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Predicting vertical accretion rates at an archaeological site on the Mississippi River floodplain: Effigy Mounds National Monument, Iowa

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Abstract

The Sny Magill Unit of Effigy Mounds National Monument, Iowa, contains the largest cluster of prehistoric effigy mounds on public land in North America. The mounds are situated atop a low terrace of the Upper Mississippi River, where they are slowly being buried by overbank deposition during floods. The terrace surface includes forest soils with argillic (Bt) or cambic (Bw) horizons developed in up to 1 m of loamy overbank deposits on top of Pleistocene sand and gravel. Radiocarbon evidence suggests that overbank deposits have accumulated since the end of the mound-building period (about 700 years BP), yielding a vertical accretion rate of about 0.6 mm yr^{-1}. On the basis of ^{137}Cs analysis, accretion rates over the past 40–50 years average 1.25–2.07 mm yr^{-1}, with some evidence for a decreasing rate since 1964. If these accretion rates are projected forward, several of the effigy mounds could be buried by flood deposits within 150–300 years. This ^{137}Cs-derived estimate agrees closely with an estimate of burial times based on flood frequency and observed flood deposit thickness during recent floods. However, the floodplain and backwater environments of the Upper Mississippi River are aggrading much more rapidly than the Sny Magill terrace surface, suggesting that burial of the entire terrace could occur within 80–400 years and the entire mound group could be buried within 150–850 years. The projected accretion rates and time to burial are subject to large uncertainties because of environmental change in the watershed, including recent trends toward increasing flood stages and decreasing suspended sediment loads.
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1. Introduction

Overbank deposition of suspended sediment during floods progressively raises the elevation of floodplain surfaces by vertical accretion. Where rivers are vertically incising into or laterally migrating across their floodplains, overbank sediment is typically eroded faster than it is deposited. In such cases, overbank deposits represent a small proportion of the alluvial valley fill. In aggrading rivers, or those where channel migration is minimal, overbank deposits persist and may comprise a large proportion of the valley fill (Leopold et al., 1964; Ritter et al., 1973; Kesel et al., 1974; Nanson and Hickin, 1986). Given widespread human occupation of floodplains and alteration of land cover in watersheds, it is not surprising that accelerated vertical accretion has become a problem in recent centuries. In some cases, overbank deposits have buried roads, bridges, small dams, buildings, valuable farmland, and other cultural features (Gilbert, 1917; Happ et al., 1940; Trimble, 1974; Trimble and Lund, 1982; Trimble, 1983; Knox, 1987; Barnhardt, 1988; Thoms and Walker, 1993; Phillips, 1997; Trimble, 1998).

Theoretical models of overbank deposition suggest that the accretion rate on a floodplain surface decreases over time as its elevation rises, the inundation period is reduced, and progressively larger floods are required to add more

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sediment to the surface (Wolman and Leopold, 1957; Moody and Troutman, 2000). Such models assume stable channel bed elevation and channel size, along with stationary flood frequency and suspended sediment regimes, conditions that are seldom met. In fact, prediction of vertical accretion rates is complicated by a host of geomorphic factors that influence inundation frequency, sediment availability, and local hydraulics. For instance, accretion rates are influenced by changes in surface roughness, development of natural levees, and sudden planform changes such as avulsions (Knight and Demetriou, 1983; Zwolinski, 1992). Even in a fairly stable floodplain environment, the flood frequency regime and sediment load of most rivers vary over time scales of decades to centuries in response to external controls such as climate change and anthropogenic impacts (Knox, 2000, 2001). More subtle changes to the sediment regime, including seasonal effects, hysteresis, and flood sequencing, have also been shown to complicate the stratigraphic record of flood events contained in floodplains (Gomez et al., 1995; Magilligan et al., 1998; Benedetti, 2003).

Field studies have successfully measured vertical accretion rates in many floodplain environments. Most of these studies have involved the use of historical markers such as buried soils, cultural features, radiocarbon, and radioisotopes. Difficulties arise in interpreting these measurements as a result of time averaging and incompleteness of the depositional record. In general, the longer the time period involved, the lower the measured accretion rate will be, as periods of non-deposition or erosion are folded into the measurements of sediment thickness over time (McShea and Raup, 1986; Gardner et al., 1987; Schumm, 1991). Thus, simple extrapolation from observations of individual flood deposits will typically overestimate the actual accretion rates over periods of decades or longer.

