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Holocene evolution of the Assiniboine River paleochannels and Portage la Prairie alluvial fan[1,2]

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The Portage la Prairie alluvial fan was constructed by numerous successive paleochannels of the Assiniboine River along the western side of the Lake Agassiz basin as the level of the lake rapidly declined beginning 9500 years ago. The history of the paleochannels during the first several thousand years is not known. Paleochannel morphologies and cross-cutting relations, soil maturity, and radiocarbon dates, however, indicate that by 6000–7000 years ago flow was northward into Lake Manitoba. This direction was maintained until about 3000 years ago, when avulsion redirected the Assiniboine eastward to the Red River near Winnipeg. The morphologies of the paleochannels suggest that channel-forming discharges and sediment loads of the ancestral rivers have not differed significantly from the modern values despite palynological evidence that the climate was warmer and drier during much of the Holocene.

Le cône de déjection de Portage la Prairie a été édifié par de nombreux paléochenaux successifs de la rivière Assiniboine, le long du côté occidental du bassin du lac Agassiz, il a 9500 ans et moins, alors que le niveau du lac déclinait rapidement. L'histoire des paléochenaux durant les premiers milliers d'années de leur existence n'est pas connue. Cependant, les morphologies des paléochenaux et leurs relations d'entrecoupements, la maturité des sols et les dates au radiocarbone indiquent qu'il y a 6000–7000 ans l'écoulement se faisait vers le nord dans le lac Manitoba. Cette direction fut maintenue jusqu'à il y a environ 3000 ans avant présent, lorsqu'une avulsion réorienta l'écoulement de l'Assiniboine en direction est vers le rivière Red, près de Winnipeg. Les morphologies des paléochenaux suggèrent que les débits creusant les chenaux et les charges de sédiments transportés par les rivières ancestrales n'étaient pas significativement différents des valeurs actuelles, malgré la preuve palynologique d'un climat plus chaud et sec durant la majeure partie de l'Holocène.

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Introduction

The lower Assiniboine River between Portage la Prairie and Winnipeg (Fig. 1) has shifted its course substantially during the Holocene; during part of this period, its waters emptied into Lake Manitoba, while at other times they bypassed the lake, flowing east to join the Red River. This change in course has been the natural consequence of processes operating on an "abnormal" alluvial fan that forms the divide between the two drainage basins. The morphology and distinctive aspects of this fan have been described elsewhere by Rannie (in press) and will be only briefly summarized here. The principal objectives of this paper are to describe the evolution of the alluvial fan and paleochannels of the lower Assiniboine River and to relate this to the Holocene hydroclimatology of the Assiniboine drainage basin.

Alluvial-fan morphology

The Portage la Prairie fan has its apex near Portage la Prairie (Fig. 1), where the Assiniboine River emerges from a deep confining valley, eroded into the late-glacial Assiniboine Delta, onto the nearly flat plain of glacial Lake Agassiz (Fig. 2). Compared with other, "normal" alluvial fans, the Portage la Prairie fan is large (about 1300 km^2, with a radius of 30–45 km), has an exceptionally gentle gradient (0.0005), and has been produced by processes more typical of floodplains. The fan is composed of sediments associated with repeated construction and abandonment by avulsion of major alluvial ridges disposed in a radial pattern outward from the head of the fan (Fig. 2). There are at least eight such alluvial ridges, each clearly marked by distinct natural levees that rise as much as 4.5 m above the adjacent terrain, and by associated channels and scroll bars that, although not always apparent on the ground, show clearly on aerial photographs (Fig. 3). These ridges, channels, and scroll bars provide the only relief on an otherwise imperceptible downfan slope. While the main alluvial ridges determine the overall morphology of the fan, numerous secondary distributary channels are present in the intervening flood basins. Fan sediments are up to 10 m thick near the apex, becoming thinner and increasingly concentrated in the ridges toward the fan margin.

The coarsest sediments (fine to coarse sand) are found in the scroll bars and channels. In the flood basins between the ridges, the sand grades laterally into silty clay. The morphology of the paleochannels appears to be related to the texture

