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Chapter 30

Pedology in archaeology

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INTRODUCTION

Most archaeologists recognize that a relationship exists between the cultural remains they find in the ground and the soils. Beyond that simple relationship, however, archaeologists' understanding of what can be learned from soils and indeed what a soil is and is not varies tremendously. In general, the applications of soil studies in archaeology are either very large scale, such as the capability of regional soils to support agriculture or use of soils as stratigraphic markers, or very small scale, for example, studying the particle-size distribution or chemistry of a soil. There is a significant middle ground in soil studies that is often overlooked. This involves investigation of soils as three-dimensional bodies intimately related to the landscape, focusing on their classification and genesis. This study of soils and their natural setting is a part of soil science called “pedology.” The aspect of pedology most directly related to archaeology evolves from Quaternary geology and geomorphology (rather than agriculture) and sometimes is referred to as soil-geomorphology (e.g., Ruhe, 1983; Birkeland, 1984; Catt, 1986). This chapter will review basic aspects of pedology, and how they apply to archaeology in North America.

There is considerable literature concerning the use of soils in archaeological investigations. Much of the initial, substantive work was done in Great Britain (e.g., Cornwall, 1958, 1960), establishing a tradition that continues (e.g., Limbrey, 1975; Shackley, 1981). In North American archaeology, soils were originally used primarily as stratigraphic markers and continue to be so used with considerable success (e.g., Judson, 1953; Haynes, 1968, 1975; Hallberg and others, 1974; Hoyer, 1980; Reider, 1980, 1982a, b; Bettis and Thompson, 1982; Ferring, 1982; Wiant and others, 1983; Styles, 1985). There are some applications of pedology (1) to landscape and climate reconstruction in archaeological contexts at general and site-specific levels (Haynes and Grey, 1965; Reeves and Dormaar, 1972; Thompson and Bettis, 1980; Reider, 1980, 1982a, b), and (2) for dating (Foss, 1977; Bischoff and others, 1981). There are also several general discussions of applications of pedology to archaeology (Lotspeich, 1961; Tamplin, 1969; Rutter, 1978; Olson, 1981). Finally, studies of soil chemistry, particularly phosphorus, are useful in indicating the presence and measuring the degree of human occupation (Solecki, 1951; Ahler, 1973; Eidt, 1977, 1985; Woods, 1977; Gordon, 1978; White, 1978).

Butzer (1977), in reviewing Limbrey (1975), comments on the absence of a “usable methodology” for soil science in archaeology. Therefore, some basic terminology and techniques of pedology and soil-geomorphology will be outlined to provide a basis for establishing an appropriate methodology for use in archaeological geology. In addition, the factors of soil formation will be reviewed, followed by a discussion of how they (1) can be applied in archaeology, and (2) affect soil-stratigraphy.

TERMS AND TECHNIQUES

There is a sizeable body of nomenclature in pedology for describing and classifying soils and an almost overwhelming variety of techniques for their study. This chapter is not a review of soils nomenclature and analytical techniques, but a brief summary of both is necessary in order to understand the main points under discussion. The soil horizon nomenclature commonly used in the United States is based on that of the U.S. Department of Agriculture (Soil Survey Staff, 1951, 1975), with an update discussed by Guthrie and Witty (1982; see also Bettis, 1984). Excellent summaries are provided by Buol and others (1980) and Birkeland (1984), and the Soil Science Society of America (1978) has a useful glossary of soil science terms.

Terms

The word “soil” is used by different individuals in different ways. To the farmer, the agricultural scientist, and some soil scientists, it is simply the medium for plant growth. To the engineer, some geologists, and probably many archeologists, it is unconsolidated sediment including loose or weathered rock or regolith. To the pedologist, however, soil has a specific definition not always properly understood. A soil is a natural entity, a type of weathering phenomenon occurring at the immediate surface of the earth in sediment and rock; it acts as a medium for plant growth, and the result of the effects of the sediment or rock, construction, and vegetation.
Figure 1. Examples of soil profiles and soil-horizon nomenclature: a, Mollisol in limestone, central Texas; b, Alfisol in eolian sediments, Texas plains (scale in centimeters and decimeters); c, Alfisol in till, northern Michigan (reproduced from Marbut Memorial Slide Set, 1968, by permission of the Soil Science Society of America); d, buried and unburied soils at the Lubbock Lake site (b3 = buried Lubbock Lake Soil, Fig. 4). See Table 1 for definition of soil-horizon symbols.
climate, flora, fauna, and landscape position, all acting through time (modified from Soil Science Society of America, 1978). Key concepts are: (1) that soils form in or are an alteration of sediments and rocks over time; (2) that there is some interaction with flora and fauna and an accumulation of organic matter; (3) that there is some movement or redistribution of soil constituents; (4) that soils form on stable land surfaces and are approximately parallel to the land surface; and (5) that soils are extremely complex systems and soils similar in appearance may be the result of different processes.

The most obvious features of soils in the field are horizons, which are zones within the soil that usually parallel the land surface; have distinctive physical, chemical, and biological properties; and develop as a result of soil-forming processes (Fig. 1). A soil profile is the vertical arrangement of soil horizons in a two-dimensional exposure down to and including the parent material. The careful description of soil profiles and horizons is a critical element of pedology and requires considerable training and practice. Specifics on the data necessary to describe soils are provided by the Soil Survey Staff (1951, 1975), Buol and others (1980), and Birkeland (1984). These summaries, however, are no substitute for practical field experience and instruction. Interpretations of soils are only as good as the field descriptions and observations. Furthermore, an understanding of the principles and applications of pedology and soil geomorphology requires a strong background in geology and/or physical geography.

The nomenclature for describing soil horizons is based almost entirely on qualitative features of the soil observed in the field. There are six master or major horizons and a considerable number of subhorizon symbols (Table 1) which are used as modifiers of the master horizons. Generally, only a few of the master horizon and subhorizon symbols ever occur together in a single profile (Fig. 1).

