An optical age chronology of Late Pleistocene fluvial deposits in the northern lower Mississippi valley

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Abstract

The lower Mississippi valley (LMV) contains many large braided channel belts that are preserved west of the Holocene floodplain. Previous efforts to establish geochronologic control on channel-belt construction have been hindered by the lack of organic material for radiocarbon dating. Luminescence techniques provide a burial date for the sediment itself and may prove useful in this context. Samples from three channel belts in the northern LMV were analyzed using the single aliquot-regenerative technique on 90–125 µm quartz. Optical ages (19.7–17.8, 16.1–15.0 and 12.5–12.1 ka) are consistent with geomorphic relationships and indicate that channel belts were formed in the late Pleistocene under glacial conditions. These optical ages provide the first detailed chronology of LMV channel-belt formation and are the first step towards developing a chronology for the entire LMV.

1. Introduction and background

The lower Mississippi valley (LMV) is a broad alluvial valley that contains large braided channel belts with dimensions of the order of 10’s of km wide and 100’s of km long. The Mississippi River currently drains North America between the Appalachian and Rocky Mountains, but during the late Pleistocene its drainage basin was enlarged to include meltwater from the Laurentide ice sheet and large glacial lakes such as Lake Agassiz (Fig. 1) (Teller, 1990; Licciardi et al., 1999). In addition, the lower Mississippi River experienced high-amplitude variations in eustatic sea-level during the last glacial cycle (Chappell et al., 1996).

Braided channel belts in the LMV have been examined by three generations of researchers over the past 65 years. Conflicting interpretations of channel belt ages and the importance of sea level and meltwater discharge in channel belt formation have been proposed. For example, Fisk (1944) suggested that the entire LMV was deeply incised during the last glacial eustatic lowstand. Coarse-grained braided channel belts formed in response to early to middle Holocene sea-level rise, with transition to a fine-grained meandering stream during the late Holocene sea-level highstand. Saucier (1994a,b, 1996) in contrast, proposed that braided channel belts formed during deglaciation and the transition to a meandering regime occurred in the early Holocene due to a loss of glacial sediment and meltwater discharge. The chronology proposed by Saucier (1994a,b) places channel belt formation during deglaciation in marine isotope stage (MIS) 4 and 2. Blum et al. (2000) concurred with Saucier’s glacial forcing mechanism but proposed that major channel belt surfaces represent MIS 6 and 2 deglaciations, with MIS 4 channel belts only preserved in isolated locations.

All previous studies of LMV channel belts were based on relative age relationships, with a limited number of radiocarbon age estimates. Only a few reliable radiocarbon ages have been obtained after years of study by various groups, most of which only constrain the minimum timing of channel belt abandonment (see Blum et al., 2000). Collection of material for radiocarbon dating has been difficult in the LMV because the braided channel-belt deposits often lack organic material or are too old for the radiocarbon technique. In addition, bulk organic sediments are commonly contaminated by lignite, producing age overestimates. Hence, channel belt ages and their correlation to forcing mechanisms have remained poorly resolved.

Because of the difficulty in obtaining reliable radiocarbon ages, optically-stimulated luminescence (OSL) were applied to the LMV to develop a chronology of channel belt formation. Since the deposits are primarily...
composed of sand with few gravel lenses, the selection of suitable sample localities was much easier than for radiocarbon and allowed multiple ages to be obtained for each channel belt surface. This paper reports initial results from these efforts and presents the first detailed chronology of LMV channel belts.

2. Methods

Samples for optical dating were collected from three previously mapped, cross-cutting channel belts in the northern LMV. The channel belts sampled, listed from the highest (oldest) to lowest (youngest) surface, are Pve, Pvl 2 and Pvl 1, using the map unit names of Saucier (1994a) (Fig. 2). These channel belts have the best radiocarbon age control and offer the best opportunity to test previous age models, as well as test the suitability of optical dating in this setting. All samples were processed at the Luminescence Geochronology Lab at the University of Nebraska-Lincoln.

