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## Mineralogical and textural criteria for recognizing remnant Cenozoic deposits on the Piedmont: evidence from Sparta and Greene County, Georgia, U.S.A.

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### Abstract

Two soil/saprolite profiles from ridge crest sites in central Georgia were investigated for mineralogical and textural trends to help elucidate the relationship between Cenozoic Coastal Plain deposits landward of the Fall Line and the Piedmont. Result from the study of a 10.5 m thick sequence in Sparta, Georgia reveal a deep lateritic profile showing complete loss of plagioclase, gradational loss of K-feldspar, vermiculitization of biotite and precipitation of kaolinite and halloysite within the lower 6 m. The middle section of the sequence is characterized by authigenic kaolinite, halloysite and goethite. The upper 1.35 m is quartz-rich, but also contains K-feldspar, hydroxy-interlayered vermiculite (HIV) and gibbsite. A comparison of grain shape and size indicates a slight textural difference between the upper and middle sections, with the fine sand grains of the upper section being more spherical and less angular.

Preliminary results from the study of a 6.35 m sequence in Greene County, Georgia also reveal a deep lateritic profile. A sharp soil fabric contact, from slightly mottled to highly mottled, occurs 3.1 m below the surface. This profile is characterized by a bimodal clay mineral abundance distribution as a function of depth. This includes an antithetical relationship between kaolinite and HIV, where HIV is abundant at the surface, decreases with depth, increases again at the fabric interface and then decreases with depth.

It is suggested that the profiles contain paleosols that are a result of deep lateritic weathering, subsequent allochthonous deposition of a sedimentary cap and then further chemical weathering. The exact relationship between the depositional ages of the veneers and the age, duration and climatic conditions for past weathering events are currently poorly constrained. Recognition of paleo-weathering surfaces has potential importance for our understanding of the record of geologic and paleoclimatic change in the southeastern United States. Identification of such Cenozoic sedimentary veneers and paleosols on the Piedmont also has potential importance for land use practices from the standpoint of better understanding regional soil terrain properties.

**Keywords:** Paleosol; Kaolinite; Vermiculite; Granite; Weathering

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## 1. Introduction

Knowledge of the landward extent of coastal plain deposition on the southeastern United States Piedmont bears importantly on both our understanding of modern land use and our understanding of Cenozoic geologic history. Demarcation of the Fall Line (the surficial boundary between the Coastal Plain and the Piedmont provinces) on geologic maps of Georgia (Hertrick and Fridell, 1990; Pickering and Murray, 1976) are known to exclude small pockets of Eocene clays deposited unconformably on Paleozoic Piedmont rocks (Hurst and Pickering, 1989). The extent to which remnants of younger Cenozoic sediments unconformably overlie the Piedmont rocks landward of the Fall Line is not well documented. The inability to recognize such remnant deposits is largely due to intense weathering and pedogenic processes that have operated throughout the Cenozoic. This study represents the results of a mineralogical and textural reconnaissance of two Piedmont sites, examining evidence of remnant coastal plain sedimentary veneers. The purpose of this study is to establish mineralogical and textural criteria in soil profiles of the Piedmont region that are consistent with an origin of allochthonous deposition on an older Paleozoic surface and subsequent development of a soil profile.

## 2. Previous work

Veatch and Stephenson (1911) first reported the presence of fluvial terraces on the coastal plain in Georgia. Carver and Waters (1984) subsequently suggested that Pleistocene fluvial terrace remnants extend well into the Piedmont Province. Within coastal plain and Piedmont provinces of the Savannah, Ogeechee, Oconee, Ocmulgee and Flint Rivers, Carver and Waters (1984) found six correlative terraces at levels of 3–6, 9–15, 16–24, 33–40, 43–49 and 52–58 m above present river elevations. The similarity of terrace gradients on the coastal plain and present-day river gradients indicates relative tectonic stability for the coastal plain throughout the Pleistocene. One exception to this trend occurs in west Georgia near Columbus, where there appears to be as much as 30 m of post-Sangamon uplift (Markewich et al., 1995). Correlation of terraces on the Piedmont is more tenuous, therefore, estimates on regional

uplift are not well constrained. Staheli's (1976) topographic analysis of the Georgia Piedmont topography suggested that coastal plain sediments extensively covered the Piedmont. Subsequent stream erosion in the Upper Piedmont province, largely controlled by northeast-trending geologic structures, has left an extremely thin and discontinuous sediment cover. Staheli (1976) further suggested that the dendritic stream development in the Lower Piedmont occurred on now-missing Oligocene strata. Present-day streams are now superimposed on Piedmont bedrock.

