.747	0.214	0.712	0.632	0.093	0.459	0.039	0.153
	P ₂ O ₅	0.705	0.458	0.420	0.679	0.112	0.643	0.760	0.616	0.277	0.678
	SO ₃	0.373	0.953	0.859	0.444	0.799	0.919	0.760	0.339	0.540	0.721
	SiO ₂	0.812	0.368	0.701	0.674	0.490	0.985	0.481	0.794	0.277	0.036
	SrO	0.605	0.601	0.757	0.655	0.408	0.389	0.918	0.718	0.259	0.265
	TiO ₂	0.391	0.809	0.760	0.695	1.000	0.793	0.640	0.268	0.672	0.028
Molecular Weathering Ratio	Σbases/Al	0.444	0.641	0.681	0.674	0.571	0.870	0.729	0.674	0.433	0.189
	CIA-K	0.756	0.571	0.430	0.409	0.729	0.701	0.546	0.452	0.349	0.202
	Al/Si	0.320	0.490	0.170	0.257	0.810	0.778	0.206	0.337	0.111	0.408
	Ca/Ti	0.388	0.648	0.701	0.729	0.729	0.870	0.812	0.701	0.546	0.154
	Mg/Ti	0.067	0.189	0.177	0.546	0.542	0.927	0.841	0.870	0.952	0.702
	Na/Ti	0.394	0.121	0.490	0.211	0.717	0.334	0.070	0.185	0.046	0.179
	K/Ti	0.351	0.143	0.032	0.050	0.481	0.498	0.165	0.622	0.050	0.641
	(K +Na)/Al	0.943	0.323	1.000	0.962	0.256	0.877	0.906	0.256	0.363	0.836
	%CaO	0.922	0.695	0.492	0.625	0.922	0.846	0.846	0.432	0.770	0.275
	COLE	0.919	0.770	0.477	0.610	1.000	0.846	0.760	0.375	0.770	0.221
	CEC	0.922	0.770	0.432	0.625	1.000	0.770	0.846	0.275	0.625	0.232
	pH	0.770	0.625	0.557	0.557	1.000	0.770	0.683	0.375	0.625	0.322
Climofu nction	MAP (CIA-K)	0.984	0.353	0.241	0.225	0.441	0.490	0.374	0.475	0.330	0.189
	MAP (CALMAG)	0.652	0.301	0.164	0.250	1.000	0.770	0.770	0.375	0.625	0.322
	MAT	0.941	0.870	0.841	0.430	0.502	0.522	0.121	0.701	0.469	0.057

		Lower									
depth (cm)		0-25	0-50	0-100	0-150	25-50	25-100	25-150	50-100	50-150	100-150
Oxide (wt%)	Al ₂ O ₃	0.464	0.528	0.903	0.013	0.274	0.855	0.017	0.855	0.005	0.004
	BaO	0.830	0.365	0.905	0.176	0.150	0.830	0.178	0.620	0.105	0.090
	CaO	0.495	0.159	0.715	0.024	0.162	0.761	0.124	0.952	0.004	0.009
	Cr ₂ O ₃	--	--	--	1.000	--	--	1.000	--	1.000	1.000
	Fe ₂ O ₃	0.083	0.798	0.426	0.272	0.255	0.903	1.000	0.761	0.761	1.000
	K ₂ O	0.478	0.187	0.576	0.706	0.099	0.326	0.402	1.000	0.972	0.502
	MgO	0.258	0.842	0.055	0.490	0.736	0.069	0.903	0.268	0.780	0.730
	MnO	0.878	0.844	0.724	0.213	0.593	1.000	0.556	0.972	0.695	0.624
	Na ₂ O	0.238	0.733	0.193	0.844	0.328	0.056	0.944	0.162	0.814	0.332
	P ₂ O ₅	0.433	0.078	0.035	0.025	0.197	0.069	0.055	0.196	0.315	0.889
	SO ₃	0.353	0.674	0.250	0.624	0.076	0.742	0.945	0.014	0.109	0.726
	SiO ₂	0.093	0.562	0.855	0.078	0.175	0.173	0.952	0.463	0.542	0.268
	SrO	0.588	0.833	0.191	0.083	0.865	0.396	0.232	0.344	0.108	0.208
