A Guide for Using Soil and Weathering Profile Data in Chronosequence Studies of the Coastal Plain of the Eastern United States

U.S. GEOLOGICAL SURVEY BULLETIN 1589–D

Prepared in cooperation with the U.S. Department of Agriculture, Soil Conservation Service

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Chapter D

A Guide for Using Soil and Weathering Profile Data in Chronosequence Studies of the Coastal Plain of the Eastern United States

By H.W. MARKEWICH, M.J. PAVICH, M.J. MAUSBACH, R.G. JOHNSON, and V.M. GONZALEZ

Prepared in cooperation with the U.S. Department of Agriculture, Soil Conservation Service

Physical and chemical data from chronosequence studies in the Coastal Plain of the Eastern United States are summarized and interpreted, and suggestions are made as to the data needed for a nonstatistical use of soil and weathering profiles in determining surface ages

U.S. GEOLOGICAL SURVEY BULLETIN 1589

PEDOLOGIC STUDIES IN THE EASTERN UNITED STATES: RELATIONS TO GEOLOGY

DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, Jr., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

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PREFACE

Some geologic investigations of Quaternary deposits, especially in the conterminous United States, have attempted to use relative degrees of weathering and soil formation to establish chronosequences of glacial and (or) fluvial landforms. Most studies have been in the glacial terrane of the midcontinent and the Western United States. Few such studies have been conducted in the Eastern United States, especially in the unglaciated Middle Atlantic and Southeastern States.

From 1979 to 1984, the U.S. Geological Survey and the U.S. Department of Agriculture's Soil Conservation Service conducted cooperative regional studies of the relations between soils and geology in the Middle Atlantic and Southeastern States. The primary goal of the studies was to determine if soil properties could be used to estimate ages of associated landforms. Coral, wood fragments, and peat were sampled from constructional landforms of fluvial and marine origin in order to estimate ages by isotopic analyses; these ages were then related to regional biostratigraphic and lithostratigraphic correlations. Specific site investigations were conducted on Pliocene to Holocene marine and fluvial terraces in the Atlantic and eastern Gulf Coastal Plains and the Appalachian Piedmont. Soils on granite, schist, and quartzite parent rocks of the Appalachian Piedmont were sampled to test the use of soil properties as indicators of soil age. Each chapter of this bulletin series examines the relation of soils to geology in a specific geographic area.

The cooperative study involved research scientists from both agencies and field personnel from State offices of the Soil Conservation Service. Responsibility for sample analysis was divided between the Department of Agriculture's National Soil Survey Laboratory in Lincoln, Nebr., and the U.S. Geological Survey in Reston, Va. This report was prepared by scientists from both agencies who participated in specific site investigations or in studies of pedogenic processes.

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A Guide for Using Soil and Weathering Profile Data in Chronosequence Studies of the Coastal Plain of the Eastern United States

By H.W. Markewich,[1] M.J. Pavich,[2] M.J. Mausbach,[3] R.G. Johnson,[3] *and* V.M. Gonzalez[2]

Abstract

Data from soil and weathering profiles developed on constructional landforms in the Coastal Plain province of the Eastern United States indicate that there are positive correlations between specific physical and chemical properties of altered parent material and ages of associated landforms. Diagnostic properties of profiles developed on essentially unmodified constructional surfaces include depth of oxidation, percentage of labile minerals, thickness of solum, thickness of argillic horizon, clay mass, clay mineralogy, rubification, iron chemistry, and bulk chemistry. The depth of oxidation, the thickness of the solum, and the total thickness of the argillic horizon increase with the age of the landform. The percentage of labile minerals decreases with age and increases with depth from the surface. With increasing age, a complex clay mineral suite is replaced by a mineral assemblage dominated by kaolinite. $(Fe_2O_3+Al_2O_3)/SiO_2$ shows a linear trend with the percentage of clay, the thickness of the solum, and the intensity of rubification. The weight percentage of SiO_2 and the clay mass increase with age in profiles younger than 1 Ma; SiO_2 decreases with age in profiles older than 1 Ma.

Pedons developed on the least-modified positions of morphostratigraphic units of fluvial and marine origin are described and sampled. Ages of these morphostratigraphic units have been determined by biostratigraphic and lithostratigraphic correlations and by isotopic analyses. The oldest recognizable morphostratigraphic units are estimated to be latest Miocene in age. Measurements of properties of the soil and weathering profiles associated with these morphostratigraphic units reflect the length of time that the surface has been exposed to subaerial alteration. Any age determined by these measurements is a minimum. Reliability and refinement of soil, and therefore of surface, age are dependent on the degree of modification of the surface, the number of profiles sampled per surface, and the number and type of analyses performed. There is an inverse relation between soil (surface) age and pedon variability, the younger surfaces showing more variability in pedon characteristics than the older surfaces do.

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INTRODUCTION

In the United States, chronosequence studies that use the degree of soil development as a means of establishing relative ages of surfaces and (or) associated parent material traditionally have been restricted to glaciated and (or) loess-covered terranes of the midcontinent and the alpine West. In the past 10 years, there has been an increase in the number of soil chronosequence studies in the unglaciated river valleys and marine terraces of California (Birkeland and others, 1987; Harden, 1987; Harden and others, 1986; Muhs, 1982; McFadden and Weldon, 1987), in the intermontane basins of the Western United States (Reheis, 1987), and in the loess-covered deltaic sequences of the lower Mississippi Valley (B.J. Miller, J.C. Lewis, J.J. Alford, and W.J. Day, unpublished field trip guidebook, 1982; Miller, in press). Regardless of the terrane, most data generated by these studies pertain to soils that are developed on parent materials younger than 1 Ma.

The predominantly offlap sequence of upper Cenozoic sediments of the Coastal Plain of the Eastern United States provides the opportunity to study soil and weathering profiles in the context of time or as chronosequences. This report summarizes data that have been generated through the study of such profiles developed on constructional landforms that are mappable morphostratigraphic units in the Atlantic Coastal Plain physiographic province of the Eastern United States. These morphostratigraphic units range in age from several thousand to several million years. These data can be quantified, as Harden (1982) has demonstrated with soils data elsewhere, and they can be valuable tools for the field geologist in establishing both relative and absolute ages of constructional morphostratigraphic units in a field area. The data also show that soil properties continue to change as long as pedogenic processes (geochemical and biogeochemical reactions) are active and soil is not removed by erosion.

The combination of adequate regional and local geologic mapping and numerous age determinations provides the basis on which personnel of the U.S. Geological Survey (USGS) and the Soil Conservation Service (SCS) undertook this long-term cooperative project. Its overall purpose was to study the properties of soil and weathering profiles developed in the Piedmont and Coastal Plain provinces of the Eastern United States. The results of this effort are being published as a series of chapters in USGS Bulletin 1589 (Markewich and others, 1986, 1987a, 1988). This chapter summarizes data from the Coastal Plain province and compares those data with other available published and unpublished data for the same region.

The primary purpose of this chapter is to present systematically obtained field and laboratory data from soil and weathering profiles[4] developed from deposits of known age and from morphostratigraphic units for which order-of-magnitude age estimates can be made on the basis of biostratigraphic or morphostratigraphic correlation. Rather than precisely defining the age relations of soil properties, its intention is to demonstrate that systematically assembled soil data do show age-related trends. Although this chapter is not a primer on soils for field geologists mapping upper Cenozoic deposits, its secondary purpose is to demonstrate the utility of "low-tech" data that can be easily obtained in the course of mapping or stratigraphic studies. Soil and weathering profile data are invaluable sources of information in age correlation and in reconstruction of the geologic and paleoclimatic history of an area such as the Coastal Plain of the Eastern United States.

Data presentation in this report follows the format of soil chronofunction data presented by Bockheim (1980), who compiled analyses of the changes of soil properties with time in the framework of the chronofunction as first defined by Jenny (1941). Bockheim's two major findings were (1) that the equation $Y=a+(b \log X)$ yielded the best correlation between soil properties and time and (2) that changes in some soil properties do not necessarily reach a steady state, as Nikiforoff (1949) suggested. Bockheim showed that soil properties plotted against the log of time provide statistically significant functions. Data herein are presented graphically so that they can be easily used by geologists and soil scientists in estimating ages of morphostratigraphic units in their field areas. These data do not come from a specific chronosequence, nor do they represent all types of analyses that could be valuable in a chronosequence study. They do, however, represent the simplest and, currently, the most reliable techniques for determining soil age relations for constructional surfaces in the Coastal Plain of the Eastern United States. The "Introduction" includes discussions of factors important in establishing chronosequences. Data for comparisons are presented graphically in "Discussion of Data."

[4]The soil in this study comprises the A and B horizons, referred to as solum by pedologists. The weathering profile includes the solum and the subjacent C horizon or parent material altered by oxidation, hydration, and other chemical weathering processes.

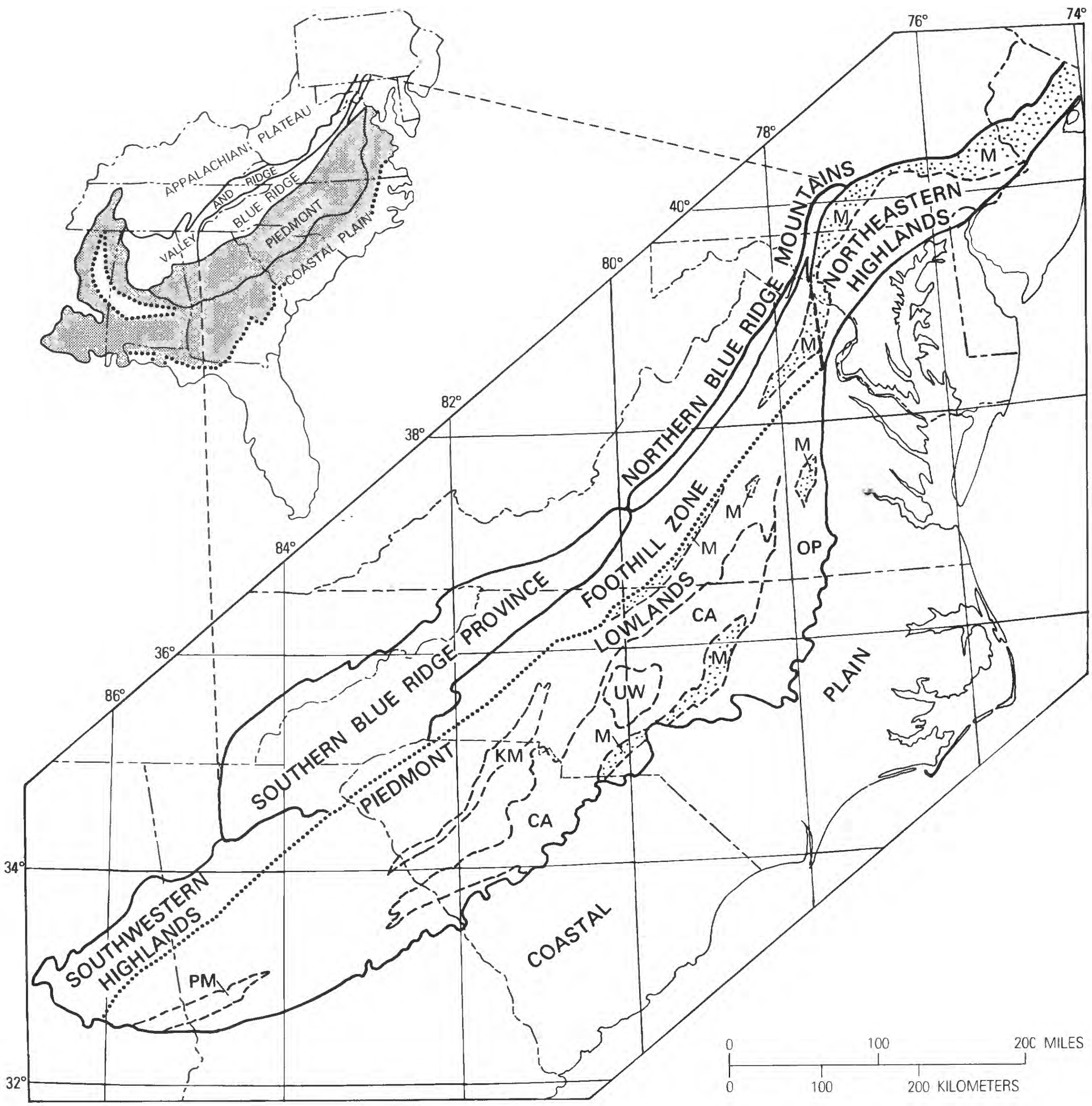
Acknowledgments

We would like to express our appreciation to J.P. Owens, R.B. Mixon, and J.T. Hack of the U.S. Geological Survey and to R.A. Daniels and Klaus Flach of the U.S. Department of Agriculture's Soil Conservation Service for their initiative in suggesting a cooperative project between the two agencies and for their encouragement throughout the study period. We also extend our thanks to the State Soil Scientists of Virginia, North Carolina, South Carolina, and Alabama for their assistance in the field and for the participation of Soil Conservation Service field personnel in sampling the study profiles. The paper benefited greatly from discussions with the late B.J. Miller, professor of agronomy at Louisiana State University in Baton Rouge, La.

Geologic and Physiographic Setting

The major physiographic provinces of the United States are shown in figure 1*A*. This study pertains to the Coastal Plain, the largest single physiographic province in the Eastern United States. Strata of the Coastal Plain of the Eastern United States consist of a series of gently seaward dipping marine and fluvial sediments that range in age from Early Cretaceous through Holocene. The lower Coastal Plain, specifically that part of the province less than 80 m in altitude, has post-middle Miocene to Holocene alluvial and marine strata exposed at the surface. Much of the middle and southeastern Atlantic Coastal Plain has been mapped in sufficient detail to regionally correlate the Quaternary strata. Isotopic, biostratigraphic, and lithostratigraphic analyses have provided a probable range of ages for many of the marine units (Blackwelder and Ward, 1979; Owens and Denny, 1979; Owens and Minard, 1979; Cronin and Hazel, 1980; Cronin and others, 1984; DuBar and others, 1980; McCartan and others, 1982, 1984; Mixon and others, 1982; Hazel, 1983; Mixon, 1985; Owens, 1989). Limited data are also available from alluvial terraces in both the Atlantic Coastal Plain and the eastern Gulf Coastal Plain (Markewich and Christopher, 1982; Colman, 1983; Mixon and others, 1989; Markewich, 1985; Soller, 1988).

Physiographically, the Atlantic Coastal Plain from New York through Georgia is a seaward-sloping plane about 1,600 km long and having a maximum altitude of 230 to 245 m and a maximum relief of 60 to 90 m. It is bounded



EXPLANATION

TALLAPOOSA-RAPPAHANNOCK LINE

SUBDIVISIONS OF PIEDMONT LOWLANDS

CA	Carolina slate belt	OP	Outer Piedmont of North Carolina and Virginia
UW	Uwharrie Mountains	KM	Kings Mountain belt
M	Mesozoic basins	PM	Pine Mountain belt

Figure 1A. Physiographic provinces of the Middle Atlantic and Southeastern United States and subdivisions of the Piedmont lowlands (from Hack, 1982). Stipple pattern denotes Mesozoic basins in the Piedmont lowlands. The Tallapoosa-Rappahannock line separates areas of higher and lower relief in the Piedmont physiographic province.

