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Landscape evolution, alluvial architecture, environmental history, and the archaeological record of the Upper Mississippi River Valley

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ABSTRACT

The alluvial fill in the Upper Mississippi River Valley (UMV) is a palimpsest of past landscapes, environments, and physical evidence of human life ways. The valley has undergone significant changes in fluvial style during the time humans have occupied its landscapes, including changes in channel pattern, location of depocenters, and sediment lithology. Remnants of late-glacial braidplains that predate human presence in the Upper Midwest occur as sandy terraces and terrace fills. A subsequent major change in alluvial architecture resulted from fundamental changes in seasonal water and sediment input that marked the end of glacial meltwater input into the valley about 12.4 ka (10,500 ^{14}C yr B.P.). A shift to net transport of sandy bedload and storage of fine-grained overbank sediment on the floodplain accompanied the change to an island-braided channel pattern at that time. The Holocene channel belt has been significantly narrower, and the zone of sediment storage is reduced relative to that of the late-glacial river. Major Holocene depocenters include alluvial fans and colluvial slopes, floodbasins, natural levees, and fluvial fans at the junction of large tributaries.

Climate models, and paleobotanical, and isotopic studies indicate that shifts in large-scale patterns of atmospheric circulation and moisture transport into the mid-continent of North America induced hydrologic and vegetation changes that strongly influenced flood frequency and magnitude, the delivery of sediment from tributary basins, and the evolution of the UMV landscape. Understanding the alluvial architecture of the valley, and the temporal/spatial distribution of biotic environments and processes that have buried, mixed, altered, or destroyed archaeological deposits is essential to develop strategies for sampling the valley for evidence of past human activity and for properly interpreting the archaeological record.
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1. Introduction

The geomorphology, sedimentology, and architecture of fluvial systems reflect many scales of interactions among internal and external factors acting on continental land systems. In continental interiors climate, tectonics, and drainage-basin characteristics (geology, soils, vegetation, land use) dictate the conditions that control the discharge and sediment dynamics of rivers. Long-term fluvial-system response is partially recorded in valley sediments that may also contain other paleoenvironmental archives such as pollen and plant macrofossils as well as a partial record of human use of the valley landscape. Relating the sedimentary record of rivers to environmental conditions reconstructed from associated paleoenvironmental archives yields important insights into how climate influences fluvial response, how soon vegetation and soil/slope systems respond and affect the fluvial response, and ultimately how the interaction of physical, biological, and cultural systems shape the archaeological record.

All elements of drainage systems are not equally responsive to environmental change, nor do changes in stream response or sediment movement occur concurrently throughout drainage basins (Knox, 1983; Blum and Valastro, 1994; Bettis and Hajic, 1995; Knox, 1999; Andres et al., 2001; van Huissteden et al., 2001; Bettis and Mandel, 2002). Fluvial sedimentary records are, therefore, not uniform through drainage systems. This necessitates the reconstruction of fluvial and environmental history from a range of drainage elements across a basin to decipher the relationships among climate, vegetation, and fluvial-system response (Hajic, 1987, 1990a; Bettis and Hajic, 1995; Mandel, 1995; Bettis and Mandel, 2002). Low-order drainage elements integrate fluvial response over relatively small areas and, therefore, provide a clearer picture of the effects of environmental factors on the delivery of sediment and water to the fluvial system than can be derived from larger valleys. On the other

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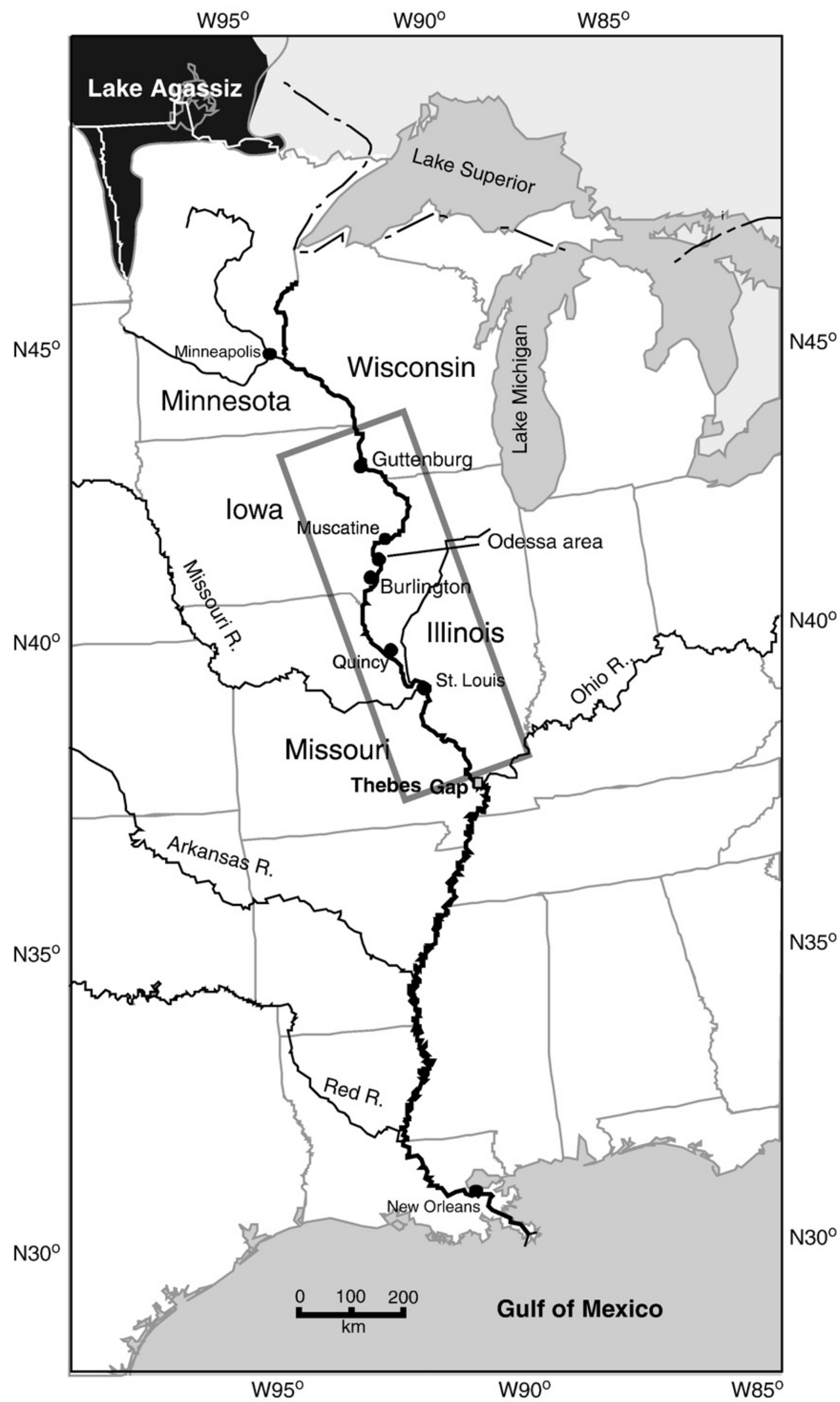

Fig. 1. Map showing the location of the Upper Mississippi River Valley region discussed in the text (area inside rectangle). Lake Agassiz was a large late-glacial lake whose discharge had significant effects on the evolution of the Mississippi Valley.

hand, low-order drainage elements tend to have shorter long-term sedimentary records than do the larger valleys to which they drain.

This paper provides an analysis of the effects of environmental change on the evolution of the fluvial style of the Upper Mississippi Valley (UMV) during the last-glacial–interglacial cycle ca. 25.1 ka[1] (ca. 21,000 ^{14}C yr B.P.) to the present and suggests how the fluvial style of this large valley conditions our understanding of the record of the human past. We integrate several independent lines of evidence of environmental conditions from alluvial stratigraphy and chronology, pedology, pollen, macrofossils of vascular-plants and bryophites and speleothem isotopic records to provide an integrated picture of environmental change and fluvial-system response. We then use the results of archaeological surveys in the area of the Mississippi and Iowa River junction to postulate how environmental and cultural processes have acted to produce the archaeological record.

The UMV and its major tributary, the Missouri River Valley, are ideally suited for studies unifying diverse late-Quaternary geomorphic systems and paleoenvironments. They drained a large portion of the southern Laurentide ice sheet and covered last-glacial climatic and

[1] We use calendar ages as determined from the calibration curve of Fairbanks et al. (2005) followed by ^{14}C ages in this paper.

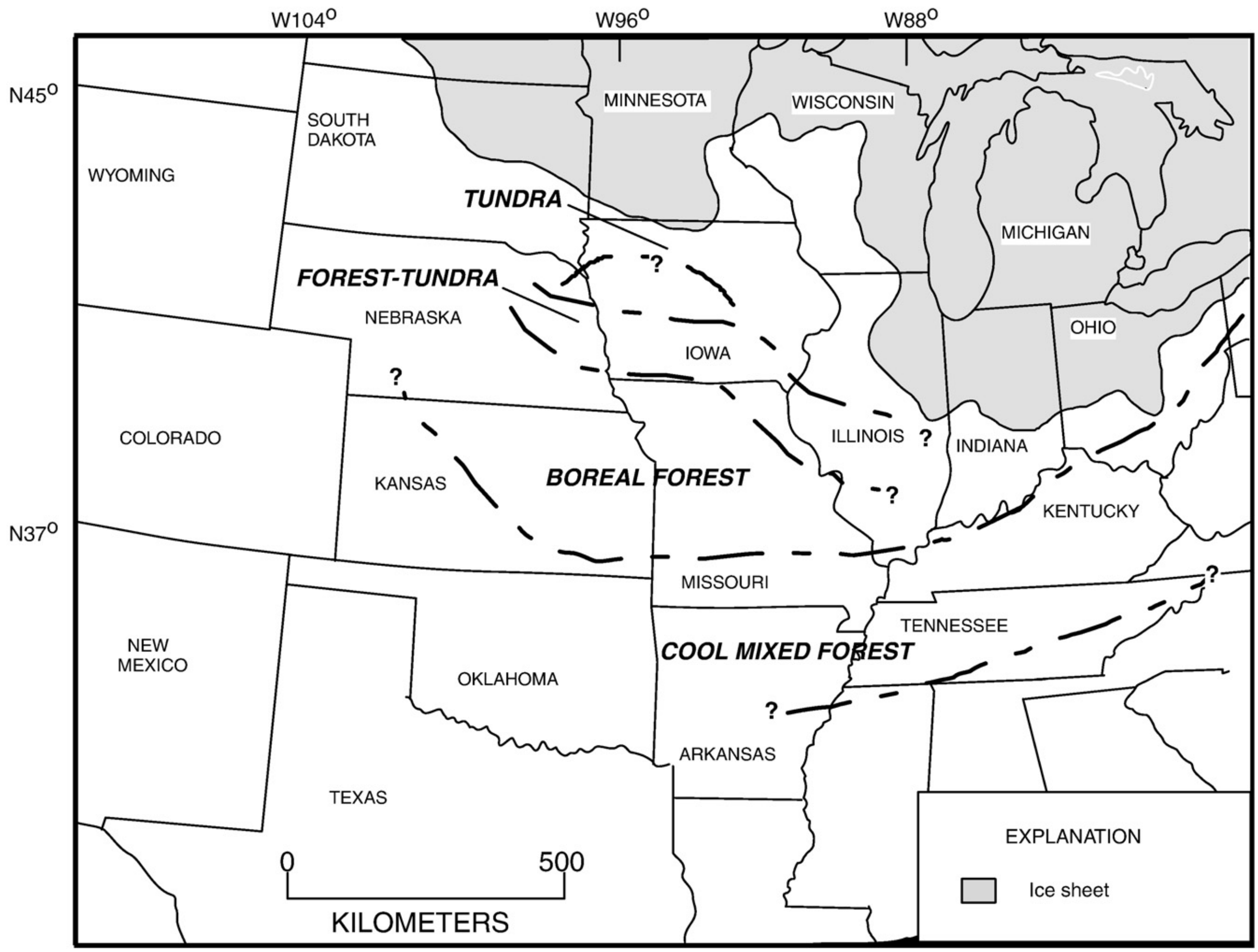

Fig. 2. Map showing the position of the Laurentide ice sheet and vegetation zones south of the ice sheet during the full-glacial period, approximately 25.1 ka to 19.6 ka (21,000 ^{14}C yr B.P.–16,500 ^{14}C yr B.P.). References for vegetation reconstruction are given in the text.

biotic gradients from the ice margin through the periglacial zone and southward into boreal and mixed deciduous-boreal forests during the colonization of the continent by Paleo-Indian people (Figs. 1 and 2). During the post-glacial period, the valleys carried water and sediment from a geologically, climatically, and biotically diverse region that extended from the eastern Rocky Mountains across the unglaciated Great Plains and the till plains of the Central Lowland. In this paper we discuss the UMV from Thebes Gap to Muscatine, Iowa, a part of the valley that includes the Missouri River drainage basin, but not the basin of the Ohio River (Fig. 1).

