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The Kankakee Torrent and other large meltwater flooding events during the last deglaciation, Illinois, USA

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ABSTRACT

Evidence of the Kankakee Torrent (Ekblaw and Athy, 1925) includes boulder bars formed on a scoured bedrock surface west of Kankakee, Illinois, and overflow channels that connect several moraine-dammed basins (Wauponsee, Watseka, and Pontiac; Willman and Payne, 1942). Geomorphic evidence of a large scale flood event in the Illinois Valley includes features such as erosional residuals (Hajic, 1990). The age of the Kankakee Torrent is about 19,000 cal yr BP based on the pooled mean of four radiocarbon ages of tundra plant stems and leaves from the Oswego channel complex (median probability = 18,930 cal yr BP, $\sigma 1$ range, 18,870–18,970 cal yr BP). Analysis of recently obtained sediment cores from the middle Illinois River valley near Havana, Illinois, has revealed the bedrock surface is defended by a mantle of bouldery debris buried by 15 m of mostly slackwater lake sediment. Radiocarbon ages of needles archived in the lake sediment reveal evidence for an early lake phase that postdates the Kankakee Torrent (18,030–17,530 cal yr BP) and a later lake phase (15,690–13,040 cal yr BP). The radiocarbon ages indicate that the deeply buried bouldery rubble was deposited by the Kankakee Torrent. Consideration of isostasy indicates that the earlier lake phase at Havana may have been associated with downward flexure of land surface in response to glacier loading. The younger lake phase was caused in part by deposition of a sediment dam (the Savanna–Deer Plain terrace) at the mouth of the Illinois River. The lake shoaled due to passing of the isostatic forebulge across the area.

1. Introduction

The landscape of northeastern Illinois is characterized by ground moraine and lake plains interrupted by subtle, arcuate, low-relief (<40 m) moraines cross-cut by river valleys (Fig. 1). The largest valleys have long reaches that are relatively deep and steep-sided, and contain evidence of large-scale flooding, such as erosional residuals, pendant, alcove, and other large bars, and a well-defined inner channel (Lord and Kehew, 1987; Hajic, 1990; Clayton et al., 1999). The Kankakee Torrent (KT) was hypothesized by Ekblaw and Athy (1925) to account for an area with rubble bars and boulders on bedrock strath terraces located west of the City of Kankakee, Illinois (Fig. 2). The first geologists working in the region (Bradley, 1870; Chamberlin, 1883; Leverett, 1899) attributed vast plains formed of surficial deposits of well-sorted fine sand and stratified silt and clay to proglacial lakes named glacial lakes Wauponsee, Watseka, Pontiac, and Ottawa by Willman and Payne (1942; Fig. 2). Following Bradley (1870), Ekblaw and Athy (1925) speculated that the lake water was meltwater sourced from glacial margins in northwestern Indiana and southern Michigan. Willman and Payne (1942) reasoned that meltwater flowed into Wauponsee Basin, filling it to overflowing, and eventually breaching the Marseilles Morainic System. In general, we agree with their history of subsequent basin fillings and overflow events. Our contribution to the understanding of the KT is improved estimates of its age. In addition, we present a GIS-based evaluation of probable overflow routes, lake and overflow sill altitudes, and lake extent using new digital elevation models (DEMs) that have been adjusted to account for glacial isostasy at 19,000 cal yr BP.

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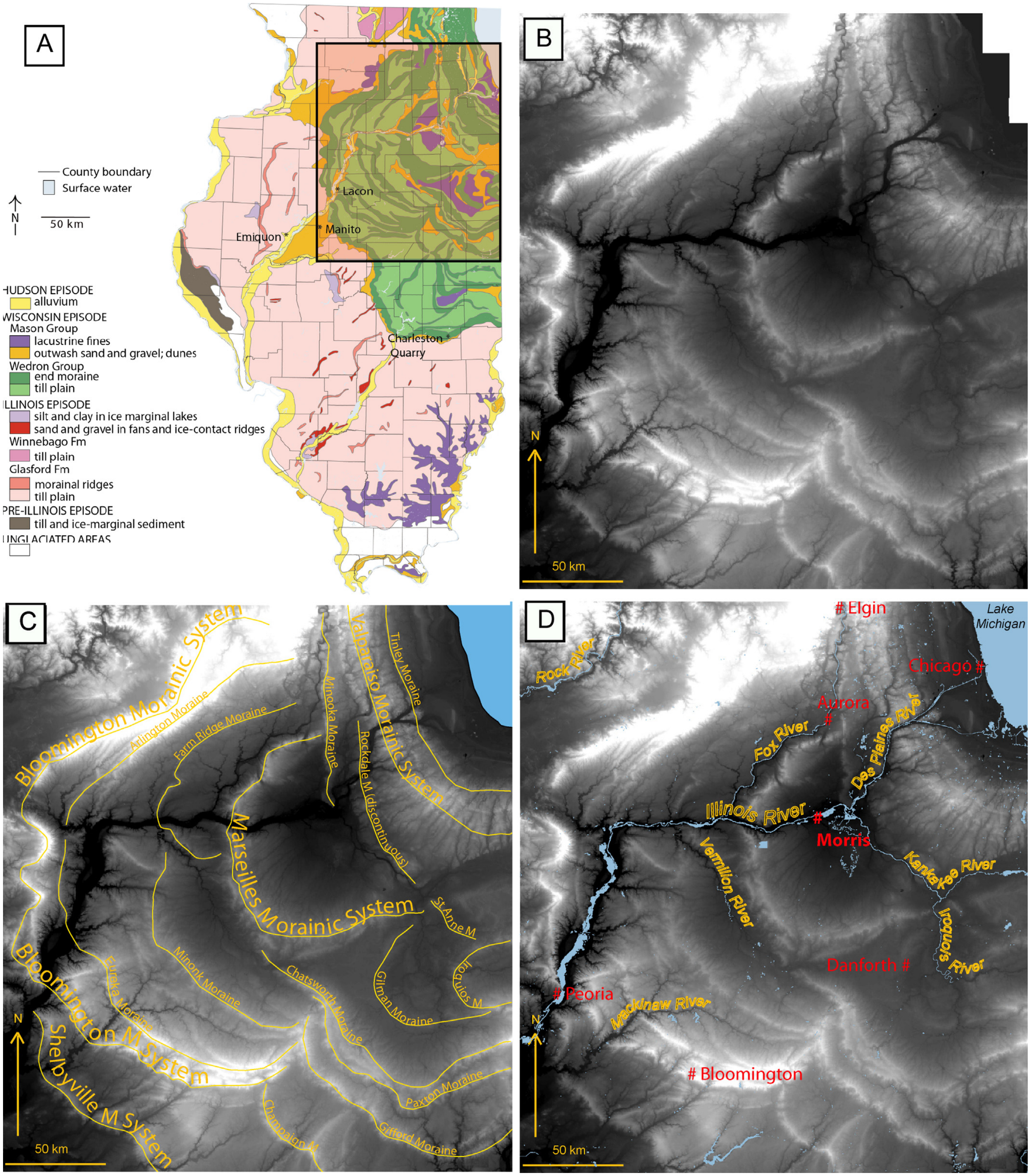

Fig. 1. A. Simplified surficial geologic map of Illinois. The locations of Fig. 1B–D are indicated by the large, shaded rectangle. Also noted are the locations of Charleston Quarry, Emiquon National Wildlife Refuge, Manito, and Lacon sites discussed in the text. Fig. 1B–D. The base maps are a shaded 30-m digital elevation model (DEM) of northeastern Illinois, with black shades denoting the lowest elevations, and white shades, the highest. The elevations have been adjusted to reflect isostatic crustal warping due to the weight of the Laurentide Ice Sheet at 19,000 yr (Clark et al., 2008). Fig. 1C indicates the crests of named moraines and morainic systems. Fig. 1D highlights rivers and communities.

1.1. Lithostratigraphic and chronological framework

Evidence for fluctuations of the Lake Michigan lobe of the south-central Laurentide Ice Sheet during the last deglaciation is revealed in glaciogenic successions exposed and interpreted from outcrops and cores. Radiocarbon ages on wood fragments at several key sections and cross-cutting geomorphological relationships provide the framework for the diachronic (time) classification of Hansel and