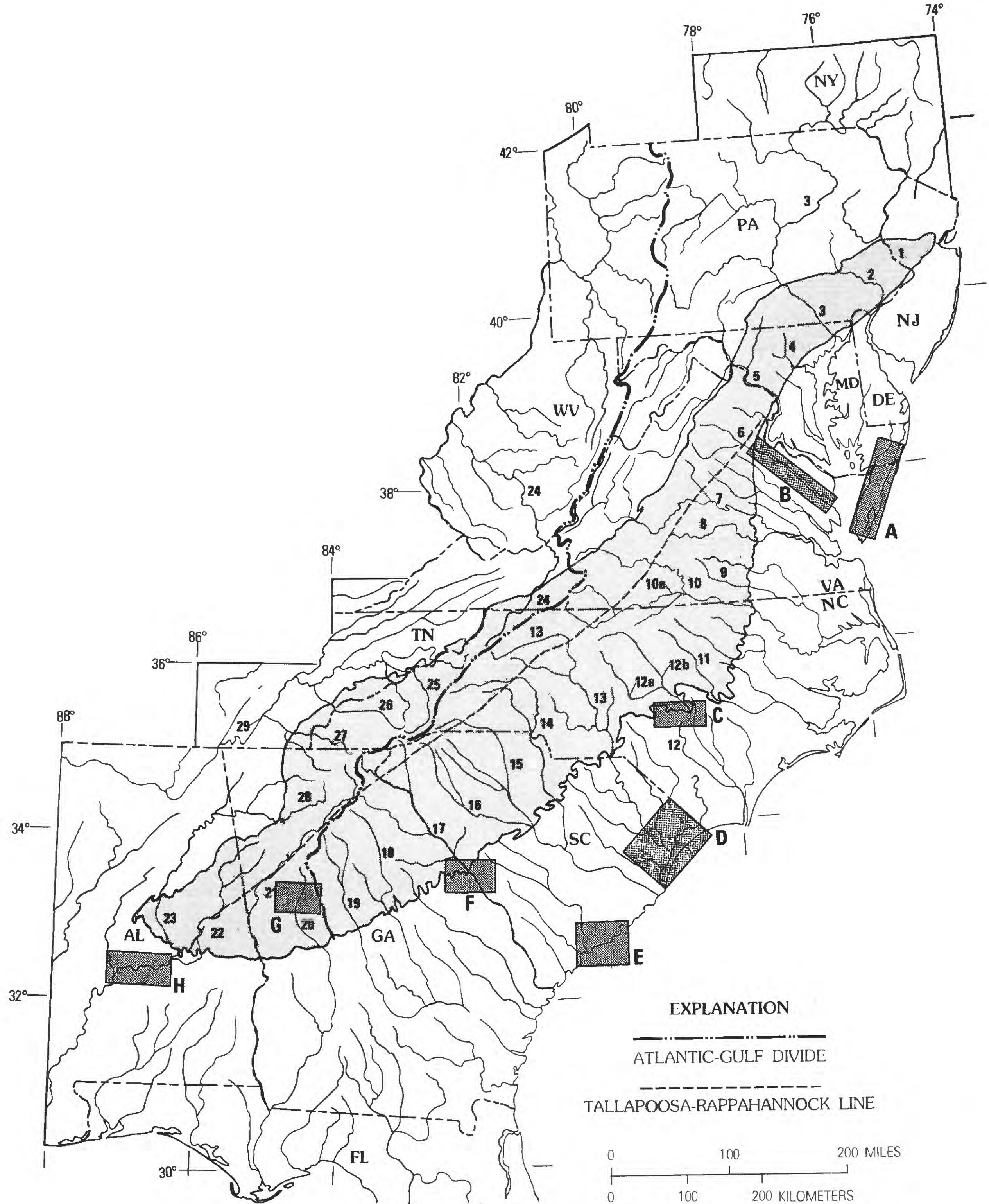


Figure 1*B*. Areas of soil sampling on a base map of major rivers of the Middle Atlantic and Southeastern United States (from Hack, 1982). Shaded area indicates Appalachian highlands. Sampling areas, shown by dark rectangles, are identified by letters, which correlate with those used in figures 3 through 9 and in the appendix. Rivers are identified by number: 1, Delaware; 2, Schuylkill; 3, Susquehanna; 4, Patapsco; 5, Potomac; 6, Rappahannock; 7, James; 8, Appomattox; 9, Meherrin; 10, Roanoke; 10a, Dan; 11, Neuse; 12, Cape Fear; 12a, Deep; 12b, Haw; 13, Yadkin; 14, Catawba; 15, Broad; 16, Saluda; 17, Savannah; 18, Oconee; 19, Ocmulgee; 20, Flint; 21, Chattahoochee; 22, Tallapoosa; 23, Coosa; 24, New; 25, French Broad; 26, Tuckasegee; 27, Hiwassee; 28, Etowah; 29, Tennessee.

on the east by the Atlantic Ocean and on the south by the Gulf of Mexico. The late Cenozoic strata of the lower Coastal Plain underlie numerous constructional landforms, such as alluvial terraces and barrier–back-barrier systems, that can be mapped as morphostratigraphic units (Thom, 1967a; Daniels and others, 1971, 1978; Owens and Denny, 1979; Owens and Minard, 1979; McCartan and others, 1984; Mixon, 1985; Mixon and others, 1989; Owens, 1989). Coastal Plain streams are of three types: (1) those that drain the Blue Ridge and (or) Valley and Ridge, Piedmont, and Coastal Plain physiographic provinces; (2) those that drain only the Piedmont and Coastal Plain provinces, and (3) those that drain only the Coastal Plain (fig. 1*B*). Provenances are similar enough to allow comparison of alluvial terraces among like drainage types.

Climate

The Coastal Plain of the Eastern United States (excluding Florida) extends from lat 30° to 40° N. and has a humid subtropical to humid temperate climate (fig. 2*A*). South of Maryland, the Coastal Plain is in the *thermic* soil temperature regime (that is, the mean annual soil temperature ranges from 15 °C to 22 °C at a depth of 50 cm, and the difference between mean summer and mean winter soil temperatures is greater than 5 °C) (fig. 2*C*). The northern part of the Coastal Plain, from Maryland to New York, is in the *mesic* soil temperature regime (that is, the mean annual soil temperature ranges from 8 °C to 15 °C at a depth of 50 cm, and the difference between mean summer and mean winter soil temperatures is greater than 5 °C).

The Coastal Plain is in the *udic* soil moisture regime (that is, in most years, the soil moisture control section is not dry in any part for as long as 90 days, cumulative). Rainfall is seasonal in the Coastal Plain of the Eastern United States; evapotranspiration is greater than precipitation for a minimum of 3 months a year.

Preliminary data from numerous research projects in various aspects of the agricultural sciences suggest that climatic variations in the Coastal Plain contribute to differences in the degree of weathering and in the degree of pedogenic development in parent materials of similar ages and having similar histories of subaerial exposure. In Maryland, at the northern end of the study area, soil temperatures (at a depth of 50 cm) range seasonally from 2 °C to 25 °C (Miller, 1974), the annual mean being 16 °C. These soil temperatures were taken over a 1-year interval. Study sites are located in Monmouth fine sandy loam at Upper Marlboro, Md. In southwestern Georgia, detailed soil temperature data are taken from Ultisols in a peanut field that was monitored for a USGS–Environmental Protection Agency cooperative study on pesticide migration. These soil temperature data range from 6 °C to 29 °C, the annual mean being 22 °C. The measurements were periodic (about three observations a week) recorded over a 3-year interval (S.C. Cooper, written communication, 1986). Since many pedologic processes are temperature dependent, it is significant to note that, even at a depth of 114 cm, the soil temperatures in southwestern Georgia are greater than 20 °C for 6 months of the year.

Variation in precipitation and in the seasonality of precipitation is extremely important in both weathering and pedogenic development. Precipitation in the Coastal Plain of the Eastern United States ranges from 1,000 to 1,600 mm/yr (Nichols and others, 1985) (fig. 2*B*). Seasonality of precipitation varies from 100 percent of total precipitation as rain in southern Georgia to 90 percent as rain and 10 percent as snow in Maryland. Both total precipitation and runoff have significant spatial variability in the Coastal Plain. (Fig. 2*D* shows the variability of these parameters for the State of Georgia.) Figure 2*B* shows the variability of precipitation for the entire Coastal Plain.

Differences in the physical and chemical characteristics of well-drained Coastal Plain soils developed in similar parent materials in similar geomorphic positions appear to be related to latitudinal position. Data suggest the presence of a transition zone between North Carolina and South Carolina. Weathering and soil development appear to have proceeded at a more rapid rate south of this transition zone. Profiles of similar ages, developed in lithologically similar parent materials, are more deeply oxidized and have greater solum thicknesses in South Carolina and Georgia than do their counterparts in Virginia and Maryland. Comparison of soil temperature data from southwestern Georgia and Maryland suggests that climatic causes for these variations probably include a higher mean annual soil temperature, a longer period of time each year during which mean annual soil temperatures are above 25 °C, a higher mean summer soil temperature, and higher mean soil temperatures at greater depths. In addition, comparison of runoff and rainfall (fig. 2*D*) suggests a very high loss of soil moisture by evapotranspiration in the more southerly States.

Weathering and Pedogenesis

Weathering

Weathering is generally considered to be the physical disintegration and chemical alteration of rock or unconsolidated sediments at or near the Earth's surface. The exact limits on the depth to which weathering occurs and on the types of processes included in the general term "weathering" are usually arbitrarily defined for a given region. There is, however, a consensus that weathering is a collective term for Earth-surface-temperature biogeochemical and physical processes (usually at $pH<7$ and $Eh>0$) that occur as a result of the subaerial exposure of rock-forming minerals to ground water.

JANUARY

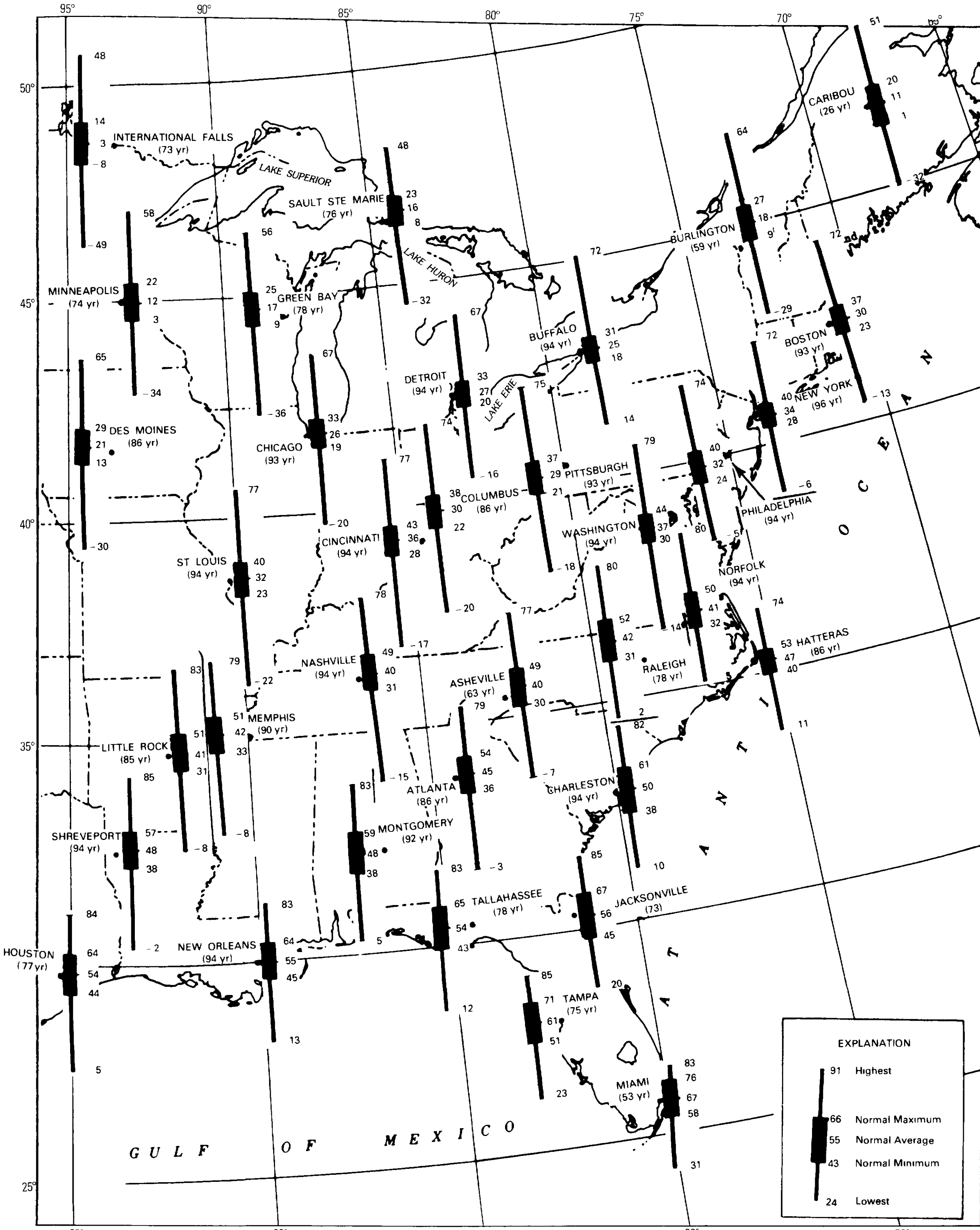
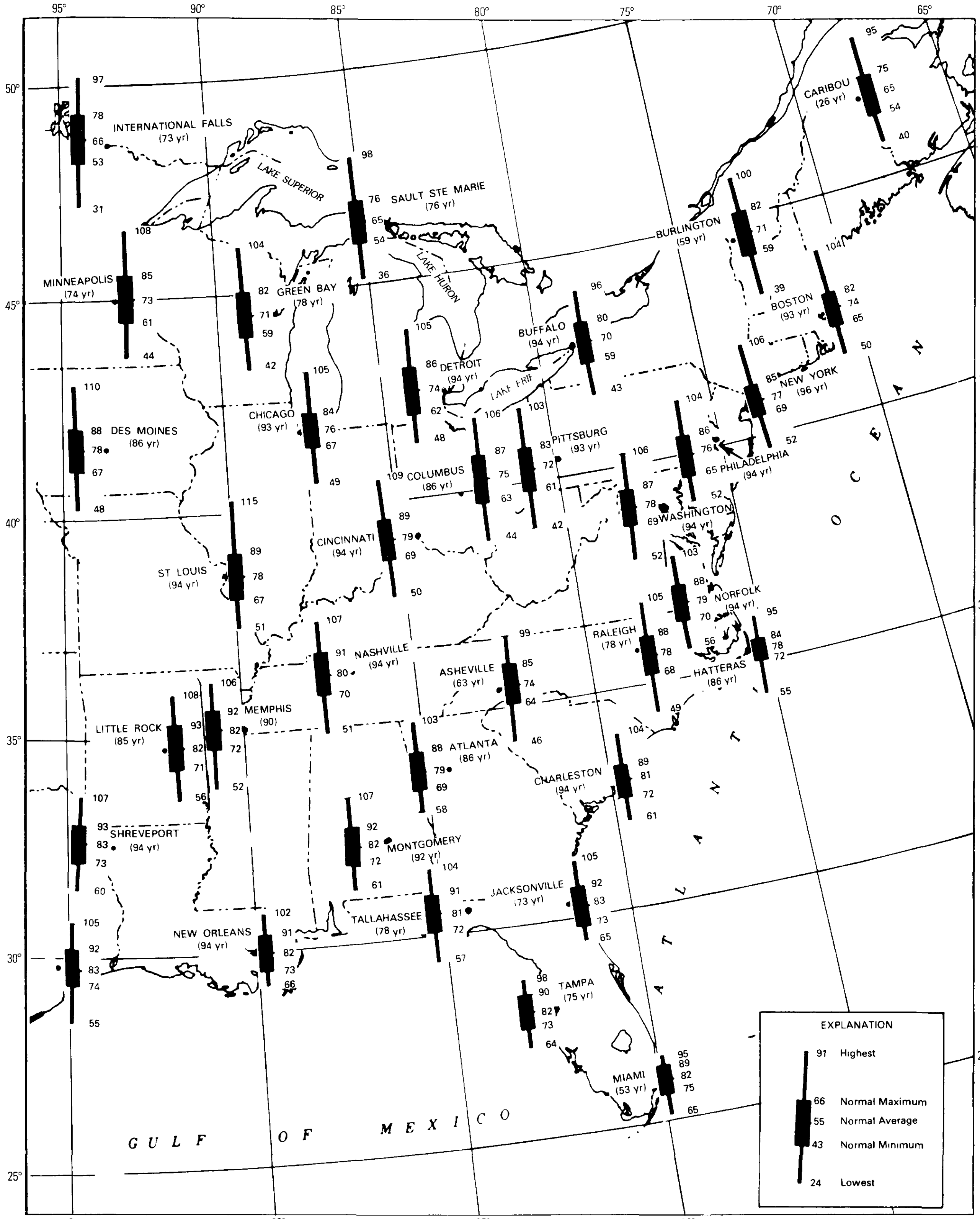


Figure 2A. Daily maximum, average, minimum, and extreme temperatures (in degrees Fahrenheit) for January and

JULY



July for the Eastern United States (from Ruffner and Bair, 1977).