The Mississippi River underwent significant changes in channel morphology and fluvial depositional style during the last-glacial–interglacial cycle, including changes in channel pattern, the location of depocenters, and the lithology of sediment stored in the valley. We describe four episodes of stream response during the last-glacial–interglacial cycle that produced the alluvial architecture of the UMV; 1) last-glacial, 2) last-glacial/Holocene transition, 3) early and middle Holocene, and 4) late Holocene. The first period, for the most part, predates known human use of the basin, while the other three periods encompass human colonization of the valley and subsequent changes in human subsistence strategies and population density.

2. Extent and limitations of data

Geologic and paleoenvironmental data are not evenly distributed in space and time. Some data gaps are present because certain areas have not been thoroughly investigated, others exist because environments are not conducive to preservation of certain types of data, and many data gaps are products of erosion and other geologic processes that destroy or compromise archives of past environments. Many paleoenvironmental studies have documented last-glacial and Holocene environmental changes in the Upper Mississippi River basin. The majority are studies of pollen sequences from numerous lakes and peat deposits formed in areas glaciated during last-glacial advances of the Laurentide ice sheet (Wright, 1992; Bradbury and Dean, 1993; Webb et al., 1993). Much less is known about climatic shifts across the Great Plains and areas south of the last-glacial margin because of the limited number of pollen sites. Paleoenvironmental studies focusing on fluvial archives have significantly extended the available data in regions beyond the glacial margin (Baker et al., 1993, 1996, 1998, Denniston et al., 1999a,b; Baker, 2000, Baker et al., 2002). Full-glacial and late-glacial paleoenvironmental data are well represented along a zone approximately 200 km wide centered on the UMV. To the west, data on pre-Holocene paleoenvironments are very patchy. The distribution of vascular-plant macrofossil, bryophite, insect, and vertebrate records is similar to that of pollen spectra. Isotopic evidence from cave speleothems provides high-resolution records of last-glacial and Holocene climatic change at a few localities along the length of the UMV, but speleothem records are absent to the west where carbonate rocks are not present (Dorale et al., 1992, Denniston et al., 1999a,b). High-resolution isotopic and geochemical records of Holocene climatic change are also present in saline lakes of the northern Great Plains (Fritz et al., 1994; Laird et al., 1996, 1998).

The alluvial deposits of the basin have been well studied, with the exception of those in the Missouri River Valley and the northern Great

Plains. Some studies have focused on regional patterns of stream response and the relation to climatic change (Johnson and Martin, 1987; Knox, 1996, 1999), while others emphasize patterns of stream activity through drainage basins (Hajic, 1991; Bettis et al., 1992; Bettis and Hajic, 1995; Mandel, 1995; Bettis and Mandel, 2002). The spatial and temporal distribution of information about past stream response and paleoenvironments is sufficient to provide a first approximation of the effects of basin-wide paleoenvironmental change on the fluvial style of the Upper Mississippi River.

Archaeological and geoarchaeological investigations have produced a detailed outline of the culture history of the UMV, but a sketchy and uneven picture of prehistoric human adaptive strategies and settlement patterns in the valley landscape. Few studies have investigated deeply buried contexts, especially in floodplain settings where a high water table complicates the studies. Only a few parts of the valley have been tested sufficiently to allow for estimates of site density. Later in this paper we focus on one of those areas, the Lake Odessa Environmental Management Project.

3. Last-glacial environment and fluvial response

Southward expansion of the Laurentide ice sheet began to significantly affect water and sediment discharge to the UMV between 30 ka (25,000 ^{14}C yr B.P.) and 25.1 ka (21,000 ^{14}C yr B.P.). The ice sheet reached its maximum extent in the southern Great Lakes region about 25.1 ka (21,000 ^{14}C yr B.P.), but the maximum ice advance along the western margin of the ice sheet occurred later, ca. 20.1–16.3 ka (17,000–14,000 ^{14}C yr B.P.; Mickelson et al., 1983; Bettis et al., 1996; Michelson and Colgan, 2003). Pollen, plant macrofossil, and faunal studies indicate the presence of tundra conditions north of central Iowa and Illinois from about 25.1 ka (21,000 ^{14}C yr B.P.) until about 19.6 ka (16,500 ^{14}C yr B.P.; Fig. 2; Baker et al., 1986, 1989; Garry et al., 1990; Woodman et al., 1996; Schwert et al., 1997; Baker and Mason, 1999; Curry and Yansa, 2006). The presence of ice-wedge casts (Péwé, 1983; Johnson, 1990; Walters, 1994) and extensive frost-shattered colluvial and solifluction deposits (Bettis and Kemmis, 1992; Bettis, 1994; Mason and Knox, 1997) suggest the significant impact of full-glacial climates on upland and valley-margin landscapes beyond the glacial margin. Regional accumulation of Peoria Loess began on stable landsurfaces between 31.2 ka (26,000 ^{14}C yr B.P.) and 28.7 ka (24,000 ^{14}C yr B.P.) and continued until about 16.3 ka (14,000 ^{14}C yr B.P.; Bettis et al., 2003). Silts and fine sand deflated from the last-glacial Mississippi River braid plain and upland erosion surfaces accumulated as loess and associated aeolian sand on uplands and high terraces east and west of the valley.

The Mississippi River floodplain began to aggrade by 25.1 ka (21,000 ^{14}C yr B.P.) as massive amounts of sediment entered the valley via tributaries that drained the proto-Des Moines, Lake Michigan, and Lake Erie Lobes of the Laurentide ice sheet (Hajic, 1990a; Curry and Follmer, 1992; Hansel and Johnson, 1992; Michelson and Colgan, 2003). Tributaries draining the periglacial region south of the ice sheet and in the Missouri River basin to the west also delivered sediment to the Mississippi Valley during the full-glacial period. Alluvium dating to the full-glacial period in valleys that drained the periglacial region is lithologically and sedimentologically very much like the valley-train outwash in the Great Lakes region. These deposits consist of trough-crossbedded pebbly sand indicative of deposition in braided streams (Fig. 3). The braided channel pattern in valleys draining the tundra region was probably fostered by high sediment and water discharge events caused by rainfall on landscapes underlain by permafrost. Meteorological conditions analogous to those that occurred along the southern margin of the Laurentide ice sheet during the full glacial do not occur in modern tundra regions. The mid-latitude location of the Mississippi River Basin, and its proximity to the Gulf of Mexico moisture source, would have resulted in higher insolation and moister conditions than are typical of Arctic tundra regions today.

By about 25.1 ka (21,000^{14}C yr B.P.) meltwater from the western margin of the Laurentide ice sheet began entering the UMV via tributary valleys in Iowa and the Missouri River Valley to the west. As coarse-grained alluvium accumulated in the UMV and raised the base level, the lower reaches of tributary valleys aggraded with fine-grained alluvium transported from the basins, and with silts and clays back-flooded into the tributary mouths during Mississippi River floods (Flock, 1983; Hajic, 1991; Bettis et al., 1992;). The sediments in the lower reaches of tributaries preserve records of moderate Mississippi River floods during the period ~25.1 ka (21,000 ^{14}C yr B.P.) to 15.1 ka (13,000 ^{14}C yr B.P.) that range in size up to the modern 500-year flood on the Mississippi River (10,000–15,000 m^3 m^3 s^{-1}; Knox, 1999). Extensive aprons of colluvium, derived from frost-shattered Paleozoic rocks exposed along valley margins and from mass wasting of upland loess, accumulated along valley margins during this period and interfingered with valley alluvium (Bettis and Kemmis, 1992; Mason and Knox, 1997).

Large discharges with low sediment concentrations from glacial lakes along the ice margin in the Lake Michigan basin, such as the so-called Kankakee Torrent, spilled into the Illinois Valley headwaters and produced one or more flows in the Mississippi Valley that deposited clay beds 15 m above modern floodplain near the mouth of the Illinois River between 19.1 ka (16,000 ^{14}C yr B.P.) and 18.7 ka (15,500 ^{14}C yr B.P.; Hajic, 1991). This event also triggered incision of the full-glacial floodplain in the Mississippi Valley near the Illinois Valley and Missouri Valley junction, significantly altered the gradient of the Upper Mississippi River, and produced a measurable shift in the isotopic record in the Gulf of Mexico (Hajic and Johnson, 1989; Hajic, 1991; Kehew, 1993). Farther up the Mississippi Valley the full-glacial floodplain continued to aggrade until about 15.1 ka (13,000 ^{14}C yr B.P.). Shortly after 14.5 ka (12,500 ^{14}C yr B.P.) the Laurentide ice sheet began a general phase of northward retreat, and numerous large glacial lakes

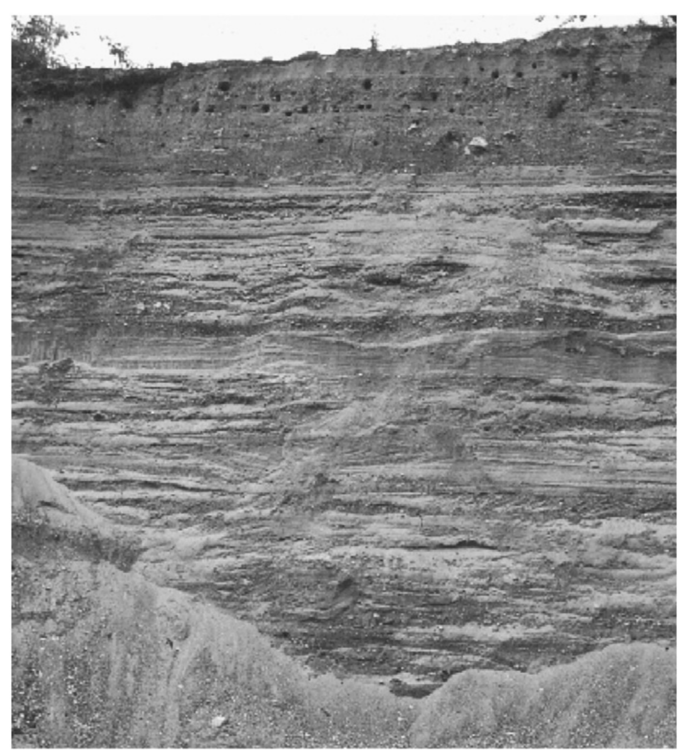

Fig. 3. Photograph of late-glacial trough-crossbedded pebbly sand deposits in the Turkey River Valley, an unglaciated tributary of the UMV in northeastern Iowa. Valleys draining the tundra and forest-tundra vegetation zones during the full-glacial period contained braided streams that deposited alluvium similar to valley-train alluvium deposited contemporaneously in the Mississippi River Valley. Exposure is 5.2 m high.

formed at the ice margin and behind moraines that marked former ice margins (Mickelson et al., 1983; Teller, 1987; 1990). Many of these discharged large amounts of water with low sediment concentration when the outlets were lowered by rapid downcutting (Clayton, 1983; Kehew and Lord, 1986, 1987; Clayton and Attig, 1989; Fisher and Lowell, 2006). Proglacial-lake drainage caused downcutting in the Upper Mississippi Valley and left the full-glacial floodplain as a terrace elevated above the late-glacial floodplain, such as the Savanna Terrace and its equivalent the Wood River Terrace in the American Bottoms near St. Louis, Missouri.