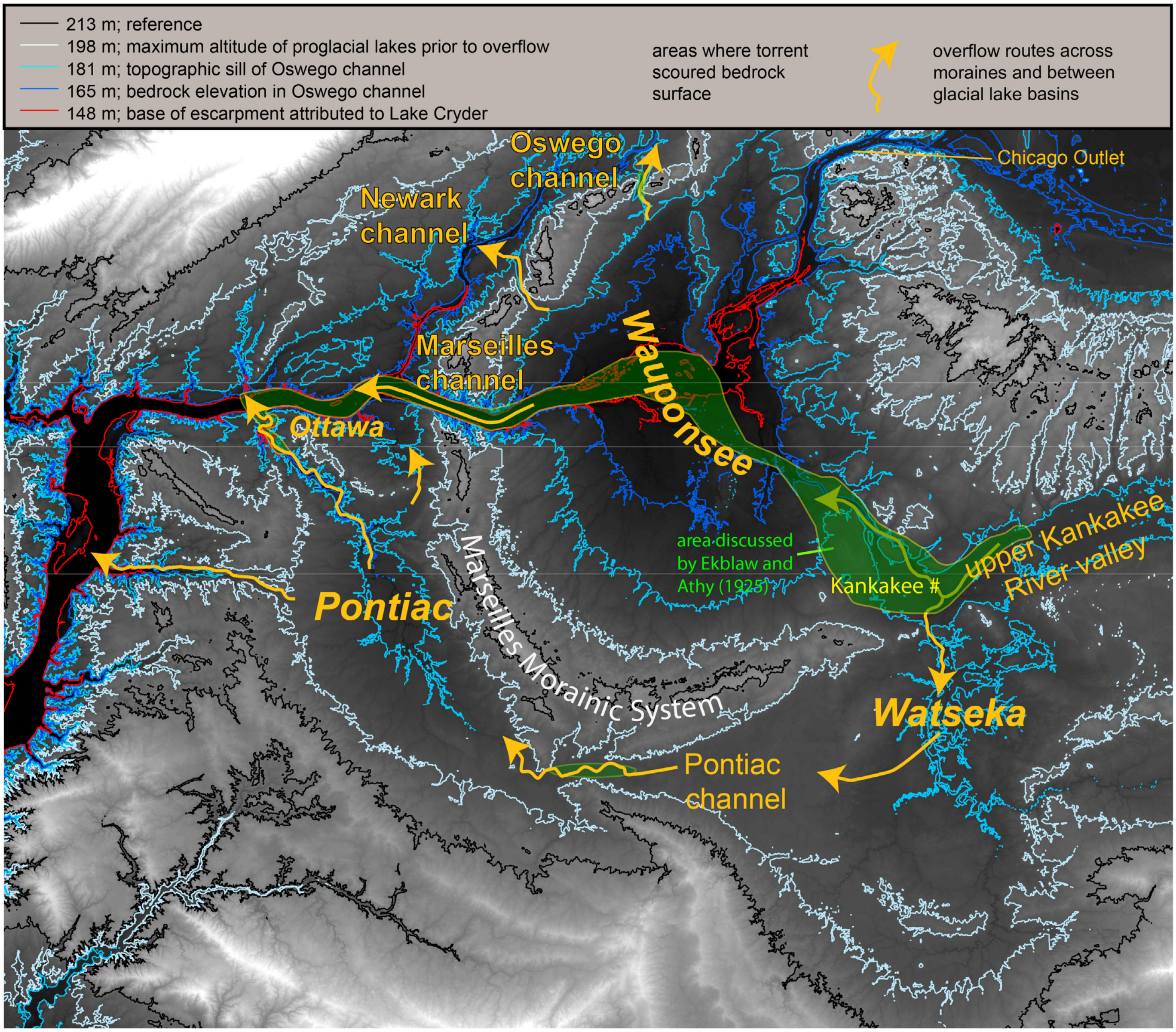

Fig. 2. Basins associated with major proglacial lakes outlined in part by 198 m contours (lightest blue), including the Wauponsee, Watseka, Pontiac, and Ottawa Basins. Orange arrows show overflow pathways between basins and across the Marseilles Morainic System. The system was graded to bedrock surfaces which are locally exposed in the areas shaded green. The shaded DEM is from 30-m topographic data, and has been isostatically adjusted to conditions at 19,000 yr using the model of Clark et al. (2008). On the map, lowest elevations are shaded black and highest elevations, white.

Johnson (1992, 1996), though results presented here pose new questions for some stratigraphic correlations and geomorphic interpretations. The history of the last deglaciation of the Lake Michigan lobe began after the lobe advanced to its southernmost point near Charleston, Illinois, at 39.33° N at about 23,290 cal yr BP (Table 1; Fig. 3; Hansel and Johnson, 1996; Hansel et al., 1999; Curry and Petras, 2011). By about 17,000 cal yr BP, the Lake Michigan lobe had retreated into Glacial Lake Chicago (the name given to proto-Lake Michigan during the last deglaciation) never again to become a land-based glacier in Illinois.

The radiocarbon ages of tundra plant fossils archived in the laminated sediments of former ice-walled lakes scattered on moraines provide unprecedented temporal control on the age of most glacial phases (Curry et al., 2010; Curry and Petras, 2011). The ice-walled lakes formed in stagnant, dead-ice permafrost; radiocarbon ages of the tundra fossils from the base of the lacustrine successions provide a minimum age for the onset of stagnation. Ages from the top of the lacustrine successions provide a minimum age for the persistence of dead glacier ice. The collective radiocarbon data indicates that individual ice-walled lakes persisted on the deglacial landscape for about 250 to 1500 years (Curry, 2008; Curry et al., 2010; Curry and Petras, 2011). The ice-walled lake plains located on the Marseilles Morainic System adjacent to the Newark channel indicate dead-ice permafrost lasted from about 22,140 to 21,430 cal yr BP (Fig. 3; Curry and Petras, 2011).

2. Glacial isostasy

In this region, glacial-isostatic rebound must be considered when evaluating deglacial meltwater routes and correlating the

Table 1

List of radiocarbon and OSL ages. The radiocarbon ages were calibrated on-line with IntCal13 (Reimer et al., 2013) using Calib 7 (Stuiver and Reimer, 1993).

Lab number	Site	Material dated	Ref.	^{14}C age	σ1 error	Calibrated age			Pooled mean statistics (Ward and Wilson, 1978)	
						σ1 (up)	σ1 (down)	Median prob.	Student's *T*-test	Chi-squared
Time–distance diagram (Fig. 3)										
ISGS-2842	Charleston Quarry	Wood	1	19,980	150	23,855	24,230	24,040		
ISGS-2918	Charleston Quarry	Organic debris	1	19,340	180	23,050	23,519	23,290		
UCIAMS-26265	Woodstock M	Leaves, stems	2	14,860	40	17,974	18,142	18,060		
UCIAMS-46834	Woodstock M	Leaves, stems	2	14,880	80	17,976	18208	18090		
UCIAMS-26262	Tinley Moraine	Leaves, stems	2	14070	40	17009	17197	17,100		
UCIAMS-26263	Tinley Moraine	Leaves, stems	2	14,110	35	17,063	17,256	17,170		
UCIAMS-26264	Tinley Moraine	Leaves, stems	2	14,420	40	17,490	17,649	17,570		
UCIAMS-46829	Deerfield Moraine	Leaves, stems	2	13,650	40	16,336	16,547	16,450		
UCIAMS-63075	Deerfield Moraine	Leaves, stems	2	13,695	40	16,392	16,622	16,520		
UCIAMS-63076	Deerfield Moraine	Leaves, stems	2	13,910	35	16,767	16,984	16,860		
Glacial Lake Chicago										
ISGS-1549	Glenwood spit	Wood	3	13,870	170	16,525	17,064	16,800		
ISGS-1649	Glenwood spit	Wood	3	13,890	120	16,623	17,031	16,830		
Oswego channel complex										
UCIAMS-26255	Oswego Channel	Charcoal	New	12,370	30	14,209	14,499	14,380		
UCIAMS-26256	Oswego Channel	Leaves, stems	2	15,750	45	18,910	19,045	18,990		
UCIAMS-26257	Oswego Channel	Leaves, stems	2	15,660	60	18,826	18,961	18,990		
UCIAMS-26258	Oswego Channel	Leaves, stems	2	15,670	140	18,766	19,070	18,930		
UCIAMS-26259	Oswego Channel	Leaves, stems	2	15,470	110	18,624	18,839	18,730		
Pooled mean (4)				15,690	35	18,871	18,973	18,930	6.043	7.81
Emiquon National Wildlife Refuge										
B-207031	Lower lake phase	Conifer wood, bark	4	14,830	50	17,941	18,115	18,030		
B-210774	Lower lake phase	Wood, bark, needles	4	14,560	60	17,640	17,843	17,740		
B-207033	Lower lake phase	Wood, bark, needles	4	14,440	50	17,500	17,682	17,600		
B-210773	Lower lake phase	Wood, bark, leaves, seeds	4	14,380	80	17,406	17,649	17,530		
B-207030	Upper lake phase	Needles, wood, bark	4	13,080	40	15,598	15,792	15,690		
B-207028	Upper lake phase	Conifer wood, bark	4	12,890	40	15,268	15,478	15,380		
B-207030	Upper lake phase	Conifer wood, single piece	4	12,430	40	14,341	14,696	14,540		
ISGS-A2179	Upper lake phase	Leaves (1432–1435 cm depth)	New	12,360	40	14,185	14,490	14,370		
ISGS-A2221	Upper lake phase	Wood (1422–1432 cm depth)	New	12,680	40	15,033	15,200	15,110		
ISGS-A2220	Upper lake phase	Needles (1422–1432 cm)	New	12,695	35	15,066	15,208	15,130		
ISGS-A2222	Upper lake phase	Wood (1432–1435 cm depth)	New	12,795	35	15,169	15,300	15,240		
Pooled age (3 above samples)	Upper lake phase		New	12,727	21	15,114	15,224	15,170	5.991	5.99
B-207030	Upper lake phase	Diffuse porous wood fragments	4	11,720	140	13,438	13,719	13,550		
B-207035	Upper lake phase	Rotten wood and bark	4	11,300	40	13,097	13,188	13,150		
B-207032	Upper lake phase	Bark, wood, leaves	4	11,160	40	13,009	13,081	13,040		
Emiquon area										
W-381	Mouth of Spoon R.	Wood fragments	5	15,600	600	18,199	19,578	18,890		
Deer Plain–Savanna Terrace										
ISGS-1531		Wood, bark, needles, debris	6	13,710	270	16,193	16,976	16,580		
ISGS-894		Wood, bark, needles	6	13,390	190	15,818	16,365	16,110		
ISGS-875		Wood, bark	6	13,360	100	15,927	16,221	16,070		
ISGS-900		Wood, bark, needles, charcoal	6	13,010	140	15,330	15,766	15,570		
ISGS-415		Spruce log	6	12,325	75	14,117	14,494	14,340		
Ice-walled lake plain, Woodstock Moraine										
UCIAMS-124001		Leaves, stems	7	14,490	60	17,551	17,765	17,660		
UCIAMS-124002		Leaves, stems	7	14,410	40	17,481	17,638	17,560		
UCIAMS-124004		Leaves, stems	7	14,410	50	17,473	17,647	17,560		
UCIAMS-124005		Leaves, stems	7	14,580	50	17,668	17,856	17,760		
UCIAMS-97044		Leaves, stems	7	14,690	70	17,776	17,985	17,880		
Pooled mean (5 above samples)				14,487	23	17,565	17,727	17,660	17.95	9.49
UCIAMS-124003		Leaves, stems	7	15,415	45	18,628	18,748	18,690		
UCIAMS-124006		Leaves, stems	7	15,380	60	18,587	18,729	18,660		
UCIAMS-124007		Leaves, stems	7	15,610	70	18,783	18,923	18,860		
UCIAMS-124008		Leaves, stems	7	15,770	45	18,926	19,071	19,010		
UCIAMS-97042		Leaves, stems	7	15,515	50	18,716	18,836	18,780		
UCIAMS-97043		Leaves, stems	7	15,370	60	18,578	18,721	18,650		
Pooled mean (6 above samples)				15,523	22	18,739	18,825	18,780	49.64	11.1
UCIAMS-97045		Leaves, stems	7	17,990	110	21,621	21,933	21,790		
UCIAMS-97046		Leaves, stems	7	18,330	110	22,058	22,360	22,200		
Land and Lakes (Chicago Outlet)										
ISGS-1418		Wood	8	12,770	180	14,897	15,578	15,120		
ISGS-1332		Wood	8	12,500	110	14,441	15,012	14,700		
ISGS-1433		Wood	8	12,040	160	13,721	14,118	13,910		
ISGS-1413		Wood	8	11,880	110	13,558	13,810	13,700		

(*continued on next page*)

Table 1 (*continued*)

