Meander migration rates and age of the lower Assiniboine River

Christopher W. Bater, University of Winnipeg

Abstract: A 36-km reach of the lower Assiniboine River west of Winnipeg was studied to determine the age of its modern channel and rates of meander migration. The age of the modern channel was established by collecting samples from alluvium for radiometric or dendrochronological dating. *Bison bison bison* (Linnaeus) bones, removed from a depth of 2.4 m in a 2.6-m thick section of overbank and backswamp deposits, were dated at 2115 +/- 50 yrs BP (BGS-2318) and represent a minimum age for the channel. To establish rates of meander migration, four subfossil *Quercus macrocarpa* (Michx.) logs were collected from within two point bar sequences for dating, and meanders shown on aerial photographs from 1948, 1959 and 1968 were measured. Two logs, 45 m apart, had outermost ring dates of AD 1555 and 1622, indicating a lateral accretion rate of 0.61-0.67 m/yr. Two logs, 104 m apart, had radiocarbon dates of 480 +/- 40 yrs BP (BGS-2317) and 305 +/- 40 yrs BP (BGS-2316) indicating a lateral accretion rate of 0.41-1.09 m/yr. Migration rates for six meanders between 1948 and 1968 ranged from 0 to 1.0 m/yr, with mean and median rates of 0.4 and 0.3 m/yr respectively. Migration rates vary with differences in bank material on the concave sides of meanders, as the river is partially confined by Lake Agassiz clays. Migration rates of meanders eroding into glaciolacustrine clay ranged from 0 to 0.1 m/yr, while meanders eroding into alluvium had rates ranging from 0.3 to 1.0 m/yr.

Key words: Assiniboine River, fluvial geomorhology, meander migration, paleochannels, dendrochronology, radiocarbon dating

Introduction

Downstream of Portage la Prairie, the Assiniboine River has deposited an unusual floodplain fan (Rannie 1990) through a process of repeated alluvial ridge development and abandonment. As a result it has, at different times, flowed into either Lake Manitoba or the Red River (Rannie *et al.* 1989). A spatially dynamic history such as this brings into question the exact age of the lower Assiniboine River's modern channel, as it has implications for both the hydrological and sedimentological histories of

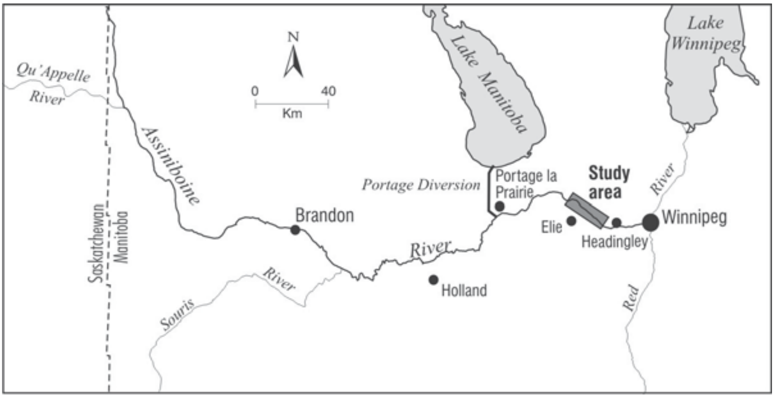

Figure 1: *The central and lower Assiniboine River.*

Lake Manitoba and the Red River, and for the geomorphological history of the landscape east of Portage la Prairie. Another aspect of the river's past is its rate of meander migration. This is of interest from a geomorphological perspective because lateral accretion sediments are a major component of a river's floodplain. However, rates of lateral migration may be of greater concern from a human perspective, because many people living next to the Assiniboine River have lost valuable land as a result of erosion of the concave banks of meanders (Riesen and Brown 1958). Thus, the goals of this study were: 1) to determine the age of the lower Assiniboine River's modern channel; and, 2) to measure its rates of meander migration.