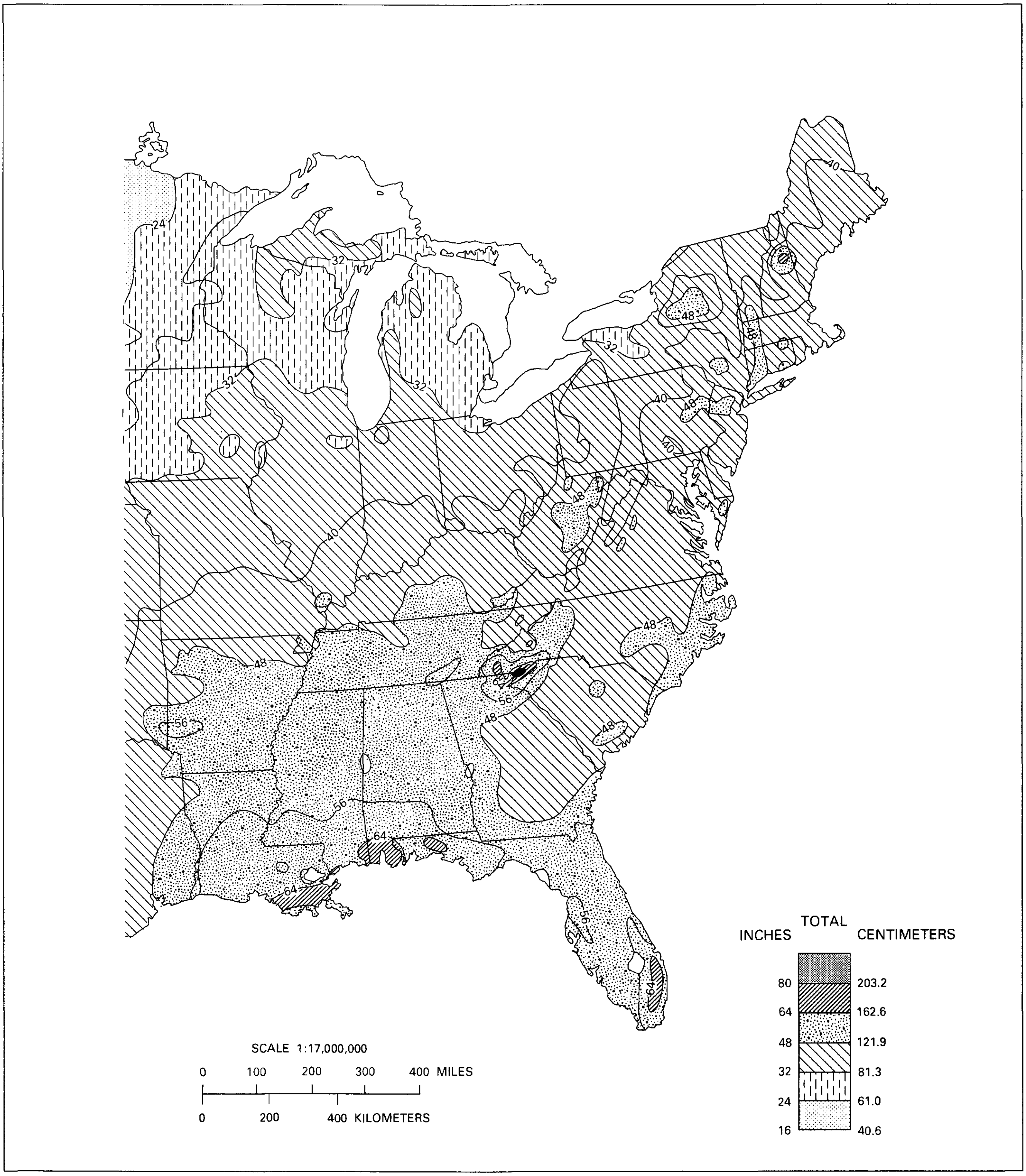


Figure 2*B*. Mean annual precipitation for the Eastern United States (from U.S. Geological Survey, 1970).

In the Coastal Plain of the Eastern United States, the dominant process involved in weathering is leaching or chemical dissolution by acidic, oxygenated rain and (or) ground water. This dominance of chemical processes in postdepositional alteration of sediments of the Coastal Plain of the Eastern United States (Owens and others, 1983) is the result of a humid temperate to subtropical climate in an area of relatively low relief (0–70 m/100 km^2), limited local

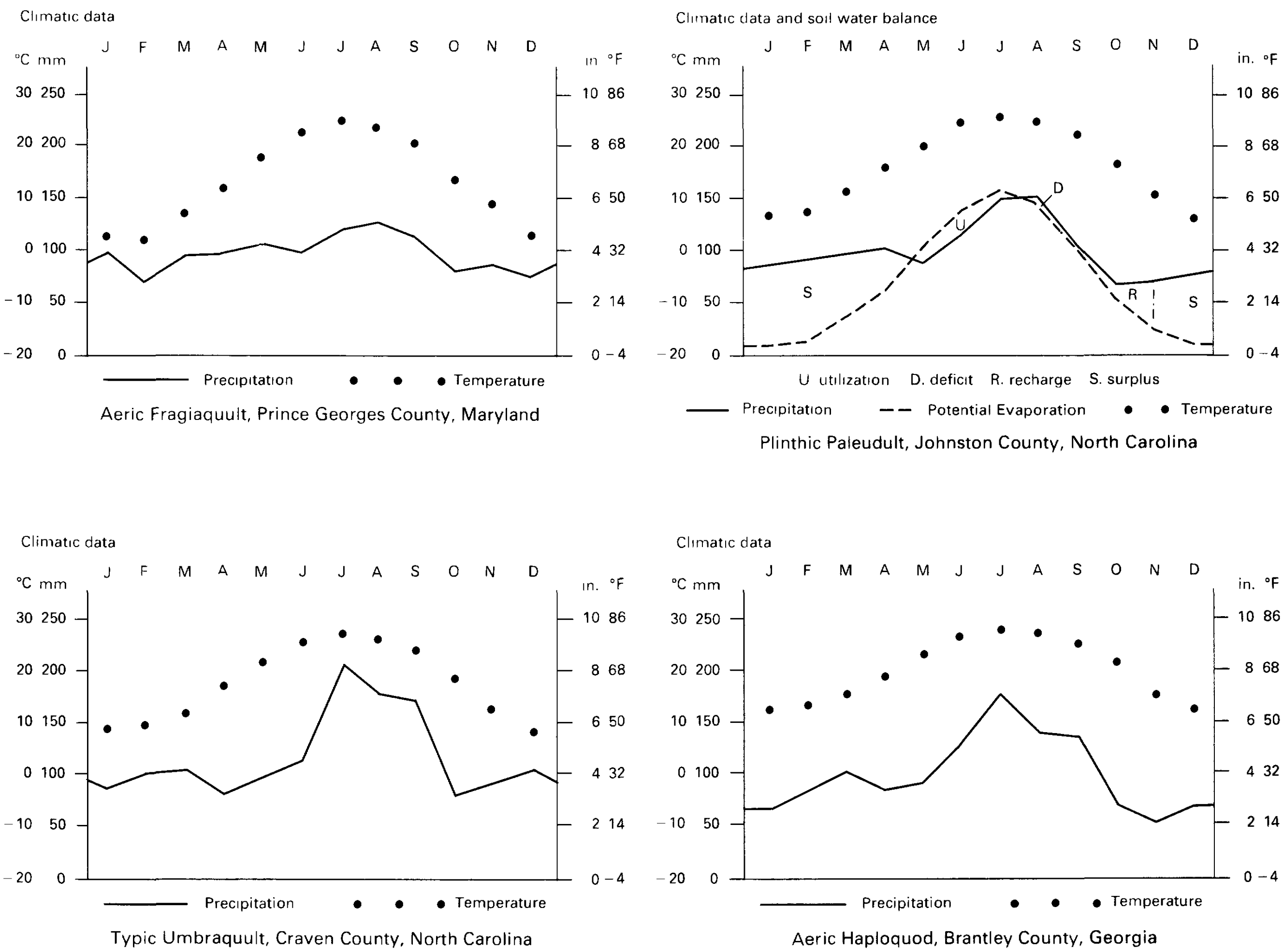


Figure 2C. Annual soil temperature and precipitation for sites in Maryland, North Carolina, and Georgia and soil water balance for a site in North Carolina (from Soil Survey Staff, 1975).

tectonics, and slow regional uplift (10–20 m/Ma). (Prowell (1988) has summarized tectonism in the Atlantic Coastal Plain region.) The rapid chemical alteration of parent material and the concomitant soil development result in a blanket of surficial material that has remnant characteristics of the original parent material and weathering characteristics that can be described and geochemically analyzed. Comparing units having similar origins but differing ages can provide a means of estimating relative ages and order-of-magnitude "absolute" ages for surficial units where other age-determining techniques are not applicable.

Owens and others (1983) and Soller (1988) have provided the only studies relating the degree of postdepositional weathering to compositional maturity and formation age. Other data are measurements of physical parameters that can be determined in the field. Many of the published and unpublished data on depth of weathering in the Coastal Plain are measurements of the depths of oxidation (Thom, 1967a, b; McCartan and others, 1984; H.W. Markewich, unpublished data, 1983–85). These data are summarized in figure 3.

Pedogenesis

Soil development or pedogenesis from a geologic perspective is in large part the result of dissolution of minerals in the parent material (for example, weathered rock or sediment), simultaneous formation of new minerals composed of the less soluble elements released from parent minerals, and physical rearrangement of the parent fabric and structure into soil fabric and structure. In the middle and lower Coastal Plain of the Eastern United States, soil development follows one of two distinctly different pathways, depending on parent material and local drainage. The less common pathway, occurring in very well sorted quartz sand, is toward development of a Spodosol (or of a spodic Ultisol) under conditions of low pH and high water table. The other, more common pathway in less well sorted

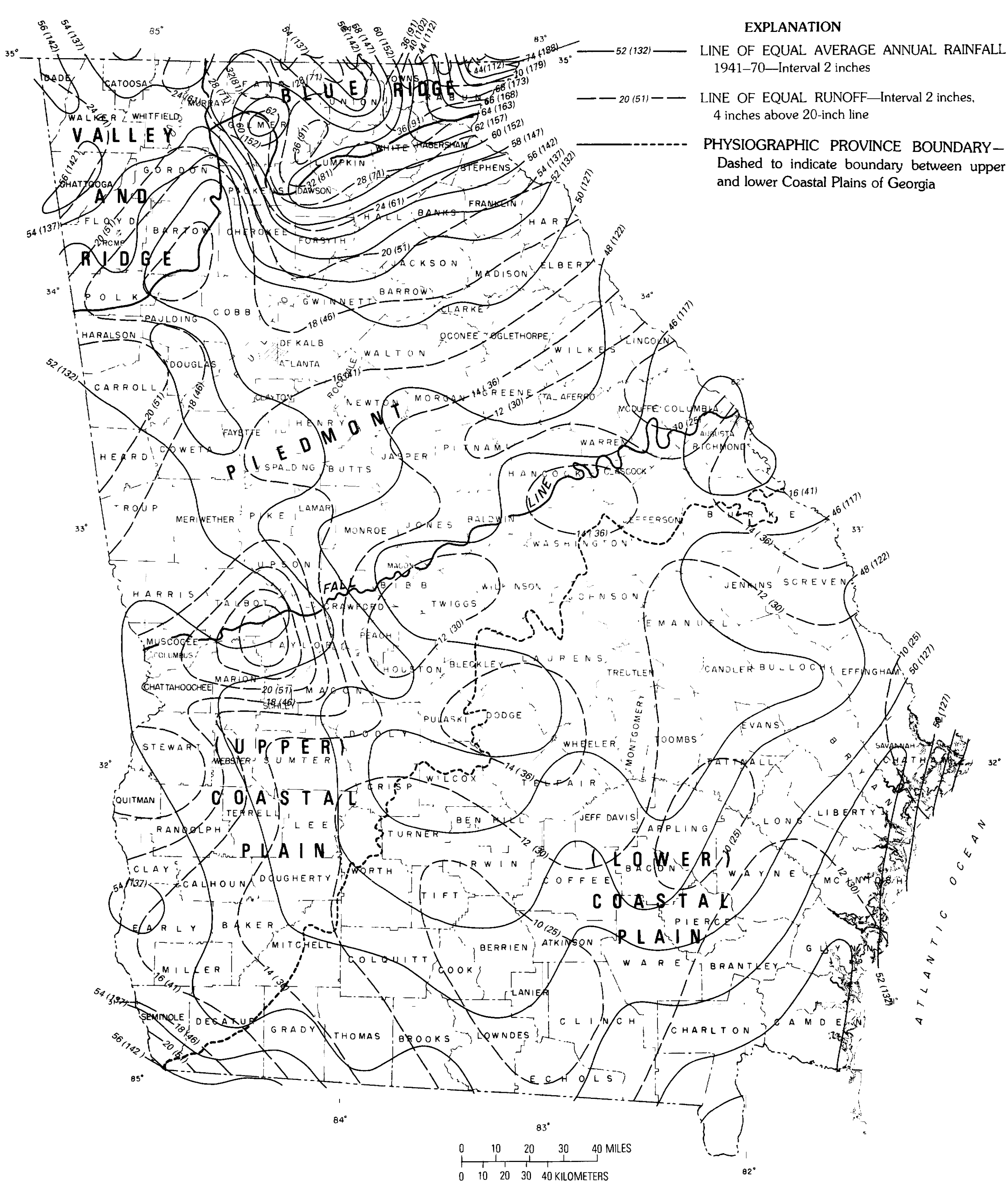


Figure 2*D*. Areal variation of average annual rainfall (solid lines) and runoff (dashed lines) in Georgia, 1941–70 (from Carter and Stiles, 1983). Values shown in parentheses are millimeters.

sediment of mixed mineralogy is toward an Ultisol in which a well-defined E horizon overlies an argillic B horizon that is commonly difficult to subdivide.

Coastal Plain soils that exhibit argillic horizons and that have developed on constructional landforms in sediments of mixed mineralogy and poorly sorted particle-size

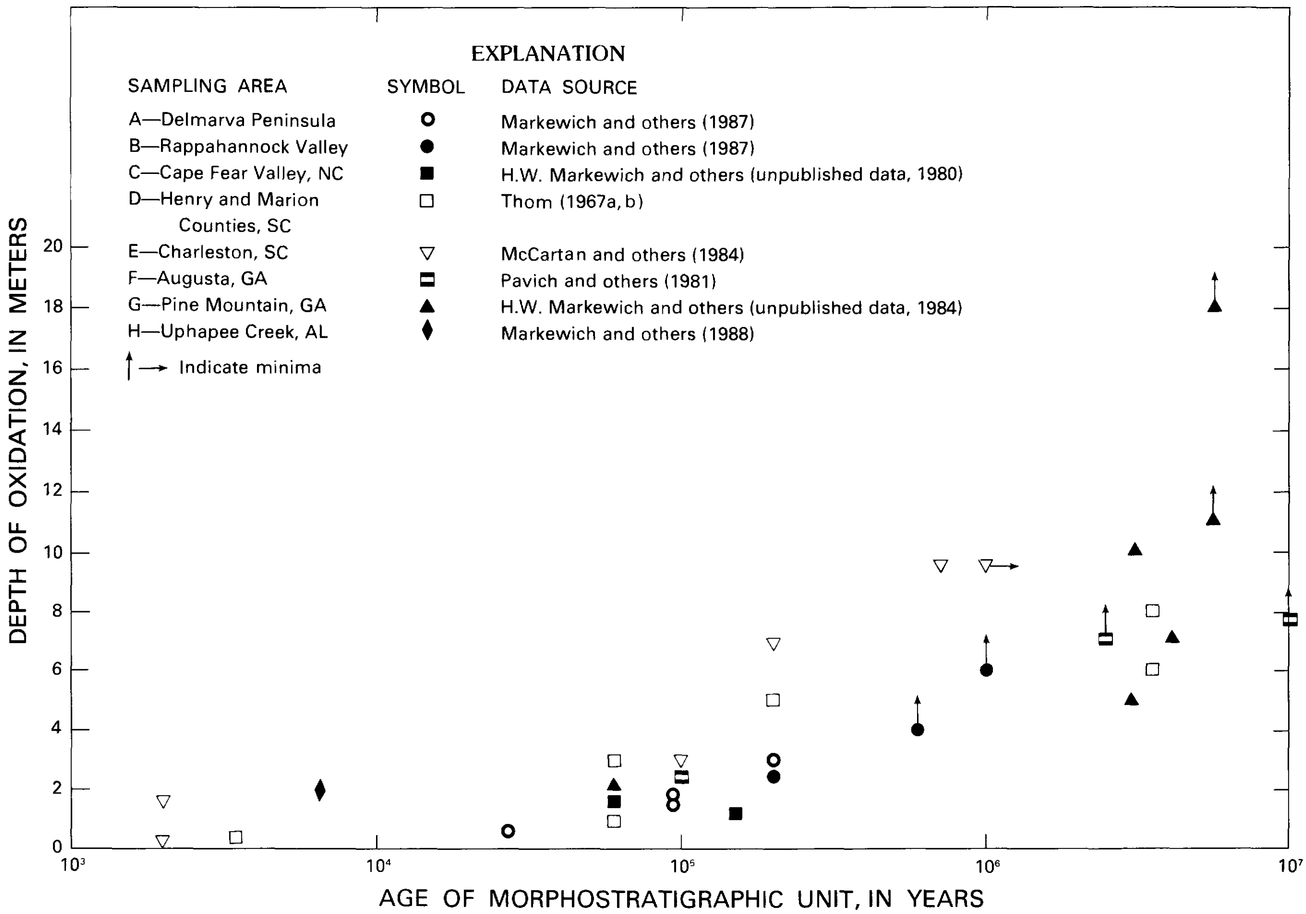


Figure 3. Depth of oxidation versus age of morphostratigraphic unit. Data are based on field exposures and drill holes. Data for sampling areas A through H are given in the appendix.

distribution are ideal for chronosequence studies. Soil development or evolution appears to progress from Inceptisol to Alfisol to Ultisol (which goes from Hapludult to Paleudult); this progression roughly corresponds to the increasing age of soil and the associated morphostratigraphic unit. Data suggest that quartzose or siliceous soils are extremely difficult to adequately describe and analyze and cannot easily be compared with soils of mixed mineralogy (Markewich and others, 1986). However, siliceous soils, which are commonly associated with marine barrier deposits, can be compared to one another and are discussed elsewhere (Markewich and others, 1986). Available published and unpublished data from argillic Coastal Plain soils developed in sediments of mixed mineralogy are summarized in figures 3 through 10. Published data used in constructing these figures are summarized in the appendix. Interpretations of the data and suggested limitations on the use of those data are discussed in "Data Comparison" on p. D12.

