Fluvial evolution of the lower Mississippi River valley during the last 100 k.y. glacial cycle: Response to glaciation and sea-level change

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ABSTRACT

The lower Mississippi valley contains multiple large braid belts for which age control has been limited. Application of the optically stimulated luminescence technique has produced a new chronology of lower Mississippi valley channel-belt formation and insight into the valley's evolution during the last glacial cycle. Fluvial deposits range from last interglacial meander belts (85 ± 7 to 83 ± 7 ka) to multiple braid belts (64 ± 5 to 11 ± 1 ka) and record large-amplitude responses of the Mississippi River to glacially induced changes in discharge and sediment supply during the last glacial cycle. Slackwater deposits in buried tributary valleys from the middle Mississippi valley and northern lower Mississippi valley suggest that the river was flowing at a position 8–21 m below the present flood plain during the last interglacial, then rapidly aggraded and switched to a braided regime to form the highest and oldest braid belt by 64 ± 5 to 50 ± 4 ka, coincident with initial glaciation of the upper drainage basin. The Mississippi River remained braided until final meltwater withdrawal from its headwaters in the earliest Holocene. Braid-belt formation and incision was controlled by fluctuations in meltwater and sediment discharge, while glacio-eustatic sea level controlled the elevation to which the river was graded, causing late glacial braid belts to dip below the Holocene flood plain in the southern lower Mississippi valley. Moreover, avulsions in the middle Mississippi valley and northern lower Mississippi valley during the last glaciation have pinned the river over regions of shallow bedrock, preventing the modern river from incising to its last interglacial profile. The new chronology and longitudinal profiles presented here provide insight into the response of this continental-scale river system to climatic (glacial) and base-level forcing during the last 100 k.y. glacial cycle.

Keywords: Mississippi River, lower Mississippi valley, braid belt, longitudinal profile, fluvial evolution, meltwater discharge, sea-level change.

INTRODUCTION

The Mississippi River receives discharge from the Missouri and Ohio Rivers and drains North America between the Appalachian and Rocky Mountains (Fig. 1). Fluvial dynamics of the Mississippi River are influenced by sediment-load contributions and the hydrologic regime of the midcontinent. During glacial periods, fluvial dynamics were also influenced by variations in sediment and meltwater discharge from the

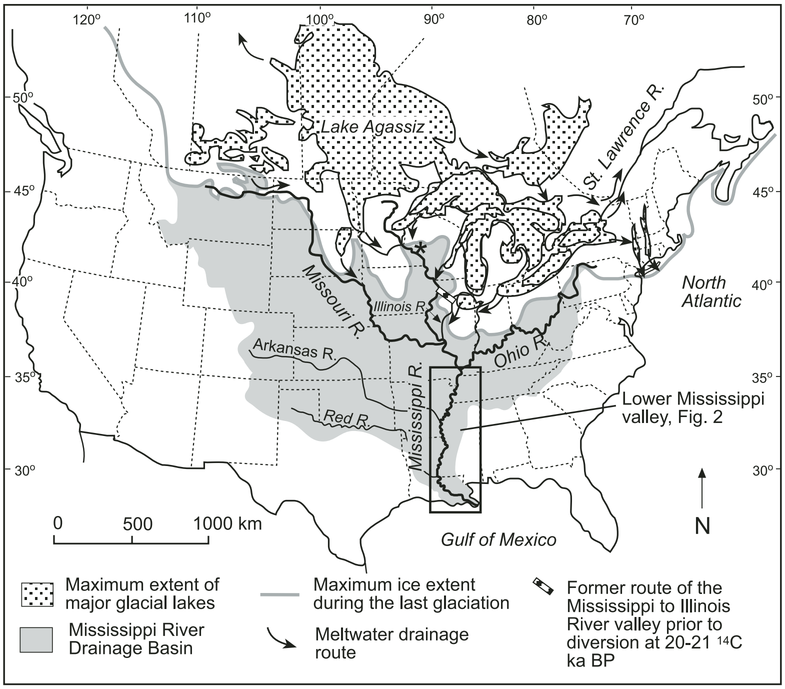

Figure 1. The Mississippi River and its drainage basin. Also shown are the Last Glacial Maximum extent of the Laurentide ice sheet and the maximum extent of glacial lakes and major drainage routes (arrows). Asterisk indicates the starting point of the longitudinal profiles in Figure 10.

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Laurentide ice sheet (Teller, 1987, 1990a, 1990b; Licciardi et al., 1999) and base-level changes from glacio-eustatic sea-level fluctuations (i.e., Shackleton, 1987; Chappell et al., 1996). Study of the sedimentary and geomorphic record within the Mississippi valley provides information on the response of this continental-scale river to these external forcings.

Pleistocene fluvial deposits are only preserved in isolated locations along the narrow, bedrock-confined upper and middle Mississippi valley, or are buried by younger Holocene sediments in this largely aggradational environment. In contrast, extensive braided channel belts fill the broad, nearly 1000-km-long lower Mississippi valley. These braid belts have been the focus of several generations of researchers who have produced different channel-belt chronologies and interpretations of the importance of eustatic sea level versus glacial meltwater discharge (see Fisk, 1944; Saucier, 1994a, 1994b; Blum et al., 2000). These studies have been based on relative-age relationships with only a limited number of radiocarbon ages. In order to obtain age control for lower Mississippi valley fluvial deposits, the optically stimulated luminescence (OSL) dating method, which provides an age estimate of the time since sediment was last exposed to sunlight, was applied to the channel-belt sediments. The application of OSL dating to lower Mississippi valley fluvial deposits has produced the first ages for many of the channel belts. The methods used to produce this OSL chronology and the channel-belt ages were presented in Rittenour et al. (2003, 2005).

Here we present a revised model of lower Mississippi valley fluvial evolution during the last glacial cycle. The timing and character of lower Mississippi valley channel-belt formation, fluvial dynamics, and longitudinal profiles of the river are reconstructed for key time slices during the past 100 k.y. We also discuss the importance of river-channel avulsions on the longitudinal profile of the Mississippi River with respect to fluvial evolution during the last glacial cycle. The concluding discussion concentrates on the effect of upstream glacial and downstream sea-level influences on lower Mississippi valley fluvial evolution.

GEOGRAPHY OF THE RESEARCH AREA

South of Cape Girardeau, Missouri, the Mississippi River emerges from its bedrock-confined upper and middle valley into its broad lower alluvial valley (Fig. 2). This change in river-valley geomorphology is due to the transition from Paleozoic bedrock uplands into the more easily eroded Tertiary and younger sediments of the Mississippi Embayment.

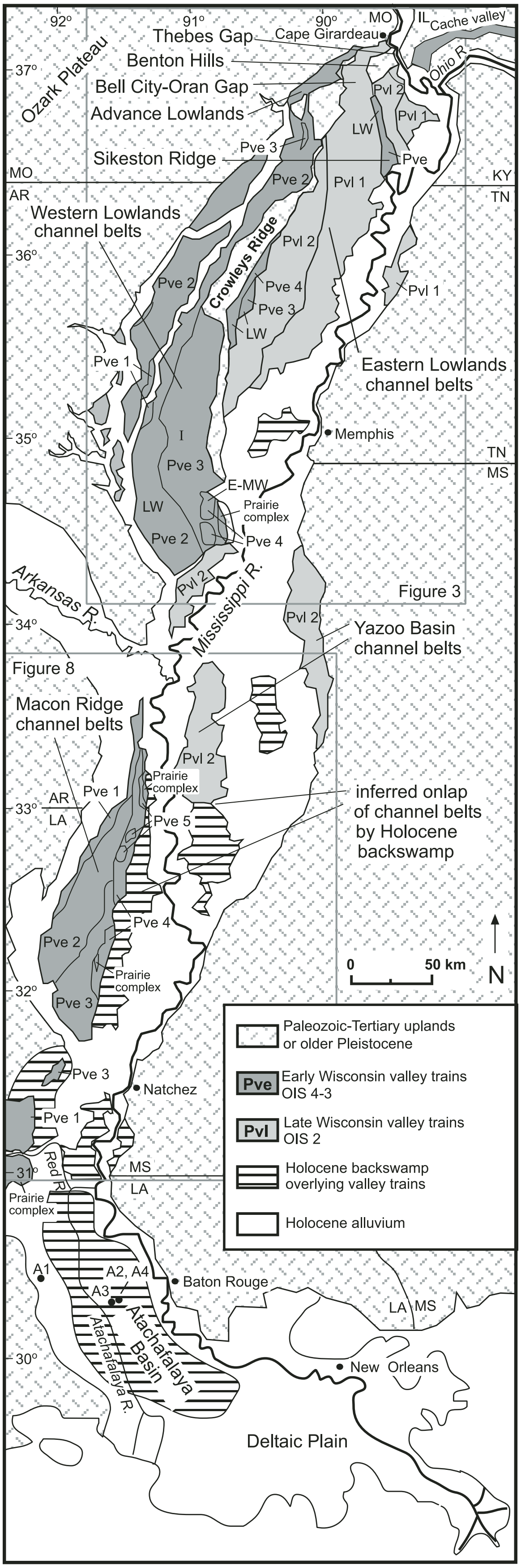

Figure 2. Generalized map of the lower Mississippi valley indicating key features discussed in text (modified from Saucier, 1994a). Map unit ages proposed by Saucier (1994a) are indicated by shades of gray and Pve and Pvl labels; proposed revisions of Saucier's map units by Blum et al. (2000) in the Eastern Lowlands and southern Western Lowlands are indicated by LW (late Wisconsin, oxygen isotope stage [OIS] 2), E-MW (early to middle Wisconsin, OIS 4-3) and I (Illinoian, OIS 6). Locations of radiocarbon age sites A1–A4 from Table DR1 (available as Data Repository item 2007132 at http://www.geosociety.org/pubs/ft2007.htm or by request to editing@geosociety.org.), and the locations of Figures 3 and 8 are also indicated.

The Mississippi River has entered the lower Mississippi valley through three channel paths: (1) the Advance Lowlands, an opening cut between the Ozark escarpment and the northern end of Crowleys Ridge, (2) the Bell City–Oran Gap, a 15-km-wide break between the northern end of Crowleys Ridge and the Benton Hills, and (3) Thebes Gap, the narrow (1.5 km wide) bedrock gorge currently occupied by the Mississippi River (Figs. 2 and 3). The Ohio River has two entry points into the lower Mississippi valley: its current river valley, and the Cache valley, an abandoned course ~20 km north of the modern Ohio valley (Figs. 2 and 3).

Braid belts in the lower Mississippi valley can be separated into four physiographically distinct channel courses (Fig. 2). In the northern lower Mississippi valley, the Western and Eastern Lowlands are separated by Crowleys Ridge, a linear remnant of early Quaternary Upland Complex gravels overlying Tertiary and older formations (Autin, 1996). In the southern lower Mississippi valley, the Macon Ridge braid belts are located west of the modern Mississippi River and are higher in elevation than the Yazoo Basin braid belts to the east (Fig. 2). Braid belts are exposed at the surface in the northern lower Mississippi valley and dip below the modern Mississippi flood plain and become buried by backswamp mud to the south (Fig. 2). South of the Mississippi-Louisiana state line, all braid belts have either been removed by erosion or are buried below the modern flood plain and dip to increasing depths seaward.

PREVIOUS RESEARCH

The pioneering work of Fisk (1944) developed the first model of lower Mississippi valley evolution and emphasized the role of glacio-eustatic sea-level change. In this model, the entire lower Mississippi valley was incised during the last-glacial eustatic lowstand, with the formation of braid belts during early to middle Holocene sea-level rise, and the transition to a meandering regime during the late Holocene highstand. This model had a large influence on the fields of fluvial geomorphology and sequence stratigraphy, and persists in the literature today in descriptions of alluvial-river response to sea-level change, although many aspects of this model have been shown to be incorrect (i.e., Saucier, 1994a, 1994b; Blum et al., 2000).

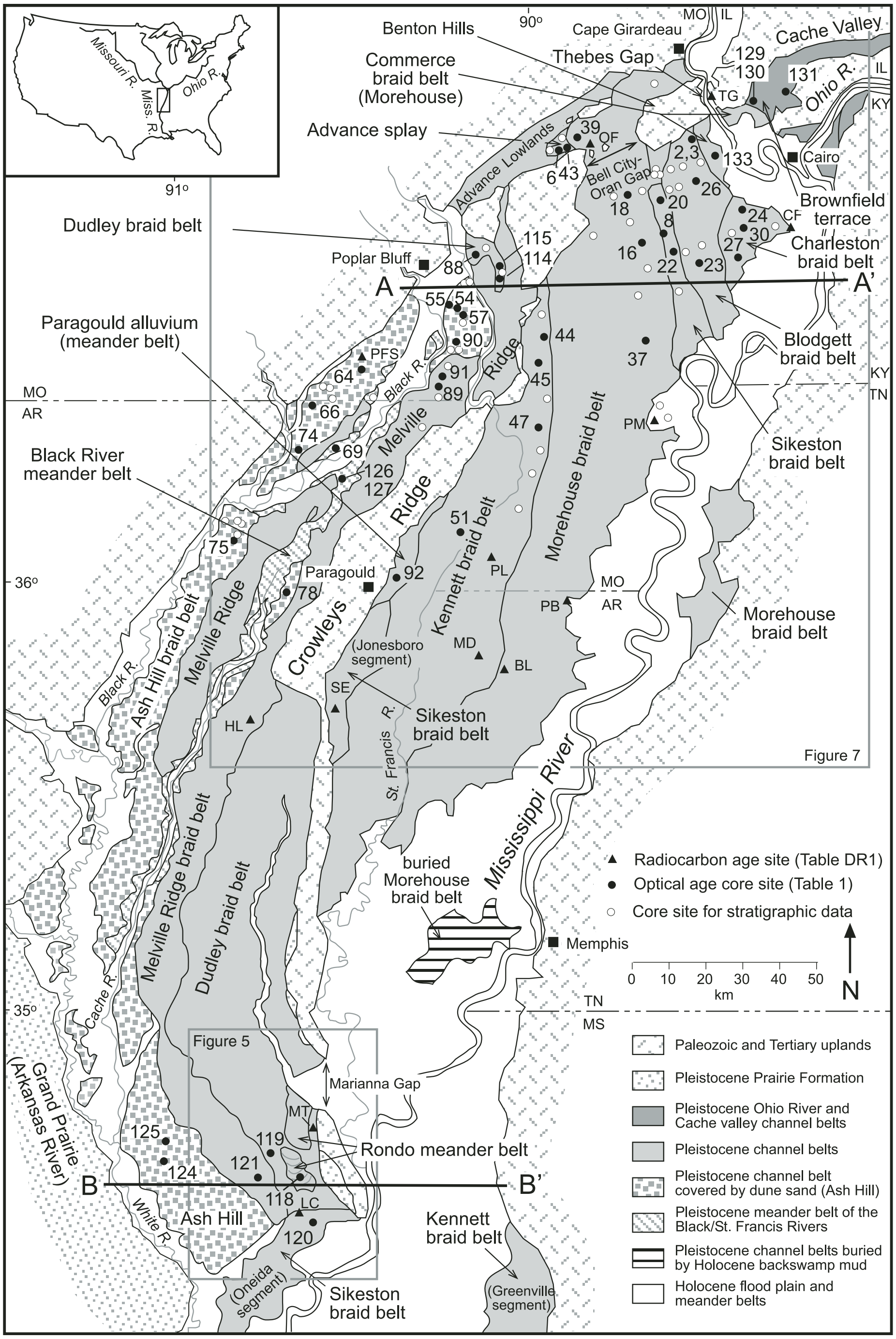

Figure 3. Map of the northern part of the lower Mississippi valley indicating channel-belt names and locations of core sites for optical and radiocarbon ages and stratigraphic analysis. The locations of Figures 5 and 7 and the positions of cross sections in Figure 6 are also indicated. Map modified from Saucier (1994a).

Key aspects of Fisk's model were revised by Saucier (1968, 1974, 1978, 1981, 1994a, 1994b, 1996). Saucier assigned most braid belts (or valley trains in his terminology) to the early to middle and late Wisconsin glacial stages, marine oxygen isotope stages (OIS) 4-3 and 2 (Pve and Pvl map units, respectively, Fig. 2). He suggested that the braid belts formed in response to glacially induced increases in discharge and sediment load, with the transition to a meandering regime due to the loss of glacial sediment and meltwater. The upstream effect of sea-level change was considered minor, only affecting the lower 250–350 km of the river.