Most recently Markewich et al. (1995) examined the nature of soils and weathering profiles on residual and transported material in the Piedmont of west-central Georgia. Estimates of absolute ages in their study were made by comparing geochemical data from profiles of known ages with similar profiles from Virginia to Alabama. They concluded that these regional soils developed in erosional remnants that are no younger than early Pleistocene, with estimated ages between late Miocene and late Pliocene. The transported deposits examined in their study are clearly alluvial fans and landslides. The youngest (Pleistocene) soils are those developed on resistant quartzite ridges. In all cases Markewich et al. (1995) assumed that the Piedmont surfaces in their study area have not experienced coastal plain onlap since the Mesozoic. Interestingly, if the regional uplift estimates of Carver and Waters (1984) are correct for west Georgia then this latter assumption is at odds with the model of Staheli (1976) who suggested that coastal plain deposits occurred to at least the Brevard Zone, which is a 1–5 km wide cataclasis belt approximated by the location of the Chattahoochee River (Fig. 1).

## 3. Materials and methods

### 3.1. Sampling sites

Samples for this study were recovered from two locations in the central Georgia Piedmont (Fig. 1). These locations were chosen specifically for having the attributes of homogeneous parent materials and for their position along topographic highs, so as to minimize effects of downslope colluvial transport. The first location is an inactive granite quarry

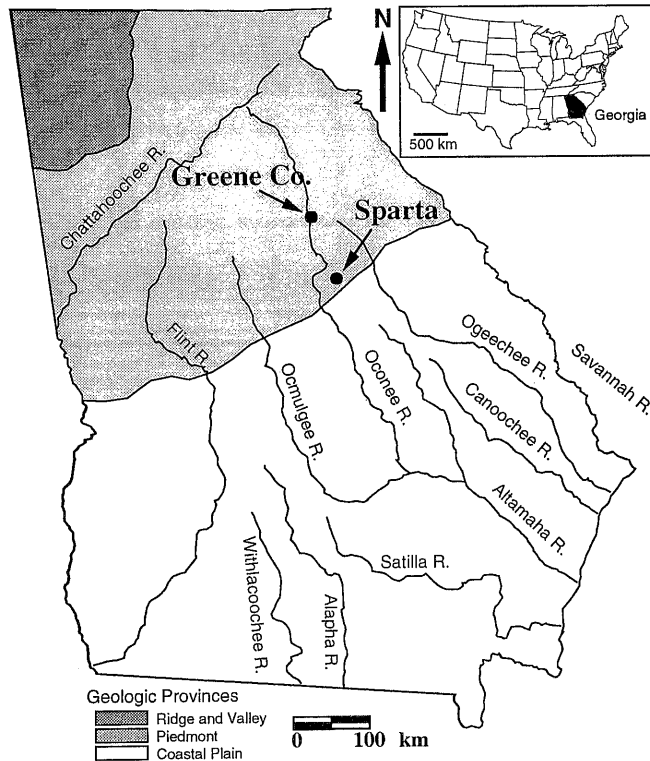


Fig. 1. Location map of study sites in Georgia. The Fall Line is approximated by the boundary between the coastal plain and Piedmont provinces. The Brevard Zone is approximated by the position of the Chattahoochee River.

located about 3 km east of Sparta, Georgia, at an elevation of 168 m (550 ft). Approximately 10.5 m of soil/saprolite sequence has been exposed from quarry activity (Fig. 2). Samples from the surface to 10.5 m were collected by augering. The Sparta Granite is medium-grained, equigranular and has quartz, plagioclase, K-feldspar and biotite as major constituents (Kim, 1994). Some biotite has been deuterically altered to chlorite. Biotite also contains inclusions of zircon, apatite and ilmenite.

The second site is located at a road cut in Greene County, Georgia about 2 km south of the Oconee/Greene County border, east of Highway 15 and east of the Oconee River (Fig. 1), currently at an elevation of 183 m (600 ft). The site is underlain by an eastern extension of the Elberton Granite (Whitney and Wenner, 1980). Ten samples were collected via augering at representative intervals to a depth of 6.35 m. Saprolite indicative of a granitic parent material was reached at 6.35 m. However, the unweathered parent rock was not encountered. The

estimated depth to unaltered granite is about 20 to 25 m.

### 3.2. Sample pretreatment and analytical methods

Both bulk rock and soil material and size-fractionated materials were examined. The clay-size fraction ( $<2 \mu\text{m}$ ) was separated using wet sieving and centrifugation techniques (Hathaway, 1956). Major bulk mineral modal analysis and clay mineralogical analysis were performed using X-ray powder diffraction (XRD). XRD analyses were conducted using a Scintag XDS-2000 diffractometer. Experimental parameters included  $\text{CuK}\alpha$  radiation, 40 kV, 35 mA,  $1^\circ/2^\circ$  divergence slits,  $0.5^\circ/0.3^\circ$  receiving slits and a scan rate of  $5^\circ 2\theta/\text{min}$ . The clays were pretreated for identification of hydroxy-interlayered vermiculite (HIV), gibbsite and kaolinite. Kaolinite and halloysite were identified separately by scanning electron microscopy (SEM), but were not discriminated in XRD results. Therefore, all  $7.1 \text{ \AA}$  phases repre-