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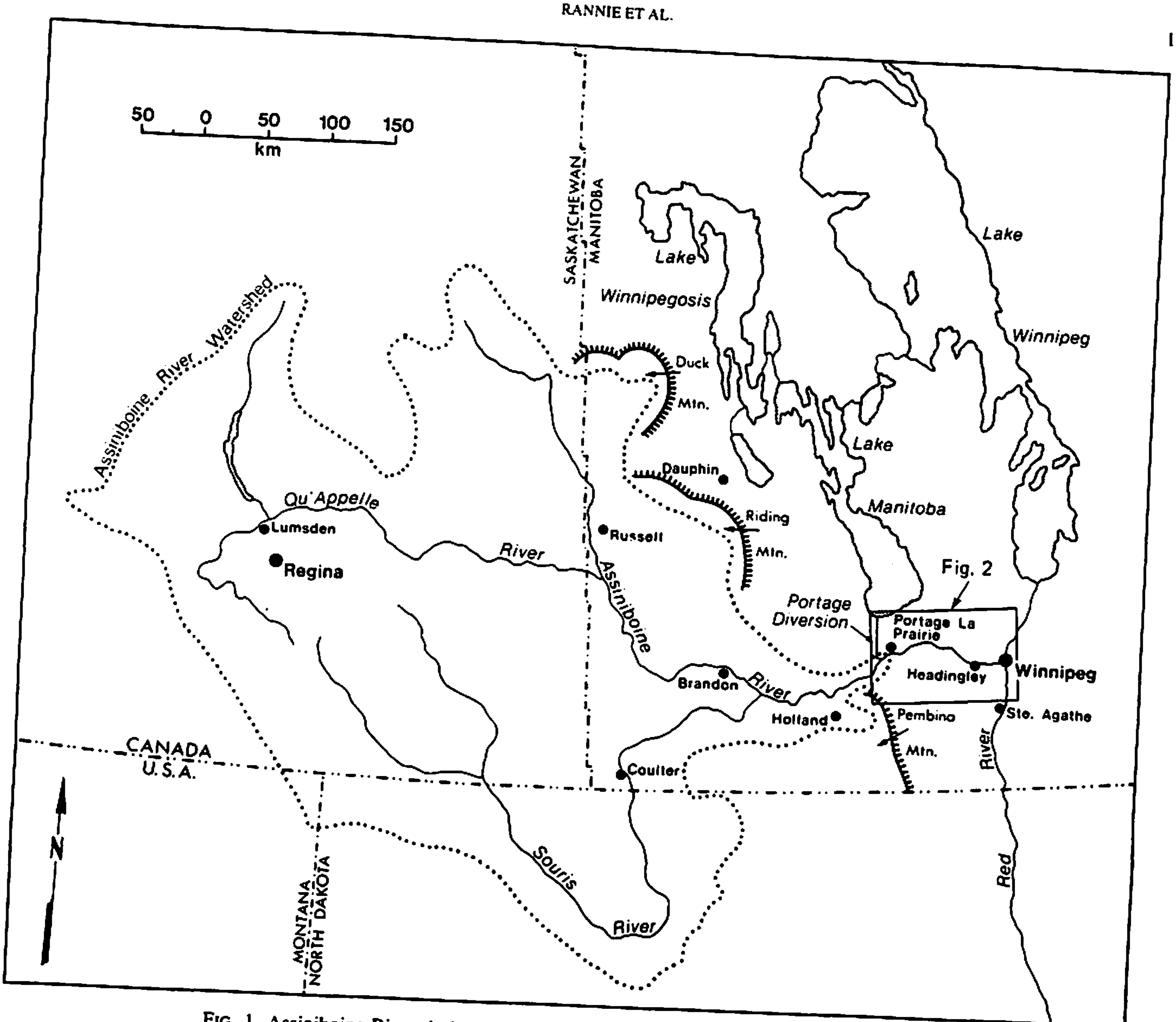

FIG. 1. Assiniboine River drainage basin and location of major features mentioned in text.

and thickness of the alluvium. On the upper fan, where the channels are formed in sand, sinuosity, meander wavelength, and meander amplitude are large; scroll bars are well preserved, and the channels have been able to freely migrate laterally (Fig. 3). Farther downfan, as the channels reached the level of the cohesive underlying Lake Agassiz clay, lateral activity was restricted; there, meander wavelength and amplitude decrease, and the alluvial ridges become more pronounced. Downstream of the fan, where the channels were incised into Lake Agassiz clay and lateral migration was virtually absent, the channels are deeper and narrower and there are no alluvial ridges because there was little locally generated overbank flow. The profiles of the two longest channels, the modern Assiniboine River and the La Salle paleochannel (both of which join the Red River) are gently concave up except near Winnipeg, where they steepen in distinctly incised reaches as they approach the Red River.