Field and Laboratory Methods

Chronosequence studies ideally should include at least three morphostratigraphic units that differ in age but have similar forms and origins. In the Coastal Plain province of the Eastern United States (fig. 1), the units most suited to chronosequence studies are alluvial terraces. There is enough similarity in terrace sediment provenances within subprovinces of the Coastal Plain that weathering and pedologic data can be compared between drainages (for example, between the Cape Fear and Savannah Rivers in fig. 1*B*). Morphostratigraphic features of marine origin, such as barrier–back-barrier systems, are more difficult to delineate and are spatially distributed over a much greater area than are alluvial terraces. Commonly, however, the greater the size of the feature, the greater the variation in parent material, in depth and type of weathering, and in degree and type of pedogenic development. Therefore, the number of samples needed to adequately characterize morphostratigraphic units of marine origin is greater than the number needed to characterize those that are fluvial in origin.

Wherever possible, soil and weathering profiles should be described and sampled as one continuous exposure (trench, core, outcrop, borrow pit, and so on). If an exposed cut face of a roadcut or borrow pit is used, then at least 0.5 m of material should be removed from the face before samples are taken to ensure that conditions are similar for those pedons sampled from recently opened trenches or from core and for those that have been exposed at the surface for a considerable length of time.

If the thickness of the sola or the depth of weathering exceeds 3 m, then backhoe excavation will not be adequate to obtain a complete profile. (This situation is common for morphostratigraphic units older than 1 Ma.) Several closely spaced, undisturbed cores should be obtained to acquire a volume of sample adequate for field description and laboratory analyses.

Profiles should be described and samples taken from several different topographic positions on the landform. These positions should include the middle of the upper surface of the landform (for example, near the drainage divide) and a place near but not on the edge of the landform. Obvious poorly drained low spots or closed depressions should be avoided.

Field descriptions of soil and weathering profiles such as those presented by Markewich and others (1986, 1987a, 1988) should include the following observations:

1. Soil horizonization, including structure, texture, color, clay skins, silt coatings, $CaCO_3$ content, mineralogy of sand-sized and coarser fractions, nodules, plinthite, pans, and mottles (see appendix for examples).
2. Position of water table, if evident.
3. Position on the landscape (interfluve, side slope, bottomland, and so on).
4. Surface modifications such as windblown sand (dunes and (or) sand sheets), periglacial features, closed depressions, and so on.
5. Depth of oxidation.
6. Layers of iron oxide, calcium carbonate, or calcium sulfate accumulation below the solum.
7. Detailed description of parent material(s), including mineralogy, fabric and foliation, and so on.
8. Estimate of the age(s) of soil and (or) parent material and a short explanation of the importance of the morphostratigraphic unit in understanding the geologic history of the area.

Laboratory analyses should include the following:

1. Particle-size distribution.
2. Clay mineralogy by X-ray diffraction.
3. Mineralogy of the heavy and light components of the very fine sand-sized fraction.
4. Bulk chemistry.

Standard laboratory soil characterization data (for example, cation exchange capacity, pH, water retention, and so on), differential thermal analysis, and trace-element analyses are not necessary for age comparisons but may be desirable for studies in weathering and soil-forming processes. Other laboratory data (see appendix) and X-ray diffraction are used in constructing figures 6, 8, 9, and 10.

DISCUSSION OF DATA

Data Comparison

Three requirements must be met before comparing soil and weathering profile data from constructional landforms in an eroding subaerial environment. The first requirement is that, at the highest uneroded positions on a morphostratigraphic unit, the rates[5] of chemical weathering and soil formation are greater than the rate of erosion for time periods approaching the total residence time of the depositional unit. The second requirement is that, in similar positions on similar morphostratigraphic units, the dominant processes active in weathering and soil formation are also similar. The third requirement is that pedogenic and weathering processes are continuous through time. For example, Daniels and others (1975b) noted that a change of drainage due to headward erosion changed the dominant processes affecting the distribution of iron. Observations in many areas indicate that sediments become more weathered (for example, rubification and depth of oxidation increase) and that soils become more developed the longer the morphostratigraphic unit is exposed to subaerial alteration. There is an undefined time limit or an unidentified position in the regional landscape at which the erosion rate accelerates and removes the entire unit.

Figures 3 through 8 show that a number of processes involved in weathering and soil formation are active through time. The slopes of the plots suggest that these soils continue to alter chemically and do not reach a static condition at any period of formation. The increase of hue (or rubification) through time (fig. 7) indicates the continuous formation and accumulation of iron oxyhydroxides in the solum. Data also indicate increases in the depth of oxidation (fig. 3), in the thickness of the solum (fig. 4), in the thickness of the argillic horizon (fig. 5), and in the clay mass (grams of clay per square centimeter of solum) (fig. 6) with increasing age of the morphostratigraphic unit. These parameters provide several means of estimating the rate(s) of parent material alteration throughout the late

[5]The rate of soil formation or erosion can be expressed in units of length-time (that is, in centimeters per year beneath the original surface) or mass/area-time (that is, mass of soil component summed through a unit area of the solum normal to the soil surface). These two parameters are related by bulk density (mass/volume): $cm/yr \times mass/cm^3 = mass/cm^2 \cdot yr$.

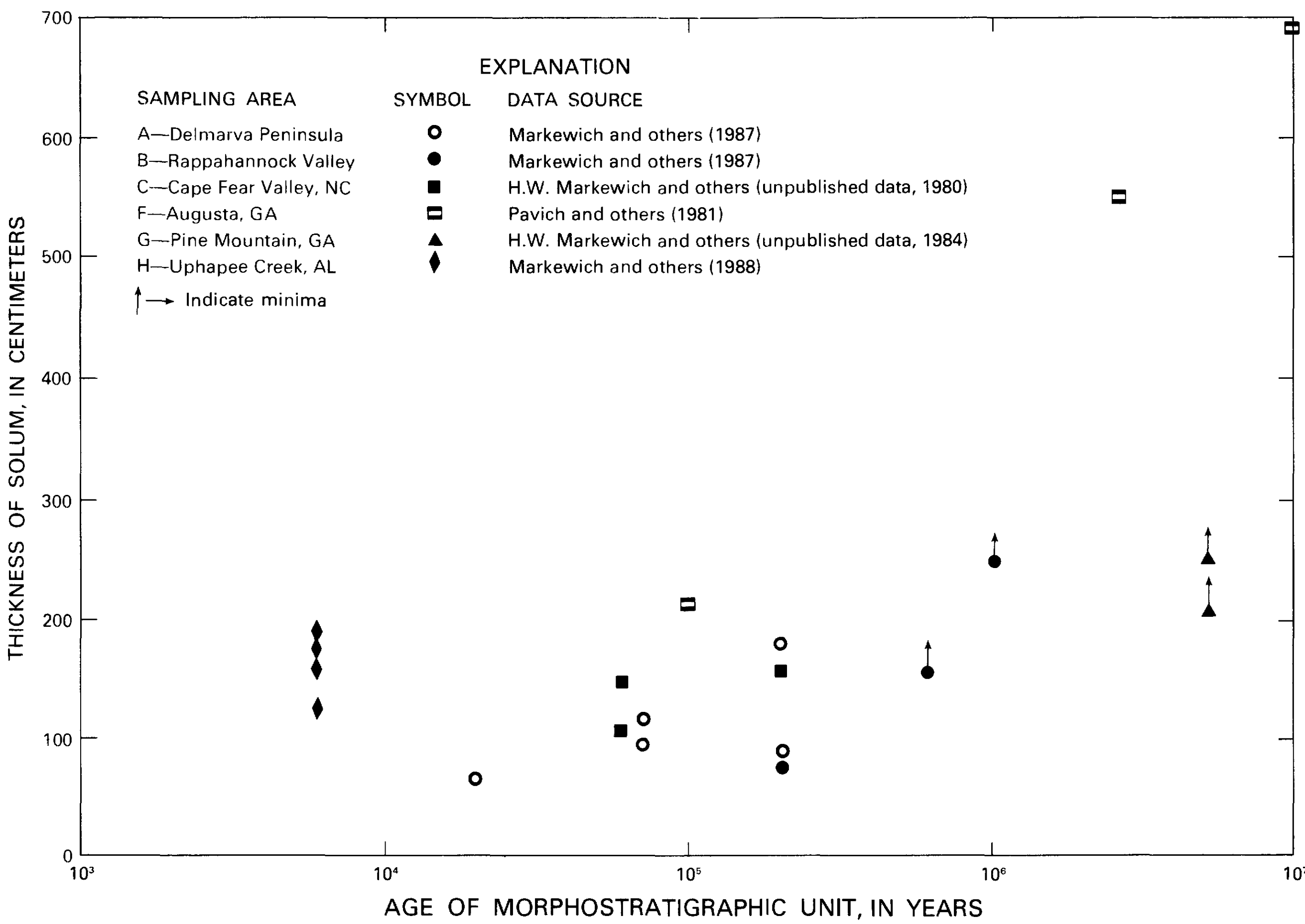


Figure 4. Thickness of solum versus age of unit. The solum comprises the A and B horizons of the weathering profile. Thicknesses were measured on outcrops or in backhoe excavations. Minima are indicated where the base of the B horizon was not reached in sampling. Data for sampling areas A through C and F through H are given in the appendix.

Cenozoic. The data have not been treated statistically by regression analysis because of the small number of pedons sampled and the age uncertainties. Continued investigations may provide enough data for rigorous statistical analysis. Switzer and others (1988) have discussed appropriate statistical methods.

These graphs can be considered to be only semiquantitative because of uncertainties about absolute ages and, in some cases, because of incomplete exposure of the entire weathering profile. For example, depth of oxidation values (fig. 3) are minima estimated or measured on outcrops, cores, or borings for chromas greater than four and (or) hues redder than 10YR. Where an age range is used for the age of a depositional unit or soil, the point is plotted in the middle of that age range. For example, the Joynes Neck site (area A, fig. 1*B*; A-2, appendix) may range from 60 to 125 ka (Mixon, 1985). It is plotted at 92.5 ka. The purpose of this plot is to show that the depth of oxidation increases with each order-of-magnitude change in age. As Bockheim (1980) discussed, climate also appears to have a significant effect on the depth of oxidation.

A detailed comparison of the data has shown that local variations in parent material, drainage, and landscape position correlate with differences in soil and weathering profiles (Markewich and others, 1986, 1987a, 1988). Figures 9*A* and *B* show solum thickness and clay mass plotted against maximum $(Fe_2O_3+Al_2O_3)/SiO_2$ for several 200-ka units and thus show the range of values for profiles developed at different sites under different drainage conditions. The variance in these values shows that, before soil and weathering profiles can be used to estimate relative or absolute age, several sites must be compared to adequately characterize the unit. **Knowledge of regional stratigraphy and local geologic setting is needed to accurately interpret the derived data.**

Clay mineral data, summarized in figures 10*A*, *B*, and *C*, indicate that in situ formation of soil clay minerals is a dominant process in the formation of argillic horizons. The formation of clay by alteration of aluminosilicate parent minerals occurs simultaneously with illuviation. In situ formation of clay is indicated by the dominance of pedogenic 14-A hydroxyinterlayered vermiculite in the

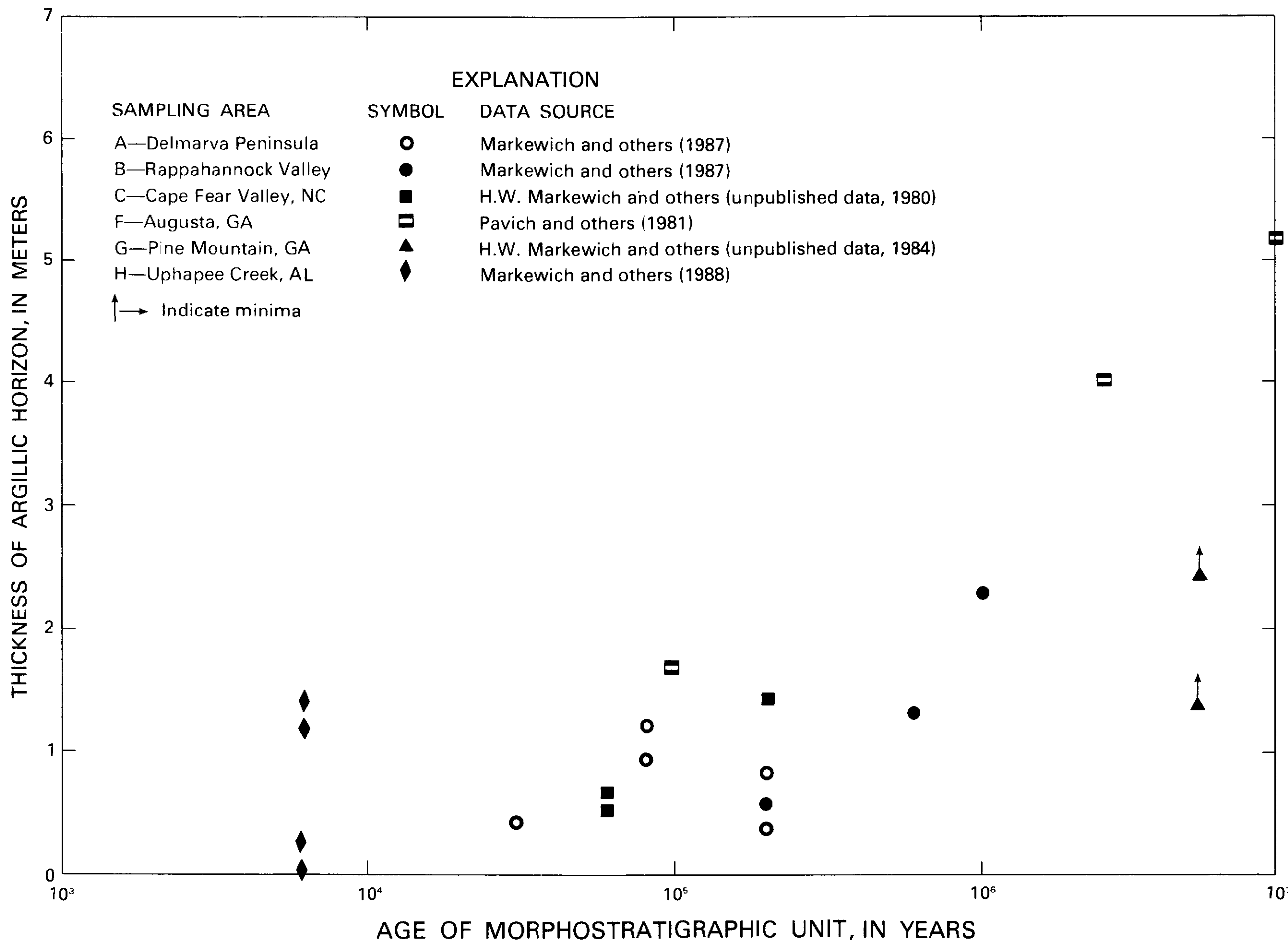


Figure 5. Thickness of argillic horizon versus age of unit. Argillic horizons are B (Bt) horizons as defined by the Soil Survey Staff (1975). Data for sampling areas A through C and F through H are given in the appendix.

soil and in the upper part of the weathering profiles (profile A–3, fig. 10*A*). Mineralogy of the clay fraction changes from a more complex mixed mineralogy (kaolinite, vermiculite, and gibbsite) to a simpler, dominantly kaolinitic mineralogy through time. This transition in the mineralogy of the clay fraction is particularly evident in soils 1 Ma old or older (compare profiles B–2 and B–3, fig. 10*A*).

Weathering and Pedogenesis

Comparison of measured physical and chemical parameters of soil and weathering profiles is a useful tool in estimating the ages of morphostratigraphic units on the Coastal Plain of the Eastern United States. Comparisons are valid if data are from units that (1) are composed of similar parent materials, (2) are in similar positions in the local landscape, and (3) have developed under similar climatic conditions. The following three sections discuss some of the effects that these factors can have on the pedogenic development of Coastal Plain soils.

