5

Hydrological systems II: rivers and lakes

5.1 Introduction

We have already seen how a fluvial system can be traced from the watershed, via the slopes to the valley bottom (Fig. 4.1). On the slopes there is both subsurface groundwater flow, which can affect both soils and the underlying geology, and overland flow, which can produce rill and gully features and slope deposits. In the case of slopes, different areas of the slope are more prone to erosion than others, while other portions of the slope may be wetter (e.g. springs) and/or more likely to accumulate colluvium (Table 4.1 and 5.1). The lowermost valley slope environment, however, is commonly the wettest and here colluvium may interfinger with fluvial sediments, producing interdigitated colluvium and alluvium that may well be influenced by groundwater. In this chapter we focus on the valley bottom channel and floodplain environment. Since many streams flow into closed depressions forming wetland and lakes, we also discuss lacustrine sediments (Table 5.2).

Fluvial environments are distributed throughout the globe from the subarctic to the tropics, reflecting a wide range of variability as a function of local environmental conditions, such as moisture, temperature, seasonality, and other climatic variables. Arid fluviatile systems are different from those in more humid areas, for example, in their lower frequency but potentially greater intensity of streamflow, and the geometry of the channel patterns (Huckleberry, 2001). In these chapters we examine some of the most important aspects of the fluvial system that would be useful to the geoarchaeologist in understanding why and where sites might be located, eroded, or buried in a given area. In Chapter 4, we deal with the watershed, fluvial systems on slopes and slope deposits, and associated archaeological features such as terraces, lynchets, and human impact, for example clearance (see Chapter 9), while in Chapter 5 the focus is rivers, and wetland, and their associated deposits.

5.2 Stream erosion, transport, and deposition

Water and sediment from the slopes eventually arrive at the valley floor where they enter the channel system. There, water and sediment inputs reflect physical characteristics of drainage basin (Ritter, 1986: 204). Furthermore, clastic materials in fluvial systems, as with slopes, can be further subjected to erosion, transportation, and deposition.

Rivers flow at various volumes during the course of the year. During periods of low flow (*base flow*), in which most of the water entering the stream is from springs or groundwater, volumes of water and *discharge* (the volume of

TABLE 5.1 Characteristics of valley sediments (modified from Summerfield, 1991)

Locus of deposition	Type	Characteristics
Channel	Transitory channel deposits	Mostly bedload temporarily at rest; may partially be preserved in more long-lasting channel fills or lateral accretions
	Lag deposits	Segregations of larger or heavier particles, more persistent than transitory channel deposits
	Channel fills	Accumulation in abandoned or aggrading channel segments; range from coarse bedload to fine-grained oxbow lake sediments
Channel margin	Lateral accretion deposits	Point and marginal bars resulting from channel migration
Overbank floodplain	Vertical accretion deposits	Fine-grained suspended load of overbank flood water; includes natural levee and backswamp deposits
	Splays	Localized bedload deposits spread from channel onto adjacent floodplain
Valley margin	Colluvium	Slope deposits, poorly to moderately sorted, stony to fine grained material, accumulated by slopewash and gravity (e.g. creep); commonly interfingers with channel margin and floodplain deposits
	Mass movement deposits	Debris avalanche and landslide deposits intermixed with colluvium; mudflows generally in channels but spill over banks

water carried per unit time, e.g. $m^3\ s^{-1}$) are relatively low; little change in the stream morphology occurs during these periods of base flow (Butzer, 1976). In northern temperate areas, base flow is particularly low in summer months; in drier areas, flow ceases for much of the year except for the rainy season, when it essentially results from contributions by runoff (*ephemeral* flow). However, in periods of flood, such as in spring with melting of snow or during major storms (e.g. hurricanes), associated with major precipitation events, discharges can increase dramatically resulting in the condition when the stream channel is full (*bankfull* stage), even overtopping its banks and resulting in *overbank* flow. Most fluvial changes, however, take place with frequent and continual flow when at $\frac{1}{2}$ to $\frac{3}{4}$ of the bankfull level (Butzer, 1976).

Within the stream channel, water flows at different velocities, depending on location. The maximum velocity is near the surface of the water, above the deepest part of the channel. However, next to the channel walls and along the channel bed, where friction is greatest, flow velocities are much lower. Thus (all things being equal), greater velocities occur in deeper, narrower channels than in shallow, broad ones, which have a proportionately larger wetted perimeter and a greater amount of external friction along the channel.

A stream transports different material in different ways, and these substances are known as *load*. *Dissolved load* refers to various materials like salts that are transported in solution, such as carbonates, sulfates, nitrates, and oxides. These are mixed throughout the water column. The *suspended load* is composed of finer particles (generally silt, clay, colloids, and organic matter) that are kept in suspension by turbulence. Coarser materials are carried as part of the *bedload* along or close to the bottom of the channel. These sand-size and larger particles move by bouncing (*saltation*), rolling, or sliding. Associated with this movement is the overall organization of the material being transported, and we see that the movement of sand-size grains is associated with different types of *bedforms* (see Chapter 2) that change according to flow velocity and mean sediment size (Fig. 5.1).

The load that a stream can actually transport is expressed in two ways. *Capacity* is the total amount of material that a stream can transport

Table 5.2 Types of river patterns and characteristics (modified from Morisawa, 1985)

Type	Morphology	Load type	Width/depth ratio	Erosion	Deposition
Straight	Single channel with pools and riffles; meandering talweg	suspension-mixed load or bedload	<40	Minor channel widening and incision	shoals
Sinuous	Single channel with pools and riffles; meandering talweg	Mixed	<40	Increased channel widening and incision	shoals
Meandering	Single channels	Suspension or mixed load	<40	Channel incision, meander widening	Point bar formation
Braided	Two or more channels with bars and small islands	Bedload	>40	Channel widening	Channel aggradation, mid-channel bar formation
Anastomosing	Two or more channels with large, stable islands	Suspension load	>10	Slow meander widening	Slow bank accretion

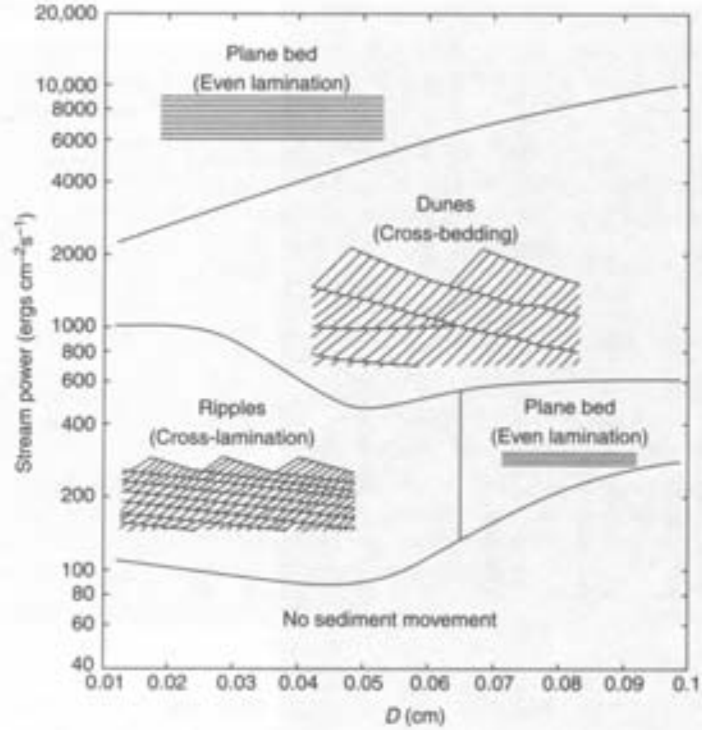


FIGURE 5.1 Bedforms in relation to grain size (mostly sand) and stream power (modified from Allen, 1971).