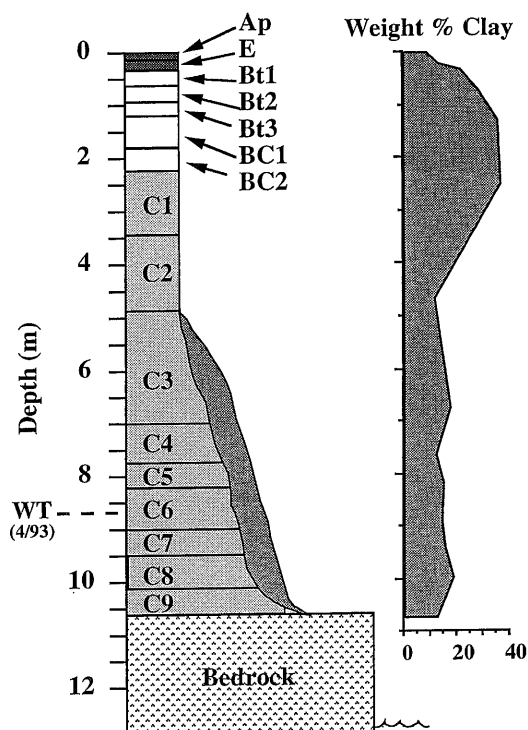


Fig. 2. Schematic profile of the Sparta, Georgia soil/saprolite section. Classification: Typic Kanhapludult or Ultisol (Soil Survey Staff, 1990). Subhorizon classes correspond with sample intervals found in Table 1. WT indicates location of the water table at the time of sampling. Weight percent clay was determined using standard settling methods.

sented in the diffractograms are hereafter collectively referred to as kaolinite. Clay samples were sedimented to infinite thickness on glass petrographic slides and air-dried. Treatments included Mg- and K-saturation, followed by ethylene glycol saturation and heating to 300°C and 500°C.

Quantitative XRD measurements for quartz, K-feldspar, plagioclase and kaolinite were made using reference-intensity-ratios derived from an  $\alpha$ - $\text{Al}_2\text{O}_3$  internal standard under the exact same experimental conditions (Chung, 1974a,b). Peaks for the mineral phases listed above at 50.1°, 27.5°, 28.0° and 24.8° 2 $\Theta$ , respectively, were referenced to the internal standard peak (20% by weight  $\alpha$ - $\text{Al}_2\text{O}_3$ ) at 43.3° 2 $\Theta$ .

Image analysis of the fine-sand fraction was conducted on four samples (0.35, 0.75, 1.35 and 2.50 m depths) from the Sparta sequence. The 0.2 to

0.3 mm size fraction was separated by wet sieving and dried grains were sprinkled onto a petrographic slide. Sixty to seventy-five grains per sample were analyzed for major and minor axis lengths. The major axis length is defined by searching all border pixels of a grain and choosing the two that are farthest apart. The minor axis is defined by the two pixels that are farthest apart on a line perpendicular to the major axis. Axial lengths ( $L$ ) are then calculated as  $L = \sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2}$  where  $X$  and  $Y$  are the two respective pixel coordinates for each axis.

Grain size analyses were performed using standard wet sieving and pipette settling methods. Size classes of very coarse, coarse, medium and fine sand, silt and clay are reported by weight percent according to Folk (1974).

A SEM, petrographic microscope and electron microprobe were employed to examine detailed grain morphological changes and for mineral identification. Grains were prepared for SEM study by mounting on Al stubs with double-stick carbon tape and subsequent Au-Pd coating. Thin sections were prepared using standard vacuum epoxy impregnation methods. Sections were polished and selected grains were analyzed chemically and with backscatter electrons using a JOEL Superprobe® operating at 15 kV and 15 nA.

## 4. Results

### 4.1. Sparta soil/saprolite

The soil/saprolite sequence at Sparta appears to display textural and mineralogical attributes typical of an entirely residual weathering profile (Figs. 2 and 3). The B horizon samples contain an abundance of clay-sized material interpreted as representing an accumulation of both authigenic and translocated clay minerals (see also Tables 1 and 2). The XRD, SEM and microprobe data also indicate that the lower 9 m of the sequence is a characteristic residual sequence. Fig. 4 shows the depletion of K, Mg and Fe and enrichment of Si and Al in coarse grains that were once biotite. The XRD analyses of these individual grains show transformations from biotite  $\rightarrow$  hydrobiotite  $\rightarrow$  vermiculite and biotite  $\rightarrow$  kaolinite (Table 2). These are reaction pathways well recognized in