	TiO ₂	0.195	1.000	0.572	0.263	0.318	0.285	0.814	0.382	0.507	0.162
Molecular Weathering Ratio	Σbases/Al	0.233	0.323	0.903	0.009	0.408	0.903	0.038	1.000	0.007	0.017
	CIA-K	0.528	0.211	0.808	0.011	0.323	0.855	0.068	1.000	0.004	0.013
	Al/Si	0.205	0.712	0.726	0.096	0.917	0.379	0.068	0.610	0.268	0.140
	Ca/Ti	0.478	0.193	0.952	0.030	0.255	0.808	0.135	1.000	0.003	0.013
	Mg/Ti	0.016	0.744	0.268	0.194	0.528	0.463	0.463	0.903	0.761	0.808
	Na/Ti	0.490	0.897	0.264	0.834	0.877	0.103	0.727	0.116	0.917	0.556
	K/Ti	0.562	0.231	0.626	0.296	0.514	0.626	0.346	0.952	0.485	1.000
	(K +Na)/Al	0.442	0.011	0.167	0.173	0.025	0.315	0.051	0.834	0.484	0.975
	%CaO	0.578	0.375	0.938	0.047	0.578	0.938	0.219	0.938	0.016	0.016
	COLE	0.529	0.446	0.938	0.078	0.529	0.938	0.297	1.000	0.047	0.078
	CEC	0.578	0.578	0.938	0.109	0.938	0.938	0.297	0.938	0.078	0.047
	pH	0.295	0.813	0.688	0.031	0.688	0.938	0.219	1.000	0.219	0.150
Climofu nction	MAP (CIA-K)	0.433	0.252	0.808	0.011	0.348	0.903	0.068	1.000	0.002	0.013
	MAP (CALMAG)	0.469	0.813	1.000	0.078	0.938	0.938	0.219	1.000	0.078	0.047
	MAT	0.744	0.323	0.078	0.025	0.298	0.158	0.005	0.241	0.049	0.153

		Unconsolidated									
depth (cm)		0-25	0-50	0-100	0-150	25-50	25-100	25-150	50-100	50-150	100-150
Oxide (wt%)	Al ₂ O ₃	0.850	0.116	0.380	0.910	0.110	0.569	0.569	0.970	0.339	0.021
	BaO	0.269	1.000	0.265	0.773	1.000	0.685	0.423	0.518	1.000	0.322
	CaO	0.677	0.052	0.424	0.910	0.233	0.519	0.791	0.850	0.622	0.092
	Cr ₂ O ₃	1.000	--	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Fe ₂ O ₃	0.791	0.569	0.850	0.583	0.021	0.970	0.970	0.110	0.077	0.677
	K ₂ O	0.814	0.136	0.195	0.346	0.224	0.239	0.556	0.845	0.965	0.233
	MgO	0.838	0.969	0.894	0.301	0.374	0.970	0.129	0.814	0.197	0.410
	MnO	0.725	0.798	0.575	0.554	0.331	0.540	0.575	0.553	0.683	0.358
	Na ₂ O	0.362	0.019	0.047	0.593	0.326	0.119	0.844	0.878	0.220	0.138
	P ₂ O ₅	0.362	0.513	0.154	0.235	0.859	0.783	0.906	0.593	0.363	0.824
	SO ₃	0.153	0.610	0.477	0.695	0.197	1.000	0.625	0.033	0.213	0.965
	SiO ₂	0.970	0.052	0.339	1.000	0.042	0.380	0.850	0.850	0.380	0.110
	SrO	0.089	0.198	0.276	0.551	0.710	0.186	0.227	0.915	0.588	0.685
	TiO ₂	0.929	0.266	0.182	0.721	0.212	0.350	1.000	0.583	0.666	0.031
Molecular Weathering Ratio	Σbases/Al	0.850	0.021	0.380	0.969	0.176	0.519	0.677	0.910	0.470	0.052
	CIA-K	0.791	0.064	0.301	0.970	0.301	0.569	0.850	0.677	0.470	0.052
