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Deposits for Archaeologists

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INTRODUCTION

Stratigraphic excavations in archaeology are based on the concept of deposits and depositional events, and the classification and interpretation of deposits have changed through the decades. The concept of the deposit has been used for many purposes: to establish human antiquity, to provide relative dates, to reconstruct the environment, and to analyze site formation processes.

Noting the type of deposit and appropriate contextual association of artifacts was an essential part of the early history of archaeology when human antiquity was being established in Europe (Grayson 1983; Daniel 1976). In North America, establishing the timing of the peopling of the New World has focused the attention of archaeologists on the analysis of deposits (Meltzer 1984), initially at the Trenton Gravel Site, New Jersey (Abbot 1876, 1877, 1878; Shaler 1877; Wright 1889), and later at Folsom, New Mexico (Cook 1927; Figgins 1927; Bryan 1929, 1937), at Clovis, New Mexico (Howard 1935; Antevs 1935; Holliday 1985), at Sandia Cave, New Mexico (Bryan 1941), Ventana Cave, Arizona (Bryan 1950), and Meadowcroft Rockshelter (Adovasio *et al.* 1979).

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In some cases the discovery of Ice Age deposits located below those containing artifacts allowed archaeologists to infer an age for the artifacts. For example, the identification of solifluction-lobe deposits located below the bone- and wood-bearing deposits found at Star Carr, England, allowed Clark (1954) to assign a postglacial date for the site. At the Boylston Street Fishweir Site in Boston, Massachusetts, Johnson (1942, 1949; Judson 1949) was able to assign a date to the fish weir on the basis of the sedimentary characteristics of the deposits in which it was found. These sediments indicated that sea level was lower at the time of the fish weir's construction, leading Johnson to propose that the fish weir was of great antiquity, but that it did not date to the Ice Age. In the lower Mississippi River delta, postglacial sites were dated on the basis of the deposits in which they were found (Fisk 1940, 1944; Ford 1951; Ford and Quimby 1945; Ford *et al.* 1955; Ford and Webb 1956; Gagliano 1984; Kniffen 1936; McIntire 1958; Pearson 1986; Russell 1936; Saucier 1974). The law of superposition dictated that the sites could not be older than the deposits on which they rested. Those deposits could be dated on the basis of geological correlation of deltaic deposits.

The analysis of deposits became crucial when a more ecological orientation began to overshadow the approach of cultural history. The new orientation, called either an ecological approach (Watson *et al.* 1984), the geographical perspective (Daniel 1976; Haag 1957), or environmental archaeology (Willey and Sabloff 1980), focused on the reconstruction of landscape, fauna, and flora. These activities all required a new awareness of the contextual associations of sedimentary particles in deposits. Initially, the artifacts were associated with geomorphic landforms (Clark 1936, 1952; Crawford 1912; Fox 1932; Guest 1883; Piggott 1949; Childe 1956). In some cases the orientation expanded into a more ecological approach that considered the environments's effect on past cultural systems (Braidwood and Howe 1960; Braidwood *et al.* 1983; Butzer 1960, 1976b; Byers 1967; Kroeber 1939; McDonald and Rapp 1972; Quimby 1954, 1955, 1960; Rapp and Aschenbrenner 1978; Taylor 1948; Wedel 1941).

Following from the ecological orientation, archaeologists recognized that the record is a contemporary phenomenon with a complicated history (Binford 1968, 1976, 1979, 1981a,b; Schiffer 1972, 1975, 1976, 1979, 1983, 1987; Hughes and Lambert 1977; Reid 1985; Reid et al. 1975; Sullivan 1978; Willey and Sabloff 1980; Raab and Goodyear 1984; Wood and Johnson 1978). This new emphasis, that of focusing on the formation processes of the archaeological record, forced archaeologists to examine deposits closely. Following the example of Schiffer (1972, 1976, 1983, 1987), most research on site formation has focused on two very different aspects. The first considers the artifacts contained in the deposits to explain "how the archaeological record is produced in terms of explicit models, theories, and laws of how cultural systems operate'' (Schiffer 1972:156). The second, equally important for attaining the stated goal, is the examination of the ''non-cultural domain'' (Schiffer 1972:156) or ''N-transforms'' (Schiffer 1976:15–16). Most archaeologists agree that the archaeological record contains both cultural and natural elements and that they are related to each other in the context of the deposit. Yet most archaeologists believe that these two elements should somehow be analyzed separately. Thus, although the focus of archaeologists has shifted toward examining the deposit, it is thought to contain two types of information that require two separate types of analytic techniques.

In archaeology the deposit has been recognized as an important unit of study for dating, environmental reconstruction, and for the study of site formation processes. Yet archaeologists excavate, describe, and interpret ''the deposit'' in grossly different ways. In this chapter the concept of the ''deposit'' is examined: initially by defining what a deposit is and how it can be described and related in space and time to other deposits (stratigraphy) and then by examining various methods of describing (attributes) and interpreting the contents of deposits.

THE DEPOSIT

A deposit has been defined in archaeology (Schiffer 1983, 1987) as a three-dimensional unit that is distinguished in the field on the basis of the observable changes in some physical properties. Thus, the deposit is defined on the basis of its physical properties and the boundaries that define its three-dimensional character. In geology the equivalent of a deposit is a bed (Campbell 1967; Reineck and Singh 1980). A bed is a single ''sedimentation unit formed under essentially constant physical conditions . . . (with) constant delivery of the same material during deposition'' (Reineck and Singh 1980:96). The internal character of the bed can be layered, the layers being called laminae and produced as a result of some minor fluctuations in rather constant physical conditions.

In geology and in archaeology, a bed or deposit is an aggregate of sedimentary particles. Sediments are particulate matter that has been transported by some process from one location to another (Blatt *et al.* 1972; Krumbein and Sloss 1963; Hassan 1978; Stein 1985). Because geologists do not restrict the transport agents of these particles to noncultural agents, all particles (including artifacts) found in arachaeological deposits can be viewed as sediments.

Geologists study sediments by initially classifying the sediment as clastic or chemical. Chemical sediments are formed by compounds precipitating out of solution, such as salt deposits and carbonates. Clastic deposits are formed mechanically from the detritus of pre-existing rocks and are produced when rocks (either igneous, metamorphic, or sedimentary) are attacked by mechanical or chemical weathering processes (Birkeland 1984). Weathering is capable of transforming a hard, smooth rock surface into a mass of unconsolidated particles consisting of individual mineral crystals or fragments of the rock itself. Once the weathered particles (not yet called sediments because they have not been transported) are exposed, they can be transported by gravity, water, ice, wind, or biological agents. Transportation continues until the competence of the agent is decreased, at which time the particle (now a sediment) is deposited. The site of deposition is the place where the transporting agent's competence decreased below a critical threshold. After deposition, the sediment can be altered by soil-forming processes or by lithification.

These events (weathering, transport, deposition, post-depositional alteration) are defined by the principles of sedimentation (Blatt *et al.* 1972; Krumbein and Sloss 1963; Reineck and Singh 1980; Twenhofel 1950; Stein 1985a; Stein and Rapp 1985). These four aspects of the principles of sedimentation are the four stages through which a sediment passes and are the aspects that must be reconstructed if the sediment's depositional history is to be reconstructed. They represent the interpretations that flow from the description of the sediment.

All sediments in a deposit are part of one depositional event. As long as the specific history of the sediment (e.g., sources, transport agents, environment of deposition) remains the same, the resulting deposit represents one depositional event. A depositional event is the result of the collection of sediments from one or many sources, the transport of that material by any competent agent or group of agents, and the deposition of the sediments whenever and wherever the competency of the transport agent is reduced and where a suitable "basin" is located. Each deposit represents one depositional event, during which time the sources, transport agents, and environment of deposition remained the same. The duration of such a depositional event is not often known. A single deposit may represent either continuous or abrupt deposition over either long or short periods of time.

The sedimentary particles in the deposit (e.g., sherd, rock, bone, seed, or charcoal fragment) may come from diverse sources, be of diverse ages, or be transported by diverse agents. Any particle contained in the deposit is related to any other particle in that they are part of one depositional event. If appropriate attributes of the particles are described adequately, then the interpretation of the processes responsible for bringing all the sediments together within the deposit is discernible.

A deposit is described by the physical and chemical properties, or attributes, of the sediment that it contains. Selected on the basis of their relationship to geological processes operating in modern systems, attributes of sediments can be used to infer the processes responsible for their formation. The attributes observed in modern situations are correlated with the depositional processes responsible for their creation. These descriptions can be considered as good predictors of the processes because the descriptions and processes are related by laws of physics and chemistry, which operate uniformly through time and space. For example, the presence of clay can be interpreted as an indicator of a low-velocity or zero-velocity transport agent. As the velocity of a transport agent decreases the competence also decreases. It can no longer carry large-sized particles, because the force vectors operating in directions opposite to gravity are no longer greater than or equal to those of gravity. The object falls. Thus, a deposit containing clay can be interpreted as having a transport agent that did not have sufficient turbulence (opposite force vectors) to keep a particle with a diameter of .0039 mm in suspension. Following from physical laws, the transport agent is thought to have very low or zero velocity.

These description-interpretation relationships are used when studying ancient sediments also. If the attributes of the ancient sediments are the same as a modern analog, then by analogical argument the same interpretation can be applied to the ancient sediments. The earth is changing constantly, but the physical and chemical laws that govern the processes are unchanging. The physical and chemical processes operate according to laws defined by continuum mechanics and atomic theory. The processes, operating on an infinite number of sedimentary particles, produce uniform physical characteristics in the past, the present, and the future.

COMPARISON OF GEOLOGICAL AND ARCHAEOLOGICAL CONCEPTS OF DEPOSIT

Geologists and archaeologists are both concerned with deposits. Yet they have approached the concept of the deposit in different ways.

The beginnings of modern geology are grounded in the observations made by scientific observers that rocks of great antiquity had chronologic significance, and that they contained sediments whose physical characteristics were similar to characteristics observed in modern environments. Thus two approaches developed in geology: identifying and mapping of rock units on the basis of their physical attributes and content and ordering the rock strata according to time. The dual purpose in geology has lead to the classification system of sedimentary rocks into lithostratigraphic units, biostratigraphic units, chronostratigraphic units, geochronologic units, and geochronometric units (ACSN 1961; NACOSN 1983; Hedberg 1976; Krumbein and Sloss 1963; Matthews 1984).

Geologists recognize that there are two fundamentally different types of stratigraphic units. Those stratigraphic units that are based on "direct observations of the tangible features and characteristics of the strata and are independent of interpretations regarding the significance of these observations" (Krumbein and Sloss 1963:28) or in other words, those that are based on descriptions of material referents (NACOSN 1983:848), have been called *observable units* (lithostratigraphic and biostratigraphic units). The second type of stratigraphic units, *inferential units*, are those based on interpretations of the strata and their contents (Krumbein and Sloss 1963:29). Inferential units are almost always chronologic classifications of strata (chronostratigraphic, geochronologic, and geochronometric units) that rely on inferences from observable units (lithostratigraphic and biostratigraphic units).

Because the same two-fold purpose is needed in studying unconsolidated deposits in archaeology (i.e., the necessity to describe the contents of the deposit, as well as to place it in chronological order), a comparison of the basic geological units and archaeological units is warranted.