The Setting

The Assiniboine River is a 1,290-km long perennial, meandering, suspended load stream with a gross drainage basin at Headingley, Manitoba, of 153,000 km^2 in eastern Saskatchewan, northwestern North Dakota and southwestern Manitoba (Rannie 1990) (Figure 1). However, much of the basin is internally drained, reducing the river's effective drainage area to approximately 60,000 km^2 at Headingley (Ashmore 1990). The flow regime of the Assiniboine River is almost entirely dependent on prairie runoff during the spring snowmelt (Figure 2). The Qu'Appelle and Souris rivers account for 64% of the Assiniboine River's effective drainage area; however, because of the relative dryness of the region, these tributaries accounted for only 38% of the mean annual discharge at Holland

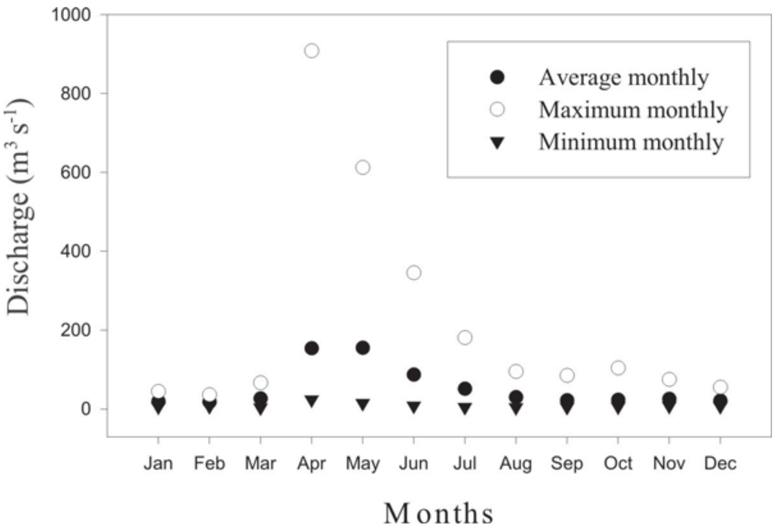

Figure 2: *Mean monthly flows at Holland, Manitoba, 1961-1998 (Environment Canada 2000).*

between 1975 and 1984. Thus, the streams draining the moister uplands of Manitoba are critical for maintaining flow (Ashmore 1990).

Between Brandon and Portage la Prairie, the Assiniboine River is confined by the Pleistocene glaciodeltaic sediments of the Assiniboine Delta, and it is probably in this reach that the river entrains most of its sediment (Rannie 1990). Downstream of Portage la Prairie, the river is not confined and experiences a reduction in slope as it encounters the Lake Agassiz clay plain, resulting in the deposition of an atypical alluvial floodplain fan through a process of repeated alluvial ridge building and avulsion. This process has left at least seven Assiniboine River paleochannels poised above the landscape east of Portage la Prairie and south of Lake Manitoba (Rannie 1990).

The grain sizes of suspended and bed loads decrease downstream. At Holland, bed material is approximately 20% gravel, but at Portage la Prairie and Headingley it is almost entirely sand (Rannie 1990). On average, the suspended load is more than 50% silt from Portage la Prairie to Headingley, and the sand fraction decreases from about 25% at Holland, to 15% at Portage la Prairie, to 3% at Headingley (Rannie 1990).

In 1970 the Portage Diversion and Reservoir began operation, significantly altering the downstream hydrology and sedimentology of the river. The Diversion and Reservoir have: 1) more than doubled the river's ability to convey discharges without overbank flooding; 2) reduced average daily discharge during April and May; 3) augmented flows during the summer, fall, and winter; and, 4) intercepted approximately 40% of the river's sediment load (Ashmore 1990). Furthermore, the Diversion and Reservoir have resulted in the cessation of alluvial fan building by almost eliminating the possibility of avulsion during low frequency discharges (Rannie 1990).

History

Nielsen *et al.* (1993) believed that by 7490 +/- 80 yrs BP (GSC-4839) (Table 1) the Assiniboine River occupied the same position as it does today based on the radiocarbon dating of a wood sample found in silty clay, in association with water-worn bison bones and freshwater pelecypod shells, and overlying fluvial gravels. Following this initial route to the Red River, the Assiniboine River has what is essentially a two-phase history.