Holocene hydroclimatology of the Assiniboine River basin

Pollen, diatom, and ostracod analyses in and near the Assiniboine drainage basin indicate that during the early Holocene the climate of the region was warmer and drier than at present (e.g., Ritchie 1967, 1983; Ritchie and Licht-Federovich 1968; Delorme 1971; Ritchie and Haddon 1975; Ritchie and Koivo 1975; Nambudiri and Shay 1986). During this early Holocene "Prairie Period," the area of grassland expanded, and in the period of maximum aridity (about 9000–5000 years ago) small water bodies dried completely (Delorme 1971) and even large lakes such as Devil's Lake, North Dakota, and Lake Manitoba experienced low-water or dry phases (Callendar 1968; Teller and Last 1981). According to Ritchie (1983), the demise of the Prairie Period in this region began about 6500 years ago and ended about 3500 years ago; the modern climate and vegetation was established by 2500 years ago.

Interestingly, the drier Holocene climate is not reflected in the morphology of the major paleochannels on the Portage la Prairie fan. Comparison of the fan reaches of the modern and ancestral Assiniboine channels (Table 1) indicates that no significant differences exist (at $p = 0.05$) in mean meander wavelengths and channel widths. Consequently, we infer that the channel-forming discharges of the paleochannels were also

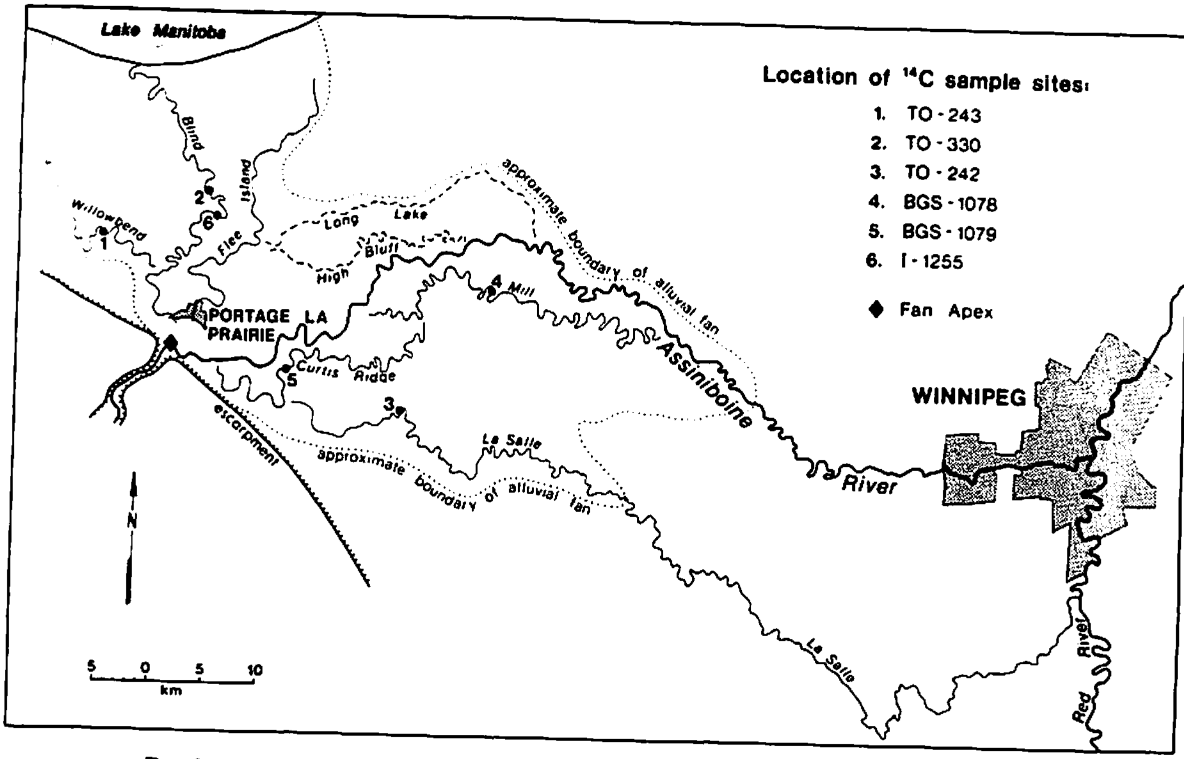

FIG. 2. Portage la Prairie alluvial fan, major paleochannels, and location of ^{14}C sample sites.