Geological Classification of Deposits by Depositional Events

A lithostratigraphic unit is a subdivision of the rocks in the earth's crust, distinguished and delimited on the basis of lithologic characteristics. The unit is generally but not invariably layered and tabular and conforms to the law of superposition. The limits of a lithostratigraphic unit is determined on the basis of its boundaries, defined by positions of lithologic change. Boundaries can be placed at sharp contacts called unconformities (which represent surfaces of erosion or nondeposition), conformities (surfaces where depositional regime has changed but no significant time has elapsed), or can be fixed arbitrarily within zones of gradation.

The fundamental unit in lithostratigraphic classification is the formation. A formation is defined by homogeneity of physical characteristics (lithologies). It has well-defined boundaries and is recognized on a scale convenient in mapping. The classification is standardized through procedures of nomenclature and uses of type-section identification.

A formation can be subdivided into members or beds. Members are contained in formations and usually are more local in lateral extent. They have physical properties different from formations and many have different shapes. If a member terminates on all sides within the formation it is called a lentil (or lens). If it extends beyond the formation in one direction it is called a tongue. A bed is smaller than a member, the smallest unit that can be defined (Campbell 1967; Reineck and Singh 1980), but no absolute size limits are implicit.

A lithostratigraphic unit is a material unit defined on the basis of content. An example of a lithostratigraphic unit is the Navajo Sandstone.

Geological Classification by Fossil Assemblages

A biostratigraphic unit is defined as a body of rock strata characterized by its fossil content, which must be contemporaneous with the deposition of the strata. Because fossils represent once-living forms, they are indicators of habitat or environments of deposition. Because organisms represented by the fossils were subjected to evolutionary change, the irreversibility of organic evolution makes it possible to partition enclosing strata temporally. To provide these environmental and temporal inferences, the fossils found in the rock must represent organisms that lived when the sediment in the formation was deposited. They cannot be derived from older sediments, washed in from other environments, or intruded by later turbations.

Biostratigraphic units are based on criteria that differ fundamentally from those for lithostratigraphic units. Their boundaries may or may not coincide with the boundaries of lithostratigraphic units and are characteristically and conceptually diachronous; that is, they have either one or two bounding surfaces that are not synchronous (which transgress time) (NACOSN 1983:862).

Biostratigraphic units are named according to biozones. Three principal kinds of biozones are recognized: interval zones (a body of strata between two specified, documented lowest and/or highest occurrences of single taxa), assemblage zones (characterized by the association of three of more taxa), and abundance zones (characterized by quantitatively distinctive maxima of relative abundance of one or more taxa).

Analogical reasoning and the use of the uniformitarian principle is only partially successful when applied to biological assemblages. Examination of modern biological assemblages can provide inferences on habitat but cannot provide relative information to predict future actions of individuals. Unlike the processes governing depositional events (influenced by physical and chemical laws), biological behaviors (actions of an individual) are not predictable. Thus observations of the actions of biological organisms living today do not provide lawlike statements of how individual creatures behaved in the past. In addition, because modern analogs for many fossil organisms do not exist (e.g. trilobites, dinosaurs, australopithecines), the biostratigrapher is often forced to examine the lithostratigraphic unit and the mechanics of the skeletal structure to infer the habitat conditions of a fossil assemblage. Thus, the habitat of the biological assemblage is inferred from the lithology of the rock and the mechanics of the skeletal remains (inferences deduced from physical and chemical laws), and the behavior (or actions) of individual organisms cannot be inferred.

Geological Classification of Deposits by Age

Rock units can be placed in chronological order because of principles identified first by a Danish geologist working in Italy (Steno 1669, 1916; Conkin and Conkin 1984; Faul and Faul 1983). According to Steno's observations, layers of sedimentary rocks can be arranged in a temporal sequence as defined in the law of superposition, which states that in any normal or undisturbed succession of sedimentary strata (deposits) the youngest stratum is at the top and the oldest at the bottom. The first layer had to be completely deposited before the next higher layer could be laid down. The law of superposition enables geologists and archaeologists to order depositional events in time.

The only qualification to the law of superposition is the case in which the whole stratigraphic sequence has been overturned (as in overturned folds). In such cases the deposits have been tilted past the vertical and thus have had their order reversed. Archaeologists sometimes record "reversed stratigraphy" in archaeological deposits, but this term does not refer to the aforementioned exception. When refering to reversed stratigraphy archaeologists usually are describing evidence of a constructional event that resulted when the dirt from an excavation was piled adjacent to the opening of the hole. Because the uppermost layer of the surface that is being excavated is cut and dumped first, followed by the piling up of more deeply buried layers, the stratigraphy of the pile appears to be reversed from the stratigraphy exposed in the sides of the pit. This stratigraphic relationship is not an exception to the law of superposition, because each layer, as it was removed from the hole and dumped at the edge, represents a new depositional event. The sedimentary content of the deposit, the structures, and the geomorphic shape of the unit have all changed. It is a new deposit, a new depositional event.

When labeling this sequence as reversed stratigraphy, archaeologists are usually referring to the temporal order of the age of manufacture for the objects contained in the deposit. Many of the objects contained in the newly created deposit are older than the deposit itself. Their age of manufacture may be the youngest in the sequence, yet they are located in the deposit at the base of the column of strata. Archaeologists will often misconstrue such a sequence of deposition as being reversed, because they are not focusing on the correct analytical unit, the deposit. The law of superposition applies only to deposits, and not to the sedimentary particles they contain.

In addition to the law of superposition, Steno defined the law of original continuity, which states that a sedimentary layer forms at the time of its deposition a continuous sheet that ends either by thinning to disappearance, by gradually changing to a bed of different composition, or by abutting against a barrier or wall. From the law of original continuity an erosional episode (such as a pit) is made obvious.

Another principle (or law) that Steno noted is the principle of original horizontality, stating that sediments are deposited in layers that are not far from horizontal and are parallel or nearly parallel to the surface on which they are accumulating. Exceptions to this principle have been discovered and therefore the power of the principle has been diminished, but for many geological environments, especially for water-laid sediments, the principle holds true.

Finally, a geological principle applied more frequently to igneous rocks but applicable to archaeological chronology is the principle of cross-cutting relations. The rock unit that cuts across the boundaries of another unit is more recent in the ordering of the depositional sequence. For example, a rodent hole, filled with physically different sediments, is younger than the deposits through which it passes.

Two categories of geologic time units are recognized: "those based on material standards or referents (specific rock sequences or bodies), and those independent of material referents" (NACOSN 1983:967). Both of them are conceptual, rather than material in nature. Chronostratigraphic units are based on material referents, while geochronologic units and geochronometric units are independent of material referents.

Chronostratigraphic units are bodies of rock established to serve as the material reference for all rocks formed during the same span of time (NACOSN 1983:868). Such a unit represents all rocks, and only those rocks, formed during that time span (e.g., Devonian System). The chronostratigraphic unit may be based upon the time span of a biostratigraphic unit, a lithic unit, a magnetopolarity unit, or any other feature of the rock record that has a time range. The boundaries of the unit should by synchronous and based on observable paleontological or physical features of the rocks. The hierarchy of chronostratigraphic units, in order of decreasing rank, is econothem, erathem, system, series, and stage. The system is the primary unit and encompasses a timespan and an episode of earth history sufficiently great to serve as a worldwide chronostratigraphic reference unit. The purpose of the chronostratigraphic classification provides a framework for (1) temporal correlation of the rocks in one area with those in another; (2) placing the rocks of the crust in a systematic sequence and indicating their relative position and age with respect to earth history as a whole; and (3) constructing an internationally recognized Standard Global Chronostratigraphic Scale (NACOSN 1983:868).

Geochronologic units are divisions of time traditionally distinguished on the basis of the rock record as expressed by chronostratigraphic units (e.g., Devonion Period). They correpond to the time span of an established chronostratigraphic unit (NACOSN 1983:869). The hierarchy of geochronologic units in order of decreasing rank is eon, era, period, epoch, and age. Each of these units is the time represented by rocks of a corresponding chronostratigraphic unit: eon: eonothem; era: erathem; period: system; epoch: series; age: stage.

Geochronometric units are established through the direct division of geologic time, expressed in years. Unlike geochronologic units, geochronometric units are not based on the time span of designated chronostratigraphic units but are simply time divisions of convenient magnitude for the purpose for which they are established. Their boundaries are arbitrarily chosen or agreed-upon ages in years. A separate hierarchy of units does not exist for geochronometric units. They can be either geochronologic rank terms (eon, era, period, etc.) in those cases in which they have been distinguished on the basis of an arbitrarily chosen boundary of time (as for the Precambrian), or they can correspond to chronostratigraphic units (econothem, erathem, system, etc.), even though they are not defined by them.

All geologic time units require an interpretation of the deposit as well as a description. Unlike the lithostratigraphic and biostratigraphic units, which are defined on the basis of described characteristics, identification of the geologic time units requires an interpretation to be made of the age of deposition.

Other stratigraphic units have been proposed in the North American Stratigraphic Code, but for the purposes of this comparison with archaeology, lithostratigraphic, biostratigraphic, and geologic time units (chronostratigraphic, geochronologic, and geochronometric) are most pertinent.

ARCHAEOLOGICAL CONCEPT OF DEPOSIT

Since scientific observers became concerned with the antiquity and development of hominids, they have been classifying the deposits in which these remains were found, referring to them as layers, beds, levels, strata, cuts, horizons, or units. The predominant goal in these classifications has been to order the deposits in chronological sequence. Only since the depositional environment of the deposit has become a focus for research have the physical characteristics of the deposit and all its contents become objects of interest.

Archaeological Classification of Deposits by Depositional Events

Most archaeologists refer to any archaeological deposit that was identified according to its physical properties rather than its chronological properties as a stratum. This term is used most frequently in association with excavating by "natural layers," an excavation unit determined by stratigraphy. Strata, or natural layers, are identified by changes in physical characteristics such as color, compaction, or texture. Not all excavators use similar criteria in differentiating natural layers. In fact, most archaeologists acknowledge that the sequence could be subdivided by different excavators in many different ways. The criteria for making the subdivisons are based on decisions made in the field and usually arrived at pragmatically and informally.

A formal classification system of archaeological deposits that included standardized names for physically different strata as well as temporally different strata was provided by Gasche and Tunca (1983) and elaborated in Meyer (1984). Other classification systems have also been proposed. For example, Schiffer (1972, 1976, 1983, 1987) proposed a system with the emphasis of classification based on the objects found within the deposits and not on the physical characteristics of the deposits themselves. Shaw (1970) also discussed using the archaeological term of "culture" (referring to assemblages of artifacts) as a possible stratigraphic unit. Harris (1977, 1979) proposed a sophisticated classification system based on temporal significance of deposits. However, Gasche and Tunca (1983) were the first to separate terminology into three classification systems, classifying deposits on the basis of the physical attributes of the deposits, the biological (or artifactual) assemblage, and the temporal criteria (Farrand 1984a,b).

The lithologic unit is the name given by Gasche and Tunca (1983) to describe a

> three-dimensional body characterized by the general presence of a . . . (dominant) . . . lithologic type, or by the combination of two or more of these types, or even by the presence of other particularities that confer on the unit a homogeneous character. Among other particularities, detailed attention should be paid to the structure, texture, and color of the deposits forming the unit. (1983:328)

Lithological units are named layers (the basic unit used in stratigraphic correlation), sublayers (lithologic units that form part of a layer), and inclusions (smaller units that are part of a layer or sublayer). These names are comparable to the geological lithostratigraphic units of formation, member, and bed.

Gasche and Tunca propose that lithologic units be described in terms of "their lithologic content, the structure and texture of this content, the degree of erosion or denudation and the geometry" (1983:329), which are similar to attributes designated by sedimentologists as helpful indicators of depositional processes. Yet by mentioning "erosion or denudation" Gasche and Tunca suggest that the boundary of lithologic units can only be created by erosion: in other words, by an unconformity. However, there seem to be no valid reasons to eliminate units to be considered just because they are bounded by conformable surfaces.