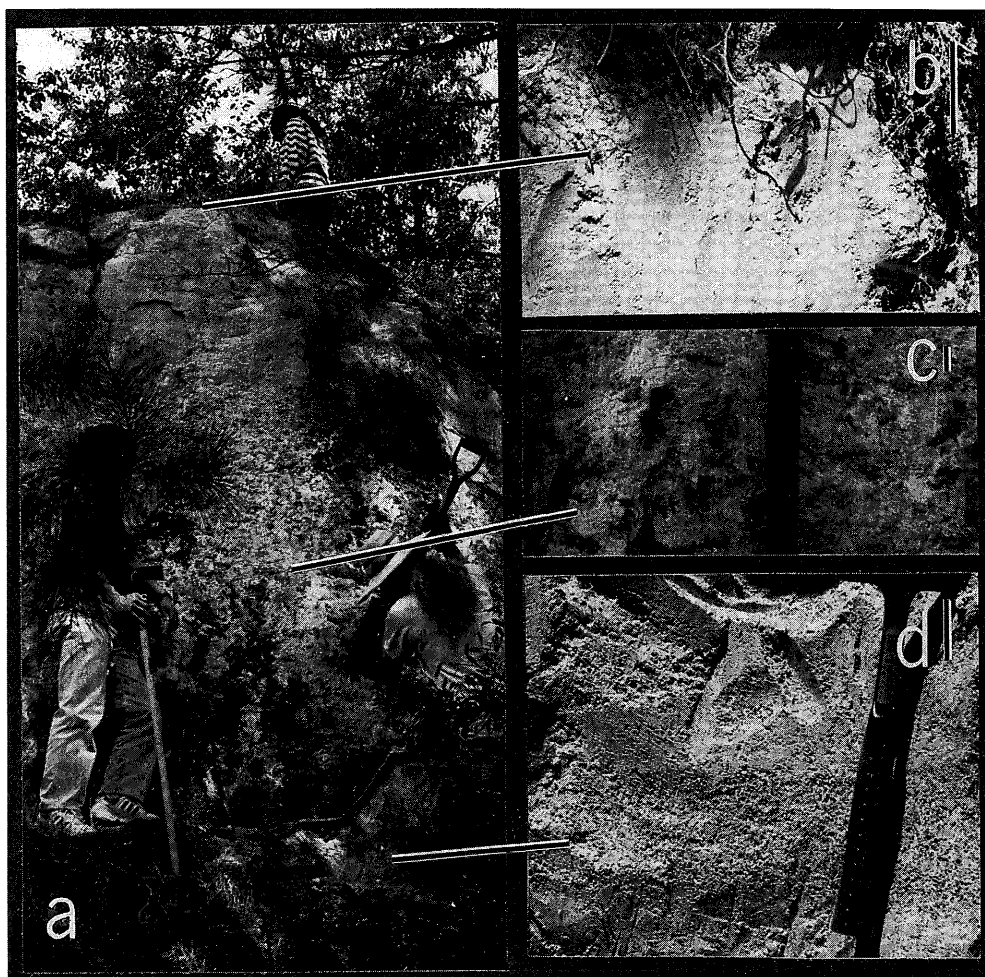


Fig. 3. Sparta, Georgia saprolite outcrop. (a) The upper 6 m are exposed as a result of quarry activity. (b) Homogenized quartz-rich surface veneer containing K-feldspar, HIV and gibbsite. (c) Mottled saprolite showing mobilized iron associated with intense chemical weathering and plant root exudates. (d) Saprolitized vein structure in Sparta Granite, bearing a composition of 99% quartz, kaolinite and halloysite. The vertical scale bar in (b), (c), and (d) is 5 cm.

other studies of biotite weathering (e.g., Banfield and Eggleton, 1988; Graham et al., 1989a,b). Quantitative XRD results also show the immediate and total dissolution of plagioclase feldspar (Fig. 5). K-feldspar abundances also decrease away from parent material towards the surface. Because kaolinite is the principle product of feldspar dissolution, it shows a commensurate increase, with decreasing feldspar content in the lower part of the section. The increase in quartz away from the parent material merely reflects the net loss of feldspar.

The middle portion of the profile (2 to 8 m)

is characterized by the complete disappearance of feldspar and biotite, each of which have been dissolved and re-precipitated or transformed to kaolinite and halloysite (Figs. 3c and 5). Analysis of the clay fraction by XRD (not shown) also indicates that vermiculite is absent from the middle portion of the profile. The texture of the saprolitized Sparta Granite is very well maintained, showing original igneous textural features such as late stage veins (Fig. 3d).

Mineralogical analysis, most surprisingly shows the presence of K-feldspar in the uppermost four samples from 0 to 0.75 m in depth. These samples,

Table 1  
Data table for the Sparta study site, including horizon designations, depth and particle size distribution

