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Late Quaternary chronostratigraphic framework of terraces and alluvium along the lower Ohio River, southwestern Indiana and western Kentucky, USA

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ABSTRACT

The lower Ohio River valley is a terraced fluvial landscape that has been profoundly influenced by Quaternary climate change and glaciation. A modern Quaternary chronostratigraphic framework was developed for the lower Ohio River valley using optically stimulated luminescence (OSL) dating and allostratigraphic mapping to gain insights into the nature of fluvial responses to glacial–interglacial/stadial–interstadial transitions and Holocene climate change. River deposits, T0 (youngest) to T7 (oldest), were mapped along a 75 km reach of the lower Ohio River and were dated using 46 OSL and 5 radiocarbon samples. The examination of cores combined with OSL and radiocarbon dating shows that fluvial sediments older than marine oxygen isotope stage (MIS) 2 are present only in the subsurface. Aggradation during MIS 6 (Illinoian glaciation) filled the valley to within ~7 m of the modern floodplain, and by ~114 ka (MIS 5e/Sangamon interglacial) the Ohio River had scoured the MIS 6 sediments to ~22 m below the modern floodplain surface. There were no fluvial sediments in the valley with ages between MIS 5e and the middle of MIS 3. The MIS 3 ages (~39 ka) and stratigraphic position of T5 deposits suggest the Ohio River aggraded 8–14 m during MIS 4 or MIS 3. Near the end of MIS 3, the Ohio River incised the mid Last Glacial (mid-Wisconsinan) deposits ~10 m and began aggrading again by ~30 ka. Aggradation continued into MIS 2, with maximum MIS 2 aggradation occurring before ~21 ka, which is coincident with the global Last Glacial Maximum (LGM). As the Ohio River adjusted to changing fluxes in sediment load and discharge following the LGM, it formed a sequence of fill-cut terraces in the MIS 2 outwash that get progressively younger with decreasing elevation, ranging in age from ~21 ka to ~13 ka. From ~14 ka to ~13 ka the Ohio River rapidly incised ~3 m to form a new terrace, and by ~12 ka at the onset of the Holocene, the Ohio River established a meandering channel pattern. The river formed a broad floodplain surface from ~12 ka to ~6 ka, and then incised ~1 m and formed a fill-cut terrace from ~6 ka to ~5 ka. After ~5 ka, likely in response to mid-Holocene drought in North America, the Ohio River incised ~5 m, and by ~4 ka the river began aggrading again. The Ohio River has aggraded ~4 m since aggradation began at ~4 ka. The chronostratigraphic framework and reconstructed history developed here suggest that the lower Ohio River is highly sensitive to glacial–interglacial transitions and abrupt Holocene climate change and responds rapidly to these allogenic forcings.

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1. Introduction and background

Rivers are dynamic systems that continuously adjust to their environmental conditions, making them very sensitive to variables such as crustal deformation, changes in base level, and sediment load and runoff volume changes caused by climate oscillations (e.g.

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Leopold et al., 1964; Schumm, 1977: Schumm et al., 1987; Bull, 1991; Maddy et al., 2000, 2001; Blum, 2007). Fluvial terraces and deposits, therefore, represent useful archives for the study of paleoenvironmental change and landscape development.

The landforms and sediments of major rivers that drain the midwestern United States provide an important record of Quaternary paleoenvironmental change and landscape development for the mid-continent. Yet there are few studies that use modern techniques, particularly numerical dating, to study these system. Of particular note, however, is the work of Rittenour et al. (2003, 2005, 2007) and Shen et al. (2012) on the lower Mississippi valley that presents detailed and robust chronologies for terrace formation based on optically stimulated luminescence (OSL) dating. These studies are shedding light on the timing and nature of environmental changes that influenced rivers in the central continental United States during the late Quaternary.

The Ohio River is the largest river in the eastern United States, traversing much of the glaciated northeast through the physiographic provinces of the Appalachian highlands of Pennsylvania, the glaciated Central Lowlands of Ohio, the Interior Low Plateaus of Kentucky and Indiana, and onto the Coastal Plain at its confluence with the Mississippi River (Fenneman, 1928, Fig. 1). During the Tertiary and early Pleistocene, the master drainage of the northeastern United States was the Teays–Mahomet River system; the headwaters of the Ohio River were in south-central Indiana and it was a relatively small 2nd or 3rd order tributary of the Cumberland River (Fowke, 1925; Wayne, 1952; Ray, 1974; Melhorn and Kempton, 1991). The repeated advance and retreat of Pleistocene ice sheets disrupted and reorganized the Teays–Mahomet system (Tight, 1903; Ver Steeg, 1946; Ray, 1974; Melhorn and Kempton, 1991), and by ~1.5 Ma the Teays drainage system was permanently captured by the Ohio River (Granger et al., 2001).