Although Gasche and Tunca (1983) were the first to offer a comprehensive definition of a lithologic unit, Fedele (1976) suggested a term and a definition for a unit described on the basis of physical attributes. An elemental sediment unit (ESU) "is a term suggested for a unit constituting the smallest geologically homogeneous entity as preceived in excavation . . . (and) contained between two consecutive recognizable discontinuities" (Fedele 1976:34). An ESU could be a stratigraphic division, a lateral (facies) differentiation, or a pedological horizon.

This definition stresses that an ESU is differentiated by two things: its discontinuities (or boundaries) and its lithologic homogeneity. For Fedele the specific physical attributes selected for the definition of an ESU are irrelevant to the definition. The unit's boundaries and physical homogeneity are the critical factors. Also stressed is the nature of the identification. These units are the smallest ones identifiable in excavation by any given excavator.

Fedele (1984) refined the concept of ESU in a reply to the proposed Guide to Classification of Gasche and Tunca (1983). Fedele expanded his discussion of ESU through suggesting a new unit called an operational unit or cut (1984:9). A cut refers to a "geometric unit of dissection or digging" (1984:9) and a "minimum volume of deposit that we are willing to cut as a single whole" (1984:11). Cuts are not based on lithology alone but also on convenience during excavation, such as the arbitrary removal of 5-cm-thick layers in exceptionally thick deposits. After excavation is complete, cuts are grouped into elemental sediment units (ESU) on the basis of the structure of the deposit and not on excavation conveniences. Thus a cut is arbitrary and an ESU is a "formally named fact in the structure of a given site, whose mappable distribution can eventually be used as a marker" (1984:11)

Harris (1977, 1979) also proposed a classification system for deposits based on physical parameters. His classification is based on interpretations of mode of deposition, rather than on the observed empirical phenomena. Harris divides stratification into strata and interfaces. The term strata (also called layers and deposits) is subdivided into "natural strata," defined as materials in an archaeological situation transported by man or nature, and "man-made layers," defined as material transported entirely by man and deposited through human planning and actions (Harris 1979:36–37). To differentiate these two kinds of strata the observer must look at attributes and determine the relative proportion of human versus natural agents of transport and deposition. Harris (1979:37) also suggested the term "upstanding strata . . . . . used for unique types of man-made stratification" (such as walls).

Clearly, Harris is classifying deposits on the basis of interpretations of their sources, transport agents, depositional mechanisms and post-depositional alterations (principles of sedimentation). Because he does not consider a deposit in terms of its attributes, but instead in terms of its reconstruction, he cannot provide a mutually exclusive and exhaustive classification system. Each object in a deposit has experienced its own history, a history that is possibly very different from the history of other particles in the deposit. Harris would like to classify deposits on the basis of the interpretations of the agents involved in the history of all sedimentary particles in the deposit, but defining all the possible interpretations for any given deposit would be difficult. He will need a large number of terms to name the large number of possible combination of agents contributing to the deposition of every deposit.

The terms proposed by Harris are not technically comparable to rock stratigraphic unit. Because they are based on interpretations of depositional environments of objects found within deposits, they are not comparable to any classification system thus far discussed. However, if his system could be implemented, the resulting classes would be comparable to geological interpretations of environments (e.g., near-shore, fluvial), which in turn are based on descriptions of lithostratigraphic units and biostratigraphic units. Therefore, Harris needs to define the attributes on which his interpretations are based and to standardize the names of possible "environments" to be used in the classification system.

Stein and Rapp (1985) offer the term 'facies' as a descriptive reference for depositional units in archaeological sites. Facies are defined as the products of any one depositional event. One stratum, identified on the basis of observable attributes, is a facies if it differs from the strata above, below, and lateral to it. "The attributes can be any measurable characteristic but should most frequently be attributes of sediments as defined by sedimentologists. Each facies in an archaeological site must be analyzed separately to designate scource, transport agents, depositional mechanisms, and post-depositional alterations" (1985:154).

In geology the term facies can mean a variety of things. Most often the use refers to the physical or chemical characteristics of the rock, the environment in which the rock was formed, or the fossil assemblage associated with the rock (Teichert 1958). Because the term is borrowed from geology, where it has had a 150-yr history of use (AAGP 1974; Reading 1978; Teichert 1958; Walker 1984), it has accumulated many connotations and thus may not be the best choice for defining a nomenclature of archaeological deposits. Yet the concepts expressed in the definition of facies, especially those associated with gradual changes across vertical and horizontal distances, are ones that are basic to the understanding of deposits in archaeology.

Archaeological Classification of Deposits by Artifact Assemblages

Gasche and Tunca (1983:331) suggest the term *ethnostratigraphy* to denote the stratigraphic classification of deposits on the basis of their anthropic content (i.e., artifacts). The terms: "Supra-Zone" (contains one or more Zones), "Zone" (the basic unit), and "Sub-Zone" (subdivision of a Zone) are offered for the nomenclature of the ethnostratigraphic unit.

When introducing biostratigraphic units, geologists specify that the assemblages of fossils must be ones that are contemporaneous with the deposition of the strata. Archaeological stratigraphers note this same condition for classifications using the artifactual contents of a deposit. Gasche and Tunca advise that "prudence, however, is necessary in evaluating, given the wide range of possible interference, the length of usage of certain objects observable in any archaeological context, and also the limitations of our methods of excavation" (1983:331). They also acknowledge the roles of the person examining the artifacts and the person responsible for arranging the artifacts into classes and selecting the classes that are important.

Harris (1979:93) suggests that "Indigenous Remains" are those made at about the time of the formation of a layer in which they are found. "Residual Remains" are those objects made at a much earlier time than the formation of the layer in which they are found (either those that were dug up or have remained in circulation). Finally, "Infiltrated Remains" are those objects that were made at a later time than the layer in which they are found and were introduced into that layer by various means. Harris does not suggest that we name a deposit on the basis of its contents (he prefers the name layer or strata), but that we use the content to order the layers into a chronologic sequence.

Artifacts Contemporaneous with Deposition

Although Gasche and Tunca and Harris are careful to note that "fossils" used to construct biostratigraphic units must be contemporaneous with deposition, cultural historians often lose sight of establishing that relationship. They often base chronological interpretations on groups of objects found within deposits, assuming that those objects were contemporary with the deposits and misidentifying the analytical unit to which the law of superposition applies. As noted, the law states that for a succession of sedimentary strata the youngest stratum is at the top and the oldest at the bottom. The law applies only to the analytic unit of deposit and does not apply to the objects contained inside the deposit. Objects may be older than or contemporary with the deposit.

Cultural historians, operating under the assumption that all objects were contemporary with the deposits in which they were found, introduced erroneous terminology into the discipline, terms such as "reversed stratigraphy," "primary deposits," and "secondary deposits." The stratigraphy of a deposit cannot be reversed unless a sequence of lithified deposits are overturned. In archaeology the term "reversed stratigraphy"

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refers to the temporal ordering not of the deposits, but of the contents of the deposits. The Iron Age object that is found in a layer below the Stone Age object is reversed in chronological order, but the deposits in which these objects are found actually conform to the law of superposition.

The terms "primary" and "secondary deposits" do not refer to the term "deposit" as defined in this paper. A deposit is laid down only once. When its contents are moved and deposited a second time a new layer is created, a layer that possesses a new depositional history, a new source, transport agent, and environment of deposition. The term primary and secondary refer to the inferred history of the contents of the deposit. An Acheulian hand axe may be deposited within a cave, eroded and deposited in river gravel, picked up and placed on a hilltop, and only then discovered by an archaeologist. The deposit on the hilltop, in which the hand axe was found, contains clues relevant only to the last depositional event. The complex history of the hand axe is not preserved in the hilltop deposit. Just as the exhaustive history of a quartz grain found on the beach is not known, the history of the hand axe is preserved only as can be inferred from the last deposit in which it rests. Thus all deposits must be, by definition, primary deposits.

The concept of secondary deposit actually refers to the source of the individual particles within the deposit. Contents of deposits often possess attributes suggesting that the object has witnessed a long or short depositional history prior to the event that last deposited it. Such attributes are used to infer the source of an individual sedimentary particle. The use of terms such as reversed stratigraphy, primary deposit, and secondary deposit demonstrate the extent of the confusion in archaeology over the application of the law of superposition and establishing the relationship between artifacts and depositional events.

Inferences Based on Artifact Assemblages

In geology, if the relationship between fossil and depositional event can be identified as contemporaneous, then the fossils can be utilized for two purposes: (1) establishing chronologies by tracing irreversible evolutionary changes, and (2) reconstructing physical conditions on the basis of habitat requirements. In geology sequences of fossil assemblages are used to trace evolutionary events. In archaeology attributes of artifacts are used to detect change through time. In geology, fossils are used to infer habitat, (e.g., dinosaurs lived in water if the mechanics of the skeleton indicate that the animal could not support his own weight). Similarly, archaeologists can infer habitat requirements from archaeological sites. People must have air to breathe, water to drink, food to eat, and shelter from the elements.

However, in archaeology most researchers have inferred from artifacts in deposits more than temporal orders or habitat requirements. The majority of this work has focused on the artifacts and not on the deposit. Yet Schiffer (1972, 1976, 1983, 1987), who has focused on the deposit, has suggested that deposits be classified on the basis of their inferred depositional history and that the classification focus on inferences of cultural behavior. He offers three different criteria to be used in the nomenclature: simple properties of artifacts, complex properties of artifacts, and other properties of deposits (this last group includes sediments, ecofacts, chemical properties, structure and context of deposit, and site morphology, or in other words, sedimentology). From the above attributes, Schiffer would like to infer the cultural behaviors of procurement, manufacture, use, maintenance, and discard and then to classify deposits according to the behavior responsible for the deposition of the layer. These behavioral processes are applicable to artifacts, that is, elements that have been altered by human modification. Schiffer suggests that all artifacts (elements) flow through a systemic context (the five processes), after which they become refuse. Refuse is the termination of an element's use-life and the material that encompasses the archaeological context. Refuse can be further classified depending on where during the previously described five processes of an element's life history, it was incorporated into the archaeological context. Primary refuse is discarded in the same location that it is used; secondary refuse is not discarded where it is used; *de facto* refuse is incorporated into the archaeological context when the inhabitants abandon a site and leave usable materials behind.

Schiffer proposes that the behavioral aspects of artifacts, that is, procurement, manufacture, use, maintenance, and discard, can be obtained from analysis of artifacts found in deposits. He would like to classify deposits into "biostratigraphic" units according to these behavioral inferences. However, these "biostratigraphic" units are conceptually quite different from those units discussed in this paper. They are based on inferred transport agents and use rather than on descriptive attributes, and like the system proposed by Harris (1979) for stratigraphic units based on lithological parameters, Schiffer's units are interpretive units, not observable units. Schiffer (1987) correctly notes the difficulty in applying such a behavioral classification system to deposits. Because any one deposit can contain artifacts that have witnessed diverse histories and have diverse ages, his behavioral classification types could not be applied to the concept of deposit as defined here. His system can best be applied to the interpretation of artifacts.

Obtaining inferences about behavior from artifacts has been controversial because such inferences rely on analogy, that is, comparisons with empirical generalizations derived from observations of modern cultural communities. The behavior (or individual actions) of modern people is not regulated by any rigorously tested laws. Thus inferences concerning behavior of individuals of past cultural groups are based on analogies of actions that are not governed by laws, and which some scholars believe can provide clues or plausible statements but which others have deemed unacceptable (Ascher 1961, 1962, 1968; Gould and Watson 1982; Wylie 1982, 1985).