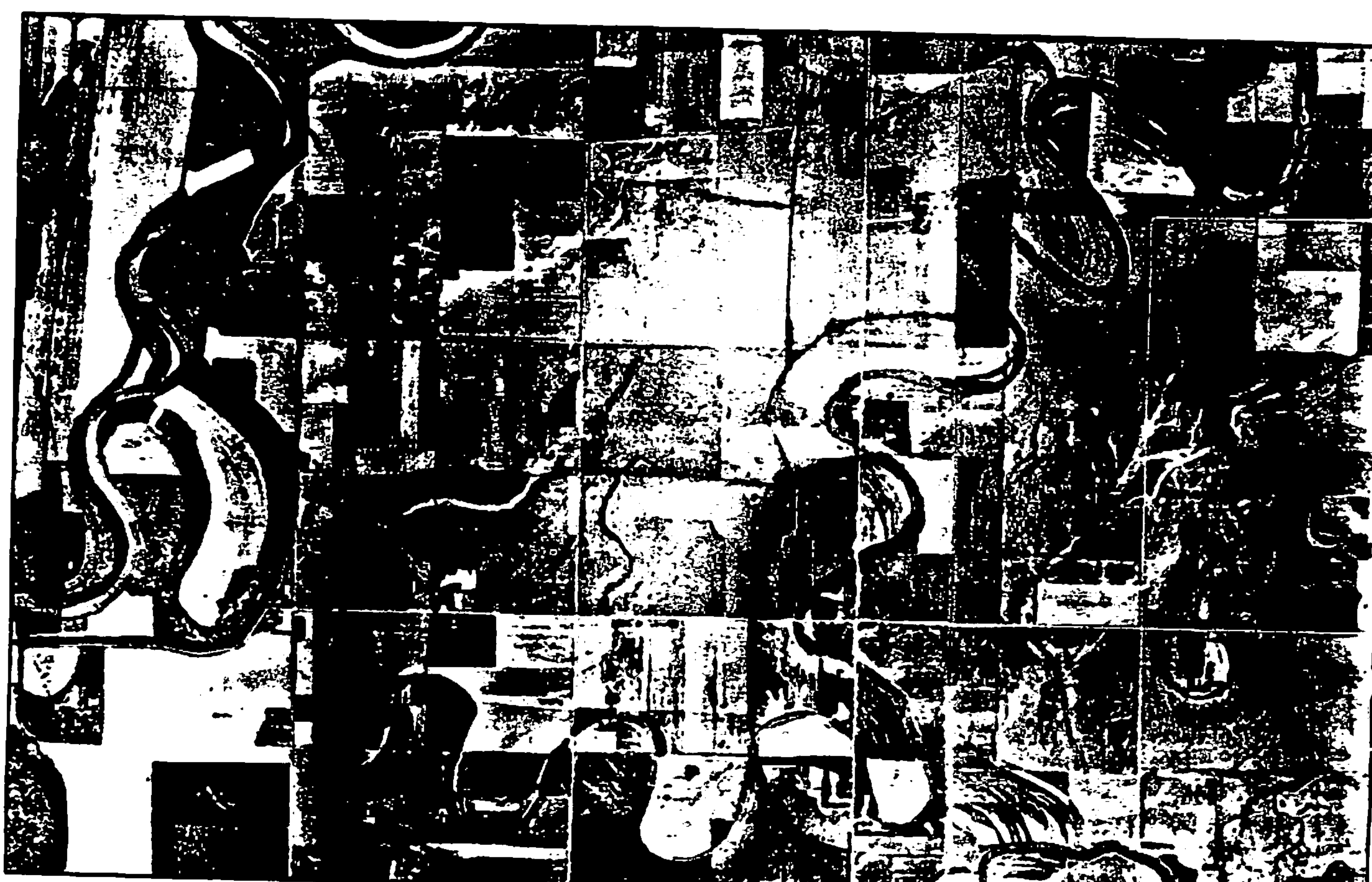

FIG. 3. Airphoto mosaic of a portion of Mill Creek paleochannel. The Assiniboine River appears on the left. (Manitoba Department of Natural Resources, mosaic of tp. 12, rge. 4, W 5th mer.)

TABLE 1. Comparison of meander wavelengths and channel widths for fan reaches of the modern and ancestral Assiniboine channels

	Assiniboine River	Paleochannels
Meander wavelength		
Mean (m)	1495	1395
Median (m)	1425	1400
Range (m)	550–3000	550–2850
n	30	112
Channel width		
Mean (m)	107	108
Median (m)	108	102
n	19	28

similar to that of the modern Assiniboine, despite clear paleobiological evidence in the region for lower effective precipitation and, by implication, for reduced streamflow. However, because most indicators used to infer the climate during the Prairie Period reflect summer conditions, they provide an unsatisfactory basis for reconstructing the paleohydrology of rivers such as the Assiniboine, whose flow is dominated by runoff from snowmelt and early spring rainfall. On the modern Assiniboine and its larger tributaries, 60–80% of average annual total streamflow and virtually all peak flows of consequence occur in the period April to June (Fig. 4). During the 1930's — a possible modern analogue to the warmer, drier summer climate of the Prairie Period the spring freshet was even more dominant in terms of total flow (Fig. 4), and in that decade 90% of peak-flow events occurred in April. Thus, analyses of paleoclimate that exclude spring snowpack, melt rates, and early spring rainfall provide little information on the nature of past discharges in the "channel-forming" range (such as mean annual flood or bankfull discharge).