Rannie *et al.* (1989) reconstructed a chronology of events based on radiocarbon dates, channel cross-cutting relationships, and soil maturity which showed the Assiniboine River draining into Lake Manitoba from approximately 7000 BP to 4500 BP, and then into the Red River from 3000

Table 1: *Selected radiocarbon dates from sites along the Assiniboine River and blind channel.*

Location	Age (years BP)	Lab No.	Depth (metres)	Material	Reference
Assiniboine River in Winnipeg	7490+/-80	GSC-4839	10.7	Wood	Nielsen *et al.* 1993 Morlan *et al.* 2000
Blind Channel	4230+/-70	BGS-1851		Wood	Morlan *et al*. 2000
Assiniboine River South of Marquette	2450+/-80	BGS-1635	1.0	Paleosol	Morlan *et al.* 2000
Site CWB-01-9	2115+/-50	BGS-2318	2.4	Bone	This paper
Site CWB-00-3	1660+/-45	BGS-2267	0.7	Bone	This paper
Site CWB-00-7	595+/-40	BGS-2304	5.0	Wood	This paper
Site CWB-00-4	520+/-50	BGS-2268	4.0	Wood	This paper
Site CWB-00-2	310+/-40	BGS-2266	4.2	Wood	This paper
Site CWB-00-5	125+/-40	BGS-2269	2.5	Wood	This paper
Site CWB-00-5	110+/-40	BGS-2303	3.6	Wood	This paper
Site CWB-00-8	480+/-40	BGS-2317	4.0	Wood	This paper
Site CWB-00-8	305+/-40	BGS-2316	3.3	Wood	This paper

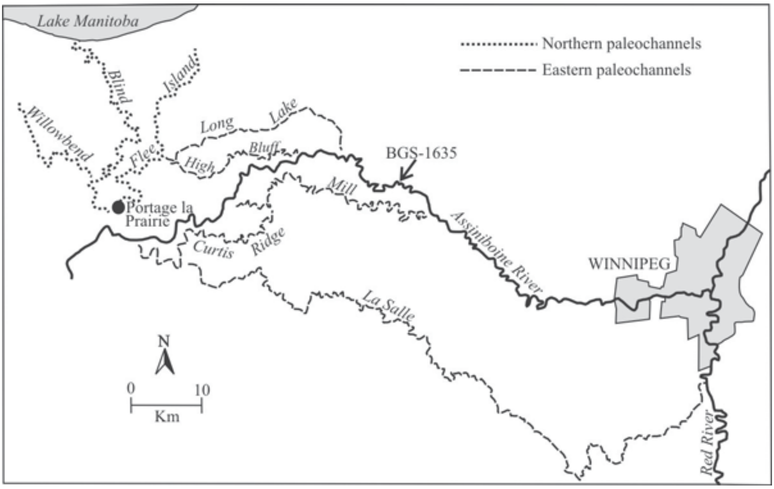

Figure 3: *Assiniboine River and paleochannels (redrawn from Rannie et al. 1989; Morlan et al. 2000).*

BP to the present (Figure 3). The initial drainage into Lake Manitoba was through the Willowbend and then Flee Island channels. This may have been interrupted by a period of eastward drainage into the Red River via the undated Long Lake and High Bluff channels, which may have had their outlets at the Forks in Winnipeg where the modern Assiniboine River joins the Red River. Drainage into Lake Manitoba had resumed by 4500 BP via the Blind channel (Rannie 1989), and in 1995 Nielsen collected a sample from that paleochannel, dating it at 4230 +/-70 yrs BP (BGS-1851; Morlan *et al.* 2000).

Rannie *et al.* (1989) determined that the Assiniboine River was draining into the Red River through the La Salle channel at about 3000 BP, and believed that the present channel on the lower portion of the floodplain fan, with its outlet at the Forks in Winnipeg (and the reach that concerns this study), was established sometime before 1300 BP via the Mill channel. However, a paleosol, formed on Lake Agassiz varved clay on the bank of the modern Assiniboine River (Figure 3), was dated by Nielsen and suggests that overbank sedimentation had begun by 2450 +/- 80 yrs BP (BGS-1635; Morlan *et al.* 2000). Nielsen (2001) noted that this date may be old because of the possible presence of old carbon, yet radiocarbon dates obtained from archaeology sites at the Forks also suggest that the channel was established prior to 1300 BP, and possibly soon after 3000 BP (Rannie 1999). By 700 BP the river was flowing through the Curtis Ridge channel immediately east of Portage la Prairie, and the entire modern channel of the

Assiniboine River was established sometime after 700 BP (Rannie *et al*. 1989).

Thus, the history of the Assiniboine River west of Winnipeg is complex. However, it seems certain that its most recent channel was in place by 1300 BP at the latest, and possibly soon after 3000 BP if the date obtained by Rannie *et al.* (1989) for the La Salle channel represents that phase's maximum age (Rannie 1999).