Lab number	Site	Material dated	Ref.	^{14}C age	σ1 error	Calibrated age			Pooled mean statistics (Ward and Wilson, 1978)	
						σ1 (up)	σ1 (down)	Median prob.	Student's *T*-test	Chi-squared
ISGS-1417		Wood	8	10,530	200	12,155	12,677	12,370		
ISGS-1455		Log	8	10,180	110	11,615	12,077	11,840		
Other radiocarbon ages										
ISGS-2054	South Elgin	Leaves, stems	9	13,670	140	16,268	16,714	16,500		
CAMS-81854	Elgin	Leaves, stems	9	13,980	40	16,876	17,079	16,980		
ISGS-271	St. Anne	Organic debris	6	12,990	120	15,333	15,719	15,540		
OSL ages (yr)										
UNL-1205	Lacon, Illinois	Medium sand	10	19,450	1400					
ISGS-043	Manito, Illinois	Medium sand	11	19,500	1400					
ISGS-047	Manito, Illinois	Medium sand	11	16,500	1400					
ISGS-046	Manito, Illinois	Medium sand	11	17,100	1500					
ISGS-033	Manito, Illinois	Medium sand	11	17,700	1100					
ISGS-045	Manito, Illinois	Medium sand	11	17,600	1200					
ISGS-030	Manito, Illinois	Medium sand	11	12,000	800					
ISGS-032	Manito, Illinois	Medium sand	11	12,200	1200					
ISGS-048	Manito, Illinois	Medium sand	11	12,400	600					

References: 1- Hansel and Johnson (1986); 2- Curry and Petras (2011); 3- Hansel and Johnson (1992); 4- Hajic et al. (2007); 5- Hajic and Johnson (1989); 6- Hajic (1990) and Hajic et al. (1991); 7- Curry (2013; new); 8- Hansel and Johnson (1986); 9- Curry (2007); 10- Kemmis et al. (2007); 11- Wang et al. (2012).

elevations of outlets with former glacial lake levels. Clark et al. (2008), for example, demonstrate that glacial-isostatic rebound contributed to the sequential opening of overflow channels across a bedrock-defended cuesta in east-central Wisconsin. Their isostatic model is used in our analyses of overflow routes by Glacial Lake Wauponsee, and a large slackwater lake that once occupied the valley of the middle to lower reaches of the Illinois River. In the case of the latter lake, the Clark et al. (2008) model was extrapolated 1° latitude south to account for changes in the relative altitude of the Savanna–Deer Plain terrace, discussed below.

The glacial-isostatic adjustment of the earth depends upon its viscoelastic properties and the thickness history of the Late Wisconsin ice sheets. Although neither of these parameters is known, advances over the past 20 years have narrowed the uncertainties of the mantle's viscosity (Peltier, 2004). We have used Peltier's VM2 viscosity structure in a numerical model of the viscoelastic relaxation process on a spherical viscoelastic earth. Because any surface load affects the entire earth, it is necessary to include in the modeling all of the ice sheets and the meltwater loading of the oceans. Uncertainty in the ice sheet thickness is problematic. The ICE-3G model of Tushingham and Peltier (1991) resulted in predicted tilt three times greater than tilt interpreted across the extent of Lake Oshkosh in eastern Wisconsin (Clark et al., 2008). A better fit was obtained by reducing the ICE-3G ice sheet thickness by 40%, which is what was adapted for this study.

With the glacio-isostatic adjustment parameters thus defined earth deformation may be modeled anywhere on the Earth's surface during the past 30,000 years. To evaluate lake extent and outlet locations, we used the hydrology extension of Spatial Analyst in ArcMap on high-resolution digital elevation models (DEMs)

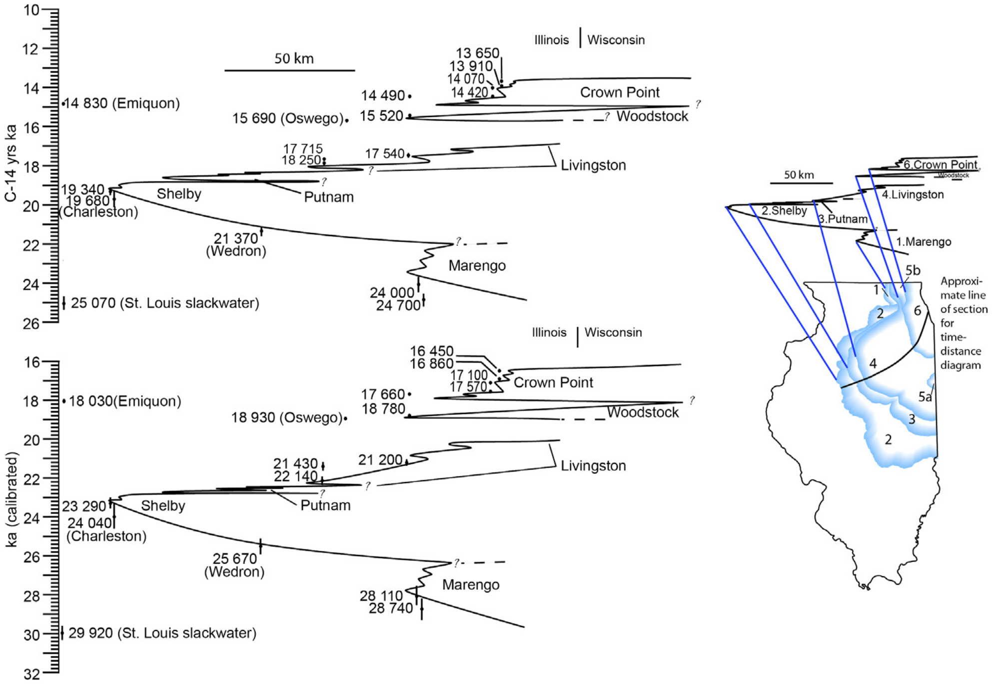

Fig. 3. Time–distance diagram of the Lake Michigan lobe (modified from Curry and Petras (2011)) based on new data (Curry, 2013).

warped to reflect predictions of glacial-isostatic adjustment. Loading from the weight of lake water was assumed to be negligible (Clark et al., 2007). To reflect the age of the KT, discussed below, our paleogeographic maps and altitudes discussed herein reflect conditions at 19,000 cal yr BP. (e.g., Fig. 2; Table 2).

Located near the edge of a thin ice sheet, there was considerable vertical movement of the Wauponsee Basin area due to glacial isostasy during the last deglaciation. Although it lies south of the "hinge line" proposed by others (Leverett and Taylor, 1915; Hough, 1958) the fact that tilting is occurring over the entire region even at present and in a pattern easily understood by the glacial isostatic adjustment process, suggests that the hinge line concept is in error. However the magnitude of tilting is not as great as some have suggested who have been critical of the hinge line idea. Fig. 4 displays the amount of deformation predicted at several of the Lake Wauponsee outlets (locations shown in Fig. 5; Table 2). These predictions indicate that all outlets were isostatically depressed at 22,000 cal yr BP, the approximate age of the formation of the Marseilles Morainic Complex. Due to the migrating forebulge, all sites experienced about 55 m of uplift culminating at about 10,000 cal yr BP, followed by subsidence during the Holocene (Fig. 4). In terms of local drainage development, it is the degree of differential tilt across individual basins that controlled aspects of overflow history.

3. Overflow route analysis

The relationship between the levels of Glacial Lake Wauponsee and development of overflow channels was controlled by the Lateglacial geomorphic evolution of the Marseilles Morainic System which is cross-cut by at least three generations of channels (Fig. 5). The altitudes of their drainage divides indicate age relative to the strath terrace surface attributed to the KT just west of Kankakee (Ekblaw and Athy, 1925; Fig. 2; Table 2). Five channels comprise the oldest group and are characterized by ice-stagnation features such as kettle basins at or near the present-day drainage divides. From south to north, the channels are named: (1) Odell, (2) Blackstone, (3) Pavilion, (4) Schlapp and, (5) Gilmore (Fig. 5). The channels, possibly tunnel channels, formed during glaciation, and were significantly modified during deglaciation (Fig. 5A). The altitude of the divides ranged from about 198 to 206 m (Table 2). In plan view, the valleys are linear to curvilinear, less than 0.4 km wide and 10 m deep. The ice stagnation features associated with the channels indicate the sediment fill is approximately the same age as the ice-walled lake plains that dot the surface of the Marseilles Morainic System (22,140–21,430 cal yr BP; Curry and Petras, 2011).

Table 2
Altitudes (msl) of key features in the study area. Data in column A give elevations of channel floors and other features at 19 ka based on the isostatic model of Clark et al. (2008). Values in column B are modern elevation data, and values in column C are the difference between the values in columns A and B. The locations of the Cryder and Willow terraces, and Lisbon delta, are shown on Fig. 5B.

Channels and other features	A 19 ka Elev.	B Modern Elev.	C (A–B) Elev.
Oswego channel complex (ground surface)	180.7	196.0	15.2
Oswego channel complex (bedrock surface)	164.9	180.0	15.1
Gilmore channel	197.5	213.7	16.2
Newark overflow channel	185.0	197.8	12.8
Schlaap channel	199.9	215.2	15.2
Pavillion channel	201.2	216.4	15.2
Blackstone channel	201.2	210.9	9.8
Odell channel	205.7	214.0	8.2
Lisbon Delta	178.3	192.6	14.3
Willow terrace (top)	161.5	174.0	12.5
Willow terrace (bottom)	158.5	171.0	12.5
Cryder terrace (top)	153.9	166.1	12.2
Cryder terrace (bottom)	147.8	160.6	12.8
Pontiac channel (bottom)	191.1	198.4	7.3
Pontiac channel (terrace)	198.1	205.4	7.3
St. Anne outlet (bottom)	171.3	182.3	11.0
St. Anne outlet (terrace)	177.7	188.7	11.0

Table 3
Relative elevations of the flood plain at Emiquon National Wildlife Refuge, and the Deer Plain Terrace at 40° N latitude based on isostatic modeling of Clark et al. (2008). The approximate modern elevations are 135 m at Emiquon, and about 135 m at the Deer Plain—Savanna Terrace.

Age (cal yr BP)	Lower		
	Emiquon	Deer Plain	Difference
0	0.0	0.0	0.0
2000	2.2	1.3	0.9
5000	9.1	6.3	2.8
6000	13.5	9.5	4.0
8000	26.1	19.0	7.1
9000	31.9	25.0	6.9
10,000	33.1	27.5	5.6
11,000	32.0	27.0	5.0
12,000	30.4	26.0	4.4
13,000	26.1	23.0	3.0
14,000	23.4	21.0	2.4
15,000	16.8	17.0	−0.2
15,100	16.0	17.0	−1.0
15,200	15.2	16.6	−1.4
15,300	14.4	16.1	−1.7
15,400	13.6	15.3	−1.7
15,500	12.8	14.7	−1.9
15,700	11.3	14.0	−2.7
16,000	9.3	12.6	−3.3
16,500	7.1	11.0	−3.9
16,600	6.8	10.5	−3.7
17,000	6.0	9.7	−3.7
17,800	5.3	9.3	−4.0
18,000	5.0	9.1	−4.1
18,400	4.0	8.3	−4.3
19,000	1.8	7.0	−5.2
20,000	−1.9	3.0	−4.9
21,000	−4.8	−0.6	−4.2
22,000	−8.1	−3.3	−4.8
23,000	−12.7	−7.1	−5.6

The second generation of channels includes the Oswego channel complex and the Newark channel, large features that cut completely across the Marseilles Morainic System (Fig. 5 and 5A). Both channels are steep-sided with more than 30 m of cross-valley relief. A long linear 9-m deep trough was eroded to bedrock at an altitude of about 181 m in the Oswego channel complex; the basin later was filled with about 9 m of lacustrine and palludal sediment (Fig. 5A; Appendix).