Functional attributes of artifacts can provide inferences concerning the depositional environment or habitat of prehistoric peoples (who were contemporary with the depositional event), just as fossils provide inferences of habitat. But these are inferences that should not play a role in stratigraphic classification. Stylistic attributes of artifacts can provide inferences concerning the temporal ordering of the deposits, just as evolutionary traits of fossils provide inferences of age.

Archaeological Classification of Deposits by Chronological Events

As noted in the discussion of time stratigraphic units, geologists perceive that rocks should be classified by their lithology and their fossils, and that rocks can be arranged in chronological order on the basis of their superposition. Geologists also recognize that it is the properties of lithostratigraphic units and biostratigraphic units that are used to create (interpret) geological age stratigraphic units. For example, fossils are used to define habitat (which is the environment of deposition) and also to denote evolutionary change (which is a function of time). Lithologic boundaries are used to define formations (based on depositional characteristics) and also to denote surfaces of erosion or nondeposition (which are functions of time).

Archaeologists, like geologists, note that archaeological deposits should be grouped according to physical appearances and artifact assemblages, and that deposits can be arranged in chronological order on the basis of their superposition. For archaeologists the properties used to establish units of time have not been standardized. There also exists a confusion over the fact that the boundaries of deposits are not themselves time stratigraphic units but are important to consider when constructing chronological events.

Archaeological Units of Time

Gasche and Tunca (1983) suggest that archaeological time stratigraphic units should be called chronostratigraphic units (as in the geologic code) and propose the following terms. A "phase" is the basic time unit. A "set" is a group of phases. The "subphase" is a subdivision of a phase (1983:330).

The phase is to be a grouping of adjacent strata of anthropic origins, with a separate grouping of adjacent strata for those of natural origins. Thus to identify a phase, a deposit must be examined and assigned either a cultural or natural origin (i.e., its depositional history must be interpreted).

The phase is an inferential stratigraphic unit, as are all time stratigraphic units, but not one based solely on time. It is also based on inferences concerning the source, transport agent, or environment of deposition, which either have been affected by culture (anthropic) or not affected by culture (natural). The use of such inferential units requires that stratigraphers decide what is natural and what is anthropic. In many cases the attributes observed could have been produced by many agents and do not allow the stratigrapher to discriminate between cultural and natural effects. A deposit that contains evidence of both anthropic and natural events is called "complex" by Gasche and Tunca (1983:333). Therefore, the phase seems to be a grouping of strata into units of time but contains (as part of its definition) a restriction as to the kinds of deposits that can be grouped.

Time stratigraphic units of a sort already exist in archaeology. Archaeological "cultures," "phases," and "stages" are essentially expressions of time, based on assemblages of artifacts, which change through time. Cultural historians were able to order assemblages by noting the relative frequencies of certain stylistic attributes defined as historical types and observed on objects in "natural layers." They assumed that the objects were contemporary with the deposits (Gruber 1978) and used the stylistic variability of those objects to produce seriations, from which chronologies were inferred (Dunnell 1970; Marquardt 1978; Willey and Sabloff 1980). Once a chronology was established, certain assemblages, or groups of assemblages of the sequence, were grouped into cultures, or phases. These cultures and phases (closely parallel to the biostratigraphic units of geology) are really time stratigraphic units. They have historic significance.

Significance of Boundaries for Time Units

Geologists have classified the boundaries of units, called discontinuities or contacts, into those forming conformable relationships and unconformable relationships. (Krumbein and Sloss 1963:303–309). Conformable relationships are those surfaces of contact between vertically successive deposits where no significant evidence of interruption of deposition can be recognized between adjacent units (also refered to as bedding planes, Campbell 1967). The change in lithologic character reflects a shift in the conditions of deposition or in the materials brought to the location. Conformable contacts may be abrupt, gradational, or intercalated. The three types of conformities reflect the manner in which the shift in depositional regimes occurred. Yet in each type there is continuous deposition with no major breaks in time.

Unconformable relationships are those surfaces of contact between vertically successive deposits where a period of nondeposition or erosion has occurred between adjacent units. The unconformity represents a passage of time not represented by any deposit locally in the geologic column. Three types of unconformities are recognized (Krumbein and Sloss 1963:305): angular unconformity (a surface separating tilted or folded strata from overlying undisturbed strata; disconformity (a surface separating essentially parallel strata); and nonconformity (an erosion surface cutting an igneous or metamorphic rock and covered by sediments). Such unconformities are recognized by sedimentological, paleontological, and structural criteria. Sedimentary criteria include the presence at the unconformity of residual highly weathered rocks, buried soil profiles, or secondarily deposited mineral cements. Paleontological criteria include abrupt changes in faunal assemblages, gaps in evolutionary development, and the occurrence of resistant bone and tooth concentrations (indicating erosion). Structural criteria include discordance of dip in the sediment structures above and below the contact, or an undulatory surface of contact between deposits.

The importance of the boundary of a deposit and its role in the inference of chronological ordering have been explicitly noted by Harris (1977, 1979). He suggests the term "interface" to refer to the surfaces or boundaries of layers. Harris (1979:43) recognizes the same two types of contacts as do geologists, "those which are surfaces of strata and those which are surfaces in themselves as formed by the removal of pre-existing masses of stratification." He suggests the term "layer interface" for the surfaces of strata that do not show evidence of erosion. There are two types of layer interfaces, "horizontal layer interfaces" (surfaces of strata laid down more or less horizontally) and "upstanding layer interfaces" (vertical surfaces of upstanding strata such as walls). He suggests the term "feature interface" for surfaces of strata that are produced through erosion. There are two types of feature interfaces, "vertical" (which results from digging holes) and "horizontal" (which are associated with upstanding strata and mark the levels at which parts of deposits have been destroyed).

In addition to layer interfaces and feature interfaces, which correspond roughly to the geological concepts of conformities and unconformities, Harris (1979:47) introduces a concept called the "period interface." The period interface represents all surfaces exposed at any one time in the past. Because it is not restricted to describing the boundaries of lithostratigraphic units, but rather is describing all deposits exposed at the surface at any given time, the period interface is considered the equivalent of a unit "established through the direct division of geologic time, expressed in years," a geochronometric unit.

A problem with the classification system of Harris is assigning the subdivisions of the layer interface and the feature interface. A pit could contain both horizontal and vertical feature interfaces that grade into each other as the slope of the pit boundary changes. A deposit may have boundaries that are horizontal layer interfaces, upstanding layer interfaces, horizontal feature interfaces, and vertical interfaces. The definitions of these terms do not provide the precise information needed to assign the term in an archaeological situation (e.g., angles of dip above or below which one assigns the name of vertical or horizontal layer interface). Thus even if archaeologists agreed on the attributes that should be used to distinguish a change in depositional regime (conformity) from an erosive event (unconformity), the assigning of the subdivisions of Harris's term will be subjective.

Thus chronological units in archaeological stratigraphy (time stratigraphic units) are inferential. The ordering of those units, according to the law of superposition, is valid only if the time stratigraphic units are correlated with observable units and the units are in contact with each other. (Here a unit refers to the deposit, not to the contents of the deposit.) Assigning relative ages for a sequence of strata follows from the law of superposition. Assigning an absolute age for the sequence requires the acquisition of datable material, an evaluation of the depositional history of each layer (to ascertain that the dated materials were contemporaneous with the depositional events), and a determination of the nature of the layer's boundaries.

Geological and Archaeological Codes: Conclusions

This comparison of geological and archaeological concepts of "deposit" has demonstrated how similar are the purposes of geology and archaeology in studying unconsolidated deposits. Geologists have prepared a code of stratigraphic nomenclature (NACOSN 1983) after 4 yr of deliberation by and for the North American earth scientists, under the auspices of the North American Commission on Stratigraphic Nomenclature. The code was reviewed by an unprecedented number of scholars and represents a revision of many earlier codes. Archaeologists, however, have just begun to consider a code (Farrand 1984a,b; Gasche and Tunca 1983; Meyer 1984). Following this review of the similarity of the needs of the two disciplines and the comparison of the new archaeology code and the geology code, I would like to suggest that archaeologists do not create a new code. Rather, they should consider using the already existing geological code, which contains all the units that are needed in archaeological research, and in which definitions and terms have already been thoughtfully expressed.

Opposition to accepting the geological code as relevant for archaeological research will undoubtably focus on the fact that artifacts are not included in the geological code. Yet artifacts are in essence fossils (i.e., the remains of past civilizations are sedimentary deposits similar to coral reefs or other biologically produced deposits) and the considerations of geological time are identical to those of archaeological time. If we consider artifacts as sediments, people as biological agents (which are part of nature rather than as opposed to nature), and prehistoric and historic time periods as geological time periods, then the North American Stratigraphic Code or the International Stratigraphic Code (ISSC 1976) are acceptable classification systems for archaeological deposits. Archaeologists need only become aware of their existence and their use.

ATTRIBUTES OF SEDIMENTS

In any deposit of clastic sediments the characteristics of the particles are influenced by the environment of deposition. In the study of archaeological deposits the source and transport agents of each particle contained within the deposit, as well as the environment of deposition of the deposit as a whole, are all part of the formation processes that created the deposit. Defining these aspects of a deposit and determining the contribution of natural and biological processes is accomplished by analyzing certain attributes of the clastic particles. Sedimentologists have identified those attributes, which are regulated by dynamic surficial processes (i.e., those regulated by continuum mechanics), as texture, composition, and structure. Each of these attributes, along with the interpretations of types of environments that they indicate, will be discussed in turn.

Texture

Texture refers to the properties and relationships of individual grains, such as the mean grain size, grain size distribution, grain orientation (fabric), grain shape, roundness, sphericity, and grain surface markings.

Grain Size

The size of particles is measured by using various techniques, sieving for gravel- and sand-sized particles, calculation from settling velocities for the particles finer than sand-size (i.e., silt and clay), and impregnating sediments and examining grain sizes in thin sections. The technique of sieving and settling will be discussed here, along with the kinds of analyses that the output generates. When a sample is shaken in a nest of sieves the particles are sorted into size groups according to the diameter of the sieve openings. When small spheres settle in water their size can be estimated according to Stoke's law, which states that the settling velocity varies as the square of the particle diameter (Folk 1980), if other parameters are constant. The results of grain size analysis are expressed in reporting grain size statistics (mean, standard deviation, skewness, kurtosis) and in graphing grain size distributions. The distribution can be illustrated graphically in histograms, frequency curves, or cumulative curves. Statistics such as the mean, standard deviation, skewness, and kurtosis are usually calculated from a graph of the cumulative percentages (plotted on log normal paper) of the grain sizes measured.

Grain size parameters of clastic detrital sediments are a measure of the energy of the transport medium and the energy at the basin of deposition. In general, coarser sediments are found in high-energy environments and fine-grained sediments in ones of low energy. Yet the sizes of grains available in the source area must always be considered, because the availability of only small-sized particles will limit the size of grains found in deposits no matter what the energy level of the transport medium or basin of deposition (Reineck and Singh 1980; Gladfelter 1985; Shackley 1975).

Many sedimentologists have tried to relate depositional environments with grain size parameters. The shape of certain grain size distributions and the magnitude of certain grain size statistics have been related to environments such as dune, beach, or lagoon (Folk and Ward 1957; Mason and Folk 1958). The parameters, however, have never effectively separated modern environments, perhaps because of sampling problems (sampling more than one microscopically thin depositional event) or because environments have parameters that overlap (agents of sorting are similar in each environment).