The terms used in soil classification are strictly defined (Tables 2, 3). Many terms and their definitions, while bewildering at first, are quite usable and useful. Buol and others (1980) provide a good introduction to soil classification, but formal instruction is recommended. The classification system used in the United States is the U.S. Comprehensive Soil Classification System, published as Soil Taxonomy (Soil Survey Staff, 1975). It is often, but incorrectly, referred to as the 7th Approximation, a title for an earlier version of the classification system (Soil Survey Staff, 1960). Strictly speaking, Soil Taxonomy is the 8th approximation, although it is seldom referred to as such. The U.S. system was developed in the 1950s and 1960s and was a revolutionary concept in soil classification. Most earlier schemes were based in large part on the presumed genetic history or agricultural potential of soils, which were almost never immediately apparent, rather than properties of the soils themselves. As well, many of the terms used in the earlier systems derived from various foreign languages, folk terms, and coined names, were generally poorly defined, and not always mutually exclusive (Buol and others, 1980). The new U.S. classification system is based entirely on soil

### Table 1. General Definitions of Soil Horizons

**Master Horizons**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Surface horizon dominated by organic material and very dark.</td>
</tr>
<tr>
<td>A</td>
<td>Mineral horizon that forms at the surface or below an O horizon characterized by accumulation of organic matter mixed with mineral matter, but not like an E or B horizon, typically darker than underlying horizons.</td>
</tr>
<tr>
<td>E</td>
<td>Mineral horizon typically below an A or O and characterized by loss of clay, iron, and/or aluminum and concentration of more resistant materials and usually lighter in color than underlying horizons due to the loss.</td>
</tr>
<tr>
<td>B</td>
<td>Mineral horizon usually underlying an A, O, or E horizon with little or no evidence of original rock or sediment structure, typically redder than underlying or overlying horizons and characterized by: accumulation of carbonates, gypsum, clay, iron, or aluminum or any combination of these; leaching of carbonates; development of blocky or prismatic structure; or any combination of these characteristics.</td>
</tr>
<tr>
<td>R</td>
<td>Hard bedrock.</td>
</tr>
<tr>
<td>K†</td>
<td>A mineral horizon impregnated by carbonate such that the carbonate dominates its morphology; generally well cemented.</td>
</tr>
</tbody>
</table>

**Selected Subordinate Horizons**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>Buried mineral horizon. **</td>
</tr>
<tr>
<td>g</td>
<td>Strong gleysing; iron has been reduced; colors are typically olive, yellow, or neutral and often mottled.</td>
</tr>
<tr>
<td>h</td>
<td>B horizon with an accumulation of organic matter; usually associated with an E horizon.</td>
</tr>
<tr>
<td>e</td>
<td>B horizon with accumulation of iron and/or aluminum; usually associated with an E horizon.</td>
</tr>
<tr>
<td>n</td>
<td>Accumulation of exchangeable sodium.</td>
</tr>
<tr>
<td>k</td>
<td>B horizon (sometimes C horizon) with a zone of visible accumulation of calcium carbonate.</td>
</tr>
<tr>
<td>t</td>
<td>B horizon with accumulation of clay.</td>
</tr>
<tr>
<td>w</td>
<td>B horizon with color and/or structural development, but no accumulation of other material (weakly developed B).</td>
</tr>
<tr>
<td>y</td>
<td>B or C horizon with accumulation of gypsum.</td>
</tr>
<tr>
<td>z</td>
<td>B or C horizon with accumulation of salts more soluble than gypsum.</td>
</tr>
</tbody>
</table>

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*For more complete definitions see Buol and others (1980), Birkeland (1984), Soil Survey Staff (1975), or Soil Science Society of America (1978).*

*Not officially recognized by the Soil Conservation Service; see Gile and others (1965).*

*These are suffixes to the Master Horizon symbols (e.g., Ab, Bk), for full list see Guthrie and Witty (1982) or Wilding and others (1983, p. 385-388); any given master/subordinate horizon symbol can be subdivided using letters (e.g., Bw1, Bw2).*

**Added to all horizons of buried soils (e.g., A-Bw-Ab-Bt-Bkb-Cb); if multiple buried soils are present the b can be numbered (e.g., A-Bw-Ab1-Bb1-Ab2-Cb2).**
properties that are observable in the field and/or measurable in the laboratory (Soil Survey Staff, 1975).

The U.S. soil classification system is based on a variety of differentiating characteristics, including diagnostic horizons (Table 2) (not to be equated with the horizon symbols used in field descriptions, although there is often a general correlation) and related properties, soil moisture, and soil temperature. The terms for the different characteristics were derived from Greek and Latin roots. The classification system is hierarchical, with six categories (from general to specific): order (Table 3), suborder, great group, subgroup, family, series. A formative element of the term used at each higher category is carried down through successive lower categories. At the subgroup level the classification consists of two words. For soil-geomorphological and geoarchaeological research, an understanding of the classification to the great group or possibly subgroup is usually sufficient.

The soil classification system now used in the United States is criticized by some, particularly geologists (e.g., Hunt, 1972; Morrison, 1978). Hallberg (1984) provides an excellent overview and critique of Soil Taxonomy from the perspective of a geologist. Much of the criticism of the new classification system is aimed at the terminology introduced, the absence of genetic information, and the difficulty of applying it to buried soils. The last point is of concern in soil-geomorphic studies. However, much of the basic terminology found in Soil Taxonomy remains useful in such circumstances, even if full classification is not. While some terms appear odd at first, they are easily learned. Once the basic diagnostic terms are known, a vast number of classifying words can be created. The result is that a single word describes a large amount of qualitative and quantitative information. Moreover, the system is used by most soil scientists, and one has to be familiar with the system to understand the basic soil literature.

Knowing how to describe or classify a soil is the first step in using soils in archaeology, as such knowledge is a tool for interpretation. The number of archaeological site reports with descriptions and classifications of soils, but no further discussion of them, suggests that this aspect of classification is poorly understood by many archaeologists and collaborating soil scientists and geologists.