Parent Material

Quartz sand.—Composition of the parent material is an important component in both the rate and the type of weathering and pedogenesis. Particularly important in Coastal Plain soils is the percentage of quartz sand in the parent material and the homogeneity of sorting of the unit. For example, a thick (more than 3 m) surface unit consisting of nearly pure quartz sand can weather rapidly and have no pedogenic development other than lamellae or staining caused by iron oxyhydroxides. Weathering of extremely permeable quartz sand commonly results in Entisols (commonly Psamments or Grosspsamments) or Ultisols of low clay content developed on surfaces that are older than 1 Ma (Markewich and others, 1986; Soil Survey Staff, 1975). Commonly, soils older than 1 Ma have been mapped as Ultisols exhibiting sandy surficial horizons. These soils can be representative of the few meters at the surface of a much more deeply weathered unit (see Gamble (1965) and Markewich and others (1986) for data from soils having these characteristics).

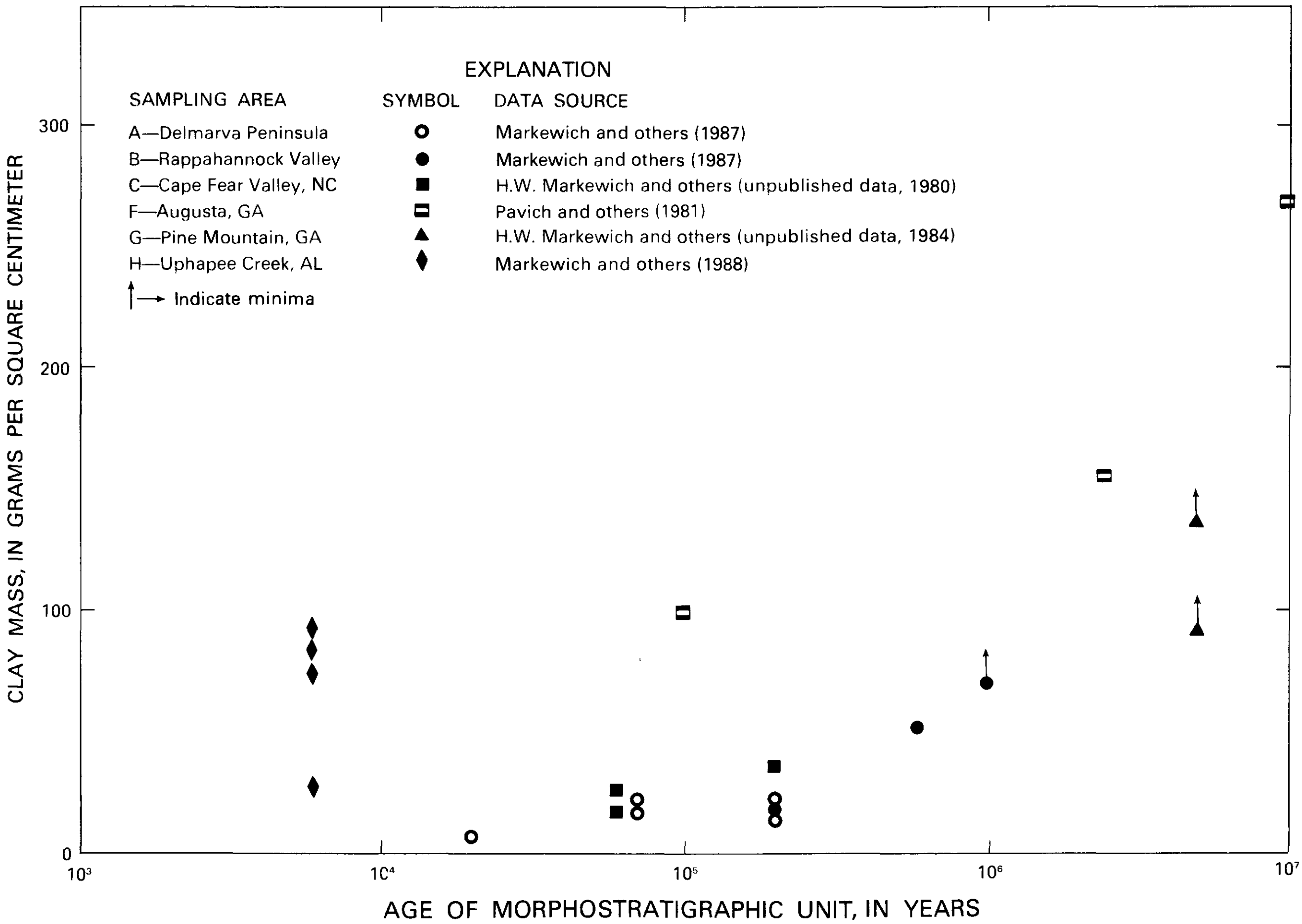


Figure 6. Clay mass versus age of unit. Clay mass (measured in grams of clay per square centimeter) is the product of the bulk density (measured in grams per cubic centimeter) times the percentage of clay times the thickness of the horizon from each horizon of the Bt in the solum. Minima are given where the base of the Bt was not reached during sampling. Data for sampling areas A through C and F through H are given in the appendix.

The percentage of very fine sand-sized quartz is important to the formation of silt-sized and coarse clay-sized quartz in the soil. Numerous articles have been written on the pedogenic origin of quartz silt (Vita-Finzi and Smalley, 1970; Pye, 1983; Nahon and Trompette, 1982; M.J. Pavich, unpublished data, 1982). There has also been some discussion in the literature on whether the formation of silt-sized quartz is an important process in the development of argillic horizons (Markewich and others, 1987a) and (or) whether the presence of significant amounts of silt- and clay-sized quartz in a profile is indicative of eolian activity (Foss and others, 1978; Soller, 1988).

Interlayered sand and clay.—Clay interlayers in marine terrace sediments commonly restrict the downward percolation of water, the result being a locally high water table and the development of Ultisols exhibiting attenuated profiles, mottled clay-rich zones, and horizons having uncommon characteristics and either diffuse or very abrupt boundaries. Spodic horizons commonly are present in the sandy epipedon above the clay lenses or beds (Markewich and others, 1987a).

Pyrite.—The effect of parent material composition on soil chemistry is readily apparent in the aluminum saturation of the soils developed in Holocene-age alluvium on the terraces of Uphapee Creek in east-central Alabama (Markewich and others, 1988). This saturation is apparently a direct result of "natural" acidification caused by the release of $SO_4^{=}$ by the oxidation of pyrite, the formation of sulfuric acid, and the mobilization of aluminum from parent minerals. Flood water, shallow subsurface water, and rain water react with the pyritiferous and lignitic Tuscaloosa Formation (Cretaceous) exposed in the stream channel and along the valley walls (Markewich and others, 1988) to produce low pH solutions that increase the solubility of

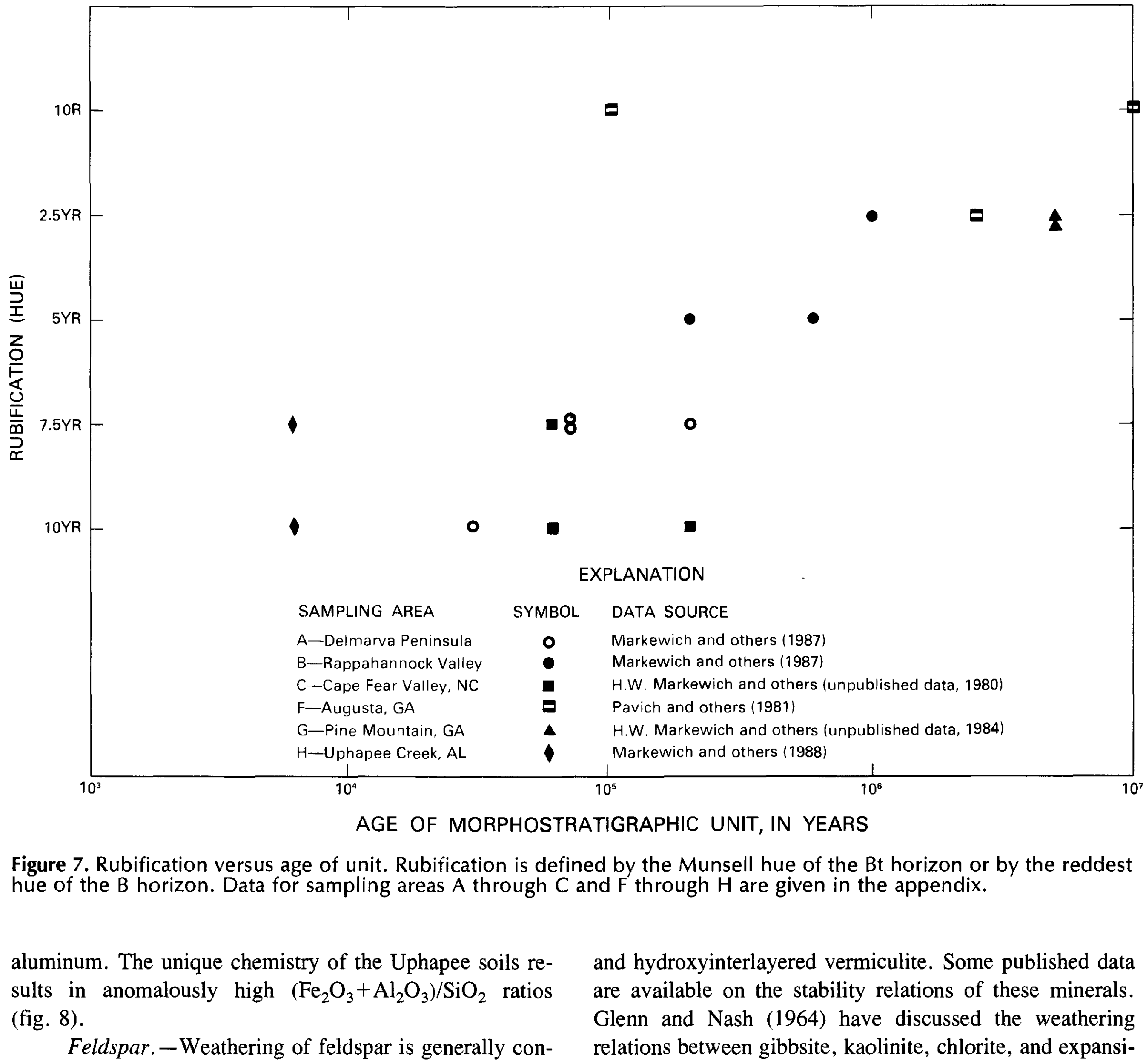


Figure 7. Rubification versus age of unit. Rubification is defined by the Munsell hue of the Bt horizon or by the reddest hue of the B horizon. Data for sampling areas A through C and F through H are given in the appendix.

aluminum. The unique chemistry of the Uphapee soils results in anomalously high $(Fe_2O_3+Al_2O_3)/SiO_2$ ratios (fig. 8).

Feldspar.—Weathering of feldspar is generally considered to be the dominant process by which kaolinite and gibbsite are formed in the zone of subaerial alteration. Following the work of Jackson (1965), many studies have dealt with the generation and evolution of clays and oxyhydroxides as products of pedogenic processes (Kittrick, 1986; Torrent and others, 1980). Plagioclase feldspar alteration is significant because of rapid dissolution kinetics relative to other aluminosilicates (for example, muscovite and potassium feldspar) and quartz. Silica release to solution has been studied by Holdren and Berner (1979) and White and Claassen (1979). In addition to reaction kinetics, drainage conditions appear to be a dominant factor determining the removal of dissolved silica. Silica removal is necessary for producing amorphous aluminum hydroxide or gibbsite (Kittrick, 1969).

Gibbsite is one of the three most common minerals found in clay-sized (<2 μm) fractions of weathered soils in the Southeastern United States; the other two are kaolinite and hydroxyinterlayered vermiculite. Some published data are available on the stability relations of these minerals. Glenn and Nash (1964) have discussed the weathering relations between gibbsite, kaolinite, chlorite, and expansible silicate clays in the Mississippi Coastal Plain. Weaver (1975) has documented the presence of quartz coexisting with gibbsite in Brazilian soils. Karathanasis and others (1983) have provided an excellent summary of the problem of the stability relations of quartz,hydroxyinterlayered vermiculite, and gibbsite.

The presence of labile aluminosilicate minerals and drainage conditions both appear to be important controls on the formation of gibbsite. Despite evidence that gibbsite can form in less than 1 ka (Loughnan, 1969) in a well-drained environment, it has been used as an indicator of age and of climatic change for a number of Coastal Plain units (Clarke, 1971; Owens and Minard, 1979; Owens and others, 1983; Soller, 1988). Investigations of gibbsite formation indicate that it may be formed directly and rapidly by weathering of feldspar in tropical, subtropical, and temperate latitudes (Watson, 1962; Bakker, 1967; Green and Eden, 1971; Lodding, 1972). Data from these studies suggest that

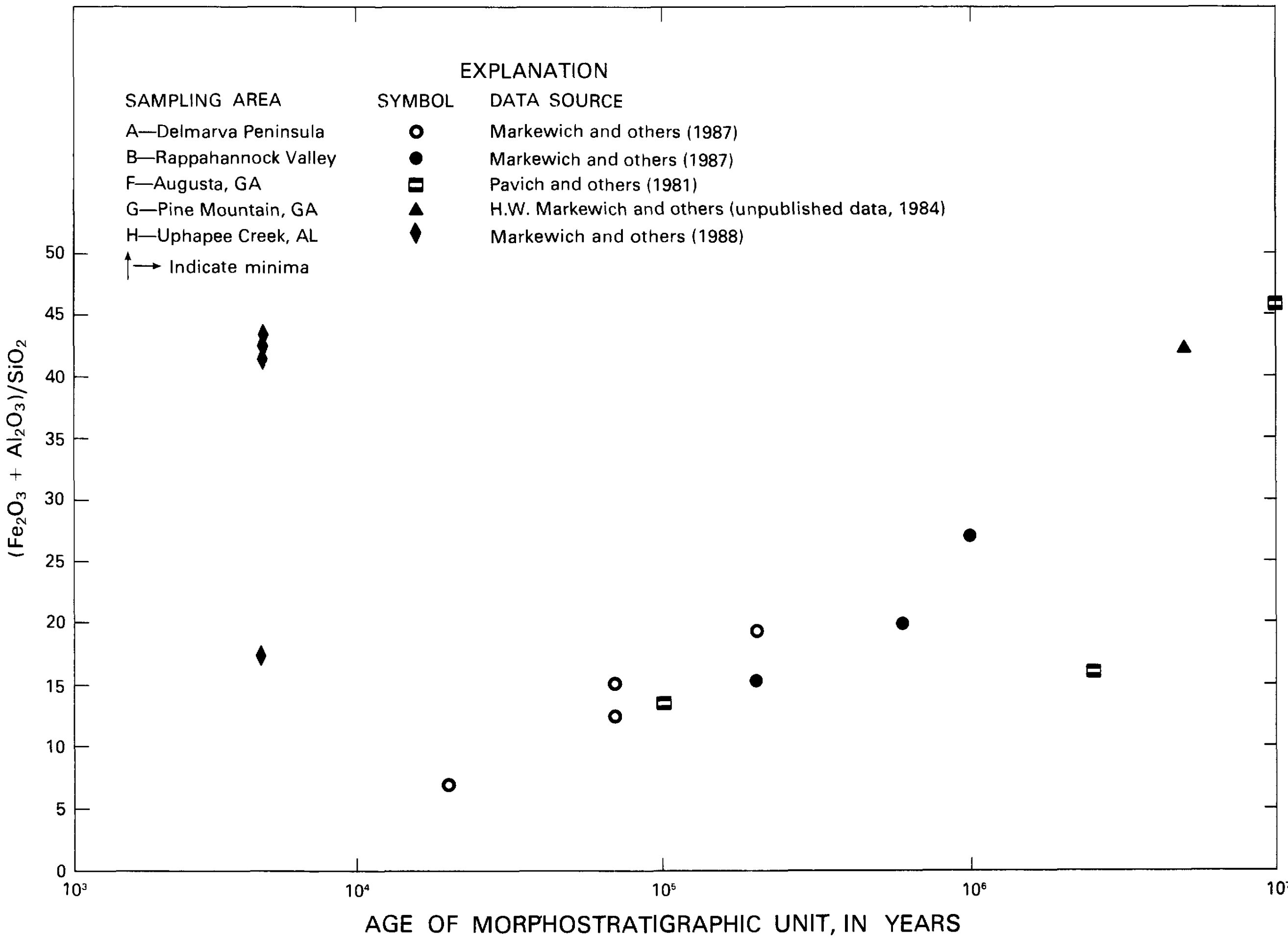


Figure 8. Percentage of $(Fe_2O_3+Al_2O_3)/SiO_2$ versus age of unit. This ratio is determined from the major-element chemistry of the Bt horizons or of the most clay-rich part of the B horizon. Data for sampling areas A, B, and F through H are given in the appendix.

gibbsite formation in soils is specifically related to the mineralogy of the parent material and to local drainage conditions and becomes relatively less abundant in soils as weathering proceeds and clay phases are produced.