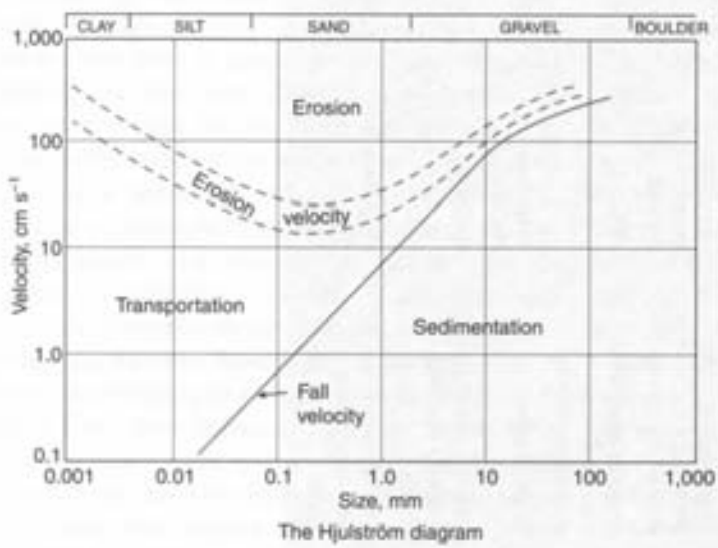


FIGURE 5.2 Hjulström's diagram showing velocity associated with the erosion, transport, and deposition of different sizes of particles.

and depends on the current velocity and the discharge. *Competence* refers to the size of the largest particle that a stream can carry under existing conditions. It depends mostly on velocity.

The proportion of the types of load that a stream carries varies from year to year, and within the year; it is also a function of climate. For example, streams in arid climates transport little dissolved load, but much bed load, especially during flooding; dissolved load is obviously more important in humid climates. Thus, the ability of a stream to erode and transport sediment is related to velocity and discharge; it is evident that most erosion and transport is carried out during major flow events, such as spring flooding or during exceptional events such as hurricanes and other storms.

A classical study (Hjulström, 1939), related erosion, transportation, and deposition to particle size and mean velocity (Fig. 5.2). This figure shows that coarse sand-size grain (ca 0.5 to 1 mm) is the most readily eroded sediment by water, requiring more energy for both coarser and finer sediment; the latter is due to the cohesion of finer particles requiring higher energies to entrain them and lower drag force. The diagram also shows the relatively low velocities required to keep finer material entrained and transported.

5.3 Stream deposits and channel patterns

Deposition takes place predominantly along the bottom where discharges fluctuate in response to inputs of water or sediment. In the case of point bars, for example (see below), which are built vertically during bank full and high stage events, deposition takes place along channel sides. In addition, different types of deposits occur in response to certain related conditions, such as energy of the stream (e.g. low flow versus flooding conditions), whether flow is confined to the channel or outside the channel, and extraneous inputs from the valley walls (Table 5.1).

The type of sediment being transported is generally linked to the morphology of the stream, which in turn is related to the flow conditions; both can be ultimately conditioned by climate (e.g. precipitation regime, vegetation). Geomorphologists and sedimentologists recognize several types of stream patterns (Fig. 5.3). Familiarity with these types of patterns and associated deposits is important because it can aid in the geoarchaeological interpretation of specific fluvial deposits and facies (see Chapter 2) that can then be valuable in looking for (or avoiding) certain loci for past human settlement. Low energy deposits occurring outside the channel, for example, are more likely to preserve *in situ* archaeological material compared to those from high energy gravel bars that are found within active channels (Figs 5.4–5.6). Moreover, an understanding of stream morphology and processes, including associated rates of change, may help explain an absence of surface sites in some areas (Guccione *et al.*, 1998).

Channels can be characterized as single or divided, with shapes that vary from straight, sinuous, meandering, braided, and anastomosing (anabranching) (Fig. 5.3; Table 5.2). These different types represent an average condition as channel morphology can change from season to season and year to year, and often grade into each other (Bridge, 2003; Ritter *et al.*, 2002). Such short-term changes, however, are not normally visible on the geoarchaeological scale, especially with older, Lower Palaeolithic sites, in East Africa for example, (Rogers *et al.*, 1994; Stern *et al.*, 2002).

Straight, single channels, tend to be rare and carry a mixture of suspended and bedload materials. The latter commonly accumulates on opposite sides of the channel (Ritter *et al.*, 2002), called *alternate bars*; shallow zones are called *riffles*, whereas deeper areas are called *pools*. The path that connects the deepest parts of the channel is called the *thalweg*. Erosion is relatively minor, with slight lateral widening or vertical incision. Deposition occurs along bars during the flood stage.

In *braided systems* rivers tend to be straight and many small channels are split off from the main channel; separating the channels are raised portions (bars), which are covered during periods of high water. Braided channels are characteristically found in arid and semi-arid areas (Fig. 5.4a,b), especially in alluvial fans, (see below), and in areas of glacial outwash. Braiding occurs in such locales where there are rapid shifts in water discharge, in the supply of sediment (generally coarse), and the stream banks are easily erodible (Boggs, 2001); the ratio of bedload to suspended load is high. Deposition of coarse material results in the formation of mid