Blum et al. (2000) built on loess stratigraphic data presented by Rutledge et al. (1985, 1996), West and Rutledge (1987), and Guccione et al. (1988a) to revise Saucier's chronology for the northern lower Mississippi valley. In contrast to Saucier (1994a), Blum et al. (2000) suggested that northern lower Mississippi valley braid belts were Illinoian and late Wisconsin in age (OIS 6 and 2) with only a few early to middle Wisconsin (OIS 4-3) braid belts (Fig. 2).

METHODOLOGY

This study builds upon the detailed mapping of the lower Mississippi valley by Saucier and colleagues (Saucier, 1964, 1967, 1994a; Kolb et al., 1968; Smith and Saucier, 1971). Saucier's (1994a) map unit names (Pve 5–Pve 1 and Pvl 2–Pvl 1 for Pleistocene valley trains of early-middle and late Wisconsin age) were replaced with informal morphostratigraphic units. The braid belt and meander belt units identified here include the channel belt and associated deposits of former braided and meandering channel courses. The correlation between Saucier's original numbering scheme and the unit names proposed here is made in Table 1.

Channel-belt sediments and the overlying soil and loess stratigraphy were described from sediment exposures and from more than 100 cores collected throughout the lower Mississippi valley using a Giddings soil probe, Vibracorer, or hand auger. Description of soils follows standard soil survey procedures (Soil Survey Staff, 1993). OSL samples were collected from the same cores and outcrops that were described in the field. For more information on core sites and descriptions see Rittenour (2004).

GEOCHRONOLOGY

Previous models of lower Mississippi valley fluvial evolution have been purely conceptual (Fisk, 1944) or based primarily on relative age relationships with limited radiocarbon age control (Saucier, 1994a; Blum et al., 2000).

TABLE 1. OPTICALLY STIMULATED LUMINESCENCE AGES FROM SAMPLE SITES

Channel-belt name Rittenour (2004)	Site number Figs. 3 and 8	UNL Lab no.	Saucier (1994a) map unit	Optical age[†] (ka)
		Last interglacial meander belts		
Paragould alluvium	92	UNL-331	Pve 4	84.9 ± 6.8
Rondo meander belt	118	UNL-604	Pve 4	83.3 ± 6.7
		Mississippi River braid belts		
Dudley	119	UNL-603	Pve 3	63.5 ± 4.8
	114	UNL-384	Pve 3	58.5 ± 4.3
	115	UNL-359	Pve 3	52.2 ± 3.9
	88	UNL-229	Pve 2	50.1 ± 4.0
Melville Ridge	101	UNL-373	Pve 4	41.6 ± 3.0
	108	UNL-378	Prairie	40.0 ± 2.9
	85	UNL-183	Pve 4	39.9 ± 3.3
	86	UNL-182	Pve 5	39.7 ± 3.0
	95	UNL-367	Pve 4	39.6 ± 3.1
	121	UNL-607	Pve 2	38.5 ± 2.9
	107	UNL-377	Pve 5	38.5 ± 2.8
	111	UNL-380	Pve 3	36.2 ± 2.7
	93	UNL-330	Pve 1	37.7 ± 2.7
	116	UNL-548	Pve 1	37.6 ± 2.8
	91	UNL-350	Pve 2	37.3 ± 2.9
	112	UNL-383	Pve 3	36.6 ± 2.8
	113	UNL-381	Pve 3	35.1 ± 2.8
	89	UNL-461	Pve 2	34.5 ± 2.5
Lower Macon Ridge	102	UNL-374	Pve 2	33.3 ± 2.4
	98	UNL-370	Pve 1	33.0 ± 2.5
	82	UNL-185	Pve 2	32.7 ± 2.5
	99	UNL-371	Pve 1	32.4 ± 2.4
	83	UNL-184	Pve 3	31.9 ± 2.4
	109	UNL-379	Pve 3	30.0 ± 2.1
Ash Hill	64	UNL-344	Pve 2	27.3 ± 2.1
	74	UNL-422	Pve 2	26.2 ± 2.0
	57	UNL-345	Pve 2	25.9 ± 1.9
	78	UNL-621	Pve 2	25.6 ± 1.9
	125	UNL-611	Pve 2	24.6 ± 1.8
Advance Splay	43	UNL-342	Pve 2	21.4 ± 1.6
	6	UNL-075	Pve 2	19.1 ± 1.4
Sikeston	22	UNL-120	Pve	19.7 ± 1.6
	120	UNL-614	Pvl 2	19.6 ± 1.5
	80	UNL-550	Hmp 4	19.1 ± 1.4
	8	UNL-168	Pve	18.5 ± 1.3
	20	UNL-346	Pve	17.8 ± 1.3

(*continued*)

TABLE 1. OPTICALLY STIMULATED LUMINESCENCE AGES FROM SAMPLE SITES (*continued*)

Channel-belt name Rittenour (2004)	Site number Figs. 3 and 8	UNL Lab no.	Saucier (1994a) map unit	Optical age[†] (ka)
		Mississippi River braid belts		
Kennett	47	UNL-125	Pvl 2	16.1 ± 1.2
	44	UNL-343	Pvl 2	15.8 ± 1.1
	45	UNL-124	Pvl 2	15.1 ± 1.1
	51	UNL-353	Pvl 2	15.0 ± 1.1
	132	UNL-618	Pvl 2	14.7 ± 1.1
	122	UNL-608	Pvl 2	14.7 ± 1.1
	123	UNL-609	Pvl 2	14.4 ± 1.1
Morehouse	37	UNL-169	Pvl 1	12.4 ± 1.0
	39	UNL-123	Pvl 2	12.4 ± 0.9
	16	UNL-119	Pvl 1	12.2 ± 0.9
	18	UNL-365	Pvl 1	12.1 ± 0.8
(Commerce)	133	UNL-719	Pvl 1	11.3 ± 0.9
		Ohio River or combined Mississippi and Ohio River braid belts		
Charleston	30	UNL-122	Pvl 1	14.9 ± 1.2
	27	UNL-333	Pvl 1	14.7 ± 1.1
	24	UNL-351	Pvl 1	14.1 ± 1.0
Brownfield terrace	129	UNL-616	Ptb	14.1 ± 1.0
	130	UNL-617	Ptb	13.5 ± 1.0
	131	UNL-618	Ptb	13.4 ± 1.0
Blodgett	3	UNL-074	Pvl 2	13.6 ± 1.0
	2	UNL-073	Pvl 2	13.5 ± 1.1
	26	UNL-332	Pvl 2	13.2 ± 1.0
	23	UNL-352	Pvl 2	13.0 ± 0.9
		Meander belt of the combined Black and St. Francis Rivers		
Black River meander belt	126	UNL-612	Ptc	21.1 ± 1.6
	127	UNL-613	Ptc	20.7 ± 1.5
	69	UNL-549	Ptc	18.0 ± 1.3
		Sand dunes on the Ash Hill braid belt		
Eolian deposits on Ash Hill braid belt	55	UNL-366	Ps	25.5 ± 1.9
	54	UNL-386	Ps	22.9 ± 1.6
	90	UNL-349	Ps	21.4 ± 1.6
	75	UNL-619	Ps	20.6 ± 1.6
	66	UNL-421	Ps	19.4 ± 1.4
	124	UNL-610	Ps	19.1 ± 1.4

Note: UNL—University of Nebraska, Lincoln.

[†] Supporting data for optical ages presented in Rittenour et al. (2003, 2005).

Collection of datable material has been difficult, because channel-belt sediments often lack organic material or are too old for radiocarbon dating. In addition, bulk-sediment dates are commonly contaminated by lignite, which could produce age overestimates. Because of these difficulties, we employed OSL dating (see Rittenour et al., 2003, 2005) and description of the loess and/or paleosol stratigraphy overlying channel-belt sediments to provide age control for lower Mississippi valley channel belts. Optical ages are consistent within and between channel belts with little sign of incomplete bleaching (for details see Rittenour et al., 2003, 2005), a potential problem in fluvial settings.

The lower Mississippi valley loess stratigraphy is presented in Table 2 (following Rutledge et al., 1996). In summary, three principle loess units and intervening paleosols were deposited and/or formed during the time period of interest. The Loveland Loess was deposited in association with the OIS 6 (Illinoian) glaciation and is capped by the Sangamon Geosol, which began to develop in the OIS 5 interglacial (Follmer, 1983; Pye and Johnson, 1988; Markewich et al., 1998). The Roxana Silt was deposited during OIS 3 (middle Wisconsin) based on radiocarbon and luminescence ages between 55-27 ka (Leigh and Knox, 1993; Rodbell et al., 1997; Markewich et al., 1998) and is capped by the Farmdale Geosol (Follmer, 1983). The late Wisconsin (OIS 2) Peoria Loess is found extensively throughout the midcontinent, and was deposited ca. 25–12 ^{14}C ka B.P. (McKay, 1979; Ruhe, 1983).

Research into loess stratigraphy in the lower Mississippi valley has been primarily limited to upland positions (West et al., 1980; Pye and Johnson, 1988; Mirecki and Miller, 1994; Rodbell et al., 1997; Markewich et al., 1998). However, a few studies have investigated the loess and/or paleosol stratigraphy on channel belts in the Western Lowlands (Rutledge et al., 1985; Wysocki et al., 1994, 1995; Blum et al., 2000) and on Macon Ridge (Rehage, 1980; Miller, 1981; Miller et al., 1984).

TABLE 2. AGE OF LOESS UNITS IN THE LOWER MISSISSIPPI VALLEY, AFTER STRATIGRAPHY OF RUTLEDGE ET AL. (1996)

Loess or soil unit	Age	Oxygen isotope stage
Peoria Loess	25–12 ka†	OIS 2
Farmdale Geosol		
Roxana Silt	55–27 ka‡	OIS 3
Sangamon Geosol		
Loveland Loess	ca. 190–120 ka§	OIS 6

†Based on radiocarbon ages (McKay, 1979; Ruhe, 1983).

‡Based on radiocarbon and luminescence ages (Leigh and Knox, 1993; Rodbell et al., 1997; Markewich et al., 1998).

§Based on luminescence ages (Markewich et al., 1998; Forman and Pierson, 2002). However, thermoluminescence ages suggest that Loveland Loess deposition may have continued into OIS 5 (Rodbell et al., 1997).

In the field, loess and paleosol units were identified based on stratigraphic position, degree of pedogenesis, and to a lesser extent color and grain size. In the lower Mississippi valley the Peoria Loess deposits overlying channel-belt surfaces range from 0 to 15 m thick, are pale brown to yellowish-brown (Munsell soil color 10YR 6/3–4, 5/4, 4/6), and have silt loam to silty clay loam textures. The Roxana Silt is 0–3 m thick, is stratigraphically below the Peoria Loess, and can easily be identified by its darker brown to reddish-brown color (10YR 4/4–3, 3/6; 7.5YR 4/4), coarser grain size (silty clay loam to fine sandy loam), and the well-developed argillic horizon with clay coats on ped faces of the Farmdale Geosol developed in the upper parts or throughout this unit. In upland positions, the Loveland Loess is characterized by its stratigraphic position below the Peoria Loess and Roxana Silt (if present) and the well-developed Sangamon Geosol in its upper surface. It is typically reddish-brown to yellowish-brown (5YR 4/4; 7.5YR 4–5/6), and has a silty loam to silty clay loam texture below the influence of pedogenesis.

CHANNEL-BELT CHRONOLOGY

Past investigations of lower Mississippi valley fluvial evolution have produced differing interpretations of channel-belt ages and the importance of sea level and meltwater discharge in channel-belt formation. We present a revised chronology of lower Mississippi valley channel belts produced from new optical ages, loess stratigraphy, and geomorphic relationships. For ease of discussion, channel belts are grouped by age, as determined here, and are described in chronological order.

OIS 5 Channel Belts

Geomorphic relationships and loess stratigraphy indicate that the Rondo and Paragould channel courses are the oldest lower Mississippi valley channel belts studied here (a number of similar channel belts, mapped by Saucier [1994a] as the last interglacial Prairie Complex, were not investigated). The Rondo channel belt is preserved as two small remnants in the southern Western Lowlands, and the Paragould channel belt is preserved as a narrow remnant along Crowleys Ridge in the Eastern Lowlands (Fig. 3).

A core (#118, Figs. 3 and 4) collected from the southern segment of the Rondo channel belt contained 5.4 m of Peoria Loess overlying weakly developed paleosols in 9 m of organic-rich channel-fill silts that grade into fine sand at a depth of 14.5 m. While not seen in this core, Roxana Silt has been described in cores to the north (Blum et al., 2000). Core stratigraphy from the Paragould channel belt (core #92, Figs. 3 and 4) is similar, and indicates that it is overlain by 4.5 m of Peoria Loess over Roxana Silt with a paleosol developed into the underlying fluvial silts. The thickness of the Roxana Silt and characteristics of the underlying paleosol cannot be determined due to the limited core recovery between 4.6 and 5.3 m depth caused by the resistance of this soil horizon to coring. The presence of Peoria Loess and Roxana Silt overlying a paleosol on the Rondo and Paragould channel belts indicates that they formed during or prior to OIS 3.

The thick loess cover on the Paragould channel belt and the northern segment of the Rondo channel belt prevents identification of the underlying fluvial topography. However, the southern segment of the Rondo channel course, which has a thinner loess cover, is characterized by large arcuate ridges and swales, similar in morphology and scale to the scroll-bar topography of the Holocene Mississippi River (Fig. 5). The thick channel-fill sediments, similar to Holocene fills on point-bar swales (Aslan and Autin, 1998), and its scroll-bar topography suggest that the Rondo channel course formed during a meandering phase of the Mississippi River.

Samples from the base of cores collected from the Rondo and Paragould channel belts produced optical ages of 83 ± 7 and 85 ± 7 ka, respectively (Table 1), indicating that they formed during OIS 5a. A similar luminescence age of 99 ± 9 ka was obtained from overbank deposits overlying channel sands at 8 m depth from the mouth of a tributary adjoining the Paragould channel belt (McVey, 2005). These last interglacial ages agree with the interpretation that they formed during a meandering regime of the Mississippi River, and suggest that the Paragould and the Rondo channel belts may have been part of the same meander-belt system.

Based on the OSL age estimates, the Paragould and Rondo meander belts should have the last interglacial-age Sangamon Geosol developed into their fluvial surfaces. The limited core recovery on the Paragould channel belt precludes interpretation of the buried paleosol below the Peoria Loess and Roxana Silt as the Sangamon Geosol. In the Rondo meander belt, the weakly developed stacked soils in the channel-fill silts underlying the Peoria Loess and Roxana Silt are not as well developed as the last

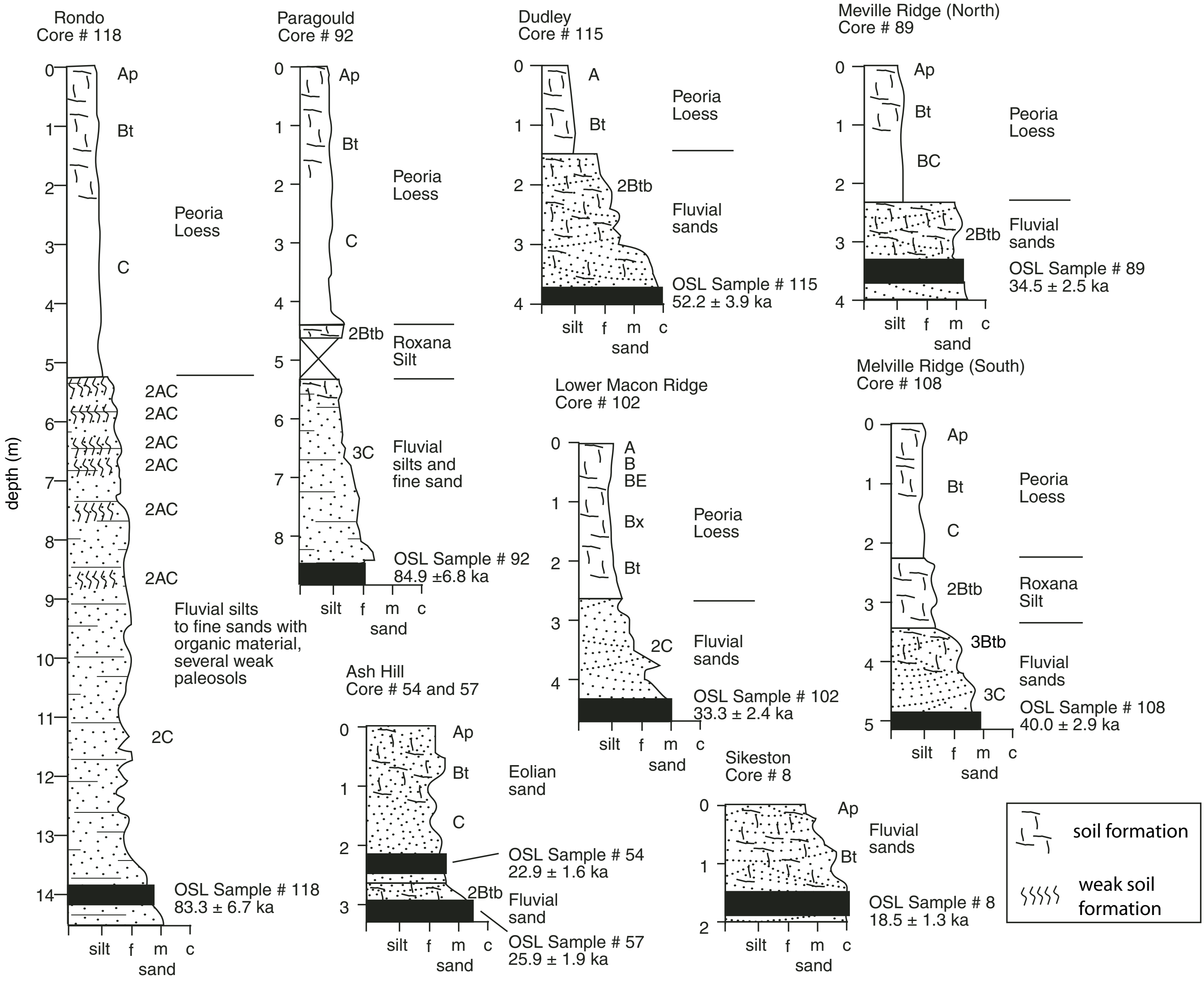

Figure 4. Stratigraphy from eight cores collected from key channel belts in the lower Mississippi valley (see Figs. 3 and 8 for core locations). Description of soils follows standard soil survey procedures (Soil Survey Staff, 1993). Depths of optically stimulated luminescence (OSL) samples are represented by black bars.