	Al/Si	0.858	0.117	0.721	0.306	0.189	0.556	0.563	0.083	0.721	0.656
	Ca/Ti	0.791	0.042	0.470	0.910	0.176	0.569	0.733	0.850	0.569	0.092
	Mg/Ti	0.233	0.339	0.266	0.301	0.092	0.077	0.204	0.380	0.850	0.970
	Na/Ti	0.182	0.014	0.233	0.677	0.233	0.534	0.824	0.850	0.266	0.450
	K/Ti	0.677	0.850	0.569	0.622	0.969	0.875	0.677	0.569	0.233	0.875
	(K +Na)/Al	0.256	0.789	0.409	0.326	0.919	0.689	0.345	0.327	0.167	0.583
	%CaO	0.094	0.156	0.219	1.000	0.844	0.438	0.563	0.438	0.563	0.094
	COLE	0.093	0.094	0.219	1.000	1.000	0.438	0.438	0.438	0.563	0.094
	CEC	0.094	0.094	0.156	0.844	1.000	0.438	0.438	0.438	0.563	0.094
	pH	0.115	0.156	0.313	1.000	0.844	0.438	0.563	0.563	0.688	0.156
Climofu nction	MAP (CIA-K)	0.677	0.064	0.339	0.970	0.301	0.569	0.733	0.677	0.519	0.042
	MAP (CALMAG)	0.156	0.156	0.313	0.844	1.000	0.438	0.563	0.563	0.563	0.156
	MAT	0.850	0.301	0.034	0.204	0.875	0.480	0.456	0.071	0.136	0.754

		Lithified									
depth (cm)		0-25	0-50	0-100	0-150	25-50	25-100	25-150	50-100	50-150	100-150
Oxide (wt%)	Al ₂ O ₃	0.668	0.553	0.702	0.098	0.966	0.426	0.054	0.935	0.054	0.019
	BaO	0.280	0.950	0.833	0.138	0.578	0.837	0.385	0.571	0.754	0.074
	CaO	0.078	0.966	0.899	0.210	0.520	0.972	0.685	0.615	0.313	0.038
	Cr ₂ O ₃	--	1.000	1.000	0.371	1.000	1.000	0.371	--	1.000	1.000
	Fe ₂ O ₃	0.637	0.750	0.446	0.166	0.932	0.638	0.390	0.314	0.443	0.795
	K ₂ O	0.704	0.511	0.385	0.897	0.741	0.548	0.945	0.516	0.695	0.404
	MgO	0.296	0.260	0.013	0.230	0.199	0.065	0.689	0.249	0.781	0.833
	MnO	0.754	0.920	0.776	0.185	0.831	0.920	0.298	0.615	0.320	0.126
	Na ₂ O	0.227	0.741	0.767	0.155	0.601	0.965	0.222	0.835	0.235	0.254
	P ₂ O ₅	0.338	0.010	0.027	0.014	0.024	0.037	0.065	0.314	0.465	0.695
	SO ₃	0.753	0.799	0.123	0.208	0.599	0.151	0.272	0.074	0.151	0.933
	SiO ₂	0.084	0.966	0.949	0.092	0.700	0.545	0.578	0.306	0.305	0.072
	SrO	0.138	0.122	0.056	0.200	0.888	0.339	1.000	0.540	0.759	1.000
	TiO ₂	0.042	0.396	0.808	0.172	0.944	0.708	0.465	0.112	0.550	0.216
Molecular Weathering Ratio	Σbases/Al	0.060	0.743	0.548	0.129	0.786	0.709	0.381	0.633	0.385	0.091
	CIA-K	0.197	0.966	0.775	0.248	0.812	0.874	0.633	0.524	0.443	0.092
	Al/Si	0.113	0.128	0.661	0.808	0.493	0.661	0.986	0.695	0.897	0.935
	Ca/Ti	0.070	0.790	0.849	0.222	1.000	1.000	0.633	0.633	0.290	0.043
	Mg/Ti	0.005	0.034	0.006	0.025	0.399	0.095	0.198	0.656	0.424	0.465
	Na/Ti	0.576	0.932	0.835	0.164	0.626	0.884	0.222	0.783	0.255	0.244
	K/Ti	0.137	0.056	0.038	0.025	0.223	0.235	0.074	0.974	0.135	0.935