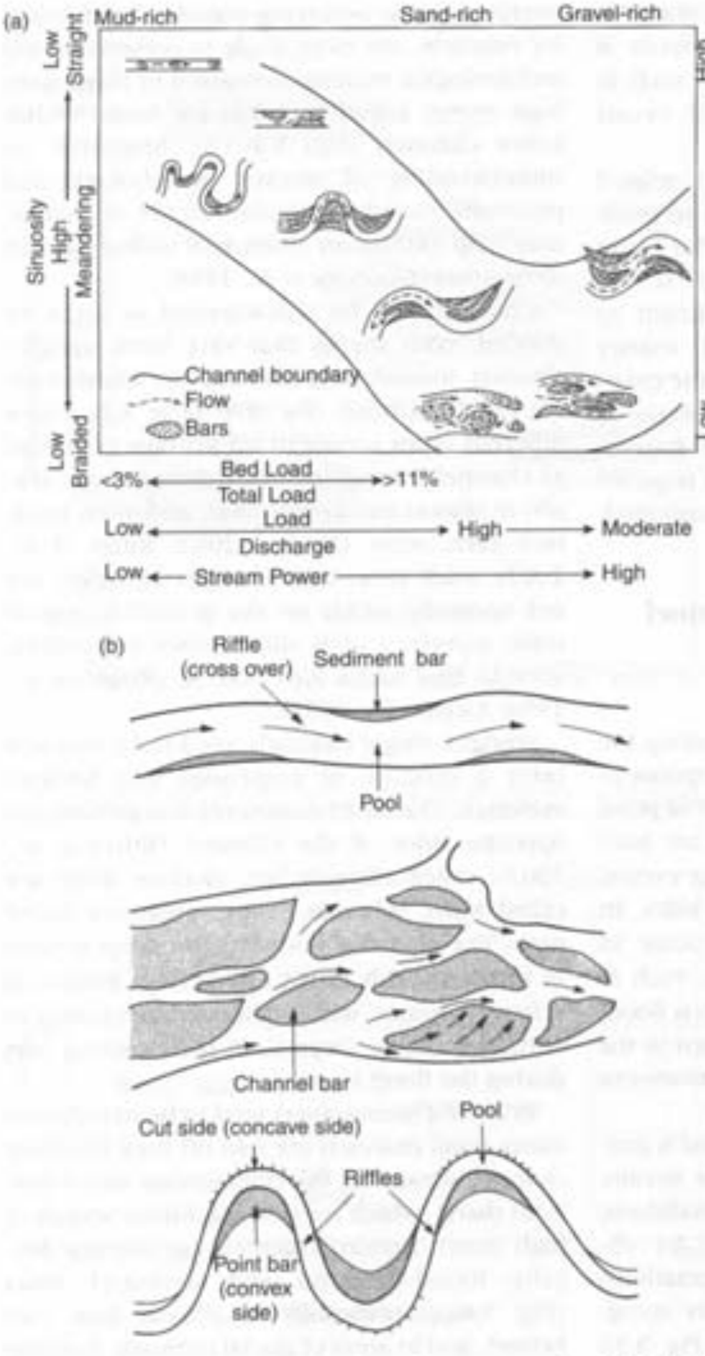


FIGURE 5.3 (a) Different fluvial channel pattern types showing the interrelation between channel form, sediment load, stream power, and stability (modified from Boggs, 2001. (b) Detailed view of straight, braided and meandering patterns (modified from Reineck and Singh, 1980, figure 372).

channel bars, which direct the flow around them during high water discharges. Through time, valley floors can accumulate several meters of braided stream deposits, which appear as nested, lens-like masses of gravels (Fig. 5.5). It is not surprising that in light of the periodically high discharges, the likelihood of finding intact archaeological sites within such deposits is low. Nevertheless, archaeological sites can be found on *abandoned* braided stream deposits, such as those on old alluvial fan surfaces. In Sinai, for example, deflated remains of coarse bouldery deposits (*lags*) are commonly exploited as large building stones; these can be difficult to distinguish from the natural bouldery surface cover (Fig. 5.6).

In *Anastomosing channels*, in contrast to braided channels, flow is around bars that are relatively stable and not readily eroded. In the Welland Valley area of eastern Britain, anastomosing channels are inclined to represent cold, periglacial conditions between 10,900 and 10,00 years ago (French, 2003). However, they are relatively infrequent in the archaeological record.

Meandering channels and systems are widespread in geoarchaeological settings and many sites are associated with them. Unlike braided streams, in meandering ones, flow is within a single channel. They also differ in having lower sinuosity, shallower gradients, and finer sediment loads (Boggs, 2001). The principal aspects of a meandering river system are illustrated in Figure 5.7.

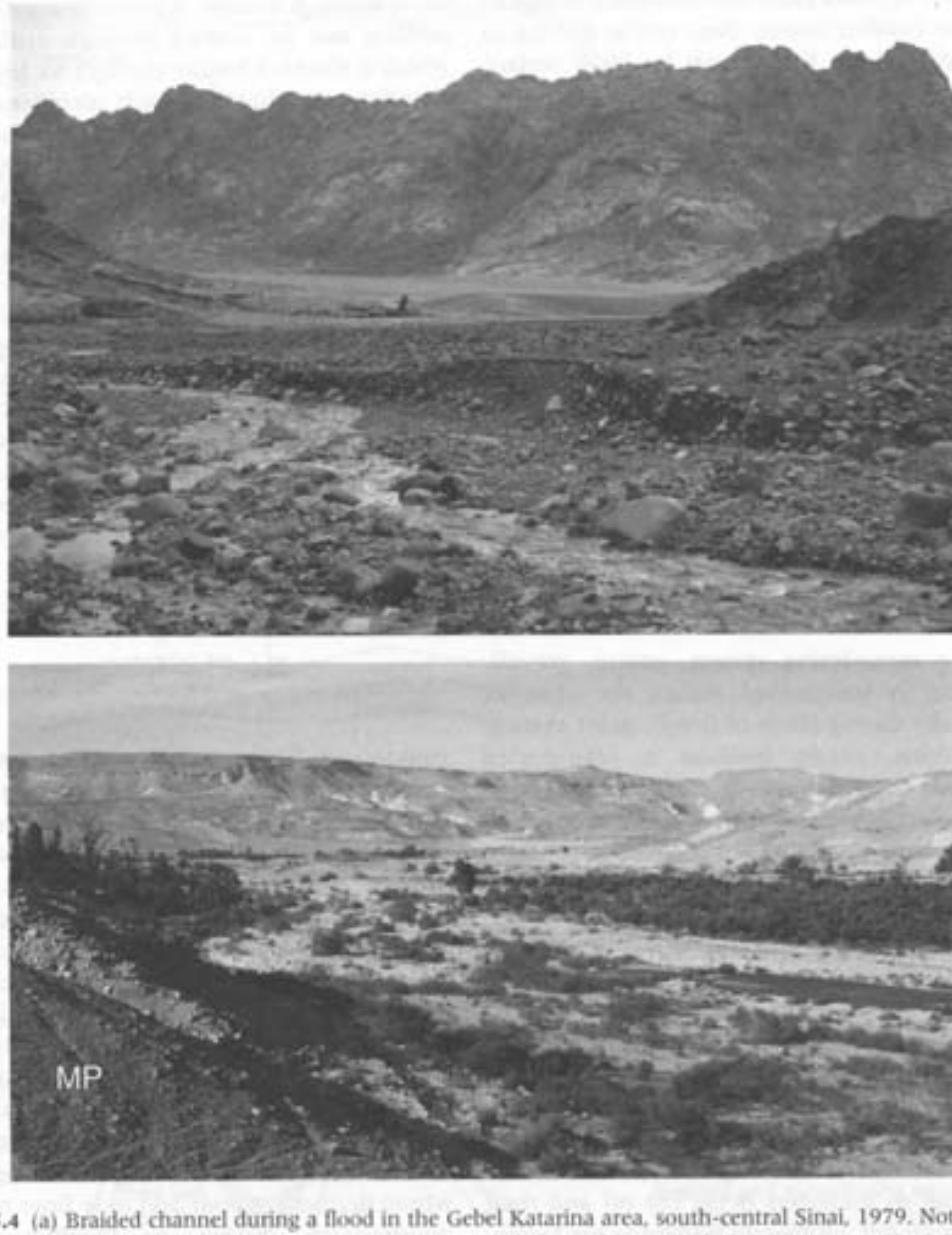
In a meandering system, coarse, gravelly material is transported within the channel, generally during times of flood; under average conditions, sandy bedload is transported (Walker and Cant, 1984) (Table 5.1). Erosion takes place along the outer reaches of meander beds where velocities are higher. In contrast, deposition occurs in the inner part of the meander loop, leading to the formation of the point bar (Figs 5.3 and 5.7). Thus, through time the point bar can be seen to shift laterally across and downstream along the valley bottom and floodplain. This process of *lateral accretion* leads to the formation of a package of sediment that fines upward from gravel, sand, and finer silts and clay.