2.1. Sample collection and preparation

Samples were collected in aluminum tubes pushed into sediment exposures or by coring with a vibracorer. Sample depth, elevation, and latitude/longitude were noted for calculation of cosmic contribution (Prescott and Hutton, 1994). Representative samples for the determination of water content and dose rate were collected from within 30 cm of the sample tube in sediment exposures, or from within the core tube from samples collected by vibracorer. In situ water content was measured by drying the samples at 100°C. The bulk sediment concentration of K, Rb, U and Th was measured using ICP-MS and ICP-AES techniques. For this analysis, the sample was ground to 75 μm and dissolved in a hydrofluoric–nitric–perchloric acid digestion (performed by CHEMEX Labs, Sparks, Nevada). Representative duplicates were checked for complete dissolution using a fusion flux dissolution technique. Finally, dose-rates incorporating water content, chemistry and cosmic contribution were calculated using the methods of Aitken (1998) and Prescott and Hutton (1994) (Table 1).

Samples were opened in the laboratory under dim amber light and wet sieved to separate the 90–125 μm fraction. To isolate the quartz component, the samples were treated with 10% hydrochloric acid to remove carbonates and floated in 2.7 g/cm³ sodium polytungstate to isolate heavy minerals. To remove feldspars and etch the quartz grains, the samples were first treated with 10% hydrofluoric acid for one hour to remove the highly reactive minerals. This solution was then
decanted and replaced with 48% hydrofluoric acid for a minimum of 50 min, followed by 23% fluorosilicic acid for 48 h. This was followed by one hour in 47% hydrochloric acid to remove any fluorides produced. A mechanical agitator was used to ensure continual stirring during the acid treatments. The rinsed and dried sample was then re-sieved to remove the < 75 μm fraction. Infrared stimulation was used to detect the presence of feldspar and to assure the purity of the quartz separate. If necessary, the sample was treated a second time with concentrated hydrofluoric acid and fluorosilicic acid to remove residual feldspars.

2.2. Optical measurement setup

The 90–125 μm quartz fraction was mounted in a 2-mm diameter region on aluminum disks using Silkspray (a silicone based spray). Optical measurements were performed on a RISO TL/OSL-DA-15B/C reader with blue-green light stimulation (470 nm, Hoya U340 filter), using the single aliquot regenerative (SAR) protocol of Murray and Wintle (2000).

To determine the proper preheat temperatures, preheat plateau tests were measured between 200°C and 300°C at 20°C increments, using 5 aliquots per temperature step. Equivalent dose values were not affected by preheat temperatures between 220°C and 260°C, but showed greater scatter above 260°C. Therefore, a preheat temperature of 240°C was selected. Cutheat temperature was 160°C, with optical measurements conducted at 125°C.

Dose recovery tests were performed by applying a beta dose of 21 Gy to samples after bleaching. Dose recovery, using regenerative doses of 11 Gy (regenerative dose 1 and 4), 21 Gy (regenerative dose 2) and 43 Gy (regenerative dose 3), and 5 Gy test doses, was within 0.5–3% of the applied dose, suggesting that the SAR method with the above preheat and cutheat temperatures is suitable for LMV channel belt samples.

3. Equivalent dose distributions

Previous workers have shown that partial bleaching can be a problem in fluvial environments (Murray et al., 1995; Olley et al., 1998, 1999), especially in proglacial systems (Hutt and Jungner, 1992; Majdal and Funder, 1994; Gemmell, 1999). Partial bleaching was of some concern for this study because the Mississippi River is known to have received glacial meltwater and sediment from the Laurentide ice sheet during deglaciation. To help identify partial bleaching, small quantities of sand (~100 grains) were used in each aliquot in order to approach single-grain distributions (Olley et al., 1999). This caused the data from some aliquots to be discarded due to low response, but increased sensitivity to partially bleached populations.

Equivalent dose ($D_e$) distributions in histograms and cumulative probability plots were examined for evidence of asymmetry symptomatic of partial bleaching (Olley et al., 1998, 1999). Most $D_e$ distributions were roughly Gaussian in nature, with some distributions slightly skewed toward higher values (Fig. 3). In addition, standardized $D_e$-signal intensity plots (Colls, 1999; Colls et al., 2001) had low correlation ($r^2 = 0.2$) and $D_e(t)$ plots (Bailey et al., 2002) showed no increase in $D_e$ with measurement time, both indicating a lack of evidence for partial bleaching. This was surprising, given the glacio-fluvial environment and high suspended sediment concentrations in the river system, as
indicated by thick slackwater deposits (Robnett, 1997; Blum et al., 2000). Despite these conditions, long transport distances on the order of several hundred kilometers appear to have been sufficient for complete sediment bleaching. Due to the limited evidence of partial bleaching, the mean $D_e$ was used to calculate the optical ages (Table 2). This was justified by the nearly Gaussian $D_e$ distributions and close agreement between the mean $D_e$, median $D_e$ and the peak cumulative probability $D_e$ (see Fig. 3).