Several rapid aggradation episodes followed by downcutting and terrace formation occurred in the UMV during the late-glacial period. The valley continued to serve as a conduit for meltwater and sediment issuing from the Laurentide ice front, punctuated by episodic large discharges caused by glacial-lake drainage. Lake Agassiz was the largest of the proglacial lakes to affect the UMV during this period. The lake began forming about 13.6 ka (11,700 ^{14}C yr B.P.) and discharged into the UMV during the period 13.1 ka (11,300 ^{14}C yr B.P.) to about 12.7 ka (10,800 ^{14}C yr B.P.; Teller, 1987; Fisher, 1995, 2002). Lake Agassiz discharged an enormous volume of water into the UMV during this period, enough to produce measurable effects in the Gulf of Mexico (Kennett and Shackelton, 1975; Teller, 1990; Knox, 1996; Brown and Kennett, 1998; Aharon, 2006). Lake Agassiz flows sculpted a series of late-glacial terraces inset several meters below the Savanna Terrace along the extent of the UMV. This series of terraces is referred to collectively as the Kingston Terrace (Hajic, 1991). Colluvial slopes that formed during the full-glacial period were truncated by the downcutting events that formed the Kingston Terrace (Mason and Knox, 1997). The last late-glacial aggradation episode in the UMV occurred from 13.8 ka to 12.9 ka (12,000 to 11,000 ^{14}C yr B.P.), following an episode of erosive outburst floods, as meltwater from the Des Moines, Superior, Green Bay, and Lake Michigan lobes of the Laurentide ice sheet and, after 13.1 ka (11,300 ^{14}C yr B.P.), drainage from Lake Agassiz was discharged into the valley. This aggradation was ended by an entrenchment episode from 12.8 ka to 12.4 ka (10,900 to 10,500 ^{14}C yr B.P.) that formed the lowest level of the Kingston Terrace (=Bagley Terrace of Knox, 1996; Keach School Terrace in the Lower Illinois Valley) in the UMV and isolated the Pvl-2 (Morehouse and equivalent braid belts) surface in the Eastern Lowlands at the head of the Lower Mississippi Valley (Blum et al., 2000; Rittenauer et al., 2007). The sedimentology of pebbly sand-dominated deposits underlying the Kingston Terrace indicates sediments accumulating in braided streams, and braid patterns are preserved on the terrace surface in many areas (Fig. 4). The late-glacial valley gradient, represented by the Kingston and Savanna terrace surfaces, decreased during the late-glacial period. Dune fields formed on the larger Savanna Terrace remnants in the UMV during the period 16.3 ka to 12.9 ka (14,000 ^{14}C yr B.P. to 11,000 ^{14}C yr B.P.; Benn et al., 1988). The largest and most extensive dunes are located near the channel margin of the terrace, and suggest that the sandy sediments exposed along the terrace scarp were probably the primary sand source.

Paleoenvironmental reconstructions of the late-glacial period indicate a general warming trend that began shortly after 19.1 ka (16,000 ^{14}C yr B.P.) and continued through the period. Spruce-larch boreal forests that occupied the Upper Mississippi River basin during most of this period began a south to north shift to mixed conifer-hardwood forests by 12.9 ka (11,000 ^{14}C yr B.P.; Baker et al., 1992; Webb et al., 1993). Upland erosion surfaces and colluvial slopes stabilized around 13.8 ka (12,000 ^{14}C yr B.P.), probably in response to a combination of decreases in soil disturbance related to frost activity and the termination of regional loess deposition (Bettis and Kemmis, 1992; Mason and Knox, 1997). This significantly reduced sediment delivery to large and moderate-size valleys from adjacent uplands and slopes and was accompanied by the storage of fine-grained sediment in low-order valleys throughout the Upper Mississippi River basin (Bettis, 1990; Bettis et al., 1992; Bettis and Autin, 1997; Mandel and Bettis, 2001).

4. Late-glacial/Holocene transition

Under the influence of regional climate warming and drying, vegetation during the late-glacial/Holocene transition (ca. 12.9–10.8 ka; 11,000–9500 ^{14}C yr B.P.) changed from conifer-dominated forests to mixed conifer-hardwood forests to mesic deciduous oak (*Quercus*) forests by the end of the period (Baker et al., 1992, 2000). In the Central Plains prairie was established on well-drained uplands as early as 13.8 ka (12,000 ^{14}C yr B.P.), and in the eastern Plains as early as 11.5–12.4 ka (10,000–10,500 ^{14}C yr B.P.; Watts and Bright, 1968; Watts and Wright, 1966; Van Zant, 1979; Laird et al., 1996). The Upper Mississippi River underwent major changes in fluvial style during this period. By 12.9 ka (11,000 ^{14}C yr B.P.) all discharge from the Laurentide ice sheet passed through proglacial lakes before entering the UMV, trapping coarse fractions of the load in the proximal lake basins and damping out seasonal variations related to meltwater production in the UMV. This produced a shift from a late-glacial mode of sediment and water discharges forced by the response of the Laurentide ice sheet to an interglacial mode of regional meteorological control on water and sediment discharge. By 12.4 ka (10,500 ^{14}C yr B.P.) the

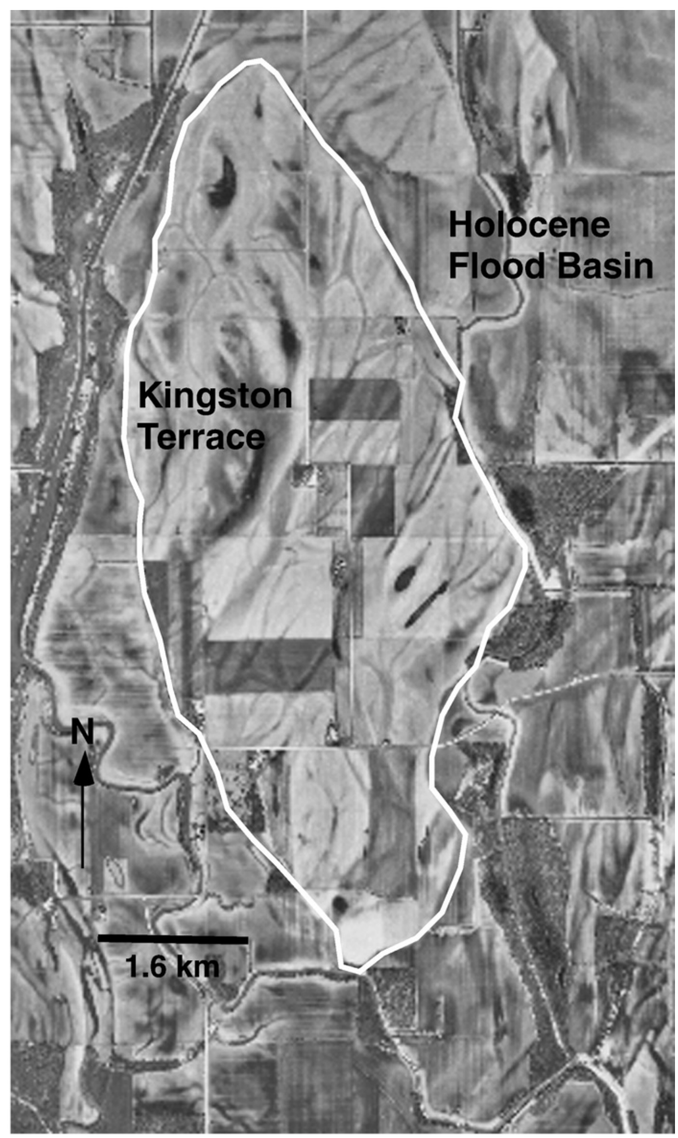

Fig. 4. Braid pattern evident on a late-glacial Kingston Terrace remnant surrounded by Holocene flood-basin sediments in the UMV near Kingston, Iowa. Portion of NAPP photo 2068-49.

channel pattern had changed from braided to island-braided and floodplain sedimentation shifted from coarse to fine-grain-dominated (Teller, 1990; Hajic, 1991; Bettis et al., 1992). Between 11.3 ka and 11.1 ka (9900 ^{14}C yr B.P. and 9700 ^{14}C yr B.P.) large floods produced by overflow of Glacial Lake Duluth (in the Lake Superior basin) passed down the Mississippi River Valley via the St. Croix Valley (Hudak and Hajic, 2002; Hajic and Hudak, 2005). These floods transported distinctive reddish brown clay that was deposited in quiet-water environments along the length of the UMV (Hajic, 1991; Bettis et al., 1992; Hajic et al., 2006).

5. Early and middle Holocene

Holocene climate and biotic patterns in the Upper Mississippi River basin reflect the interplay of three North American air masses (Bryson, 1966). Warm, dry Pacific air largely controls the extent of prairie, maritime tropical air from the Gulf of Mexico provides summer humidity and determines where deciduous forest is present, and continental Arctic air supports northern conifer-hardwood forests. A wide range of paleoenvironmental proxies from the northern (Boutton et al., 1998; Laird et al., 1998) and central (Grüger, 1973; Baker et al., 2000) Great Plains shows evidence of increasing aridity (Pacific air dominance) during the early and middle Holocene, with the driest interval occurring from 8.9 ka (8000 ^{14}C yr B.P.) to about 5.2 ka (4500 ^{14}C yr B.P.). This drying trend also occurs farther to the east in central Iowa and Minnesota where prairie replaced forest by about 8.9 ka (8000 ^{14}C yr B.P.) and lake level and speleothem records suggest maximum aridity from about 7.8 ka to 4.5 ka (7000 ^{14}C yr B.P. to 4000 ^{14}C yr B.P.; Wright et al., 1963; Watts and Winter, 1966; Van Zant, 1979; Baker et al., 1992; Dorale et al., 1992; Baker et al., 1996, 2001). The eastward extent of middle Holocene aridity, as marked by the prairie/forest border did not extend to the Mississippi River Valley, probably because maritime tropical air from the Gulf of Mexico blocked the eastward expanse of Pacific air into the region east of the Mississippi River Valley (Baker et al., 1992, 1996, 2002). Between 6.3 ka and 3.1 ka (5500 ^{14}C yr B.P. and 3000 ^{14}C yr B.P.) the blocking by maritime air relaxed, allowing dry Pacific air to extend eastward more frequently, and prairie extended east of the Mississippi Valley into Illinois.

Knox's (1999) reconstructions of Holocene floods in Mississippi River tributaries in southwestern Wisconsin and northwestern Illinois show that high-frequency bankfull floods and low-frequency overbank floods were responsive to Holocene climatic changes. Bankfull floods, during the period 10.2–7.4 ka (9000–6500 ^{14}C yr B.P.), were smaller than modern counterparts, and overbank floods were very rare. During that interval, persistence of northwesterly airflow shifted the storm tracks south of the upper part of the basin and reduced winter snowfall and summer rains (Knox, 1999). From 4.4 ka to 5.7 ka (6500 ^{14}C yr B.P. to 5000 ^{14}C yr B.P.) the magnitude of bankfull-stage floods increased dramatically, probably because of increased snowmelt runoff. This brief episode of larger than modern bankfull floods ended about 5.7 ka (5000 ^{14}C yr B.P.) and was followed by a period of smaller overbank and bankfull-stage floods that lasted until about 3.2 ka (3000 ^{14}C yr B.P.).