Increased erosion along the outer cut banks can lead to meanders being cut off and their abandonment, ultimately leading to the formation of an oxbow lake (Fig. 5.7). The sediment in these depressions consists of fine silt and clay, and is typically organic rich; they may contain diatoms, molluscs, and ostracods. Since they are away from the channel and contain water before being silted up, they are attractive to vegetation, game, and human occupation. A similar type of depression and infilling can be formed through *avulsion*, in which a channel breaks through its levee and abandons its channel. Such abandoned and isolated basins are not uncommon in the rivers that drain eastern Texas upto the Gulf of Mexico. A considerable part of the Late Paleoindian occupation at the Wilson–Leonard site, for example, took place next to an *avulsed channel* (see Box Fig. 2.5). A banana-shaped accumulation of organic silty clays within the avulsed channel was accompanied by bison kills (Bousman *et al*., 2002; Goldberg and Holliday, 1998). At the Aubrey Clovis site on the Trinity River in north-central Texas, a cutoff channel was the scene of a groundwater spring-fed pond which slightly predates and is partly contemporaneous with the Clovis occupation (Humphrey and Ferring, 1994).

5.4 Floodplains

Floodplains, flat to gently sloped areas adjacent to stream channels, are notable in geoarchaeology, for not only are they one of the most widespread of fluvial landscapes – past and present – but they served as significant loci for past occupations, which can be well preserved. They are dynamic landscapes that exhibit a variety of local sedimentary environments and processes (Brown, 1997) which change over time as the floodplain evolves (Fig. 5.8). Close to the channel, for example (Fig. 5.9), sand and silt are found in raised, natural levees. These deposits grade laterally into finer silts and clays that accumulate in lower, backswamp areas where drainage is poor and only finer material accumulates during a flooding event. Consequently, although the backswamp might appear as an attractive locale for game, actual habitation is more likely to occur closer toward the levee, where the deposits are coarser and drainage is better. On the other hand, the position of these environments continually changes as the meanders sweep across the floodplain.

(a)



(b)

FIGURE 5.4 (a) Braided channel during a flood in the Gebel Katarina area, south-central Sinai, 1979. Note the gravel bar between two branches of the channel. (b) Braided channel from Qadesh Barnea area, Sinai. The braided channels are shown in the central part of the photograph with the main channel carrying water, and abandoned channels adjacent to it. The entire area between the vegetated areas on the right and left is covered during occasional flooding events that occur in winter; this area currently receives <100 mm of rainfall per year. On the left is a terrace riser (MP) composed of gravel and associated with Middle Palaeolithic artifacts. The height of the terrace is ca 19 m above the present valley floor and indicates that during the Middle Palaeolithic, the valley was filled with gravel to this height (Goldberg, 1984).

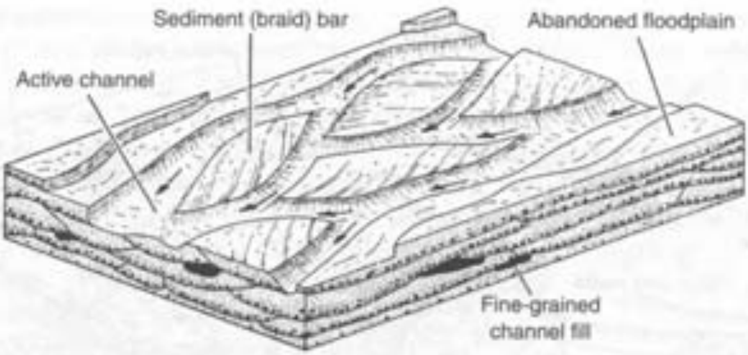


FIGURE 5.5 Block diagram showing surface morphology of a braided stream with active channels and bars. The depth dimension shows deposition of sediments within lenticular bodies, beginning with gravels that grade upward to finer sand and gravel. An abandoned floodplain on the right exists above the braided channel area The preservation potential of intact sites within such deposits is low.
(modified from Allen, 1970, figure 4.7).

FIGURE 5.6 Coarse alluvium exposed at the surface of an alluvial fan in southwestern Sinai. This coarse lag of boulders and gravels was originally deposited by braided channels of the fan when it was active.
O. Bar-Yosef and N. Goren-Inbar examine the remains of a Bronze Age building whose inhabitants exploited these boulders for construction.