	(K +Na)/Al	0.983	0.410	0.556	0.744	0.627	0.793	0.506	0.887	0.868	0.743
	%CaO	0.110	0.850	0.850	0.424	1.000	0.791	0.970	0.910	0.470	0.151
	COLE	0.142	0.791	0.563	0.410	1.000	0.791	0.970	0.875	0.367	0.195
	CEC	0.176	0.850	0.677	0.569	0.733	0.791	0.970	0.677	0.970	0.204
	pH	0.142	0.569	0.424	0.204	0.970	0.791	0.910	0.791	0.519	0.289
Climofu nction	MAP (CIA-K)	0.223	0.941	0.517	0.374	1.000	0.708	0.865	0.524	0.388	0.085
	MAP (CALMAG)	0.320	0.898	0.898	0.898	0.791	0.850	0.910	0.677	0.622	0.176
	MAT	0.920	0.539	0.799	0.849	0.833	1.000	0.610	0.899	0.889	0.922

		Vertisols									
depth (cm)		0-25	0-50	0-100	0-150	25-50	25-100	25-150	50-100	50-150	100-150
Oxide (wt%)	Al ₂ O ₃	0.931	0.407	0.284	0.832	0.832	0.647	0.610	0.265	0.551	0.041
	BaO	0.798	0.438	0.625	1.000	0.262	0.222	0.525	0.072	0.203	0.430
	CaO	0.705	0.523	0.580	0.417	0.799	0.865	0.551	0.702	0.196	0.037
	Cr ₂ O ₃	--	1.000	1.000	1.000	1.000	1.000	1.000	1.000	--	1.000
	Fe ₂ O ₃	0.862	0.887	0.372	0.523	0.472	0.327	0.879	0.099	0.246	0.058
	K ₂ O	0.571	0.338	0.316	0.446	0.535	0.500	0.603	0.616	0.943	0.442
	MgO	0.589	0.586	0.369	0.728	0.642	0.570	0.170	0.931	0.115	0.663
	MnO	0.350	0.484	0.897	0.629	0.755	0.862	0.691	0.601	0.977	0.468
	Na ₂ O	0.929	0.622	0.917	0.124	0.916	0.777	0.109	0.776	0.047	0.082
	P ₂ O ₅	0.778	0.232	0.538	0.020	0.233	0.349	0.012	0.609	0.087	0.125
	SO ₃	0.944	0.183	0.859	0.812	0.083	0.722	0.636	0.032	0.068	1.000
	SiO ₂	0.610	0.468	0.966	0.182	0.865	0.966	0.394	0.580	0.284	0.284
	SrO	1.000	0.573	0.918	0.472	0.598	0.809	0.572	0.953	0.398	0.462
	TiO ₂	0.442	0.795	0.816	0.212	0.959	0.983	0.458	0.687	0.587	0.147
Molecular Weathering Ratio	Σbases/Al	0.538	0.610	0.580	0.551	0.899	0.832	0.580	0.393	0.468	0.038
	CIA-K	0.899	0.495	0.523	0.468	0.932	0.734	0.468	0.671	0.265	0.034
	Al/Si	0.399	0.332	0.024	0.316	0.667	0.088	0.380	0.021	0.359	0.491
	Ca/Ti	0.670	0.580	0.610	0.442	0.932	0.832	0.551	0.580	0.229	0.027
	Mg/Ti	0.016	0.442	0.212	0.265	0.740	0.495	0.932	1.000	0.887	0.508
	Na/Ti	0.706	0.887	1.000	0.124	0.528	0.619	0.133	0.828	0.059	0.134
	K/Ti	0.338	0.016	0.010	0.005	0.289	0.212	0.067	0.663	0.256	0.679
	(K +Na)/Al	0.434	0.683	0.064	0.055	0.319	0.050	0.041	0.045	0.065	0.900
	%CaO	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	COLE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	CEC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	pH	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Climofu nction	MAP (CIA-K)	1.000	0.263	0.306	0.678	0.644	0.579	0.678	0.671	0.265	0.034