interglacial Sangamon Geosol at upland loess localities in the lower Mississippi valley, possibly due to the depositional setting at the core locality and continual position near or below the water table. Autin and Aslan (2001) described the paleosols formed in fluvial point-bar sands under loess in a similar last interglacial meander belt in the southern lower Mississippi valley (Avoyelles Prairie). They found that soil drainage characteristics and water table significantly affected the degree of pedogenesis, and cautioned against the use of relative soil profile development as a function of time in high-water-table flood-plain settings. Despite the lack of definitive evidence for Sangamon Geosol development on these surfaces, the scroll-bar topography on the Rondo meander belt (Fig. 5), the loess stratigraphy (Fig. 4), and the crosscutting and relative age relationships between the Rondo and Paragould channel belts and the surrounding braid belts (Figs. 3 and 5) support their age assignment to the last interglacial.

OIS 4 to OIS 2 Channel Belts

Seven major Mississippi River braid belts have been identified and correlated throughout the lower Mississippi valley on the basis of loess stratigraphy and geomorphic relationships. In addition, two braid belts in the northern lower Mississippi valley are interpreted to have formed by the Ohio River or combined Ohio-Mississippi River. The ages from a major tributary stream channel belt and a large crevasse splay formed by the Mississippi River are also described in the following.

Dudley Braid Belt

The oldest braided channel belt in the northern lower Mississippi valley is the Dudley braid belt (Fig. 3), which crosscuts the scroll-bar topography of the Rondo meander belt in the southern Western Lowlands (see Figs. 5 and 6). Cores indicate that the Dudley braid belt is covered by Peoria Loess (<2 m in the north and as much as

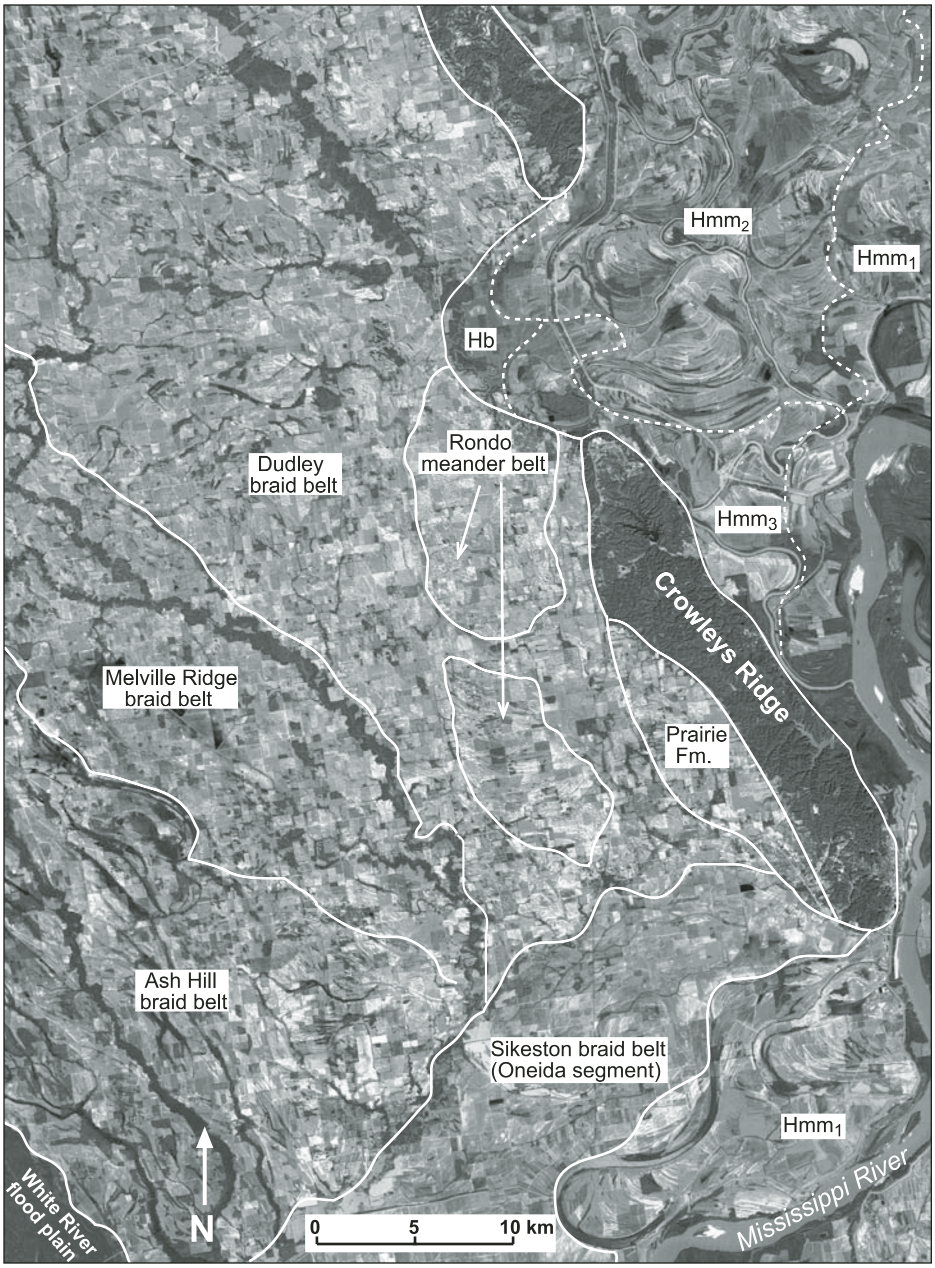

Figure 5. LANDSAT thematic mapper image (bands 4, 3, 2) of the southern part of the Western Lowlands, illustrating the geomorphic relationships between channel belts and morphology of channel forms on each surface. Holocene meander belts (Hmm1–Hmm3) and backswamp sediment overlying older Pleistocene channel belts (Hb) mapped by Saucier (1994a) are also indicated. Note arcuate channels on the southern segments of the Rondo meander belt. Location shown in Figure 3.

7.5 m in the south), overlying a well-developed paleosol, reddened in places, with moderate subangular blocky structure and an argillic horizon with illuvial clay accumulation on ped faces (Fig. 4). Although not recognized here, previous studies have identified Roxana Silt under the Peoria Loess on this surface (Wysocki et al., 1994, 1995; Blum et al., 2000). Past researchers have interpreted the paleosol developed in the underlying fluvial sediments as the Sangamon Geosol (OIS 5) on the basis of its stratigraphic position, degree of soil development (Rutledge et al., 1985), and clay mineralogy (Wysocki et al., 1994, 1995; Blum et al., 2000), suggesting that the Dudley braid belt is Illinoian (OIS 6) (Blum et al., 2000). However, luminescence ages from sites surrounding the lower Mississippi valley suggest that some soils originally identified as the Sangamon Geosol on the basis of stratigraphic relationships and soil development are developed in late OIS 5 to OIS 4 deposits and are younger than originally interpreted (Forman et al., 1992; Forman and Pierson, 2002; Rodbell et al., 1997). To avoid misinterpretations of this paleosol age, we interpret the loess and paleosol stratigraphy to suggest only that the Dudley braid belt formed significantly prior to Peoria Loess and Roxana Silt deposition to allow a well-developed paleosol to form in the underlying sediments, or prior to OIS 3.

Optical ages from Dudley braid belt fluvial sands range from 64 ± 5 to 50 ± 4 ka (Table 1), and indicate that it is late OIS 4 to early OIS 3 in age. This interpretation is corroborated by crosscutting relationships with the last interglacial Rondo meander belt (Fig. 5).

Melville Ridge and Equivalent Braid Belts

The Melville Ridge braid belt crosscuts the Dudley braid belt and is preserved as an elongate remnant along the length of the Western Lowlands (Figs. 3 and 7). Cores from the Melville Ridge braid belt indicate it is overlain by 2–5 m of Peoria Loess (thinning to the north) over a paleosol developed in fluvial sands with moderate subangular blocky structure and argillic horizon (Fig. 4). The presence of Peoria Loess over a paleosol suggests that the Melville Ridge braid belt formed prior to OIS 2. Optical ages from fluvial sediments range from 39 ± 3 to 35 ± 3 ka (Table 1), in agreement with this age assessment.

In the southern lower Mississippi valley, the Melville Ridge braid belt can be correlated to a narrow, discontinuous braid belt along the eastern margin of Macon Ridge and two braid-belt remnants to the south (the Wallace Ridge and Catahoula segments), collectively named the Upper Macon Ridge braid belt (Fig. 8) (Rittenour, 2004). Loess stratigraphy from cores on Macon Ridge indicate that this braid belt is covered by 1.2–4.5 m of Peoria Loess (thinning to the south and west) over a thin, discontinuous layer of Roxana Silt (0 to <1 m) over a paleosol developed in the underlying fluvial sands (Fig. 4) (Rittenour, 2004). Cores from the southern braid-belt segments contain ~1.5 m of Peoria Loess with a basal mixing zone over fluvial sands with no intervening paleosol. These loess stratigraphy observations suggest that the Upper Macon Ridge braid belt formed during or prior to OIS 3 Roxana Silt deposition.

OSL ages from the Upper Macon Ridge braid belt suggest that it formed between 42 ± 3 and 35 ± 3 ka (Table 1), consistent with the loess stratigraphic evidence. The agreement between

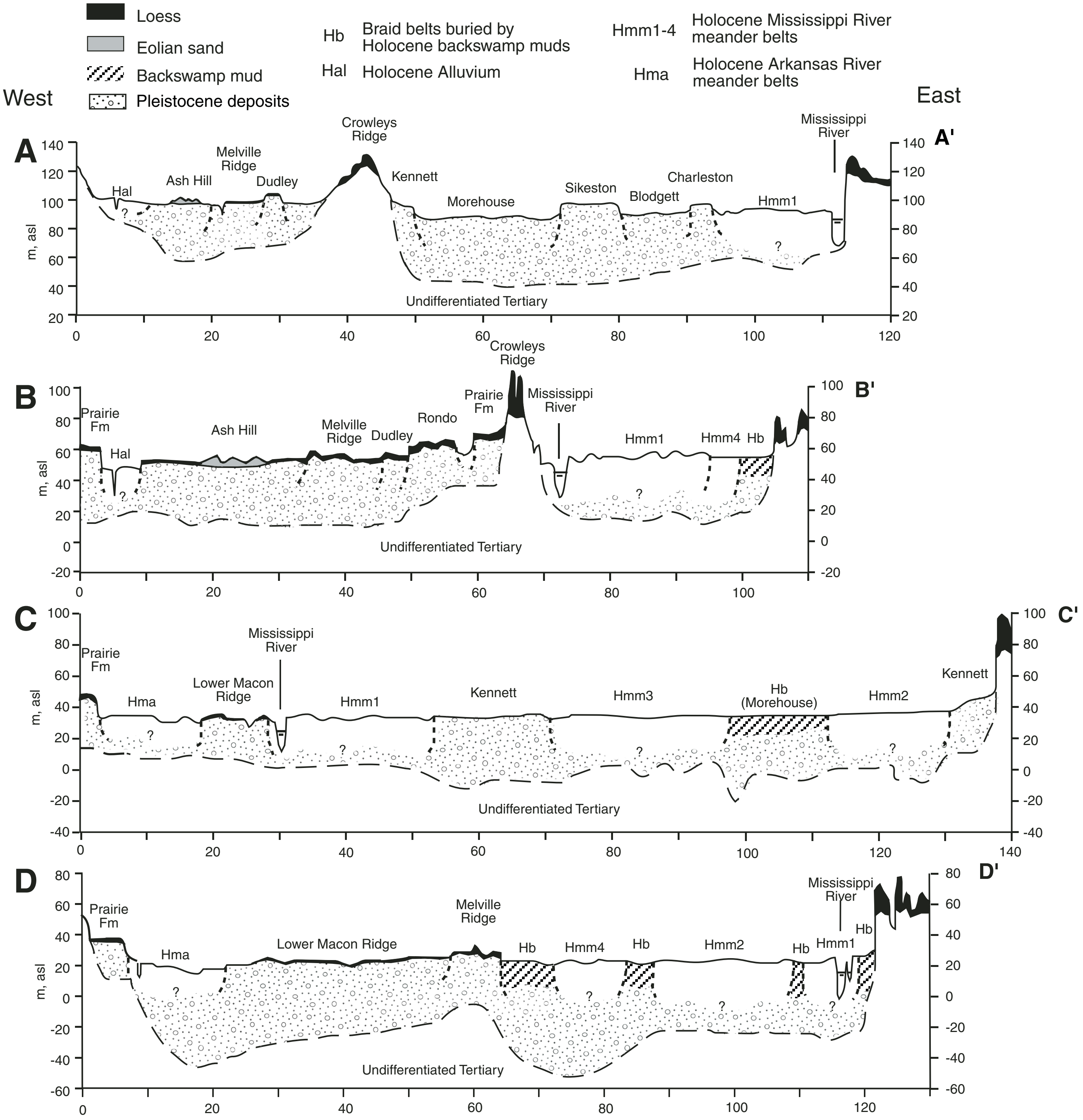

Figure 6. Stratigraphic cross sections showing relationships between channel belts at four locations in the lower Mississippi valley (see Figs. 3 and 8 for locations). Modified from Saucier (1994a).

