Terminal Pleistocene braided to meandering transition in rivers of the Southeastern USA

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Abstract

Thirteen paleomeanders on the oldest parts of meander belts on floodplains in the Coastal Plain of Georgia and the Carolinas (southeastern USA) were selected for radiocarbon dating to determine the onset of meandering following braiding during the Late Pleistocene during Oxygen Isotope Stage 2. The radiocarbon ages were compared to previously reported Late Pleistocene ages for braid bars and eolian dunes. Results indicate that meandering commenced at circa 15,000 to 16,000 cal years BP and continued throughout the terminal Pleistocene and Holocene. Correlation with other paleoenvironmental records indicates that this shift to meandering was associated with global warming and moister conditions in the southeastern United States that led to a denser vegetation cover and a reduction in sediment yield. The shift to meandering was also associated with some incision and terracing of the Late Pleistocene braided fluvial surfaces. Paleodischarge of the bankfull condition of early Holocene meandering channels was apparently greater than under modern conditions, suggesting wetter conditions at that time than at present. This braided to meandering transition in the southeastern United States provides an example of river response to global climate change in a relatively low latitude region of the world that was not influenced by glacial or periglacial landscape conditions.

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1. Introduction

Paleoenvironmental conditions of climate and hydrology during the Late Pleistocene caused rivers in the southeastern Atlantic Coastal Plain of the USA to exhibit braided patterns (Leigh et al., 2004), and braiding changed to meandering by Holocene time (Schuldenrein, 1996; Leigh and Feeney, 1995). However, the timing of the braided to meandering transition is not well established. Thus, the main objective of this paper is to determine the time of the braided to meandering transition and its correlation with changing environmental conditions in the southeastern United States.

Worldwide shifts from braided to meandering patterns near the end of the Late Pleistocene and marine Oxygen Isotope Stage 2 (OIS 2; circa 29,000–11,000 cal. years BP) are well documented in response to changes in glacial meltwater discharge and sediment yield related to the latest Pleistocene deglaciation (e.g. Schumm and Brakenridge, 1987; Knox, 1995; Starkel, 1995; Blum and Törnqvist, 2000; Blum et al., 2000). In addition, unglaciated drainages at relatively high latitudes in Europe exhibited braided to meandering transitions at the end of the Pleistocene in response to a shift from periglacial to non-periglacial conditions (e.g. Kozarski, 1991; Kasse et al., 1995; Straffin et al., 2000). The braided to meandering transition of rivers in the southeastern United States is somewhat unusual, because it lacks glacial meltwater or periglacial drivers, and it represents a response to more subtle hydrologic changes related to changes in climate and vegetation cover in a relatively low latitude humid subtropical climate zone. New radiocarbon dates are presented here that establish the timing of that planform transition in Georgia and the Carolinas of the southeastern Coastal Plain, USA. This allows correlation of the planform transition with known changes in paleovegetation and landscape conditions derived from pollen records in the region.

2. Methods

A chronology for Late Pleistocene braided river patterns (Leigh et al., 2004) and related eolian dune sedimentation
on floodplains (Ivester et al., 2001) is well established for the Atlantic Coastal Plain of the southeastern United States, and that chronology is used here to illustrate the period when floodplains exhibited sand-dominated braided fluvial systems during the latest Pleistocene cold climate of OIS 2. Radiocarbon dates from paleomeanders that represent the earliest meander scars preserved on floodplains are used to determine the onset of the transition to meandering that occurred following the cessation of latest Pleistocene braided conditions. The locations of paleomeander sample sites for radiocarbon dating are shown in Fig. 1, and the coordinates for these sites are given in Table 1. All of the sites are in the Coastal Plain physiographic province, but most of the drainages have their headwaters on the Piedmont. The drainage basins of these sites range from about 1000 to 25,000 km², which typifies the sizes of most rivers on the Coastal Plain.