Horizon	Depth (m)	Sand					Silt		Clay
		VC	C	M	F	VF	CS	FS	CL
Ap	0.00–0.05	3.9	12.8	17.1	22.5	7.2	12.6	15.3	8.6
E	0.05–0.25	4.0	13.7	17.1	17.2	11.1	5.8	17.7	13.4
Bt1	0.25–0.35	2.4	10.7	15.5	18.8	8.7	5.8	16.5	21.6
Bt2	0.25–0.75	4.8	13.4	14.0	15.1	10.3	3.9	10.1	28.4
BC1	0.75–1.20	7.3	14.2	11.4	9.6	6.8	4.6	10.3	35.8
BC2	1.20–1.30	6.6	14.4	11.3	8.3	4.0	1.0	17.3	37.1
C2	2.40–2.50	15.9	17.9	8.8	5.6	4.4	7.5	28.2	11.7
C3	4.50–4.60	15.2	14.1	6.6	5.3	5.8	6.4	29.0	17.6
C4	6.50–6.60	14.7	16.6	8.1	7.7	7.5	6.5	26.6	12.3
C5	7.40–7.50	12.7	16.9	7.8	5.1	5.2	6.9	30.3	15.1
C6	7.90–8.00	13.6	16.1	8.0	5.6	6.6	6.6	29.0	14.5
C7	9.10–9.20	12.0	16.0	8.6	6.5	7.7	6.1	27.5	15.6
C8	9.65–9.75	13.3	14.0	8.9	10.4	7.6	6.1	20.9	18.8
C9	10.50	10.6	15.6	13.0	14.0	9.0	5.0	20.0	12.8

VC, very coarse; C, coarse; M, medium; F, fine; VF, very fine; CS, coarse silt; FS, fine silt; CL, clay.

Table 2  
Minor mineral abundance data for the Sparta study site based on XRD, SEM, microprobe and thin-section studies (see Fig. 5 for major mineral abundances)

Depth (m)	K-spar	Plag	Biotite	Chlorite	Verm	H/B	Gibbsite	HIV	Illite
0.00–0.05	t	–	–	–	–	–	t	t	–
0.05–0.25	t	–	–	–	–	–	+	+	–
0.25–0.35	+	–	–	–	–	–	+	+	–
0.25–0.75	+	–	–	–	–	–	+	+	–
0.75–1.20	+	–	–	–	–	–	t	t	–
1.20–1.30	–	–	–	–	–	–	–	–	–
2.40–2.50	–	–	–	–	–	–	–	–	–
4.50–4.60	–	–	–	–	–	–	–	–	t
6.50–6.60	–	–	–	–	t	–	–	–	t
7.40–7.50	t	–	–	–	t	–	–	–	t
7.90–8.00	t	–	–	–	t	–	–	–	t
9.10–9.20	+	–	–	–	t	–	–	–	t
9.65–9.75	++	t	t	t	t	+	–	–	–
10.50	++	+	t	t	t	t	–	–	–
Parent rock	++	++	+	+	–	–	–	–	–

– = absent; t = trace; + = minor concentration; ++ = abundant; K-spar = K-feldspar; Plag = plagioclase; Verm = vermiculite; H/B = hydrobiotite; HIV = hydroxy-interlayered vermiculite.

as well as the sample from 1.3 m depth also contain HIV and gibbsite. Grain shape analysis of the fine sand fraction from selected intervals in the upper 2.5 m of the profile was also conducted. Fig. 6 graphically shows a plot of major axis lengths versus minor axis lengths for grains sampled from depths of 0.75 m and 2.50 m. The mean aspect ratios for the sample from 0.75 m and 2.50 m depths

are 1.39 (standard deviation  $\sigma = 0.03$ ) and 1.52 ( $\sigma = 0.07$ ), respectively. The boxed areas are visual aids to show what a Student’s *t*-test confirms, namely that the grain shapes from the two different depths constitute different populations. The *t*-test value of 2.32, derived from comparing the aspect ratio of the two populations, indicates that they are different at the 2.2% significance level (Davis, 1986).

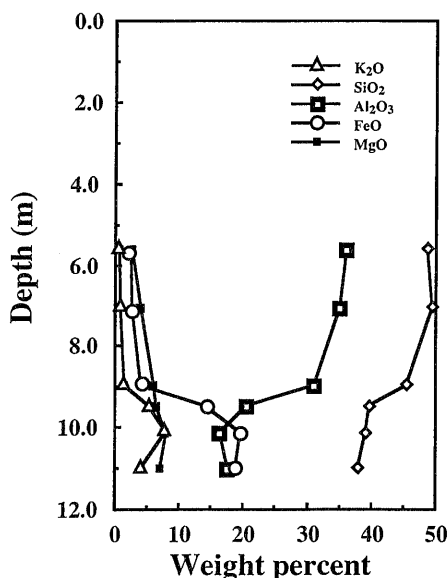


Fig. 4. Electron microprobe results of coarse (sand-sized) remnant biotite compositions as a function of depth in the Sparta, Georgia saprolite sequence. All grains analyzed showed flaky (pseudomorphic) mica habit. Lower-most sample is pristine biotite. Upper-most sample (no such grains were observed above 5 m) almost stoichiometrically matches an Fe-bearing kaolinite.