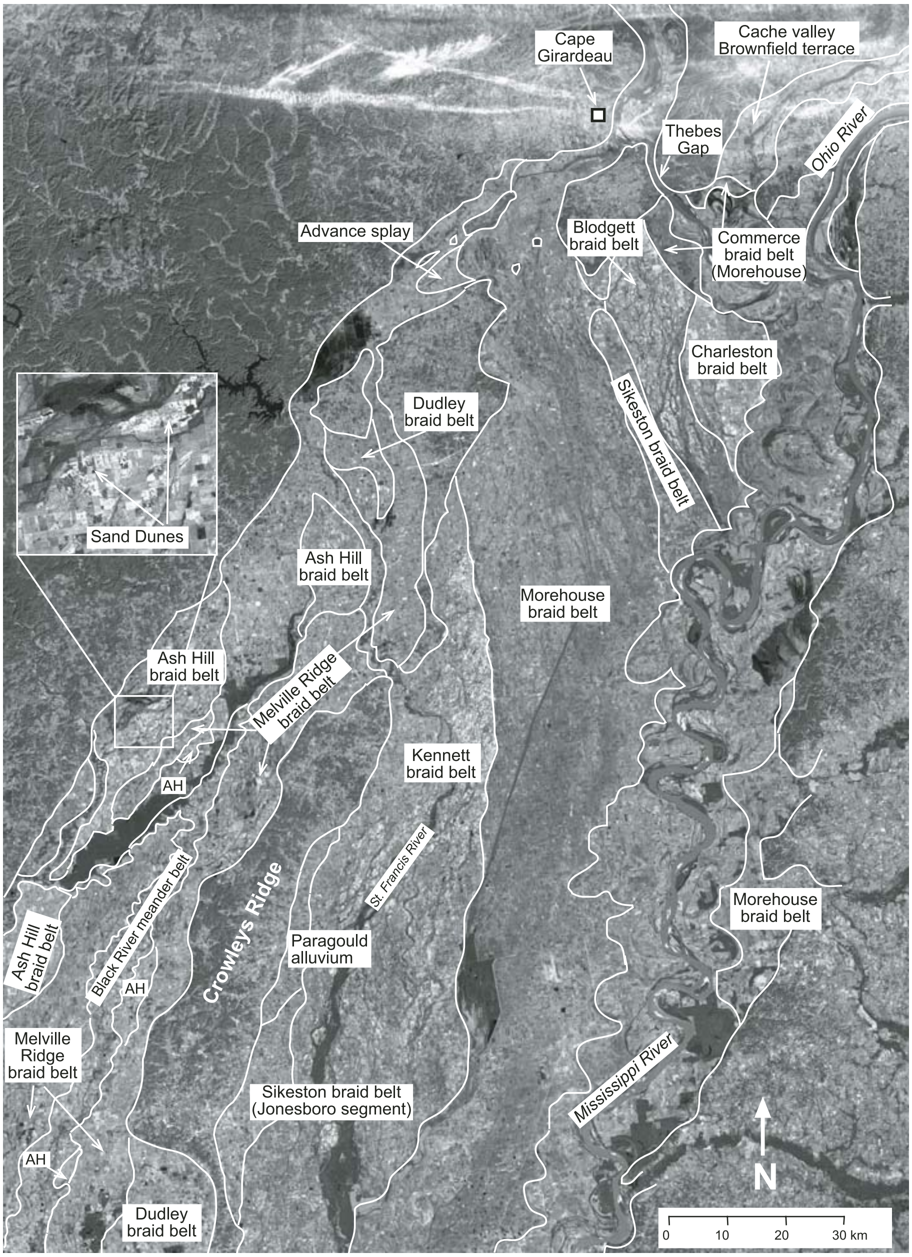

Figure 7. LANDSAT thematic mapper image (bands 4, 3, 2) of the northern lower Mississippi valley with channel belts labeled. AH indicates small remnants of the Ash Hill braid belt. Location shown in Figure 3.

these ages and those obtained from the Melville Ridge braid belt to the north (39 ± 3 to 35 ± 3 ka) confirms the correlation of these braid belts. By convention, the name given to the northernmost identified channel belt in this study is used to refer to all correlated channel belts. Therefore, the total OSL age range for the Melville Ridge braid belt is 42 ± 3 to 35 ± 3 ka (Table 1).

Lower Macon Ridge Braid Belt

The Lower Macon Ridge braid belt (Fig. 8) is differentiated from the adjoining southern extension of the Melville Ridge braid belt by its generally lower fluvial surface (Fig. 6) and major crosscutting relationships. Loess stratigraphy from cores indicates 0–3 m of Peoria Loess (thinning to the west) over, in places, a weak to moderately developed paleosol in the underlying fluvial sands (Fig. 4). In some cores, a thin layer of Roxana Silt was observed under the Peoria Loess, suggesting that this braid belt formed during OIS 3. Optical ages indicate that the Lower Macon Ridge braid belt formed between 33 ± 2 and 30 ± 2 ka (Table 1). These age estimates are consistent with radiocarbon ages of 29,100 ± 1200 and 31,200 ± 2400 ^{14}C ka B.P. collected from a shell-rich deposit underlying the Peoria Loess and overlying the sand on this surface (Saucier, 1968) (see GSA Data Repository Table DR1[1]).

Ash Hill Braid Belt

The Ash Hill braid belt in the Western Lowlands is characterized by large interchannel bars covered by sand dunes (Figs. 3, 5, and 7). Geomorphic relationships indicate that this braid belt represents the last major flow of the Mississippi River into the Western Lowlands. Peoria Loess on this surface is as thick as 3 m in the southern Western Lowlands, but is absent to the north, suggesting that the Ash Hill braid belt is contemporaneous with Peoria Loess deposition in OIS 2.

Optical ages of 27 ± 2 to 25 ± 2 ka (Table 1) indicate that the Ash Hill braid belt formed during early OIS 2 and agree with a radiocarbon age of 17,370 ± 170 ^{14}C ka B.P. (20.6 cal ka; conversion to calendar years using CALIB 5.0 [Stuiver and Reimer, 1993] and IntCal04 calibration curve [Reimer et al., 2004]) from a post-abandonment channel-fill deposit (Royall et al., 1991) (Table DR1). Dune sand ranges in age from 26 ± 2 to 19 ± 1 ka (Table 1), which suggests, along with the presence or absence of an intervening paleosol, that some dunes were contemporaneous with braid-belt formation, while most stabilized after its abandonment.

Black River Meander Belt

The youngest Pleistocene channel course in the Western Lowlands is a high-sinuosity, large-wavelength meander belt of the combined Black and St. Francis Rivers, which occupied abandoned channel courses of the Ash Hill braid belt after meltwater flow into the Western Lowlands had ceased (Figs. 3 and 7). Discharge in the Black River meander belt was limited to contributions from local drainages coming off the Ozark Plateau. Loess has not been recognized on the Black River meander belt, but the presence of Dalton-period archaeological sites suggests that the meander belt formed prior to 10,500–9500 ^{14}C yr B.P. (12.2–10.9 cal ka) (Morse and Morse, 1983; Saucier, 1994b). Optical ages from two separate channel courses indicate that the Black River meander belt occupied the present route of the Cache River at 21 ± 2 ka and avulsed to the westernmost side of the Western Lowlands by 18 ± 1 ka (Table 1; Fig. 3).

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[1] GSA Data Repository item 2007132, Table DR1 and Figures DR1 and DR2, is available on the Web at http://www.geosociety.org/pubs/ft2007.htm. Requests may also be sent to editing@geosociety.org.

Advance Splay

The Advance splay, first recognized by Robnett (1997), is a large crevasse splay that formed by the spilling of water from the Eastern Lowlands into the Western Lowlands (Figs. 3 and 7). Blum et al. (2000) used the lack of loess on its surface and crosscutting relationships with younger channel belts in the Eastern Lowlands to suggest that it represented the last flow of meltwater into the Western lowlands during the late Wisconsin (OIS 2). Optical ages support this interpretation and suggest that the Advance splay formed between 21 ± 2 and 19 ± 1 ka (Table 1).

Sikeston and Equivalent Braid Belts

The Sikeston braid belt is the oldest braided channel belt preserved in the Eastern Lowlands, and can be traced as discontinuous remnants to the central lower Mississippi valley (Figs. 3 and 8). In the northern Eastern Lowlands, it is preserved as a high remnant landform south of the Benton Hills (Sikeston Ridge) (Figs. 2, 3, and 7). Channel orientations indicate that it was created by flow from both the Mississippi and Ohio Rivers. To the south, the Sikeston braid belt is preserved as segments along the eastern side of Crowleys Ridge, south of the Western Lowlands, and in the northern Yazoo Basin (Jonesboro, Oneida, and Winstonville segments, respectively) (Figs. 3 and 8). South of Greenville, Mississippi, the Sikeston braid belt is no longer exposed at the surface and is buried below backswamp muds of the Holocene flood plain.

In the northern lower Mississippi valley the Sikeston braid belt has a well-developed reddened surface soil with additions of silt that may suggest a thin accumulation of loess has been mixed into the surface soil (Fig. 4). Alongside Crowleys Ridge the Sikeston braid belt is buried by 1–2.5 m of Peoria Loess with no intervening paleosol (Blum et al., 2000), and in the central lower Mississippi valley it is covered by 3 m of Holocene splay and overbank deposits.

Optical ages indicate that the Sikeston braid belt formed between 19.7 ± 1.6 and 17.8 ± 1.3 ka (Table 1), in agreement with a radiocarbon age of 16,570 ± 60 ^{14}C yr B.P. (19.7 ± 0.2 cal ka; Table DR1) collected from plant material within fluvial sands of the Jonesboro segment (Blum et al., 2000).

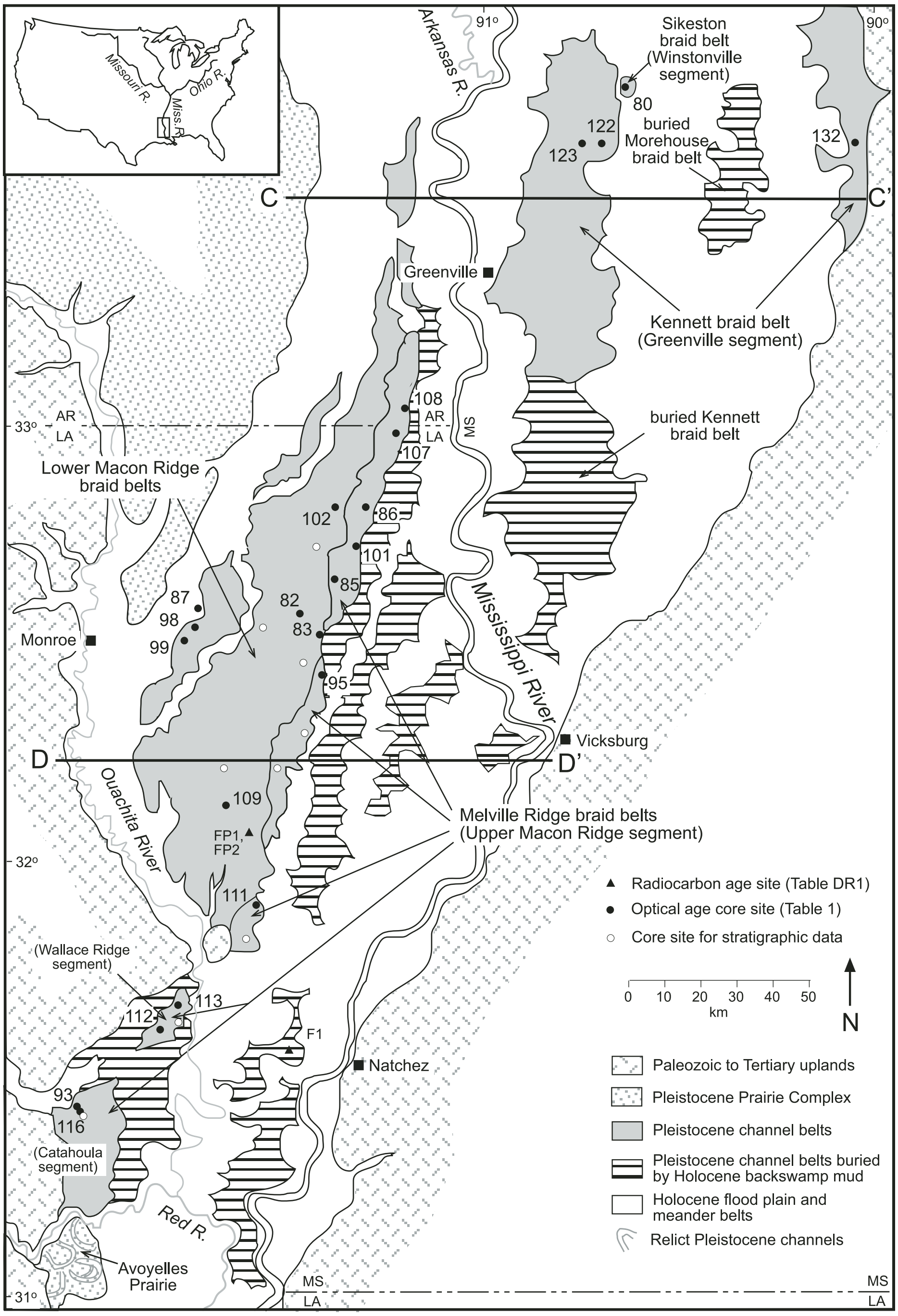

Figure 8. Map of the southern lower Mississippi valley indicating channel-belt names and locations of core sites for optical and radiocarbon ages and stratigraphic analysis. The positions of cross sections in Figure 6 are also indicated. Map modified from Saucier (1994a).

Kennett and Equivalent Braid Belts

The Kennett braid belt can be traced from the Eastern Lowlands, where it has the surficial expression of a terrace landform, to the Yazoo Basin, where it dips below the modern flood plain and becomes buried by Holocene backswamp mud (Greenville segment) (Figs. 3 and 8). This geometry is due to the steeper gradient of the Kennett braid belt in comparison to the Holocene Mississippi River (Fig. 9). The elevations of the Kennett and Sikeston braid belts are similar (Fig. 9); however, they can be distinguished by crosscutting relationships, the higher density of narrow distributary channels on the Kennett braid belt (Fig. 7), and the presence of as much as 2.5 m of loess on the Jonesboro segment of the Sikeston braid belt. Loess was not identified on the Kennett or any younger braid-belt surfaces. Age estimates of ca. 25–11 ka (i.e., Pye and Johnson, 1988; Rodbell et al., 1997; Markewich et al., 1998; Forman and Pierson, 2002) from Peoria Loess surrounding the lower Mississippi valley and its distribution and fining trends (i.e., West et al., 1980; Rutledge et al., 1985) suggest that the Sikeston and younger

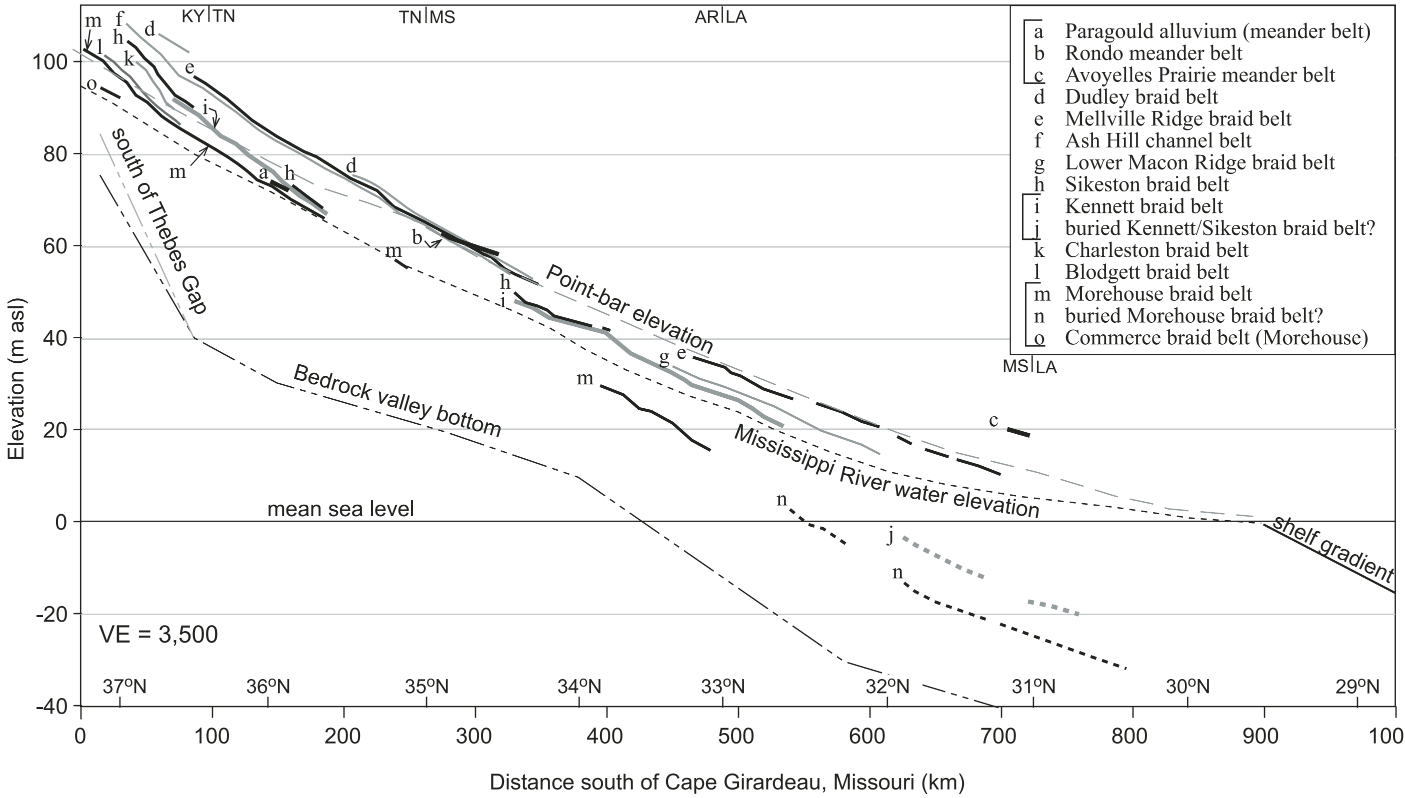

Figure 9. Longitudinal valley profiles of key channel-belt surfaces in the lower Mississippi valley, starting at the entrance of the valley just south of Cape Girardeau, Missouri, and following channel-belt paths through either the Eastern or Western Lowlands. The bedrock base of the valley from Saucier (1994a) and the profile of the modern Mississippi River water and point bars elevations are shown for comparison with channel-belt positions and slopes. Correlative fluvial deposits between the northern and southern lower Mississippi valley are indicated by brackets in the legend. Note that the late glacial Morehouse and Kennett-Sikeston braid belts dip at least 40 m below modern sea level in the Atachafalaya Basin. The profile extends to the shelf edge directly south of the Atachafalaya Basin and does not follow the modern river to its mouth. The elevation of the Avoyelles Prairie meander belt in the southern lower Mississippi valley has been influenced by upwarping due to flexural isostasy from loading of the shelf. Figure DR1 (see footnote 1) is an enlarged color version.

braid belts may have served as the source for the wind-blown silt.

