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Geoarchaeology in Alluvial Landscapes

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1. Introduction

This chapter is a discussion of geoarchaeology in fluvial environments ranging from temperate to arid. This environmental framework is chosen because of the striking differences in fluvial systems that pertain to alluvial records across different environments. The archaeological objectives in these different settings may differ slightly, owing to unique or specialized forms of adaptation in different environments; for example, the use of irrigation. But in the main, it is the characteristics of alluvial landforms, deposits, and soils that vary across bioclimatic clines, rather than the kinds of archaeological questions and problems that are pursued there. In this sense, geoarchaeological methods employed for defining stratigraphic frameworks, dating deposits and sites, and reconstructing environments and site formation histories are not specific to certain bioclimatic settings.

On the other hand, bioclimatic clines correlate with significant differences in the processes that underlie construction of the geoarchaeological records, such that those records look different. So, my purpose here is not to examine the rationale for studying site formation, or for constructing detailed geochronologies, or to demonstrate that we need to establish the effects of geomorphic

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change on site preservation and site visibility. Rather, I characterize the archaeological significance of some important parameters of fluvial systems and alluvial geology across bioclimatic clines from temperate to arid to summarize and illustrate methods used in the course of geoarchaeological research in those settings. These discussions deal primarily with fluvial environments in midlatitude, low–altitude contexts.

1.1. Perspectives

Most prehistoric archaeologists conduct most of their fieldwork in fluvial environments. This especially true in the United States, where Cultural Resources Management (CRM) investigations are concentrated in alluvial settings. Understanding the fundamental aspects of fluvial geology is essential for producing sound fieldwork. Unfortunately, many archaeologists have not had the opportunity to obtain this familiarity, either through academic preparation or through long interaction with geologists. And, one might add, many geologists have not availed themselves of corresponding archaeological fluency! A number of textbook approaches to fluvial geology are available to archaeologists (e.g., Rapp and Hill, 1997; Waters, 1992). These can provide students of alluvial geology with an introduction to the principles of fluvial systems and also to the methods used to study them.

Processes and factors of alluviation, comprising independent variables in fluvial equations, are critically reviewed by in this volume by Frederick (Chapter 3). He outlines both concepts and methods for relating alluvial sedimentation to factors such as climate change, tectonism, and eustacy. In this chapter, my emphasis is on the dependent variables in those equations, namely the sediments that contain archaeological records. Variations in alluvial sediments are discussed with respect to different environmental settings and over varying temporal ranges.

1.2. Time, Environments, and Fluvial Systems

Variability in alluvial records is discussed here at two temporal scales. The first is that period considered here as the Holocene period. (I intentionally avoid the arbitrarily set date of 10,000 B.P. for the end of the Pleistocene, because the physical and the bioclimatic shift from "glacial to postglacial" environments is the only empirical concern, and that shift is notoriously time transgressive; see Holliday, Chapter 1, this volume). The Holocene encompasses late Paleo–indian and younger occupations of the New World. It begins roughly at the shift from Epipaleolithic to Neolithic in the Near East and from Upper Paleolithic to Mesolithic in much of Europe. The late Holocene, roughly the last five millennia, witnessed the emergence of all of the world's complex cultures. In essence, the Holocene is the period of substantial and lasting human modifications of landscapes, including fluvial systems (cf. Binford, 1968).

The Post-Pleistocene is distinctive in regards to fluvial systems as well. It can be generalized that this period is one of common floodplain aggradation, manifesting the lack of macroclimatic change and near–modern sea level (Schumm and Lichty, 1965). Bull (1991) stressed that in all climatic and tectonic settings, the end of the Pleistocene corresponded with "... strong shifts to the aggradational side of the threshold of critical power" (p. 276). At the same time, it is important to note that there were significant climatically driven differences in the tempo of aggradation in many drainages; those include episodic periods of dynamic equilibrium that caused cut–fill cycles. Overall, however, the major variations in post-Pleistocene alluvial records are geographic (interdrainage or interregional) rather than temporal. Comparison of chronostratigraphic columns from valleys in the midwestern to the southwestern United States illustrate regional variability. These patterns illustrate the necessity of local perspectives on alluvial geologic records and their geoarchaeological implications.

The second scale is the Pleistocene. This period encompasses the initial peopling of the New World and practically all of the human occupations in the Old World. Both the magnitude and the qualitative parameters of environmental change, including changes in fluvial environments, are very different for these two time scales (Table 4.1). And, significantly, the Pleistocene was a time of comparatively minimal and/or transitory human impacts on their environments. The Pleistocene fluvial records were created in a context of net long-term entrenchment of rivers that is registered by alluvial deposits associated with terraces. Minimally, terraces are evidence of punctuated hydrogeomorphic evolution of drainage basins. Likewise, the alluvial deposits, including enveloped artifacts and ecofacts, are "punctuated" within and between terraces. Both the

Table 4.1. Comparison of Fluvial Environments at Pleistocene and Holocene Scales

Parameter	Holocene	Pleistocene
Macroenvironment	Quasistable	Macroenvironmental changes common
Fluvial environments	Final succession to modern environments	Cycles of glacial–interglacial or stadial–interstadial environments
Marine base levels	Fluctuations about near-modern levels	Major cycles of change, notably the last transgression
Floodplains	Period dominated by construction of modern floodplains via episodic alluviation; uncommon terraces[a]	Cycles of floodplain construction and abandonment (creation of terraces)
Meltwater effects	Negligible in most cases	Major cycles of meltwater discharge; effect changes with glacier–coast distance
Channel adjustments	Usually minor shifts, controlled by internal, self-regulating mechanisms (e.g., avulsion) and/or by minor cycles of climate change	Major changes in stream class
Soils genesis	Monogenetic soils of subequilibrium age (azonal to weakly zonal)	Polygenetic soils representing serial equilibria

[a]Terraces predominantly in loessal regions or those with neotectonics or glacioeustatic rebound.

completeness of geoarchaeological records and the difficulties in dating and correlating those records are increased in proportion to the age of the deposits.

2. Fluvial Environments, Geology, and Archaeological Implications

This section contains a brief overview of the geologic results of fluvial change at both spatial and temporal scales. The causes of those changes, considered in detail by Frederick (Chapter 3, this volume) are the subject of major works by a number of principals, including, for example, Bull (1991), Knox (1983), Leopold et al. (1964), and Schumm (1977). Alluvial processes and results are integral to geomorphology (e.g., Bloom, 1991; Cook and Warren, 1973; Glennie, 1970; Lewin, 1978; Thorns and Brunsden, 1977). Additionally, the literature in alluvial sedimentology is similarly extensive (e.g., Allen, 1965; Collinson and Lewin, 1983; Miall, 1981, 1992; Reineck and Singh, 1980). The emphasis here is on those aspects of fluvial geology that are most important to archaeologists: landforms, sediments, stratigraphic markers, and associated evidence for past environments.