The term "paleosol" is widely used in archaeology and other Quaternary studies and is variously defined (Fenwick, 1985). The definitions include: soils of obvious antiquity (Morrison, 1967, p. 10), ancient soils (Butzer, 1971, p. 170), soils formed on a landscape of the past (Ruhe, 1965, p. 755; Yaalon, 1971, p. 29) or under an environment of the past (Yaalon, 1983), or as soils formed under conditions generally different from those of today (Plaisance and Cailleux, 1981, p. 702). Specific types of paleosols include buried soils, which are soils covered by sediment (Fig. 1); relic soils, which are soils formed on preexisting landscapes and never buried; and exhumed soils, which are soils that were buried and subsequently reexposed (Ruhe, 1965; Valentine and Dalrymple, 1976). In these definitions, exactly what constitutes a preexisting or past landscape or a past environment or how old the soil must be is never defined. Because landscapes are always subjected to some modification—the environment is never static—and because all soils take some time to form, one might argue that all soils are paleosols and all unburied soils are relic soils, making such terms redundant. Following the arguments of Catt (1979, 1986) and Kemp (1985) among others, my preference is simply to use the term "soil"; it can then be described as a surface or buried soil. Subsequent discussions can then review its genetic history.

There are several proposals for formal soil-stratigraphic terminology (similar to the group-formation-member terminology used for lithostratigraphic units; Parsons, 1981; North American

<table>
<thead>
<tr>
<th>TABLE 2. GENERAL CONCEPTS FOR SELECTED DIAGNOSTIC HORIZONS IN SOIL TAXONOMY*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Epipedons</strong>†</td>
</tr>
<tr>
<td>Moll—Deep, dark, humus-rich surface horizon with abundant cations (A, A and B).</td>
</tr>
<tr>
<td>Histic—Surface horizon very high in organic matter (O).</td>
</tr>
<tr>
<td>Anthropic—Mollile epipedon high in phosphorous content.</td>
</tr>
<tr>
<td>Ochric—Surface horizon that does not meet the qualifications of any other epipedon (A).</td>
</tr>
<tr>
<td><strong>Subsurface Horizons</strong></td>
</tr>
<tr>
<td>Alble—Light-colored horizon with significant loss of clay and free iron oxides (E).</td>
</tr>
<tr>
<td>Argillie—Horizon of significant clay accumulation (Bt).</td>
</tr>
<tr>
<td>Natric—Argillie horizon high in sodium (Bnn).</td>
</tr>
<tr>
<td>Spodie—Horizon of significant accumulation of aluminum and organic matter with or without iron (Bh, Bs, Bhs).</td>
</tr>
<tr>
<td>Oxic—Horizon virtually depleted of all weatherable primary minerals and very low in bases.</td>
</tr>
<tr>
<td>Cambie—Some reddening and/or structural development; reorganization of carbonates if originally present (Bw).</td>
</tr>
<tr>
<td>Calcie—Horizons of significant accumulation of calcium carbonate (Bk).</td>
</tr>
<tr>
<td>Petrocalcite—Calcic horizon strongly cemented by calcium carbonate (K).</td>
</tr>
</tbody>
</table>

*For complete list and criteria see Soil Taxonomy; considerable field and laboratory data are necessary to determine diagnostic horizons. Diagnostic horizons are not exact equivalents of field designations (Table 1) (e.g., not all Bt horizons are argillic horizons), although there is a general relationship. Some probable field equivalents are given in ( ).

†Epipedons are surface horizons.
TABLE 3. GENERAL CONCEPTS OF THE SOIL ORDERS IN SOIL TAXONOMY*

<table>
<thead>
<tr>
<th>Soil Order</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entisols</td>
<td>Little evidence of pedogenesis (A-C, A-R); very few diagnostic horizons.</td>
</tr>
<tr>
<td>Inceptisol</td>
<td>More pedogenic development than Entisol with diagnostic surface and subsurface horizons, but not as well developed as most other orders (A-Bw).</td>
</tr>
<tr>
<td>Aridisols</td>
<td>Soils formed in desert conditions (Entisols can also be found in deserts) or under other conditions restricting moisture availability to plants (high salt content; soils on slopes); with or without argillic horizon (A-Bw-Bk; A-Bt-K).</td>
</tr>
<tr>
<td>Mollisols</td>
<td>Have mollic epipedon and are high in bases throughout.</td>
</tr>
<tr>
<td>Alfisols</td>
<td>Have argillic horizon, but no mollic and are lower in bases than Mollisols (A-Bt).</td>
</tr>
<tr>
<td>Spodosols</td>
<td>Soils with spodic horizons (O-A-E-Bh/Bs/Bhn).</td>
</tr>
<tr>
<td>Ultisols</td>
<td>Have argillic horizons, but are very low in bases (A-Bt).</td>
</tr>
<tr>
<td>Oxisols</td>
<td>Have oxic horizon.</td>
</tr>
<tr>
<td>Histosols</td>
<td>Organic soils.</td>
</tr>
<tr>
<td>Vertisols</td>
<td>Soils high in clay content that shrink and swell markedly.</td>
</tr>
</tbody>
</table>

*To properly classify a soil one must follow the guidelines and criteria for diagnostic horizons and classification in Soil Taxonomy.

Commission on Stratigraphic Nomenclature, 1983). Some of the terms, such as “geosol,” were proposed for several decades (e.g., Morrison, 1967). However, few investigators found the terms useful, judging from their absence in the literature.

Soil surveys

Systematic, county soil surveys have been carried out in the United States since the turn of the century. The program is now directed by the Soil Conservation Service, U.S. Department of Agriculture. The mapping of the United States is far from complete, but the surveys are available for many counties. With proper interpretation, much information can be gleaned from the surveys for use in archaeological and soil-geomorphic investigations. The surveys often contain a good map base, useful aerial photographs, and some geological information. Most archaeologists are aware of this resource, but sometimes seem to overestimate or misunderstand their usefulness (Voight and O'Brien, 1981) as the purpose and preparation of soil surveys impose limits on their utility.