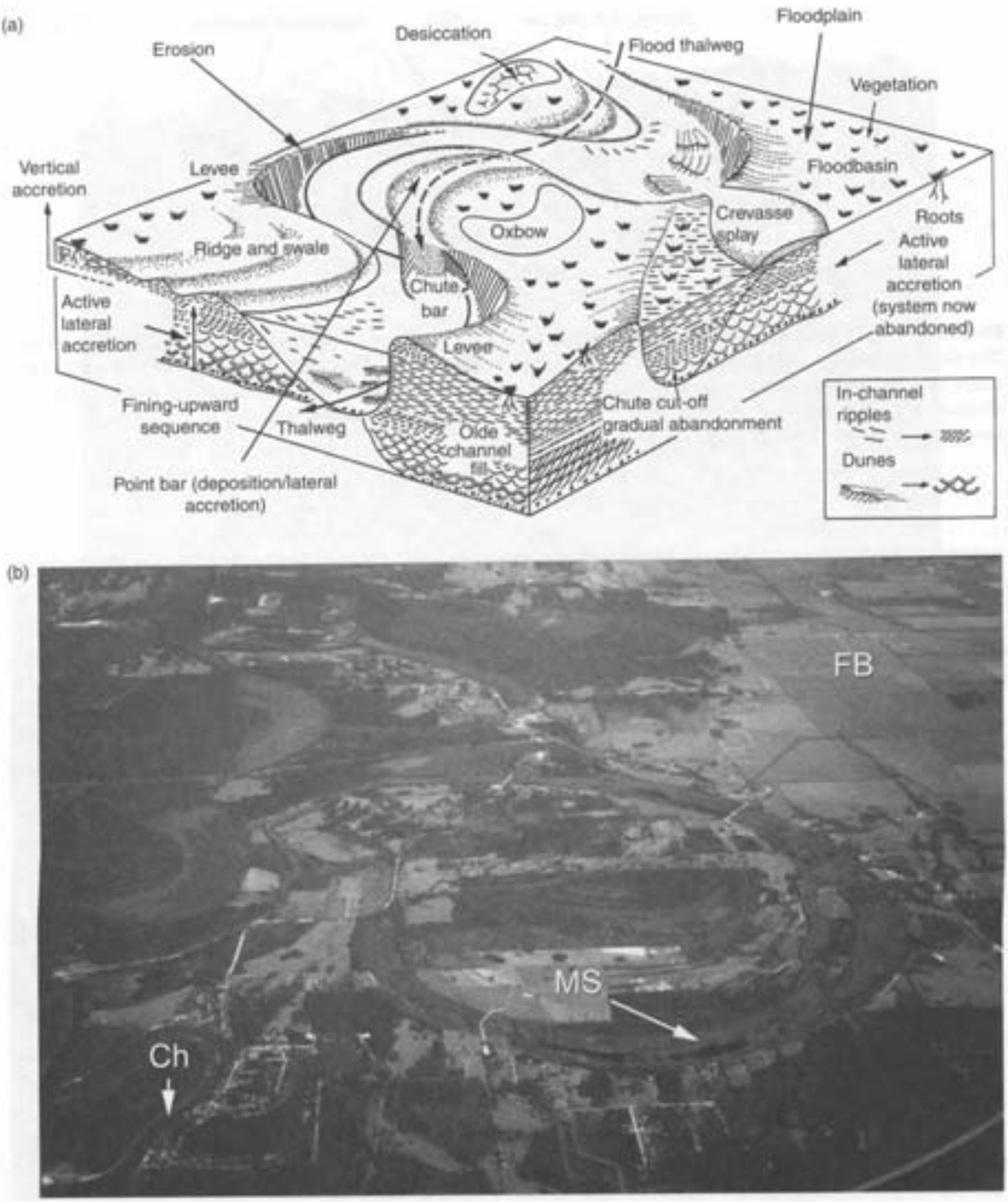


FIGURE 5.7 (a) Block diagram illustrating the major features of a meandering river system (modified from Walker and Cant, 1984 figure 1). (b) Aerial view of meandering river system showing flood basin (FB), present channel (Ch), and abandoned meander (MS) and associated ridge and swale topography along the point bar.

covering or erasing previous deposits. Along the meanders of the Red River, Arkansas, for example (Guccione *et al.*, 1998) found sites of different ages associated with different positions of the meander. The most recent meander belt (limits of meanders within the valley bottom) is about 200 to 300 years old and has covered many previous artifacts or sites with 1 to 2 m of alluvium. An older prehistoric site, on the other hand, is found on the surface associated with a 500 to 1,000 year old abandoned meander belt. Finally, they indicate:

> *At locations proximal to the river, the site may be buried by overbank sediment 0.4 m thick, but at more distant locations the site is at the surface or only buried by thin overbank sediment because of low sedimentation rates (0.04 cm yr^{-1}) over the span of a millennium. Sites, such as 3MI3/30, [Fig. 5.9] that are occupied contemporaneous with overbank sedimentation may be stratified; however, localized erosion and removal of some archeological material may occur where channelized flow crosses the natural levee. (Guccione et al., 1998: 475)*

The study of Guccione *et al.* (1998) elegantly demonstrates the active nature of meander belts, even within the last few centuries. Furthermore, it establishes that one must take into account issues, such as the vigor of the meander belt when working in such geomorphologically dynamic areas. Many of the techniques discussed in Chapter 15 (e.g. aerial and satellite photos, trenching, soil surveys) are helpful in evaluating the age of a fluvial landscape and rates of change, and whether sites of a given age will be likely preserved, if at all, either on the surface or beneath it.

5.4.1 Soils

Soils play an important part in fluvial geoarchaeology. They provide a window into understanding the relationships between sedimentation, pedogenesis, and archaeological site formation processes (Ferring, 1992). Furthermore, their formation can reflect regional landscape and climatic conditions, which in turn can be used as time parallel (roughly synchronic) stratigraphic marker horizons (see Chapter 2).

Soil visibility on floodplains involves a balance between rate of pedogenesis and geogenic sedimentation. At one extreme, in cases with continuous deposition in the same location, there is little chance for a mature profile to form: horizons (perhaps as defined in the strictest

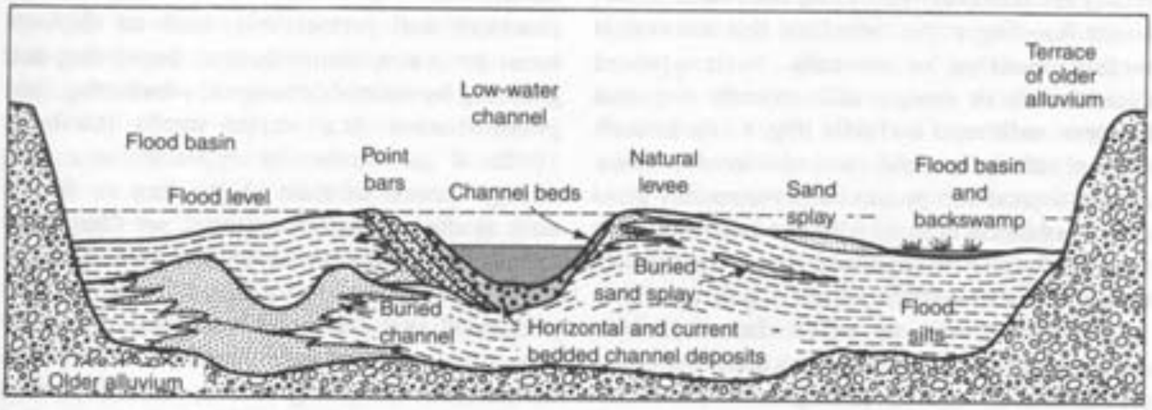


FIGURE 5.8 Lateral variations in deposits and facies are clearly shown in this schematic view of a floodplain. Buried and active channel gravels interfinger with finer grained flood silts, some associated with point bar deposits, which here are migrating from left to right. In this example, the entire floodplain sequence is set into an eroded valley consisting of older, gravelly alluvium, which forms a terrace on the valley flanks (modified from Butzer, 1976a, figure 8.3).