2.1. General Factors

The general factors of alluvial geology are those that would be considered in virtually any fluvial system. At least ten factors must be controlled in order to quantitatively model the behavior of a graded stream, one that is neither aggrading nor eroding its channel (Bloom, 1991). These first include the resistive framework of the system, including bedrock lithology and structures (Bull, 1991:133; Knox, 1976; Patton and Schumm, 1981). Tectonics (Bull, 1991; Miall, 1981; Summerfield, 1991; Vita-Finzi, 1986) and/or glacio-eustatic rebound (Brakenridge et al., 1988) are endogenic factors of system change. Climatic control on fluvial systems is probably the dominant theme in the process literature. Much too extensive to treat here, that literature considers climatic patterns (e.g., annual precipitation, flood frequency and magnitude, seasonality) as direct factors in dynamic parameters such as sediment yield, stream discharge, stream load, and channel shape, sinuosity, and so on. (e.g., Leopold, *et. al.*, 1964; Schumm and Lichty, 1965). A deficiency in research on alluvial morphogenesis is the shortage of studies on chemical denudation, which, in some humid environments is subequal to mechanical denudation of metamorphic rocks (Cleaves et al., 1970).

Much of the research concerning climatic controls on fluvial systems is based on short-term records within basins (Harlin, 1978, 1980), or on comparison of modern fluvial systems among different climatic regions (Knox, 1983; Schumm and Lichty, 1965). Longer-term records matched with independent climatic proxies are also studied in this respect (Baker and Penteado-Orellana, 1977).

Despite significant risks of circular reasoning, it is also common to use quantitative or semiquantitative climate-response models such as the Langbein–Schumm (1958) sediment yield function as devices for inferring past climates from alluvial geology (e. g., Hall, 1982, 1990a,b; see Knox, 1983). Last, contributions are made by measuring the impacts of human land use on fluvial process (McDowell, 1983). Several parameters of fluvial systems and their geologic records are discussed below, with an emphasis on patterns expressed across temperate to arid environments. The purpose of these discussions is to identify empirical and methodological implications for geoarchaeology.

2.2. Vegetation, Weathering, and Sediment Yield

The interdependent factors of bedrock, climate, vegetation, and rates of weathering are the principal controls on sediment yield (Langbein and Schumm, 1958). The sediment yield in basins has been of great interest to geomorphologists because this factor is diagnostic of soil loss, reservoir filling, and flood properties. The controls on sediment yield are important to the research of Quaternary scientists because sediment yield is a major aspect of landscape evolution. For geoarchaeologists, sediment yield is important for somewhat different reasons. The amount and distribution of sediment yield are factors that largely define where, when, and at what rate sediments will be eroded or deposited. If even moderately accurate, such a sediment yield model would allow identification of places on past landscapes where archaeological materials could be preserved by burial. Indeed, predicting site locations and site contexts in fluvial environments can benefit greatly from a diachronic sediment yield model, coupled with known patterns of settlement choice based on resource distributions or on other cultural factors. Examples of this are presented later.

The Langbein–Schumm (1958) curve (L–S) is the model most frequently invoked in the interpretation of alluvial deposits, despite the fact that the curve is only a fit to a remarkably variable data base. Significantly different patterns of sediment yield are associated with environments different from those used in the L–S model (Walling and Webb, 1983), cautioning against its unpracticed use. The L–S model indicates peak sediment yields ca. 800 mm annual precipitation, corresponding to a grassland environment, and decreasing yields with either less (desert) or more (forest) rainfall. In equilibrium conditions, the majority of the sediment yield is stored on slopes as colluvium, and a fraction is deposited as alluvium, the principal focus of alluvial geoarchaeology.

2.3. Channel Patterns and Stream Load

Schumm and Brakenridge (1987) used variables such as stream power, sediment load, sediment size, and channel patterns to classify channels (Figure 4.1). This well-known scheme associates channel shape and stream load properties with grades of stability and specific modes of change (see Baker and Penteado-Orellena, 1977).

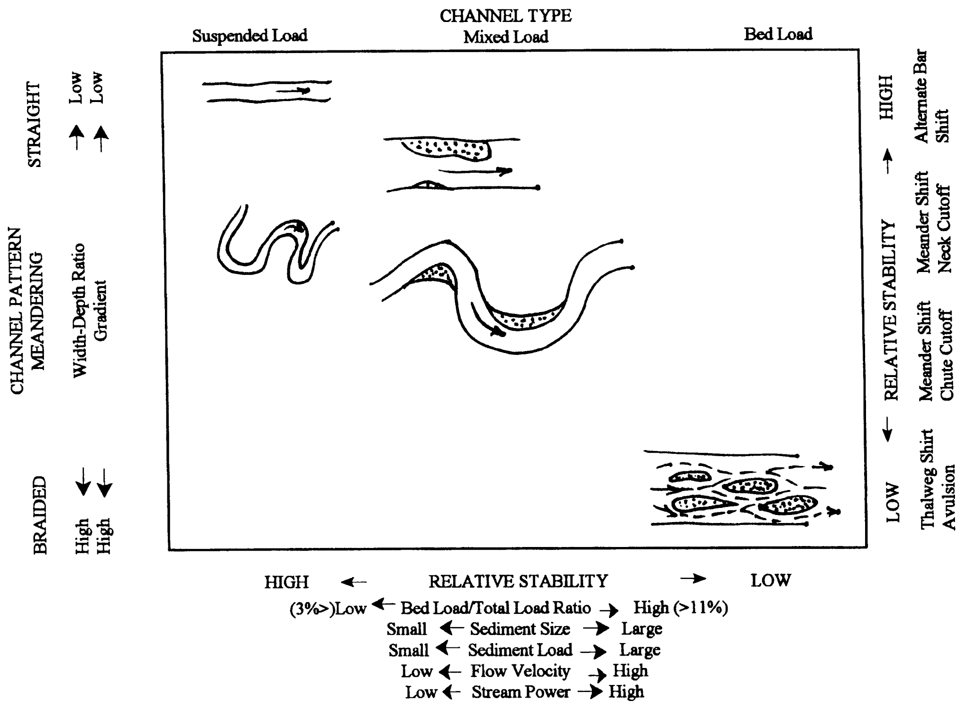

Figure 4.1. Channel classification based on pattern, stability, and type (from Schumm and Brakenridge, 1987).

Two features of their classification are very significant regarding geoarchaeology: channel form and the ratio of bed load to total load. Channel forms are important in that they correlate with key patterns of erosion and deposition on floodplains (Table 4.1). Both the rates and the styles of channel shifting may be inferred from channel patterns. For example, the instability of braided channels denotes low preservation potentials compared to straight ones. Relatively unstable, meandering channels are associated with higher rates of levee and splay construction, which are important factors in constructing floodplain landforms for occupation. They are also associated with rapid site burial. Unstable channels also have higher rates of avulsion, one of the larger scale changes in floodplain depositional morphology (Allen, 1965; Lewin, 1978), and concomitant changes in site formation contexts (Ferring 1986, 1992). Channel stability in meandering streams is also related to meander cutoff style (chute versus neck cutoff), which largely defines site formation processes in the cutoff channels.

The type of stream load is strongly correlated with flow velocity and stream power. Sediment texture, as a correlate to stream load, also has postdepositional significance for archaeological formation processes. Low sand content, for example, promotes more rapid soil development (Birkeland, 1999). In sum, it is possible to deduce from stream class and stream load an array of alluvial features that bear on site formation processes that operated before, during, and after occupations.