Soil surveys are prepared for land-use planning, soil conservation programs, planning agriculture programs, and financial credit. They also are being used more often for zoning, construction and engineering purposes, and land evaluation (Buol and others, 1980). However, they are not designed for use as guides to local geology or geomorphology, or for reconstructing prehistoric vegetation patterns (e.g., Tiffany and Abbott, 1982). The surveys usually include a description of the local bedrock and landforms, but the degree to which survey reports accurately depict soil-geomorphic relations varies from survey to survey, depending on the mapping scale, the area, and the training and experience of the mappers. During the course of the survey there is generally little emphasis on, or data gathered concerning, the origin or historical development of the soils.

In the interpretation of soils at a specific site, soil surveys are generalizations (Hole and Campbell, 1985). The boundaries of a particular mapping unit are not always actual soil boundaries because soils generally grade from one type into another, rather than having sharp contacts like many geologic units. In addition, the distribution of soils in a given area may be quite complex, and the mapping units will be generalizations of the complexities.

Analytical techniques

The analyses of soils in soil-geomorphic research include field and laboratory procedures. Different investigators have attempted to quantify field data as a means of assessing the relative degree of pedogenesis (soil-profile indices). The more successful approaches are summarized by Birkeland (1984, p. 24-28). Some of the most commonly and successfully used laboratory analyses include particle-size distribution (relative percentages of sand, silt, and clay); bulk density (weight per unit volume of soil); content of organic matter, calcium carbonate, iron, aluminum, and phosphorous; and micromorphology (the study of microscopic aspects of pedogenesis, typically using thin sections of the soil).

There are many laboratory analytical techniques that can be used for characterizing and quantifying various physical and chemical parameters of soils. Compendia of the more widely used and useful techniques in pedology and archaeological geology include Shackley (1975), Brewer (1976), Page (1982), Soil Conservation Service (1984), Bullock and others (1985), Klute (1986), and Singer and Janitzky (1986). Choosing a particular technique depends on a variety of factors, including what questions are being asked about the soils, the degree of precision required, whether one wants to compare results with those of another worker, and of course, the cost in time and money. Beyond finances, two basic considerations should be kept in mind when the question of analysis subsequent to field work is raised: the necessity of the analysis and the type of analysis required. My experience is that laboratory work on soils from many archaeological sites was done with no problem orientation; it was done because it was felt it should be done (see also Limbrey, 1975). Analytical data can be very important in the interpretation of soils and their application to archaeological problems, but there are occasions when the field work alone could solve the problems.
or when laboratory work is simply of no use or will not answer the question being asked.

Once the decision is made to proceed with laboratory work, selection of particular techniques is critical. For most routine analyses there are a variety of procedures or techniques, and the results of each are not always comparable nor reported in similar terms. For example, in determining particle-size distribution, there are different definitions of what constitutes the size ranges of each category (e.g., Shackley, 1975; Briggs, 1977; Blatt and others, 1980), and there are various pretreatment procedures (such as removal of organic material or carbonates) that can profoundly affect the resulting particle-size data. Phosphorous determination, commonly employed in archaeological research, also provides an example. Phosphorous occurs in a variety of forms in the soil (Walker, 1964; Eidt, 1985). Different laboratory procedures extract different forms (Blakemore and others, 1977; Eidt, 1984, 1985), and the results are not always comparable (e.g., White, 1978). In summary, the types of analyses and techniques used to analyze soils depend on the research objectives and on the analyses and techniques others have used to reach the same objectives. Also, when comparing analytical results, all terms and techniques must be either referenced or defined.

FACTORS OF SOIL FORMATION

The "state factor" approach to soil genesis (Jenny, 1941, 1980) is the theoretical framework for much of pedology. Jenny (1941, 1980) defined the factors of soil formation as climate, organisms (flora and fauna), relief (or landscaping setting), parent material, and time, often written as the equation:

\[ S = f(d, o, r, t, p, l) \]  \hspace{1cm} (1)

where \( S \) is the whole soil. Equation (1) defines the state of the soil as a function of the five factors and other, unspecified factors of local or minor importance. No one solved the equation as a whole, but Jenny (1941, 1980) proposed solving the equation by studying soil variation as a function of one factor, while keeping the others constant. For example, one could study the variation in a soil due to differences in climate by keeping all factors except climate constant. Variations in any soil property or properties can then be attributed to variations in climate. This is written:

\[ S \text{ or } s = f(c, o, r, t) \]  \hspace{1cm} (2)

where \( s \) denotes a soil property or properties. Qualitative statements about a soil forming as a function of one factor are called "sequences" (climosequence, biosequence, toposequence, lithosequence, chronosequence); and quantitative statements, where functions are solved for one factor, are called "functions" (climofunction, biofunction, topofunction, lithofunction, chronofunction).

The "state-factor" approach to the study of soil genesis, although criticized, is summarized by Birkeland (1984, pp. 162–168). In particular, the factor approach treats the factors individually, although they often act together, as do climate and biota. Additionally, there are other theoretical approaches to soil genesis (see Runge's, 1973, energy model); some of these are summarized and compared by Gerrard (1981). For the most part, however, the general validity of the state-factor approach is upheld (e.g., Yaalon, 1975; Bockheim, 1980; Birkeland, 1984) and applies to related fields (e.g., Major, 1951). This approach to pedology is particularly useful "... from the point of view of a field-oriented geologist-pedologist, working with a wide variety of soils at the earth's surface" (Birkeland, 1984, p. 166). As the same point of view is taken by many geoarchaeologists, the state-factor approach is valid in archaeological pedology.

THE STATE-FACTOR APPROACH
TO ARCHAEOLOGICAL PEDOLOGY

The soil-forming factors that are generally of most concern in archaeology are time and climate since soils are used as indicators of age, past climates, and climate change. The following sections deal with the archaeological applications of the state-factor approach to time and climate in pedogenesis. The influences of the other factors are then discussed. Some examples are not related to archaeological research, because little of this type of work has been done in archaeological contexts, but these examples can be used to illustrate the principals and the potential for archaeology.