Other sedimentologists have realized that the shape of the grain size distribution curve is really dependent on the mode of sediment transport (Visher 1969). There are three main modes of sediment transport: rolling, saltation,and suspension. Rolling transport moves sediment grains along the surface. In a grain size distribution of deposits transported by air or water, this transport mode usually contributes the coarsest fraction. In a frequency curve it can be discerned as a modal peak, or in a cumulative curve (plotted on log normal paper) as a break in slope. Saltation transport moves grains by bouncing them along the surface. The maximum grain size transported by saltation is dependent on the energy of the transport medium, the depth of the water (for aqueous transport), and nature of the bed (bed roughness). The portion of a deposit transported by saltation is identified as a change in slope on cumulative curves (plotted on log normal paper) and as a modal peak in frequency curves.

Suspension transport moves sediment grains entirely within the medium. The maximum grain size transported in suspension is dependent on the turbulent energy of the medium (for water and air) and the viscosity of the medium. Viscous and solid transport mediums such as mud, ice, and biological agents can carry all grain sizes, including coarse-grained particles, in suspension. These transport agents can transport the whole range of grain sizes available in the source area. They will produce deposits whose grain size distributions represent one transport mode: suspension transport.

The grain size distribution curves produced by viscous or solid transport mediums will commonly reflect the grain size distributions of the source deposits (Stein 1980, 1982). Frequency curves for such suspension modes of transport are usually multimodal and cumulative curves have complex sequences of changing slopes.

People are only one of many biological agents that are capable of transporting, in suspension, a wide variety of grain sizes (Binford 1981b). Such biological transport can result in grain size sorting that is detectable in the archaeological record. Distributions of various material types within the sand-sized fractions can be used to determine the history of a deposit (Dunnell 1986; Stein and Teltser 1986). Grains transported by biological suspension that enter the record already small (such as debris produced in lithic manufacture) exhibit a different grain size distribution from the grains that enter the record large (such as pottery).

The grain size distributions of lithic debris reflect the mechanical aspects of lithic manufacturing techniques by exhibiting modes in gravel, sand, and silt fractions. For example, material produced during core reduction seems to have a modal size in the gravel-sized range, and material detached during flake reduction has a modal size in the gravel/sand-sized range. The shatter that is produced by any percussion or pressure flaking is represented by the mode in the sand/silt fraction. The distributions of lithic debris in any one sample may reflect only a portion of the manufacturing process or may reflect post-depositional destruction of lithic debris (Fladmark 1982; Lancaster 1986).

The distributions of ceramic grains will reflect the manner in which the ceramics entered the record, and the history of the ceramic as the deposit was altered post-depositionally. Specifically, the distribution should have a modal peak at the size in which the ceramics entered the record, the slope of the curve gently tapering off in the direction of the fine-sized grains and steeply dropping off in the direction of the coarse grains (i.e., display finely skewed texture). This suggests the mechanical breakdown of sherd size either before transport or during post-depositional alterations. The shape of the curve would allow reconstruction of transport agents (i.e., people acting as the suspension mode of transport), the source area of certain types and sizes of particles found in the deposit, and the post-depositional alterations witnessed by the deposit.

Analysis of grain size distributions of sedimentary particles transported by biological agents and separated by compositional types requires a methodological change in traditional grain size analysis. For each grain size fraction the composition of a portion of the particles is identified (usually 1000 grains per size category). The portion is converted to a percentage of weight (of the fraction), allowing grain size distributions to be drawn for each compositional type that is to be identified (Chayes 1956; Daniels *et al.*

1968; Galehouse 1971; Weibel and Elias 1967a,b). Such grain size distributions separated by compositional types, allow identification of objects that entered the record small, those that entered the record large, and those that entered either large or small but which have been physically altered to include a whole range of sizes (all smaller than the original size).

In archaeology many people have suggested that all sizes of grains (including fine-grained particles) are artifacts (Butzer 1982; Schiffer 1983; Stein 1985; Wittlesey *et al.* 1982). The potential of small-sized artifacts (called microartifacts) has already begun to be explored (Clark 1982, 1984a,b; Dunnell 1986; Fladmark 1982; Hull 1984; Nicholson 1983; Rosen 1986; Stein 1986; Stein and Teltser 1986; Vance 1985, 1986).

Grain size analysis has frequently been used in archaeological research to reconstruct the source of the site matrix. Gardner (1977) uses grain size analysis as one variable in the identification of loess at Tell Fara, Israel. Donahue (Adovasio *et al.* 1977, 1978, 1979), in his analysis of the sediment in Meadowcroft Rockshelter, relied heavily on grain size analysis to reconstruct the source and transport agent of the rockshelter's sedimentary matrix. At Sitagroi Tell, Greece, Davidson (1973) used grain size analysis to determine that nearby alluvium was the source for mud bricks. Gray (1984) used grain size and a fining upward sequence to establish the alluvial chronology of the Ohio River near Louisville, Kentucky. Because artifacts were incorporated into the alluvium, his model of floodplain deposition can predict where deeply buried archaeological sites will be best preserved. Stein (1980, 1982, 1985) determined two sources for the sediment incorporated into the Carlston Annis shell midden using a comparison of the grain size distributions of the possible sediment sources and the sediments found in the midden. Sullivan (1984) also used grain-size analysis to determine the source of the inorganic portion of a shell midden in New South Wales. Two sources for sediment in the Bronze Age village site of Nichoria, Greece, were discovered using grain size parameters and distributions (Stein and Rapp 1978). With the same technique, Ahler (1973b, 1976) discovered the source of sediments at Rodgers Rockshelter, and Kittleman (1977) the source of sediment at Dirty Shame Rockshelter. Farrand has identified the source of sediment in rockshelters located in France (1975a,b), Greece (1981), and Israel (1979).

Other researchers have used grain size analysis in archaeological research to reconstruct the environmental setting. Butzer has used grain size analysis very frequently in Egypt (1960, 1981b), Spain (1965, 1981a) South Africa (1973, 1974a, 1974b, 1976a, 1978b), and the United States (Illinois) (1977, 1978a). His work can be used as a model, especially for grain size techniques and the proper method of reporting grain size data (Butzer 1982). Roberts (1982) reconstructed the setting around Catal Huyuk, Turkey, using sediment size as well as geomorphology. Kirch (1975) used sediment size in combination with land snail studies to pinpoint the timing and effects of land clearance and human colonization on the island of Molokai, Hawaii. At the Capsian site in Algeria, Hassan (Lubell *et al.* 1976) analyzed grain size distributions to suggest that during the occupation of the site the climate was wetter. Haynes (1980) used grain size as well as geomorphology and diagenesis to reconstruct pluvial climates in Egypt. Stein *et al.* (1983) relied on grain size analysis to establish the recent environmental alterations associated with the location of historic Fort Jefferson, Kentucky. Waters and Field (1986) used grain-size data to investigate settlement patterns of Hohokam sites along alluvial fans of the Tortolita Mountains. Waters (1986) refers to grain sizes when reconstructing the alluvial chronology of Whitewater Draw.

Grain size data has been used in the analysis of cave sediments most frequently to determine Pleistocene climatic events. Where alternative dating techniques are lacking, grain size has been used to differentiate (and date by correlation) periods of cold and warm climate (Bonifay 1955, 1956; Bryan 1941, 1950; Collcutt 1979; Farrand 1985; Laville 1976; Laville et al. 1980). Grain size data are used to define cold, warm, wet, and dry periods. Coarse-grained sediments (eboulis) are suggested as being produced during periods of extreme cold, while a mixture of larger and smaller grains are produced during less severe cold temperatures. Wet periods are denoted by the presence of very fine-grained sediment, presumably transported by surface water and weathering during the development of soils. The suggestions that eboulis is produced only in cold climate by cryoclastic weathering has been challenged by Farrand (1985). The suggestion that very fine-grained sediment and layering in those sediments is the result of soil-forming processes has been challenged by Goldberg (1979a).

Grain Shape and Roundness

Another attribute of a particle is its shape and roundness, which depends both on the relative lengths of the particle's dimensions and on the nature of the grain edges. There are many ways to determine the shape and roundness of grains (Reineck and Singh 1980; Folk 1980). A frequently used method compares a grain with a chart displaying drawings of grains of various shapes and rounding. Comparisons allow visual estimation of roundness and shape (Powers 1953:118).

The shape and roundness of a grain depends in part on the medium and mode of transport. With increasing abrasion during transport, grains become more rounded and more spherical. However, many factors control a particle's shape and roundness. The composition, internal structure, and original form of a mineral grain can exercise control over its final shape and roundness (Reineck and Singh 1980; Krumbein and Sloss 1963; Pettijohn

1957). Shape and roundness may not always provide direct clues to depositional environment because new angular edges and shapes can be created by breakage during transport and during diagenesis and pedogenesis.

Sedimentologists suggest that in a few particular cases the shape of a particle can provide clues to depositional environments. For gravel-sized objects those found on high-energy beaches tend to be flatter than gravel from rivers (Reineck and Singh 1980). Gravels in dry deserts are faceted through small-scale erosion produced by saltating sand particles. In these deserts the frequency with which the wind blows from any one direction and the depth of burial of the gravel will create shapes of gravel-sized objects known as ventifacts. Shape is less suggestive for sand-sized particles of any one depositional environment. With increasing abrasion occurring during transport (in water or air), sand grains will become more spherical. The shape is predominantly dependent on composition of the grain.

Grain roundness usually indicates increased transport. Grain rounding is dependent on mode of transport. For gravel-sized objects transported in the rolling transport mode (in water or air), the longer the transport time the more abrasion occurs and the more rounded the edges become. Thus roundness indicates long periods of a rolling mode of transport. In sand-sized objects roundness is a function of grain size, which in turn dictates mode of transport. Coarse and medium-sized sands transported as saltation loads exhibit increased rounding of their edges with increased transport. Fine sands do not as a rule exhibit increased roundness with increased transport. Fine sands are often transported in suspension, limiting contact of grains and holding abrasion to a minimum.

Taphonomic studies of bone have indicated that abrasion of bone (rounding) also increases with length of transport and decreases with decreased size of the bone. Also, rounding depends on bone hardness in a manner similar to its relation to mineral hardness (Behrensmeyer 1975; Behrensmeyer and Hill 1980; Gifford 1981; Shipman 1981; Voorhies 1969).

The use of grain shape and roundness to reconstruct transport agents and environments of deposition in archaeological research is well established. Butzer (1965) analyzed the shape of gravel to determine the transport mechanism (mass wasting versus alluviation) at Torralba and Ambrona, Spain, and the shape of sand to determine the source (fluvially transported quartz versus decomposed bedrock associated with the aquifer) at Amanzi, South Africa (Butzer 1973). The shape of the gravels at the Garnsey Site, New Mexico, aided Speth and Parry (1980) in the reconstruction of the history of arroyo deposits. Rick (1976) discovered that the shape of gravel-sized objects is one of many properties that influence the post-depositional movement of artifacts and thus the patterning of artifacts on a talus slope outside of Ccurimachay, Junin, Peru.