Stream classes in temperate environments are predominantly meandering to straight, with perennial discharge. With fine-grained sediment supply, these streams exhibit meanderbelt features including point bars, natural levees, crevasse splays, and cut-off channels/ oxbows (Lewin, 1978). Regional variations are caused by different bedrock substrates and/or tectonism, resulting in changes in discharge, channel migration patterns, or rates of avulsion. Major changes in stream class are well documented in temperate settings, both at Pleistocene and Post-Pleistocene temporal scales. During the Holocene, large midwestern U.S. river channels evolved from meandering to straight (Bettis and Hajic, 1995). In the same region, significant differences in Holocene alluviation are registered for small, medium, and large drainages. Similar variability is also well documented in Central Plains valleys (Johnson and Logan, 1990; Mandel, 1994a,b; 1995; May, 1989). In Poland, river channels shifted from straight or braided to meandering in the early Holocene, yet the timing of this change varied between drainages (Schumm and Brakenridge, 1987).

In semiarid to arid environments drainages may be classified as either allogenic or ephemeral. Through–flowing (allogenic) rivers that cross deserts are maintained by headwaters usually emanating from distant higher elevations. Allogenic rivers are the settings for many of the early civilizations in the Old World. Those rivers in deserts include the Tigris–Euphrates, the Nile, and the Indus, which were all transformed by irrigation systems in the fourth and third millennia B.C.E. Examples in the New World include the Gila River in Arizona that nourished the Hohokam culture (Haury, 1976) and the rivers crossing the coastal deserts of Peru where Archaic peoples constructed some of the first mound-dominated ceremonial complexes in the New World (see Wells, Chapter 5, this volume).

Most archaeological work in arid to semiarid regions is conducted along ephemeral streams (Bull, 1991; Leopold and Miller, 1956; Schumm, 1977:150; Schumm and Hadley, 1957). These are variously called wadis, nahals, draws, or arroyos. The behavior of these streams differs significantly from those in temperate settings (Table 4.2). These desert streams are prone to extremely "flashy" floods resulting from high runoff and brief periods of high peak discharge (Cooke and Warren, 1973:163). These streams are slow to respond to climate change (Bull, 1991) and characteristically exhibit alternating reaches of erosion and aggradation along the same channel (Patton and Schumm, 1981). Rapid changes along an arroyo that do not correspond with climate change are common.

The causes for widespread and rapid development of arroyo systems in the American Southwest over the last two centuries has been an intensely studied and debated phenomenon: "the arroyo problem." Interpretations have invoked a shift to drier climates (Antevs, 1952; Bryan, 1925; Melton, 1965), an onset of larger summer storms, or a threshold response to overgrazing. These and other internal dynamics result in interdrainage variations in alluvial records, even for adjacent tributaries. Quite commonly, then, it is difficult or impossible to extend stratigraphic correlations over multiple valleys, or even for appreciable distances down a single valley.

Table 4.2. Generalized Relations between Stream Class, Equilibrium State, and Alluvial Activity

State	Braided	Bedload	Suspended load
Erosional	Braidplain widening and incision strath development	Channel widening, shift toward braided class	Entrenchment (terrace genesis) shift to bedload, possibly braided
Stable	Limited braidplain shifting, lateral and downstream bar migration	Periodic changes in channel shape (w × d) and meander geometry	Lateral shifting of depositional geomorphic features (point bars, levees, oxbows); periodic avulsion (local shifting of meanderbelt)
Aggradational	Shift to bedload class	Shift to suspended load class	Floodplain aggradation within limits of geomorphic thresholds

In contrast to streams in temperate regions, another well-documented pattern of arroyo behavior is the increased lag time between climatic–vegetational change and the fluvial response (Bull, 1991:118). This suggests that cultural responses to environmental change may have been out of phase with stream response, adding further cautionary flags for interpreting geological–archaeological records in arid lands. When extended to the Pleistocene time scale, even terrace genesis may not correlate closely with the timing and magnitude of climatic–environmental change (Bull, 1990). But the world of arid fluvial systems is not one of total chaos at all scales.

Despite the highly variable character of arid lands streams just described, cases of regional change in fluvial systems are well documented. The late Quaternary phases of wadi aggradation along the Nile Valley is an excellent example (Butzer and Hansen, 1968; Wendorf and Schild, 1980).

2.4. Facies, Architecture, and Alluvial Geomorphology

The major components of alluvial records include geomorphic features, such as terraces, and also the packages of alluvium contained below the surfaces of terraces or floodplains. In this context, the focus on alluvial deposits is for purposes of defining sedimentary environments pertinent to archaeological inquiry. Stratigraphic study of the same sediments requires different approaches, as discussed in the following section.

2.4.1. Alluvial Facies

Sedimentary facies are bounded sediment packages that are distinct from contiguous packages in their lithology, primary structures, and sometimes biotic remains (Walker, 1992). For alluvial sediments, Miall's (1992) facies classification is well suited for use in Quaternary sediments, yet it lacks soils features of alluvial sediments. Because of the dependent relations between alluvial parent materials and alluvial soil formation, the concept of soils facies (Birkeland, 1999) or pedofacies (Krause and Bown, 1988) is necessary and very useful.

Miall's (1992) hierarchical classification of facies is based primarily on sediment textures and then on bedforms. Architectural elements are recurrent facies assemblages associated with various channel and overbank environments (Allen, 1965). Miall recognized eight architectural elements that are common in ancient alluvial deposits. Alternate definitions of elements appears useful to convey sedimentary environments pertinent to Quaternary deposits, especially those of mixed load streams (Ferring, 1993).

Facies are the constituent features that permit recognition of fluvial environments such as floodbasins, levees and splays, and point bars (Allen, 1965; Lewin, 1978). Facies description and study is necessary for defining both the ecological setting of archaeological sites and context-specific formation processes.

Alluvial fans, formed by mudflows and by ephemeral stream deposition, are especially common in arid lands (Bull 1972, 1977; Hooke, 1967). Compared to ancient, including Pleistocene fans, modern fans are small, having radii between 1.5 to 7.0 km (Schumm, 1977). These contrast with the much larger fluvial fans that form in humid environments by perennial streams. Coalesced fans, or bajadas, often occupy major areas of arid lands basins and often contain archaeological records, especially of agricultural groups (Waters, 1988, 1998). Small alluvial fans are also common in temperate settings; those fans differ from arid fans in morphology and in process (Kochel and Johnson, 1984). Because of climatic patterns and more complete vegetation cover, temperate fans tend to have gentler topography, less diverse sedimentary facies, and more common buried soils. Fans were commonly favored locations for Archaic and Woodland occupations in the midwestern United States, where upland loess supplied sediment for fan growth during the Holocene (Bettis and Hajic, 1995; Stafford *et. al.*, 1992; Wiant et al., 1983).

2.4.2. Associated Facies

Nonalluvial sediments are commonly associated with alluvium. Colluvium and alluvial fan sediments accumulate at floodplain margins and frequently contain archaeological sites. Dunes form along the lee side of braid plains or broad sandy channels; they may also form on terrace surfaces. In contrast to other regions in the Great Plains, draws on the Southern High Plains contain thick Middle and Late Holocene eolian sand that buried older alluvial and lacustrine and palustrine sediments (Holliday, 1995).

Incorporation of loess into aggrading alluvial deposits is more difficult to recognize, especially if it is the thinner and finer loess deposited farther from the source. This situation can be revealed with precise textural analyses afforded by electronic or laser–based instruments (Autin, 1992). Quantifying, or in some cases simpy recognizing loess-alluvium contacts is necessary for both sediment and soils analysis (Ruhe and Olsen, 1980). Loess mantles are common on both interfluves and alluvial terraces in the Pleistocene loessal plains of North America, Europe, and Asia (Ruhe, 1983; van Andel and Tzedakis, 1996).