The method for radiocarbon dating the time of meander initiation involved selecting the oldest looking meander scars available and using the oldest dates from these paleomeanders to infer the onset of meandering when compared to the chronology for braided patterns. Relatively old looking meander scars were identified on colour infrared, National Aerial Photography Program (NAPP) photographs (1:10,000

Table 1

<table>
<thead>
<tr>
<th>Lab. no. and location</th>
<th>Coordinate (UTM, NAD 83)</th>
<th>Material dated</th>
<th>¹⁴C date ± 1 sigma (¹³C corrected)</th>
<th>2-Sigma cal years BP range</th>
<th>Radiusₚ/ₚₒ</th>
<th>Widthₚ/ₚₒ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta-121302, Contentnea Cr., NC</td>
<td>236750E, 3951649N</td>
<td>Seeds</td>
<td>12,520 ± 120</td>
<td>14,163–15,507</td>
<td>1.4</td>
<td>3.0</td>
</tr>
<tr>
<td>UGA-9982, Canoochee R. at Ft. Stewart, GA</td>
<td>452252E, 3535440N</td>
<td>Charcoal</td>
<td>12,400 ± 50</td>
<td>14,136–15,396</td>
<td>2.6</td>
<td>3.5</td>
</tr>
<tr>
<td>UGA-9748, Canoochee R. at Ft. Stewart, GA</td>
<td>461306E, 3537598N</td>
<td>Charcoal</td>
<td>11,770 ± 50</td>
<td>13,428–14,990</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>UGA-10297*, Pee Dee River, NC</td>
<td>612431E, 3806724N</td>
<td>Acorn</td>
<td>11,470 ± 50</td>
<td>13,163–13,806</td>
<td>2.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Beta-145880, Ogeechee R. at Ft. Stewart, GA</td>
<td>465540E, 3544710N</td>
<td>Seeds</td>
<td>10,210 ± 70</td>
<td>11,441–12,355</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td>Beta-145883, Ogeechee R. at Ft. Stewart, GA</td>
<td>463565E, 3547936N</td>
<td>Peat</td>
<td>10,000 ± 60</td>
<td>11,221–11,927</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>UGA-9374, Canoochee R. at Ft. Stewart, GA</td>
<td>454608E, 3537762N</td>
<td>Acorn</td>
<td>9950 ± 40</td>
<td>11,191–11,553</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Beta-151615*, Little River at Ft. Bragg, NC</td>
<td>673946E, 3893813N</td>
<td>Wood</td>
<td>9150 ± 40</td>
<td>10,217–10,410</td>
<td>1.7</td>
<td>4.0</td>
</tr>
<tr>
<td>Beta-66165*, Mid Ogeechee River, GA</td>
<td>419950E, 3615050N</td>
<td>Hickory nut</td>
<td>8190 ± 60</td>
<td>9007–9383</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>Beta-66163*, Mid Ogeechee River, GA</td>
<td>434350E, 3603530N</td>
<td>Wood</td>
<td>7700 ± 100</td>
<td>8213–8765</td>
<td>1.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Beta-145888, Ogeechee R. at Ft. Stewart, GA</td>
<td>462692E, 3539811N</td>
<td>Charcoal</td>
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<td>6015–6302</td>
<td>1.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Beta-66164*, Mid Ogeechee River, GA</td>
<td>441650E, 3599600N</td>
<td>Wood</td>
<td>4560 ± 70</td>
<td>5069–5582</td>
<td>2.4</td>
<td>n.d.</td>
</tr>
<tr>
<td>UGA-7313, Canoochee R. at Ft. Stewart, GA</td>
<td>463738E, 3547772N</td>
<td>Charcoal</td>
<td>4180 ± 80</td>
<td>4450–4867</td>
<td>1.7</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*Previously reported in Leigh and Feeney (1995); † previously reported in Leigh et al. (2004); ‡ previously reported in Goman and Leigh (2004); § ratio of paleo bankfull discharge to modern bankfull discharge based on radius of curvature measurements; ¶ ratio of paleo bankfull discharge to modern bankfull discharge based on channel width.