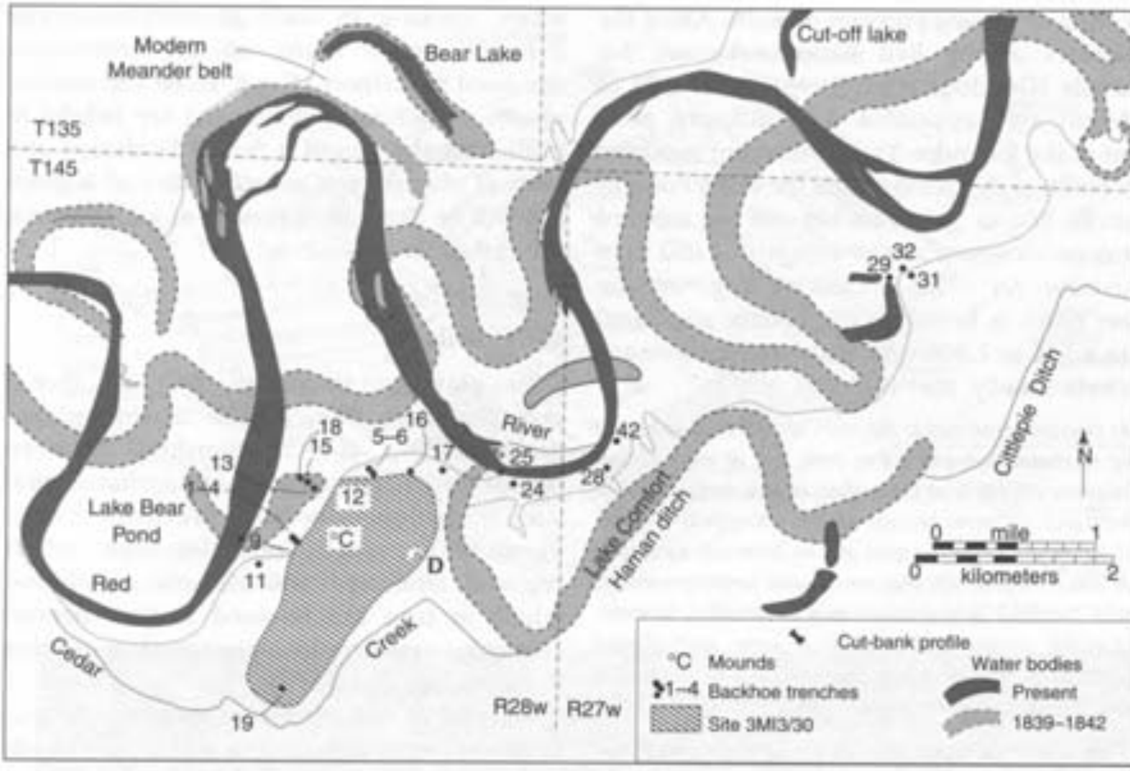


FIGURE 5.9 Changes of positions of meanders within the Red River during the past 160 years as determined by trenching and excavation. It is clear that any site situated next to the older channel (e.g. 3MI3/30, a mound site) could be buried under point bar deposits of the present meander (modified from Guccione *et al.*, 1998, figure 3).

sense) are continually forming with each subsequent flooding event, whether this interval is weekly, monthly, or annually. Such types of alluvial soils or *cumulic soils* straddle the area between sediments and soils (Fig. 5.10). In such cases of relatively rapid rates of deposition, any archaeological occupation has a reasonably good chance of being buried, with the net result that several discrete occupations can be observed throughout this overthickened A horizon.

At the other extreme, where there is little or no sedimentation, repeated occupations occur on top of each other, resulting in the formation of *palimpsests* (Ferring, 1986). As a result, it is virtually impossible to isolate individual occupations. Furthermore, inasmuch as the archaeological material lies about the surface, it can be subjected to modification and disturbance by a host of postdepositional processes and pedogenesis, such as displacement by water, (bioturbation) burrowing and gnawing by animals, chemical weathering, and pedoturbation (e.g. shrink-swell) (Limbrey, 1992). If the surface is exposed for a long enough period of time (depending on factors such as climate, parent material; see Chapter 3) soil horizon development will take place. If such a soil (now paleosol) profile ultimately becomes preserved and protected by renewed deposition, future excavation will reveal archaeological material occurring within the soil profile. Finally, since soils can be faithful recorders of local or regional (climatic) conditions (see Chapter 3) the types of soils can therefore provide palaeoenvironmental information during or close to the time of one or more of the

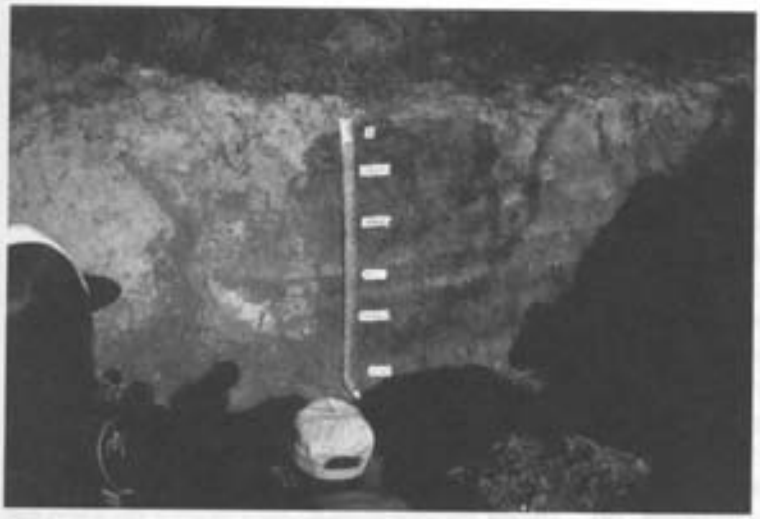


FIGURE 5.10 Photograph of late Holocene floodplain Ford alluvium in Cowhouse Creek, central Texas, United States. Shown here is sequence of buried A and A-Bw horizons (Entisols) within vertical accretion flood plain deposits consisting of silts and clays (see Nordt, 2004).

occupations. Such is the case for a calcic horizon, which is developed on red clayey alluvium in the Jordan Valley and which is universally associated with Epi-Palaeolithic (Geometric Kebaran; ca 14.5 to 13.7 ky uncal.) sites (Bar-Yosef, 1974; Maher, 2004; Schuldenrein and Goldberg, 1981).

Another indicator of landscape stability on fine-grained flood plain deposits is the formation of surface gleys. These result from poor drainage and associated oxidation/reduction conditions with the accumulation of organic matter. In addition, under wet conditions as such formerly humic topsoils and turbated topsoil material become preferentially impregnated with iron and manganese compounds (mottling), and commonly show the occurrence of pyrite or pyrite pseudomorphs (g horizon) (Miedema *et al.*, 1974; Wiltshire *et al.*, 1994).

Paleosols such as those described above also serve as temporal markers because they may have formed at roughly the same time interval in many places. In the Southern Plains, for example, soil formation took place during a period of flood plain stability between 2,000 and 1,000 BP (Ferring, 1992). Although the paleosol goes by different names in different places (e.g. Caddo in Oklahoma, Quitaque in Texas), it serves as a useful stratigraphic marker for placing Late Archaic, Plains Woodland, and Late Prehistoric sites in a firm stratigraphic and temporal framework (Ferring, 1992).

Alluvial archaeology is equally well established in Europe, particularly during the 1980s when sand and gravel extraction increased exponentially the number of CRM/"Rescue" sites (Brown, 1997; Howard *et al.*, 2003; Needham and Macklin, 1992). These studies provided insights into landscape and climatic changes. For instance, in the Fens (East Anglia), and along major rivers such as the Nene (Northamptonshire), Ouse (Bedfordshire), and Upper Thames (Oxfordshire), entire prehistoric landscapes have been buried by fine alluvium dating to Iron Age through to Medieval times (Robinson, 1992) (Fig. 5.11). The original landscape consisted of coarse silty Pleistocene/early Holocene river terrace deposits in which the soils had developed by mid–Holocene times. Ritual and burial monuments and landscape divisions (e.g. avenues, barrows, cursuses) exhibited treethrow features that could date back as early as the Late Mesolithic–Early Neolithic transition, some 6,000 years ago (French, 2003; Lambrick, 1992; Macphail and Goldberg, 1990).