Heavy minerals.—Owens and others (1983) and Soller (1988) have published the only available data on using heavy minerals to estimate relative ages of deposits in the Coastal Plain. Both used heavy mineral data in conjunction with the clay mineralogy of deposits to determine if the weathering profiles developed on units were adjusted to the ages of those units. The conclusion of both papers was that heavy mineral data could be used to establish relative ages if care were taken to compare deposits of similar provenance and if other mineralogical data were available. Sudom and Arnaud (1971) provided a general discussion of the use of quartz, zirconium, and titanium as indices in pedological studies. The reader is referred to that paper and to papers by Owens and others (1983) and Soller (1988) for a more complete review of the method and its reliability.

Geomorphic Position

Edge effect.—Variations in weathering and pedogenic development dependent on geomorphic position were discussed by Daniels and Gamble (1967). To emphasize the importance of the "edge effect" in pedogenic development on alluvial and marine terraces, they presented data from pedons developed in different positions on the same geomorphic surface. Pedons developed near an erosional "edge," or on an original edge slope of a constructional landform, are thicker than pedons developed near the center of the terrace back-barrier flat or on the broad, flat barrier ridge; pedons situated on or near such an edge are also oxidized to greater depths. Colman (1983) showed the relation of terrace steps and risers to colluvial sediments generated during progressive changes in the morphology of terraces along the Rappahannock River in southeastern Virginia. The older the surface, the more dissected and modified the original surface and the greater the possibility of composite surficial units. For example, pedons on the inner edge of a terrace are commonly developed on parent material that is a combination of colluvium from the next higher terrace and the subjacent alluvial or marine sediments. The soils developed on these deposits are not representative of the soils developed on the terrace itself.

Markewich and others (1986) used the edge effect hypothesis to explain the differences between the sola thicknesses and chemical properties of the soils analyzed in their profiles and those described by Thom (1967a) from the same morphostratigraphic units in the Coastal Plain of northeastern South Carolina. Thom described pedons associated with the edges of marine barriers, whereas Markewich and others described pedons from the broad, flat upper surfaces of the same barriers. Results from the two studies are not directly comparable, but detailed micromorphological analyses and clay mineralogical analyses resulted in the same relative age distribution for both studies. (Isotopic age determinations were available to Markewich and others, who did their fieldwork in the early 1980's, but not to Thom, who published in 1967.)

Geomorphic position is also important in soil chemistry. Well-drained profiles are necessary to adequately compare $(Fe_2O_3+Al_2O_3)/SiO_2$ data for relative age determinations. Soils over shallow water tables in the Coastal Plain contain less total iron and less iron extractable by oxalate, dithionite, and HCl than do soils above deep water tables. Therefore, soils nearer drainages are considered to experience oxidizing conditions almost continuously and to have lost relatively little iron. By comparison, soils nearer the centers of interstream divides experience periodic saturation and reducing conditions that cause removal of soluble ferrous iron (Daniels and others, 1975a).

Closed depressions.—As mentioned previously, closed depression soils, such as those developed in Carolina bays, commonly have been attenuated by high water tables and have spodic horizons (humates) developed near the base of the solum or in the weathered parent material. Parent material beneath these organic soils is commonly so extensively leached of iron that all red-yellow color has been removed. Few data are available on the chemistry of spodic horizons (humates) or on the conditions necessary for their formation in subtropical and tropical environments. Schnitzer (1977) has determined the composition of some humic substances in spodic horizons, and Leenheer (1980) has discussed the conditions necessary for the existence of spodic horizons in the alluvial terrace soils of the Amazon Basin, as DeConinck (1980) did for the Spodosols in general.

Spodic horizons in the Coastal Plain of the United States have been studied by Malcolm (1964), Swanson and Palacas (1965), Thom (1967b), Holzhey and others (1975), Daniels and others (1975b, 1976), and Markewich and others (1986). However, none of these studies has looked in detail at the processes involved in the development of spodic horizons (humates) or at the length of time necessary for the formation of a spodic horizon. The chemical signatures of spodic horizons are different from those of the adjacent mineral horizons. Generally, they are high in base-soluble organic material (humic acids) and insoluble organics (humin). In exceptional cases, they are enriched in metals such as Al^{+3} and Fe^{+3}, complexed with organics. Because of the unusual chemistry associated with spodic horizons and because of the attenuated weathering and soil profiles associated with soils affected by high water tables, we do not recommend spodic soils for chronosequence studies or other comparative studies. Data from soils and weathered parent material associated with these depressions have not yet been shown to be useful in age estimations or comparisons.

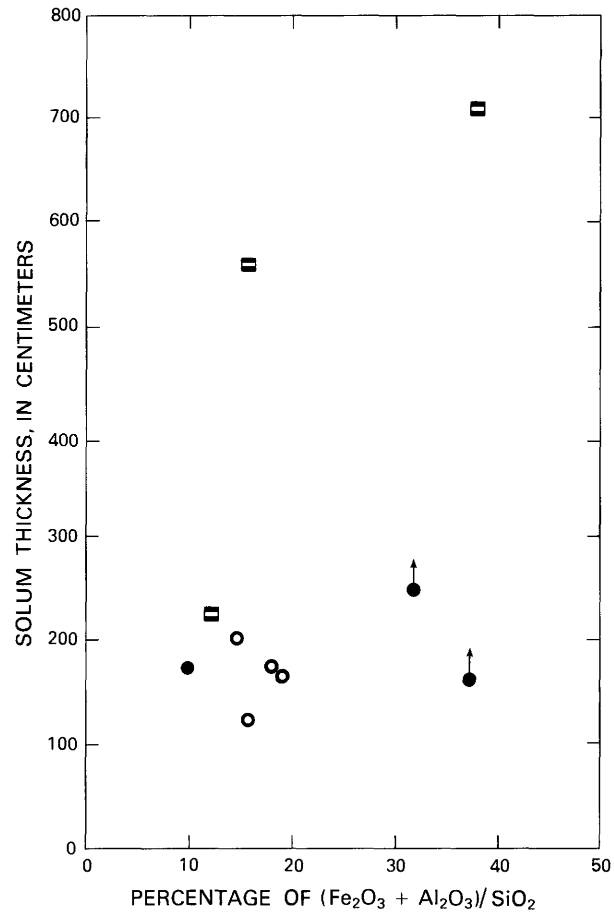


Figure 9A. Thickness of solum versus maximum percentage of $(Fe_2O_3+Al_2O_3)/SiO_2$ for several 10-ka to 10-Ma units. Thickness of solum and major-element ratio are explained in figures 4 and 8, respectively. Open circles, Delmarva Peninsula (sampling area A) (Markewich and others, 1987a); solid circles, Rappahannock Valley (sampling area B) (Markewich and others, 1987a); open block, Augusta, Ga. (sampling area F) (Pavich and others, 1981). Arrows indicate minima. Data for sampling areas A, B, and F and ages of specific sites are given in the appendix.

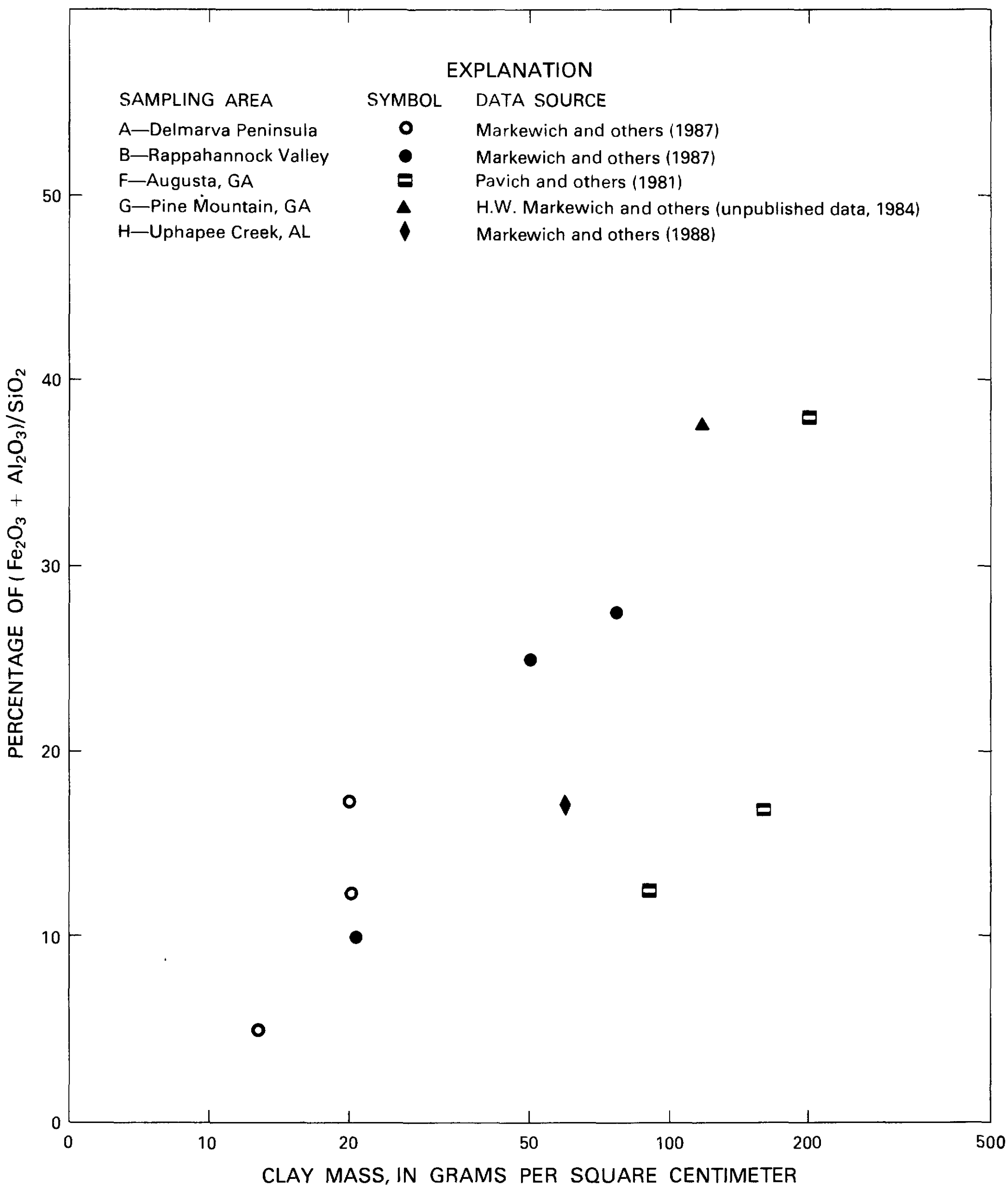


Figure 9*B*. Clay mass versus maximum percentage of $(Fe_2O_3+Al_2O_3)/SiO_2$ for several 5-ka to 10-Ma units. Log scale. Clay mass and major-element ratio are explained in figures 6 and 8, respectively. Data for sampling areas A, B, and F through H and ages of specific sites are given in the appendix.

Climate

Latitudinal differences.—Only preliminary data are available on the differences in the degree and type of weathering and soil development in the Middle Atlantic Coastal Plain versus those in the Coastal Plain of the Southeastern United States. Figure 3 shows a systematic difference in the depth of oxidation of sediments in the Charleston area of South Carolina (area E, fig. 1*B*) (McCartan and others, 1984) when they are compared with units of similar age in the Coastal Plain of Virginia and North Carolina (areas A, B, and C, fig. 1*B*). Unpublished depth of oxidation data from Pliocene- and Pleistocene-age sediments in Georgia (H.W. Markewich, unpublished data, 1984–86) show depths similar to or greater than those reported from the Charleston area. Although the density of data is not adequate to construct a line or transition zone between the more intense weathering of the South Carolina and Georgia Coastal Plain and the less intense weathering of the Virginia Coastal Plain, weathering appears to be more intense in the Piedmont and the Coastal Plain of South Carolina, Georgia, and eastern Alabama. The Coastal Plain of Georgia has mean annual temperatures of 15 °C to 16 °C

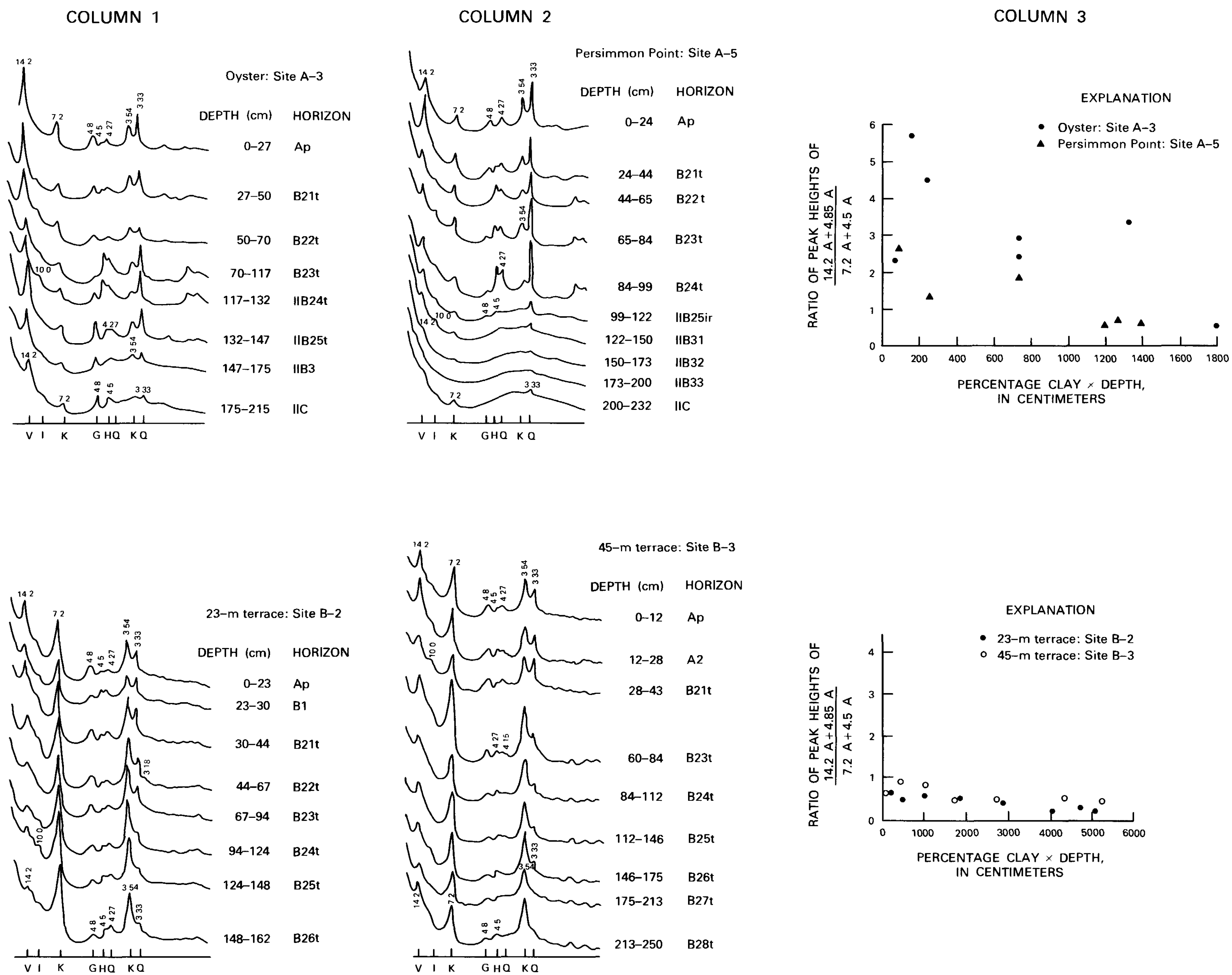


Figure 10A. Clay mineral data for Pleistocene-age soils developed on 60- to 125-ka and 200-ka marine terraces on the Delmarva Peninsula and for 200-ka to >1-Ma fluvial marine terraces of the Rappahannock River in Virginia. X-ray diffraction patterns in columns 1 and 2 are from selected soil horizons on the Delmarva Peninsula (sites A-3 and A-5) and in the Rappahannock Valley (sites B-2 and B-3). Traces illustrated are of oriented, untreated clay. Peak spacings above the peaks are in angstroms. Depths of horizons are in centimeters. Mineral identifications at the bottom of each set of patterns are as follows: V, hydroxyinterlayered vermiculite; I, illite; K, kaolinite; G, gibbsite; H, halloysite; Q, quartz. Column 3 shows the ratio of peak heights of 14.2 A+4.95 A/7.2 A+4.5 A peaks plotted against horizon depth times percentage of clay per horizon for sites A-3 and A-5 (upper plot) and B-2 and B-3 (lower plot). Data for percentage of clay per horizon are given in the appendix.