Qₚ = paleo bankfull discharge.
Qₒ = modern bankfull discharge.
Meander scars were preferentially selected from landscape positions that were clearly on the oldest parts of meander belts, as indicated by cross-cutting relationships and juxtaposition of outer versus inner parts of meander belts. Most of the sample sites were meander scars that scalloped braided river terraces. Both paleo and modern discharges were estimated based on the equations of Leigh and Feeney (1995) that predict (or retrodict) discharge based on radius of curvature and channel width dimensions. Their equations are based on channel dimension measurements from modern gaged rivers in the region that were correlated with modern bankfull discharge. These estimates of discharges were then expressed as ratios of paleo to modern bankfull discharge. While the error of the estimate for discharge by this method may be large (172–182 m$^3$ s$^{-1}$ in Table 1 of Leigh and Feeney, 1995), this technique is used primarily to provide a discharge-based comparison of the obvious differences in channel sizes.

All radiocarbon dates are calibrated to calendar years using the Calib 4.4 program (Stuiver et al., 1998) using a 50-year smoothing function. Radiocarbon samples were obtained with a bucket auger or a Russian corer from either the base of fine-grained or organic paleochannel fill immediately on top of channel-bed sands and gravels or from organic material preserved directly in the paleochannel bed material. Materials for radiocarbon dating were carefully selected only to include material that appeared fresh and not reworked by transport, such as whole acorn caps, unbroken twig fragments, and angular fragments of charcoal. All radiocarbon samples were measured by the accelerator mass spectrometer method (AMS) following a thorough cleaning of the sample with an acid–alkali–acid (NaOH–HCl–NaOH) leaching procedure.

### 3. Results

Radiocarbon dates obtained from the base of sediment that fills meandering paleochannels indicate a maximum age of about 15,000 to 16,000 cal years BP for the earliest dated meandering channels (Table 1). The three oldest dates have their upper boundary of the 2-sigma age estimate at 14,990–15,507 cal years BP, with the calendar-age intercepts ranging from 14,209 to 14,835 cal years BP. This indicates that these oldest meandering channels were probably active at (or shortly prior to) 15,000 cal years BP, because the sample material probably dates the time of meander abandonment.

Comparison of age estimates obtained from braided patterns and eolian dunes against the radiocarbon dates from the meandering patterns clearly indicates a 14,000–16,000 cal years BP transition from braiding to meandering (Fig. 3). Ivester et al. (2001) indicated that eolian dunes on river valleys of the southeastern Coastal Plain were “source bordering” dunes that had a genetic linkage to river channels that exposed abundant sources of sand for eolian transport. Thus, the dunes bear a stratigraphic linkage to braided river patterns and in themselves date the time of a radically different river system. A zone of overlap between braiding, dunes, and meandering is apparent at 14,000–16,000 cal years BP, which probably reflects the analytical error in the age estimates in addition to the true variability in the age range in timing of the braided to meandering transition. One date from a braid bar (BC-1 of Leigh et al., 2004) is younger than the 14,000–16,000 cal years BP zone of overlap (Fig. 3), but the old end of the 2-sigma error bars on this date is 14,400 cal years BP, which is well within the 14,000 to 16,000 cal years BP transition zone. Although this
is a relatively small set of radiocarbon dates \((n = 13)\), it nonetheless indicates a low probability that any of the latest Pleistocene paleomeanders would pre-date 15,000–16,000 cal years BP.

No radiocarbon dates are reported for ages less than 4000 cal years BP and this is simply a function of the deliberate bias towards sampling the oldest meander scars. However, Landsat and NAPP imagery clearly shows that meandering patterns were present continuously after 14,000 cal years BP, because nothing but meandering patterns can be recognized on geomorphic surfaces younger than those selected for radiocarbon dating at each site and their vicinity.