In addition, the Assiniboine watershed contains several quite disparate hydrologic regions. The two largest tributaries, the Souris and Qu'Appelle rivers, drain the dry western and southern portions of the basin (Fig. 1). Together, they constitute approximately 73% of the Assiniboine basin above Portage la Prairie but contribute only 27% of the total Assiniboine discharge (Environment Canada 1985). Mean annual runoff from this region is only about 3.5 mm, less than 1% of annual precipitation. In contrast, tributaries that drain the more humid, forested Manitoba uplands (Riding and Duck mountains, Fig. 1) typically have runoff of 35–45 mm (Environment Canada 1985), or about 7–10% of precipitation. This region is the most important long-term source of water for the Assiniboine and modulates the effects of drought. For example, during the 1930's, total annual flow in the Souris River was only 10% of the long-term average, whereas in the Assiniboine, total flow was maintained at 48% of the average and, more importantly, average peak flow was 75% of the long-term average (Environment Canada 1985). Although grassland did invade the Manitoba uplands during the Prairie Period, Ritchie (1983) suggested that mean annual precipitation there was only about 3 cm (or about 6%) less than the modern value. Thus, while annual runoff from this region during the Prairie Period might have been somewhat smaller than modern values, there is no compelling evidence to suggest that channel-forming discharges in the spring freshet were significantly lower.

In the discussion above, we assumed that the watershed boundaries of the Assiniboine River have not changed during the evolution of the paleochannel system, despite clear evidence that the Souris River drainage was captured by the Assiniboine at an elbow about 40 km south of Brandon (Upham 1895; Elson 1955; Brooks 1968). This capture added about 59 000 km² to the Assiniboine watershed, but Elson (1955) and particularly Brooks (1968) provided convincing arguments that the diversion occurred in late-glacial time (early Lake Agassiz I or Lockhart Phase). Thus, the diversion predated the earliest events described here by several thousand years, and it does not appear possible that the Souris River capture could explain the apparent maintenance of Assiniboine flow during the dry period of the Holocene.

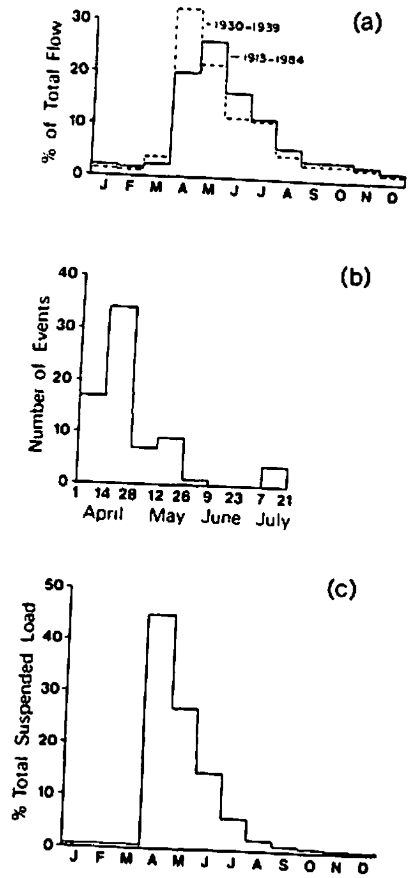

FIG. 4. Monthly distribution of aspects of water and sediment discharge for the Assiniboine River at Headingley. (*a*) Average percentage of annual flow, 1913–1984 and 1930–1939 (Environment Canada 1985); (*b*) date of annual peak-flow occurrence, 1913–1984 (Environment Canada 1985); (*c*) average percentage of annual suspended-sediment discharge, 1962–1978 (Environment Canada 1980).