Minimum age estimates for the abandonment of the Kennett braid belt have come from radiocarbon ages from wood (11,100 ± 100 ^{14}C yr B.P., 13.0 ± 0.2 cal ka) and a paleo-llama bone (10,890 ± 130 ^{14}C yr B.P., 12.9 ± 0.2 cal ka) from channel-fill deposits in the Eastern Lowlands (Wesnousky and Leffler, 1992) (Table DR1). In addition, Dalton-period archaeological sites on Kennett braid-belt surfaces in the Yazoo Basin (Brain, 1970) indicate that they were abandoned and suitable for human habitation prior to 10,500–9500 ^{14}C yr B.P. (12.2–10.9 cal ka) (Morse and Morse, 1983). Optical ages better delimit the timing of braid-belt formation to between 16.1 ± 1.2 and 14.4 ± 1.1 ka (Table 1).

Charleston Braid Belt

The Charleston channel belt was first studied by Ray (1964), who suggested that it was a fine-grained alluvial fan deposited during a flood event that cut Thebes Gap, and that the Charleston "fan" was the youngest Pleistocene deposit in the lower Mississippi valley. Porter and Guccione (1994) obtained a minimum radiocarbon age estimate of 10,590 ± 200 ^{14}C yr B.P. (12.4 ± 0.5 cal ka) (Table DR1), and suggested that it formed during an early glacial Lake Agassiz drainage event.

The interpretation of the Charleston braid belt as a fan was based on its relatively high slope (0.30 m/km) in comparison with the modern flood plain (0.14 m/km) and other channel belts (Ray, 1964). However, similar alluvial fan–like slopes (0.26–0.30 m/km) are seen in the first 20–40 km of all Eastern Lowlands braid belts (Fig. 9). This fan-like slope may be due to increased deposition at the entrance to the lower Mississippi valley, as water flowed from the narrow, bedrock-confined middle Mississippi valley into the broad lower valley. The position of the relatively small remnant of Charleston braid belt at the point of maximum slope on other channel belts gives the appearance of a fan (Fig. 9). However, the comparable slopes of other braid belts suggest that it was formed by similar processes and is not the result of a catastrophic flood.

The Charleston braid belt was interpreted as being derived from Thebes Gap, based on the projection of its surface to the north (Ray, 1964; Porter and Guccione, 1994). It is equally plausible, however, that it was derived from the Cache valley of the Ohio River (see Figs. 3 and 7). Optical ages from the Charleston braid belt range from 14.9 ± 1.2 to 14.1 ± 1.0 ka (Table 1).

Blodgett Braid Belt

The Blodgett braid belt has a distinct network of braided channels that crosscut the Charleston and Sikeston braid belts (Figs. 3 and 7). The position of the Blodgett braid belt directly across from the mouth of the Cache valley, channel orientation on its surface (Fig. 7), and correspondence of elevation with the Brownfield terrace

(Alexander and Prior, 1968) in the Cache valley suggest that the Blodgett braid belt formed by discharge through the Cache valley of the Ohio River. In addition, optical ages are similar for the Blodgett braid belt (13.6 ± 1.0 to 13.0 ± 0.9 ka) and the Brownfield terrace (14.1 ± 1.0 to 13.4 ± 1.0 ka) (Table 1), suggesting they are part of the same braid belt.

Morehouse and Equivalent Braid Belts

Geomorphic evidence indicates that the Morehouse braid belt formed during the last discharge of the Mississippi River through the Bell City–Oran Gap, prior to avulsion into its current location through Thebes Gap (Fig. 3). The Morehouse braid belt can be correlated from the northern to the southern Eastern Lowlands, where it initially becomes buried by 5–8 m of backswamp sediment at the latitude of Memphis, Tennessee, and into the Yazoo Basin, where it is buried by 10 m of backswamp sediment adjacent to the Greenville segment of the Kennett braid belt (Fig. 8). Buried channel belts farther downvalley, adjoining and south of Macon Ridge, may also represent the continuation of the Morehouse and Kennett-Sikeston braid belts (see following).

Minimum age estimates for the abandonment of the Morehouse braid belt in the Eastern Lowlands have come from radiocarbon ages from the base of backswamp mud over fluvial sands (9050 ± 150 ^{14}C yr B.P., 10.1 ± 0.4 cal ka) (Guccione et al., 1988b) and a basal date from peat overlying fluvial sands (8810 ± 90 ^{14}C yr B.P., 9.9 ± 0.3 cal ka) (King and Allen, 1977) (Table DR1). Optical ages delimit the formation of the Morehouse braid belt to between 12.4 ± 1.0 and 12.1 ± 0.8 ka (Table 1).

Commerce Braid Belt (Morehouse Braid Belt Segment)

The youngest braided channel course in the Eastern Lowlands is preserved south of Thebes Gap along an erosional scarp cut into the Blodgett braid belt and the Cache valley of the Ohio River (Figs. 3 and 7). Braid-channel orientations indicate that the Commerce braid belt formed under discharge entirely from Thebes Gap. Braid-belt sediments, under 5 m of Holocene overbank deposits, are at an elevation similar to that of the modern Mississippi River (~93 m above sea level [asl]), indicating that Thebes Gap had been cut to nearly its present depth by the time the Commerce braid belt formed. Radiocarbon ages from a pre-Dalton to Dalton period archaeological site 6 m above the river in Thebes Gap indicate that Thebes Gap had been cut by 9975 ± 125 to 9115 ± 100 ^{14}C yr B.P. (11.6–10.3 cal ka) (Gramley and Funk, 1991) (Table DR1).

The Commerce braid belt was the last braided channel course formed by the Mississippi River prior to switching to a meandering system. A minimum age for the initiation of meandering has come from a bulk-sediment radiocarbon age of 9050 ± 150 ^{14}C yr B.P. (10.1 ± 0.4 cal ka) (Table DR1) from the base of overbank mud overlying Morehouse braid-belt sediment (Guccione et al., 1988b).

Crosscutting relationships limit the age of the Commerce braid belt to after formation of the Blodgett braid belt and the Brownfield terrace in the Cache valley (younger than 13.0 ka), but before the initiation of meandering (older than 10.2 ka). An optical age from the Commerce braid belt indicates that the Mississippi River had been fully captured into Thebes Gap and had cut its channel to near its present level by 11.3 ± 0.9 ka (Table 1).

The Commerce braid belt is only preserved in a small area south of Thebes Gap in the northern lower Mississippi valley. However, projection downvalley suggests that it merges with the Morehouse braid belt, formed under flow from the Bell City–Oran Gap (Fig. 7). Therefore, the full age range of occupation of the Morehouse braid belt, where flow derived from both entry points would have converged, is 12.4 ± 1.0 to 11.3 ± 0.9 ka (Table 1). Moreover, projection of the Commerce braid belt surface to the south also suggests that it correlates with a Morehouse-elevation braid belt preserved at the mouth of the Ohio River valley (Fig. 3), suggesting that the youngest Ohio River braid belt is similar in age.

Age of Buried Braid Belts

In the central and southern lower Mississippi valley there are low-elevation, low-relief regions covered by Holocene overbank deposits that have not been occupied by the surrounding Mississippi River meander belts (Hb map unit of Saucier, 1994a; Fig. 2 herein). Saucier (1994a) used cores from these regions to indicate that coarse-grained channel-belt deposits are buried below the backswamp sediments, and identified such buried channel belts in the southern Eastern Lowlands, in the Yazoo Basin, to the east of Macon Ridge, and in the Atchafalaya Basin (Figs. 2, 3, 6, and 8). Correlation of these channel-belt surfaces indicates that they are exposed at the surface in the northern lower Mississippi valley and dip below the Holocene flood plain to the south (Figs. 8 and 9). Depths of channel-belt burial obtained from cross sections and core depth descriptions from Fisk (1952), McFarlan (1961), Saucier (1964, 1967, 1994a), Kolb et al. (1968), Smith and Russ (1974), and Aslan and Autin (1999) indicate that there are at least two buried channel-belt levels, separated by ~10 m, preserved in the lower valley (Fig. 6).

Radiocarbon ages from wood collected from the base of backswamp mud over channel-belt sand indicate that the lowest buried channel belt in the Atchafalaya Basin was abandoned by 9950 ± 200 to 9650 ± 200 ^{14}C yr B.P. (11.5–11.1 cal ka), and a channel belt ~10 m higher was buried by 9600 ± 200 ^{14}C yr B.P. (10.9 ± 0.7 cal ka) (McFarlan, 1961) (Table DR1). Geomorphic data bracket the age of these buried channel belts, and suggest that they are younger than the Lower Macon Ridge braid belt (younger than 30 ka), which is subaerially exposed in the same reach (Fig. 8).

Projection of the Morehouse and Kennett braid belts downvalley suggests that they correlate to the buried channel belts in the lower Mississippi valley. This correlation is based on the relative elevation difference between these braid belts in the Yazoo Basin. At this location, the Greenville segment of the Kennett braid belt is near the surface and begins to dip below the flood plain to the south, while the Morehouse braid belt is buried by ~10 m of backswamp mud (Figs. 6 and 9). The Morehouse braid belt can be confidently traced to this region from its last exposure at the surface in the Eastern Lowlands through a section buried by 5–8 m of backswamp mud near Memphis, Tennessee (Fig. 3). Based on the 10 m difference between the Morehouse and Kennett braid belts in the Yazoo Basin, the lowest buried channel belt in the Atchafalaya Basin is assumed to be the Morehouse braid belt, and the ~10 m higher buried channel belt is assumed to be the Kennett braid belt. However, it is equally plausible that the higher buried channel belts may also include the Sikeston braid belt, which is nearly equivalent to the Kennett braid belt in height and slope (Fig. 9). No cores for this study have been collected from these buried channel belts to confirm their ages or correlation to channel belts to the north.

COMPARISON WITH PREVIOUS MODELS

The new optical ages and stratigraphic and/or geomorphic relationships presented here provide the first age control for many of the channel belts and an alternative model of lower Mississippi valley fluvial evolution to those of Saucier (1994a) and Blum et al. (2000) (summarized in Table 3). While similarities exist, there are differences between some of the channel-belt ages presented here and previous relative-age assessments. Most notable are the ages assigned to the older channel belts in the Western Lowlands.

TABLE 3. SUMMARY OF OPTICAL AND RADIOCARBON AGES AND LOESS STRATIGRAPHY FROM EACH CHANNEL BELT WITH COMPARISON TO PREVIOUS AGE MODELS

Channel-belt name	Optical age range (ka) (see Table 1)	Saucier (1994a) age	Blum et al. (2000) age[†]	Radiocarbon age data (cal ka)[†] (Table DR1; see text footnote 1)	Overlying loess and paleosols (see Table 2)
Last interglacial meander belts					
Paragould alluvium	85 ± 7	OIS 4-3	OIS 2	NA	Peoria and Roxana over a paleosol
Rondo meander belt	83 ± 7	OIS 4-3	OIS 4-3	NA	Peoria and Roxana over a paleosol
Mississippi River braid belts					
Dudley	64 ± 5–50 ± 4	OIS 4-3	OIS 6	NA	Peoria and Roxana over a paleosol
Melville Ridge	42 ± 3–35 ± 3	OIS 4-3	OIS 2	> 11.8 ± 0.9	Peoria and Roxana over a paleosol
Lower Macon Ridge	33 ± 2–30 ± 2	OIS 4-3	—	>29.1 ± 1.2 ^{14}C ka	Peoria and Roxana
Ash Hill	27 ± 2–25 ± 2	OIS 4-3	OIS 2	>20.6 ± 0.5	Peoria
Advance Splay	21 ± 2–19 ± 1	OIS 4-3	OIS 2	NA	no loess
Sikeston and equivalents	19.7 ± 1.6–17.8 ± 1.3	OIS 2	OIS 2 full glacial	19.7 ± 0.2	no loess to thin Peoria
Kennett and equivalents	16.1 ± 1.2–14.4 ± 1.1	OIS 2	OIS 2 13.5–12.5 ka	>13.0 ± 0.2 >12.9 ± 0.2	no loess
Morehouse and equivalents	12.4 ± 1.0–11.3 ± 0.9	OIS 2	OIS 2 12.5–10.7 ka	>10.1 ± 0.4 >9.9 ± 0.3	no loess
Ohio River or combined Mississippi and Ohio River braid belts					
Charleston	14.9 ± 1.2–14.1 ± 1.0	OIS 2	OIS 2 13.5–12.5 ka	>12.4 ± 0.5	no loess
Brownfield terrace	14.1 ± 1.0–13.4 ± 1.0	OIS 2	—	<25.3 ± 0.5 ^{14}C ka >9.1 ± 0.5	no loess
Blodgett	13.6 ± 1.0–13.0 ± 0.9	OIS 2	OIS 2 full glacial	NA	no loess

[†] Conversion to calendar year using Calib 5.0 (Stuiver and Reimer, 1993); samples older than 21.4 ^{14}C ka B.P. shown in radiocarbon years. OIS—oxygen isotope stage.

Saucier (1994a) mapped Western Lowlands channel belts as early to middle Wisconsin in age (OIS 4-3), while Blum et al. (2000) mapped them as Illinoian (OIS 6) and late Wisconsin (OIS 2) in age, with an early to middle Wisconsin channel belt in the southern Western Lowlands (Fig. 2). OSL ages and geomorphic relationships presented here, however, suggest that the oldest channel belt formed during the last interglacial (OIS 5a), and the others are early to late Wisconsin in age (OIS 4-2).

The greatest differences between chronologies involve the ages assigned to the Rondo and Dudley channel belts. Saucier (1994a) mapped these channel belts as early to middle Wisconsin in age (OIS 4-3), map units Pve 4 and Pve 3, respectively, his oldest valley trains in the northern lower Mississippi valley. This assignment was based on their high elevations, crosscutting relationships, and his assumption that all channel belts formed by glacial discharge during either the early-middle or late Wisconsin (OIS 4-3 or 2). However, Blum et al. (2000) suggested that the Dudley braid belt was Illinoian in age (OIS 6), based on its loess and soil stratigraphy, and the Rondo channel belt was early to middle Wisconsin (OIS 4-3) in age and its higher elevation was primarily due to its loess thickness (as thick as 15 m on the northern segment). These chronologies were based on relative age relationships. OSL ages indicate that the Rondo meander belt formed during the last interglacial (OIS 5a, 83 ± 7 ka) and the Dudley braid belt formed during OIS 4 (64 ± 5 to 50 ± 4 ka), and are consistent with meandering channel pattern on the Rondo surface and crosscutting relationships that indicate that the Dudley braid belt is younger than the Rondo meander belt (Fig. 6).

With the exclusion of the last interglacial (OIS 5) Paragould channel belt, mapped by Saucier (1994a) as early to middle Wisconsin (OIS 4-3) and by Blum et al. (2000) as late Wisconsin (OIS 2), the optical ages for the remaining lower Mississippi valley channel belts are generally consistent with previous relative age assignments.

LOWER MISSISSIPPI VALLEY LONGITUDINAL PROFILES

The application of OSL dating has allowed channel belts to be correlated between isolated regions of the lower Mississippi valley and longitudinal profiles to be constructed for the first time. The longitudinal profiles in Figures 9 and 10 (Figs. DR1 and DR2; see footnote 1) were created using the upper fluvial surface of the channel belts (elevation due to loess thickness removed) and plotted versus the length of the channel-belt path, through either the Western or Eastern Lowlands.

Examination of the lower Mississippi valley longitudinal profiles in Figure 9 indicates that the late Pleistocene braid belts have steeper gradients than the modern Mississippi River. This is most evident in the northernmost and southernmost reaches of the lower Mississippi valley. In the northern lower Mississippi valley, the first 40 km of braid belts have a convex profile and steep gradients of 0.30–0.23 m/km that diminish downstream to 0.20–0.18 m/km. This alluvial fan–like slope may be due to increased deposition at the mouth of the lower Mississippi valley as sediment-laden water flowed from the narrow bedrock-confined middle Mississippi valley into the broad alluvial lower valley.