Such sites thus provide the opportunity to investigate the archaeology and environment over long periods. Treethrows provide windows into the formation and state of prehistoric landscapes, such as at Raunds, Northamptonshire (Early Neolithic and Early Bronze Age monuments; Healy and Harding, Forthcoming), Roman and Saxon settlements, and at Drayton Cursus (Upper Thames). In the latter, the Neolithic Cursus seals treethrow hollows, and subsequent prehistoric soils are buried by Roman and Saxon alluvium (Barclay *et al.*, 2003). At both sites the alluvium buried early to mid-Holocene Alfisols, which provide "control soils" that can be used to compare soil development in later prehistory and historic times (Macphail and Goldberg, 1990). At Raunds, the consensus interpretation of the environmental data is for a Neolithic and Bronze Age grazed floodplain landscape on which stock concentrations produced trampled and phosphate-enriched soils that were sealed by numerous earth monuments (Macphail and Linderholm, 2004). Textural pedofeatures associated with this soil disturbance were readily differentiated from "Saxon and Medieval" clay inwash induced by alluviation (Brammer, 1971) (see Chapter 9; Fig. 16.1b, Table 16.1b).

A number of other riverine sites suffered the effects of increased wetness during the Holocene. For example, at Three Ways Wharf, Uxbridge Upper Palaeolithic artifacts (ca 10,000 BP) were biologically worked throughout the earliest Holocene soil, whereas flints from the Early Mesolithic (ca 9,000–8,000 BP) occupation (ca 1,000 years later) remained near or on the surface because they were sealed by a fine charcoal-rich humic clay (and peat) associated with wetter conditions. Similar peaty deposits formed throughout the Colne River valley during the early Boreal period (Lewis *et al.*, 1992). This wetness essentially stopped bioturbation of the Mesolithic artifacts at this site. The Upper Palaeolithic site was located on a low bar of a braided stream and functioned as a likely ambush camp at a river crossing. In contrast, by early Mesolithic times the site was swampy and humans were seemingly affecting the coniferous landscape by the use of fire.

The Upper Palaeolithic site of Pincevent in France, famous for the preservation of its living floors and activity areas (Leroi-Gourhan, 1984)

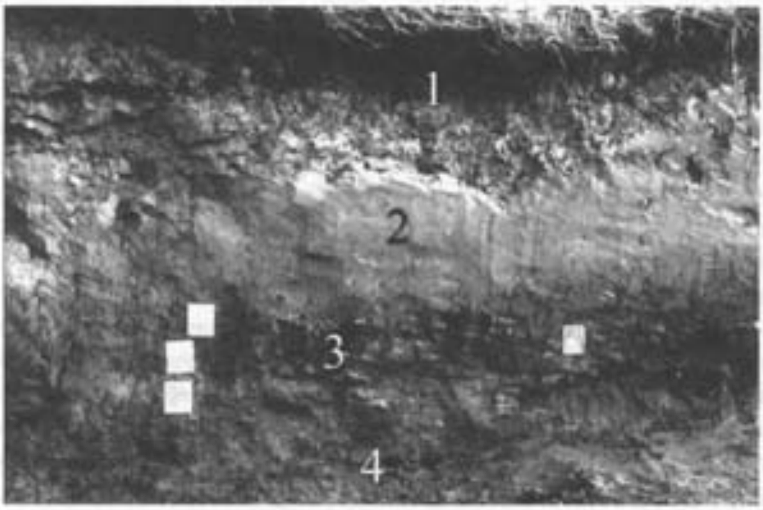


FIGURE 5.11 Section through charcoal and burned soil-rich remains of prehistoric treethrow hole fill buried by a meter of Saxon and Medieval fine alluvium at Raunds, Northamptonshire, United Kingdom. 4 – subsoils and gravels of Holocene Alfisols formed in Nene river terrace sandy silty sands, sands, and gravels; 3 – truncated burned tree hollow with burned soils with high magnetic susceptibility values (e.g. $\chi = 894\ 10^{-8}$ SI kg^{-1}); 2 – Saxon-medieval fine alluvium (e.g. clay loam); 1 – modern pasture soil with grass rooting and earthworm burrowing into top of fine alluvium.

exhibits exceptional preservation, due in large part to its location on the floodplain of the Seine. Here, low energy overbank flooding led to interment of the occupational remains, without movement of the artifacts. Lastly, it can be recorded that alluviation of the Lower Thames at London led to the deposition of highly polluted (P, Pb, Cu, and Zn) moat deposits at the Tower of London (Macphail and Crowther, 2004).

5.5 Stream terraces

As discussed earlier, channels constantly shift their position, either on a seasonal or yearly basis. In meandering channels, the stream sweeps across the valley floor resulting in the lateral accumulation of point bar deposits that over time can lead to vertical net accumulations. Similar net accumulation of deposits can occur in braided systems.

5.5.1 Characteristics of terraces

In many environments and locales, this net accumulation is interrupted by a marked change in hydraulic regime, resulting in the vertical incision (*entrenchment*) by the stream into previously deposited alluvium, or even bedrock. Such incision often leaves behind a geomorphic feature, a *terrace*, which consists of a flat portion (the "tread") and a steeper sloping surface (the "riser") that connects the tread to the level of the new floodplain or a lower terrace surface (Fig. 5.4; 5.12). Thus, in many cases, terraces represent abandoned floodplains that existed when the river flowed at this higher elevation. However, it should be kept in mind that terraces are essentially a geomorphic/topographic feature that can form on bedrock, or previously deposited alluvium or other sediment(s) (Fig. 5.12).

Two types of terraces are commonly recognized: erosional and depositional. Erosional terraces are produced by downcutting associated with lateral erosion, producing stepped surfaces as shown in Figure 5.12. If the underlying material is bedrock, they are commonly called *strath terraces*. With depositional terraces the tread and riser are composed of valley alluvium (Fig. 5.13).

Although processes involved in the formation of terraces are complex, varied, and often a product of combined factors, a phase of valley accumulation (*aggradation*), must be followed by a phase of downcutting (entrenchment). Similarly, aggradation occurs when the supply of material is greater than the ability of the system to remove it. This in turn can be brought about by (1) inputs of glacial outwash, (2) changes in local or regional base level caused by changes in sea level (brought about by eustatic or tectonic causes), (3) inputs of coarse sediment related to tectonic uplift, or (4) climate change (Ritter *et al.*, 2002) (see Box 5.1). Entrenchment arises from similar causes, principally tectonism or climate change. In valleys adjacent to the Dead Sea, for example, terraces were formed as the streams incised their channels in response to a lowered base level resulting from the shrinking of the Pleistocene Lake Lisan, the precursor to the modern Dead Sea (Fig. 5.12) (Bartov *et al.*, 2002; Bowman, 1997; Niemi, 1997; Schuldenrein and Goldberg, 1981).