The youngest (third generation) channel is the Marseilles channel, presently occupied by the Illinois River (Fig. 5). The altitudes of paired high-level terraces adjacent to the channel are similar to that of the floor elevation of the primary Oswego channel complex (Fig. 5B, 180 m). The nearly concordant altitudes are consistent with the interpretation that the Marseilles channel initially formed at the same time as the Oswego and Newark channels by overflow of Glacial Lake Wauponsee. The Marseilles channel eventually pirated the overflow due to the lower altitude of the tunnel valley floor. This is speculative, however, because of subsequent erosion of the valley floor. Another contributing factor may have been the relative erodability of the glacial drift and bedrock, but the Oswego, Newark, and Marseilles channels are all floored by Paleozoic sedimentary rocks (Willman and Payne, 1942; Kolata, 2005).

Our analysis indicates that in Illinois, the meltwater initially flowed from Indiana along the upper Kankakee River valley into the Wauponsee and Watseka Basins at an elevation of about 178 m. The

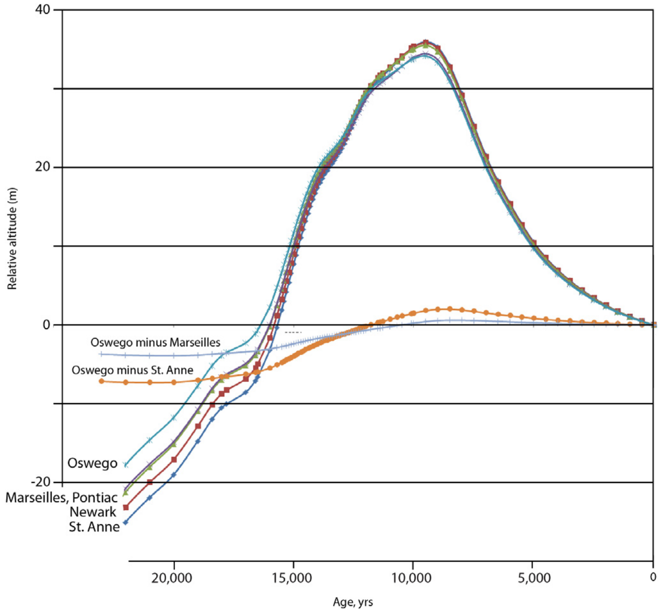

Fig. 4. Changes in the relative altitudes of the point of overflow in the Newark, Marseilles, Oswego, and Pontiac channel floors, and the St. Anne outlet from 22,000 yr to the present based on the isostasy model of Clark et al. (2008). At 19,000 yr, the Oswego channel complex was about 7.0 m lower than the St. Anne outlet, and 3.8 m lower than the Marseilles channel. The locations of the features on this figure are shown in Figs. 2 and 5.

levels of Glacial Lakes Wauponsee and Watseka rose to about 198 m (Fig. 2). Assuming an east- (STET) a least-bounding ice margin at the position of the Minooka Moraine, maximum lake areas were about 1500 km^2 and 750 km^2, respectively (Fig. 6). The sedimentology and geomorphology of the Lisbon Delta, a 5–7-m high ridge composed of steeply dipping beds of sand and gravel (Fig. 5B), suggested to Willman and Payne (1942) an ice-contact origin. Although the deltaic origin of this landform is questionable, we agree that it was likely formed by ice-contact, suggesting that at one time, the basin was partially occupied by the Lake Michigan lobe, thus reducing the effective size and volume of Glacial Lake Wauponsee. Willman and Payne (1942) suggested that the Newark Channel formed as a result of overflow of a high-level proglacial lake (which they named Glacial Lake Lisbon) when the retreating glacier was anchored at the Lisbon Delta. This scenario may be correct, but it also possible that the channel significantly predates the Lisbon Delta. Hence, we prefer to consider this early phase part of the ontogeny of Glacial Lake Wauponsee. The limiting altitude of this early-stage lake level is estimated from the altitude of the drainage divide of the Gilmore channel (198 m), a tunnel valley that was not exploited by overflow (Fig. 5; Table 2). Little sediment was deposited in Glacial Lake Wauponsee.

As glacial lakes Wauponsee and Watseka approached the 198 m level, they simultaneously overflowed eroding four bedrock-floored channels. Sill altitudes reveal the order in which the channels were abandoned as lake levels lowered, starting with the Pontiac–Watseka channel (sill altitude = 191 m), Newark channel (185 m), Oswego channel complex (<180.7, but > 164.9 m), and the Marseilles channel (sill eroded; elevation unknown; Fig. 2). Overflow from the Pontiac–Watseka channel spilled into Pontiac basin, forming Glacial Lake Pontiac, with ponding downstream of the Marseilles Morainic System, forming Glacial Lake Ottawa. The oldest, highest level of Glacial Lake Pontiac is not known, but it was less than 198 m because lower passes to the valley of the Illinois River were available.

Evidence for a middle phase of the proglacial lake in Wauponsee Basin (named Glacial Lake Morris by Culver, 1922) includes deposits of laminated silt loam as much as about 10 m thick, but typically less than 3 m thick. Detailed examination of the new shaded relief topographic maps of LiDAR data from Kendall and Grundy counties have not revealed erosional or depositional features indicative of lake extent. Deposits of lacustrine sediment are thin (<1 m) or absent above altitudes of about 165 m; we adopt this elevation as the highest level of Glacial Lake Morris (Fig. 6). Sediment successions are comprised of unfossiliferous, rhythmically bedded 1 cm-thick beds of uniform silty clay and silt loam intercalated with laminae of coarse silt and very fine sand. The relatively high elevation of some Glacial Lake Morris deposits indicates that the lake was dammed on the east by the Joliet Sublobe (Lake Michigan lobe) probably at positions now marked by the Minooka or Rockdale moraines (Fig. 5 and 5B).

The youngest phase of Glacial Lake Wauponsee, named Lake Cryder by Culver (1922), is marked by an escarpment that steps down from about 154 to 148 m (Figs. 5B and 6). Also visible with new height enhanced hillshade imagery is an older arching scarp north of the escarpment attributed to Lake Morris (Fig. 5B). We name this landform the Willow terrace. It steps down from about 162 to 159 m, and is eroded into thin silty and clayey lacustrine deposits covering Pennsylvanian siltstone, whereas the Lake Cryder scarp is formed of medium sand with occasional boulders (see Fig. 39, p. 91, Culver, 1922). The absence of fines in Lake Cryder sediment and other features such as beach ridges indicated to Culver (1922) that "the water of Cryder Lake was able to transport most of the sand and silt brought to it (suggesting that)… Cryder Lake was little more than a widened river…".

The timing of the KT is bracketed by the minimum ages of the Marseilles Morainic System and Oswego channel complex. Both ages are from multiple radiocarbon assays of tundra plant fossils sampled at the base of glaciolacustrine successions. Four samples from two ice-walled lake plains on the Marseilles Morainic System yielded a pooled mean age of 22,140 cal yr BP (Fig. 3; Table 1; Curry and Petras, 2011). Four samples of tundra plant fossils preserved in the basal facies of a glaciolacustrine deposit that fills a KT-scoured basin in the Oswego channel complex yielded a pooled median probability of 18,930 cal yr BP (Table 1; Appendix). By assuming a short lag between torrent erosion and lacustrine sediment deposition, a reasonable age estimate for the KT is 19,000 cal yr BP. This age is consistent with limiting ages of plant fossils preserved on ice-walled lakes on the (younger) Woodstock and Tinley Moraines of about 18,780 and 17,570 cal yr BP, respectively (Table 1; Curry and Petras, 2011; Curry, 2013). In the lower middle reaches of the Illinois River near Havana, radiocarbon ages and optically stimulated luminescence (OSL) ages of deposits sampled in sand pits are consistent with a KT age of about 19,000 yr, including OSL ages of high-level sand and gravel deposits of 19,450 ± 1450 yr (UNL-1205) at Lacon, Illinois (Kemmis et al., 2007), and 19,500 ± 1400 yr at Manito, Illinois (Table 1; Wang et al., 2012).

Additional attributes of the KT and subsequent slackwater lakes in the middle Illinois River valley have been explored through recent investigations of 53 sediment cores at the Emiquon National Wildlife Refuge near Havana, Illinois (Fig. 7; Table 1; Hajic et al., 2007). Here, about 14 m of fossiliferous lacustrine sediment is in sharp contact with a 1–2 m thick lag of bouldery debris that covers the bedrock surface. The bouldery debris is a deposit attributed to the KT. The oldest calibrated radiocarbon age – 18,030 cal yr BP – is about 900 yrs younger than the pooled mean of four ages from the Oswego channel complex of 18,930 cal yr BP (Table 1; using 2σ errors, the minimum difference in age is about 350 yrs). Two lake phases dating from 18,030–17,530 cal yr BP and 15,690–13,040 cal yr BP are suggested by the distribution of the radiocarbon ages from Emiquon (Table 1).