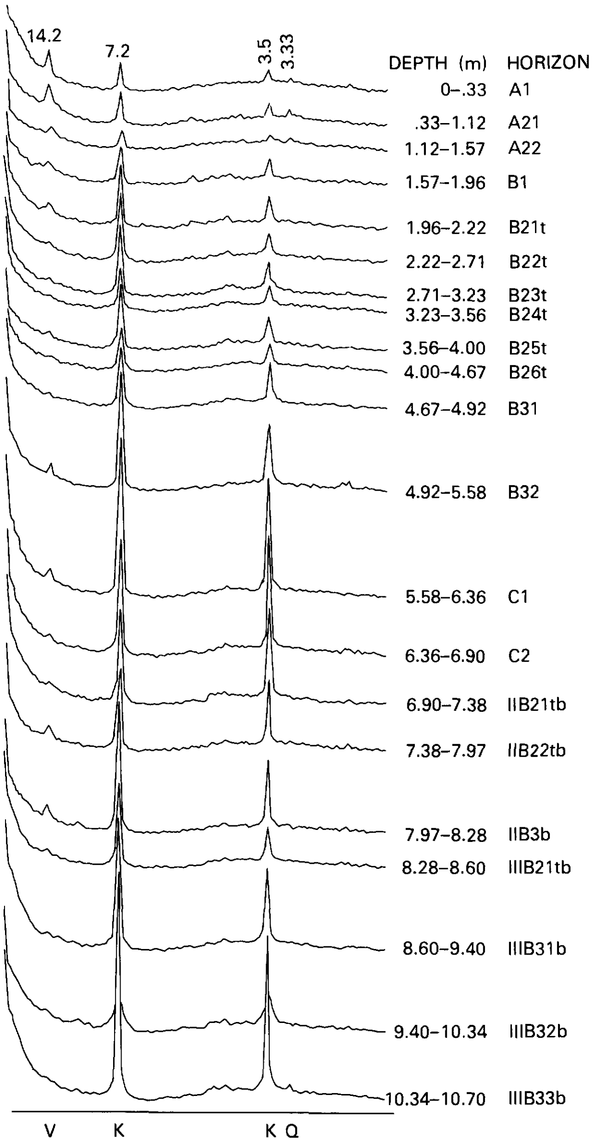


Figure 10*B*. Clay mineral data for a Pliocene-age soil from Augusta, Ga. X-ray diffraction data (Pavich and others, 1981) are taken from a topographically high remnant of Pliocene colluvium overlying earlier Tertiary sediment from the inner Coastal Plain near the Savannah River (site F-3, appendix). Traces illustrated are of oriented, untreated clay. Peak spacings above the peaks are in angstroms. Depths of horizons are in meters. Mineral identifications at the bottom of each set of patterns are as follows: V, hydroxyinterlayered vermiculite; K, kaolinite; Q, quartz.

and mean annual precipitation of around 1,200 mm. It is a subprovince of the area outlined on figure 1*A* as having low-activity clay (LAC) soils,[6] which make up as much as

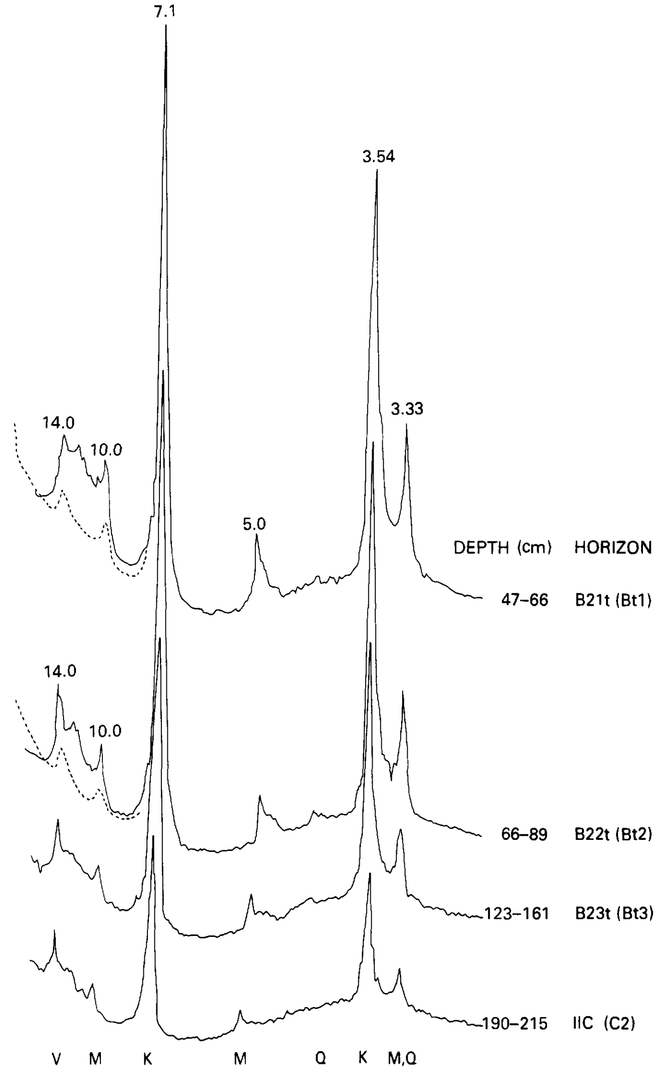


Figure 10*C*. Clay mineral data for a Holocene-age soil developed in the Alabama Coastal Plain. X-ray diffraction patterns of magnesium-saturated and glycol-solvated (magnesium-saturated) clay (dotted line) are from site H-3 (appendix). Peak spacings above the peaks are in angstroms. Depths of horizons are in centimeters. Mineral identifications at the bottom of each set of patterns are as follows: V, vermiculite; M, muscovite; K, kaolinite; Q, quartz.

65 percent of the region's soils. According to L.P. Wilding (written communication, 1986):

> Genetically, the predominance of LAC is important because it reflects specific parent materials from which the soils formed or an advanced state of weathering.

The recognition and eventual delineation of the subprovince of intense weathering within the LAC soil province are essential for accurate comparison of soil and weathering profile data. As Nichols and others (1985) stated, the greatest concentration (of LAC soils) occurs above 29 m altitude. In the Carolinas, this altitude is approximately coincident with the landward limit of the 800-ka to 1-Ma marine terraces (Dubar and others, 1980; McCartan and others, 1984; Owens, 1989; Soller, 1988).

[6]Cation exchange capacity is less than 16 meq/100 g clay (determined by NH_4OAc at pH 7) or an effective value of less than 12 meq/100 g clay (determined as the sum of exchangeable bases plus KCl extractable Al).

Data from McCartan and others (1984) and fieldwork done by D.C. Prowell (unpublished data, 1981–86) and H.W. Markewich (unpublished data, 1981–84) suggest that these LAC soils are thicker and more intensely weathered than non-LAC soils and that they occur on morphostratigraphic units as young as 200 ka in the Coastal Plain of South Carolina and southeastern Georgia. (Although most of the included data are from the tropics, we refer the reader to a Soil Science Society of America (1986) report.)

Although they are not discussed in detail in this paper, weathering profiles developed on sediments no younger than early Pliocene in age in the southeastern Atlantic and eastern Gulf Coast sections of the Coastal Plain of the Eastern United States are commonly weathered to depths of greater than 15 m and have 1- to 5-m-thick sandy surface horizons and sola thicknesses of 7 to 10 m (H.W. Markewich, unpublished data, 1980–85). These profiles are associated with constructional landforms such as marine barriers and alluvial fans or with erosional surfaces on sandy sediments that have been stable for several million years. The origin of these sandy surficial horizons in Atlantic Coastal Plain soils was studied by Gamble (1965) and Gamble and others (1970). Recently, MacVicar and others (1985) studied the origin of similar sandy surficial layers in soil profiles developed on the coast of Natal, West Africa. Studies in both the United States and West Africa concluded that there are no significant differences between the composition, grain size, or origin of the sand that forms the surficial horizons and those of the sand in the underlying argillic horizons and weathered parent material. The uniformity of the sand and the transitional contact between surficial and subjacent horizons suggest that the surficial horizons result from eluviation and chemical dissolution and are not the result of more recent eolian or fluvial sedimentation. The fact that comparable profiles do not constitute a significant component of Coastal Plain soils north of southeastern Virginia can be interpreted as another indicator of more intense weathering and (or) greater age in the Coastal Plain of the Southeastern States.

Precipitation and prevailing winds.—Large dune fields and expansive sand sheets suggest that, at least through the late Quaternary and possibly from the Pliocene into the middle Holocene, the wet-temperate to subtropical climatic regimes of the Middle Atlantic and Southeastern States were interrupted by periods of decreased runoff and high winds (Veatch and Stephenson, 1911; Pickering and Jones, 1974; Thames, 1982; Owens and Denny, 1979). Detailed mapping of these dune fields and sand sheets in Georgia (H.W. Markewich, unpublished data, 1986) and on the Delmarva Peninsula of Delaware and Maryland (Owens and Denny, 1979) suggests that there have been several periods of dune development and that individual dune fields and adjacent sand sheets can extend several miles from their source areas. Thus, some of the sand incorporated in the near-surface horizons of soils developed in Coastal Plain sediments may be eolian in origin, and an overprint of characteristics common to more arid climates may be incorporated into the soil and weathering profiles of the middle Atlantic and southeastern Coastal Plain.

Soil Chemistry and Mineralogy

To date, the most reliable chemical parameter to use as an indicator of soil age is $(Fe_2O_3+Al_2O_3)/SiO_2$. In general, both dithionite-extractable and iron and total iron increase with soil age. Other studies have shown an increase of hematite and redness with soil age and an association between redness and hematite in the fine-earth fraction (Davey and others, 1975; Torrent and others, 1980; Arduino and others, 1986). Although our data show a trend of increasing redness with soil age, we do not yet have sufficient data to substantiate an increase in hematite content correlated with an increase in redness or soil age. X-ray diffraction data do not show significant amounts of hematite. Goethite is the dominant iron oxyhydroxide in the clay-sized fraction of the southeastern Coastal Plain.

Clay mineral data may also help in differentiating soils of different ages if the soil parent materials are of the same provenance. Figure 10*A* shows a plot of clay peak ratios for 60- to 125-ka and 200-ka marine terraces on the Delmarva Peninsula and for 200-ka to >1-Ma fluvial marine terraces of the Rappahannock River in Virginia (Markewich and others, 1987a). Figure 10*B* shows a plot from a Georgia Coastal Plain soil considered to be no younger than early Pliocene in age (Pavich and others, 1981). With increasing age, the percentage of kaolinite increases, whereas the percentages of vermiculite and gibbsite decrease. Since provenance and climate vary significantly from region to region, clay minerals are probably of limited use in making age correlations across major latitudinal, parent material, or topographic boundaries. For example, Holocene terraces from Alabama (fig. 10*C*) show very high percentages of kaolinite in the parent material and soil clay fractions, a reflection of the different provenance for the soil parent material in Delmarva and Alabama.

CONCLUSIONS

It is possible to estimate order-of-magnitude ages (10 ka versus 100 ka versus 1 Ma) of morphostratigraphic units in the Coastal Plain of the Eastern United States on the basis of their degrees of weathering and soil development.

Parent material, relief (topography and geomorphic position), and time are the most important controls on weathering and soil development within a given climatic regime.

The most reliable indicators of soil age are the thickness of the solum, the thickness of the argillic horizon, rubification, clay mass, and $(Fe_2O_3+Al_2O_3)/SiO_2$. This oxide ratio is particularly useful in differentiating between soils that range in age from about 200 to 800 ka, although data are not sufficient to determine which parameters are reliable determinations of soil age within this age range.

Depth of oxidation is a reliable indicator of soil age if only the best-drained sites are compared; commonly, these sites are located near but not on the eroded boundaries or primary sloping parts of the landform (that is, the edge of an alluvial terrace nearest the present channel or the side slope of a marine barrier).

There is an evolution of Coastal Plain soils from Inceptisols to Alfisols to Ultisols (Hapludults to Paleudults). Inceptisols appear to be as young as Holocene and no older than a few tens of thousands of years. Hapludults are associated with a wide variety of ages from a few tens of thousands of years to several hundred thousand years. Paleudults are associated with morphostratigraphic units that are older than 800 ka. (Data are not sufficient to differentiate soils in the 200- to 800-ka range.)

Most soils that are older than 800 ka and that have a parent material greater than 80 percent quartz sand have bisequal profiles and sola thicknesses greater than 3 m.

On similar parent materials of the same age under different climates in Virginia and Georgia, there are differences in the depths and types of weathering and development of soils. These differences apparently are directly related to climate but are manifested as differences in clay mineralogy and the mineralogy of the clay-sized fraction, in the depth of oxidation, in the pattern of iron segregation, in horizonization, and in the thickness of the solum. Identification of these differences is essential in comparing soil and weathering profiles in the middle Atlantic and southeastern sections of the Atlantic Coastal Plain.

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APPENDIX

Field and Laboratory Data Used to Construct Figures 3 through 10

Site A-1. Eastern Neck Island, Delmarva Peninsula (28 ka)
[Data from Markewich and others (1987a)]

Depth (cm)	Horizon[1]	Moist color[2]	Texture[3]	Clay (<2 μm) (percent)
0–13	A1	10YR5/1	sl	5.8
13–31	A2	10YR5/1	sl	5.3
31–43	B21	10YR6/4	sil	4.4
43–69	B22	10YR5/6	sl	6.0
69–92	B3	10YR6/4	s	1.6
92+	C	10YR5/6	s	10.5

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]sl, sandy loam; sil, silty loam; s, sand.

Site A-2. Joynes Neck, Delmarva Peninsula (60–125 ka)]
Data from Markewich and others (1987a). —, no data]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–28	Ap	10YR4/3	1.65	fsl	8.6	8.3
28–45	B21t	7.5YR4/4	1.62	sl	15.9	12.9
45–67	B22t	7.5YR4/4	1.48	l	17.1	14.5
67–86	B23t	7.5YR5/6	1.61	l	17.5	14.0
86–106	B24t	7.5YR6/5	1.72	l	16.3	13.7
106–122	B25t	7.5YR5/6	1.67	sl	12.1	9.9
122–146	Cl	7.5YR5/8	1.50	ls	6.4	5.9
146–188	C2	10YR5/6	[5]1.60	s	2.4	3.3
188–202	B'h	10YR6/6	[5]1.70	ls	2.0	4.5
202–235	IIC3	10YR5/4	[5]1.70	ls	.4	4.0
235–245	IIC4	10YR5/4	[5]1.70	s	—	2.3

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]fsl, fine sandy loam; sl, sandy loam; l, loam; ls, loamy sand; s, sand.
[5]Estimated.

Site A-3. Oyster, Delmarva Peninsula (60–125 ka)

[Data from Markewich and others (1987a)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–27	Ap	10YR4/3	1.83	sl	5.3	4.9
27–50	B21t	7.5YR5/6	1.79	l	17.1	12.2
50–70	B22t	7.5YR5/6	1.57	l	22.1	18.1
70–117	B23t	7.5YR5/6	1.67	l	18.8	12.4
117–132	IIB24t	7.5YR5/8	[5]1.80	sl	7.3	6.6
132–147	IIB25t	7.5YR5/8	1.81	sl	5.2	7.5
147–175	IIB3	10YR5/6	[5]1.80	ls	1.6	3.5
175–215	IIC	10YR8/3	[5]1.80	s	.8	4.7

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]sl, sandy loam; l, loam; ls, loamy sand; s, sand.
[5]Estimated.

Site A-4. Nelsonia, Delmarva Peninsula (140–220 ka)

[Data from Markewich and others (1987a)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–12	Ap	10YR4/3	[5]1.60	fsl	6.8	6.1
12–22	A12	10YR4/3	[5]1.60	fsl	8.2	7.7
22–40	B21t	7.5YR4/4	[5]1.50	l	22.9	16.3
40–63	B22t	7.5YR4/4	1.53	l	23.4	18.7
63–79	B23t	7.5YR5/6	[5]1.50	sl	13.4	10.3
79–95	B31	7.5YR5/6	1.56	sl	6.4	4.7
95–121	B32A'2	10YR5/6	[5]1.60	lfs	3.6	2.5
121–130	B'21hir	10YR5/6	1.60	lfs	3.3	5.0
130–150	B'22hir	7.5YR4/4	1.55	s	.8	3.9
150–159	B'23h	7.5YR4/4	1.60	ls	.8	1.9
159–169	B'24h	5YR3/2	1.60	ls	.4	1.8

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]fsl, fine sandy loam; l, loam; sl, sandy loam; lfs, loamy fine sand; s, sand; ls, loamy sand.
[5]Estimated.