Knox's (1983) review of alluvial sequences from the North American mid-continent points to widespread fluvial discontinuities that occurred around 8.9 ka, 8.3 ka, 6.8 ka, and 5.2 ka (8000 ^{14}C yr B.P., 7500 ^{14}C yr B.P., 6000 ^{14}C yr B.P., and 4500 ^{14}C yr B.P.). He further suggests that these widespread erosional episodes are probably triggered by bioclimatic conditions that favor more frequent recurrences of moderate to large floods capable of destabilizing a channel system. In the prairies of the central and eastern Plains the early and middle Holocene was a period of net erosion and sediment movement from small valleys, sediment storage in large valleys, and episodic accumulation of alluvial fans along the margins of large and medium-size valleys (Artz, 1995; Mandel, 1995; Bettis, 1990; Mandel and Bettis, 2001; Bettis and Mandel, 2002; Bettis, 2003). In the savanna and deciduous forest of the mid-continent the pattern was similar, but smaller volumes of sediment were moved through the system because of less runoff and soil erosion under forest and savannah vegetation. The response of the Mississippi River to transport of sediment and water from upper elements of the drainage system during the early and middle Holocene is recorded in channel patterns and sediments stored on its floodplain and along the valley margins. Statigraphic studies along the valley extending from Muscatine, Iowa, to just above Thebes Gap, near the Ohio River junction provide a rather detailed picture of river response during the period. Between 12.4 ka and 7.8 ka (10,500 ^{14}C yr B.P. and 7000 ^{14}C yr B.P.) avulsions in wide valley reaches and channel migration in narrower valley segments formed a series of abandoned channel belts that records former channel positions and that demonstrates the persistence of an island-braided

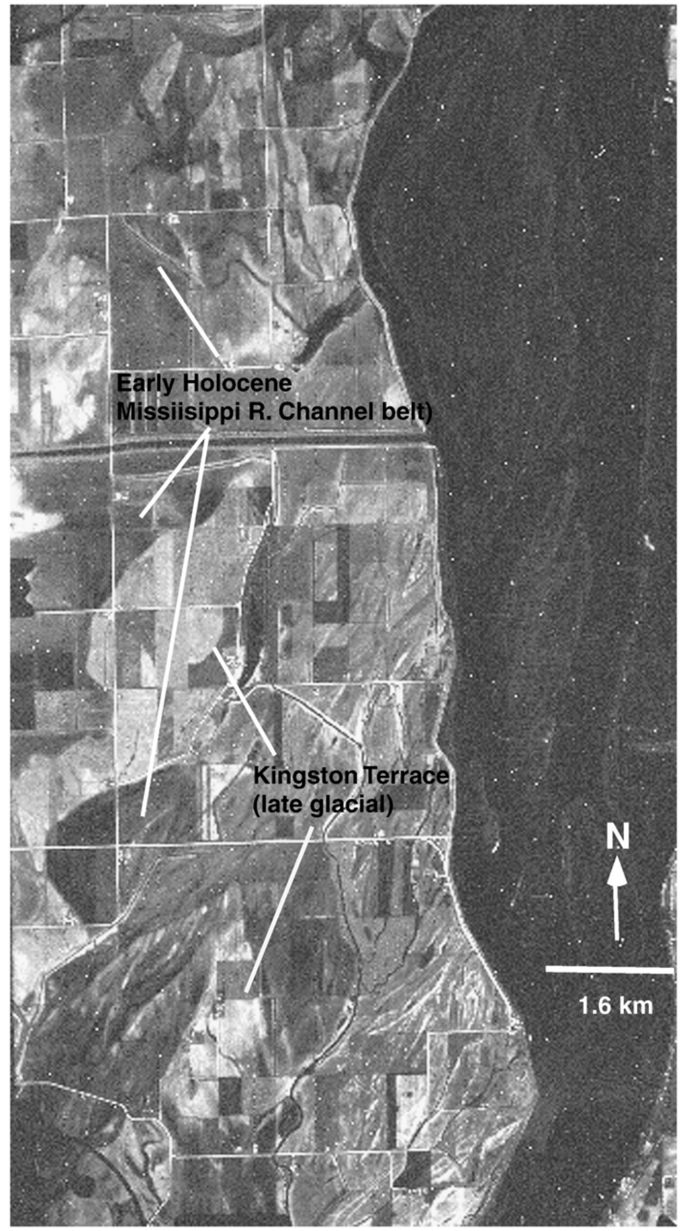

Fig. 5. Abandoned early Holocene Mississippi River island-braided channel belts surround a Kingston Terrace remnant near Oquawka, Illinois. Several avulsions in wide valley reaches during the early Holocene formed low-lying floodplain areas that evolved into flood basins during the middle and late Holocene. The dark area on the right side of the image is the Mississippi River floodplain inside of a human-constructed levee. Portion of air photo 419009HAP 83.

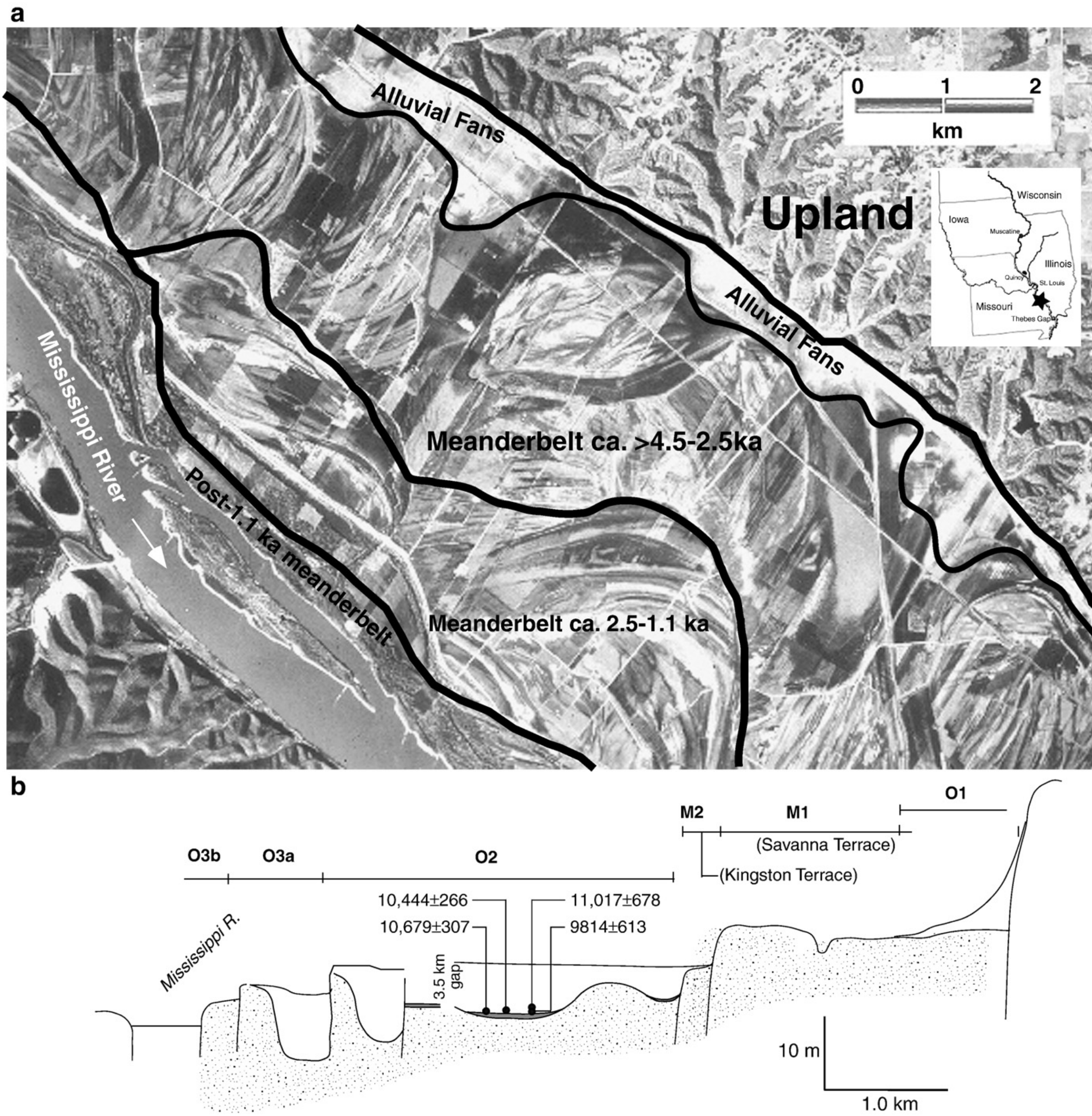

Fig. 6. Annotated air photo and schematic cross-section of the Mississippi River Valley downstream of the Missouri River Valley junction. a—Alluvial fans along the valley margin prograde a late-middle Holocene Mississippi River meander belt. During the late Holocene, the amplitude and wavelength of Mississippi River meanders decreased until sometime around 1 ka (1100 ^{14}C yr B.P.), when the channel pattern shifted to island-braided. These changes were controlled by suspended sediment load delivered by the Missouri River Valley. b—Schematic cross-section showing stratigraphic relationships among the Muscatine and Oquawka alloformations in the American Bottoms near St. Louis, Missouri. All dates are calendar ages derived from the calibration curve of Fairbanks et al., 2005. Solid gray indicates superior-source reddish brown clay deposits.

pattern along the upper valley through the period (Fig. 5). The channel position began to stabilize by about 7.8 ka (7000 ^{14}C yr B.P.) except at and just above large tributary valley junctions where sediment input, hydraulic damming, and channel movements by the tributaries fostered continued instability in channel position. Broad fluvial fans crossed by tributary streams formed in the Mississippi Valley at the junction of tributaries such as the Des Moines, Skunk, Iowa, and Missouri valleys. The island-braided channel pattern in the Mississippi persisted after 7.8 ka (7000 ^{14}C yr B.P.) in the valley above the Missouri River junction, but farther downstream the channel pattern shifted to meandering sometime prior to 5.7 ka (5000 ^{14}C yr B.P.; Smith and Smith, 1984; Bettis and Hajic, 1995). The shift to a meandering-channel pattern downstream from the Missouri River junction was probably a response to an increase in suspended load delivered by the Missouri River that resulted from transport of large volumes of fine-grained sediment out of Great Plains drainages.

Fine-grained alluvium accumulated on the Mississippi River floodplain during the early and middle Holocene. Overbank sedimentation was initially focused in abandoned late-glacial/Holocene transition channel areas, but with time avulsion and channel migration expanded the area susceptible to overbank flooding. After the Mississippi River channel position stabilized about 7.8 ka (7000 ^{14}C yr B.P.), a natural levee/crevasse splay complex began to form adjacent to the channel in the wide valley reach downstream of Muscatine, Iowa. Extensive backswamps with intermittent lakes came into existence, and the Sny anabranch system developed east of the Mississippi channel from Quincy to Mosier, Illinois (Van Nest, 1997).

Alluvial fans and colluvial slopes began to accumulate along the margins of the Mississippi and other large valleys about 9.5 ka (8500 ^{14}C yr B.P.; Leigh, 1992; Bettis and Hajic, 1995; Bettis and Mandel, 2002). These landforms were formed by several sediment–soil cycles that consisted of periods of sediment accumulation lasting on the order of centuries, followed by shorter periods of reduced sedimentation and pedogenesis (Hajic, 1990b). Colluvial and alluvial fan sedimentation occurred during periods of erosion and sediment transport from valley slopes and small tributary streams, while periods of pedogenesis on fans and colluvial slopes corresponded to relative slope and tributary basin stability. The soil–sediment cycles associated with the greatest rates of sedimentation, and by inference the greatest degree of slope instability (colluvial slopes) or movement of sediment from the tributary basin (alluvial fans), began about 9.5 ka and 7.4 ka (8500 ^{14}C yr B.P. and 6500 ^{14}C yr B.P.). Each sediment–soil cycle was initiated during a shift to relatively more arid conditions, with sedimentation continuing throughout the drier climatic regime (Hajic, 1990b). A shift to relatively wetter conditions in the latter part of each cycle reduced the rate of sedimentation and fostered soil development. Sediment–soil cycles were driven by interactions among climate-related changes in vegetation communities that produced changes in ground cover, and in the magnitude, frequency, and seasonal occurrence of precipitation events that altered the effectiveness of sheetwash and rainsplash erosion and controlled runoff (Knox, 1999). The first major fan-building episode records increases in the delivery of sediment from slopes along with transport of sediment out of small valleys. This was fostered by increases in the frequency and persistence of drought, accompanying decreases in vegetation cover, and increases in runoff. After about 5.7 ka (5000 ^{14}C yr B.P.), rates of sedimentation on colluvial slopes and alluvial fans slowed across the region, following a shift to more moist conditions and greater vegetation cover that reduced sediment yield from valley slopes and small valleys.