In the Three Rivers area (comprising the confluence of the Missouri and Illinois Rivers with the Mississippi River), Hajic (1990)

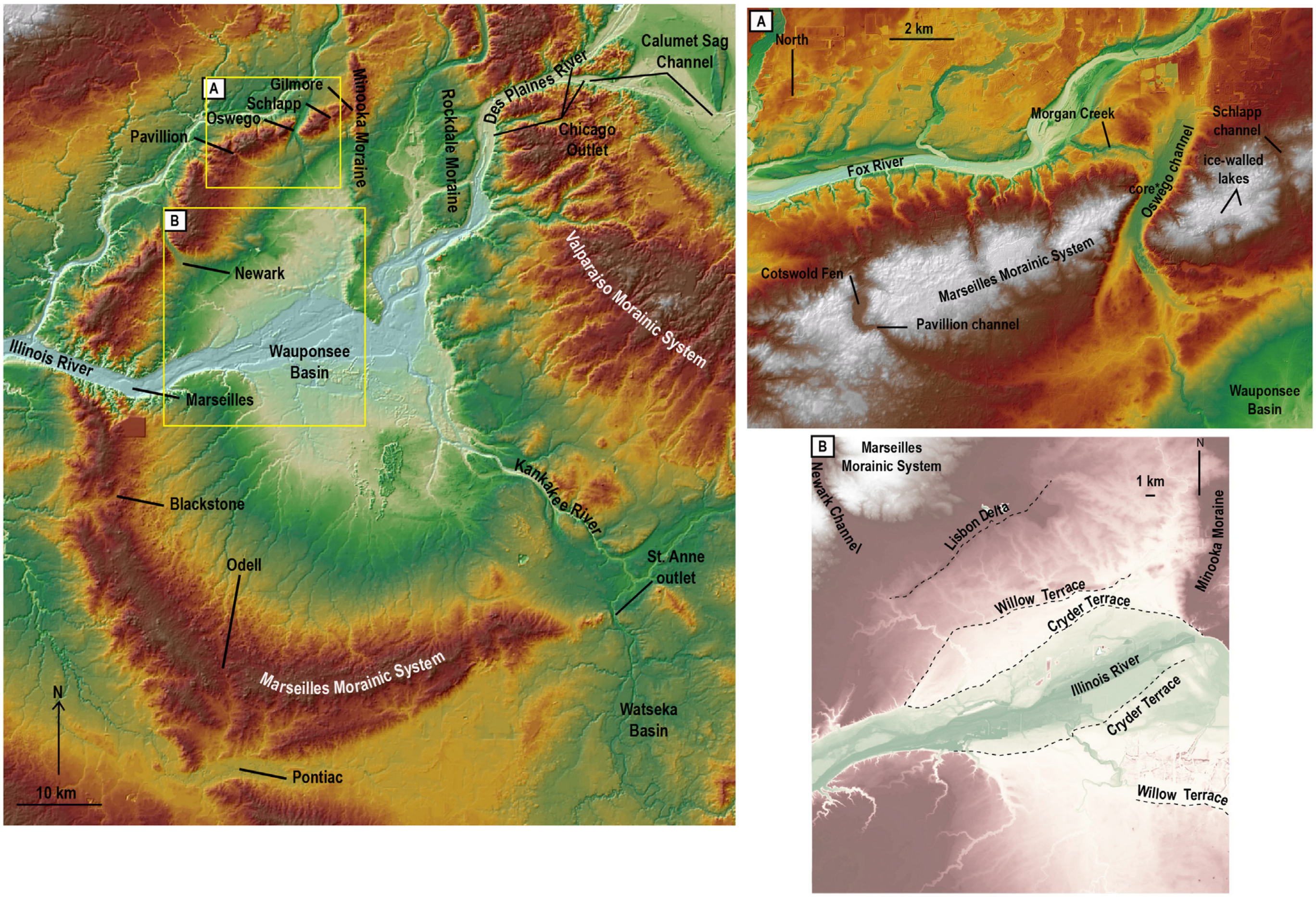

Fig. 5. Tunnel channels of the comma-shaped Marseilles Morainic System. The Gilmore, Schlapp, Pavillion, Blackstone, and Odell channels are tunnel channels with altitudes too high for overflow to have occurred. The Marseilles, Oswego, and Newark channels were tunnel channels modified by overflow of Glacial Lake Wauponsee (which contributed to the Kankakee Torrent). Later, the Marseilles channel was deepened and widened by sustained meltwater discharge and other "torrents" that impacted the Illinois River. The boxes indicate the locations of inset Fig. 5A and B. Fig. 5A. Detail of Fig. 5 comparing the geomorphology of the Pavillion and Schlapp tunnel valleys versus the Oswego channel complex, an overflow channel. When lake levels rose to critically high altitudes, overflow occurred across the Oswego channel complex, eroding through the clayey diamicton of the Marseilles Morainic System to bedrock; the altitudes of the Pavillion and Schlapp channels were too high for overflow exploitation. After overflow ceased, a lake formed in the Oswego channel complex, depositing more than 9 m of lacustrine and palludal sediment at a core site (*; Fig. 13; Appendix). Tundra plant fossils archived at the base of the lacustrine succession yielded four radiocarbon ages with a pooled, median age of 18,930 cal yr BP (Table 1). The base map is a shaded relief map of LiDAR data from Kendall County. Fig. 5B. Shaded DEM of enhanced elevation data from southern Kendall and northern Grundy counties showing the Newark channel, Lisbon Delta, and the Willow and Cryder terrace scarps in the Wauponsee Basin. The mapped lines have been located at the foot slopes of the landforms. Cryder terrace was first identified by Culver (1922) who associated it with "Lake Cryder". The figure center is located at 41.378°N, −88.407°W.

characterized the geomorphology (including age) of a flight of terraces, including the Deer Plain–Savanna Terrace (Fig. 8) which acted as a sediment dam at the mouth of the Illinois River from about 16,580 to 14,340 cal yr BP (Table 1; Hajic et al., 1991). The second lake phase at Emiquon is an upstream extension of the Deer Plain phase of Lake Calhoun, the lake impounded behind the valley mouth sediment dam (Hajic, 1990). Where the sediment dam would have completely bridged the valley, the terrace has surface elevations of about 135 m. Accounting for glacial isostasy (Fig. 9), the maximum possible lake depth at ca 15,800 cal yr BP at Emiquon was about 18 m, and by 13,000 cal yr BP was less than about 1 m (Figs. 7 and 9). The results of the isostatic model imply that shoaling of the slackwater lake at Emiquon was hastened by gradual crustal upward tilting to the north caused by the onset of the forebulge. The recurrence of dune sand at Manito at about 12,250 yr (1-σ range of 13,400–11,000 yr; Wang et al., 2012; Table 1) is consistent with deflation of sandy alluvium deposited by overflow of Glacial Lake Chicago after the Calumet Phase and following dissipation of the slackwater lake.

There is no evidence for a sediment dam corresponding with the age of the older Emiquon lake phase (18,030–17,530 cal yr BP). The end of the earlier phase predates existing ages associated with the Deer Plain–Savanna Terrace by about 1000 yrs; the beginning of the earlier phase postdates the next-oldest terrace, the ca 20,580 cal yr BP Cuivre Terrace, by about 2500 yrs (Fig. 8; Hajic et al., 1991). Consideration of the isostatic model suggests a sediment dam was not necessary for the occurrence of the early lake phase. From about 19,000 to 17,000 yr the glacial isostasy model suggests that the Emiquon area was more than 5 m lower than the mouth of the Illinois River. The collective data suggests that the KT may have eroded Cuivre terrace remnants and most of the associated sediment from the Illinois River valley (Hajic, 1990).

3.1. Other torrents?

Meltwater incised deep-sided channels across and within other moraines in northeastern Illinois. Some channels have features that suggest some events were catastrophic, but others may have

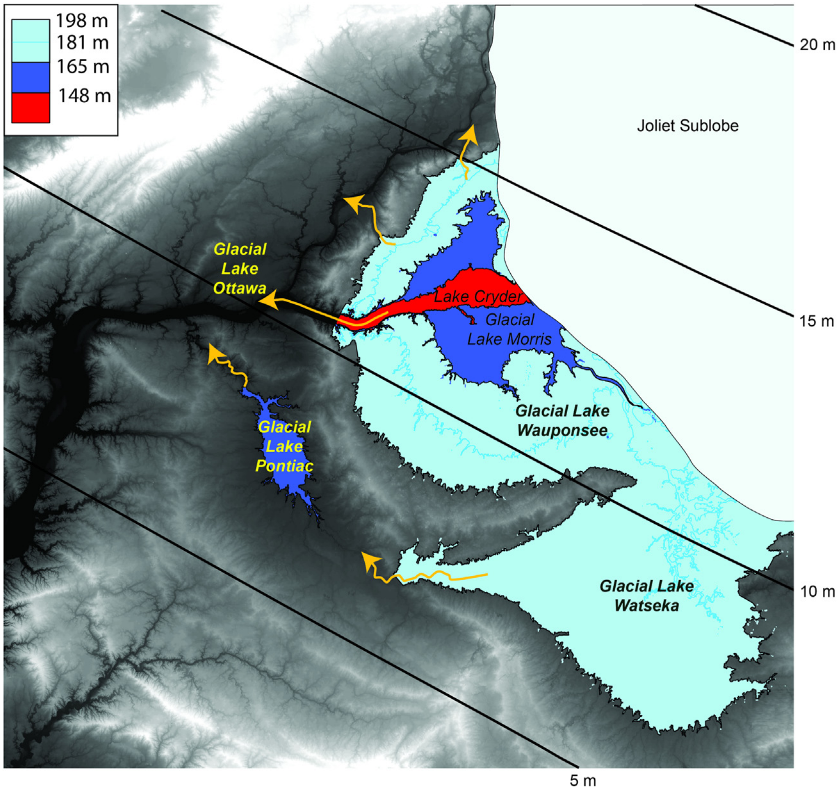

Fig. 6. Maximum extent of Glacial Lakes Wauponsee and Watseka, and minimum extent of Glacial Lake Pontiac, with lower stands of Glacial Lake Morris and Lake Cryder. Also shown are the isobases (5, 10, 15, and 20 m) for the isostatic adjustment at 19,000 cal yr BP.

formed by sustained flow. Three channels are notable: 1) the Algonquin reach of the Fox River valley, 2) the East Branch DuPage River valley and 3), the Chicago Outlet (Fig. 10). The Algonquin reach (42.205° N, −88.215° W) includes the part of the Fox River that crosses the Woodstock Moraine downstream to near Elgin, Illinois. Here, high-level terrace deposits on abandoned meanders and point bars (e.g., 42.133° N, −88.289° W) are composed of bouldery gravel and point to catastrophic discharge (Curry, 2005, 2007) named the Fox River Torrent by Alden (1904). Recent mapping suggests that the channel formed by breaching of the moraine by a large, unnamed proglacial lake in the Chain O′ Lakes region. The minimum age of the Woodstock Moraine, based on 6 radiocarbon ages from tundra plant fossils in ice-walled lake sediment (Curry, 2013), is about 18,780 cal yr BP. Using 1-σ errors (68% confidence), this age is statistically unique from the minimum age of the KT indicated at Oswego (18,930 cal yr BP; Table 1), but consideration of 2-σ errors (95% confidence) indicates that the ages overlap (18,820–18,870 cal yr BP). Hence, it is possible with the chronological data on hand that the Fox River and Kankakee Torrents occurred simultaneously, although there is no supporting geomorphological data. The age of the Fox River Torrent is consistent with radiocarbon ages of fossils obtained from post-torrent slackwater sediment filling tributaries to the Fox River (16,900 and 16,500 cal yr BP; Curry, 2007; Table 1).