	MAP (CALMAG)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MAT	0.761	0.317	0.799	0.766	0.932	0.248	0.571	0.167	0.508	0.966

		Inceptisols									
depth (cm)		0-25	0-50	0-100	0-150	25-50	25-100	25-150	50-100	50-150	100-150
Oxide (wt%)	Al ₂ O ₃	0.671	0.231	0.404	0.058	0.122	0.495	0.065	0.231	0.018	0.023
	BaO	1.000	0.311	1.000	0.099	0.204	0.796	0.058	0.672	0.058	0.022
	CaO	0.267	0.182	0.821	0.900	0.043	0.379	0.980	1.000	0.638	0.127
	Cr ₂ O ₃	1.000	--	1.000	0.346	1.000	1.000	0.414	1.000	0.346	1.000
	Fe ₂ O ₃	0.523	0.983	0.821	0.175	0.265	0.706	0.433	0.495	0.175	0.159
	K ₂ O	0.925	0.338	0.268	0.679	0.394	0.121	1.000	0.856	0.925	0.201
	MgO	0.334	0.507	0.064	0.478	0.962	0.127	0.712	0.121	0.485	0.423
	MnO	0.824	0.148	0.722	0.553	0.323	0.374	0.684	0.721	0.507	0.066
	Na ₂ O	0.469	0.172	0.478	0.909	0.142	0.244	0.938	0.875	0.510	0.414
	P ₂ O ₅	0.776	0.182	0.410	0.979	0.083	0.221	0.675	0.670	0.393	0.182
	SO ₃	0.042	0.594	0.066	0.155	0.673	0.407	0.722	0.042	0.375	0.906
	SiO ₂	0.130	0.393	0.528	0.706	0.074	0.175	0.980	0.632	0.433	0.023
	SrO	0.905	1.000	0.121	0.597	0.673	0.089	0.673	0.611	1.000	0.611
	TiO ₂	0.176	0.924	0.300	0.910	0.422	0.172	0.900	0.191	0.756	0.062
Molecular Weathering Ratio	Σbases/Al	0.156	0.317	0.796	0.298	0.094	0.717	0.323	0.706	0.222	0.187
	CIA-K	0.468	0.265	0.669	0.940	0.154	0.464	0.940	0.821	0.632	0.175
	Al/Si	0.255	0.887	0.214	0.209	0.522	0.047	0.201	0.201	0.514	0.959
	Ca/Ti	0.246	0.246	0.860	0.821	0.048	0.404	0.860	0.980	0.528	0.159
	Mg/Ti	0.080	0.393	0.252	0.597	0.670	0.980	0.528	1.000	0.597	0.816
	Na/Ti	0.981	0.207	0.669	0.940	0.421	0.408	0.798	0.856	0.632	0.597
	K/Ti	0.557	0.766	0.528	0.623	0.832	0.918	0.376	0.744	0.266	1.000
	(K +Na)/Al	0.955	0.420	0.618	0.705	0.864	0.200	0.652	0.078	0.484	1.000
	%CaO	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	COLE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	CEC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	pH	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Climofu nction	MAP (CIA-K)	0.468	0.265	0.669	0.940	0.154	0.464	0.940	0.821	0.632	0.175
	MAP (CALMAG)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MAT	0.983	0.551	0.034	0.034	0.610	0.117	0.093	0.029	0.051	0.959

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