6. Late Holocene

After about 3.2 ka (3000 ^{14}C yr B.P.), Arctic air flow increased across the central part of the Mississippi River basin and forest expanded from valleys (Baker et al., 1992, 1996). The magnitudes of bankfull and overbank floods in southwestern Wisconsin and northwestern Illinois increased markedly in response to cooler temperatures and changes in the seasonality and magnitude of precipitation events (Knox, 1999, 2000). Tributary valleys throughout the Upper Mississippi River and Missouri River basins began to aggrade between about 4.5 ka and 3.2 ka (4000 ^{14}C yr B.P. and 3000 ^{14}C yr B.P.; Bettis and Hoyer, 1986; Bettis, 1990; Mandel, 1995; Baker et al., 1996). During this late Holocene period of aggradation, several region-wide entrenchment episodes produced alluvial discontinuities at about 1.9–1.7 ka (2000–1800 ^{14}C yr B.P.) and about 0.7 ka (800 ^{14}C yr B.P.; Mandel, 1992, 1995; Knox, 1996; Bettis and Mandel, 2002). Fan-head trenches developed, and most alluvial fans and colluvial slopes stabilized about 2.6 ka (2500 ^{14}C yr B.P.; Bettis and Hajic, 1995; Bettis, 2003). Tributary sediments that had accumulated in fan and colluvial slope depocenters along valley margins during the early and middle Holocene were transported farther into large valleys during the late Holocene, and accumulated in distal fan lobes and flood basins or entered main river channels via tributary channels that flowed across the floodplain. The large tributary fluvial fans that formed where major tributaries joined the UMV stabilized during the late Holocene as tributary rivers settled into more stable meander belts that crossed the fluvial fans.

Episodic aggradation on the Mississippi River floodplain continued during the late Holocene with valley-wide periods of slower sedimentation and soil formation at about 4.6–3.8 ka, 1.7–1.6 ka, and 0.8–0.7 ka (4100–3500 ^{14}C yr B.P., 1800–1700 ^{14}C yr B.P. and 900–800 ^{14}C yr B.P.). The resulting sequence of late Holocene buried soils, referred to as the Odessa Sequence, has been recorded beneath the Mississippi floodplain from southern Wisconsin to the Des Moines River junction in southern Iowa (Benn, 1996). Late Holocene floodplain aggradation overlapped the middle Holocene (post-7.8 ka; 7000^{14}C yr B.P.) floodplain landscape, suggesting that the late Holocene increases in flood magnitude, documented in tributaries by Knox (1999), probably also occurred on the Mississippi River. Three late Holocene paleochannel belts that are traceable from the Missouri River junction to the entrance of Thebes Gap record late Holocene metamorphosis of the Mississippi River below the Missouri River junction (Hajic, 1992). The oldest channel belt (active ca. >5.2–2.6 ka; >4500–2500 ^{14}C yr B.P.) is a meander belt characterized by relatively large-amplitude meanders, wide channels, high sinuosity, and abundant cutoff meanders, very similar to the previous late-middle Holocene meander belt (Fig. 6a). Substantial natural levees and overbank sediments are associated with this meander belt. The next younger channel belt, also a meander belt, is characterized by meander amplitude, channel width, and sinuosity smaller than the previous meander belt. Cutoff meanders are few. The smaller-scale meander belt was active between about 2.6 ka and 1 ka (2500 ^{14}C yr B.P. and 1100 ^{14}C yr B.P.). The youngest late Holocene (pre-modern) channel belt formed during a shift to an island-braided pattern that began about 1 ka (1100 ^{14}C yr B.P.) and persisted until major Historic channel modifications. The late Holocene decrease in meander amplitude and wavelength recorded in this part of the valley was probably a response to storage of sediment in low-order drainage elements of the Missouri River basin that translated into decreases in suspended sediment input from the Missouri River basin through the period.

7. Alluvial architecture and stratigraphic framework

Changes in sediment and water input into the Upper Mississippi River basin during the last-glacial–interglacial cycle have had significant impacts on fluvial style and alluvial architecture of this large river. The sediment and water discharge in the last-glacial Mississippi River was driven by the glacial meltwater system and proglacial lake activity in headwaters of the basin, as well as by local climatic and meterological conditions south of the ice margin. The glacial braided channel pattern of the Mississippi was a product of large inputs of sediment, including significant amounts of sand, and significant diurnal and seasonal discharge variations at the glacier front, combined with episodic pulses of sediment and water input from tributaries draining unglaciated or recently deglaciated portions of the basin. A decrease in the intensity and extent of permafrost and frost-affected soils in the basin during the late-glacial period reduced sediment delivery to the UMV from tributaries and intensified the influence of the glacier margin and proglacial lakes on the response of the Mississippi River. The alluvial architecture of the late-glacial UMV consists of wedges of poorly sorted colluvium along valley margins that change abruptly to trough-crossbedded pebbly sand along the valley axis. Colluvial deposits bury pre-last-glacial Mississippi River deposits along the valley margins, interfinger with Mississippi River deposits that accumulated between about 29 ka and 13.8 ka (24,000^{14}C yr B.P. and 12,000^{14}C yr B.P.), and are cut out by Mississippi River deposits younger than 13.8 ka (12,000^{14}C yr B.P.). Thick wedges of sandy and mixed sandy/fine-grained alluvium emanate from large tributary valleys into the Mississippi Valley and can have either interfingering or cutout relationships with main valley sediments.

Changes in channel pattern and alluvial architecture, conditioned by the response of proglacial and moraine-dammed lakes in the upper basin, transformed the UMV from about 12.9 ka to 10.8 ka (11,000 ^{14}C yr B.P. to 9500 ^{14}C yr B.P.). Sediment trapping in proglacial lakes and

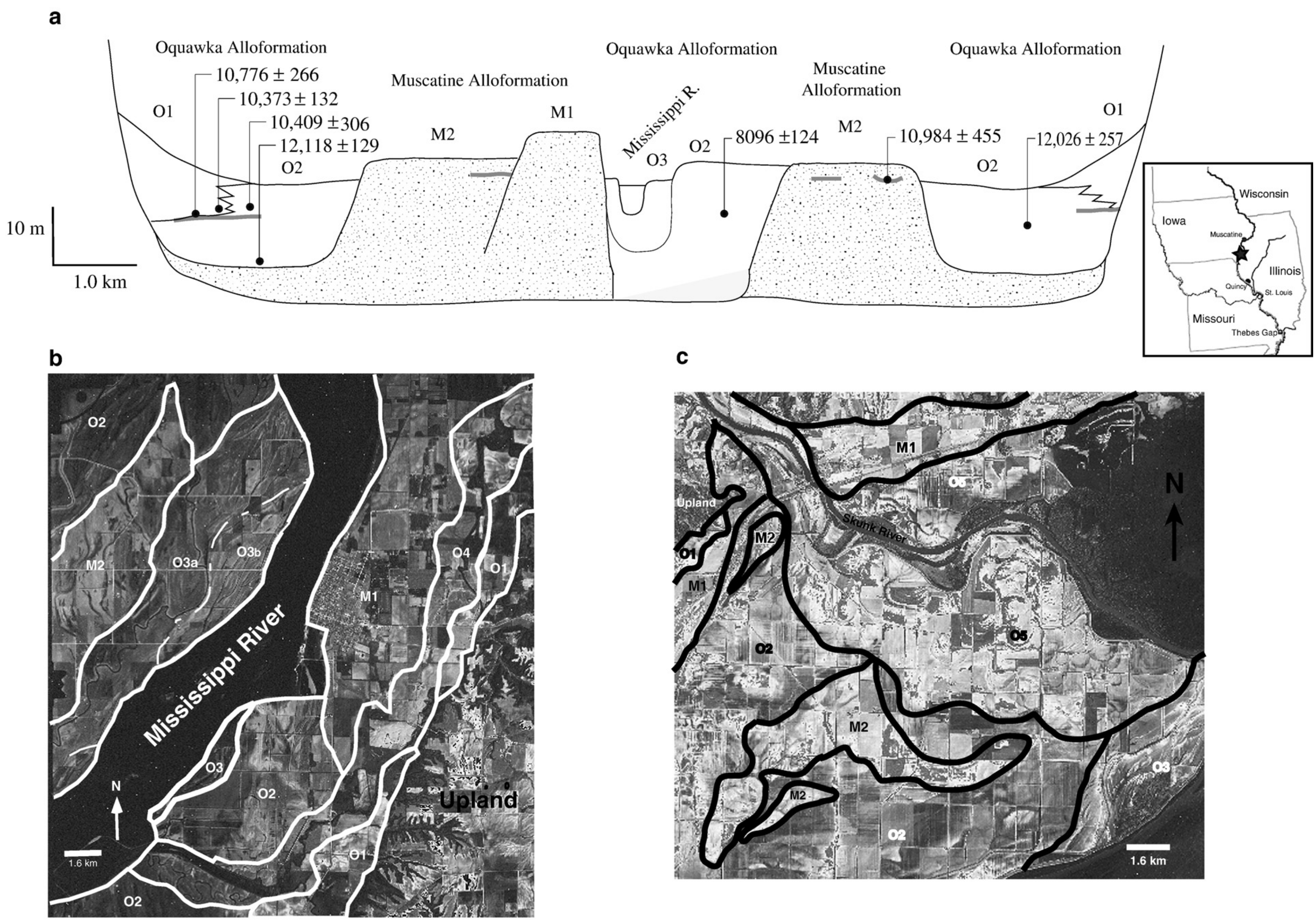

Fig. 7. Annotated photos and schematic valley cross-sections that illustrate relationships among allounits formed during the last-glacial–interglacial cycle in the UMV. a—Schematic cross-section showing stratigraphic relationships among the Muscatine and Oquawka alloformations in the Muscatine, Iowa/Illinois area of the UMV. All dates are calendar ages derived from the calibration curve of Fairbanks et al., 2005. Solid gray areas indicate Superior-source reddish brown clay deposits. b—Annotated air photo of the Oquawka, Illinois area showing surficial relationships among the Muscatine (M) and Oquawka (O) alloformations. c—Annotated air photo of the Skunk River junction with the Mississippi Valley in southeastern Iowa, that shows surficial relationships among the Muscatine (M) and Oquawka (O) alloformations.

episodic large discharge events produced by lake drainage fostered degradation and net sediment removal from the UMV above Thebes Gap. Significant reduction in sediment input combined with less diurnal and seasonal discharge variations caused an abrupt channel-pattern change from braided to island-braided along the length of the UMV. This upper-valley change coincides with the channel-pattern change from braided to meandering that occurred between 12.4 ka and 10.2 ka (10,500 ^{14}C yr B.P. and 9000 ^{14}C yr B.P.) at the head of the lower Mississippi River Valley below Thebes Gap (Blum et al., 2000). A shift to accumulation of fine-grained alluvium on the floodplain accompanied this channel-pattern change.