Time and pedogenesis

The concept that some time must elapse before a soil can form is probably one of the most significant aspects of pedology in archaeology. The presence of a soil in an archaeological site is evidence that there was a significant period of landscape stability (i.e., relatively little or no erosion or deposition). In my experience, many investigators apparently assume that in an archaeological site of some depth, especially a stratified site, sedimentation occurred more or less continuously. However, in many situations, such as alluvial or eolian depositional environments, deposition can occur relatively instantaneously, conceivably in a matter of days, certainly in a matter of years or decades. Soils almost invariably take longer to form; usually it takes at least 100 or several hundred years, commonly thousands of years to form. A good case in point is the Lubbock Lake site on the Southern High Plains of Texas, where I conducted geological and pedological studies for several years (Holliday, 1982, 1985a, b, c, d, e). Sediments ranging from 3 to 6 m thick accumulated episodically over the past 11,000 years. The periods of deposition and soil formation are well dated by over 100 radiocarbon ages (Holliday and others, 1983, 1985), and from a plot of sedimentation rates through time (Fig. 2) we see that the landscape was stable and soils were forming for 6,000 of the past 11,000 years.

The degree of development of a soil profile or specific pedologic features in a profile can be used as relative indicators of time
Pedology in archaeology

provide an age for natural or cultural deposits (Fig. 3) in similar situations elsewhere. The Lubbock Lake site is such a situation. A late Holocene chronosequence was defined at the site (Holliday, 1985c). Rates and characteristic features of soil development were established by combining field and laboratory data with the well-dated geochronology (Holliday, 1982; Holliday and others, 1983, 1985; Figs. 4, 5). The resulting information on pedogenesis is now being used to determine the age of soils, and by inference their parent materials, at other localities in similar settings on the Southern High Plains.

In comparing soils from site to site for dating purposes, the soils being compared must be in similar landscape positions and parent material. Both factors influence soil morphology even in very young soils (see below). Furthermore, other considerations, such as stratigraphic relationships and archaeology must be taken into account: soils similar in morphology can form at different periods in time.

Baseline studies on rates of soil development such as that described for Lubbock Lake have been conducted in other parts of the United States, albeit with varying degrees of age-control reliability. In the Sandhills dune field, also on the Southern High Plains of Texas, Gile (1979, 1985) documented the rates and nature of argillic horizon formation in dunes of various ages. Gile and others (1981) summarized a classic investigation of soil-geomorphic relations in the desert around Las Cruces, New Mexico, including information on rates of argillic and calcic horizon formation in parent materials of different lithologies and in different landscape positions. Scott (1963), Machette (1975; Fig. 3), and Holliday (1987a) discussed various aspects of soil development on terraces of the South Platte River in eastern Colorado, an area famous for its abundance of Paleoindian sites (e.g., Anderson and Holliday, 1984). Shlemon (1978) defined a chronosequence in the southeastern Mojave Desert of California and Arizona and used these data to provide age estimates for several controversial archaeological sites in the area (Bischoff and others, 1978, 1981; Shlemon and Badinger, this volume).

McFadden and others (1986) also carried out research on rates of pedogenesis in the eastern Mojave, and McFadden and Weldon (1987) conducted a similar study in the Transverse Ranges of California. In Wyoming, Reider and others (1974) established a late Quaternary chronosequence in the Laramie Basin and incorporated their data into related archaeological investigations. Several Holocene chronosequences were investigated in the northeastern United States, including the Ridge and Valley area of central Pennsylvania (Bilzi and Ciolkosz, 1977b), and the upper Susquehanna River basin of New York (Scull and Arnold, 1981). Limited information on the degree of profile development at archaeological sites in the Brooks Range of Alaska is also available (Reanier, 1982). Finally, Harden and Taylor (1983) presented a fine example of the use of soil indices for comparing pedogenesis in chronosequences in different climatic regimes.

In defining various chronosequences and determining rates of pedogenesis, the effects of climate cannot be held constant elapsed after deposition of parent material and, in some situations, as an approximate indicator of age. This application of soils is derived from the concept of the state factors of soil formation. In a situation where there are a number of soils and where the influence of parent material, landscape position, climate, and flora and fauna can be considered negligible, held constant, or otherwise accounted for, the soils with stronger profile development can be considered older than those that are less developed. Pedologic features that are time dependent include overall profile morphology, as determined by soil indices (Bilzi and Ciolkosz, 1977a; Harden, 1982); profile thickness (Machette, 1975; Birkeland, 1984); illuvial clay content and reddening of the B horizon (Gile and others, 1981; Harden, 1982; Birkeland, 1984; McFadden and others, 1986); calcium carbonate accumulation Gile and others, 1981; Machette, 1985; McFadden and others, 1986); alteration or formation of certain clay minerals (Shroba and Birkeland, 1983; Birkeland, 1984; McFadden and Hendricks, 1985); and alteration or translocation of certain forms of iron, aluminum, and phosphorous (Scott, 1977; Birkeland and others, 1979; Birkeland, 1984; McFadden and others, 1986).

In an archaeological site with a chronosequence and also containing time-diagnostic artifacts, radiocarbon ages, or some other form of absolute age control, one can determine rates of soil formation and, using stratigraphic correlation techniques, can

Figure 2. Plot of sedimentation rates at Lubbock Lake over the past 11,000 years. Note the episodic nature of depositional events and the relatively long intervals of landscape stability and soil formation. Numbers = strata; letters = soils. Fv, Firstview Soil; Yh, Yellowhouse Soil; Li, Lubbock Lake Soil; Ap, Apache Soil; Sg, Singer Soil (from Holliday, 1985a).
**Age of Soils (yr BP)**

Maximum CaCO₃% in Calcic (k,K) Subhorizons

Figure 3. A chronosequence from the South Platte drainage in Colorado. Note that the maximum soil development is on parent materials of different ages. The three youngest soils formed in sandy alluvium, the 140,000-yr soil in pebbly sand, and the two oldest soils in sandy gravel (modified from Machette, 1975, with permission). See Table 1 for soil-horizon symbols.