In the central lower Mississippi valley, braid belts have reduced gradients (0.15 m/km) in

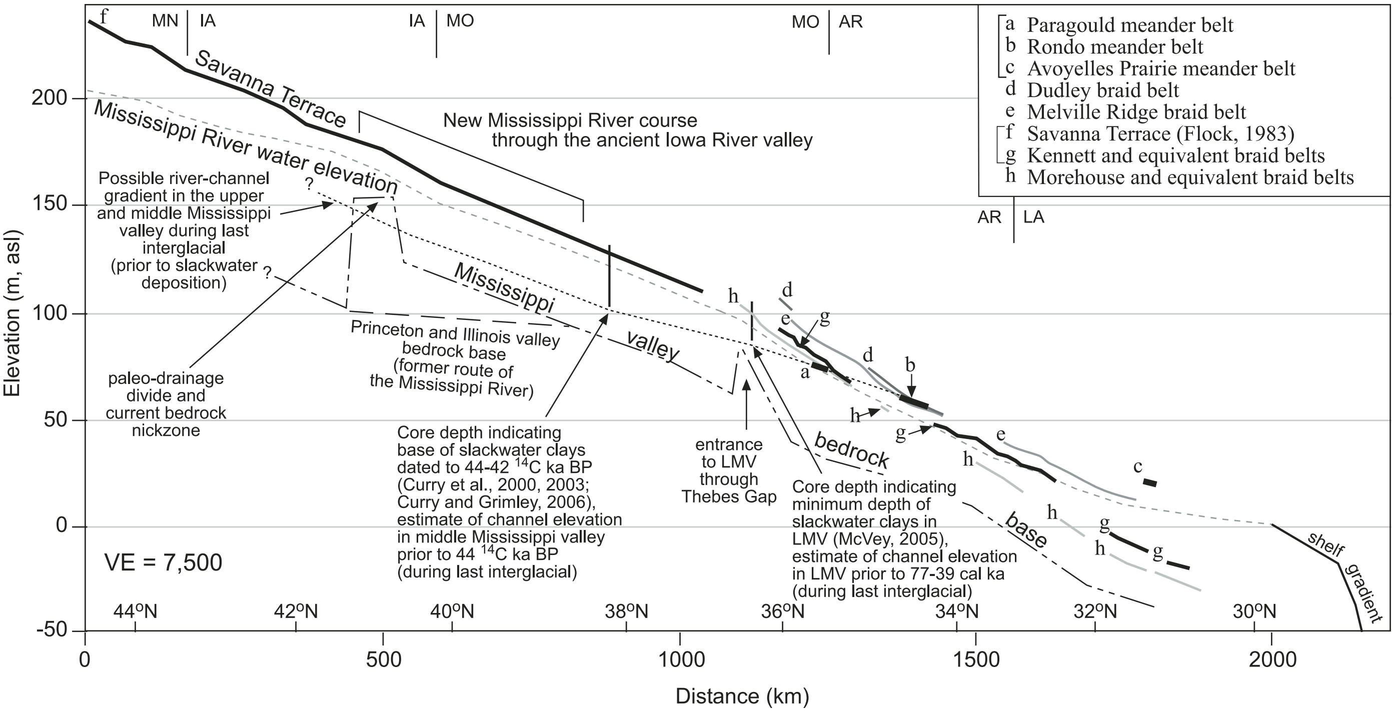

Figure 10. Longitudinal profiles of the Mississippi valley from Minnesota to the Gulf of Mexico; starting point is indicated by an asterisk in Figure 1. Profile of the Savanna Terrace in the upper Mississippi valley from Flock (1983). Bedrock valley profile of the upper Mississippi and Illinois valley (former route of the Mississippi River prior to 20–21 ^{14}C ka B.P.) is from Horberg (1950); lower valley profile same as Figure 9. Correlative fluvial deposits between the upper and lower Mississippi valley are indicated by brackets in the legend. The thickness and base of slackwater clays from the northern lower Mississippi valley (LMV) and middle Mississippi valley are shown (as vertical bars representing cores) in order to approximate last interglacial profile of the Mississippi River prior to slackwater aggradation when the Mississippi River flowed through the Illinois River Valley. Figure DR2 (see footnote 1) is an enlarged color version.

comparison to the northern and southern valley (Fig. 9). Most braid belts have gradients relatively similar to the average elevation of modern Mississippi River point-bar deposits (0.14 m/km). The Morehouse braid belt, however, has a steeper gradient (~0.18 m/km) and it begins to dip to below the Holocene flood plain in the central lower Mississippi valley (Fig. 9).

In the southern lower Mississippi valley, the OIS 3 braid belts remain exposed at the surface near the elevation of the modern flood plain until just north of lat 31°N (Figs. 8 and 9). South of this point they are either not preserved due to subsequent erosion, or they may be present in the subsurface. Late glacial Morehouse and Kennett-Sikeston braid belts, however, are buried in the southern lower Mississippi valley and dip to greater depths seaward (Fig. 9).

Two last interglacial (OIS 5) meander belts have been identified in this study that were previously mapped by Saucier (1994a) as early to middle Wisconsin (OIS 4-3) valley trains. These meander belts may correlate to Prairie Complex meander belts in the southern lower Mississippi valley (see Mateo, 2005) to create a tentative longitudinal profile of the Mississippi during the last interglacial. Correlation of these meander belts suggests that the last interglacial Mississippi River was similar in elevation and gradient to the modern river in the central and southern lower Mississippi valley (Fig. 9). The lower elevation of the Paragould channel belt may suggest that the OIS 5 river profile in the northern lower Mississippi valley was different from that today. The elevation of the Avoyelles Prairie meander belt in the southernmost lower Mississippi valley (Figs. 8 and 9) has been affected by flexural isostasy due to loading of the shelf.

EARLY WISCONSIN (OIS 4) AGGRADATION

Slackwater Deposits in Tributary Valleys

Slackwater clay deposits have been described in many tributary valleys of the middle Mississippi, Wabash, Illinois, and Ohio Rivers (Shaw, 1911, 1915; Frye et al., 1972; Heinrich, 1982; Flock, 1983; Trent, 1994). Slackwater deposits are buried at depth and fill formerly incised bedrock valleys below modern tributaries in the middle Mississippi valley and northern lower Mississippi valley. Flock (1983) suggested that these slackwater clays were derived from glacial meltwater spilling into drowned tributary valleys during meltwater floods and rapid main-channel aggradation.

Radiocarbon age estimates from upper slackwater clays in middle Mississippi River tributary valleys range from 19.2 to 9.6 ^{14}C ka B.P. (23–11.2 cal ka) (Hajic, 1990, 1991). Curry et al. (2000, 2003) and Curry and Grimley (2006) identified basal slackwater deposits overlying bedrock at 34.1 m depth at the mouth of a tributary valley near St. Louis, Missouri (21 m below the modern Mississippi River flood plain), that date to ca. 44.2–41.7 ^{14}C ka B.P. (This is near the limit for radiocarbon dating, and may represent minimum age estimates; no agreed-upon calibration is available for radiocarbon ages older than 21.4 ^{14}C ka B.P. [Reimer et al., 2002].)

In the northern lower Mississippi valley, Robnett (1997) identified slackwater deposits as much as 17 m below the flood plain at the mouths of filled tributary valleys (see also Blum et al., 2000). Radiocarbon ages indicate that deposition began prior to 22.8 ^{14}C ka B.P. (Table DR1; Fig. 3). Fine-grained luminescence ages from similar basal slackwater clays at 18.6 m depth and overbank deposits overlying slackwater clays to 13 m depth (5 and 8 m below the modern Mississippi flood plain, respectively) have produced basal ages of 40 ± 4 and 77 ± 4 ka, respectively, with cessation of deposition by 8814 ± 70 ^{14}C yr B.P. (9.9 ± 0.3 cal ka) (AA53822, McVey, 2005).

Interpretation of Slackwater Deposits

Evidence from slackwater deposits at the base of tributary valley fills in the middle Mississippi valley and northern lower Mississippi valley indicates that prior to initial OIS 4-3 slackwater deposition, the river was flowing at an elevation at least 8–21 m below the modern flood plain (Robnett, 1997; Blum et al., 2000; Curry et al., 2000, 2003; McVey, 2005; Curry and Grimley, 2006). These are minimum estimates of paleovalley elevation because they come from tributary valleys along the side of the main valley, which may have been lower in elevation. One interpretation of these data is that there was a large incision event during the early to middle Wisconsin stage (OIS 4-3), as suggested by Blum et al. (2000). An alternative interpretation is that the river was flowing at a lower elevation at the end of the last interglacial in the middle and northernmost lower Mississippi valley, and the valley rapidly aggraded during early Wisconsin glaciation (OIS 4), causing tributaries to fill with slackwater sediment.

The OIS 4-3 ages of initial slackwater deposition at 8–21 m depth in the middle Mississippi valley and northern lower Mississippi valley are roughly contemporaneous with the braid-belt record of valley aggradation and formation of the Dudley braid belt by 64 ± 5 to 50 ± 4 ka (Table 1). OSL ages from the Dudley braid belt, and all other channel belts, were collected from the upper 2–4 m of fluvial sediments and therefore represent the latest occupation and reworking of the channel-belt surface. More than 30 m of sediment underlie the Dudley braid belt (Fig. 6), although deep cores have not been collected to determine the depth of individual channel-belt fills or temporal limitations on aggradation. Therefore, the OSL ages from the Dudley braid belt are assumed to represent the end of valley aggradation and the period of channel stabilization at this level. The slackwater deposits in the northern Western Lowlands provide evidence for the timing of initial valley aggradation and suggest that aggradation of the Dudley braid belt may have begun by 77 ± 4 ka (McVey, 2005). The difference between the elevation of the Dudley braid-belt surface (~100 m asl) and the base of slackwater deposits (81–85 m asl; McVey, 2005) indicates that the northern lower Mississippi valley aggraded at least 15–19 m by the time of late OIS 4 to form the Dudley braid belt.

The depths of slackwater deposits and paleotributary valley bottoms are greater in the middle Mississippi valley than the northern lower Mississippi valley (21 m and 8 m below the modern flood plain, respectively). In the central and southern lower Mississippi valley, similar slackwater sediments are not present and the last interglacial meander belts are near the elevation of the Holocene meander belts. This trend suggests that the middle Mississippi valley was more deeply incised than the northern lower Mississippi valley, with little to no relative incision to the south.

MODERN VERSUS LAST INTERGLACIAL RIVER PROFILE

The presence of OIS 4-3 slackwater deposits at the base of buried tributary valleys of the middle Mississippi valley and northern lower Mississippi valley and buried OIS 5 channel sediments in a northern lower Mississippi valley tributary suggests that the river was flowing at a position as much as 8–21 m below the modern flood plain in the middle Mississippi valley and northern lower Mississippi valley during the last interglacial. This difference in river profile may be due to recent avulsions of the Mississippi River into the ancient Iowa River valley and through Thebes Gap.

During the last interglacial, the Mississippi River flowed toward the east in northern Illinois through the now-buried Princeton valley and occupied the current Illinois River valley (Horberg, 1950; Shaffer, 1954) (Fig. 1). Advance of the Lake Michigan lobe 21–20 ^{14}C ka B.P. (25–24 cal ka) blocked the Illinois valley and forced the river into its present course through the ancient Iowa River valley (from Clinton, Iowa, to the confluence with the Illinois River) (Horberg, 1950; Shaffer, 1954; Glass et al., 1964; Curry, 1998). This diversion routed the Mississippi River over a 60-km-long paleodrainage divide composed of Illinoian (OIS 6) glacial till over shallow Paleozoic bedrock (see Fig. 10) (Horberg, 1950). The Mississippi River currently flows through narrow bedrock gorges in this reach, and, prior to damming, dropped nearly 6 m over bedrock-controlled rapids (Horberg, 1950). The bedrock under the former Mississippi route through the Princeton and Illinois valleys is more than 60 m lower than in its new bedrock-confined reach (Fig. 10) (Horberg, 1950). Moreover, in the northern lower Mississippi valley the avulsion of the Mississippi River through Thebes Gap by 11.3 ± 0.9 ka similarly pinned the Mississippi River over shallow bedrock (Fig. 10).

The base of slackwater fill deposits can be used as an estimate of the elevation of the Mississippi River prior to aggradation and slackwater deposition in OIS 4. Core descriptions and OSL ages collected by McVey (2005) indicate that basal slackwater deposits and buried OIS 5 tributary channel deposits are found at similar elevations in the northern lower Mississippi valley, taking river gradient into account. This suggests that there was no major incision event preceding slackwater deposition, although cores containing OIS 5 channel deposits conformably overlain by slackwater deposits have yet to be found.

Using the elevation of OIS 5 meander belts, core data from the northern lower Mississippi valley (Robnett, 1997; Blum et al., 2000; McVey, 2005), and core data from the middle Mississippi valley (Curry et al., 2000, 2003; Curry and Grimley, 2006), we can estimate the longitudinal profile of the Mississippi River during OIS 5 (Fig. 10). These data suggest that the Mississippi River was flowing at an elevation at least 21 m below the modern flood plain in the middle Mississippi valley and 8 m below present in the northern lower Mississippi valley during the last interglacial, a situation only possible when the Mississippi River occupied the Princeton and Illinois valleys, where bedrock is at 60 m depth.

Regions of shallow bedrock along the modern river course through the ancient Iowa River and through Thebes Gap may have acted as impediments, preventing the Holocene Mississippi River from incising to its former level of the last interglacial. These bedrock influences appear to dissipate downstream near the latitude of the last interglacial Rondo meander belt, which is at an elevation similar to modern Mississippi point bars (Fig. 9). This difference in river gradient has produced the 8–21 m of relative aggradation recorded in slackwater sediments and may explain why fluvial deposits older than 25 ka are not seen at the surface in the upper and middle Mississippi valley.

CORRELATION TO UPPER AND MIDDLE MISSISSIPPI VALLEY TERRACES

Terraces in the upper and middle Mississippi valley have been examined by a number of researchers over the past century (see reviews by Hajic, 1990, 1991). Terrace correlation has been difficult due to the patchy terrace preservation, identification of correlative slackwater deposits in tributary valleys, and variable loess thicknesses.

Hajic (1990, 1991) identified five terraces at the confluence region of the Mississippi, Missouri, and Illinois Rivers: the loess-covered Gilead and Cuivre levels of the St. Charles Group, and the loess-free Savanna Terrace, Kingston Terrace, and the East Chouteau paleogeomorphic surface. The Savanna Terrace was previously recognized by Flock (1983), but the other terrace names were first developed by Hajic (1990, 1991) to group previously uncorrelated terraces.

The most likely candidate for correlation to lower Mississippi valley braid belts is the Savanna Terrace, which Flock (1983) traced from southern Minnesota to within 60 km of Thebes Gap (Fig. 10). The Savanna Terrace, which also includes the Deer Plain Terrace (Rubey, 1952), is an aggradational terrace capped by red and gray clay laminae in the main valley and composed of reverse-sloping slackwater clays at tributary mouths (Flock, 1983). Radiocarbon age estimates indicate aggradation between 13.7 and 13.0 ^{14}C ka B.P. (16.5–15.6 cal ka) and terrace abandonment by 12.3 ^{14}C ka B.P. (14.4 cal ka) (Hajic, 1990, 1991). Because the Savanna Terrace has a reverse slope at tributary mouths, the profile in Figure 10 may represent a minimum terrace elevation.

The Savanna Terrace (16.5 ka to older than 14.4 ka) is correlative in age with the Kennett braid belt (16.1 ± 1.2 to 14.4 ± 1.1 ka). Extension of the Savanna Terrace to the Kennett braid belt and proposed correlative buried channel belts in the Atchafalaya Basin provides a glimpse at the long valley profile of the Mississippi during deglaciation (Fig. 10), acknowledging that some level of isostatic rebound has occurred in the northern drainage basin (i.e., Clark et al., 1994). Additional research is needed to more accurately date the Savanna Terrace and other middle Mississippi valley terraces in order to produce long profiles of the entire Mississippi valley and provide more information about how the river responded to deglaciation at key time periods.

EVOLUTION OF THE LOWER MISSISSIPPI VALLEY

The new optical ages, correlations, and stratigraphic and/or geomorphic relationships presented here (summarized in Table 3) can be used to reconstruct the fluvial evolution of the lower Mississippi valley during the last glacial cycle. Key elements of this model for the northern lower Mississippi valley are summarized in Figure 11 and are discussed in the following.