2.5. Alluvial Morphogenesis and Pedogenesis

With or without changes in external factors including climate, tectonics, or base level, alluvial systems will undergo geomorphic change as a result of internal factors (Knox, 1976; Schumm, 1977). On floodplains, these morphogenic changes range from lateral channel shifting to buildup of depositional geomorphic features such as levees or splays (Allen, 1965; Lewin, 1972). Even floodplain abandonment and terrace formation can ensue development of geomorphic instability through reduction in floodplain gradient (Knox, 1976, 1983). So common are these kinds of change that these processes need to be first ruled out before invoking climate or other factors as forcing agents in alluvial morphogenesis (Ferring, 1986). Cleaves et al. (1970) demonstrated the significant role of geochemical weathering geomorphic change in alluvial basins.

Formation of soils in alluvial environments is intimately related to internal morphogenesis, because soil development is usually contingent on local rates of deposition (Ferring, 1986). Because of different rates of deposition across a floodplain, associated with different sedimentary environments, soils genesis will proceed with very different rates, on different parent materials, and in different biotic and hydrologic settings (see Mandel and Bettis, Chapter 7, this volume).

It is always true, however, that an alluvial soil is evidence of local geomorphic change at some scale, ranging from periodic internal adjustments to major geomorphic response to extrinsic factors. Field recognition and study of soils is therefore intimately and necessarily integrated into alluvial geomorphology (Birkeland, 1999; Bull, 1990, 1991; Gerrard, 1987; Gile et al., 1981). These relationships are discussed below, first as they pertain to floodplain development and second as they relate to terrace morphogenesis.

2.5.1. Floodplains: Depositional Geomorphic Features

On floodplains, depositional geomorphic features are those landforms constructed through differential patterns and rates of channel migration and sedimentation (Lewin, 1978). These include natural levees, crevasse splays, oxbows, and alluvial ridges. Avulsion of a meanderbelt is the abandonment of an alluvial ridge and creation of a new meanderbelt reach in a lower part of the floodplain (Allen, 1965). The potential scale of the process is illustrated by the 200-mile shift in the Yellow River channel in 1851 (Schumm, 1977:297). After avulsion, both depositional and pedogenic processes change, and different sequences of pedofacies form in the position of the old and new meanderbelts (Ferring, 1986, 1992). Avulsion has had dramatic impacts on cultures, for example the site abandonment accompanied by an 18th century A.D. avulsion of the Middle Ucayali River in the Amazon Basin (Prässinen et al., 1996). Avulsion has been related to both occupation site selection and later site preservation processes along meandering rivers (Guccione et al., 1998) and alluvial fans (Stafford et al., 1992).

2.5.2. Floodplains: Soils

The formation of soils on floodplains is largely controlled by the patterns of depositional geomorphic change (Ferring, 1992). Because all parts of a floodplain receive sediment at least every few years, all floodplain soils are to some degree cumulic soils. This term denotes a soil that is "overthickened" through deposition of parent material concurrently with pedogenesis. However, floodplain soils are "cumulic" at different scales for two related reasons. Both the rate of deposition and the texture of the alluvium vary across floodplain environments (facies), and both of these factors influence the rate of pedogenesis. In many cases, rates of deposition and sediment texture are correlated, such as in meandering suspended load systems, in which clay-rich floodbasin sediments are deposited more slowly than sandier levee or splay facies. For this reason it is important that alluvial soils should be compared within facies, not between them, for purposes of stratigraphic correlations based on floodplain histories. Soils in floodbasin or vertical accretions deposits will yield a much more accurate record of overall aggradation (Knox, 1983), whereas soils in channel–associated facies will yield irregular if not misleading patterns. However, Borchardt and Hill (1985) analyzed clay minerals, especially smectite, to establish relative ages of Holocene soils in wetter environments. That study also is an excellent example of parent material analysis as a control on rates of pedogenesis.

In arid environments, aside from the climatic controls on weathering, patterns of deposition on floodplains, and indeed the styles of deposition and erosion in general, are such that soils genesis is substantially different than in temperate regions. Cumulic soils are rare in arid settings, and climatic factors usually override sedimentary controls on soil morphology as seen in temperate settings.

Flood patterns and groundwater hydrology are major factors in formation of floodplain soils. In temperate regions, overbank flooding is common and streams are generally effluent. Thus, floodplain soils are subjected to high throughput of water and are saturated at least seasonally. This promotes leaching, shrink-swell of clay, and gleying of the lower parts of soil profiles. (Hayward and Fenwick, 1983; Veneman et al., 1976; Walker and Coventry, 1976).

In arid climates, overbank flooding is rare, the streams are influent, and both leaching and groundwater removal of soluble salts is reduced. Floodplain soils are rarely gleyed, although organic-rich Cienega soils form in locally saturated and grassy areas near springs or arroyo heads (Cooke and Warren, 1973:171). Seasonal drying of clay-rich floodplain soils often results in Vertisols that may also exhibit silt coats on crack surfaces.

2.5.3. Terraces: Alluvial Morphogenesis and Soils

Floodplain abandonment immediately changes the environment of soil formation, principally through cessation of flooding and deposition, but also through changes in vegetation and groundwater (Bull, 1990). Terrace soils manifest the state of the floodplain prior to abandonment, as well as the sum of conditions since that event. Through time, the original floodplain soil features will be lost, but sedimentary facies are generally preserved. If soil parent materials are similar, chronosequences of terrace soils can be defined, but the environmental significance of those soils is lost to compounded changes in different environments over time (Birkeland, 1999). Bryan and Albritton (1943) identified "polygenetic soils" as those that formed over a period with distinct changes in climate.

Terrace soils in temperate environments are usually Alfisols, Mollisols, or Vertisols. The development of soil morphology over time may be expressed through different indices of soil development (Ponti, 1985). Later addition of loess to terrace surfaces complicates analysis of the original soil that formed in alluvium by creating "welded" soils (Ruhe and Olsen, 1980). In mesic environments, where calcic soils are not dominant, calcic horizons form by the redistribution of primary (inherited or allogenic) carbonate (Machette, 1985).

In arid environments, terrace soils are usually Aridisols, Entisols, or Vertisols. These are largely formed by infiltration and illuviation of dust and by buildup of soil carbonates (Gile et al., 1981). Rates of calcic horizon development in arid environments are generally assessed for soils formed on stable surfaces (Machette, 1985). Overall, rates of weathering and development of soils morphology are so slow that chronosequences are useful for surfaces more than 500,000 years old (Gile et al., 1981).

2.6. Alluvial Response to Climatic Change

The relationships between climate change and fluvial responses is a dominant theme in fluvial research (Bull, 1991; Knox, 1983; Schumm and Brakenridge, 1987). In geoarchaeology, neither actualistic nor theoretical studies of these relations are sufficient to justify detailed reconstruction of past climates based on sediments and soils alone. This conclusion is based on the detail of records cited below that could not have been identified from either of those avenues of pure research. Moreover, Quaternary research has shown that the high degree of variability within and between drainages provides ample warnings against simplistic interpretations. General relations between specific patterns of climate change and fluvial responses such as aggradation and erosion have been defined for both arid and temperate settings (Knox, 1983; Bull, 1991). Yet the invitations of those authors to use these relations to deduce geologic records for a specific drainage are noticeably lacking. In addition to the spatial complexity of responses, the deficiencies of independent records of climate commonly deplete the left side of the "climate = response" equations. We are simply in a better position to define the response in most cases.