Rounding of the edges of gravel-sized stone artifacts has been studied most frequently in association with Paleolithic artifacts found in fluvial deposits. Shackley (1974) found that hand axes were abraided and damage to their edges increased as transportation time increased. Rounding, as well as distribution of large-sized handaxes, was noted by Isaac (1967, 1977) in his analysis of Olorgesailie fluvial processes. In studies of the Paleolithic caves of France grain roundness has been used (in addition to grain size analysis previously discussed) to determine the amount of chemical dissolution that has occurred as a result of weathering (Laville *et al.* 1980). Large angular gravel indicates cold environments; rounded gravel and sand indicates either deposition during warmer periods or chemical alteration of previously deposited sediment. The difference is thought to be related to chemical weathering that can occur only when abundant liquid water is present. Goldberg (1979a) studied, among other attributes, the shape and size of quartz grains to determine that the sand and silt in Hayonim Cave, Israel, were transported by the wind and trapped in the cave. Shape of the grains allowed Bull and Goldberg (1985) to determine wind transport also at Tabun Cave, Israel. Other researchers have also utilized grain roundness data to determine depositional regimes of cave deposits (Butzer 1973, 1981a; Butzer *et al.* 1978; Dort 1975; Farrand 1975a,b, 1979, 1981, 1985; Palmieri 1977; Schmid 1967; Shackley 1972; Tankard and Schweitzer 1976).

Rounding of the edges of ceramics has been examined by Skibo and Schiffer (1987) and Skibo (1987). Tumbling experiments have suggested that sherd abrasion is greatest in wet conditions, and that three stages of abrasion can be detected. Schiffer (1987) presents evidence that rounding of sherd edges can be used to detect a variety of events, such as transport, trampling, and use wear.

The post-depositional effect of trampling also effects grain roundness. Experiments have suggested that gravel- and sand-sized lithics and bone contained within a sandy or silty matrix will be moved horizontally and vertically and will exhibit edge damage after biological trampling has occurred (Cahen and Moeyerson 1977; Cahen *et al.* 1979; Gifford *et al.* 1985; Levi-Sala 1986; Stockton 1973; Villa and Courtin 1983). The edge damage is most pronounced on gravel-sized angular lithics (Gifford *et al.* 1985) and weathered bone (Villa and Courtin 1983). These trampling experiments suggest that biological agents affect grain roundness and that the rounding occurs, not during transportation, but after deposition.

Surface Features of Grains

The surface of sediment particles are often marked with minor features that can be helpful in deciphering environments of deposition. The types of surface features are nonuse (no surface alteration); polished (glazing of grains, most probably occurring during aqueous transport but also attributed to pitting caused by bombardment of sand grains in aeolian transport); striated (small-scale grooves, observed in gravel-sized particles and indicative of glacial transport); and crescentic impact scars (seen in gravel-sized grains and resulting from percussion in high-velocity aqueous or aeolin transport) (Reineck and Singh 1980).

Surface features are more easily observed on and interpreted for gravel-sized particles. For sand-sized grains, environmental interpretations of surface features have been discussed (Krinsley and Donahue 1968; Krinsley and Doornkamp 1973; Krinsley and Takahashi 1962). However, the study of surface features on sand-sized quartz grains is problematic (Brown 1973). The grains may be carried in suspension by either water or air and not regularly marked. They may be reworked and represent surface features created during a previous depositional event. The surfaces may also be chemically etched post-depositionally.

Archaeologists have utilized surface features in some types of research (see summary in Tankard 1974). Butzer (1974b), for instance, examined the surface features of sand grains using a scanning electron microscope (SEM) in an attempt to determine the provenience of the Taung Child skull. Although his results confirm the problems of interpreting grain surface features discussed by Brown (1973), they did allow him to differentiate the sources of the quartz grains. Cavollo (1981), using SEM, examined surface features of sand grains to reconstruct the environmental setting of the Turkey Swamp Site in New Jersey. He concluded that on the basis of the kinds of grain surface features he observed the sediment had been transported in an aqueous medium for a short duration in a fluvial setting. The lack of well-developed surface features on the sand-sized quartz grains was interpreted to mean a short distance of transport. Crumley (1966, 1973) reported surface features (presence of frosted grains as well as evidence of polishing and abrasion) as one bit of evidence to reconstruct the aeolian dune environment of the Schmidt and Kantzler sites in southeastern Michigan.

Bull and Goldberg (1985) examined surface features of grains using SEM. Their results indicated that sediments from Tabun Cave, Israel, had been transported by aeolian processes, confirming an interpretation previously made using grain size data. The examination of surface features also suggested that chemical alterations of the deposits had occurred, alterations probably associated with a wetter climate. The SEM pictures showed that the alterations had been produced post-depositionally. A previous suggestion that the chemical alteration may have occurred concurrently with sedimentation was thus eliminated as a possible explanation.

Perhaps the most significant use of surface features is associated with the work on lithics that addresses microwear analysis (Keeley 1980). Many of the features observed on or near the edges of paleolithic stone implements have been attributed to use wear produced by prehistoric peoples. New research suggests that some of these surface features may be attributable to movements of the tools within the deposit, occurring after burial (Keeley 1980; Levi-Sala 1986; Moss 1983; Rottlander 1975; Stapert 1976). Such surfaces are obviously useful for deciphering histories of deposits.

Grain Orientation

The attitude of a nonspherical grain with respect to horizontal and vertical planes is called the grain orientation. If a significant number of grains within a deposit have the same orientation, the deposit is said to exhibit a preferred orientation, called the primary fabric. The primary fabric of a deposit is a result of the medium of transport, the type of flow, the direction and velocity of currents, and the morphology of the surface of deposition (Reineck and Singh 1980:145). The primary fabric is usually described in terms of the direction of orientation of the long axis of the grains and their inclination with respect to a horizontal plane. It can be measured on two main forms: flat equidimensional grains and elongated grains.

The examination of the primary fabric of a deposit is often an obvious attribute that allows deposits to be differentiated. If gravel-sized particles are being examined, a change in the fabric is an attribute easily recognized in vertical and horizontal exposures. In sites where shell is a dominant component, the flat equidimensional structure of the shell displays primary fabric more readily than any other attribute other than color. In shell middens, deposits that are either dipping, truncated, or with random orientation are easily differentiated. Gorski (1979; Stein 1980) used orientation of shell to differentiate undisturbed shell midden deposits from shell midden deposits that had been disturbed post-depositionally by intrusions of human burials. Grain orientation is also extremely important to research connected with taphonomy. The orientation of the bone is often used to determine if the bone in the deposit has been transported in an aqueous medium rather than laid down in a death position (Shipman 1981; Voorhies 1969).

The size of the grain used to determine the orientation of the entire deposit is irrelevant when defining the primary fabric. If particles smaller than sand sized are used, their preferred orientation is referred to as microfabric (or micromorphology in soil science) (Brewer 1964; Goldberg 1980, 1983). The study of micromorphology in soil science includes more than just the orientation of elongate or platelike objects. It entails the analysis of the morphology of soil at a scale smaller than can be observed without magnification. Micromorphology is divided into the study of the plasma (soil material capable of being moved by soil-forming processes), skeletal grain (soil material not readily transported), voids (spaces between solid soil material), and pedological features (units distinguished for any reason having to do with origin, difference in concentration, or arrangement) (Buol *et al.* 1973). The skeletal grains are most significant for determining preferred microfabric orientation as discussed here.

Goldberg (1979b) noted the orientation of granular- and sand-sized skeletal grains in deposits from Qafzeh Cave, Israel, that were oriented in aggregates, suggesting to him that they had originated from previously deposited layers and had been transported as an aggregate to the cave. At Tell Lachish, Israel, Goldberg (1979c) noted that orientation of both mineral grains and organic inclusions in mud bricks pinpointed post-depositional modifications of those bricks, allowing him to differentiate between undisturbed and disturbed ones.

Composition

Sediments are defined in mineralogical or chemical terms following sedimentologists' primary subdivision into clastic (detrital) residues and chemical precipitates. In clastic sediments the grains have a source and are carried mechanically to the site of deposition. Compositional information is used to designate the source of clastic residues, and the textural data are used to designate the transport agent. As a detrital grain is exposed to increased transport (and increased weathering) the composition of the grains change. The most commonly found minerals are quartz, feldspar, mica, ferromagnesian minerals (hornblende, augite, etc.), and clay minerals. Yet in mature sediments minerals such as the ferromagnesium minerals, sodium and calcium feldspars, and montmorillinite clays are easily weathered, increasing the concentrations of the more resistant minerals and weathering products (e.g., quartz, potassium feldspars, and kaolinite clays). Thus composition provides information on more than just source areas. Along with textural data it provides data on transport agents and maturity (Folk 1980). The size and composition of the detrital grains give rise to the classifications of clastic sediments such as quartz sandstone, arkose, and chert conglomerate. Accompanying these minerals may be rock fragments, that is, pieces of igneous, metamorphic, and sedimentary rocks, or other inclusions (Shotton and Hendry 1979).

Nonclastic sediments are formed by chemical or biological agents from material in solution (chemical percipitates). Thus the physiochemical and biochemical conditions in the medium control the chemical composition and the size of the interlocking crystals, which in turn give rise to the classification of nonclastic sediments such as crystalline limestone, micrite, dolomite, limonite, and gypsum. Accompanying the common minerals of calcite, gypsum, and halite are fossil inclusions and chemical aggregates (e.g., oolites). Nonclastic sediments that form in solutions within the solum are especially important to archaeological investigations (Carr 1983).

Composition of Coarse-Grained Fractions

Identification of the composition of gravel-sized sediments found within archaeological deposits most frequently determines the source of the material (Bullard 1985; Herz 1985; Kempe and Harvey 1983; Luedtke 1979, Michels 1982; Rapp *et al.* 1984; Stein 1980; Stein and Rapp 1978). Once the composition of the gravel fraction is identified, the nearest outcrop of similar mineral or rock is located and thought of as the source area. The assumption that the gravel was acquired from the nearest exposure of that rock or mineral type is problematic in that the object might have been derived from not the closest exposure but a variety of exposures available in any area. Rather than pinpointing the location of the source, what has been determined is the most probable source. In some cases chemical signatures of materials have been used to solve this problem. The chemical signature of the object from the site is compared to the signature of materials in source areas. This comparison is thought to eliminate some of the bias associated with assuming that the closest location is the most probable source. However, few chemical signatures can precisely define the source of material found in deposits. Rather, they usually define the conditions in a variety of exposures, leaving the researcher with the same problem of knowing only the most probable sources of the object.

The composition of sand-sized grains in archaeological deposits is frequently done by point counting the sand fraction of samples (Daniels *et al.* 1968; Galehouse 1971) and separating the heavy minerals by using heavy liquid analysis (Folk 1980). The composition of the sand-sized fraction usually provides information on the source of the sediment fraction. Composition of sediments in rockshelter deposits have been analyzed to determine the source of the grains (Ahler 1973a,b, 1976; Farrand 1975a, 1979; Feathers and Stein 1986; Goldberg 1979a,b). The determination is accomplished by comparing the suite of grains observed in the archaeological deposits with suites of grains found in samples taken from areas around the site (control areas). If the suites are similar, then the area where the control sample was taken is said to be the source of at least a portion of the sand fraction in the archaeological deposit. In most cases the suite of minerals in the archaeological deposit contains a greater diversity of minerals than is found in any one sample from a control location. This increase in diversity is explained by suggesting that the sand fraction came from multiple sources.

Compositional studies of sand-sized particles have been used to determine the source of other materials. The "grit" temper used in ceramic manufacture can provide data with which sources of the sand temper are located (Kamilli and Steinberg 1985). Small-sized artifacts, called microartifacts, defined by their composition, have recently provided clues to depositional environments as well as to post-depositional alterations (Clark 1982, 1984a,b; Dunnell 1986; Fladmark 1982; Hull 1984; Rosen 1986; Stein and Teltser 1986; Vance 1985, 1986).