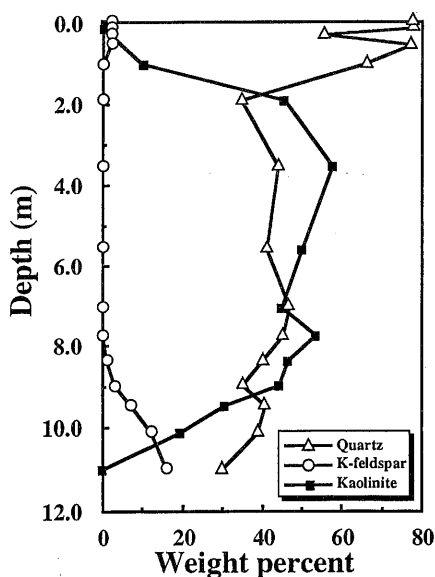


Fig. 5. Quantitative XRD analysis of the percentage of quartz, kaolinite and K-feldspar in the bulk Sparta, Georgia soil/saprolite plotted versus depth. Precision is  $\pm 5\%$  of the reported values. Accuracy is  $\pm 10\%$  of the reported values.

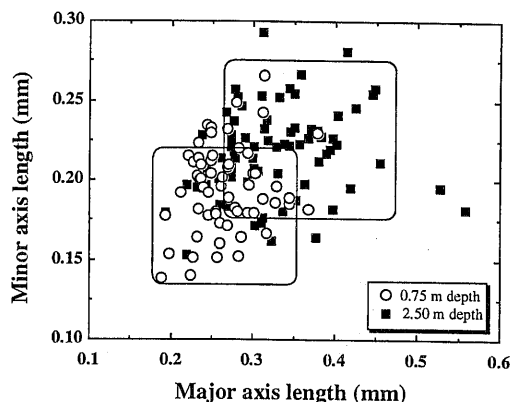


Fig. 6. Major axis lengths versus minor axis lengths of the fine-sand fraction for samples from 0.75 and 2.50 m depth in the Sparta, Georgia soil sequence. Boxes are intended to visually aid the differences in grain shape populations.

#### 4.2. Greene County soil/saprolite

Samples from the Greene Co. Highway 15 site were analyzed only for mineral abundances by XRD. Fig. 7a shows the overall outcrop profile. Percentages of quartz, kaolinite and K-feldspar corresponding to the ten sampling intervals in the 6.35 m profile are shown in Fig. 8. The maximum quartz abundances of 70 to 90% are similar to those observed in the surface veneer at the Sparta site. However, in contrast to the Sparta site, the Greene Co. site has a marked change in the soil fabric at a depth of 3.1 m. Above 3.1 m the soil has a lightly mottled appearance grading upward to the forest floor which has a thin organic-rich layer (Fig. 7b). Below 3.1 m depth there is a sharp contrast into a highly mottled saprolite (Fig. 7c), which then grades into the identifiable saprolitized textural features of the underlying Elberton Granite (Fig. 7d). The abrupt change in mottling texture is accompanied by mineralogical changes. Kaolinite increases from the surface to a depth of about 1.5 m (Fig. 8). At 3.1 m depth the percent of kaolinite is less than higher intervals, suggesting a transition into the C horizon. However, the amount of kaolinite then proceeds to increase with depth once again. The quartz profile also reflects these changes, where decreases in quartz likely are a result of the accumulation of authigenic and translocated clays typical of the B horizon in a solely residual weathering profile.



Fig. 7. Greene County, Highway 15 saprolite outcrop. (a) The upper 6 m are exposed as a result of a road cut. (b) Homogenized quartz-rich surface veneer is devoid of soil fabric or structure. (c) Sharp contact between mildly mottled zone above (showing evidence of iron mobilization from plant root exudates) and highly mottled zone below. (d). Saprolitized Elberton Granite. The vertical scale bar in (b), (c), and (d) is 5 cm.

The break in mottling intensity observed at 3.1 m is further supported by changes in the clay mineral fraction. Fig. 9 shows the relative area of the 14 Å (1.4 nm) peak observed by XRD in the  $<2 \mu\text{m}$  fraction. Given that the 14 Å (1.4 nm) peak is only a relative measure of HIV abundance, the trend shows a decrease in HIV with depth, and then an increase once beyond 3.1 m depth.

## 5. Discussion

The origin of quartz-rich veneers located on topographic highs of the Lower Piedmont province and their relationship to coastal plain development is not well understood. Potential interpretations for their genesis are several-fold and may include: (1) residuum of chemical weathering events; (2) flu-



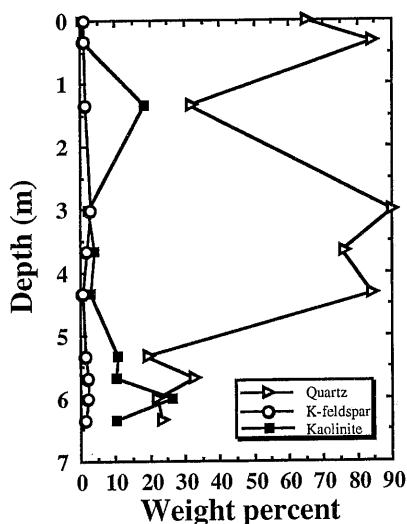


Fig. 8. Quantitative XRD analysis of the percentage of quartz, kaolinite and K-feldspar in the bulk Greene County, Highway 15 soil/saprolite plotted versus depth. Precision is  $\pm 5\%$  of the reported values. Accuracy is  $\pm 10\%$  of the reported values.