Figure 4. Generalized soil-stratigraphic relationships at the Lubbock Lake site. See Table 1 for soil-horizon symbols.
because climate fluctuated considerably during the Quaternary. This does not pose as big a problem as it might seem. A steady rate of soil development need not be assumed in using soils as age indicators. For relative age estimates, one simply assigns a qualitative estimate of soil age (e.g., the soil is “young” or “old”). A soil with a well-expressed profile probably took longer to form than one with a poorly expressed profile if both formed in the same area, the same parent material, and a similar landscape setting. If the degree of soil development is used to make absolute age estimates, one must start with an independent age control such as radiocarbon determinations. Then, the rate of soil development is calculated relative to either a given number of years or a specified period in the geologic past (e.g., the early Holocene). With sufficient comparative data, the effect of climate changes on soil formation should be determinable in a general manner. These data can then be applied when using soil information to determine ages for other sites in the region.

**Climate and pedogenesis**

Often, among the goals of archaeological research is the reconstruction of the climate when a site or region was occupied, or the detection of climatic change over a long period of occupation or at the time of abandonment. Certain soil properties and soil types are related to climate. Therefore, if the effects of the other soil-formation factors are constant or negligible, then soils can be used to obtain some paleoclimatic data. For a variety of reasons, however, soils probably are of limited use for reconstructing climates in archaeological investigations. In general, soils are not sensitive to discrete climate changes that may be culturally significant. Such changes are more easily detected from plant or animal remains. Furthermore, climatic changes in the Holocene, the time period that most North American archaeologists deal with, were often of insufficient magnitude to be detectable in the pedologic record. Finally, soil properties related to the time factor are often difficult to separate from those related to climate. Some pedologic properties, such as reddening of the B horizon, can be time, climate, or chemically dependent. Following a climatic change, some time is also required for a soil’s pedologic properties to reflect a new climate, and even then, properties related to the previous climate may persist. In general, therefore, the comments of Valentine and Dalrymple (1976, p. 218) are well taken: “Although soil science is under great pressure to furnish environmental evidence, it is debatable whether

Figure 5. Generalized sequence of selected late Holocene sedimentological, pedological, and cultural events at the Lubbock Lake site. Numbers 1 and 2 in figures (a) and (b) are a sequence of specific events; (f) is a diagramatic cross-section of the present-day soil-stratigraphic and geochronologic relationships along the valley margin.
we understand the interaction of the soil-forming processes with the site and environmental factors well enough yet to make confident extrapolations.”

In some situations, however, soils are useful in providing some general paleoclimatic and paleoenvironmental data. General discussions of the applications of pedologic information to the reconstruction of Quaternary climates are provided by Ruhe (1970), Yaa loans (1971), and Birkeland (1984). Climate most directly influences pedogenesis through precipitation and temperature, and indirectly through vegetation (Birkeland, 1984, p. 275). The soil properties that best reflect those climatic parameters include (1) overall profile morphology; (2) organic-matter content; (3) depth to leaching, which would affect the presence or absence of CaCO₃ and the more soluble salts; and (4) the depth to the top of the carbonate or salt accumulation zone (e.g., Gile and others, 1981; McFadden and others, 1986).

Climatic change probably is the dominant factor producing differences in the morphologies of early and middle Holocene soils, as opposed to those of the late Holocene at the Lubbock Lake site (Holliday, 1985b, c; Fig. 4). From 8,500 to about 6,300 yr BP, the Firstview Soil developed. It has dark colors (evidence that it contained abundant organic matter), a zone of reduction or gleying immediately below the surface horizon from groundwater activity just below the surface, and locally, abundant siltified plant remains in the surface horizon. The soil was buried by calcareous lake sediments. The Yellowhouse Soil formed in the calcareous sediments from before about 5,500 yr BP to no later than 5,000 yr BP. It has a thick, organic-rich A horizon. The organic-rich nature of both soils, and the gley horizon in the Firstview Soil, as well as the absence of carbonate leaching in the Yellowhouse Soil, are evidence that a high water table was present throughout the early and into the middle Holocene. In contrast, the late Holocene soils have A-Bw/Bt-Bk horizon sequences typical of well-drained soils in semiarid conditions. These data are evidence that the water table was dropping by the end of the middle Holocene, probably due to less effective precipitation. The presence of silica (in siltified plant remains) in the Firstview Soil and CaCO₃ in the Yellowhouse Soil are evidence of a geochemical change in the ground water from the early to middle Holocene, possibly related to increased temperature. The overall stratigraphic and pedologic sequence, therefore, is indicative of a general drying and warming trend through at least the early and middle Holocene. This is also apparent in soils at other localities in the region (Haynes, 1975; Holliday, 1985d, e).

Reider (1980, 1982a, b) used pedologic data for paleoenvironmental reconstructions at archaeological sites in Wyoming. The climatic trends deduced from soils at those sites are generally similar to those from the Southern High Plains. Soils of latest Pleistocene and early Holocene age are typified by dark colors and mottling (zones of alternating reduction and oxidation), which result from relatively high organic-matter production under conditions of impeded drainage and a locally high water table. Soil profiles formed later in the Holocene develop characteristics typical of well-drained conditions with zones of carbonate accumulation and sometimes more soluble salts, suggesting semiarid to arid climate. Reider and Karlstrom (1987) also used pedologic evidence to infer spring activity in the foothills of the Big Horn Mountains of Wyoming during the middle Holocene, which is otherwise characterized by arid conditions in the region.

An excellent example of using soils for climatic reconstructions is provided by Sorensen and others (1971), Sorensen and Knox (1973), and Sorensen (1977). Their research was carried out in and near the forest/tundra ecotone in northern Canada. By mapping the distribution of modern forest and tundra soils and comparing the data to the position of present-day air masses, then mapping the occurrence of buried and altered forest and tundra soils and dating the soils, they were able to reconstruct paleo-air mass frequencies and correlate these shifts to climatic changes during the Holocene.

The concept of the soil-forming interval is also important in the use of soils for climate reconstructions. This idea was formulated and expanded upon, primarily by Morrison (1967, 1978), and commonly applied in the western United States. The soil-forming intervals were defined as discrete periods of accelerated soil formation related to particular climatic episodes. Classically, the soil-forming intervals were related to warmer and wetter climate. Little soil formation would take place during intervening cooler and drier episodes. This approach was criticized by some (summarized by Birkeland, 1984, p. 330–334), who argued that soil formation always occurs when the landscape is stable, although specific aspects of pedogenesis may vary as a function of climate.