Study Area

The study area is a 36-km reach of the Assiniboine River located 45 km upstream of Winnipeg on the margin of the river's floodplain fan (Figure 4). The reach was chosen because it is easily accessible, there are numerous sections that exhibit alluvial deposits, and it was utilized by all of the paleochannels that followed the La Salle phase. As a result, samples collected from the area indicate a maximum age for the La Salle phase, and a minimum date for the initiation of the modern junction at the Forks in Winnipeg.

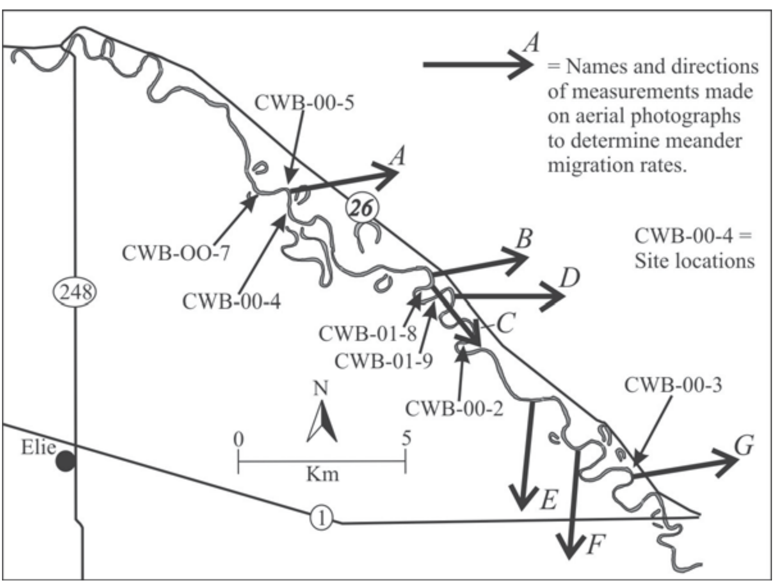

Figure 4: *The study area, site locations, and positions and directions of meander migration rate measurements.*

The reach has an unnaturally low sinuosity of 1.6 due to the large number of artificial channel cutoffs that have been constructed during the 20th Century to reduce flooding (Riesen and Brown 1958). In places, the channel is bounded by Lake Agassiz clay, which impedes its ability to meander freely (Figure 5). In many sections, glaciolacustrine sediments are found at the surface, while in others they are capped by overbank silts and clays. Channel deposits consisting of ripple cross-laminated sands and silts are common throughout the study area. The presence of Lake Agassiz sediments, coupled with the generally fine calibre of alluvium, can present a challenge when determining the provenance of sediments. A key indicator of fluvial deposition is the presence of fossil molluscs, which as a rule do not occur in Lake Agassiz sediments in Manitoba (Nielsen 2001).

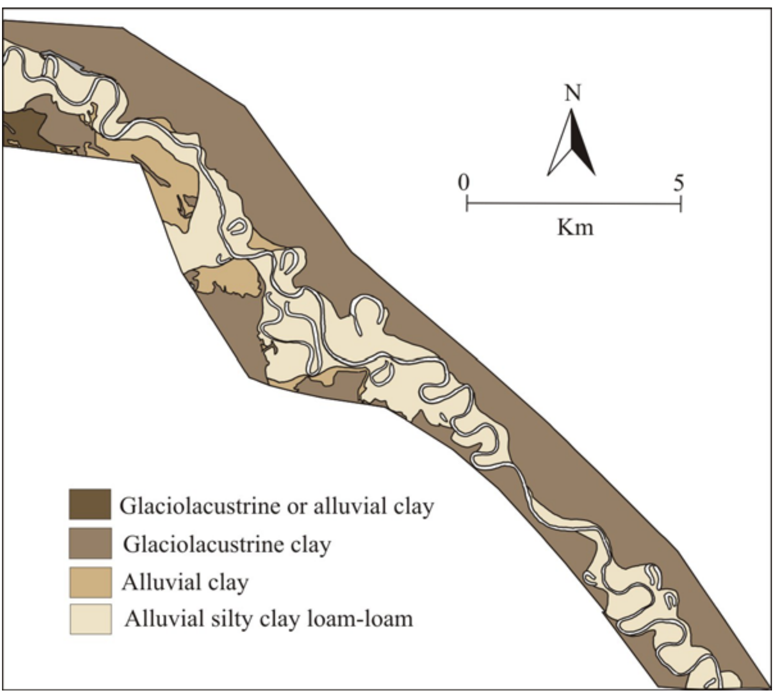

Figure 5: *Surficial materials of the study area (modified from Michalyna et al. 1975).*

Methodology

Age of the Channel:

To determine an age for the lower Assiniboine River's modern channel, material was collected from alluvium for radiocarbon or dendrochronological dating. The sections were then mapped and interpreted to establish a depositional and chronological context for the dates.