Sediment transport in the modern Assiniboine is even more dominated by the freshet and spring runoff period, when >80% of the total annual sediment discharge occurs (Fig. 4*c*). Maximum and average sediment concentrations and annual sediment yields in the major tributaries are generally low (Environment Canada 1980, 1987), and most of the total suspended load entering the alluvial fan appears to be acquired from erosion along the main stem of the Assiniboine River in the reach between Brandon and Portage la Prairie, where the river flows in a deep valley cut into glaciolacustrine and alluvial sediments of the Assiniboine Delta. From terraces and alluvial fills, Klassen (1975) suggested that although aggradation has predominated along most of the Assiniboine valley system during the Holocene, erosion has continued to the present along an approximately 50 km reach upstream of the fan apex. Thus, if freshet and spring discharges of the Assiniboine were maintained near modern values, a dry Holocene summer climate throughout the major part of the basin might not imply a significant reduction in sediment delivery to the alluvial fan and paleochannel system. Furthermore, as Schumm (1968) pointed out, a decrease in precipitation under conditions like those in this region may lead to an increase in erosion on the uplands because of a decrease in the stabilizing effect of vegetation. Thus, even a moderately smaller Assiniboine River flood may have transported the same, or an even larger, amount of sediment.

Evolution of the Assiniboine paleochannel system

The most striking aspect of the channel system is the division between channels ending in Lake Manitoba and those that join the Red River more than 80 km to the east. Several lines of evidence suggest that flow during an early part of the Holocene was northward to Lake Manitoba but that these channels were subsequently abandoned for eastward routes to the Red River. First, the trend of the Assiniboine River for the 25 km confined reach upstream of the fan is toward the north-northeast, and continuation in that direction would lead to Lake Manitoba. Fenton (1970) suggested that because this was also the approximate direction of maximum isostatic uplift, the initial course of the Assiniboine was controlled by a postglacial regional gradient toward the Lake Manitoba basin. Second, scroll-bar details, while present, are more subdued and less fresh in appearance in the northward channels than in the eastward channels, suggesting that the northward channels are older. Finally, soils adjacent to the northward channels have mature chernozemic A horizons generally exceeding 50 cm in thickness, in marked contrast with the immature black regosols with weakly developed (and presumably younger) A horizons of soils associated with the eastward channels (Michalyna and Smith 1972). Within these two channel groups, cross-cutting relations among the channels suggest the relative ages and sequential development of the major paleochannels given in Table 2.

Radiocarbon dates from several of the channels confirm this sequence. Wood and shells were recovered from pits 3–5 m deep excavated in scroll bars of five major paleochannels (Table 2; Fig. 2); several pits dug in a sixth channel (Flee Island) yielded no organic remains. Two of the samples were sufficiently large to be dated by conventional laboratory methods; three small samples were dated by accelerator mass spectrometry. The fact that all dated materials were contained within scroll bars that were accreted onto point bars as the channel was migrating laterally ensures that the dates refer to times of active channel occupance rather than to subsequent infill after abandonment.

The oldest paleochannel, Willowbend (Figs. 2, 5), was dated at 7030 ± 60 BP (TO-243), suggesting that the first alluvial-ridge element of the fan was forming within a few thousand years of the final recession of Lake Agassiz water from the area, estimated by Teller and Last (1981) to have been complete 9200 years ago. Northward drainage shifted to the undated Flee Island Channel and finally to Blind Channel, the youngest of the northward-draining channels, which contains a specimen dated at 4520 ± 60 BP (TO-330). The possibility that eastward routes to the Red River intervened between the Flee Island and Blind phases is discussed below. A date of 3375 ± 250 BP (I-1255) was obtained by J. A. Gilliland (reported in Teller 1980) from organic material near the bottom of sediments in Blind Channel, implying that Blind Channel was still active or, at most, only recently inactive, at that time.

The sediments accumulating in the ridges and backswamp areas of the Willowbend, Flee Island, and Blind channels gradually filled the space available for new northward routes. Subsequent avulsion exploited lower terrain and steeper gradients toward the east, thereby diverting the ancestral Assiniboine River from the Lake Manitoba outlet to the Red River. The first of these eastward routes was established about 3000 years ago along the course now occupied by the misfit La Salle River south of the present Assiniboine River (Fig. 2), as indicated by a date of 2980 ± 70 BP (TO-242) (Table 2) from scroll bars adjacent to that channel. The modern course of the Assiniboine River below the fan appears to have been initiated by 1330 ± 100 BP (BGS-1078) in the Mill Phase (Fig. 5), although an alternative scenerio is described below. The Curtis Ridge Channel, dated at 700 ± 70 BP (BGS-1079), differs from the Mill Channel only in the upper fan reach.

Sedimentation rates in Lake Manitoba support this reconstruction. Teller and Last (1981) obtained ^{14}C dates from organic horizons in three cores from Lake Manitoba. After they corrected some dates for contamination by old carbon, nine fell in the period 11 000 − 2555 BP. As Fig. 6 shows, most dates lie along a line indicating that sediment accumulated at an average rate of 0.11 cm/year until about 3000 years ago, when the Assiniboine River abandoned the Lake Manitoba outlet; thereafter, the average accumulation rate appears to have declined to 0.04 cm/year.