For example, the semiarid cycle of erosion (Graf et al., 1987; Schumm, 1977; Schumm and Hadley, 1957) applies to some, but not all desertic settings. This cycle includes processes that accommodate simultaneous erosion and deposition in the same channel system. Feedback relations between aggradation, channel floor instability and knickpoint migration. Patton and Schumm (1981) extended the semiarid cycle's implications to multiple drainages, demonstrating that among ephemeral streams on the Colorado Plateau, there was no correlation in the timing of erosion and deposition. Similarly, in the Rolling Plains of Texas, remarkable interdrainage variability in the architecture of late Quaternary sediments has been documented (Gustafson, 1986).

These situations contrast with patterns of allometric change within drainage systems, where change in one part of the system correlates well with a related change in another part of the same system (Bull, 1991). A good example of this is the patterns of erosion and deposition within Central Plains drainage systems in Kansas (Mandel, 1994b). There, erosion of small tributaries in the middle Holocene led to development of alluvial fans in midsized valley reaches downstream. Entrainment of sediment in those positions inhibited middle Holocene alluviation in the associated large valleys. In the late Holocene, multiple cycles of alluviation and pedogenesis are registered in all stream orders, suggesting storage of sediments that were delivered from valley margins.

An important point is that in arid to semiarid settings, intra- and interdrainage alluvial variability is typically high; in temperate settings it is also high, but better understood in terms of allometric change. Thus stratigraphic correlations are best established within major depositional environments, such as alluvial fans (Bettis and Hajic, 1995), or where very similar controls on sedimentation prevailed, such as the Southern High Plains (Holliday, 1995, 1997). Where differential sediment supply or other factors exist, inter-drainage variability will be enhanced. For example, late Holocene alluvial records in North Texas differ markedly between areas with easily eroded bedrock (Ferring, 1990, 1995; Ferring and Yates, 1997) and nearby valleys with resistant limestone bedrock (Nordt, 1995).

Geoarchaeologists must rely heavily on empirical evidence in all these contexts and must approach each drainage or drainage segment inductively. This approach will ensure that substantial contributions to archaeology are not compromised by high-risk assumptions, and that the important results of research may accumulate as unbiased contributions to those larger issues in fluvial geology.

3. Geoarchaeological Methods in Fluvial Environments

Geoarchaeology in fluvial settings shares goals with work in any environmental context, and to some degree the methods employed are the same as well. The following discussions stress the contexts and the methods that bear most particularly on work in fluvial environments, although there are brief allusions to some general issues. As much as possible the subjects are treated with reference to published research and by means of brief reviews of selected case studies.

3.1. Stratigraphy

Stratigraphic investigation of late Quaternary sediments in geoarchaeology is conducted with methods and databases that are largely the same as those in purely geologic investigations, although the advantage of artifacts as stratigraphic markers is notably more common in geoarchaeology. Archaeological stratigraphy is distinctive in the role it plays in excavation of sites and also in that it is exclusively the domain of cultural stratigraphy. What's more, despite the evolutionary (almost genealogical at times) terms bestowed on stone tools by their analysts, culture change as a chronometer requires much more stringent assumptions concerning succession than does biostratigraphy.

3.1.1. Morphostratigraphy

Establishing a sequence of landforms has been a defining aspect of geomorphology since its inception. Today the importance of this approach to geoarchaeology is largely seen at the Pleistocene scale, but Post-Pleistocene terrace sequences may be readily achieved as well (Borchardt and Hill, 1985; McDowell, 1983). In arid environments there is also an emphasis on dating and correlation of alluvial fans (Bull, 1972).

Landform sequences are integral to prehistoric archaeology in the Old World by virtue of the time depth of occupations. Correlation with presumed glacial stages has given way to independent dating. For many alluvial terrace sequences, long-term net incision results in flights of terraces that may contain sediments and archaeology of great age. Terraces in the Elbe–Saale region in Germany contain records of occupations dating back to the middle Pleistocene (Mania, 1996). Spring-lacustrine marls and also loess deposits complicate terrace correlations with other valleys. However, the travertines provided an opportunity for U–series dating (Schwarcz et al., 1988), yielding ages of ca. 350 to 400 ka. For the Lower Paleolithic occupations and *Homo erectus* fossils at the Bilzingsleben II locality (Mania, 1996).

In late Pleistocene and Holocene contexts, relative surface ages usually cannot be defined without ancillary evidence such as alluvial stratigraphy, soils, or cobble weathering rinds. The possible age relations of alluvial terraces that may be either cut or fill surfaces is a classic illustration of this problem (Leopold, et al., 1964:460). Additionally, as mentioned previously, the weathering-based methods for dating surfaces have much shorter applicable ranges in temperate environments than in arid ones (Bull, 1991:272), although these restrictions apply mainly to Pleistocene-scale investigations. Geomorphic–soils analysis of exposed and buried aggradation surfaces in the Duck River Basin (Tennessee) by Turner and Klippel (1989) revealed archaeological implications of differential rates of deposition and surface stability, building on Brakenridge's (1984) study of this "ingrown meandering" stream.

3.1.2. Lithostratigraphy

Allostratigraphic units are the fundamental divisions of an alluvial stratigraphic sequence (Walker, 1992; NACSN, 1983:865). These units are defined on the basis of "bounding discontinuities" including straths, erosional disconformities, soils, and surfaces of either terraces or floodplains. Autin's (1992) application of allostratigraphic principles to Quaternary alluvium in the lower Mississippi Valley is exemplary. Allostratigraphic units may incorporate any variety of alluvial facies, because the units are defined by boundaries rather than contents. The boundaries connote a significant change in depositional regimes, caused by changes in climate, tectonics, or base level. Thus defining an allostratigraphic sequence sets the stage for explaining the mechanisms that forced the changes.

A variety of methods are available for constructing and correlating stratigraphic sequences. Debusschere et al. (1989) made field descriptions of sediments and soils within an Archaic site and also in off-site sections. These were correlated using granulometry, clay mineralogy by X-ray diffractometry and total element analysis using atomic absorption. The value of these multivariate approaches is alo illustrated by correlation of anthropogenic sediments in valleys in northern China (Jing et al., 1995). To refine definitions and correlations among lithostratigraphic units, they used various statistical parameters of sediment texture, soil chemistry, and magnetic parameters including low-field magnetic susceptibility and anhysteretic remanent magnetization (ARM; Jing and Rapp, 1998). Their analyses demonstrated the effects and geoarchaeological implications of dramatic post-Neolithic alluviation. Neolithic sites were buried by as much as 10 m of alluvium, whereas subsequent predynastic site distributions register major readaptations to the altered floodplains.

3.1.3. Pedostratigraphy

Use of soils for stratigraphic correlations is one of the more common approaches in Quaternary geology (Morrison, 1978) and geoarchaeology (Holliday, 1997). Holliday (1989, 1995) intensively studied Quaternary soils on the High Plains of Texas and used them as components of his broader approach to developing interdrainage stratigraphic correlations. His work is fundamental to his geoarchaeological analysis of Paleoindian sites, which is a detailed application of regional geoarchaeology. In Holocene contexts, soils morphology can be difficult to use in correlations because local differences in parent material or in patterns of alluviation yield greater variability than does the interval of soil formation (Figure 4.2). Radiocarbon dating of soil horizons is commonly employed (e.g., Mandel, 1994b; Martin and Johnson, 1995). Correlation of fan, alluvial, and colluvial sediments based on soils morphology and radiocarbon ages has been extensively applied in geoarchaeological research in the midwestern United States (Artz, 1995; Bettis and Hajic, 1995; Bettis and Littke, 1987; Wiant et al., 1983) and in the Great Plains (Mandel, 1994a, 1995; Johnson and Logan, 1990).