Meander Migration Rates:

The measurement of meander migration rates is at best a crude affair, as meanders may move laterally very rapidly over a short period of time and then remain static for decades (Wolman and Leopold 1957; Hickin 1974). Thus, rates of lateral movement should be measured over a long period of time. Two methods were employed in this study to measure meander migration.

The first involves dating subfossil bur oak (*Quercus macrocarpa* Michx.) logs. At site CWB-00-5, two logs were found 45 m apart in lateral accretion sediments of a point bar (Figure 6). The presence of dipping lateral accretion surfaces indicated the direction of bar growth (Miall 1992). The logs were dated using a combination of radiometric and dendrochronological methods, and the distance between them was measured so that an average rate of meander migration could be calculated. In a second point bar sequence (site CWB-01-8), two logs were collected 104 m apart and radiocarbon dated.

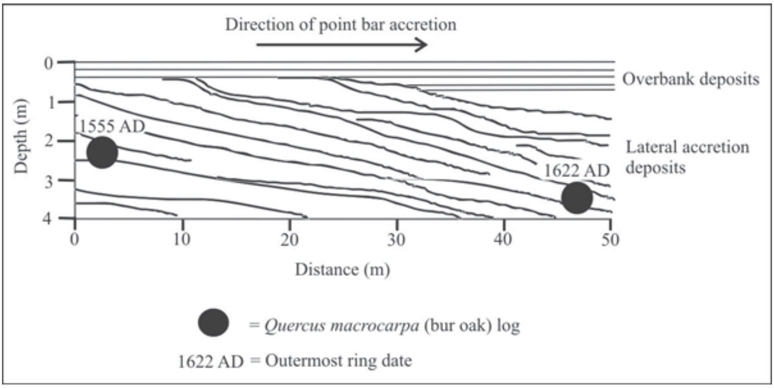

Figure 6: *Relationship between two subfossil logs dated to determine meander migration rate at site CWB-00-5.*

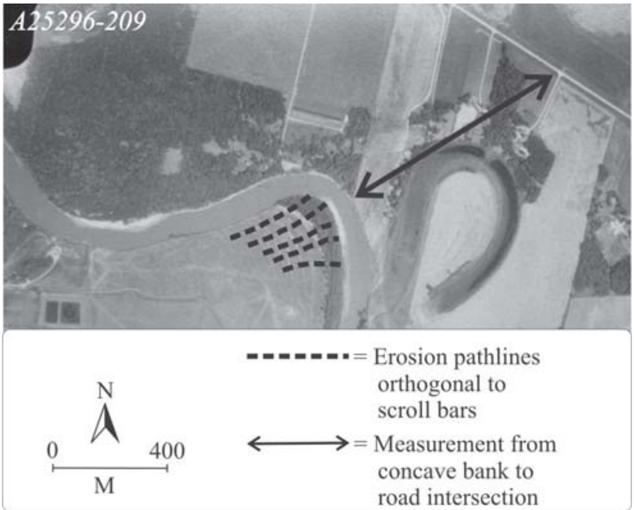

Figure 7: *Methodology used to measure meander migration rates from aerial photographs (after Hickin 1974).*

The second approach involved measuring meanders from aerial photographs taken in 1948, 1959 (scales = ~1:15,840) and 1968 (scales = ~1:20,000). Only photos predating 1970 were used to ensure that the measured rates were 'natural' and not influenced by the Portage Diversion. Because the photographs were not intended for this type of application, scales were recalculated in the vicinity of the meanders from 1:50,000 topographic maps or 1:20,000 township photographs. Meander migration rates were calculated for six meanders, with one meander having two determinations performed in different directions (Figure 4). Meanders were selected for measurement based on three considerations (Figure 7). First was the absence of any obvious human structures (such as roads) in proximity to the channel that may have produced artificial confinement. Second, meanders were examined for the presence of scroll bars, indicating that migration had occurred. The direction of these movements occurs orthogonal to the surfaces of scroll bars and can be represented by erosion pathlines (Hickin 1974). The longest orthogonal represents the direction of maximum erosion and is termed the 'erosion axis' (Hickin 1974). Third, meanders were selected based on the presence of road intersections in the vicinity of the channel, which acted as fixed points from which to measure the amount of lateral movement from photographs of different years. Thus, the angle of measurement was based roughly on the direction of migration as indicated by scroll bars. All measurements were made from the concave banks of meanders as these tend to be more vertical than the convex banks, facilitating the identification of the edge of the channel from the photographs.