Composition of Fine-Grained and Ionic Fractions

The composition of the fine-grained fraction of a deposit consists of both silt and clay-sized particles and ionic and radical compounds. This fraction has been frequently examined in relation to prehistoric agriculture (Healy *et al.* 1983; Antoine *et al.* 1982; Davidson *et al.* 1986; Overstreet 1987), ceramic technology (Perlman and Asaro 1969), and clay mineralogy as it relates to soil formation processes (primarily weathering) (Birkeland 1984; Carr 1983; Holliday 1985a,c).

Archaeologists are generally aware of the fact that the fine-grained fraction of the archaeological record provides information not only to decipher transportational and depositional agents, but also to determine the effects of post-depositional alterations (pedogenesis and diagenesis). After a deposit has been laid down it can be buried, eroded, or stabilized. If the upper boundary of the deposit is exposed at the surface and has not been eroded or buried (it has been stable), a soil will develop in the deposit (Brady 1974; Buol *et al.* 1973). Soil formation is a process dependent on parent material (the deposit), climate, biological activity, slope, and time. Soil formation can alter the original attributes of the deposit by adding new material (usually at the surface), removing material (through leaching), transforming material (chemical weathering), and transferring material (translocation of fine-grained and soluable fraction through percolation) (Simonson 1959).

Archaeological deposits, which act as the parent material for soils, have attributes that have been altered from their original character imparted during deposition (Cornwall 1958; Limbrey 1975). Through soil genesis additional organic residues are added, compounds are transferred and transformed. Carr (1983) conducted a thorough study of the effects of soil formation on archaeological deposits at the Crane Site, Illinois. He paid particular attention to how ionic and radical concentrations were affected by changes in vegetation, cropping, and fertilizing practices. Holliday (1985b) analyzed burial soils to infer the conditions pervailing during the Paleoindian Period in Texas. His work has also established the time of occupation for Paleoindian sites and the ages of the formation of the soil associated with the artifacts (Holliday *et al.* 1983). Across Cinnamon Creek Ridge many buried soils were correlated using grain sizes and radiometric ages of soil organic matter (Jorstad *et al.* 1986). Ferring (1986) examined paleosols and their organic content to calculate rates of sedimentation for the deposits in which the soils formed. Pope and van Andel (1984) used soil characteristics, especially grain size and carbonate content, to establish the nature and chronology of alluviation in the southern Argolid, Greece. Their results indicate that climatic changes can explain only some of the alluviation and stabilization events and that cultural land disturbance must also be examined as a dominant cause.

Although the composition of the fine fraction of a deposit includes the clay-sized particles as well as the ionic fraction, it is the chemical compounds that have been utilized most frequently in archaeological research. Those that have been emphasized most are the hydrogen ion concentration (pH), organic matter content, carbonate content, and phosphorus content (Beck 1974; Carr 1983; Carter 1978; Cook and Heizer 1965; Goffer 1980; Lambert 1984). Hydrogen ion concentration (activity) of a deposit has been emphasized because of its relationship to the preservation of compounds frequently observed in archaeological deposits, most notably bone and shell (Gordon and Buikstra 1981; Cook and Heizer 1965; Lambert *et al.* 1985; Stein 1984b; White and Hannus 1983). Organic matter is the organic substance that remains after decomposition and has sometimes pinpointed the nature of the original organic substance (Carr 1983; Stein 1984a). Phosphorus is added to sediments in large concentrations by excreta of mammals and the decay of their bones. Because phosphorus is easily held within the fine-grained fraction of a deposit (it is not susceptible to leaching), its presence is often indicative of the presence of mammals (Cook and Heizer 1965; Eidt 1977, 1985; White and Hannus 1983).

The research objectives associated with chemical analyses of the fine-grained fraction of archaeological desposits fall into four categories:

1. to define the boundaries of archaeological deposits
2. to differentiate archaeological deposits
3. to detect archaeological deposits that have left no trace other than a chemical signature
4. to report methods and potentials of new techniques for analysis

Defining Boundaries of Archaeological Deposits. Examples of research in which chemical parameters have been used to delimit the boundaries of archaeological deposits are numerous. Some have been frequently reported in the literature (Arrhenius 1963; Eidt 1973; Lutz 1951; Overstreet 1974; Weide 1966) and thus will not be summarized here. Other examples contain some intriguing conclusions and are less well known. Heidenreich and Narratil (1973) measured a suite of chemical elements to determine the perimeter of the Robitaille site, Ontario, finding that organic matter values did not change significantly from within the village to beyond it. Although most archaeologists assume that prehistoric people enrich the organic matter concentrations within areas of occupation, organic matter concentrations did not differ across the apparent village perimeter at the Robitaille site. It is, of course, possible that the organic matter may have been decomposed and leached from the deposits, or that the archaeologists were not really beyond the village boundary.

Another example is represented by the work of Griffith (1980), who found that the levels of organic carbon did not differ significantly when measured within or outside the Benson site, Ontario. Rather he found that at this seventeenth century Huron site, magnesium and phosphorus were the best chemical indicators of occupation areas. Griffith suggested that a whole suite of chemical agents should be measured when examining other sites to determine which will best differentiate an occupation area from its unoccupied surroundings. Members of the Hoset Project, Norway, measured phosphorus concentrations to define the boundaries of farmsteads as well as areas of habitation (Farbrgd 1977). In Georgia, Shirk (1979) utilized phosphorus to determine site boundaries, and in Alaska, Moss (1984) used phosphorus analysis to confirm identifications of some ambiguous sites and refute the presence of sites at other locales.

These examples demonstrate the utility and limitations of using compositional data to delimit site boundaries. Of course many of the limitations of these chemical tests might be due to trying to delimit boundaries of prehistoric activity that do not exist. As suggested by Dunnell and Dancey (1983), many activities do not produce sites, or concentrations of artifacts detectable with chemical analysis. Rather, a majority of activities produce isolated objects or small groups of objects and chemicals. These artifactual concentrations would not provide chemical signatures that could be differentiated as archaeological deposits with well-defined boundaries.

When sampling from the surface, delimiting the boundaries of exposed deposits is difficult. If the surface from which the samples are taken has been stable for a long period of time (beginning before the addition of cultural residues), then the deposit being examined consists of a thin or thick layer of artifacts, including ions and radicals, that were laid down in one or multiple events. In some cases such deposits may be so small that their boundaries are seen as gradual changes in chemistry across the landscape. These changes can be distinguishable only with difficulty from the chemistry of the stable surface. However defining such diffuse lateral boundaries is no different from defining the diffuse vertical boundary of a deposit exposed in a profile. Their existence should be substantiated by mapping exact locations of artifacts and chemical parameters on the surface. In this way boundaries do not have to be drawn and the gradual nature of the archaeological record can be documented (Dunnell 1985).

Differentiating Archaeological Deposits. Chemical data have also been used to differentiate archaeological deposits. Joshi and Deotare (1983) analyzed 490 samples from archaeological deposits throughout India. They concluded that phosphorus was the best indicator of archaeological deposits. Their use of control samples as a means of comparing and interpreting archaeological samples aided in their study. Rapp and Gifford

(1982) analyzed sediment samples from Troy that were collected by the University of Cincinnati Expedition in 1937. They subjected the samples to multiple tests and were able to reconstruct the sources for some of the vertical and horizontal variations in the cultural debris. From the results they also estimated the approximate net influx of such material categories as matrix, bedrock blocks, and clay. Burgess and Jacobson (1984) analyzed sediment samples from both open-air sites and rockshelters in Namibia. They used these results to evaluate the contributions of soil-forming processes, cultural processes, and geomorphic processes.

Other examples of research in which chemical data aided differentiation of archaeological strata include the work of Van Der Merwe and Stein (1972). A host of chemical tests were used to differentiate rodent burrows from post holes. Although many problems can be found with their research strategy (e.g., grouping samples into categories of "post hole" and "rodent burrow" and comparing the two groups rather than using a grouping statistic to separate the groups according to the attributes measured), magnesium and phosphate were defined as the best indicators to separate the two categories. Stein (1984b) used organic matter, carbonate, and phosphorus analyses in an attempt to differentiate two types of shell middens observed in sites in the Northwest Coast of the United States. Mattingly and Williams (1962) identified a buried soil below a Roman amphitheater on the basis of chemical data. Goffer *et al.* (1983) used chemical tests to determine if pits in Tell Beer-Sheba, which did not contain flooring or wall plaster, were actually dumping places for town refuse and perhaps used for making compost. Treganza and Cook (1948) examined organic matter values to differentiate deposits in a California coastal midden. Rather than examining site formational processes, they were interested primarily in reconstructing diet and meat weight to infer the population size supported at the site and the rate of deposition of the midden. Stein (1984a) used organic matter and carbonate data to define the source material for Oneota refuse pits in southern Minnesota. Cruxent (1962) analyzed some postulated hearths and by means of the phosphorus content concluded that they were not cultural strata. Davidson (1973) used data on phosphorus levels to unravel the complex depositional history of Sitagroi Tell in northeastern Greece. He was primarily interested in discovering from where the materials for mud bricks were obtained and if those sources, or conditions in the source areas, had changed through time.

The hydrogen ion concentration (pH) specifically has been used by many excavators to distinguish archaeological strata (Deetz and Dethlefsen 1963). Dunnell and Campbell (1977) measured pH in an attempt to distinguish features from nonfeatures. They collected samples from within features and samples from beyond the feature boundary and found that the pH values were not significantly different in the two types of deposits. Campbell

(1981) used pH values to differentiate two buried deposits at the Duwamish site, Washington. At this site both deposits contained shellfish remains and did not differ in pH. The samples were obtained from cores and the pH values could best be used to detect presence or absence of shell within the subsurface. Farrand (1975a) found that pH correlated with deposits containing the most artifactual debris and not with evidence of weathering, as had been previously interpreted from cave sediment analysis (Laville *et al.* 1980). The pH may be related to the increased amounts of organic debris introduced by people during occupation.

Identifying Archaeological Deposits in the Absence of Artifacts. Chemical analysis has also been utilized to detect some kinds of archaeological deposits that contain no other evidence of cultural deposition. The best examples of this type of research deals with bone and wood preservation and its relationship to sediment acidity. Chemical signatures of decomposed bone often define areas once rich in bone, even after the bone has decomposed (Bullen 1949; Gordon and Buikstra 1981; Hare 1980; Lambert *et al.* 1985; Tuck 1970). At Angel Mound, Ohio, Zeiner (1946) noticed that a distinctly different vegetation was growing in a ring around the Woodland Period site. The plants seemed to be responding to acid conditions produced by the decayed remains of the former wood palisade. The palisade had decomposed but had left a chemical signature identifiable by noting the response of plants.

Deposits associated with agriculture also contain little evidence other than distinct chemical traces that identify them as being transported or disturbed by people. In Mesopotamia, Hardan (1971) analyzed the quantity of various salts in samples of mud brick. He assumed that the source material for the mud brick was the soil surrounding the living area. The salt level in those bricks reflects the properties of the deposits created by agricultural manipulation (small-scale transport and deposition). The degree and type of salinity suggested to Hardan a relative age for the mud brick samples and a location of the Tigris and Euphrates rivers and irrigation agriculture at the time of mud brick deposition. In Belize, Healy *et al.* (1983) used chemical analysis to determine the reasons for the cessation of deposition within agricultural terraces. The authors proposed that aluminum toxicity (which was building up within the deposits during cultivation) coupled with increasing clay content (which is also associated with cultivation) had led to declining agricultural yields. The conclusions are intriguing but the accumulation of clay in the terrace deposits, and thus aluminum toxicity, was never demonstrated by a comparision of the terrace chemical and textural data with control samples (see Stein 1985 for discussion of the use of control samples). Lambert and Arnason (1982) used data on the acidity of deposits surrounding Mayan house platforms to help resolve the question of whether the Ramon tree associated with the platform deposits was an integral part of the kitchen garden or whether the limestone contained in the house deposit provided favorable pH conditions for the growth of the trees. The chemical and botanical results suggested that the distribution of Ramon trees is an ecological relict and not an intentional product of prehistoric Mayan subsistence.