This interpretation of the evolution of the Assiniboine River and paleochannel system as the natural consequence of construction and abandonment of alluvial ridges in an alluvial-fan context, with a simple distinction between early northern and later eastern outlets, is at variance with previous reconstructions. Fenton (1970), for example, attributed the eastward diversion to capture by a headward-eroding tributary of the Red River. This hypothesis is unlikely, given the very gentle eastward gradient of the Lake Agassiz plain and the fact that other western tributaries of the Red River are not significantly incised for more than a few kilometres from the river. Recognition of the alluvial-fan character of the paleochannel system makes such an hypothesis unnecessary. Teller and Last (1981, 1982) and Last and Teller (1983) identified several "marker horizons" within bottom sediments of Lake Manitoba that they interpreted as indicative of dry phases of the lake between 9000 and 4500 years ago. Because such dry phases seemed incompatible with input from a river as large as the Assiniboine, they suggested that prior to 4500 years ago the Assiniboine had flowed eastward to the Red River. In their interpretation, northward diversion to Lake Manitoba outlets about 4500 years ago brought an end to the low-water stage that led to the dry phases; the modern eastward drainage to the Red River resumed about 2000–2500 years ago. However, the 7030 BP date from Willowbend Channel and the fact that the relative age of Flee Island Channel is greater than that of Blind Channel, dated at about 4500 BP, suggest that Assiniboine River flow into Lake Manitoba began prior to the 4500 BP date postulated by Teller and Last (1981).

Three possibilities may be suggested to reconcile these apparently contradictory interpretations. First, because the

TABLE 2. Relative and absolute ages of major paleoAssiniboine channels

Inferred relative age			^{14}C dates		
Outlet	Relative age	Channel	Material	Laboratory No.	Age (years BP)
Lake Manitoba	Oldest	Willowbend	Shell	Isotrace TO−243	7030±60
Lake Manitoba		Flee Island	—	—	—
(Red River)		(Long Lake)[a]	—	—	—
(Red River)		(High Bluff)[a]	—	—	—
Lake Manitoba		Blind	Shell	Isotrace TO−330	4520±60
Red River		La Salle	Wood	Isotrace TO−242	2980±70
Red River		Mill	Wood	Brock BGS-1078	1330±100
Red River		Curtis Ridge	Wood	Brock BGS-1079	700±70
Red River	Youngest	Assiniboine	—	—	0

[a]Parentheses indicate uncertainty in relative age (see text).

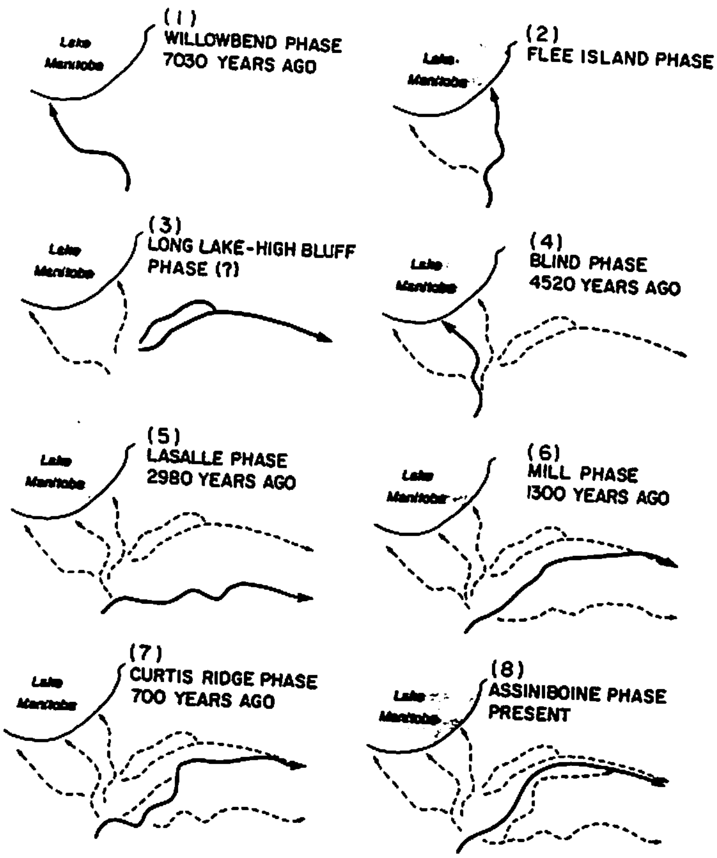

FIG. 5. Schematic sequence of paleochannel evolution.