3.2. Geochronology

Methods of dating sediments are broadly applicable (see Frederick, Chapter 3, and Rink, Chapter 14, this volume). In alluvial contexts, several guidelines are notable. Radiocarbon dating of humate fractions from floodplain soils entails risks of dating inherited organics, potentially from older sediments upstream, thereby obtaining anomalously old ages for the soil horizon. Nonetheless, dates on bulk soil can yield accurate chronologies of sediment accumulation and pedogenesis (e.g., Blum et al., 1992). Another example is the dating of bulk

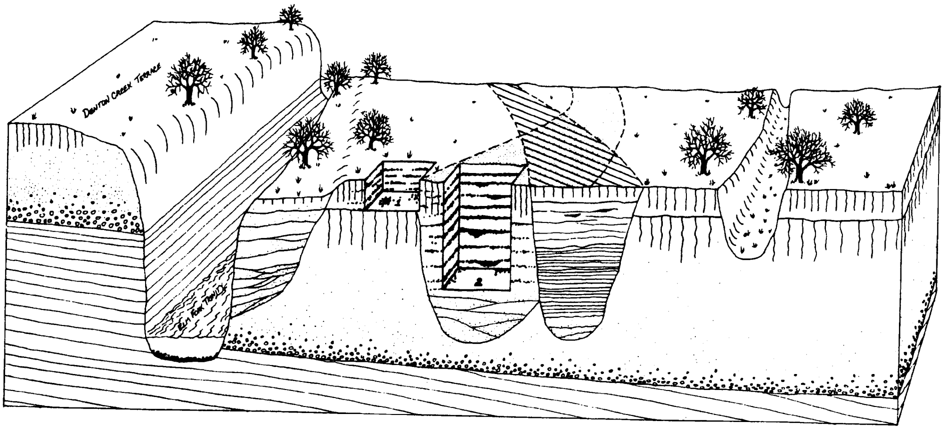

Figure 4.2. Complex series of filled channels containing stratified archaeological materials at Elm Fork Trinity River, Texas (from Ferring and Yates, 1997). Channel 1 (chute cutoff) filled with seven stratified late Archaic living surfaces over 900-year period. Channel 2 (neck cutoff) filled initially with laminated oxbow lake silts, then with subaerial clays, with cumulic soil and late Prehistoric occupation materials.

samples of floodplain clays at the Aubrey Clovis Site, Texas (Ferring, 1994). The distal floodplain sediments there had been deposited slowly enough that the 7 to 9 m section was essentially a stacked series of cumulic soils.

In all cases, careful field techniques of collection for dating, whether of particulate organic material or of bulk samples, is critical. All features that could betray displacement or translocation of the dating material must be recognized and avoided during sampling (Rink, this volume, Chapter 14). Common crayfish burrows in the sediments at the Aubrey site (Ferring, 1994) required very careful exposure of the sediments in three dimensions so that the samples would not include any of the younger burrow fill. The importance of proper cleaning of a profile prior to sample collection is highlighted by the work of Haas et al. (1986), at the Lubbock Lake locality (Texas). They measured the rate of organic matter degradation after sediments are exposed (in either natural cuts or excavated trench walls), yielding ages that are too young.

Dating alluvium that is beyond the range of radiocarbon dating can be achieved using a variety of methods (Rink, this volume, Chapter 14; Aitken, 1995). Paleomagnetism may be used for sediments older than Bruhnes (Easterbrook, 1988). Pope et al. (1984) used Uranium-series dating on pedogenic carbonates and also on groundwater carbonate crusts on Mousterian artifacts to date middle Paleolithic sites in alluvium in Greece. Their dates range from ca. 270 ka to 33 ka. Van Andel (1998) also established a U-series chronology for alluvial deposits in Greece that contain Middle Paleolithic artifacts. Nanson et al. (1991) employed U/Th and TL dating of alluvium in Australia and applied U/Th methods not only to carbonates but also to Fe/Mn oxyhydroxides/oxides.

3.3. Site Discovery Methods

The discovery of archaeological sites in alluvial contexts is a principal objective of geoarchaeology. Over the history of archaeology, sites have been discovered with little or no consideration of geology, yet this process is rife with missed opportunities as well as accumulated biases in interpretations. The main contributions from geoarchaeology are in the area of buried site discovery. This entails both prediction of site contexts and their physical detection. In this endeavor, both site construction and site preservation are important, requiring routine analysis of postoccupational alluvial histories.

3.3.1. Site Prediction

Buried site prediction models require integration of geomorphic, sedimentary, and stratigraphic data (Gladfelter, 1985; Hassan, 1985). The utility of those models is, therefore, measured by the detail of geologic research in a given setting. At the risk of sounding circular, the strength of predictive models is also a measure of how much patterning there is in alluvial geologic records. This can only be measured with reference to fluvial dynamics, as considered earlier in this chapter. A summary opinion on this matter would have to be that there are few cases, either in temperate or arid environments, where simplistic models of alluvial geology will assist in site prediction. Variability down valleys, among streams of different rank, and between drainage systems is best considered the rule. Thus the most useful site prediction models are those that are based on extensive, sound research over whole drainage systems.

Site prediction models should incorporate both contextual and site preservation components (Guccione et al., 1998). Potential site contexts must be summarized not only stratigraphically but also with consideration of sedimentary environments as controls on site locations (Kauflulu, 1990; Mooers and Dobbs, 1993; Phillips and Gladfelter, 1983; Putnam, 1994). Thus sedimentary, soils, and stratigraphic data are required. Successful (i.e., useful) examples of this are found in the detailed records established in the Midwest, including work cited previously by Bettis, Hajic, Artz, and others. Likewise, the work of Mandel, Johnson, and others has provided similarly detailed models for the Central Plains. Their models incorporate sufficient geologic data to discuss the known and probable contexts for sites of different ages, as well as the factors that have led to differential preservation and loss within different parts of a drainage system. Blum et al. (1992) used similar approaches and extensive radiocarbon dating in central Texas.

3.3.2. Surveys and Subsurface Exploration

Discovery of buried sites requires implementation of all available means to examine the target sediments. Careful inspection of natural outcrops is the cheapest method, but it is successful only when substantial natural exposures are available. This situation is more common in arid settings where vertical channel banks are common (Waters, 1986).

Where natural exposures are inadequate, which is generally the rule, artificial exposures are made by backhoe trenches, auger tests, cores, and for shallow contexts, shovel tests. Auguring or coring can be used to refine strategies for more serious site-discovery efforts. An excellent example of this is a survey done on the South Platte River in Colorado by McFaul, et al. (1994). They recovered 150 cores, each 3 in in diameter, with a Giddings drilling rig, and used sediment–soils descriptions to define areas for subsequent exploration, which was accomplished with excavation of 50 backhoe trenches. They defined patterns of geomorphic change and the age and character of alluvium and eolian deposits.