The oldest deposits identified in this study are the Paragould and Rondo meander belts, dating to the end of the last interglacial period (85 ± 7 and 83 ± 7 ka; Fig. 11A). The scroll-bar topography on the Rondo segment suggests that the last interglacial Mississippi River remained in a meandering state as late OIS 5a. Slackwater deposits in the middle Mississippi valley and northern lower Mississippi valley indicate that prior to 77 ± 4 ka the Mississippi River flowed at an elevation at least 8–21 m below present in these reaches. Initial glaciation of the Mississippi drainage basin in OIS 4 caused rapid aggradation of the main valley and the filling of tributary valleys with slackwater sediment. Less relative aggradation is recorded in the middle and southern lower Mississippi valley.

By 64 ± 5 ka, the Mississippi River had switched into a braided regime and aggraded ~15–19 m in the northern lower Mississippi valley to the level of the Dudley braid belt (Fig. 11B). The Ohio River occupied the Eastern Lowlands at that time, and the Mississippi appears to have been confined to the Western Lowlands, evidenced by the large braid plain of the Dudley braid belt. The Mississippi River remained in the Western Lowlands during the formation of the Melville Ridge braid belt from 42 ± 3 to 35 ± 3 ka (Fig. 11C). By the time of the Ash Hill braid belt (27 ± 2 to 25 ± 2 ka) (Fig. 11D), the braided character of the river changed into one with large semi-stable braid-island bars (Fig. 7). Dune fields formed on the mid-channel bars during braid-belt occupation and remained active after abandonment. The reduced width of the Ash Hill braid belt in comparison with the former widths of the Melville Ridge and Dudley braid belts (Fig. 3) suggests that either lower Mississippi valley discharge was reduced at that time or that some meltwater had been diverted into the Eastern Lowlands.

After 25 ± 2 ka, the Western Lowlands were abandoned and the Mississippi River occupied the Eastern Lowlands (Fig. 11E). This avulsion was most likely due to higher aggradation of the Mississippi River in the Western Lowlands than the Ohio River in the Eastern Lowlands, although faulting along Crowleys Ridge (Van Arsdale et al., 1994, 1995) and the initial breach of the Bell City–Oran Gap (Saucier, 1994a) have been suggested as controlling mechanisms. As initially proposed by Blum et al. (2000), the formation of the Advance Splay at 21 ± 2 to 19 ± 1 ka effectively sealed off the Advance Lowlands and prevented Mississippi River water from reentering the Western Lowlands. Significant discharge in the Western Lowlands was limited to local drainages coming off the Ozark Plateau, as documented by the Black River meander belt, which occupied old channels of the Ash Hill surface between 21 ± 2 and 18 ± 1 ka.

In the Eastern Lowlands, the combined Mississippi and Ohio Rivers formed the Sikeston braid belt at 20 ± 2 to 18 ± 2 ka (Fig. 11E). Abandonment of the Sikeston level caused flow from the Mississippi and Ohio Rivers to be separated in the northern lower Mississippi valley by the Sikeston Ridge landform (Fig. 11F). To the west of Sikeston Ridge, the Mississippi River occupied the Kennett braid belt from 16 ± 1 to 14 ± 1 ka. At that time, the Mississippi River in the middle and upper Mississippi valley occupied the correlative Savanna Terrace. Subsequently, the Charleston (15 ± 1 to 14 ± 1 ka) and Blodgett (14 ± 1 to 13 ± 1 ka) braid belts formed east of Sikeston Ridge (Fig. 11G). The river source of the Charleston braid belt is ambiguous. Its northward slope suggests that it originated from either the Mississippi River through Thebes Gap (Ray, 1964; Porter and Guccione, 1994; Blum et al., 2000) or the Ohio River through the Cache valley. The formation of the Blodgett braid belt by the Ohio River is supported by (1) projection of the Brownfield terrace in the Cache valley to the Blodgett braid belt, (2) orientation of channels on the Blodgett surface (Fig. 7), and (3) the correspondence in optical ages from the Blodgett and Brownfield terrace (Table 1).

West of Sikeston Ridge, the Mississippi River formed the Morehouse braid belt 12.4 ± 1.0 to 12.1 ± 0.8 ka (Fig. 11H). The pristine and non-reworked nature of the braid channels and bars indicates that the Morehouse braid belt was rapidly abandoned after 12.1 ± 0.8 ka as the Mississippi River was fully captured into Thebes Gap. It is likely, as originally proposed by Fisk (1944), that Thebes Gap started to form earlier from repeated flood overflow into an upland valley in the highly dissected Benton Hills while most of the flow was discharging through the Bell City–Oran Gap. Following this avulsion, the Mississippi incised to the Commerce level, which was graded to the lowest braid belt at the mouth of the Ohio valley and to the elevation of the Morehouse braid belt south of Sikeston Ridge (Fig. 9). This completed avulsion into the narrow bedrock gorge of Thebes Gap was most likely driven by the lower elevation of the Ohio River in comparison to the fan-like aggraded channel path of the Mississippi River through the Bell City–Oran Gap (see Fig. 9). By 11.3 ± 0.9 ka, the late glacial Mississippi River in the northern lower Mississippi valley was flowing at about the same elevation as the modern Mississippi River, and Thebes Gap had been cut to its present depth (Fig. 11I). Crosscutting relationships with the Brownfield Terrace suggest that the Ohio River had abandoned the Cache valley by that time. After 11.3 ± 0.9 ka, the Mississippi River switched to a meandering regime (Fig. 11J).

RELATIONSHIP TO EXTERNAL FORCING

Previous models of lower Mississippi valley fluvial evolution have suggested that braid-belt

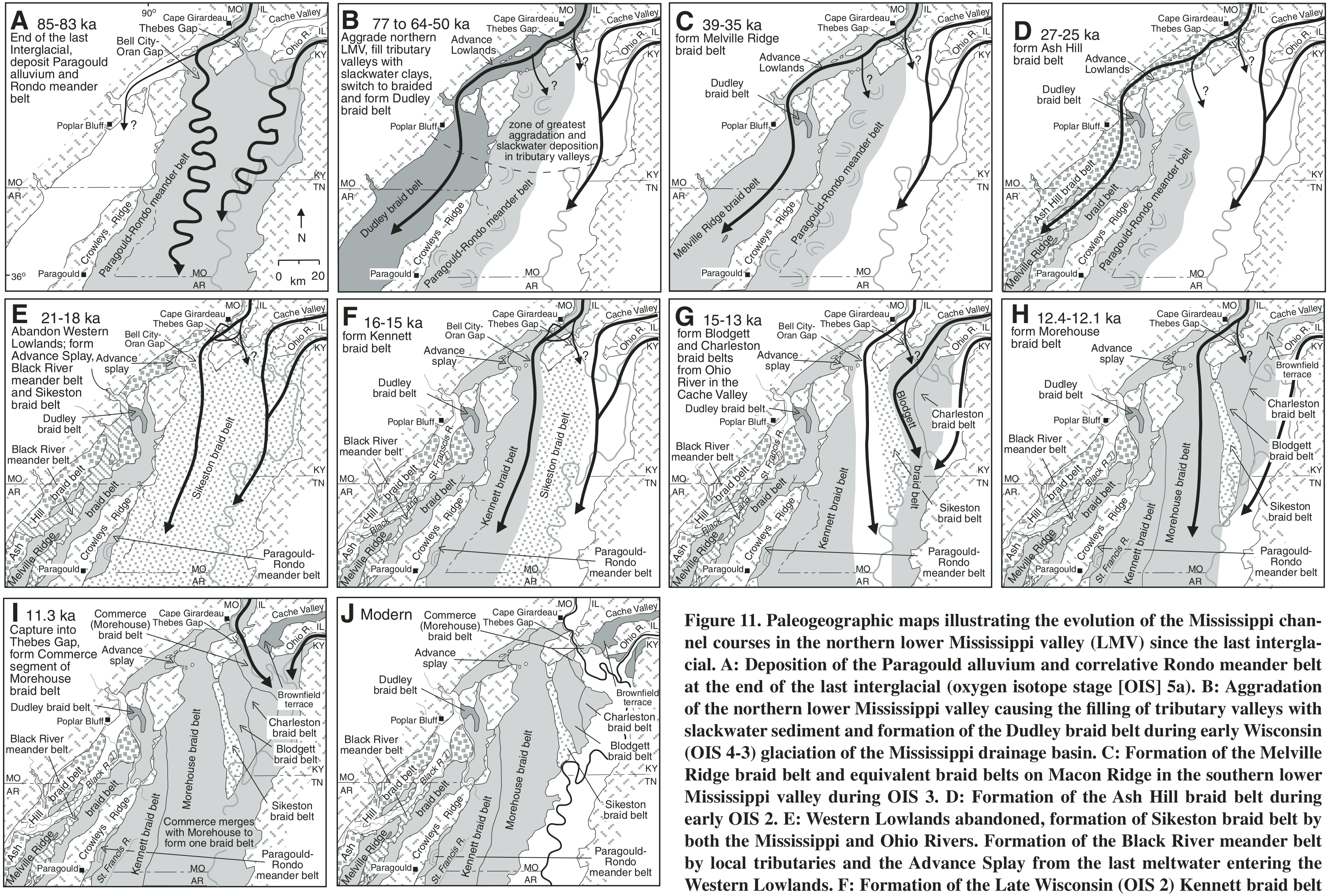

Figure 11. Paleogeographic maps illustrating the evolution of the Mississippi channel courses in the northern lower Mississippi valley (LMV) since the last interglacial. A: Deposition of the Paragould alluvium and correlative Rondo meander belt at the end of the last interglacial (oxygen isotope stage [OIS] 5a). B: Aggradation of the northern lower Mississippi valley causing the filling of tributary valleys with slackwater sediment and formation of the Dudley braid belt during early Wisconsin (OIS 4-3) glaciation of the Mississippi drainage basin. C: Formation of the Melville Ridge braid belt and equivalent braid belts on Macon Ridge in the southern lower Mississippi valley during OIS 3. D: Formation of the Ash Hill braid belt during early OIS 2. E: Western Lowlands abandoned, formation of Sikeston braid belt by both the Mississippi and Ohio Rivers. Formation of the Black River meander belt by local tributaries and the Advance Splay from the last meltwater entering the Western Lowlands. F: Formation of the Late Wisconsin (OIS 2) Kennett braid belt during deglaciation. G: Deposition of the Blodgett and Charleston braid belts by the Ohio River or combined Mississippi and Ohio Rivers during a period of incision of the Mississippi River. H: Formation of the late Wisconsin (late OIS 2) Morehouse braid belt during deglaciation. Ohio River has abandoned Cache valley. I: Capture of the Mississippi River entirely into Thebes Gap and continued formation of the Morehouse equivalent Commerce braid belt, the youngest braid belt in the lower Mississippi valley. J: Modern geomorphic setting.

formation and abandonment were controlled by eustatic sea-level change (Fisk, 1944) or upstream variations in meltwater and sediment discharge (Saucier, 1994a, 1994b; Blum et al., 2000). The development of a new lower Mississippi valley braid-belt chronology allows the influence of these external forcings to be investigated further.

Relationship to Glaciation

The lower Mississippi valley channel-belt and slackwater records indicate that the Mississippi River was meandering during the last interglacial as late as 85 ± 7 to 83 ± 7 ka (OIS 5a), then switched to a braided regime and aggraded ~15–19 m in the northern lower Mississippi valley to the level of the Dudley braid belt by 64 ± 5 to 50 ± 4 ka; on the basis of slackwater sediments, initial valley aggradation began as early as 77 ± 4 ka. This change in river morphology and dynamics suggests that it was responding to a change in discharge and/or sediment load, possibly due to glaciation of its headwaters. During this period (OIS 4), the Laurentide ice sheet grew to the point that ice extended into the St. Lawrence valley and the eastern Great Lakes (Lamothe and Huntley, 1988; Hillaire-Marcel and Causse, 1989; Dreimanis, 1992; Berger and Eyles, 1994). While consistent with this case, a switch to a braided channel pattern does not explicitly indicate glaciation within a catchment basin (i.e., Leigh et al., 2004; Straffin et al., 2000).

Evidence for OIS 4-3 glaciation of the Mississippi drainage basin and meltwater discharge has come from slackwater sediments indicating rapid valley aggradation in the middle Mississippi valley and northern lower Mississippi valley by 44.2–41.7 ^{14}C ka B.P. (Curry et al., 2000, 2003; Curry and Grimley, 2006) and 77 ± 4 ka (McVey, 2005), respectively, and oxygen isotope stratigraphies from the Gulf of Mexico indicating meltwater discharge in the Mississippi River during OIS 4 (Joyce et al., 1990, 1993) and OIS 3 (Hill et al., 2002, 2006). Additional evidence for meltwater discharge during OIS 3 is provided by the distribution of Roxana Silt (55–27 ^{14}C ka B.P.; Leigh and Knox, 1993), which was blown from glacial outwash in the Mississippi and Illinois River valleys (Johnson and Follmer, 1989; Leigh, 1994). Microfossil assemblages from basal slackwater deposits (Curry et al., 2000, 2003; Curry and Grimley, 2006) and oxygen and carbon isotopes from speleothems in Crevice Cave (Dorale et al., 1998) record cooler and more continental climates in the middle Mississippi valley after 55 ka due to ice-sheet growth. In addition, the presence of ice as far south as Iowa by OIS 3 is inferred from a radiocarbon age of 40,630 ± 890 ^{14}C yr B.P. (ISGS-3466, Curry, 1998) from coarse-grained basal Roxana Silt in the ancient Iowa River valley prior to the diversion of the Mississippi River into this valley (Curry, 1998).

A more detailed record of glaciation and meltwater-discharge is available for the past 20 k.y. Reconstructions suggest that most meltwater from the central Laurentide ice sheet drained into the Mississippi River during the Last Glacial Maximum (LGM) (Teller, 1990a; Licciardi et al., 1999). However, during deglaciation, ice-lobe fluctuations caused meltwater from the Mississippi drainage to be repeatedly rerouted to the North Atlantic or Arctic Ocean, causing high-amplitude discharge fluctuations in the Mississippi River (Teller, 1990a; Licciardi et al., 1999). Fluctuations in meltwater influx into the Gulf of Mexico during deglaciation have been documented by many researchers (Kennett and Shackleton, 1975; Emiliani et al., 1978; Leventer et al., 1982; Broecker et al., 1989; Spero and Williams, 1990; Flower and Kennett, 1990; Marchitto and Wei, 1995; Brown and Kennett, 1998; Aharon, 2003; Flower et al., 2004).

Comparison of the timing of formation of the youngest three major braid belts (Sikeston, Kennett and Morehouse) with meltwater records from the Gulf of Mexico and the Greenland Ice Core Project (GRIP) δ^{18}O temperature record suggests that periods of braid-belt construction correspond to colder intervals with relatively reduced discharge (Fig. 12). Periods of river incision (reflected by gaps in the OSL chronology) correspond to warmer periods characterized by high discharge and peak flood pulses. Difference in the timing of peak meltwater discharge in the marine records most likely reflects uncertainties in the individual core chronologies (Fig. 12).

A similar correlation is seen when the lower Mississippi valley braid-belt record is compared to the Licciardi et al. (1999) calculated meltwater discharge curve for the Mississippi River (Fig. 12E). Periods of braid-belt formation and/or occupation occurred during periods of reduced modeled discharge in the Mississippi River, when ice retreat opened lower drainages to the North Atlantic or Arctic Ocean. The time periods when the river was incising from one braid-belt level to the next lower level (gaps in the chronology) correlate with periods of increased calculated discharge in the Mississippi River due to ice readvance in the Great Lakes region and rerouting of meltwater into the Mississippi drainage system. Overall, the Mississippi River appears to have undergone incision during periods of high discharge and aggradation, or stabilization during reduced discharge periods.

Before further discussion of the relationship between meltwater discharge and the lower Mississippi valley fluvial record, note that the exact timing and position of ice lobes and the resultant drainage routings during deglaciation are poorly dated and there is debate over the direction of meltwater routing during the Younger Dryas (ca. 12.8–11.5 ka) (see Fisher et al., 2006; Teller and Boyd, 2006; Lowell et al., 2005; Teller et al., 2005). Due to complications in this still-unfolding reconstruction of Lake Agassiz drainage history, we use the most recent compilations and reconstructions of Licciardi et al. (1999) and Teller et al. (2005), noting that future adjustments to these reconstructions may be needed.