The oldest meandering paleochannels typically occur on the level of the modern floodplain inset 1 to 3 meters below the braided river terrace, which is typically the first prominent terrace. This indicates that incision and downcutting to the level of the modern floodplain occurred in association with the transition from braiding to meandering at circa 15,000 cal years BP. Some of the latest Pleistocene meanders exhibit distinct sandy scroll bar patterns (Fig. 2). These scrolled patterns may have evolved as a transitional planform that still transported large amounts of sandy bed material (like the preceding braided pattern), but lacked sufficient overbank deposition of silt and clay to create clay-rich vertical accretion floodplains that are more characteristic of later Holocene channels (especially those younger than 10,000 cal years BP).

The relatively large size of the latest Pleistocene and Early Holocene paleochannels (at circa 15,000 to 5000 cal years BP), compared to the small size of the modern and latest Holocene channels (Fig. 2) suggests that the latest Pleistocene and early Holocene meandering channels conveyed considerably more discharge at the bankfull stage than do the modern meandering channels. Paleodischarge measurements could not be made from the braided channels because no clearly defined bankfull channel could be identified. Using the predictive equations for discharge of Leigh and Feeney (1995), which are based on meander geometry, the ratio of paleo to modern discharge for the 10,000–15,000 cal years BP paleochannels ranges from 1.4 to 4.0, and that of 5000 to 10,000 cal years BP paleochannels ranges from 1.7 to 3.1. No data are available for paleochannels younger than 4500 cal years BP, but clearly there are much smaller paleomeanders occurring on inner parts of meander belts that are younger than the dated paleochannels.

4. Discussion

These data strongly indicate the existence of a braided to meandering transition at about 15,000–16,000 cal years BP, based on the overlapping relationship between the youngest braid and dune dates with the oldest meandering dates (Fig. 3, Table 1). This conclusion is corroborated by previously reported radiocarbon and luminescence dates obtained at the boundary between braided and meandering scroll bar patterns in the Pee Dee River valley (Leigh et al., 2004) that were reported to indicate a 14,500–17,000 cal years BP age for the braided to scrolled meandering transition. Indeed, scroll bars are apparent at some of the latest
Pleistocene sites, which suggests that a sandy scroll bar meander pattern may have been the earliest form of meandering at the end of the Pleistocene. The sandy scroll bars may have resulted as a transitional form of meandering that was still influenced by a large portion of sandy bed material following sand-bed braiding during the latest Pleistocene of OIS 2.

A 15,000–16,000 cal years BP estimate for the time of the braided to meandering transition correlates with a major shift in regional vegetation patterns towards warmer and somewhat wetter conditions than during the preceding cold climate of the Late Pleistocene full-glacial climates (Watts, 1980; Whitehead, 1981; Delcourt and Delcourt, 1985; Prentice et al., 1991; Kneller, 1996; Kneller and Peteet, 1999; Lamoreaux, 1999). A 15,000 cal years BP date also correlates with the first pronounced rise in sea surface temperature at the end of the Pleistocene (Bard, 2002, 2003). Thus, it is likely that the braided to meandering shift was driven by changes in hydrologic conditions that were related to regional changes in climate and vegetation cover, associated with global warming.

Two pollen sections located in the study area that are long enough to capture the entire transition from the Late Pleistocene through the Holocene (i.e. last 25,000 years) include White Pond near Columbia, South Carolina (Watts, 1980) and the Sandy Run Creek site at Warner Robbins Air Force Base near Macon, Georgia (Lamoreaux, 1999). Both of these sites indicate relatively cold and dry conditions during the full-glacial climatic period of OIS 2 with sparse and patchy cover of northern pine tree species (e.g. spruce, jack pine, fir) interspersed with patches of grassland. However, at circa 15,000 cal years BP a relatively rapid transformation occurred to produce an oak-dominated forest with small percentages of cool-climate deciduous trees and little pine. Spruce pollen grains are present in low numbers at both pollen sites during 15,000 to 10,000 cal years BP, but disappear by 10,000 cal years BP. Both Watts and Lamoreaux conclude that the 15,000–10,000 cal years BP period was cool and moist with a relatively dense forest cover of deciduous trees, in contrast to the colder, drier, and more sparsely vegetated conditions prior to 15,000 years BP.