The best example of the soil-forming interval in archaeological pedology in North America is the “Alithermal soil.” This is a soil profile, typically buried, reported from many Holocene, primarily alluvial, stratigraphic sequences in the central and western United States (e.g., Leopold and Miller, 1954; Malde, 1964; Haynes, 1968; Reider, 1980, 1982a, b; Albanese, 1982). The soil is characterized by a moderately well-developed Bw or Bt horizon underlain by a distinct zone of calcium carbonate accumulation (Bk). The carbonate accumulation in particular is thought to develop when pedogenesis takes place under warmer and possibly drier conditions related to the middle Holocene thermal maximum, the Alithermal.

In very few instances is the precise age of the soil known, particularly the age of burial by the overlying sediments. In the absence of such data, an alternative hypothesis is that such a soil is not related to a short interval of drier climate, but formed over a longer period of time. For example, at the famous Clovis site (Blackwater Draw Locality 1), Haynes (1975) reported a well-developed soil, which he believed formed in the middle Holocene and considered to be related to a short period of warmer and drier climatic. Now there is evidence that at the Clovis site and across the Southern High Plains the middle Holocene or Alithermal was characterized by eolian deposition, not soil formation (Holliday, 1984, 1985d). The well-developed soil observed at Clovis and reported at many other sites in the area formed in the late Holocene (Holliday, 1985c, d, e). Therefore, in at least some
situations, climatic change or climatic extremes are reflected by depositional or erosional events, rather than periods of soil formation.

Organisms, relief, and parent material

The pedologic information based on the influence of the factors of organisms, relief, and parent material are less applicable in archaeological research than data derived from studies of the state factors of time and climate. There are some aspects of their influence that have some practical applications in archaeology. Flora and fauna certainly exert an influence on the soils in which they form, and they can leave a variety of remains in the soil as clues to reconstructing floral and faunal assemblages.

There is only a limited amount of information by which pedologic features can be related to past plant and animal communities. Further, plant and animal distribution is so closely linked to climate that sorting out the effects of each is often difficult. The best reconstructions from plant and animal remains are vegetations reconstructions from restricted areas where researchers assume the regional climate was constant at any one time. Most of this work was done on the ecotone between forested and unforested (including both prairie and tundra) regions. Alfisols with E horizons and Spodosols typically form under forested conditions, while Mollisols, Alfisols without E horizons, and Inceptisols commonly form in the nonforested areas. Because the forest boundary fluctuated through time as a function of climatic change, forest soils left their imprint in some nonforested-area soils; the reverse was also true. The work by Sorenson and others (1971), Sorenson and Knox (1973), and Sorenson (1977) is an example of such a study. There, mapping and dating of buried and altered forest and tundra soils were used to reconstruct shifts in the forest-tundra boundary throughout the Holocene. A number of similar investigations were carried out along the ecotone of the forests of the midwestern United States, the prairies of the Great Plains (e.g., Ruhe and Cady, 1969; Ruhe, 1970; Albarrak and Lewis, 1978), and in an archaeological context, at the foot of the Canadian Rockies (Reeves and Dormaar, 1972). Soil morphology and chemistry, along with other evidence, was also used to dispel the long-held belief that the Southern High Plains was covered by a boreal forest at the close of the Pleistocene, the time of the earliest human occupation of the region (Holliday, 1987b).

The properties of a soil can vary as the parent material or relief changes. These variations influence soil profile morphology, making it difficult to trace a particular soil or to use it as a stratigraphic marker. This is especially significant when working on a large archaeological site or over a larger area such as a drainage basin where only limited natural or artificial exposures are available. On the time scale of the Holocene, probably one of the most significant influences that parent material imposes on a soil is in affecting water movement through the soil. Coarser-textured soils are more permeable than fine-grained soils; hence, there is faster through-flow of water. Gile and others (1966, 1981), for example, showed quite clearly how the morphology of calcic horizons varies markedly as the texture of the parent material changes. Furthermore, textural variations in parent material at one locality (e.g., an alluvial deposit consisting of a layer of fine sand over a lens of gravelly sand) can also significantly influence the resultant profile morphology.

A particular type of parent material, clay, can profoundly influence archaeological sites as it will often produce a soil classified as a Vertisol (Table 3). The shrinking and swelling characteristic of this soil can destroy the stratigraphic and cultural contexts of a site (Duffield, 1970; Wood and Johnson, 1978). In fact, Duffield (1970) suggests that in Texas, where Vertisols are widespread and were probably difficult to till by prehistoric agriculturists, Vertisols were probably a significant factor in restricting the westward spread of village farmers.

Slope position can affect soil-profile morphology in several ways. Within a large area such as a drainage basin the orientation of the slopes is important. For example, Lotspeich and Smith (1953) show that significant differences in soil morphology are apparent between north-facing and south-facing slopes. Water movement over and through soils is also influenced by slope position. In many situations, soils near the summits of slopes are better drained, but receive less effective moisture (due to run off) than soils at the foot of slopes (e.g., Ruhe, 1969; Daniels and others, 1971; Jenny, 1980; Hall, 1983; Birkeeland, 1984). Material is constantly removed from the surface of soils in upslope positions, whereas soils at the foot of a slope tend to accumulate the materials eroded from above. The morphology of a soil can therefore vary markedly along a slope (e.g., Swanson, 1985; Berry, 1987). An understanding of such pedologic variation as a function of slope position is particularly significant when using soils to date landscapes.