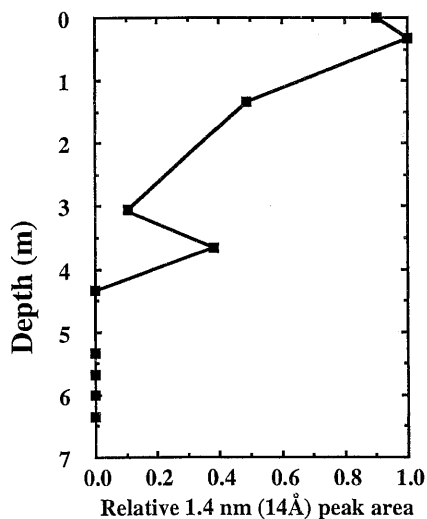


Fig. 9. Relative XRD area of 14 Å peak (hydroxy-interlayered vermiculite 001 reflection) from the  $<2 \mu\text{m}$  fraction. Samples were pretreated with cation saturated and subjected to an ethylene glycol atmosphere for 2 h at  $65^\circ\text{C}$ .

vial transport and deposition and subsequent landscape inversion; (3) eolian transport and deposition; and (4) vestigial marginal-marine deposits associated with high eustatic sea-level stands. Perhaps the most poorly constrained aspect of these surficial deposits is the age of deposition (if indeed they are depositional entities) and the length of time the surfaces have been exposed to weathering processes.

The mineralogical trends in both the Sparta and Greene County deposits strongly suggest polygenetic histories. Each case, however, is different. The presence of K-feldspar in the upper 1.35 m of the Sparta profile is difficult to explain unless it was deposited after the development of an initial weathering profile. The complete absence of K-feldspar and vermiculite in the 2 to 8 m depth interval indicates that the profile at some time prior to deposition of the quartz-rich veneer, experienced a period of intense chemical weathering. It has been postulated by several authors (e.g., Pickering and Hurst, 1989; Hurst and Pickering, 1989; Dombrowski, 1993) that the highly weathered Piedmont granites, such as the Sparta, are the source of the commercial Cretaceous kaolin deposits downdip of the Fall Line. The timing of this 'lateritic' weathering event (the term laterite is used as per Tardy, 1992) is currently unconstrained and if

indeed the Cretaceous kaolin deposits downdip were supplied by similar deeply weathered surfaces, then the Sparta deep weathering profile may be as old as Cretaceous. The more spherical and well-rounded sand populations in the uppermost section in association with the minor K-feldspar is consistent with the presence of an allochthonous veneer whose deposition post-dates the weathering of the sands below.

Pleistocene eolian deposits on the coastal plain were recognized by Carver and Brook (1989). These dune-type deposits are common along the left banks on the north or east side of streams from Georgia to Delaware. The suggested origin of these deposits is that they formed during the late Wisconsin stage of the Pleistocene epoch, when paleo-wind directions were stronger and more westerly than present day prevailing winds. Can this mechanism be invoked to explain the veneers observed at the Sparta and Greene County sites?

Most recently, Markewich and Markewich (1994) investigated in greater detail the morphology, distribution, age and sediment characteristics of Pleistocene inland dunes on the coastal plain of Georgia. Mineralogically, these dunes commonly contain K-feldspar and vermiculite. A comparison of grain size from the Sparta site and from coastal plain

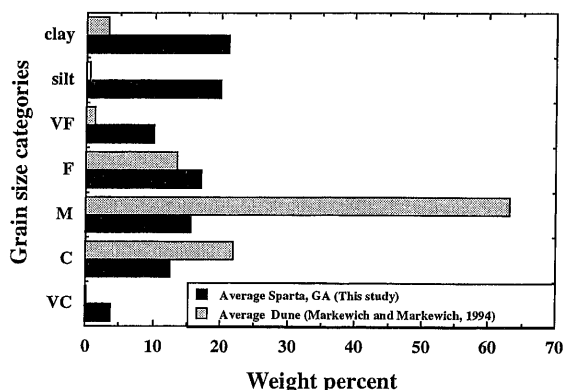


Fig. 10. Comparison of grain size distributions between Sparta, Georgia surface veneer and Pleistocene deposits from the Georgia coastal plain. Values plotted are the average of samples from approximately the upper meter for both sites. The abundance of silt and clay in the Sparta site suggests that its mode of origin is not eolian, whereas the absence of fine material in the south Georgia deposits strongly suggests dune deposits.

dune sites (Markewich and Markewich, 1994) was made to evaluate the difference in grain populations. Fig. 10 shows a comparison of the veneer (an average of the upper 1.35 m) from Sparta with a coastal plain dune deposit from the A horizon (see table 1 in Markewich and Markewich, 1994). The grain size distribution from the dune site shows the characteristic paucity of fine particles that result from winnowing during the eolian transport process. In contrast, the Sparta grain size population contains a much larger amount of fine sand, silt and clay, suggestive of a fluvial and/or marginal marine depositional mechanism. Combining the observation that the Sparta site is not located proximally north or east of a major river source, with the grain size data, it can be concluded that the Sparta veneer does not likely represent a dune deposit.