Results and Discussion

Age of the Channel:

Samples collected to determine the age of the channel had radiocarbon dates of 2115 +/- 50 yrs BP (BGS-2318), 1660 +/- 45 yrs BP (BGS-2267), 595 +/- 40 yrs BP (BGS-2304), 520 +/- 50 yrs BP (BGS-2268), and 310 +/- 40 yrs BP (BGS-2266; Table 1). Two of these dates are older than those obtained by Rannie *et al.* (1989) and will be discussed below.

The oldest sample collected was from site CWB-01-9, where a 3.5-m section exposes 1.0 m of horizontally bedded overbank silts overlying a 1.6 m thick massive clay deposit. A paleosol occurs between 1.0 and 1.7 m, and the section is slumped below 2.6 m. Gastropod macrofossils were sampled from the paleosol at a depth of 1.25 m. The shells lacked spires and so could only be identified as *Physa* spp, a genus found in a wide variety of aquatic habitats (Clarke 1981). Numerous <0.01-m thick charcoal seams were present in the otherwise massive clays below 1.7 m. A bone horizon (*Bison bison bison* Linnaeus), located at 2.4 m, was dated at 2115 +/- 50 yrs BP (BGS-2318). The lack of diagnostic facies below 1.0 m makes classifying the lower portion of the section difficult. However, the presence of molluscs indicates that the deposits are alluvial in origin (Nielsen 2001), while the fine texture of the sediments, the presence of charcoal seams, and the substantial paleosol suggest that these sediments were deposited by overbank flows (Miall 1992; Nielsen *et al.* 1993) and probably accumulated in a backswamp environment (Miall 1992).

The second oldest sample was collected from site CWB-00-3. The 4.5-m section exposes 3.1 m of horizontally bedded overbank sediments overlying 0.90 m of Lake Agassiz clay. A *B. bison bison* radius was located at 0.70 m, between two paleosols at depths of 0.53-0.62 m and 1.00-1.40 m, and was radiocarbon dated at 1660 +/- 45 yrs BP (BGS-2267). Four shells were collected between 1.6 and 2.2 m and identified as two *Vallonia cyclophorella* (Sterki), one *Nesovitrea electrina* (Gould), and one *Succinea* sp., terrestrial gastropods whose presence indicates that this was a moist, low lying environment (Harris and Pip 1973; Pip 2001). The fine texture, horizontal bedding, presence of paleosols, and the occurrence of molluscs indicate that the upper 3.1 m are overbank deposits (Miall 1992; Nielsen *et al.* 1993).

The 2.4 m of alluvium below the bone does not necessarily imply a long period of deposition prior to the emplacement of the bone, as these sediments could have been deposited rapidly after the initiation of fluvial activity. However, the presence of a 0.40-m thick paleosol immediately below the bone suggests that a lengthy hiatus in alluvial deposition occurred prior to about 1700 BP. These lower sediments may have been deposited during the Long Lake/High Bluff phases of the river's history, in which case the paleosol may have developed during the La Salle phase. Alternatively, the paleosol may represent a reduction in sedimentation rates that occurred during the current phase of the Assiniboine River. For example, Nielsen *et al.* (1993) found comparable soil development within sections along the Red River, a stream that has occupied the same channel throughout its entire history.

The date of 2115 +/- 50 yrs BP (BGS-2318) implies that the present channel of the Assiniboine River was initiated much earlier than the minimum age of 1300 BP suggested by Rannie *et al.* (1989). This modification fits within the chronology established by Rannie *et al.* (1989) for a maximum age, but suggests that the Mill phase had commenced and the La Salle phase had ended prior to about 2100 BP. An approximate age of 2100 BP also suggests that older radiocarbon dates, such as Nielsen's 2450 +/- 80 yrs BP (BGS-1635; Morlan *et al.* 2000), and those that were obtained at the Forks (Rannie 1999; Morlan *et al.* 2000), may indicate that the Assiniboine River occupied its present channel prior to 2100 BP. Though younger than 2100 BP, the additional date of 1660 +/- 45 yrs BP (BGS-2267) serves to strengthen the notion that the Assiniboine River's present channel is much older than 1300 BP.