The size and inferred large magnitude of bankfull discharge of the dated paleomeanders indicates wetter-than-modern conditions for the first half of the Holocene (circa 10,000–5,000 cal years BP), which is an observation made by others (Leigh and Feeney, 1995; Goman and Leigh, 2004). However, more data are needed to completely understand the explicit changes in paleodischarge for rivers of the Coastal Plain throughout the Holocene.

The increase in temperature and moisture at circa 15,000 cal years BP apparently was sufficient to shift the channel patterns from braided to meandering. This probably resulted from a more dense vegetation cover that reduced sediment yield in a fashion similar to that indicated by Langbein and Schumm (1958). In addition, drier conditions during the latest Pleistocene, which favored eolian dune sedimentation on floodplains, may have been associated with sparse streambank vegetation that facilitated bank instability and braiding. Another possible driver of the braided-meandering transition would have been a change in the flood regime to favor more overbank sedimentation of silt and clay, possibly related to longer durations of overbank flooding conditions, but the paleoflood regimes during this time period are not well known.

A reduction in sediment yield, particularly sandy bed material, and restabilization of riverbanks with vegetation is consistent with a shift to meandering conditions (Carson, 1984; Bridge, 2003). Similar changes in river patterns have been recognized in other parts of the world, particularly in response to a reduction in sediment supplied from periglacial sources (Kozarski, 1991; Kasse et al., 1995; Straffin et al., 2000). However, such braided-meandering pattern changes have not been well documented for relatively lowlatitude humid subtropical regions like the southeastern United States.

Frost shattering and other related periglacial phenomena are cited as drivers for braiding in unglaciated drainages of northern Europe (Kozarski, 1991; Kasse et al., 1995; Straffin et al., 2000), and one may wonder if this was also the case in the southeastern United States. However, the southern limit of discontinuous permafrost during the Late Pleistocene of OIS2 is mapped at several hundred kilometers north of the basins studied in Georgia and the Carolinas (Pewe, 1983). Furthermore, no indisputable evidence of latest Pleistocene periglacial conditions has been found on the Piedmont where most of these drainages have their headwaters. Thus, the periglacial origin seems unlikely.

There is no apparent shift back to braiding during the Younger Dryas cold period at circa 11,000 to 12,000 cal years BP. This is consistent with the suggestion of Kneller and Peteet (1999) that the southern limit of Younger Dryas cooling effects in eastern North America may have been at around 38° north latitude, having low to no impact on the study area. Alternatively, the Younger Dryas cold shift may not have been of long enough duration to change the vegetation and hydrological conditions enough to produce a noticeable change in channel patterns.

5. Conclusion

The braiding–meandering transition in the southeastern Atlantic Coastal Plain occurred at about 15,000 to 16,000 cal years BP. The best explanation for this shift in channel pattern appears to be that climate change drove reforestation and development of a denser vegetation cover, which in turn reduced erosion and sediment yield to the drainage systems, while simultaneously increasing the resistance of channel bank materials. This shift occurred in association with global warming and regional increases in moisture at the end of the Pleistocene. Terracing of the braided surfaces was accomplished in association with the onset of meandering,
and the earliest phase of meandering may have been characterized by bend morphologies that featured sandy scroll bars. The braided to meandering transition in the southeastern United States provides an example of river response to global climate change in a relatively low latitude region of the world that was not influenced by glacial or periglacial landscape conditions.

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References