In relationship to specific ice-marginal positions and modeled meltwater-flow regimes, the Sikeston (19.7 ± 1.6 to 17.8 ± 1.3 ka) and Kennett (16.1 ± 1.2 to 14.4 ± 1.1 ka) braid belts formed during the poorly dated Erie Interstade and Mackinaw Interstade, respectively, when ice retreat allowed meltwater from the eastern Great Lakes to drain into the North Atlantic via the Hudson River (see Licciardi et al., 1999, for review). Subsequent readvances diverted meltwater back into the Mississippi River and are proposed to have caused braid-belt abandonment and incision. During the Younger Dryas (12.8–11.5 cal ka), discharge in the Mississippi River was substantially reduced due to the rerouting of glacial Lake Agassiz drainage to the North Atlantic or Arctic Ocean (Teller et al., 2005). The formation of the Morehouse braid belt (12.4 ± 1.0 to 11.3 ± 0.9 ka) coincided with this low-discharge period. Overflow from Agassiz may have returned to the Mississippi River between 9.4 and 9.3 ^{14}C ka B.P. (10.6–10.4 cal ka) with final withdrawal of meltwater from the Mississippi drainage basin ca. 9.3 ^{14}C ka B.P. (10.4 cal ka) (Teller et al., 2002, 2005). This loss of meltwater discharge coincides with the transition of the Mississippi River from a braided regime to a meandering river by 9.1 ^{14}C ka B.P. (10.1 cal ka) (Table DR1) (Guccione et al., 1988b), suggesting a direct link between channel morphology and glacial sediment and meltwater input to the system.

Relationship to Sea-Level Change

Braided channel belts in the lower Mississippi valley formed between 64 ± 5 and 11 ± 1 ka, while eustatic sea level was as much as 125 m below present (Fig. 13) (Shackleton, 1987; Chappell et al., 1996). The relative influence of sea level on lower Mississippi valley channel belts can be determined from the longitudinal profile (Fig. 9). It is assumed that variations in upstream discharge and sediment load will control the formation and abandonment of channel belts throughout the lower Mississippi valley, while eustatic-controlled incision and aggradation will dissipate in the upstream direction.

Examination of the lower Mississippi valley longitudinal profile reveals that the relative relationship between channel belts is preserved throughout the valley (no crossovers), and the channel belts project to shoreline positions below modern sea level (Fig. 9). Eustatic sea-level fall did not cause incision between channel belts, because this pattern can be traced throughout the lower Mississippi valley and was controlled by fluctuations in meltwater discharge (Figs. 9 and 12). Instead, lowered sea level was necessary to allow incision to occur, and facilitated greater incision in the southern lower Mississippi valley. In addition, the incision between late glacial braid belts occurred during rapid eustatic sea-level rise. For example, the upstream-driven incision between the Kennett and Morehouse braid belts (15.0–12.4 ka) occurred during a period of rapid sea-level rise (Lambeck et al., 2002) and global Meltwater Pulse 1A (Fairbanks, 1989; Bard et al., 1996) (Fig. 13). These data suggest that, unlike as first envisioned by Fisk (1944), incision between channel belts was driven by upstream variations in discharge and sediment load, while lowered sea level controlled the elevation to which the channel belts were graded and provided the means to allow greater incision in the southern lower Mississippi valley.

In the southern lower Mississippi valley, the OIS 3 age Melville Ridge and Lower Macon Ridge braid belts (42 ± 3 to 30 ± 2 ka, collectively) are exposed at the surface, whereas the next younger and adjoining OIS 2 channel belts are buried by at least 20 m of backswamp mud (Sikeston, Kennett, and Morehouse channel belts, 20 ± 2 to 11 ± 1 ka). This relationship suggests that prior to 30 ka the lower Mississippi River profile and elevation was similar to today, with no evidence of base-level–influenced incision north of lat 31°N. Between 30 and 20 ka, >20 m of incision occurred in the southern lower Mississippi valley prior to construction of the OIS 2 channel belts graded to lower base levels. These data suggest that some threshold may have been reached just after 30 ka that initiated incision in the southern lower Mississippi valley. Recent sea-level reconstruction models suggest that sea level rapidly fell to the LGM lowstand position at 30 ka and remained low until 19 ka (Lambeck et al., 2002). This rapid drop in sea level below the continental shelf may have been the catalyst for the rapid incision in the southern lower Mississippi valley between 30 and 20 ka.

Overall, the lower Mississippi valley braid belts have a steeper gradient than the modern Mississippi River and dip below the flood plain in the southern lower Mississippi valley (Fig. 9). In the northern lower Mississippi valley this geometric relationship is due to enhanced deposition at the mouth of the valley as the river enters the

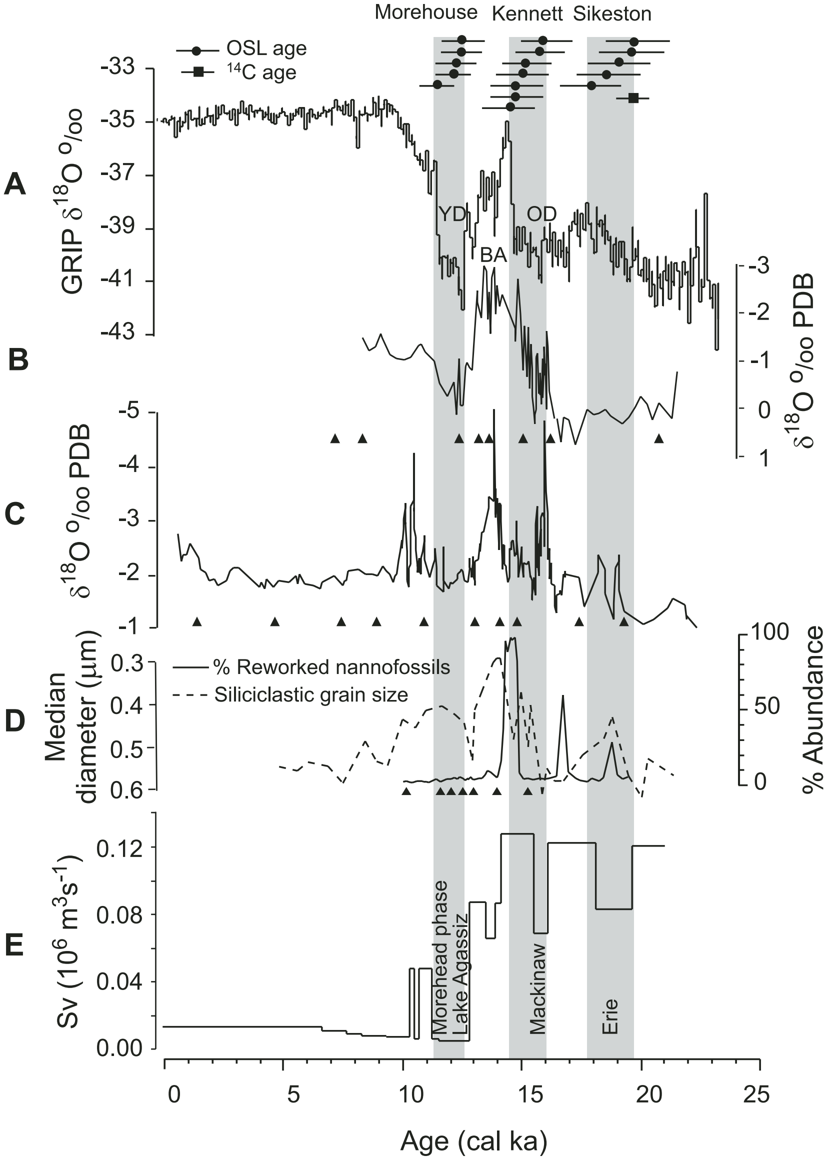

Figure 12. Comparison of the optical (OSL—optically stimulated luminescence) and calibrated radiocarbon ages of the youngest major braid belts to climate and meltwater proxy records and discharge models. A: The Greenland Ice Core Project (GRIP) δ^{18}O temperature record using the new ss09sea chronology (Johnsen et al., 2001); Younger Dryas (YD), Bølling-Allerød (BA), and Older Dryas (OD) climate events are indicated . The δ^{18}O foram records of meltwater influx into the Gulf of Mexico from (B) the Orca Basin (Flower et al., 2004) and (C) stacked δ^{18}O records from the continental shelf slope (Aharon, 2003). PDB is Peedee belemnite. D: Other records interpreted to represent flood erosional intensity and meltwater influx into the Gulf of Mexico. Decreased siliciclastic grain size (up in figure) from core EN32-PC6 (Brown and Kennett, 1998) and percent reworked calcareous nannofossils as percent of total nannofossil assemblage from core EN32-PC4 (Marchitto and Wei, 1995) are both interpreted to represent greater flood erosion in the Mississippi drainage basin. E: Licciardi et al. (1999) calculated meltwater discharge curve for the Mississippi River. The Erie and Mackinaw Interstadials, when meltwater from the eastern Great Lakes is proposed to have been diverted from the Mississippi River to the North Atlantic (Licciardi et al., 1999), are indicated along with the Morehead Phase of glacial Lake Agassiz, when drainage switched from the Mississippi River to the North Atlantic or Arctic Ocean (Teller et al., 2005). Triangles indicate the location of radiocarbon ages from marine cores; the original age model is used in all records with calibration of radiocarbon time scales to calendar yr B.P. using CALIB 5.0 (Stuiver and Reimer, 1993) where needed.

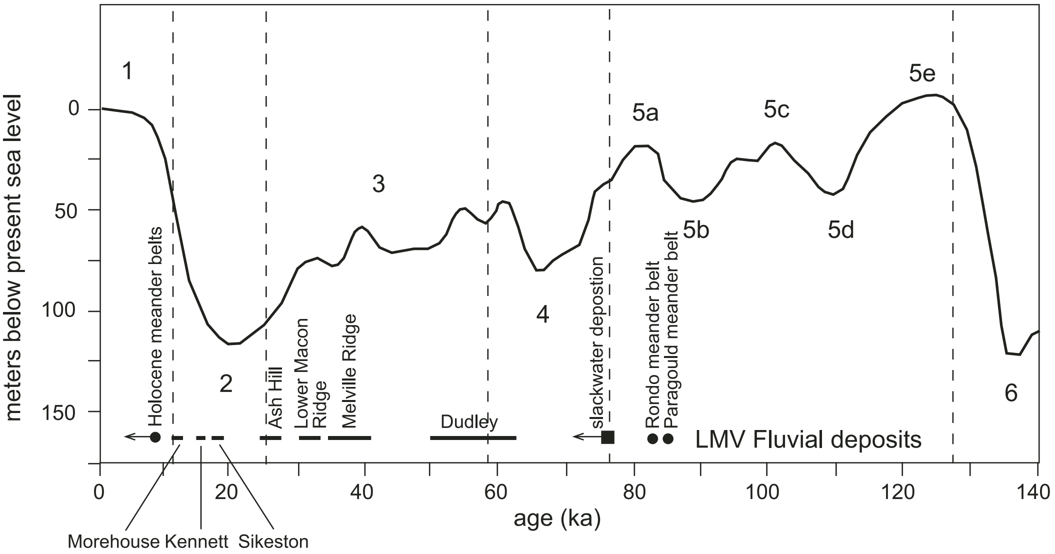

Figure 13. Composite relative sea-level curve (Waelbroeck et al., 2002) with marine oxygen isotope stages and boundaries (dashed lines). Also shown are the age ranges of major braid belts (lines), meander belts (circles), and the timing of initial slackwater deposition in the northern lower Mississippi valley (LMV) by 77 ka (McVey, 2005).

broad lower Mississippi valley. At some point downvalley, the LGM Mississippi River profiles are affected by and graded to lower sea levels. Blum and Törnqvist (2000) proposed that the upstream limit of sea-level influence on a river system is the point at which flood-plain surfaces constructed during lowstand and falling-stage sea level are buried by the modern flood plain. Using this definition, the upstream limit of sea-level influence on the lower Mississippi valley is located where the Sikeston-Kennett braid belts dips below the Holocene flood plain, ~400 km inland of the average coastal shoreline (~500 km from the present mouth of the river), near Greenville, Mississippi (Fig. 8). If this definition is extended to include late glacial channel belts, then the upstream limit of sea-level influence is located where the Morehouse braid belt is first buried by Holocene backswamp mud, 650 km inland of the coast, near Memphis, Tennessee (Figs. 2 and 3). These estimates are greater than the 250–350 km inland limit of sea-level influence proposed by Saucier (1994a) and Blum et al. (2000), but much less than the 900 km influence envisioned by Fisk (1944). This inland extent of sea-level influence may be unique to the Mississippi River and other large low-gradient rivers that occupy thick alluvial valleys along passive continental margins. Steeper-gradient rivers are expected to have less extensive sea-level influence and lowstand flood-plain burial positions closer to the modern coastline.

Relationship to Tectonic Activity

Throughout this paper, interpretations of the lower Mississippi valley fluvial records have been made assuming that tectonic warping of the region has been minimal, local in nature, and has not influenced past fluvial dynamics. However, the lower Mississippi valley contains a number of tectonically active zones, including the well-known New Madrid seismic zone, which has influenced channel patterns of the Holocene Mississippi River (Holbrook et al., 2006). In addition, the effect of regional warping on Holocene tributaries and abandoned channel courses at a number of locations has been described (i.e., Russ, 1982; Burnett and Schumm, 1983; Spitz and Schumm, 1994). Although we recognize that crustal deformation and displacement may be locally important, these low-amplitude, small-scale regions have little influence on the reconstruction of the 1000-km-long lower Mississippi valley as a whole.

CONCLUSIONS

The application of optical dating to the lower Mississippi valley channel-belt deposits has produced the first detailed chronology of lower Mississippi River evolution during the last glacial cycle. Fluvial deposits range in age from OIS 5a interglacial meander belts to large OIS 4 to OIS 2 braid belts that can be traced throughout the lower Mississippi valley. Examination of these deposits has revealed high-amplitude changes in river profile and morphology over the past 100 k.y. in response to climate-induced (glacial) changes in discharge and sediment load. For example, during OIS 4 glaciation of the Mississippi headwaters, the northern lower Mississippi valley aggraded 15–19 m from its last interglacial profile and switched to a braided regime in response to increased glacial sediment and meltwater discharge. Based on the preserved channel belt record, the Mississippi remained braided during glaciation from 64 ± 5 to 11 ± 1 ka until final withdrawal of meltwater ca. 9.3 ^{14}C ka B.P. (10.4 cal ka) (Teller et al., 2002). The formation and abandonment of braid belts were controlled by variations in glacial meltwater and sediment discharge, while glacio-eustatic sea level controlled the elevation to which the braid belts were graded, causing late glacial braid belts to dip below the Holocene flood-plain surface.

Avulsions of the river channel out of its former course down the Illinois River and through the Bell City–Oran Gap have influenced the modern Mississippi River profile. Slackwater deposits indicate that the Mississippi River was flowing at a position at least 21 m below present in the middle Mississippi valley and 8 m below the modern flood plain in the northern lower Mississippi valley during the last interglacial. Avulsions into its current course down the ancient Iowa River valley and through Thebes Gap have pinned the modern Mississippi River over regions of shallow bedrock, possibly preventing incision to its last interglacial position and slope profile.

The new chronology, braid-belt correlations, and longitudinal profiles presented here provide the opportunity to test previous models of lower Mississippi valley braid-belt formation. Fisk's (1944) pioneering research suggested that lower Mississippi valley fluvial evolution was strictly controlled by eustatic sea-level change, with deep incision during the LGM and aggradation and braid-belt construction during Holocene sea-level rise. Saucier (1994a) and Blum et al. (2000) suggested that sea level had a minimal influence (restricted to the lower 250–350 km of the valley), and instead braid belts formed in response to glacially induced changes in sediment supply and discharge during the early and late Wisconsin (OIS 4-3 and OIS 2) (Saucier, 1994a) or Illinoian and late Wisconsin (OIS 6 and OIS 2) (Blum et al., 2000).

The application of OSL dating to the lower Mississippi valley has indicated that braid belts formed throughout the last glacial cycle, from 64 ± 5 to 11 ± 1 ka (OIS 4 to early OIS 1). Correlation to meltwater proxy records in the Gulf of Mexico and calculated discharge curves suggests that braid-belt construction and abandonment was controlled by upstream fluctuations in meltwater discharge (Fig. 12), supporting Saucier's (1994a) original hypothesis. Analysis of lower Mississippi valley longitudinal profiles suggests that late glacial braid belts are graded to lower sea levels and dip below the flood plain in the southern lower Mississippi valley (Fig. 9). The upstream limit of sea-level influence may be as great as 650 km inland of the coast, near Memphis, Tennessee, where the Morehouse braid belt is first buried by the Holocene flood plain. However, unlike as envisioned by Fisk (1944), lowered late glacial sea level did not force incision, but instead provided the space to allow greater upstream-driven incision to occur in the southern lower Mississippi valley.

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