The Greene County sand veneer is proximally located to the east of the Oconee River and a large fluvial sand deposit (Fig. 1). The sandy profile examined in this study, however, is located about 31 m (100 ft) above the current river level. The elevational relationship suggests that the sand originally comprising the soil sand veneer on the hilltop likely was the source for the (Pleistocene?) fluvial sand deposits below. A detailed grain size and shape study would elucidate these relationships and aid in discounting an eolian origin for the Greene County deposit. Un-

fortunately, that information was not available at the time of this study.

Mineralogical evidence from the Greene County site, however, further suggests that an allochthonous cover exists over a preexisting surface. This evidence is found in the trend of HIV. HIV is typical in most acid soil systems and it has been found that moderately acidic conditions, low organic content, oxidizing conditions and frequent wetting and drying cycles are optimal environments for its formation (Barnhisel and Bertsch, 1989). Typically, HIV is greatest in abundance at the surface, whereas kaolinite dominates the subsurface B horizon. In fact, this trend is observed at the Sparta site. The abrupt increase in HIV, associated with the abrupt change in mottling density at 3.1 m, suggests a polygenetic history for this profile.

Implicit in these mineralogical and textural relations, therefore, is that the underlying horizons below 1.35 m and 3.1 m depth at the Sparta and Greene County sites, respectively, represent paleosols formed directly on parent Piedmont granites. Subsequent physical weathering (including clay translocation and plant root growth) and root exudate chemical modifications (i.e., phyto-mottling; see Figs. 3c and 7c) complicate the pedogenic history of each site. Redoximorphic features such as those described by Vepraskas (1992) may provide a model to explain some of the origin of the mottling features now seen (Figs. 3c and 7c). These are features that sometime form in soil/saprolites that are seasonally saturated with groundwater for sufficient periods such that the pore waters become anaerobic. When organic matter is present in the root macropore (in the form of plant exudate and/or residual root material) the carbon is oxidized and the iron is reduced locally. This redox reaction forms depletion coatings adjacent to the macropore by movement of  $\text{Fe}^{2+}$  out of the soil/saprolite matrix. The  $\text{Fe}^{2+}$  subsequently reoxidizes adjacent to the macropore where there is inherently less organic matter. This process results in an enrichment coating of iron oxides and hydroxides.

It is likely that current mineral and textural trends in both the Sparta and Greene County sites represent a composite of sedimentary and weathering events. A consequence of having polygenetic profiles is the difficulty in constraining the depositional age of the

veneers and the age, duration and climatic conditions for the weathering events. The observations made at our two study sites bring forward a question as to whether there is a coincidence of having greater saprolite thickness in places where allochthonous sand caps occur? This only can be addressed through more reconnaissance work in the Piedmont province. If this relationship is found, then other questions arise such as: Do the caps preserve deeply weathered early (Cretaceous?) formed profiles? Does the presence of sandy, highly permeable caps facilitate later weathering of the profile, or both? These postulations are complicated by the fact that the depth of a saprolite also is controlled by the density of micro-fracture permeability, which may ultimately be related to the cooling and subsequent metamorphic history of parent crystalline rocks within the Piedmont.

## 6. Conclusions

This study recognizes mineral and textural trends in ridge site soil/saprolite profiles on the Piedmont of the southeastern United States that have experienced complex depositional and pedogenic histories. It is suggested that these profiles contain paleosols that are a result of deep lateritic weathering, subsequent allochthonous deposition of a sedimentary cap and then further chemical weathering. This evidence comes from: (1) the Sparta site where there is an absence of labile feldspar at depth and a presence of K-feldspar near the surface within the same profile; (2) the Sparta site where there is more equant, spherical fine-sand-sized quartz grains in the top of the profile (relative to the more angular, less spherical fine-sand-sized quartz grains deeper in the saprolite); and (3) the Greene County site, where bimodal clay mineral abundance trends occur as a function of depth from the surface. This latter trend includes an antithetical relationship between kaolinite and HIV. HIV is abundant at the surface, decreases with depth and increases again at a sharp soil fabric interface (slightly mottled to highly mottled). The preliminary identification of these paleosols now make them good candidates for further investigation using soil micromorphology, comparative grain shape and size analysis and cosmogenic nuclide techniques.

Identification of Cenozoic sedimentary veneers

on the Piedmont has potential importance for land use practices, particularly from the standpoint of recognizing high permeability and porosity surfaces. Recognition of paleo-weathering surfaces also has important implications for our understanding of the record of geologic and paleoclimatic change in the southeastern United States. The goal of future research on these possible paleosols should be to constrain the depositional ages of the veneers and the age, duration and climatic conditions for past weathering events.

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