Site A-5. Persimmon Point, Delmarva Peninsula (200 ka)

[Data from Markewich and others (1987a). —, no data]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density [3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–24	Ap	10YR4/3	1.69	fsl	8.2	10.4
24–44	B21t	7.5YR5/6	1.69	scl	21.7	16.6
44–65	B22t	7.5YR5/6	1.51	scl	22.1	—
65–84	B23t	7.5YR5/6	[5]1.50	scl	17.1	15.5
84–99	B24t	7.5YR5/6	1.51	fsl	15.1	11.7
99–122	IIB25ir	2.5YR3/6	1.87	s	2.4	9.1
122–150	IIB31	2.5YR3/6	[5]1.80	s	1.6	3.2
150–173	IIB32	7.5YR5/8	[5]1.80	s	—	1.0
173–200	IIB33	7.5YR5/6	[5]1.80	s	.4	—
200–232	IIC	2.5YR7/6	[5]1.80	s	—	13.6

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]fsl, fine sandy loam; scl, sandy clay loam; s, sand.
[5]Estimated.

Site B-1. Norris Bridge, Rappahannock River Valley (200 ka)

[Data from Markewich and others (1987a)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–25	Ap	10YR4/3	1.71	ls	6.9	4.4
25–34	A2	10YR4/6	1.81	sl	8.9	6.5
34–48	B21t	7.5YR5/6	1.71	sl	15.3	9.4
48–70	B22t	5YR5/6	1.63	scl	17.8	10.3
70–96	B23t	5YR5/6	1.63	ls	10.5	6.5
96–138	B31	7.5YR5/6	1.58	s	7.2	4.8
138–170	B32	7.5YR5/6	[5]1.70	s	5.6	5.2
170–200	C1	10YR5/8	[5]1.70	s	4.3	1.9
200–230	IIC2	10YR5/8	[5]1.70	s	2.7	3.1

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]ls, loamy sand; sl, sandy loam; scl, sandy clay loam; s, sand.
[5]Estimated.

Site B-2. 23-m terrace, Rappahannock River Valley (600 ka)

[Data from Markewich and others (1987a)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–23	Ap	10YR4/3	1.44	sil	16.0	16.5
23–30	B1	10YR4/3	1.61	sil	18.8	17.7
30–44	B21t	7.5YR4/4	1.57	sil	26.6	22.2
44–67	B22t	10YR5/6	1.50	sicl	34.5	28.6
67–94	B23t	5YR4/6	1.54	sicl	35.3	30.1
94–124	B24t	5YR5/6	1.58	sicl	34.8	33.5
124–148	B25t	5YR5/6	1.47	sicl	34.5	37.3
148–162	B26t	5YR5/6	1.46	sicl	32.4	35.9

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]sil, silty loam; sicl, silty clay loam.

Site B-3. 45-m terrace, Rappahannock River Valley (1 Ma)

[Data from Markewich and others (1987a)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–12	Ap	10YR4/2	1.18	l	19.8	13.9
12–28	A2	10YR4/3	1.67	l	23.2	14.0
28–43	B21t	10YR4/3	1.55	l	29.4	21.2
43–60	B22t	5YR4/6	1.52	cl	33.6	22.4
60–84	B23t	2.5YR4/6	1.49	c	37.4	24.5
84–112	B24t	2.5YR4/6	1.53	c	44.0	28.4
112–146	B25t	2.5YR4/6	[5]1.50	c	42.3	27.4
146–175	B26t	2.5YR4/6	1.48	c	47.8	29.3
175–213	B27t	2.5YR4/6	[5]1.50	cl	46.4	31.5
213–250	B28t	2.5YR4/6	1.53	cl	43.5	27.3

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]l, loam; cl, clay loam; c, clay.
[5]Estimated.

Site C-1. 39-m terrace, Cape Fear Valley, North Carolina (200 ka)

[Data from H.W. Markewich, M.J. Pavich, and M.J. Mausbach (unpublished data, 1982)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–22	Ap	10YR4/1	0.70	ls	2.4
22–34	A2	10YR7/4	1.76	ls	8.4
34–46	B21t	10YR6/6	1.71	scl	16.5
46–66	B22t	10YR6/6	1.76	scl	18.6
66–90	B23t	10YR6/6	1.75	scl	25.1
90–130	B3	10YR6/1	1.70	cl	32.8
130–160	C1	10YR6/1	1.65	c	32.4
160–180	C2	10YR6/1	1.62	c	32.0

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]ls, loamy sand; scl, sandy clay loam; cl, clay loam; c, clay.

Site C-2. 30-m terrace, Cape Fear Valley, North Carolina (60 ka)

[Data from H.W. Markewich, M.J. Pavich, and M.J. Mausbach (unpublished data, 1982)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–11	Ap	10YR6/4	1.37	fsl	7.4
11–26	B1	10YR4/4	1.59	fsl	10.9
26–53	B21t	7.5YR5/6	1.56	scl	21.0
53–77	B22t	7.5YR5/6	1.56	sicl	22.7
77–114	B3	7.5YR5/6	1.54	sil	21.5
114–140	C1	7.5YR5/6	1.60	fsl	15.7
140–190	C2	10YR5/6	1.65	fsl	16.9
190–226	C3	10YR6/8	1.60	fsl	15.8
226–276	2C4	10YR5/1	1.62	sicl	23.6

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]fsl, fine sandy loam; scl, sandy clay loam; sicl, silty clay loam; sil, silty loam.

Site C-3. 30-m terrace, Cape Fear Valley, North Carolina (60 ka)

[Data from H.W. Markewich, M.J. Pavich, and M.J. Mausbach (unpublished data, 1982)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–11	A1	10YR4/1	1.11	fsl	22.0
11–29	A2	10YR7/2	1.52	fsl	13.0
29–43	B21t	10YR5/4	1.71	cl	21.2
43–65	B22t	10YR5/6	1.66	c	30.1
65–93	B23t	10YR7/2	1.60	c	28.5
93–147	B3	10YR6/2	1.63	cl	22.8
147–199	C1	10YR5/6	1.66	ls	12.9
199–250	C2	10YR6/4	1.60	fs	6.0

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]fsl, fine sandy loam; cl, clay loam; c, clay; ls, loamy sand; fs, fine sand.

Site C-4. 45-m terrace, Cape Fear Valley, North Carolina (200 ka)

[Data from H.W. Markewich, M.J. Pavich, and M.J. Mausbach (unpublished data, 1982)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–18	Ap	10YR4/2	1.78	ls	2.4
18–48	B21t	10YR5/6	1.75	scl	20.2
48–64	B22t	10YR5/6	1.66	scl	22.2
64–84	B23t	10YR5/6	1.74	scl	28.7
84–104	B24t	10YR5/6	1.69	scl	30.7
104–124	B25t	10YR5/4	1.75	scl	27.8
124–158	B26t	10YR6/1	1.79	scl	26.2
158–210	2C	10YR6/1	1.66	c	34.7

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]ls, loamy sand; scl, sandy clay loam; c, clay.

Site F-1. Augusta, Ga. (10 Ma)

[Data from Pavich and others (1981). —, no data]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–15	A1	10YR5/4	1.40	ls	5.7	—
15–48	A21	10YR6/4	1.60	s	2.4	—
48–73	A22	10YR6/4	1.70	s	4.0	—
73–100	A23	10YR6/6	1.70	s	6.8	—
100–126	A/B	10YR6/6	1.74	ls	9.6	—
126–139	B/A	10YR6/4	1.70	sl	20.2	—
139–157	B21	7.5YR5/6	1.68	sl	33.7	3
157–182	B22	7.5YR5/6	1.70	sl	35.7	11
182–322	B23t	10R4/8	1.78	sl	37.1	38
322–352	2B24tb	10R4/8	1.70	fsl	56.0	31
352–418	3B25tb	10R4/8	1.67	fsl	49.4	31
418–480	3B26tb	10R4/8	1.70	sl	46.8	26
480–519	3B27tb	10R4/8	1.70	sl	46.3	—
519–625	3B31b	10R4/9	1.75	fsl	40.5	—
625–707	3B32b	2.5YR4/8	1.70	lfs	23.6	—
707–763	Cb	2.5YR4/8	1.74	ls	16.7	29

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]ls, loamy sand; s, sand; sl, sandy loam; fsl, fine sandy loam; lfs, loamy fine sand.

Site F-2. Augusta, Ga. (2.5 Ma)

[Data from Pavich and others (1981). —, no data]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–33	A1	10YR5/1	1.50	s	2.9	—
33–112	A21	10YR6/6	1.60	s	2.4	3
112–157	A22	10YR6/6	1.60	s	2.8	14
157–196	B1	7.5YR5/6	1.70	s	9.3	16
196–222	B21t	7.5YR5/6	1.85	sl	19.7	—
222–271	B22t	2.5YR5/6	1.86	scl	22.1	—
271–323	B23t	2.5YR4/6	1.80	scl	27.0	—
323–356	B24t	2.5YR4/6	1.80	scl	33.5	11
356–400	B25t	2.5YR4/8	1.80	scl	22.9	—
400–467	B26t	2.5YR4/8	1.81	scl	30.6	—
467–492	B31	5YR5/6	1.80	scl	18.9	—
492–558	B32	5YR5/6	1.80	sl	14.5	—
558–636	C1	10YR6/8	1.80	scl	22.5	—
636–690	C2	10YR5/6	1.79	scl	24.1	—
690–738	2B21tb	5YR5/6	1.89	scl	16.9	—
738–797	2B22tb	7.5YR5/6	1.90	sl	15.7	—
797–828	2B3b	7.5YR5/6	1.87	sl	20.5	—
828–860	3B2b	2.5YR4/6	1.82	scl	30.2	—
860–940	3B31b	2.5YR5/8	1.84	sil	19.3	—
940–1034	3B32b	5YR5/6	1.80	sl	20.9	—
1034–1070	3B33b	5YR5/8	1.73	scl	33.4	—

[1]Horizon designations from Soil Survey Staff (1962).
[2]Munsell notation.
[3]1/3 bar.
[4]s, sand; sl, sandy loam; scl, sandy clay loam; sil, silty loam.

Site F-3. Augusta, Ga. (100 ka)

[Data from Pavich and others (1981). —, no data]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)	$\frac{Fe_2O_3+Al_2O_3}{SiO_2}$ (percent)
0–7	A1	5YR4/3	1.36	sl	18.0	—
7–22	B1	2.5YR3/2	1.60	scl	28.5	—
22–40	B21t	10R3/6	1.66	scl	41.0	—
40–64	B22t	10R3/6	1.60	scl	37.0	—
64–84	B23t	10R4/6	1.63	scl	36.2	—
84–110	B24t	10R4/6	1.60	scl	34.5	12
110–137	B25t	10R4/6	1.71	scl	35.7	—
137–171	B26t	2.5YR4/6	1.70	scl	29.6	—
171–192	B31	2.5YR4/8	1.66	sl	15.7	—
192–221	B32	2.5YR4/8	1.64	lcs	6.4	—
221–263	C1	2.5YR5/8	1.60	cs	4.8	2
263–290	C2	10YR8/3	1.60	cs	1.2	—

[1]Horizon designations from Soil Survey Staff (1962).
[1]Munsell notation.
[3]1/3 bar.
[3]sl, sandy loam; scl, sandy clay loam; lcs, loamy coarse sand; cs, coarse sand.

Site G-1. Alluvial fan, Pine Mountain, Georgia (5 Ma)

[Data from Markewich and others (1987b)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–18	AP	10YR4/3	1.38	sl	9.0
18–45	AB	10YR5/6	1.50	sl	5.0
45–69	BA	7.5YR5/6	1.60	sl	10.5
69–97	Bt1	7.5YR5/8	1.64	scl	23.0
97–146	Bt2	7.5YR5/8	1.71	scl	30.3
146–175	Bx1	2.5YR5/8–10YR5/8	1.70	scl	26.5
175–205	Bx2	2.5YR4/8–10YR5/8	2.16	gscl	28.3

[1]Horizon designations from Soil Management Support Services (1986).

[2]Munsell notation.

[3]1/3 bar.

[4]sl, sandy loam; scl, sandy clay loam; gscl, gravelly sandy clay loam.

Site G-2. Alluvial fan, Pine Mountain, Georgia (5 Ma)

[Data from Markewich and others (1987b)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–15	Ap	10YR5/3	1.54	sl	8.8
15–44	Bt1	2.5YR4/8	1.43	cl	51.7
44–66	Bt2	2.5YR4/8	1.30	cl	44.7
66–98	Bt2	2.5YR4/8	1.39	scl	48.0
98–130	2Bx1	2.5YR4/8	1.68	scl	40.2
130–164	2Bx2	2.5YR4/8	1.71	scl	30.0
164–195	2Bx3	2.5YR4/8–7.5YR5/6	1.80	sl	28.7
195–235	2Bx4	2.5YR4/8–10YR5/8	1.75	s	30.2
235–250	2Bx5	2.5YR4/8–10YR5/8	1.73	sl	32.6

[1]Horizon designations from Soil Management Support Services (1986).

[2]Munsell notation.

[3]1/3 bar.

[4]sl, sandy loam; cl, clay loam; scl, sandy clay loam; s, sand.

Site H-1. Uphapee Creek, Alabama (7.5 ka)

[Data from Markewich and others (1988)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–26	Ap	10YR4/3	1.46	fsl	7.4
26–47	Bw1	10YR5/3	1.36	fsl	12.2
47–73	Bw2	10YR5/4	1.43	fsl	11.7
73–97	Bw3	7.5YR4/4	1.42	cl	27.1
97–115	Bw4	10YR5/6	1.48	vfsl	22.5
115–130	BC	10YR5/6	1.53	fsl	16.7
130–170	C1	10YR6/6	1.46	lfs	8.5
170–200	C2	10YR7/2	1.51	fs	1.2

[1]Horizon designations from Soil Management Support Services (1986).
[2]Munsell notation.
[3]1/3 bar.
[4]fsl, fine sandy loam; cl, clay loam; vfsl, very fine sandy loam; lfs, loamy fine sand; fs, fine sand.

Site H-2. Uphapee Creek, Alabama (6.5 ka)

[Data from Markewich and others (1988). —, no data]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 μm) (percent)
0–20	A	10YR3/2	1.44	fsl	7.8
20–36	E	10YR5/3	1.63	fsl	7.3
36–58	Bw	5YR4/4	1.51	cl	36.1
58–78	Bwg1	10YR6/2	1.47	c	50.1
78–112	Bwg2	10YR6/1	1.53	c	40.8
112–146	Btg1	10YR6/1	1.50	c	40.1
146–176	Btg2	10YR6/1	1.61	sc	26.6
206–230	C1	—	—	g	—

[1]Horizon designations from Soil Management Support Services (1986).
[2]Munsell notation.
[3]1/3 bar.
[4]fsl, fine sandy loam; cl, clay loam; c, clay; sc, sandy clay; g, gravel.

Site H-3. Tallapoosa River, Alabama (6.5 ka)

[Data from Markewich and others (1988). —, no data]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 µm) (percent)
0–22	Ap	10YR4/3	1.43	sil	14.8
22–47	Bw	7.5YR4/4	1.45	sic	46.6
47–66	Bt1	7.5YR4/4	1.50	sic	43.1
66–89	Bt2	10YR5/6	1.56	sic	40.2
89–123	Bt3	10YR5/8	1.60	sicl	25.3
123–161	Bt3	10YR5/8	1.56	sicl	26.4
161–190	BC	7.5YR4/4	1.60	l	12.9
190–215	C	—	1.60	s	3.2

[1]Horizon designations from Soil Management Support Services (1986).
[1]Munsell notation.
[3]1/3 bar.
[4]sil, silty loam; sic, silty clay; sicl, silty clay loam; l, loam; s, sand.

Site H-4. Tallapoosa River, Alabama (5.5 ka)

[Data from Markewich and others (1988)]

Depth (cm)	Horizon[1]	Moist color[2]	Bulk density[3] (g/cm^3)	Texture[4]	Clay (<2 µm) (percent)
0–8	A	10YR3/3	1.40	sil	20.7
8–30	Bw1	7.5YR5/6	1.41	sicl	38.1
30–54	Bw2	7.5YR5/6	1.50	sicl	37.1
54–94	Bw3	10YR5/6	1.44	sicl	33.8
94–130	Bw4	7.5YR5/6	1.50	sicl	30.4
130–64	BC	7.5YR5/6	1.52	sil	22.4
164–190	C	10YR6/1	1.50	l	18.3

[1]Horizon designations from Soil Management Support Services (1986).
[2]Munsell notation.
[3]1/3 bar.
[4]sil, silty loam; sicl, silty clay loam; l, loam.

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