The channel of the East Branch DuPage River has not been studied in detail. Examination of shaded relief maps indicates that it was eroded during the formation of the Valparaiso Morainic System. Because it heads within a moraine (41.934° N, −88.057° W), the channel likely formed from focusing of meltwater discharge.

The Calumet Sag channel feeds into the Chicago Outlet where they both cut across the Valparaiso Morainic System and Tinley Moraine (Fig. 10). To the west, the Chicago Outlet bifurcates into four channels eroded across the Rockdale Moraine, with amain channel presently occupied by the Des Plaines River (Fig. 5). Geomorphic evidence suggests initial drainage was established during deglaciation (Bretz, 1951) with subsequent overflow during high periods of Glacial Lake Chicago, the Glenwood Phase (ca 17,650–14,050 cal yr BP) and Calumet Phase (13,660–13,110 cal yr BP), and subsequent Holocene Nipissing Phase of Lake Michigan (Chrzastowski and Thompson, 1992). However, the chronology of discharge events across the Chicago Outlet is poorly known from deposits associated with the outlet itself. The only site within the Chicago Outlet that has yielded chronological data is the Land and Lakes section (Hansel and Johnson, 1986). Here, wetland-fringing colluvium contains wood fragments that have yielded several median calibrated radiocarbon ages ranging from 15,190 to 12,370 cal yr BP, indicating the organic materials were redeposited (Fig. 10; Table 1). The widespread occurrence of younger lake sediments at Emiquon dating from 15,690 to 13,040 cal yr BP, and lack of sediment coarser than medium sand, indicates that younger discharge events (such as outflow via the Chicago Outlet during the Glenwood and Calumet phases) were not as large or erosive as the KT in the lower-middle Illinois River valley. Additional work is warranted in the valley of the Calumet Sag channel and other places known to be underlain by lake and paludal sediment rife with dateable organic materials for verifying and fine-tuning the history of the Chicago Outlet.

4. Downstream of the KT

The ca 19,000 cal yr BP age of the KTis approximately the same age as a 10-m rise in sea level (Yokoyama et al., 2000; Clark et al., 2004). How much of this rise could be attributed to the KT? The geomorphology of the Illinois River valley and lake level history discussed above indicates that the KT was among the largest floods during the last deglaciation of the south-central sector of the Laurentide Ice Sheet. The initial drop in lake level from ca 198 to 165 m, probably from a single event we attribute to drainage of

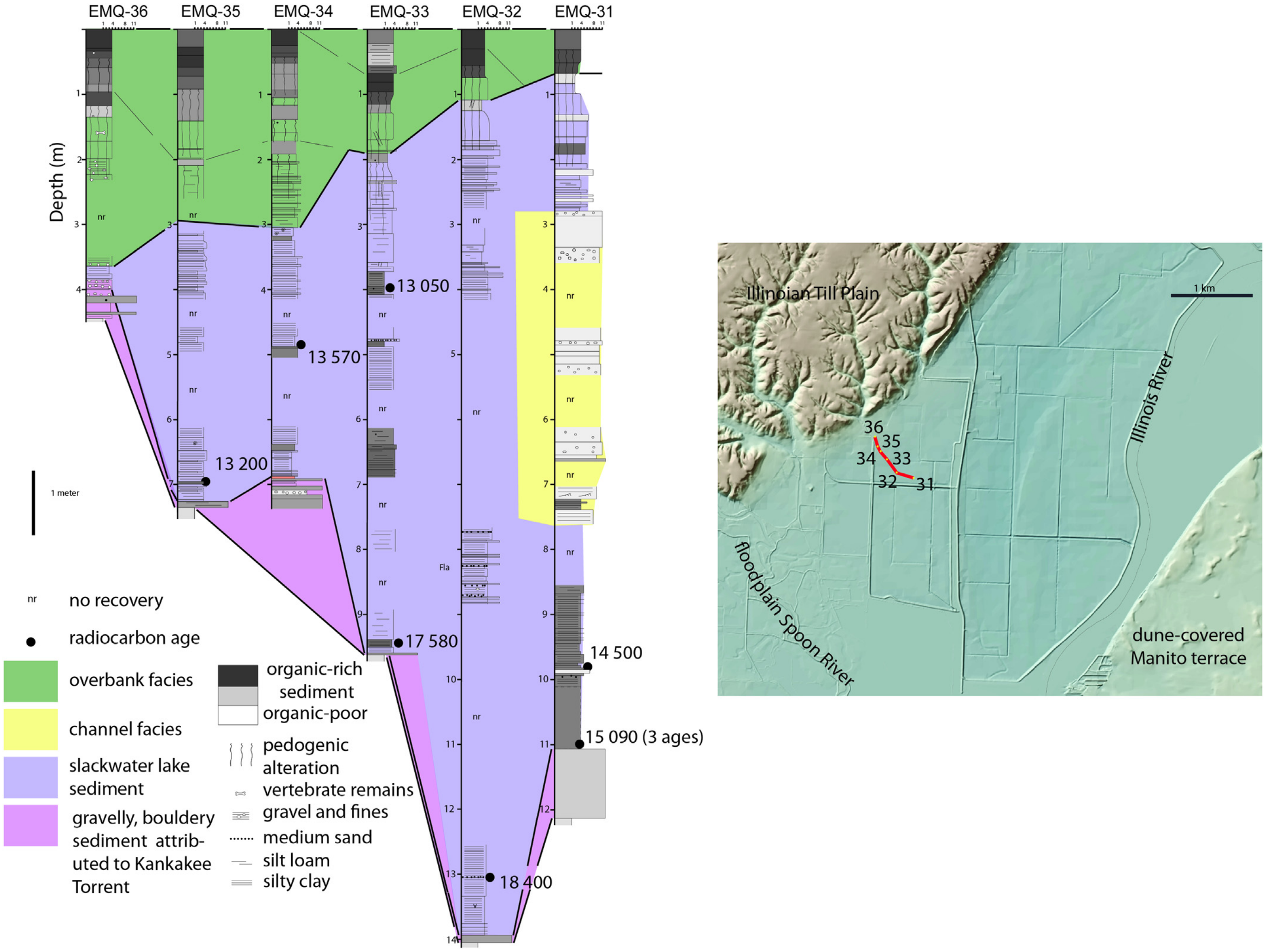

Fig. 7. Schematic cross-section of the middle Illinois River Valley at the Emiquon National Wildlife Refuge, Illinois. The KT likely scoured to bedrock in this location (see Fig. 1A), leaving a lag of gravelly, bouldery sediment. Lacustrine sediment represents post-flood infilling by deposition in a large slackwater lake dating from 18,030 to 13,040 cal yr BP. From Hajic et al. (2007).

Glacial Lake Wauponsee, released about 7.8 × 10^{10} m^3 of water. Subsequent lake level drop from 165 to 145 m (representing drainage of Glacial Lakes Morris and Cryder) released at least 2.4 × 10^{10} m^3 of water. Given that sea level was about −120 m at 19,000 yr BP (Tarasov and Peltier, 2004), dividing the meltwater volume by ocean area (3.408 × 10^{14} m^2 (ETOPO2v2, 2013)) indicates a sea level rise of about 3.0 × 10^{-4} m (3 mm). Hence, the sea level rise of about 10 m at 19,000 yr BP was not significantly affected by the KT.

Sediment records from the Orca Basin (Gulf of Mexico) indicate that illite-rich sediment was deposited from about 20,000 to 19,000 yr whereas smectite dominated the clay minerals were deposited from about 19,000 to 18,000 yr (Sionneau et al., 2010). The high illite and chlorite content of clay minerals of sediment sourced from deposits of the Lake Michigan and Huron–Erie lobes suggest correlation of the KT and Fox River Torrent with the older marine clay mineral assemblage. Other (older) significant discharge events associated with the Wabash valley system are implicated, and discussed below.

The combined discharge of the Mississippi River and KT likely resulted in deposition of braid belts in the upper Mississippi Embayment. Coincidence of age suggests correlation of the KT with Sikeston Ridge (1-σ age range of 21,300–16,500 yr; Rittenour et al., 2005; Fig. 11) and possibly the somewhat older Advance Splay.

4.1. *Upstream relationships with the KT*

The KT was sourced from ice margins of the Lake Michigan, Saginaw, and Huron–Erie lobes in southern Michigan and northern Indiana (Ekblaw and Athy, 1925; Willman and Payne, 1942; Zumberge, 1960). More recent investigations and geologic mapping provide details about the sources and magnitudes of glacial meltwater discharge (Brown et al., 1999, 2006; Kehew et al., 1999; Fisher and Taylor, 2003; Stone, 2002; Brown, 2003; Fisher et al., 2003; Stone et al., 2003; Kozlowski et al., 2005). Geomorphic relationships, primarily cross cutting meltwater channels, constrain ice-margin positions and the relative timing of ice-margin fluctuations and meltwater discharge events. However, chronological control on the events discussed below is, in general, wanting. Fisher and Taylor (2002) suggested that an outburst flood, possibly a key source of the KT, occurred when the Saginaw lobe was positioned at the Sturgis moraine in southern Michigan (location 6a, Fig. 12). Kozlowski et al. (2005) suggest that a later meltwater outburst of the Saginaw lobe created the Kalamazoo Valley (location 9, Fig. 12), but their mapping suggests this water flowed into the Glacial Lake Chicago, which postdates the KT. The cross-cutting relationships of glacial landforms in southern Michigan and northern Indiana clearly indicate that the Saginaw lobe margin was north of the Kalamazoo Valley when the Lake Michigan lobe and Huron–Erie

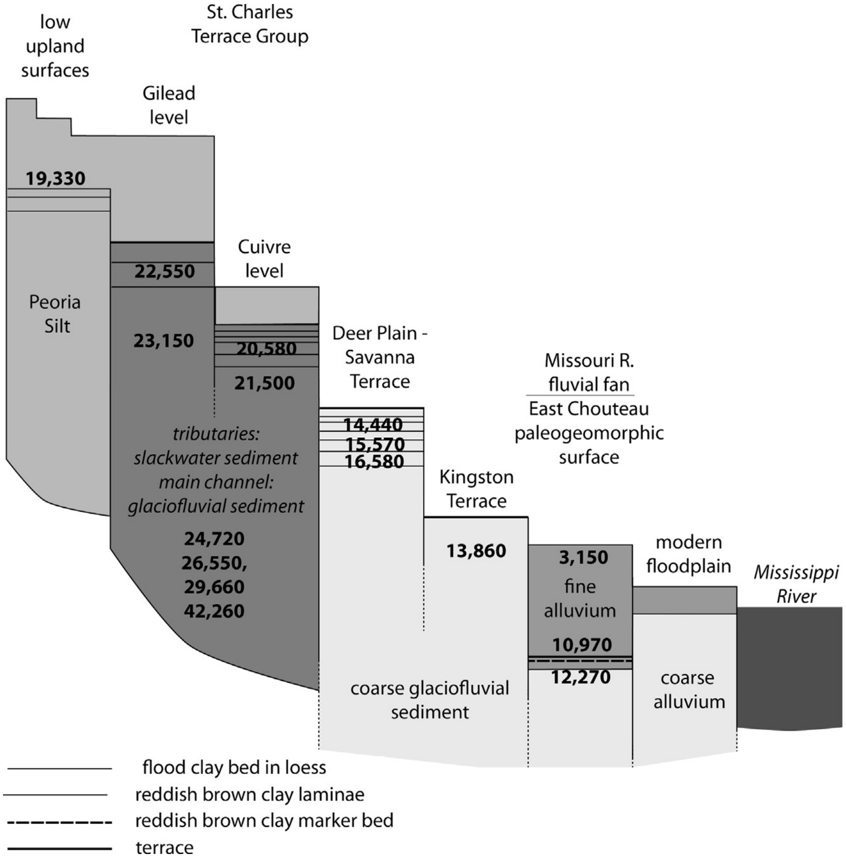

Fig. 8. Generalized stratigraphy and ages of terraces, Three Rivers area (confluence of Missouri and Illinois Rivers with the Mississippi River) modified from Hajic et al. (1991).