Successful use of coring has also been done in the intensive work of Holliday (1995) in the draws of the Southern High Plains. To actually locate sites, recovery methods must be adequate. Microscreening of core samples is effective but broadly underutilized (Sherwood, Chapter 2, this volume). A very successful program of vibracoring, diver surveys, and dredge excavations has led to discovery of sites associated with stream channels, now marine inundated, on the shallow Gulf of Mexico shelf of Florida (Faught and Donoghue, 1997). Their survey methods included prior definition of channels using a shallow seismic reflection system.

Remote sensing is more commonly used in terrestrial settings to define subsurface stratigraphy, to detect archaeological features, or both (Kvamme, Chapter 13, this volume). Resistivity profiling can reveal major lithologic changes (Darwin et al., 1990), as will seismic profiling (Noller, Chapter 6, this volume). Ground-penetrating radar can reveal shallow sedimentary–soils features, whereas magnetometry is useful for defining shallowly buried archaeological features (Wynn, 1990).

In arid lands, surveys have always been facilitated by sparse vegetative cover. However, burial of ancient deposits by sand sheets has inhibited surveys. Implementation of shuttle imaging radar (SIR) images to survey the "radar channels" of the Egyptian Sahara has been remarkably successful in revealing Plio–Pleistocene drainages (Wendorf et al., 1987). Follow-up surveys assisted by backhoe trenching and hand excavations resulted in discovery of Middle to Late Acheulian sites (ca. 0.15–0.500 Ma) associated with the buried paleodrainages (McHugh et al., 1988). Remote sensing, coupled with geographic information systems (GIS) analysis should enjoy more success in the future, especially in arid lands (Linse, 1993).

3.4. Excavations and Formation Analyses

Geoarchaeology in fluvial settings does not stop after site discovery but rather turns to different yet important goals during site excavations. These goals include documentation of site contexts, collection of dating samples, and integration of natural and cultural records. The latter is the domain of site formation processes, which are important in any geologic context (Stein, Chapter 2, this volume; Butzer, 1982; Schiffer, 1987; Wood and Johnson, 1978). Most processes of site formation are not unique to fluvial environments, but certain processes of formation and methods of investigation are encountered commonly in alluvial sites.

Transport of artifacts and ecofacts is a problem commonly encountered in alluvial sites. This is not simply a question of finding "in-place" sites, but rather is one in critical assessment of natural and cultural deposits (Hanson, 1980; Petraglia and Nash, 1987; Schick, 1987). Actualistic studies have yielded approaches for investigating sites by documenting patterns of bone transportation and reorientation at early East African sites (Behrensmeyer 1982, 1987; Irving et al., 1989). These kinds of studies require close integration of sedimentology, bone positioning data, and taphonomic observations (Johnson and Holliday, 1989; Koster,1987; Kreutzer, 1988; Steele and Carlson, 1989).

Abrasion of lithic artifacts during fluvial transport has received similar attention (Shackley, 1974, 1978). A good example is Shea's (1999) analysis of artifact abrasion and site formation processes at 'Ubeidiya, the well-known lower Paleolithic site in the Jordanian Rift.

All channel contexts are not necessarily poor site formation settings. In suspended load meandering systems, cutoff channels were sometimes favored occupation locations and were ideal preservation contexts as well. Multiple superposed occupation surfaces at the Gemma site in North Texas were found in a chute cutoff channel (Ferring and Yates, 1997). Their analysis of sediment texture and soils development illustrated that episodic deposition promoted burial of successive occupation surfaces while vegetation apparently served to baffle potentially erosive currents (Figure 4.3). At this site occupation surfaces were separated by sterile flood deposits. These ideal formation contexts may be difficult to find unless exposed by later channel migration, but they are also very amenable to detection using geophysical techniques including seismic and resistivity methods (see Noller, this volume, Chapter 6; Darwin et al., 1990).

Surface stability, soil formation, and site formation processes are intimately related in fluvial environments (Ferring, 1992; Ferring and Peter, 1987). Analysis of soil morphology, supplemented by radiometric dating, is essential to quantify those processes as they relate to the character and density of archaeological materials (Holliday, 1990). An excellent example of methods is the study of a sequence of buried soils in an alluvial terrace of the Susquehanna River in Pennsylvania by Cremeens et al., (1998). Their work revealed the syndepositional and postdepositional (overprinting) implications of pedogenesis on a series of stratified occupation surfaces.

Facies analysis, as described earlier, is essential for defining the primary contexts of archaeological site formation as well as the environmental settings of the sites. Walker et al. (1997) employed detailed facies study to define changes in depositional environments, controls of Lake Erie base-level fluctuations, and the resulting implications for site formation in a context of initial horticultural settlements in Ontario. Similar approaches work equally well in ancient deposits, such as the investigation of formation processes at a Lower-Middle Pleistocene site in the Malawi Rift, where Kauflulu (1990) used microstratigraphic facies analysis to define processes of site formation in near-channel overbank deposits.