The Mississippi River above the Missouri River junction has had a relatively stable island-braided channel pattern since the mid-Holocene. The position of the channel belt in the valley changed abruptly by avulsion several times during the period before about 7.8 ka (7000 ^{14}C yr B.P.) but has been relatively stable since that time. Post-7.8 ka (7000 ^{14}C yr B.P.), the stability of the channel position has fostered the development of large laterally continuous natural levees, persistent back-swamp areas, and anabranch systems in the wide valley reaches downstream from Muscatine, Iowa. Holocene floodplain sedimentation has been dominated by deposition of fine-grained sediment, and the Holocene alluvial architecture of the valley consists of a thick package of channel sands overlain by several meters of fine-grained flood-basin sediments. A single large natural levee with crevasse splays interfingers with back-swamp sediments and caps the channel sands along the margin of the modern and late Holocene channel belt.

Below the Missouri River junction at St. Louis, Missouri, the Mississippi River underwent metamorphosis in response to climatically driven changes in suspended sediment load of the Missouri River. The early Holocene island-braided pattern of the Mississippi River changed to meandering during the middle Holocene and back to island-braided in the very late Holocene. Alluvial architecture of the Holocene fill in this part of the valley consists of valley-marginal and channel-ward sediment packages indicative of an island-braided river, like those present above the Missouri River junction, with a broad zone of channel and point-bar sands overlain by two to four meters of fine-grained overbank and flood-basin sediments and thick, fine-grained abandoned meander fills sandwiched between.

Alluvial fan and colluvial slope sediments, derived from small tributary basins and valley-wall slopes, accumulated along the margins of the UMV during the period from 9.5 ka (8500 ^{14}C yr B.P.) to about 2.6 ka (2500 ^{14}C yr B.P.). These deposits form wedges of fine-grained sediment up to 15 m thick that prograde older valley surfaces and interfinger with early and middle Holocene alluvial-valley fill.

Topographic relationships, crosscutting channel patterns on air photos, several cross-valley drilling transects, and radiocarbon ages provide a framework for the definition of main valley allostratigraphic units that encompass the last-glacial–interglacial cycle in the UMV from Muscatine, Iowa, to Thebes Gap (Figs. 6 and 7). The Muscatine Alloformation (composed of Henry Formation lithounit; Willman and Frye, 1970) encompasses sand-dominated late-glacial sediments in the Mississippi River Valley. Two allomembers are present in this Muscatine Alloformation. The Savanna Terrace (M1) is elevated above the Kingston and often has large to moderate-size dunes on its surface, with little or no preservation of a surficial braid pattern. Deposits underlying the Savanna Terrace (M1) are trough cross-bedded and planar-bedded sand and pebbly sand exceeding 15 m in thickness. The Kingston Terrace (M2) consists of streamlined sandy terrace remnants elevated a few meters above the Holocene floodplain in the Muscatine area, and eventually overlapped and buried by a thin veneer of Holocene sediment around and downstream of the Missouri River Valley junction (Fig. 6b). Deposits underlying the Kingston Terrace (M2) consist of trough cross-bedded and planar-bedded sand and pebbly sand that is usually less pebbly than deposits beneath the Savanna Terrace. M2 deposits are greater than 10 m thick. Silty, loamy,

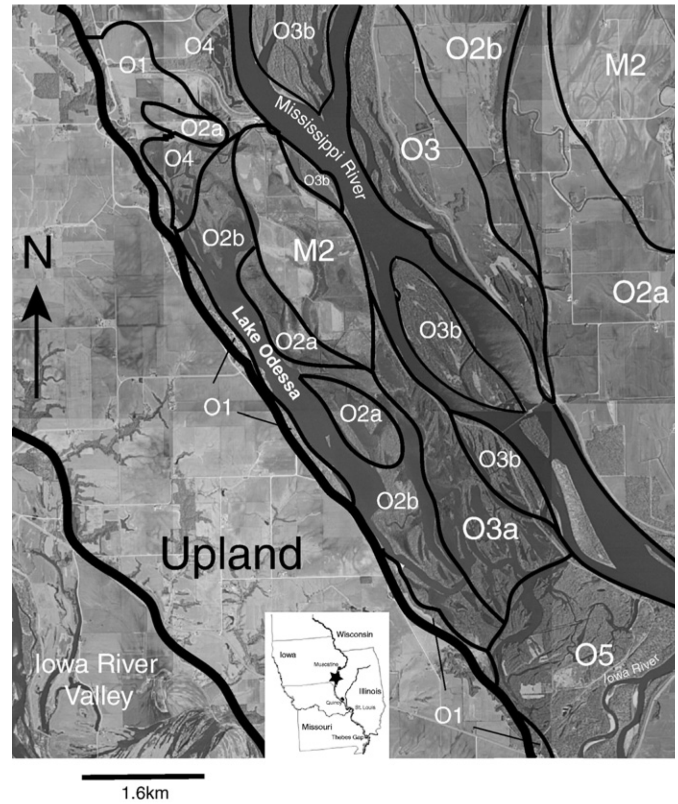

Fig. 8. Annotated photo of the Odessa (west of the Mississippi River) and Bay Bottom areas of the Mississippi River Valley south of Muscatine, Iowa that shows the distribution of members of the Muscatine (M) and Oquawka (O) alloformations. The Iowa River Valley enters the Mississippi Valley within the O5 allounit just off the lower right corner of the image. Calculations presented in Tables 1 and 2 do not include O3b allounits within the Mississippi channel area or allounits in the Bay Bottom east of the Mississippi River on this image.

and reddish brown silty clay deposits of Superior Basin-source are present in some small overflow channels on the terrace surface. Eolian dunes on the Kingston Terrace are not as large or as extensive in aerial coverage as those on the Savanna Terrace.

The Oquawka Alloformation encompasses Holocene deposits in the Mississippi Valley. This alloformation consists of sediments of the Deforest Formation (Bettis et al., 1992) and Cahokia Formation (Willman and Frye, 1970) lithounits. Several allounits are present in this alloformation (Figs. 6 and 7). Alluvial fan and colluvial slope deposits (O1) bury the Savanna Terrace (M1) and Kingston Terrace (M2) along the margins of the valley and interfinger with deposits of other Holocene allounits described below. Fans and colluvial slopes occur as a nearly continuous apron along the base of the valley wall, except where younger allounits have cut them out. Deposits comprising O1 are stratified silty, loamy, clayey, sandy, and pebbly sand alluvium derived from erosion in tributary valleys and from the valley wall. The deposits range in thickness from three to fifteen plus meters and contain several upward-fining sequences capped by buried paleosols.

O2 encompasses low-relief, slightly undulating, poorly drained, linear to broadly arcuate Holocene channel belts that mark the location of Mississippi paleochannel positions and associated islands during the early and Middle Holocene. Downstream of the Missouri Valley junction, O2 encompasses meander belt landforms and associated deposits of the meandering Mississippi River. O2 is inset into the Muscatine Alloformation and is channel-ward of and interfingers with O1 or is buried by it. On air photos O2 appears as dark channel areas 1–3 km wide with long, narrow, and broader streamlined bright areas marking swells (small levees) and paleo-

Table 1
Densities of prehistoric archeological sites in the Odessa area

Allounit[a]	Allounit area		No. of sites	ha/site	Hectares of sites	Site density	Survey coverage	
	ha	%					ha	%
M2	375.6	19.7	3	125	1.9	0.5%	39.0	10.4
O2a	203.0	10.7	6	34	5.3	2.6%	3.8	1.9
O2b	206.0	10.8	13	34	3.8	1.8%	4.4	2.2
O3a	198.4	10.4	6	33	0.5	0.3%	4.3	2.2
O3b	121.5	6.4	1	121	0.04	<.1%	2.1	1.7
O1	63.8	4.0	9	7	4.9	6.4%	4.4	5.8
O4	170.1	8.9	0	–	–	–	8.1	4.8
O5	552.8	29.0	14	39.5	1.4	0.3%	22.2	4.6
Totals	1903.5		45	42	17.9	0.9%	88.4	4.6

[a] M1 (with one site) not surveyed.

islands of the abandoned island-braided channel systems (Fig. 7b and c). Deposits comprising O2 consist of a variable thickness of loam, silty clay loam, and clay loam overbank alluvium grading downward to sandy loam, sand, and pebbly sand channel deposits. The fine-grained deposits range in thickness from about 1.5 m on swells to over 6 m in abandoned channel areas. Buried soils, formed during periods of low Mississippi River flood frequency, are common in this allounit. Near the Mississippi River channel O2 contains an extensive natural levee that consists of planar and trough cross-bedded loam, silty clay loam, sand, and pebbly sand. Coarse deposits are dominant in distributary (crevasse) channels, and the levee is sandier near the river. The levee buries middle Holocene and older soils in O2 and interfingers with O2 flood-basin sediments.

Slightly to moderately undulating, broadly arcuate areas of low relief with abundant sloughs and abandoned channels that mark the position of the Mississippi River channel and associated islands during the late Holocene are included in allounit O3 (Figs. 7 and 8). Below the Missouri River Valley junction, O3 encompasses meander belt landforms and associated deposits of the meandering Mississippi River (O3a) that change with time to landforms and sediment sequences similar to those associated with the island-braided Mississippi River above the Missouri River Valley junction (O3b; see Fig. 6). Point bars associated with O3a consist of low-relief, arcuate, moderately well-drained ridges and somewhat poorly drained swales. Associated paleochannels consist of cutoff meanders that mark paleochannel positions during the late-middle and early-late Holocene. Deposits in allounit O3 consist of a variable thickness of loam, silty clay loam, and clay loam alluvium that overlies sand and pebbly sand channel and sand-ridge deposits above the Missouri River Valley junction, and cross-bedded and planar-bedded channel and point-bar sands overlain by fine-grained overbank alluvium downstream of the junction. Deposits in allounit O3 accumulated between 5.2 ka (4500 ^{14}C yr B.P.) and the Historic Period.

Deposits associated with anabranch channel systems, included in allounit O4 (Fig. 7b), are evident as low-relief, undulating to slightly undulating, arcuate surfaces along small tributary and distributary stream channel belts that cross the Mississippi River floodplain. O4 consists of several discontinuous channel belts that contain a mosaic of criss-crossing channels and associated scroll bars, natural levees, and abandoned channels. This allounit cuts out O2 and is truncated by allounit O3. Deposits of O4 usually are cut into, but sometimes they interfinger with or are buried by alluvial fan and colluvial deposits of O1 and overlap adjacent portions of M2. O4 deposits consist of variable thicknesses of fine-grained alluvium overlying sandy and pebbly sand in channel deposits associated with the tributary and/or distributary streams. Deposits in this allounit span the Holocene, but complete Holocene records are not preserved in any one locality.

Allounit O5 contains deposits associated with fluvial fans built by major tributary rivers. These fans are slightly elevated above the Mississippi floodplain and are inset below the Muscatine Alloformation (Fig. 7c). This allounit interfingers with, buries, or truncates all other subunits of the Oquawka Alloformation, with the exception of O4. It contains abandoned channels, oxbow lakes, scroll-bar complexes, natural levees, crevasse splays, and flood basins associated with large tributary rivers. O5 deposits are quite variable. They usually consist of two to four meters of fine-grained alluvium grading downward to sand and pebbly sand. The fine-grained mantle is thinner or absent on natural levees, splays, and the ridges of recently abandoned scroll-bar complexes.

8. Archaeological contexts

The Lake Odessa Environmental Management Project (Odessa area), located about 24 kilometers south of Muscatine, Iowa, encompasses approximately 2755 ha of Mississippi Valley floodplain managed by the U.S. Fish and Wildlife Service and the Iowa Department of Natural Resources (Fig. 8). Extensive archaeological and geoarchaeological investigations were conducted in this area as a precursor to construction measures designed to mitigate the effects of environmental degradation (tree kills, bank erosion) that result from manipulation of water levels (Benn, 1996).

The Odessa area contains a mosaic of late-glacial and Holocene deposits, including the M2 member of the Muscatine Alloformation and all members of the Oquawka Alloformation (Fig. 8). Allounit mapping in the Odessa area is advanced beyond most other areas in the UMV because of extensive ground truth and radiocarbon dating. Sixty-four archaeological sites are recorded within three-dimensional landscape contexts. The coverage of intensive archeological survey for each allomember ranges from 1.7 to 10.4% of the unit (Table 1).