Reporting Techniques of Chemical Analysis. Many archaeological publications deal with the techniques of chemical analysis and the potential results of these techniques. This type of publication was the earliest literature on archaeological chemistry to appear in North America (e.g., Cook 1950; Cook and Heizer 1965; Krieger 1940; Schwartz 1967; Solecki 1951). The chemical element that has received the single most concentrated discussion concerning methods of analysis and potential of use in archaeology is phosphorus. A few publications have discussed techniques associated with other chemicals (e.g., Eidt 1985; Stein 1984a; Stross and O'Donnell 1972), but phosphorus has without doubt received the most attention (Bakkevig 1980; Dauncey 1952; Eidt 1977, 1984, 1985; Eidt and Woods 1974; Hassan 1981; King 1981; Proudfoot 1976; Proven 1971; Sjoberg 1976; Woods 1977). Reporting techniques of chemical analysis was an important step in establishing chemistry as a viable research tool in archaeology.

Structures

Structures are small-scale variations in either grain size, grain shape, composition, or pore space. They are created during deposition, soil formation, or lithification. Because the structures are so small in scale they are usually not called individual deposits but rather are considered attributes of deposits.

The kinds of structures that result from depositional events are called sedimentary structures. They are small-scale structures associated with a single sedimentary bed. If a single bed exhibits decreasing average grain size from bottom to top, the structure within the bed is referred to as a graded bed. If the grain size increases upward within a bed, it is referred to as a reversed graded bed. If the fabric of the bed results from some minor fluctuations in the rather constant physical conditions prevailing during deposition, the structural features within the bed are called primary structures. In addition to variations in conditions of transport agents such as air or water, biological organisms impart recognizable primary structures to sediments even though the organisms are not preserved.

Sedimentary structures are produced as a result of interactions between gravity and the physical and chemical characteristics of the sediment and the transport medium (Allen 1982; Collinson and Thompson 1982; Reineck and Singh 1980). They are produced by differential sorting of grains (by size, shape, and specific gravity) and are dependent on variable settling velocities, turbulence of medium, gravitational avalanching, and boundary shear stress. Because the structures are dependent on mechanical processes they are indicative of environments of deposition.

Sedimentary structures have their greatest interpretive power when examining sediments transported in an aqueous medium. Because most archaeological sites reflect the habitat conditions of human beings (i.e., located in nitrogen–oxygen atmosphere and not in an aqueous medium) few sites contain the kind of sedimentary structures so useful to sedimentologists.

Structures that are produced after deposition ceases are usually associated with pedogenesis and referred to as soil structures. Soil structures can be examined either macroscopically or microscopically. The microscopic analysis of these structures, emphasizing their examination in thin section, is the study of micromorphology (Brewer 1964; Bullack and Murphy 1983). Micromorphology can best address questions concerned with composition of sediment grains, morphology of the grains (size, shape, and roundness), and identification of structures (illuviation of clay, nature and distribution of pores, and types of bedding).

Laminae and Lamellae

In archaeological sites, structures are frequently described without reference to whether they were produced during depositional or post depositional events. The most common structures observed in deposits are sedimentary structures (primary structures, which reflect minor fluctuations in the depositional conditions) or soil structures (pedogenic features, which reflect post-depositional alterations of sedimentary deposits). Because the structures are described without consideration of their origin (i.e., before one knows whether they are sedimentary or soil structures), they are often referred to uniformly as laminae, lamellae, layers, or bands.

The terms laminae and lamellae have been borrowed from other disciplines in which their meaning is precisely defined. In sedimentology, the term "laminae" usually refers to small-scale variations in lithology observed within a deposit, usually less than 1 cm thick (Payne 1942). They reflect slight changes in the depositional environment or pulsations in the velocity of the transport agent. Because they are small they are considered attributes of the deposit, rather than as individual deposits themselves. In soil science small-scale layers are called lamellae, a soil feature produced by translocation of clay-sized particles (Birkeland 1984: 128). Lamellae are bands of more than 10% clay found in the B soil horizon. Their origin is believed to stem from water penetration associated with either particular storm events or seasons, subtle changes in grain size that retard downward movement of water, or flocculation of clay under particular subsurface conditions. Iron deposits can also be translocated within soils, producing banded structures often noted during archaeological excavations.

Problems can arise when the terms laminae and lamellae are used interchangeably. The term laminae has been used to refer to evidence of minor fluctuations in constant physical conditions (an event associated with deposition). It has also been used when describing iron deposits translocated during formation of soils, which produce banded structures often noted during archaeological excavations (events associated with post-depositional alterations). Because the term has been used in archaeology without reference to a clear definition (Stewart 1983) the association of lamellae and laminae with depositional events or post-depositional events will be difficult to distinguish.

The systematic utilization of structures, as attributes of sediments that are useful for understanding depositional events, is represented best by the studies in micromorphology (most notably Goldberg 1979a–c, 1980, 1983; Bull and Goldberg 1985). For example, at Pech-de-l'Aze II, Dordogne, France, microlaminations that had been interpreted as primary structures produced during deposition were observed in thin section and identified as illuviated clay bands, that is, lamellae (Goldberg 1979a). At Qafzeh Cave, Israel, the micromorphology of the talus sediments revealed that woody fragments were cemented in the calcareous scree (Goldberg 1980). The wood was interpreted as evidence of cultural activity. Although micromorphological studies are promising for determining small-scale depositional and pedogenic processes, the attribute of structure has just begun to be fully utilized in archaeological research.

CONCLUSION

In recent years archaeological research has in part focused on explaining how the record was formed. The record has been described as containing cultural and natural elements that are related to each other in the context of the deposit. Thus far the analytical approach for this research has been to separate the cultural and natural elements and examine them using artifact analysis for the one and sedimentological analysis for the other. Yet a more useful approach to decipher depositional histories would be to treat the record (in its entirety) as a sedimentological deposit. All components could then be described in sedimentological terms (attributes) and according to rules established in the geological code of stratigraphic nomenclature, which would allow the archaeologist to determine the contribution of biological (cultural) agents and natural agents in archaeological deposits.

A sedimentological deposit is a single "sedimentation unit formed under essentially constant physical conditions . . . (with) constant delivery of the same material during deposition" (Reineck and Singh 1980:96). The material contained in the deposit is called sediment. Each individual sedimentary particle can have a unique depositional history related to its source, transport agent, environment of deposition, and post-depositional alteration. Attributes of the sedimentary particles that can be used to interpret depositional history are texture, composition, and structures. Sedimentary particles are grouped in deposits because the sources, agents of transport, and depositional environments were constant for a sufficiently long period of time to allow them to accumulate.

Thus a deposit is an analytical unit available to the researcher, defined by its homogeneity of physical attributes, its fossil or artifact assemblage, or its chronological position. A deposit grouped on the basis of its homogeneity of physical attributes (lithology) in geology is called a lithostratigraphic unit and named formation, member, or bed. In archaeology, units described in these terms are called (in the majority of cases) strata, but new classification systems define them as elemental sediment units (ESUs) (Fedele 1976, 1984) or layers (Gasche and Tunca 1983).

Deposits identified on the basis of fossil assemblage in geology are called biostratigraphic units and named biozones. In archaeology, no systematic classification has been utilized. Rather, artifacts have been described in most cases without consideration of the deposit. The term "zone" has been suggested by Gasche and Tunca (1983) as the basic unit of ethnostratigraphic units, and the terms primary refuse, secondary refuse, and *de facto* refuse have been proposed by Schiffer (1972, 1976, 1983, 1987).

Finally, a deposit can also be grouped on the basis of chronological events. In geology, a unit described in these terms is called a geologic time unit (chronostratigraphic, geochronologic, and geochronometric units) and classified according to the units that are based on material standards or referents and those independent of material referents. In archaeology, units described in terms of their chronological events have been proposed by Gasche and Tunca (1983) and called set, phase, and subphase. The units refer to one or several strata whose sedimentation has taken place during a specific time interval and are thus equivalent to chronostratigraphic units of geology. Most other archaeologists have classified time units, focusing on determining time in terms of years-before-present. Such determinations are made by focusing on artifactual contents rather than on deposits. The artifacts are used for their chronological significance without consideration of the deposit from which they came, and without consideration of whether the artifact's age of manufacture is contemporary with its age of deposition.

Of these three classification systems for deposits, two are systems based on observations (created by "direct observations of tangible features and characteristics of the strata and are independent of interpretations regarding the significance of these observations"; Krumbein and Sloss 1963:28), and one is an inferential classification system (created by making interpretations of the strata and their contents). The classification systems based on the physical descriptions of the sedimentary particles and on the artifactual assemblage (contemporary with deposition) are observational types. The classification system based on time is inferential, because it requires an interpretation of observed data, an interpretation that could vary if the observed data vary.

When archaeological research is conducted without careful consideration of the concept of the deposit, problems can occur. The most notable problem is related to the law of superposition and the archaeological term of "reversed stratigraphy." Deposits accumulate one on top of the other (according to the law of superposition) and can only become reversed if the sequence of deposits are overturned and their structure (including boundaries) remain intact. Archaeologists have applied the law of superposition to the artifacts within the deposits and suggested that deposits are reversed in their stratigraphic order if the age of manufacture of the artifacts within the deposits is reversed. Actually, the chronological order of the contents of the deposits is the unit to which the reversal refers.

A second problem occurs when defining processes of site formation. If the analytical unit for studies of site formation is the sedimentary particle (e.g., artifact), then only the history of that one particle will be reconstructed. The history of every particle will be analyzed separately and the depositional processes of the site will consist of the histories of the millions of individual particles. Also, the law of superposition will not be applicable because it is only appropriate for arranging the order of deposits, not the order of age of manufacture. If the concept of deposit is utilized, then environments of deposition can be reconstructed for the larger grouping of sedimentary particles. Also the law of superposition, principle of original horizontality, and the law of original continuity, which are relevant only for the concept of deposit, will be applicable.

As noted by Binford (1981b), the identification of agents involved in the depositional history of material is often less than obvious. Sedimentologists have observed that grain size distributions reflect the mode of sediment transport. Grain shape and roundness indicate distance of transport. Grain surface features are suggestive of the type of transport agent involved. Grain orientation is indicative of the morphology of the surface of deposition. Composition of grains is best suited to determine the source of grains but is also the prime indicator of post-depositional alterations. Sedimentary structures can be produced during the deposition of the grains or during post-depositional changes. If archaeological deposits are treated as sedimentological deposits, then the agents involved with the formation of the deposit can be made explicit on the basis of observations and tests.

The most difficult change, which the analytical procedure suggested in this chapter requires, is for archaeologists to think of human beings as just one of many natural agents involved in deposition. Cultural activities conform to the laws of nature. Thus culture is only one of the many types of biological or mechanical agents of transport and deposition. Each individual type of agent imparts its own set of attributes on a deposit. In the analysis of archaeological deposits the attributes of sedimentary particles within deposits can be defined, and from these observations inferences can be made.

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