This paper presents a case study of recent vertical accretion on a fluvial terrace of the Upper Mississippi River (UMR), within the Sny Magill Unit of Effigy Mounds National Monument, Iowa. The primary objective of this study is to predict future vertical accretion rates to develop an estimate of how long it will take for a group of effigy mounds at the site to be buried by overbank deposition. Our approach is to measure recent accretion rates over several time intervals and to extrapolate forward with consideration of hydrologic and geomorphic factors that will influence future deposition rates at the site. Two independent methods are presented to estimate recent vertical accretion rates: one is based on ^{137}Cesium (^{137}Cs) analysis of sediment samples, the other is based on observed flood deposit thickness and magnitude–frequency analysis. This study highlights some of the difficulties in predicting future floodplain evolution given the uncertainties of environmental change.

2. The Upper Mississippi River

The post-glacial history of the UMR is one of catastrophic incision followed by slow aggradation. During the last glacial maximum, about 18,000 years BP, the river carried meltwater from a large area along the southern margin of the Laurentide ice sheet in central North America. At this time the valley was filled with coarse outwash deposits to the level of the Savanna Terrace, which is preserved at a height of 10–15 m above the active floodplain in tributary valleys (Flock, 1983; Bettis and Hallberg, 1985). Between roughly 14,000 and 9500 years BP, catastrophic outburst floods associated with the drainage of proglacial lakes scoured and entrenched into the outwash surface to an average depth of about 15–20 m below the modern floodplain of the UMR (Clayton, 1982; Knox, 1996). Scoured remnants of the outwash surface exist along the sides of the valley as terraces exhibiting braid-bar surface morphology. The post-glacial UMR, adjusted to modern hydroclimatic conditions, lacks the stream power to transport the sediment load supplied to it by the tributary rivers. Throughout the Holocene, the UMR has slowly aggraded its active floodplain within the trench created by the outburst floods.

Post-glacial aggradation rates for the Upper Mississippi River floodplain are constrained by stratigraphic evidence including radiocarbon dates, buried soils, and archeological sites (Table 1). Church (1985) cites a contact between sandy channel deposits and underlying gravel outwash at a depth of about 15 m, revealed in bore holes for a highway bridge across the floodplain at Prairie du Chien, Wisconsin. Based on this evidence, average aggradation rates since 9500 years BP average about 1–2 mm yr^{-1}. Holocene valley fills in this area include a thin veneer of silty overbank deposits overlying channel deposits of massive fine and medium sand across most of the valley. A period of relative floodplain stability prior to 2500 years BP is suggested by the presence of a prominent buried soil, dated by Knox (2000) at 2490 years BP, and elsewhere associated with archeological evidence from the late Woodland period. Human occupation of the Mississippi River floodplain during the late Woodland period appears to have been widespread, and includes the features of Effigy Mounds National Monument (Bennett, 1952; Dial, 1996). Radiocarbon ages associated with late Woodland archeological sites in Wisconsin and Iowa cluster around 2000–2500 years BP (Lass, 1978; Stoltman, 1979). Rates of aggradation for the mid- and late Holocene, based on these lines of evidence, average 1–2 mm yr^{-1}.

Historical floodplain accretion in the Upper Mississippi Valley has been measured with radiocarbon evidence,

Table 1
Selected Holocene vertical accretion rates for the Upper Mississippi River

Location	Mean rate	Years B.P.	Method	Source
UMR Pool 10	1.3 mm yr^{-1}	9000–0	Erosion surface	Church (1985)
UMR Pool 10	0.9 mm yr^{-1}	2360–0	Radiocarbon, archaeology	Knox (2000)
UMR Pool 10	1.2 mm yr^{-1}	4000–0	Radiocarbon	Knox and Daniels (2002)
UMR Pool 10	1.4 mm yr^{-1}	2500–0	Buried soils	Benedetti (2003)