One obstacle to creating prehistoric site-density models in aggradational landscapes is estimating the size of archeological deposits. Because all prehistoric deposits behind a cutbank exposure are buried, actual site size can be estimated in area or volume dimensions only by employing shovel or auger probing. This method results in a *minimum* estimate for the size of buried sites. We employed this methodology to develop estimates of the horizontal dimensions of a sample of prehistoric archaeological sites in the Odessa area (Table 1).

Prehistoric sites and the numbers employed to calculate these densities are presented in Table 1. The significant aspect in these figures is that the allounits have markedly different site densities, and these variations do not correlate with the amount of survey coverage. However, the *type* of survey coverage does influence site density in some cases. The oldest allounit, M1, covers almost 20% of the Odessa area and has been subjected to the most survey (10.4%), but it has only a 0.5% site density. The margins of M2, where sites are likely to occur because they would overlook backwater lakes, are fallow fields where minimal pedestrian survey has been conducted and shovel-test survey methods are ineffective for detecting light lithic scatters. Thus, in Odessa the M2 site density of 0.5% probably is an underestimate, and 2 to 3% may be more realistic. Although the M1 allounit is not preserved in the Odessa area, other locations in this reach of the UMV suggest that site densities on M1 are probably similar to those on M2 (2 to 3%). Allounit O2a constitutes 10.7% of the Odessa area and has a very low survey coverage (1.9%), yet O2a yielded six sites for a density of 2.6%, second highest in the project area. Allounit O2b occupies 10.8% of the Odessa area and has an exceptionally large number of sites (13) for a small area of survey coverage (2.2%). These sites are difficult to detect because they are deeply buried, so the site-density calculation of 1.8% for O2b is unquestionably an underestimate. Sites associated with O2b tend to be relatively small because many are fitted to sandy ridges in the natural levee system. In contrast to the O2a and O2b allounits, O3a contains almost as much area (10.4%) and the same survey coverage (2.2%), yet this area produced half the number of sites (6) and a low site density of 0.3%. Sites associated with O3a tend to be small and buried by late prehistoric/historic age sediments, thus, the reasons for the low site density. Allounit O5 produced the same site density (0.3%) as the O3a from twice the area of survey coverage (4.6%). The O5 site density may be nearly correct because two of its sites represent large areas of "find spots" where extensive bank exposures occur and artifact densities are extremely low. The O4 allomember, which has been 4.8% surveyed, has yielded no archaeological sites in the Odessa area. Most of this area is poorly drained and difficult to survey because of extensive thick post-settlement deposits. We suggest that the O4 allounit in the Odessa area should not be used as a model for other anabranch systems in the valley such as the Sny south of Quincy, Illinois. The O1 allounit contains the highest site density (6.4%), and one of the smallest areas (4.0% of the bottomland). This density figure may be an underestimate, because many archaeological deposits associated with O1 are represented by "find spots" that add practically no acres to the total but probably represent buried sites.

We can reasonably compare the prehistoric-site densities from the Mississippi Valley with densities from the adjacent uplands because work in the Odessa area has accounted for sites in three-dimensional landform contexts. Also a number of recent large-scale highway surveys in the uplands of eastern Iowa have produced a substantial body of systematically surveyed landscapes. Upland archaeological surveys record a site density of 46 acres surveyed per site. The comparable figure for the Odessa area is 104 acres/site. The finding that upland sites are more than twice as common as prehistoric sites in a diverse riverine landscape of the Mississippi Valley is a surprising outcome that may contradict the perceptions of field archeologists. What could be the explanation(s) for this finding? First, assuming the total site-density figures are correct, the site density for *individual* upland-survey projects and each allounit in the Odessa area vary wildly. Site densities are related to specific geographic and geomorphic context in uplands and valleys, and local environmental parameters must be considered in weighing the significance of site-density figures. The second reason for high upland-site densities is archeological methodologies. Upland sites are found under optimal survey conditions, i.e. weathered, plowed surfaces with up to 100% visibility and few deeply buried sites. The chances of finding small ("flake") sites and delineating each component are much better in the uplands than in the forested floodplain, where almost everything must be uncovered by shoveling. Given that upland-site densities are higher because it is easier to locate sites, we should anticipate that present site-density calculations for the floodplain are too low.

9. Prehistoric human settlement patterns

The process of reconstructing prehistoric settlement patterns begins with tabulating archeological components and stratigraphic contexts (Table 2). Because we know very little about the composition and functions of most of the cultural components, except for some late prehistoric sites, this initial attempt to reconstruct settlement patterns on the valley floor is basically a geographic exercise.

No Paleo-Indian or Early Archaic components are officially recorded in the Odessa area. A small number of projectile points, diagnostic of the late Paleo-Indian and Early Archaic periods, occur on Muscatine Alloformation terrace margins across the river in the Bay bottomland of Illinois (Fig. 8). These sandy terraces are surrounded by Holocene backwater lakes, which likely attracted early foragers to fish, shellfish, turtles, waterfowl, and plants. At these same locations O2a sediments overlap M2 and may bury early lithic scatters. In the UMV between Guttenburg and St. Louis M1 accounts for only 2% of the valley floor, M2 for 10%, and O2a for 23% of the valley floor, leaving a total of only 34% of the landforms and sediments pre-dating 7.8 ka (7000 ^{14}C yr B.P.) remaining in the valley today. But because a large portion of these three earliest landscapes lie along the margins of the valley where they would have been readily available and attractive to human foragers, we offer an estimate that at least 60% of the Paleo-Indian and 40 to 50% of the Early Archaic archaeological deposits in the valley have been destroyed by post-7.8 ka (7000 ^{14}C yr B.P.) channel movement.

The first intensive occupation of the Mississippi River floodplain in the Odessa area occurred during the Middle Archaic period. A total of five habitation sites are recorded on the O1, O2a, and O2b allounits that extend as much as 2 km from the bluff base (Fig. 8). The most conspicuous artifact types belong to the Osceola manifestation, which is dated ca. 4.8 ka (4200 ^{14}C yr B.P.) around the transition to the Late Archaic period. The large Osceola sites consist of extensive middens of fire-cracked rocks and large roasting pits that mark long periods of intensive occupation. Earlier Middle Archaic sites also are represented by light to moderate lithic scatters on alluvial fans and sand ridges. These Middle Archaic sites contain projectile points for hunting larger game animals, grinding equipment to process plant foods like wild rice and chenopodium, and an array of wood-working tools. Such equipment seems well suited for fashioning fishing and digging tools during seasonal habitations on the shores of ponds and sloughs. Most of the Middle Archaic settlement system appears to lie within alluvial fans (O1) and in natural levees associated with O2b. About 45% of the Middle Holocene valley landscape between Guttenberg and St. Louis has been removed by movement of the Mississippi River after ca. 4.5 ka (4000 ^{14}C yr B.P.). In the Odessa area more than half of this landscape was situated in the middle of the valley (more than 2 km from the bluff) where human occupations of all periods have been far less intensive or common. We estimate that 10–20% of Middle Archaic sites have been destroyed by river meandering.

The Late Archaic period is represented either by isolated projectile point finds or by flakes from very deeply buried (+2 m) contexts in the O1, O2, and O3a allounits in the Odessa area. In other nearby parts of the Mississippi Valley, Late Archaic materials have been collected from the surface of the M1 and M2 allounits (Benn et al., 1988) and within alluvial fans (O1 allounit) (Bettis et al., 1992; Thompson, 2006). While this information is inadequate to reconstruct the settlement system, the sparseness of the Late Archaic record contrasts sharply with the preceding Osceola record, *which is buried in the same manner on the same landforms*. Sparse Late Archaic lithic scatters are mostly encountered in deeply buried alluvial contexts, especially in the O2b and O3a allounits as well as within the upper two meters of O1. Because the sedimentary context of late Archaic sites is similar to that of the preceding Middle Archaic period we suggest that Late Archaic archaeological deposits are relatively small and dispersed across most landforms in the floodplain—a change from the pattern of large, intensively occupied villages during the Middle Archaic period. Within the UMV less than 30% of the contemporary landforms have been removed by subsequent river movements, so a significant portion of the Late Archaic settlement pattern probably is intact.

Table 2
Archeological components and allounits in the Odessa area

	M2	O2a	O2b	O1	O3a	O5	O3b O4	Totals
Allounit area	19.7%	10.7%	10.8%	4.0%	10.4%	25.5%	18.8%	
Survey coverage	10.4%	1.9%	2.2%	5.8%	2.2%	4.6%	6.5%	
Site densities (area)	0.5%	2.6%	1.8%	6.4%	0.3%	0.3%	<.1%	
								% diagnostic
Cultural components:								
Early Archaic	–	1	–	–	–	–	–	1 (1.5%)
Middle Archaic	–	3	1	1	–	–	–	5 (7.5%)
Late Archaic	–	2	(1)	2	(1)	–	–	6 (9.1%)
Early Woodland	–	2	3	5	1	–	–	11 (16.7%)
Middle Woodland	–	–	2	5(1)	–	–	–	8 (12.1%)
Late Woodland	1	2(2)	5	7(2)	4	1(1)	–	25 (37.9%)
Oneota	–	–	6	–	2	2	–	10 (15.1%)
Unassigned prehistoric	2	3	3	6	1	3	1	19
Historic	2	1(1)	1	3	3	1	1	13

( ) component age inferred from allounit context (Archaic) or by the presence of diagnostic artifacts.

More than 90% of the post-2.6 ka (2500 ^{14}C yr B.P.) Mississippi floodplain in the Odessa area is intact. Archeological deposits dating to this period (Woodland) are abundant enough in the area to analyze settlement patterns for each of the Woodland periods (Table 2). The Early Woodland period is evidenced by eleven sites in the Odessa area with incised-over-cord-roughened Liverpool pottery, occasional sherds of Marion Thick pottery, and/or stemmed projectile points (Kramer, Dickson). Most of the Early Woodland period sites belong to the Liverpool variant of the Black Sand tradition (Munson, 1982). A majority of the Black Sand sites and all Marion components in the Odessa area occur close to the valley margin on O2b and O1 allounits. A few Black Sand components also are distributed along shorelines cut into O2a, O2b and O3a up to 1.6 km from the bluff base. All of these Early Woodland components are in buried A horizons beneath 60–200 cm of prehistoric sediment. Across the river in the Bay Bottom of Illinois some Black Sand components also occur on the sandy outwash terraces (M1 and M2) that overlook extensive wetlands (Benn et al., 1988). Liverpool people preferred a wide diversity of locations for their settlements, while Marion habitations appear to have a more limited distribution. Of potential importance is the observation that only three of eleven Black Sand components are mixed with Middle Woodland Havana materials, and Black Sand components are located closer to the center of the valley floor than any Havana components. This relationship supports the proposition that the Liverpool variant represented a separate population from the Havana variant (*sensu* Munson, 1982, 1986), even as the two peoples might have overlapped in time in the Upper Mississippi basin. Lacking substantial excavations of the buried floodplain sites in the Odessa area, we do not know what resources Early Woodland people were exploiting during what seasons of the year. Farther north around Prairie du Chien, Wisconsin, the Indian Isle phase and Prairie phase peoples (ca. 300 B.C.–A.D. 100) were pursuing a pattern of seasonal gathering of medium-sized mammals, fish, turtles, mussels, and probably plants from similar floodplain settings (Theler, 1987; Stoltman, 1990). On the alluvial fans (O1) that fringe the bottomlands north of Lake Odessa substantial Black Sand components may represent habitations more permanent than the seasonal floodplain sites in the Odessa area. For instance, at the McNeal Fan, about 9 km north of the Odessa area, excavations exposed large house floors associated with numerous pits and an accumulation of broken pottery vessels that we surmise indicate prolonged occupations (Thompson, 2006).