lobes where at their geomorphically expressed maximum extents (Kehew et al., 1999; Brown et al., 2006). Meltwater discharged from these margins along channels in southern Michigan and northern Indiana (locations 4, 5, and 7, Fig. 12), crossing a landscape formerly occupied by the Saginaw lobe. These relationships suggest that the lobe margins were asynchronous in their retreat, and that there were multiple meltwater discharge events through time. The large meltwater drainage basin in southern Michigan and northern Indiana routed meltwater through spillways at the continental drainage divide at and near South Bend, Indiana (locations 1,2, and 3, Fig. 12). From this juncture, meltwater either flowed westward through the Kankakee Valley into Illinois, or southward through the Tippecanoe lowland (e.g. Fraser and Bleuer, 1988; location 8, Fig. 12) to the Wabash and Ohio valleys. However, the number (and age) of

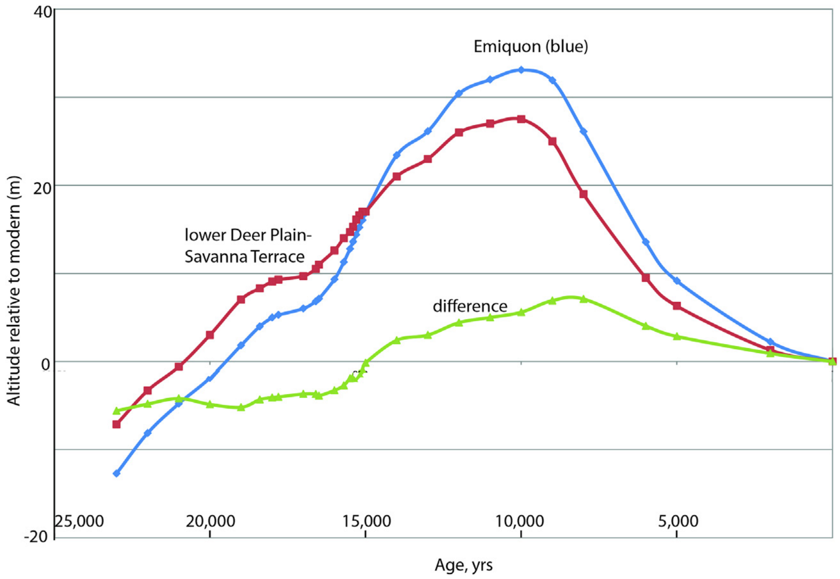

Fig. 9. Relative altitude of the floodplain at the Emiquon National Wildlife Refuge (40.35°N, −90.10°W) and lower Deer Plain–Savanna Terrace at 39° N, and the difference between the two (see Table 3). Note that prior to about 15,000 cal yr BP, Emiquon was lower in relative elevation compared to the terrace, and after 15,000 cal yr BP, Emiquon was higher.

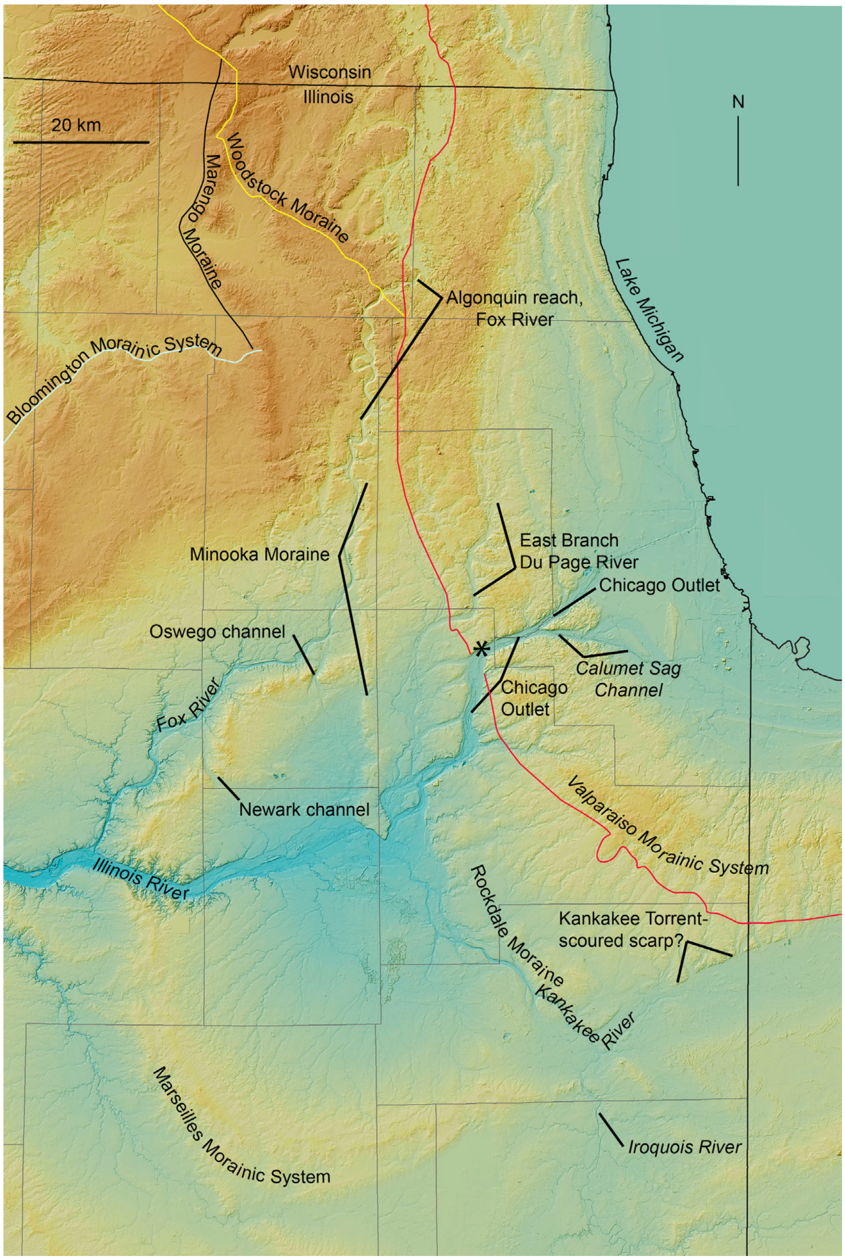

Fig. 10. Shaded relief map of northeastern Illinois (after Luman and Domier, 2013) showing the location of the Algonquin channel, East Branch DuPage River, the Chicago Outlet, and other features. The asterisk in the Chicago Outlet gives the location of the Land and Lakes Section (Hansel and Johnson, 1986).

individual meltwater events remains elusive because of poor chronological control. Water flowed across the drainage divide at South Bend until the end of the Glenwood phase of Glacial Lake Chicago (ca 14,050 cal yr BP), after which the stream capture redirected all drainage northward into the Lake Michigan basin (Kincare, 2007).

In sum, although there are several options regarding specific sources for the meltwater leading to the KT, after the KT occurred, it is not likely that catastrophic flow due to morainic dam failure occurred again in the Kankakee–Illinois River system. After the catastrophic KT widened and deepened the Illinois River valley, subsequent discharge did not accomplish as much geomorphic work, both in terms of erosion, or deposition. We can neither assess with the data on hand how quickly proglacial Wauponsee and Watseka basins filled with water, nor address the relative contribution of subglacial meltwater (i.e., Fisher et al., 2002).

5. Discussion and conclusions

During the last deglaciation in southern Michigan and northern Indiana, the margins of the eastern Lake Michigan, southern Saginaw, and northwestern Huron–Erie lobes individually or in combination provided meltwater that ponded in the upper Kankakee River basin that eventually flowed into Illinois, providing discharge for the KT. Previous to the KT, meltwater likely drained south across the Tippecanoe lowlands to the Wabash River (Brown et al., 1999, 2006; Stone et al., 2003). At approximately 19,000 cal yr BP, the Lake Michigan lobe retreated far enough north so that a hydrologic threshold was crossed as ponded meltwater flowed against the southern margin of the retreating Lake Michigan lobe westward into Illinois. This event may have occurred during either the Woodstock or Livingston phases; existing chronological data favors the Woodstock Phase (Fig. 3). Meltwater filled at least three topographic