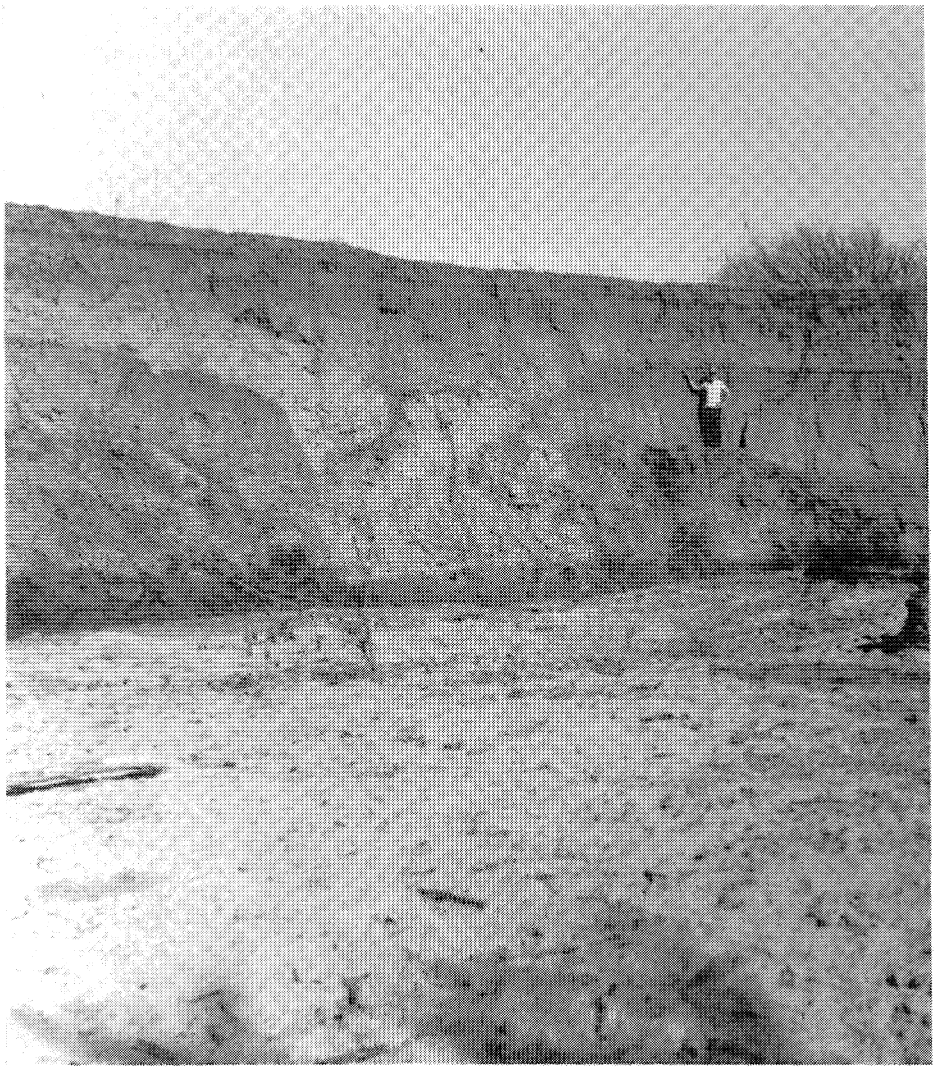

Figure 4.3. Late Holocene alluvium with buried soils at Delaware Canyon, Oklahoma. Figure is pointing to cumulic soil that formed ca. 1950–900 BP and contains Plains Woodland archaeological materials. Above that is a soil with Plains Village materials. Note that these are weakly developed A-C soils, which can be difficult to correlate between drainages based on morphology.

3.5. Landscapes, Change, and Human Settlements

Fluvial landscapes have been settings for human adaptive systems ranging from mobile forager–collectors to complex societies practicing intensive agriculture. This range of adaptive systems is broadly correlative with increasing population densities and also with human modification of the alluvial landscape. In settlement-pattern and land-use analyses therefore, geoarchaeological methods have been brought to focus on a wide array of archaeological contexts and research questions. To illustrate these methods, several case studies are described below.

3.5.1. Hunter–Gatherer Settlement Systems

Hunter–gatherer sites are essentially "embedded" in natural geologic contexts; those systems exhibited both a negligible array of constructed features and an equally small impact on alluvial environments. Geoarchaeology can improve study of hunter–gatherer settlement systems in every stage of research, from implementing site discovery models to the establishing the contexts and character of the sites. These tasks are complicated in settings where significant environmental change has occurred.

Settlement systems in the American Midwest evolved dramatically through the late Archaic, Woodland, and Mississippian periods. Because of intensive exploitation of fluvial environments by all those populations, geoarchaeology has been essential in recent decades of research along the midwestern rivers. A foundation for geoarchaeology in the Illinois Valley was set by Butzer's (1977) geomorphic protocol for defining the context of the famous Koster site, located near St. Louis. His conclusions were explicit statements concerning the relevance of paleogeography to subsistence and settlement models. All students should consider Butzer's stepwise approach toward those conclusions.

Locations of Archaic sites relative to paleomeanderbelts on the Mississippi "American Bottom" were studied by Phillips and Gladfelter (1983). Similarly, Bettis and Hajic (1995) used geomorphic, stratigraphic, and facies data to reconstruct changing site locations of Archaic occupations. In both of these cases, the paleomeanderbelts were associated with channels that were more sinuous than today, and sites were found near former channels as well as near oxbow lakes. Holocene landscape change and settlement patterns in the Upper Mississippi Valley have also been studied by Stafford et al. (1992).

In arid settings, similar objectives are met with methods appropriate for the settings, which frequently involve heterogeneous fluvial, colluvial, lacustrine, and eolian sediments (Waters, 1990). These records are especially important in Paleolithic studies, where long-term, significant environmental change has shaped desert landscapes and has left complex geoarchaeological records (Gladfelter, 1990; Goldberg, 1986; Pappu, 1999; Schuldenrein and Clark, 1994). Goldberg and Bar-Yosef (1995) summarized sedimentary records from the Southern Levant related to settlement patterns and adaptive strategies by Paleolithic through Iron Age cultures. Quite similar approaches to diverse sedimentary contexts in semiarid settings are illustrated by the late Quaternary records of the streams on the Southern Plains (Blum et al., 1992; Hester, 1972; Holliday, 1997) and the subhumid Central Plains (Johnson and Logan, 1990), and the Pleistocene rift valleys of East Africa (Helgren, 1997).

3.5.2. Agricultural Settlement Systems

All early complex societies, which emerged only after successful, large-scale agricultural systems had been developed, were situated in fluvial environments. These systems were initiated by much older shifts toward intensive plant collection and village life that did not entail significant landscape modification (Bar-Yosef and Belfer-Cohen, 1989; Roberts, 1991). Later, both irrigation and the shear size of the agricultural systems began the processes of human modification of fluvial systems that continue today. Moreover, both early and contemporary agriculturalists have demonstrated repeatedly that their control is less than complete and that farmers have always been subject to nature's will. Sufficient evidence is found in MacKay's (1945) demonstration that avulsion of the Euphrates left the cities of Ur and Lagash far from the river, stripping those locations of their long-enjoyed importance. By contrast, avulsion is not possible in the Nile Valley, helping to explain the persistence of major centers in the same locations for millennia. Geoarchaeology has been successfully applied to studying those systems and to deciphering complex patterns of cultural and geologic change.

Impacts of humans on their fluvial landscapes include changing patterns and rates of erosion. Joyce and Mueller (1992, 1997) used coring, soils analysis, and radiocarbon dating of soils to reconstruct the causes and results of increased erosion caused by intensified agriculture in the Rio Verde Basin, Oaxaca. In this case, downstream sedimentation increased agricultural potentials, and it may have prompted population growth. In the humid lowlands of Veracruz, Hebda et al., (1991) conducted detailed facies analysis, stratigraphy, and soils analysis as part of their study of late preclassic and Classic agricultural systems. Both natural changes in sedimentation and the construction of extensive canals and raised field complexes were documented.

Geomorphology and facies analysis were used by Huckleberry (1995) to define late Holocene patterns of alluvial change in the Gila River basin, Arizona, the setting for the complex Hohokam culture. Although irrigation technology had been established earlier, consolidation of the canal networks and also redistribution of settlements was necessary to adjust to adverse affects of braidplain expansion resulting from larger scale floods after A.D. 1000.

One of Courty's (1995) principal approaches to investigating complex patterns of landscape change associated with Harappan settlements in the Ghaggar Plain, India, was micromorphology. In addition to fieldwork that defined major lithofacies and soil morphology, she documented soils–hydrologic factors that influenced site locations, documented natural versus human causes for eolian activity, and assessed the role of climatic change in the decline of the Harappan civilization.

4. Conclusions

Fluvial environments are common settings for archaeology, and therefore application of geoarchaeological approaches can be of widespread utility. The complexity of alluvial records, including local variation in sedimentary environments as well as larger scale, interdrainage patterns of variation, can be and has been dealt with by Quaternary scientists. Their methods should be studied well by geoarchaeologists. Studying alluvial sediments that contain archaeological materials allows geoarchaeologists to draw on the broad foundation of Quaternary geology for concepts and methods, yet these endeavors also require careful consideration of the archaeological implications of those geologic records. Different approaches are required in different environments, ranging from temperate to arid, and at different temporal scales. Also, different approaches are required for varying archaeological problems. Hunter–gatherer studies, for example, entail emphasis on site locational strategies and environmental (habitat) reconstructions that support formational analyses (Stein, Chapter 2, this volume). Finally, studying complex social systems and their impact on past landscapes is aided by methods that are able to deal with those research challenges. The researchers cited in this chapter have all contributed to these geoarchaeological goals, either as Quaternary scientists or as archaeologists or as persons or teams who apply geoarchaeology to those problems.

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