The distribution of Middle Woodland period sites of the Havana variant, and apparently the Weaver variant as well, is restricted to O2b and O1 allounits close to the bluffline in the Odessa area. Some of these sites were year-round habitations and some of the villages are associated with mounds. The concentration of Middle Woodland settlements close to the base of the bluff has long been a theme of analysts (Struever, 1964), although the bluff-base pattern is not strictly applicable in some parts of the Upper Mississippi Valley where mid-valley settlements and mounds exist. In the Odessa area the Middle Woodland settlements near the base of the bluffline are superimposed on the same landforms as many of the Early Woodland components; materials of both periods often are mixed in the same near-surface soil horizon. Havana components are much larger and more intensively occupied, however, than Early Woodland components. Our interpretation of this geographic/stratigraphic relationship is that the Havana life way developed out of a Liverpool base by consolidating the population into permanently occupied hamlets and villages at the foot of the bluff. These settlements are situated adjacent to large zones of backwater ponds and sloughs, the places Liverpool peoples had exploited for centuries. The Weaver people of the early Late Woodland period appear to have maintained the Havana occupation pattern for a century or more (Weitzel and Green, 1994; Benn and Green, 2000) before dissolving into the Late Woodland settlement pattern.

The post-Weaver horizon (ca. A.D. 500) of the Late Woodland period marked a decided change from the Middle Woodland settlement pattern. In the Odessa area Late Woodland sites are distributed on almost every allounit throughout the bottom—the largest number by far of any prehistoric period (Table 2). Many of these sites are very small, light scatters of artifacts, but a few have artifact densities as great as Middle Woodland villages that cover smaller areas. The prolific and diffuse nature of the Late Woodland habitation pattern is mirrored by the numerous low mound groups that dot the bluffline above the Odessa bottom (Benn et al., 1988: Fig. 8.3) and throughout other reaches of the UMV. Whether or not this settlement pattern resulted primarily from population increases and/or a fissioning of the Middle Woodland social organization is a matter of conjecture (e.g., Hall 1980; Kelly et al., 1984; Green, 1987:322), but no question exists that fissioning into family-sized bands took place at least seasonally.

During the Mississippian period, the Odessa area was occupied by peoples of the Oneota culture. Sherds of their shell-tempered pottery have been found along banks cut into the O2b, O3a, and O5 allounits (Table 2). Most of the sites are small, all of the sites are located in the southern half of the Odessa area, and the principal Oneota village in this area is the McKinney site (13LA1) on the blufftop at the southern end of the Odessa area. The small sites in the floodplain appear to have functioned as temporary stations for collecting seasonal resources. Perhaps summer gardens were located in the bottoms. A similar concentration of small Oneota sites occurs in the bottomlands north of the City of Burlington, Iowa (Benn et al., 1988), where another concentration of large Oneota villages occurs (Tiffany, 1982). This settlement pattern consists of an aggregation of large Oneota villages that may have been occupied consecutively and was surrounded by a diffuse array of tiny, probably seasonal, sites, a pattern reproduced in other parts of Iowa.

With reasonable site-density data from the UMV in hand, we can compare prehistoric components by cultural period in the valley with those in the adjacent uplands of eastern Iowa. Consider first the sample sizes that expose biases because of archeological techniques. Of the 333 upland sites 269 (81%) did not yield diagnostic materials. In the Odessa area, 33% (19/57) of the sites lack diagnostic materials, while in the entire valley between Muscatine and Burlington, Iowa (Pools 17–18) 44% (81/143) of the sites did not produce diagnostic materials. Thus, more bottomland sites yield diagnostic artifacts. Most diagnostic artifacts from the Mississippi River floodplain are pottery sherds that are either not present or not preserved in the plowed fields on upland sites.

Of the 64 pre-ceramic components in the upland, 6% are Paleo-Indian and 19% are Early Archaic. Comparable figures for Pools 17–18, including the Odessa area, are Paleo-Indian/Dalton 3.3% and Early Archaic 4.1%—all from surface contexts on the oldest allounits (Benn et al., 1988). In these numbers the notably high figure is the 19% for Early Archaic upland sites, which at first seems to indicate that relatively more occupations occurred in the uplands before ca. 8.9 ka (8000 ^{14}C yr B.P.), when forests still covered these landscapes. We caution that deeply buried Early Archaic sites, however, have not been systematically surveyed in the older Mississippi Valley allounits. The proportions of Middle Archaic period sites (including Osceola) are: 8% for the uplands, 7.7% for the Odessa area, and 7.0% for Pools 17–18. Compared to the Early Archaic site numbers, relatively fewer Middle Archaic occupations occurred in the uplands, but the first widespread use of the Mississippi floodplain, including Osceola villages, happened during this period. The Middle Archaic period also was the time when prairie and savannah spread across eastern Iowa into Illinois (Baker et al., 1992), perhaps encouraging hunters and gatherers to gravitate toward the forested river valleys. Late Archaic components are represented by 33% of the components in the uplands, 9.2% in the Odessa area, and 7.4% in Pools 17–18. Again, the uplands have a disproportionately high number of Late Archaic sites, yet the numbers of Late Archaic sites remained relatively constant in the Mississippi Valley. In this data we may be detecting an expansion of the range and diversity of the Late Archaic settlement pattern in the uplands in the same way it appears to have diversified in the Mississippi Valley.

In the ceramic culture periods, components of the Early Woodland period break down as: 9% in the uplands, 16.9% in the Odessa area, and 7.8% in Pools 17–18. The Odessa area percentage is higher than the Pools 17–18 percentage, reflecting recent efforts at deep testing in the bottomlands to discover buried Early Woodland components. We expect Early Woodland sites are well represented in the UMV floodplain as Munson's (1986) model predicted, but the 9% figure for the uplands is surprisingly high even though it is substantially less than the Late Archaic number. In other words, Early Woodland people did not completely ignore the uplands to pursue subsistence in the valleys. The upland Early Woodland sites are evidenced entirely by projectile point finds. Upriver, Stoltman (1990:244) reported a similar distribution pattern for Prairie phase sites, i.e., most of the seasonal occupations occurring in the floodplain, with three sites on the outwash terrace (M1-2) and two projectile point finds in the uplands. Back in Iowa, Middle Woodland components occur at the rates of 6% in the uplands, 12.3% in the Odessa area, and 13.1% in Pools 17–18. Whereas the high visibility of Middle Woodland villages makes them more conspicuous and, thus, well represented in the site records, the proportions of Middle Woodland components are lower than the numbers of the Early Woodland sites in the uplands and in the Odessa area. These patterns may reflect population consolidation resulting in fewer but larger permanent Middle Woodland villages within river valleys. Middle Woodland components are concentrated close to the bluffline and rarely turn up in buried contexts toward the middle of the valley floor.

The data for the Late Woodland period reveals a tremendous expansion of the settlement pattern, with 19% of the components in the uplands, 38.5% in the Odessa area, and 44.3% in Pools 17–18. These numbers are a manifestation of the hypothesized fissioning of the Late Woodland social organization (see Green, 1987), which seems to have impacted the uplands as well as all portions of the large river valleys. The Late Woodland diffusion into all habitats is characteristic of settlement patterns everywhere in Iowa (Benn and Green, 2000).

10. Discussion

The UMV has displayed two major fluvial styles during the last-glacial–interglacial cycle. The glacial river was braided, deposited only pebbly sand as bed load in the main valley, and resulted in valley aggradation. This style changed abruptly to an interglacial style characterized by an island-braided channel pattern, deposition of sand and pebbly sand bed load and fine-grained overbank sediment, and very minor valley aggradation. Valley degradation, terrace formation, and net movement of stored sediment out of the UMV occurred during the very late-glacial and during the glacial/interglacial transition, and were in large part caused by the drainage of glacial lakes. The floodplain gradient of the glacial river was greater than that of its interglacial counterpart and has resulted in progressive burial of last-glacial sediments beneath a Holocene veneer south of the Iowa/Missouri state boarder.

Aggradation and degradation in the upper valley produced allounits related to dated late-glacial braid belts studied by Rittenauer et al. (2007) at the head of the Lower Mississippi Valley (LMV). The M1 allounit accumulated between about 26 ka and 16 ka, roughly the same time period the Advance Splay (21–19 ka) and Sikeston and equivalent braid belts (19.7–17.8 ka) were forming in the LMV. The Kennett, Morehouse and Charleston braid belts in the LMV were active during the subsequent degradation episode(s) that formed the Savanna Terrace (M1) in the UMV. The Brownfield (14.1–13.4 ka) and Blodgett (13.6–13 ka) braid belts were active in the LMV while the M2 allounit was forming in the UMV. Drainage of Lake Agassiz between 13 and 12.7 ka resulted in degradation and formation of the Kingston Terrace (M2) in the UMV and the capture of the Mississippi River into Thebes Gap from the Commerce segment of the Morehouse braid belt at the head of the LMV.

The meltwater system of the Laurentide ice sheet exerted a powerful control on the glacial river, but frozen ground and active loess deposition also influenced the delivery of water and sediment to the valley during the glacial period. Events and processes that metamorphosed the river during the glacial/interglacial transition were controlled by the meltwater system as well as by endogenous processes that determined the mechanism and timing of glacial-lake drainages in the upper basin. As the direct influence of the Laurentide ice sheet and associated glacial lakes diminished during the glacial/interglacial transition, sedimentary processes in the UMV were increasingly dominated by water and sediment moved from tributary basins.

The interglacial fluvial style of the river reflects meteorological and bioclimatic control of water and sediment discharge to the UMV as conditioned by endogenous processes that influence sediment routing through the basin. After an early Holocene period of shifting channels and formation of extensive wetlands in abandoned channels, the river settled into a channel belt that it has occupied since about 7.8 ka. Sediment delivered from small tributary basins was stored in extensive alluvial fan and colluvial slope complexes along valley margins isolated from the active channel belt. As the channel belt position stabilized, natural levees formed along the channel belt margin and flood basins that held shallow, ephemeral lakes developed between the natural levee and the margins of the colluvial slopes. Holocene-scale variations in sediment discharge from the Missouri River Basin related to periods of drought and sediment routing through drainages on the Great Plains had profound influences on the fluvial style of the interglacial Mississippi River below the Missouri River junction.

Distinctive glacial and interglacial fluvial styles produced characteristic associations of sediments and landforms that can be mapped and documented in three dimensions. These sediments comprise two alloformations that are subdivided according to landscape patterns, bounding disconformities, and radiocarbon dates. The allounits provide a stratigraphic framework for examining the response of the Mississippi River on scales of 10^3 to 10^4 years as well as for evaluating the archaeological record of the valley and adjacent uplands.

The distribution of the allounits in the valley provides us with a powerful tool for evaluating how non-cultural processes have filtered the record of past human use of the valley. Because of fluvial erosion, the record of Paleo-Indian and Early Archaic people's activities in the valley will probably never be sufficient to interpret the details of their settlement and subsistence strategies in the UMV. The record from younger culture periods is much more extensive, but our present understanding of settlement and subsistence strategies is conditioned by the effectiveness of archaeological discovery techniques that have been employed in the valley. Pre-ceramic archaeological deposits may be deeply buried and difficult to discover in the Oquawka Alloformation. Archaeological deposits of the ceramic period can also be deeply buried, but many are in near-surface or surface contexts in older parts of the Oquawka Alloformation.

An understanding of the history of sedimentation in the valley is also critical for designing and executing cultural-resource assessments. The stratigraphic framework presented here provides a general tool for such assessments. Details of the sedimentation history within each allounit, such as depositional environments, aggradation, erosion, and pedogenesis, as well as variations down and across valleys also provide important insight into what discovery method(s) and sequence of investigations will provide the most accurate and effective assessment of an area. Over the past two decades much progress has been made toward assessing the archaeological record of the UMV through site-specific and valley-wide geoarchaeological investigations. At this point we have a stratigraphic and temporal framework for the deposits in the valley that is sufficient to allow archaeologists to design reasoned assessments of the cultural resources in the valley. Much more data are needed, however, before we are in a position to understand prehistoric settlement patterns and subsistence strategies in the valley.

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