Diamict interpreted as MIS-6 (Illinoian) glacial drift is present within the upper Ohio River valley between Louisville, Kentucky, and Cincinnati, Ohio, and pre-Illinoian diamict is present on upland areas south of the river, indicating the upper reaches have been glaciated by multiple pre-Last Glacial (pre-Wisconsinan) ice sheets (see Ray, 1974 and references therein). The upper valley is a narrow and constricted bedrock valley where river terraces and alluvium are typically discontinuous and are either the remnants of glacial outwash or narrow bands of Holocene floodplain deposits (e.g. Swadley, 1969, 1976; Luft, 1971; Gibbons, 1972), though a few reaches of the constricted valley widen and contain more extensive alluvium (e.g. Crittenden and Hose, 1965; Kepferle, 1974). In contrast, where the lower Ohio River flows through the physiographic province of the Illinois Basin (from Tell City, Indiana to the Wabash–Ohio River confluence), the river meanders across a broad valley and has thick and continuous alluvial-fill successions with multiple river terrace levels (Ray, 1965; Moore et al., 2007, 2009). The lower Ohio River terraces and fluvial deposits provide useful geomorphic proxies that record late Quaternary hydrologic and paleoenvironmental change for the Midwest, which were greatly influenced by advance and retreat of the Laurentide ice sheet in the eastern United States. However, little modern research has been undertaken on the Quaternary fluvial record of the Ohio River. To help address this lack of knowledge, we describe the alluvium and terraces in the lower Ohio River valley and use OSL and radiocarbon dating to develop a chronology of deposition and incision for the past ~100 ka. We then compare the reconstructed fluvial responses of the lower Ohio River to that of the Mississippi River. The chronostratigraphic framework developed for the lower Ohio River will benefit future research investigating fluvial responses to Quaternary paleoenvironmental change in the American Midwest.

Owen (1859) undertook the first research on Quaternary sediments in the lower Ohio River valley, which included interpreting the loess deposits as water-lain in origin. This was followed much later by the work of Fuller and Ashley (1902) and Fuller and Clapp (1904), which resulted in two U.S. Geological Survey (USGS) folios for the region immediately northeast of the Ohio–Wabash River confluence. This work included the recognition of pre-Last Glacial (pre-Wisconsinan) glacial deposits and 1:125,000 scale surficial geologic mapping. Theis (1922) recognized multiple bedrock and alluvial terraces in Henderson County, Kentucky, and used gastropod assemblages to conclude that loess was an eolian deposit. Other research in the lower Ohio valley in the 1960s–70s included geologic mapping at a 7.5-min quadrangle scale by the USGS. However, this mapping was based on the early 20th century paradigm of four continental glaciations in North America (e.g. Walker, 1957; Ray, 1965, 1974) and the fluvial deposits were primarily mapped as a single undifferentiated unit (e.g. Johnson, 1972, 1973a, 1973b, 1974; Johnson and Norris, 1974).

Alexander and Prior (1971), Alexander and Nelson (1972), and Alexander (1974) used radiocarbon dating to study the timing of floodplain formation in southern Illinois, and determined there were three changes in vertical aggradation rates during the Holocene. Fraser (1986) drilled cores and concluded the mid-channel islands in the Ohio River were not depositional landforms of the modern flow regime but were relict braid bars that were obstructions to flow. Fraser and Fishbaugh (1986) drilled a core transect across part of the lower Ohio Valley and identified Holocene, Last Glacial (MIS 2), and pre-Last Glacial (pre-Wisconsinan) alluvium. Later, Eggert and Woodfield (1996) and Woodfield (1998) used auger cuttings, gamma logs, and several radiocarbon ages to propose that megafloods down the Wabash River were responsible for much of the tributary valley fill in the Little Pigeon basin in Vanderburgh County, Indiana. Most recently, the USGS (Moore et al., 2007, 2009) completed 1:24,000 and 1:50,000 scale surficial geologic maps, with supporting geochronology, for seven contiguous quadrangles that include parts of Vanderburgh and Warrick Counties in Indiana, and Henderson County, Kentucky.

There has been no critical evaluation of the high-level terraces on the Ohio River. High-energy fluvial environments like the braided late Pleistocene Ohio River often lack sufficient organic material for reliable radiocarbon dating. Dateable carbon (wood and charcoal) is commonly destroyed in these high-energy settings, and where carbon is preserved it is virtually impossible to tell if it was reworked from older deposits. Therefore, multiple samples from the same deposit are required to establish a reliable age for any particular unit, which is difficult given the scarcity of organic material and the associated expense of the dating. Fluvial sediments such as those present in the Ohio River, however, were transported far from glacial source areas and had ample exposure to sunlight, making them well suited for OSL dating (Duller, 1996; Stokes, 1999; Wallinga, 2002; Rittenour et al., 2003; Wintle, 2008).

2. Study area

The study area encompasses a ~75 km reach of the lower Ohio River valley along the border of southwestern Indiana and western Kentucky, immediately upstream of the confluence of the Ohio and Wabash Rivers (Fig. 1). This reach of the valley lies within the southern half of the Illinois Basin (or Eastern Interior Basin of Fenneman, 1928) and is bounded to the south by the Rough Creek graben, a Precambrian aulacogen which is the eastern extension of the New Madrid rift complex (Johnson and Schwalb, 2010), and to the west by the Wabash Valley seismic zone (Nuttli, 1979; Obermeier et al., 1991). The Green River is the only major