The concept of variation in soil morphology as a function of landscape setting can be quite useful in landscape and local environmental reconstruction. This is particularly applicable to buried soils, which are the upper portion of a buried landscape. Daniels and Jordan (1966) and Ruhe (1969), among others, applied these principles to regional and local reconstructions of Quaternary landscapes in a series of investigations in Iowa. In a strictly archaeological context, the principle is well illustrated at the Lubbock Lake site. There, Holliday (1985b) showed that there is considerable variation in the Firstview Soil as a function of landscape setting and microenvironment. Along the valley margin the soil is well drained, as indicated by oxidation colors (Fig. 4). The presence of some calcium carbonate in the profile and a thin A horizon with low organic carbon content are also evidence of relatively dry conditions. Along the valley axis the soil was very poorly drained (Fig. 4). A somewhat similar situation was described for the overlying Yellowhouse Soil. At the Clovis site in New Mexico, several early to middle Holocene soils also vary considerably due to landscape setting (Haynes, 1975; Holliday, 1985d). Other examples of archaeological uses of buried soils to reconstruct landscapes are the Delaware Canyon site (Ferring, 1982) in Oklahoma, the Napoleon Hollow site (Wiant and others...
Soils as Stratigraphic Markers

Soils are commonly used as stratigraphic markers in archaeological research. The unique physical and chemical properties that distinguish soils from sediments make soils quite useful for stratigraphic subdivision and correlation. However, the nature of soils also necessitates the exercise of a certain amount of caution in their use as stratigraphic markers.

The presence of a soil in a stratigraphic sequence marks the passage of some amount of time with little or no erosion or sedimentation, although the soil's parent material may have been deposited virtually instantaneously, as discussed earlier. If the soil in such a sequence is buried, the contact between the top of the soil and the sediments that bury it marks a gap in time. This means that cultural materials found at the top and bottom of even a thick deposit may be nearly contemporaneous, whereas an artifact near the top of the unit may be considerably older than an artifact immediately above, on the paleosurface (Fig. 5). Moreover, artifacts found on a paleosurface may well be a mixture of cultural material left on the surface during the entire period of soil formation (Fig. 5). The artifacts and occupation zones are also subject to mixing by biologic and geologic activities (Duffield, 1970; Wood and Johnson, 1978; Hole, 1981; Stein, 1983), as well as stratigraphic compression. This was encountered at the Lubbock Lake site (Johnson and Holliday, 1986), the Wilson- Leonard site in central Texas (Holliday, 1989), at several sites in southwestern Oklahoma (Ferring, 1982), the Shawnee Minisink site in Delaware (Dent, 1985), and probably occurs at many other stratified sites. On the positive side, the surface of a buried soil may be a zone likely to contain archaeological material because it was formed on a stable landscape.

The time represented by a surface of a buried soil is also important in interpreting radiocarbon ages determined on the organic matter found in buried A horizons. Because the organic matter accumulates over time, the radiocarbon age is the non-mathematical average age or apparent mean residence time of the A horizon plus the time since burial. Samples from buried A horizons are also subject to contamination by younger organic compounds moving in from overlying soils, among other problems (Campbell and others, 1967; Scharpenseel, 1971, 1979; Martel and Paul, 1974; Burleigh, 1978; Matthews, 1985). Under proper circumstances, however, such dating can be useful in providing a minimum date for deposition of the parent material and beginning of pedogenesis, as well as a maximum date for soil burial (e.g., Holliday and others, 1983, 1985; Matthews, 1985; Haas and others, 1986).

In using buried soils as stratigraphic markers, one cannot assume that the amount of time represented by the contact with the overlying sediment is always the same, since differential burial of the surface may take place (Fig. 5).

Soils can be useful in identifying various strata, but they should never be considered strata themselves or referred to as "strata" or "layers," or otherwise treated like geologic deposits. This point is well made by Tamplin (1969). At the Lubbock Lake site, almost all of the A horizons of the various buried soils were designated as some sort of strata since the first excavations in 1939. However, I must emphasize that a soil profile is imprinted over geologic deposits through time. Furthermore, the boundaries between soil horizons often bear no relation to geologic layering. Depending on the slope of the surface on which the soil forms and variations in the permeability of the parent material, soil horizons can crosscut depositional layering. At the Lubbock Lake site a prominent calcic horizon was designated as a "strata" during early investigations, and artifacts were excavated accordingly (Johnson and Holliday, 1986). Now we know that where the earlier excavations took place the calcic horizon cuts two geologic deposits and an intervening buried soil (Fig. 4). As a result, artifacts found in the calcic horizon could be as much as 6,000 years old or less than 5,000 years old.

Furthermore, pedogenesis can obscure sedimentary features as well as the original particle-size distribution of the parent material. For example, one of the criteria often used to differentiate between a B horizon and a C horizon is whether bedding in the parent material is obscured. Evidence of bedding can persist in a B horizon if the original beds included lenses of gravel; otherwise the sedimentological history of the parent material must be reconstructed from laboratory data. Further, our understanding of a site's depositional history is complicated by the fact that significant amounts of illuvial (post-depositional) clay can accumulate in Holocene soils.

CONCLUSIONS

Soils are important components of archaeological sites. Their most common use is as stratigraphic markers. Soil chemistry is also applied as a tool to identify habitation areas or specific activity areas or to detect evidence of agricultural activity. Less commonly, researchers view soils as natural entities, constituting a type of near-surface weathering phenomenon that grows as a three-dimensional body in sediment through time, under the influence of its parent material, the slope on which it develops, and the climate, flora, and fauna. With this concept in mind, soils are important as indicators of age, local environment, and by inference, the climate. In addition, archaeological data can be useful to pedologists (e.g., Sandor and others, 1986; Collins and Shapiro, 1987).

Pedology is concerned with the genesis and classification of soils and is founded on geomorphic principles and data. Many archaeologists are somewhat familiar with soil classification, but this is only one of many research tools available in archaeological pedology and soil-geomorphology. The complete integration of pedology into other areas of research requires an understanding of soils far beyond their basic terminology. No archaeologist is expected to become a pedologist any more than they are expected
to become palynologists, zoologists, or sedimentologists. However, an understanding of the basic principles of pedology, as well as other disciplines, is essential for communication with specialists in such disciplines. A knowledge of the potentials, limitations, and assumptions underlying the study of soils, as well as knowing what questions to ask a pedologist, can aid considerably in conducting an efficient and more complete investigation.

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