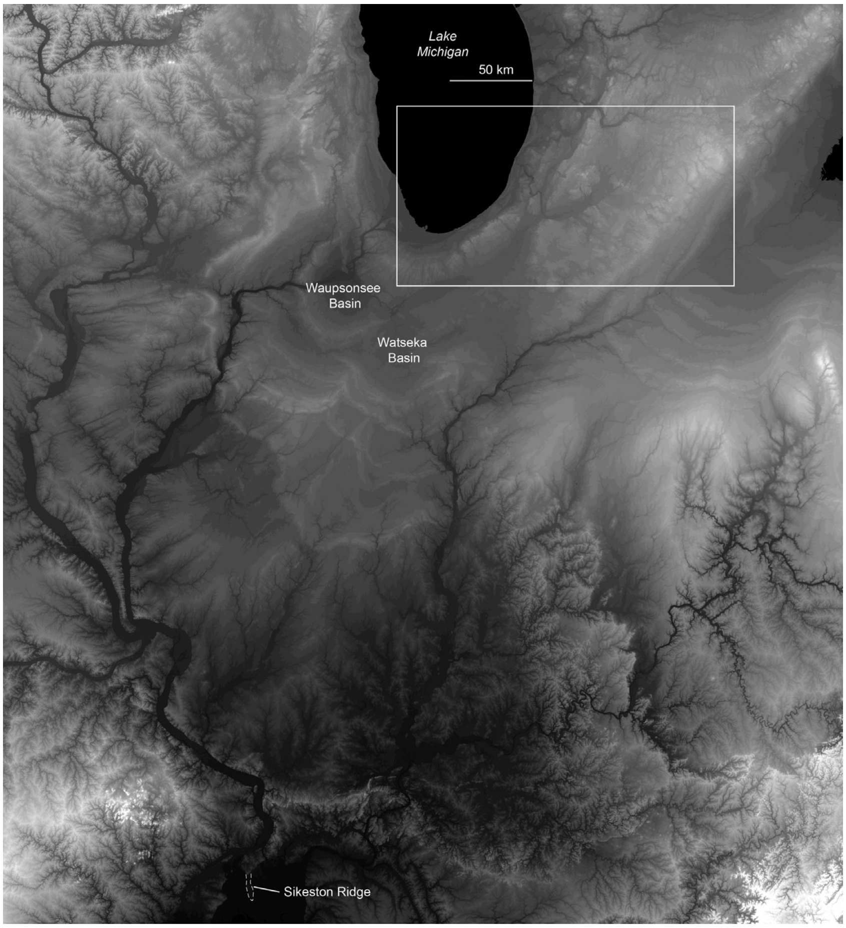

Fig. 11. Shaded 100-m DEM (downloaded from NationalAtlas.gov) showing the location of Wauponsee and Watseka basins, Sikeston Ridge in the upper Mississippi River embayment. The box outlines the location of Fig. 12, the area where much meltwater ponded and eventually flowed west to Illinois, filling Glacial Lakes Wauponsee, Watseka, and Pontiac prior to the Kankakee Torrent.

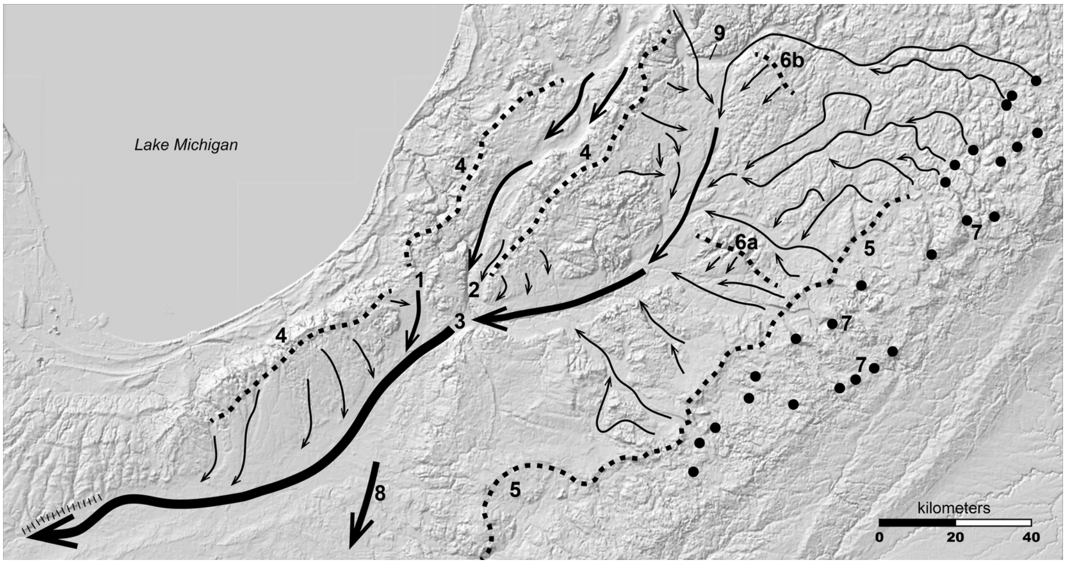

Fig. 12. Area of southern Michigan and northern Indiana showing ice-margin positions represented by a large fans and/or deltas (thick dotted lines), other point sources at the head of meltwater channels (black circles), and prominent meltwater drainage routes (black lines with arrowheads). Arrowheads show direction of meltwater flow. Thicker lines are stylized to indicate a greater volume of water. Drainage routes did not necessary develop concurrently: sources and routes are shown collectively for illustration. The vertically hachured line at the Illinois–Indiana border highlights a prominent meltwater-cut scarp possibly formed during the KT. Numbered features: 1) Spillway for Glacial Lake Madron (Stone et al., 2003); 2) Spillway for Glacial Lakes Madron and Dowagiac (Stone et al., 2003); 3) head of Kankakee Valley and continental drainage divide; spillway drainage of the southern Michigan-northern Indiana meltwater drainage basin (Brown, 2003); 4) head of fans and deltas of Lake Michigan lobe, 5) head of fans of Huron–Erie lobe, 6) head of fans of Saginaw lobe; 7) area of edges of Erie lobe; 8) route of drainage to Wabash River valley through Tippecanoe lowland; and 9) Kalamazoo River valley.

basins (Wauponsee, Watseka, Pontiac, and possibly Ottawa) before catastrophically breaching the Marseilles Morainic System dam resulting in the KT. At their highest altitude of about 198 m, proglacial lakes covered about 6.22×10^9 m^2. Overflow of Glacial Lake Wauponsee caused incision of three channels across the Marseilles Morainic System from a level of about 198 to 165 m, with slower lowering from 165 to about 145 m as the KT (or later discharge) incised into Paleozoic bedrock. We suggest that the initial 33 m drop in lake level was catastrophic and resulted in much of the landscape modification attributed to the KT in the middle reaches of the Illinois River valley (Hajic, 1990). Total discharge to the Gulf of Mexico was about 10.2×10^{10} m^3, resulting in a net sea level rise of about 3 mm. We have no evidence of sustained flow, or multiple torrents, but the temporal coincidence of the KT with a ca 10-m rise in sea level at about 19,000 cal yr BP (Yokoyama et al., 2000; Clark et al., 2004) suggests significant subglacial meltwater inputs immediately after the KT related to the loss of hydrologic head as the level of Glacial Lake Wauponsee dropped 33 m. Limiting radiocarbon ages associated with an ice-walled lake plain on the Woodstock Moraine in northeastern Illinois indicate that it was possible that the Fox River torrent was coeval with the KT. Geomorphic evidence of the Fox River torrent dissipates about 20 km from its sill (Curry, 2007), so compared to the KT, the volume of this torrent was likely negligible.

At the Emiquon site, sedimentological and chronological evidence indicate deposition of a mantle of bouldery debris above bedrock (probably deposited during the KT), followed by inundation of the middle reaches of the Illinois River valley by a large lake from 18,030 to 13,040 cal yr BP. The absence of gravelly deposits in this lacustrine succession indicates that the KT was the last large catastrophic discharge event to impact the valley.

Acknowledgments

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Appendix

Four sediment cores have been sampled along Reservation Road where it crosses Morgan Creek using split spoons, hollow stem augers, and hydraulically pushed soil corers (Curry et al., 2008; Fig. 5A). Each core revealed about 9 m of lacustrine and paludal sediment resting on shale and dolomite of the Maquoketa Group. In detail, the sediment cores include 3.6 m of gray silt loam with few interbeds of fine to coarse sand, 2.0 m of silty, organic gyttja, 0.8 m of marl, and 2.4 m of surficial peat (Fig. 13). The units were described somewhat differently by engineers of the Illinois Department of Transportation (IDOT); their log includes important moisture content and blow count data for soft, underconsolidated materials. The moisture contents range from 42.7 to 62.6% for the gray silt loam (described as “very soft gray organic clay”), 110–120% for the organic gyttja, and from 253 to 272% for the marl and peat. ISGS core recovery of marl and peat was less than 15%, whereas core recovery of the silts exceeded 100%.

Mineralogical analyses of the <2 um fraction reveals that the gray silt loam is illite-rich and likely composed of reworked diamicton of the Yorkville Member (Lemont Formation), a unit that forms most of the Marseilles Morainic System. The organic silty gyttja contains somewhat more expandable clay minerals (relative to illite) and more silt (relative to clay) than the underlying gray unit. The change in mineralogy and grain-size is consistent with some contributions of far-traveled loess to the locally derived glaciogenic sediment comprising the gyttja unit. At the Brewster Creek site in northwestern DuPage County, Illinois, contributions of loess to the lake sediment ceased at about 14,650 cal yr BP, coincident with Termination I, and the onset of Bølling Chronozone (Curry et al., 2007). The corresponding depth in this core occurs just below 3.95 m where charcoal and needles yielded at age of 14,380 cal yr BP (Table 1; Fig. 13). Fossils of ostracodes, bivalves,

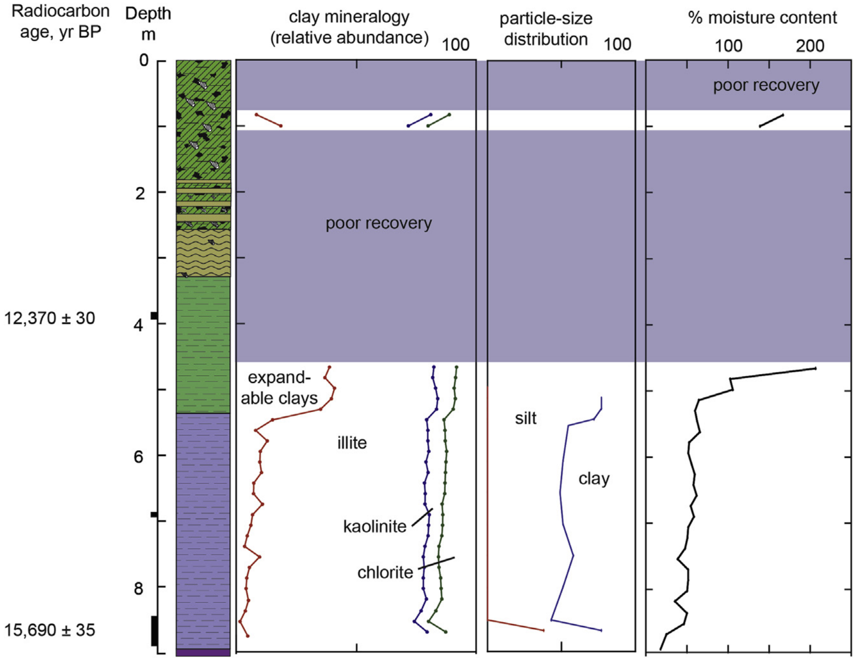

Fig. 13. Composite lithologic log of sediment cores sampled just south and east of the Reservation Road bridge crossing at Morgan Creek (Fig. 5A). Relative data for clay mineralogy and particle-size-distribution (clay $<$ 4 μm) are shown, along with moisture content.

gastropods, thecamoebians, plant macrofossils, and charcoal are abundant in the lake silts, marl, and peat, and less abundant in the gyttja.

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