Meander Migration Rates:

Logs found in the point bar sequence at site CWB-00-5 were analyzed dendrochronologically and have outermost ring dates of AD 1555 and 1622. As a result of exposure to mechanical erosion, both logs lacked their outer sapwood, so seven to fourteen years must be added to their respective outermost ring dates (Nielsen 2001). The AD 1555 log was also radiocarbon dated at 125 +/- 40 yrs BP (BGS-2269). This radiocarbon date was rejected because it was too young to calibrate and does not agree with the tree-ring analysis. A third bur oak log, collected 89 m upstream of the first log in the same point bar section, was radiocarbon dated with an uncalibrated age of 110 +/- 40 yrs BP (BGS-2303), but its tree-rings could not be cross-dated. Based on the results of BGS-2269, this radiocarbon date was also rejected. The two logs, 45 m apart and dated at AD 1555 and AD 1622, indicate a rate of lateral accretion of 0.61-0.67 m/yr. The logs removed from the point bar sequence at site CWB-01-8 were 104 m apart and had calibrated radiocarbon dates of 480 +/- 40 yrs BP (BGS-2317) and 305 +/- 40 yrs BP (BGS-2316), both of which were considered good age estimates. Their stratigraphic relationship and ages indicate a rate of lateral accretion of 0.41-1.09 m/yr.

Over a twenty-year period, meander migration rates measured from aerial photographs had mean and median rates of 0.4 and 0.3 m/yr respectively, and ranged from 0 to 1.0 m/yr. Amounts of movement were variable, with one meander migrating 17 m between 1948 and 1959, and another showing no appreciable movement in twenty years. Variations in migration rates are probably the result of the different types of bank material on the concave sides of meanders, as the river channel is partially confined by Lake Agassiz clays (Table 2). Between 1948 and 1968, migration rates of meanders bounded by glaciolacustrine clay ranged from 0 to 0.1 m/yr and averaged 0.05 m/yr, while those meanders cutting into alluvium had rates ranging from 0.3 to 1.0 m/yr and averaging 0.6 m/yr.

There is good agreement between the meander migration rates established by the subfossil bur oak logs and the aerial photographs, particularly with those modern meanders whose concave banks are composed of alluvium. Thus, meander migration rates do not appear to have changed appreciably over the last 450 years (at least prior to the operation of the Portage Diversion).

Conclusion

Table 2: *Meander migration rates and associated surficial materials of the concave banks.*

Measurement	Rate of migration, 1948-1968 metres per year	Material of concave bank
A	1.00	Alluvium
B	0.05	Glaciolacustrine clay
C	0.65	Alluvium
D	0.10	Glaciolacustrine clay
E	0.00	Glaciolacustrine clay
F	0.60	Alluvium
G	0.30	Alluvium

The occupation of the modern lower Assiniboine River was dated at 2100 BP, an age that modifies that established by Rannie *et al.* (1989). However, this date does not alter the overall structure of their chronology. Rannie *et al.* (1989) determined that the Assiniboine River was using the La Salle channel at about 3000 BP and had initiated the Mill channel by 1300 BP. Thus, a substantial gap between dates existed, and exactly when the river switched positions was unclear. The additional date of 2100 BP indicates that the Mill channel was in use approximately 800 years earlier than was previously believed. A date of 2100 BP is also in agreement with other, older radiocarbon dates associated with an active Assiniboine River (Rannie 1999; Morlan *et al*. 2000), and does not preclude the possibility that the channel was initiated shortly after 3000 BP.

Prior to the 20th Century, two point bars accreted at rates of 0.61-0.67 m/yr and 0.41-1.09 m/yr respectively. Between 1948 and 1968, meander migration rates averaged 0.4 m/yr. Modern rates were heavily influenced by the composition of the concave banks, with those meanders eroding into glaciolacustrine clays averaging 0.05 m/yr, and those eroding into alluvium averaging 0.6 m/yr. The similarity between all of the meander migration rates suggests that they may not have changed appreciably over the last 450 years.

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