### Table 2

Optical age estimates and $D_e$ values from LMV channel belt samples, $D_e$ errors reported as standard error

<table>
<thead>
<tr>
<th>Site no.</th>
<th>Sample no.</th>
<th>UNL Lab no.</th>
<th>Dose rate (Gy/ka)</th>
<th>No. of aliquots</th>
<th>$D_e$ (Gy)</th>
<th>$\sigma$</th>
<th>Optical age (ka)</th>
<th>$^{14}$C age (cal. ka)$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>MIS 06–24–22</td>
<td>UNL-120</td>
<td>1.8 ± 0.08</td>
<td>28</td>
<td>36.4 ± 0.8</td>
<td>4.1</td>
<td>19.7 ± 1.1</td>
<td>19.75 ± 0.65$^b$</td>
</tr>
<tr>
<td>8</td>
<td>MIS 03–27–8</td>
<td>UNL-168</td>
<td>1.8 ± 0.05</td>
<td>45</td>
<td>33.6 ± 0.6</td>
<td>4.1</td>
<td>18.5 ± 0.8</td>
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<tr>
<td>20</td>
<td>MIS 06–23–20</td>
<td>UNL-346</td>
<td>1.6 ± 0.04</td>
<td>27</td>
<td>28.0 ± 0.7</td>
<td>3.8</td>
<td>17.8 ± 0.8</td>
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<tr>
<td>47</td>
<td>MIS 07–03–47</td>
<td>UNL-125</td>
<td>1.8 ± 0.05</td>
<td>28</td>
<td>28.9 ± 0.5</td>
<td>3.4</td>
<td>16.1 ± 0.7</td>
<td>&gt; 13.13 ± 0.46$^c$</td>
</tr>
<tr>
<td>44</td>
<td>MIS 06–31–44</td>
<td>UNL-343</td>
<td>1.8 ± 0.04</td>
<td>27</td>
<td>27.8 ± 0.4</td>
<td>2.2</td>
<td>15.8 ± 0.6</td>
<td>&gt; 12.93 ± 0.30$^d$</td>
</tr>
<tr>
<td>45</td>
<td>MIS 06–31–45</td>
<td>UNL-124</td>
<td>1.8 ± 0.05</td>
<td>30</td>
<td>26.6 ± 0.5</td>
<td>2.6</td>
<td>15.1 ± 0.7</td>
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<tr>
<td>51</td>
<td>MIS 07–05–51</td>
<td>UNL-353</td>
<td>1.7 ± 0.05</td>
<td>34</td>
<td>25.8 ± 0.4</td>
<td>2.4</td>
<td>15.0 ± 0.7</td>
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<tr>
<td>37</td>
<td>MIS 06–28–37</td>
<td>UNL-169</td>
<td>1.6 ± 0.06</td>
<td>32</td>
<td>19.4 ± 0.4</td>
<td>2.5</td>
<td>12.5 ± 0.7</td>
<td>&gt; 10.22 ± 0.51$^e$</td>
</tr>
<tr>
<td>39</td>
<td>MIS 06–29–39</td>
<td>UNL-123</td>
<td>1.8 ± 0.06</td>
<td>29</td>
<td>21.9 ± 0.6</td>
<td>3.1</td>
<td>12.4 ± 0.6</td>
<td>&gt; 9.88 ± 0.33$^f$</td>
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<tr>
<td>16</td>
<td>MIS 06–22–16</td>
<td>UNL-119</td>
<td>1.8 ± 0.05</td>
<td>20</td>
<td>22.5 ± 0.7</td>
<td>2.9</td>
<td>12.2 ± 0.6</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>MIS 06–22–18b</td>
<td>UNL-335</td>
<td>2.0 ± 0.05</td>
<td>43</td>
<td>24.2 ± 0.5</td>
<td>3.2</td>
<td>12.1 ± 0.5</td>
<td></td>
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</table>

Radiocarbon ages were collected by previous workers from other sites and represent the age constraint on the channel belt as a whole. Site numbers refer to sample localities in Fig. 2.

$^a$ Radiocarbon ages converted to calendar years by CALIB 4.3 (Stuiver et al., 1998a,b).