5.5.2 Archaeological sites in terrace contexts

Depositional terraces provide a wealth of stratigraphic, palaeoenvironmental, and geoarchaeological information as they represent fossilized loci of human activities focussed on alluvial environments. Furthermore prehistoric sites associated with terraces provide materials (organic matter/charcoal/hearths) that are datable by ^{14}C or cultural remains that can be temporally bracketed. Within recent years the success and refinement of OSL/TL techniques shows that they can be used to date the sediments directly (Fuchs and Lang, 2001), thus

FIGURE 5.12 Photo of strath terraces from Nahal Ze'elim, western Jordan Valley. This ephemeral stream flows into the Dead Sea from the Judean Mountains during major rainfall events. During Pleistocene times a large lake, Lake Lisan, over 200 m higher than the present day Dead Sea (ca −405 m below sea level), existed in the Jordan Valley. When this lake dried up at the end of the Pleistocene (Bartov *et al.*, 2002), the base level lowered rapidly, and streams such as this one incised into their channels relatively rapidly as they moved across the valley floor. The result is this flight of terraces developed on bedrock, and fluvial and lacustrine deposits.

avoiding the problems of the charcoal being reworked or derived from old wood.

5.5.2.1 New World sites

Sites found in terrace contexts exist over the entire globe and many have been extensively studied. In central North America, terrace sequences are common along major and minor drainages, and many contain prehistoric sites with among the earliest Paleoindian sites (Blum *et al.*, 1992; Blum and Valastro, 1992; Ferring, 1986, 1992; Mandel, 1995; Nordt, 1995). The common practice is to label the lowest and youngest terrace, that is, the one closest to the level of the modern channel, T_0 and successively older and higher terraces, T_1, T_2, etc.; this practice of terrace designation is not widespread outside North America.

Geoarchaeological research in the American southwest has been intensive and extensive for over 65 years with the early work of Kirk Bryan and E. Antevs (Waters, 2000), followed by the dedicated work of Haynes (1991, 1995) and his student, Waters (Waters, 1992; Waters and Ravesloot, 2000). Waters' lifetime work in the area has sought to address a number of issues relating to alluvial stratigraphic sequences, how they reflect upon palaeoenvironments and the completeness of the archaeological record (Waters, 2000). For example, the occurrence of Clovis sites in the San Pedro Valley of southern Arizona is not matched in neighboring valleys where Clovis remains are absent. The question, of course, is: does this distribution represent a cultural preference or another, perhaps geological control of site distribution?

Detailed geoarchaeological work in these valleys is shown in Figure 5.20, which reveals some interesting patterns. It is clear that the absence of sites in the Santa Cruz River and Tonto Basin, for example, is related to the absence of sedimentary traps to store these sites; even if they were there, they are long gone. Secondly, even where deposits do exist

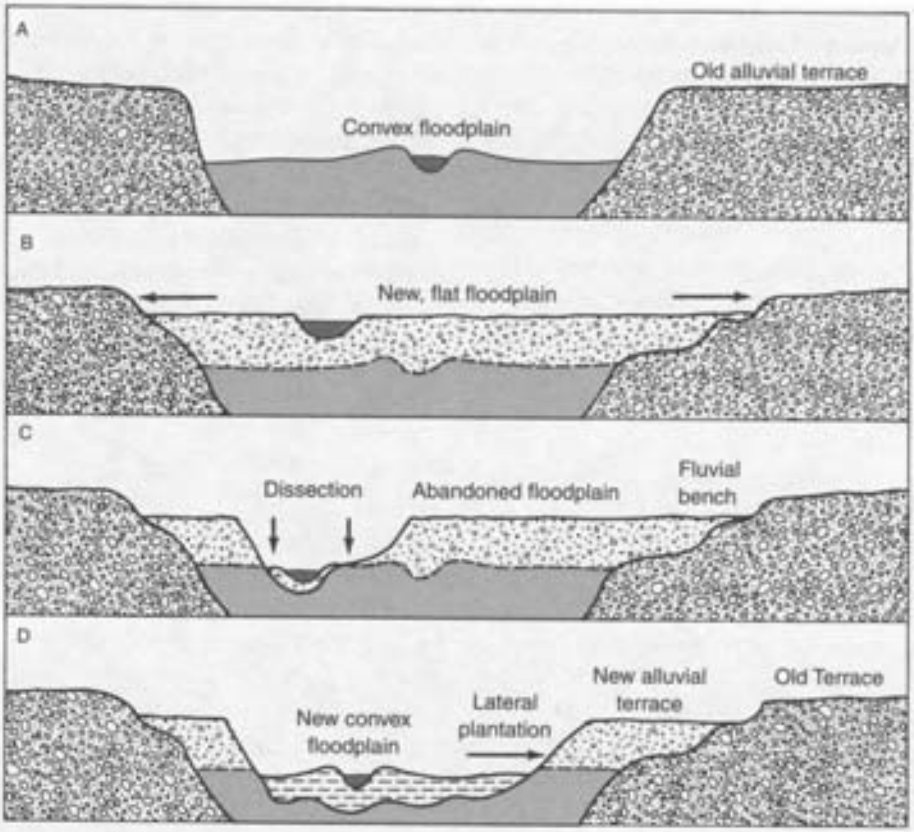


FIGURE 5.13 Idealized view of alluvial terrace formation developed in alluvium. (A) As shown here, this first stage depicts build-up (aggradation) of fine-grained alluvium within an eroded valley that formed by the downcutting through previously deposited gravelly alluvium; (B) Coarser alluvium (braided stream, perhaps dryer conditions) covers these initial deposits, enlarging the floodplain by lateral planation; (C) initial incision and downcutting (degradation) takes place due to factors such as climatic change or base level lowering, leaving behind an abandoned floodplain surface; (D) downcutting ceases and renewed alluviation takes place that is characterized by fine-grained sediments (as in (A)), with lateral planation resulting in the widening of the floodplain and removal of some of the previous alluvium from stages (A) and (B); as a consequence, a second alluvial terrace is formed at a lower elevation than the first, but it is composed of two different types of deposits (Modified from Butzer, 1976, figure 8.13, p. 170).

(e.g. Whitewater Draw, Gila River) the braided stream hydrology would result in cultural material being eroded and reworked throughout the gravelly deposits. Finally, we see that valley deposition and erosion in the Late Pleistocene and Early Holocene was not uniform throughout the area. This pattern would be expected if each valley had specific and different geomorphic variables (e.g. rock type, slopes), or if there were climatic differences among valleys, or the climate was the same but each valley reacted differently to climate changes (Waters, 2000). In any case, this research shows that a geological filter (viz. erosion) is responsible for the apparent absence of sites beyond the San Pedro River.

In the same area, Waters evaluated the effects of fluvial landscape change on Hohokam prehistoric agriculturalists who occupied the Gila and Salt River valleys from AD 100 to 1,450 (Waters, 2000). The major questions involved the change in pattern in public areas around