$^b$ Blum et al. (2000).

$^c$ Wesnousky and Leffler (1992).

$^d$ R.W. Graham, personal communication reference in Blum et al. (2000).

$^e$ Guccione et al. (1988).

$^f$ King and Allen (1977).

Fig. 3. Histograms (upper) and cumulative probability curves (lower) for two samples with individual $D_e$ and associated errors for aliquots plotted in rank order. Bin width for the histograms is 2 Gy. For the cumulative probability curves, the sum of the normal distributions ($\pm 3\sigma$) from the aliquots is plotted in black with the distribution calculated from the mean and standard deviation in grey. Units are arbitrary and reflect increasing probability.
4. Optical ages

Optical ages and radiocarbon age constraints for the three channel belt surfaces sampled are shown in Table 2. The highest channel belt surface, mapped as Pve, produced optical ages between 19.7 and 17.8 ka, whereas samples from Pvl 2 were between 16.1 and 15.0 ka, and the lowest channel belt, Pvl 1, produced ages between 12.5 and 12.1 ka. The spread in ages is consistent with a braided system that has occupied a channel belt for a period of time. Age estimates from these surfaces are in agreement with geomorphic relationships and previously determined radiocarbon ages. Of special note is the good agreement between the optical ages for the Pve channel belt and the radiocarbon age from a surface thought to correlate with Pve (Table 2). Other published radiocarbon ages are minimum age estimates for the surfaces; nevertheless the optical chronology agrees with these ages.

5. Comparison to previous channel belt chronologies

The optical ages presented here allow previous models for LMV channel belt formation to be re-examined. To reiterate from above, under Fisk’s (1944) model, all braided channel belts formed during the early to middle Holocene in response to sea-level rise (Table 3). Saucier (1994a,b; 1996) in contrast suggested that the channel belts formed in response to glacial discharge. In relationship to the specific channel belts sampled here, Saucier (1994a) placed the Pve channel belt in MIS 4 and Pvl 2 and Pvl 1 in MIS 2 (Table 3). Finally, Blum et al. (2000) proposed that the Pve surface formed during the last glacial maximum (ca 21 ka) and concurred with Saucier (1994a,b) that Pvl 2 and Pvl 1 formed during MIS 2 deglaciation between ca 13.5 and 10.7 ka (Table 3).

The optical ages presented here support a MIS 2, last glacial maximum, age for the Pve channel belt, as suggest by Blum et al. (2000). Furthermore, new optical ages greatly refine age estimates for Pvl 2 and Pvl 1, suggesting they are slightly older than what has been inferred from minimum ages obtained by the radiocarbon technique (Table 2). By providing the first numerical age estimates for LMV channel belts, these new optical ages provide an opportunity to move towards linking periods of channel belt construction and abandonment with various forcing mechanisms.

6. Conclusions

The application of optical luminescence techniques has provided the first detailed chronology for the large braided channel belts of the lower Mississippi alluvial valley. Previous chronologies have been based on relative age relationships and a limited number of radiocarbon ages. The main deterrent to obtaining age estimates in the past was the lack of datable organic material in the channel belt sediments. By contrast, the luminescence technique is ideal for the LMV since the channel belts are primarily composed of quartz-rich sand, and provide a nearly limitless selection of suitable sample localities.

Samples from three previously mapped cross-cutting braided channel belts were collected to test previous age models developed for LMV evolution. Optical ages suggest that the highest channel belt, mapped as Pve by Saucier (1994a) is 19.7–17.8 ka, the Pvl 2 channel belt is 16.1–15.0 ka, and the lowest channel belt, Pvl 1, formed 12.5–12.1 ka. Despite glacial meltwater conditions in the Mississippi during the late Pleistocene, the samples show minimal evidence of partial bleaching. Optical ages agree with relative geomorphic relationships and the available radiocarbon ages, and suggest the channel belts formed in the late Pleistocene during MIS 2 under conditions of high meltwater discharge. These new data support the glacial forcing hypothesis of Saucier (1994a) and Blum et al. (2000) for channel belt formation in the northern LMV.

The new optical chronology presented here has allowed previous models of LMV landform evolution to be tested. The ages obtained here are the first step towards a larger research objective to develop an optical chronology for the entire LMV. Once completed, it will be possible to resolve the spatial and temporal response of this continental-scale river system to adjustments in hydrology and sea level during a full glacial-interglacial cycle.

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References