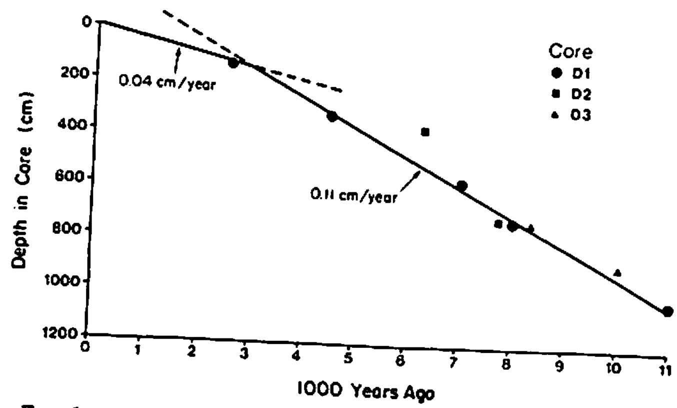

FIG. 6. Accumulation of sediment in Lake Manitoba, based on data reported in Teller and Last (1981).

Holocene was marked by a warmer, drier climate in this region (e.g., Ritchie 1976), periodic droughts may have reduced the flow of the Assiniboine sufficiently to permit a substantial lowering of Lake Manitoba's elevation prior to 4500 BP. Arguments have already been presented, however, that make this an unlikely hypothesis.

Second, the possibility exists that the Assiniboine River was diverted to the Red River temporarily and for relatively short periods before the eastward routes became permanently established. Such diversions may have occurred along two paleochannel routes (High Bluff and Long Lake, shown as dashed lines in Figs. 2 and 5). Although dates are not available for either of these channels, they appear to be offshoots of, or precursors to, Flee Island Channel and thus appear to have formed between 7030 (Willowbend Channel) and 4520 years ago (Blind Channel), the period when several of the dry phases identified by Teller and Last (1981) occurred. The High Bluff Channel has well-developed meanders but lacks the extensive scroll bars exhibited by the main paleochannels. Long Lake Channel is merely a continuous linear depression that displays few of the features common to the other paleochannels but offers an eastward "escape route" for Assiniboine flow. Both of these channels intersect the modern Assiniboine, and if this hypothesis is correct, it implies that the reach of the Assiniboine River from the lower fan to Winnipeg may have been initiated prior to the permanent eastward diversion. The apparently nearly constant "average" sedimentation rate until 3000 years ago, suggested in Fig. 6, does not preclude short-term variations in sediment influx, such as might have been caused by brief eastward diversions of the Assiniboine River. Teller and Last (1979) concluded that the uppermost marker horizon represented a 500−1000 year period but that the duration of other low- or no-water episodes ranged from only a few tens to a few hundreds of years. The less mature appearance of the High Bluff and Long Lake channels may also reflect the relatively short period of these diversions.

The third possible way to reconcile the different interpretations of when the Assiniboine River first emptied into Lake Manitoba is to re-evaluate the radiocarbon dates on which the two interpretations are based. According to Teller and Last (1981), the initiation of Assiniboine River influx 4500 years ago is based on the abrupt rise in silt, high-magnesian calcite, and organic matter content in sediment above a date of 4465 ± 165 BP (GX-5645) in a core. This date represents the minimum age for the influx, and because the influence of Assiniboine River water may not have been immediately recorded at this site, diversion may have occurred prior to 4465 BP. Of considerable importance is the fact that the only radiocarbon dates from the northward-draining channels (that is, older than 4500 BP) are on shell, which commonly give anomalously old dates because of the "hard-water effect" (e.g., Karrow *et al.* 1984). Where both calcareous and woody material have been dated from the same bed, such as south of Rossendale, Manitoba (Lowden and Blake 1980, pp. 65–66), and west of Marathon, Ontario (Zoltai and Herrington 1966), the hard-water effect is about 1000 years. Nielsen *et al.* (1982, 1987) estimated that the given age of carbonates in this region is about 400 years too old. Thus, if the shell date from the Willowbend Channel is up to 1000 years too old, and the age of the sedimentological change in the core is only a minimum age, the actual diversion of the Assiniboine River into the Lake Manitoba basin may not have occurred until about 6000 years ago. Prior to this, Assiniboine River flow may have been eastward toward the Red River, in channels no longer identifiable in the Portage la Prairie area.

Summary of channel history on the Portage la Prairie fan

As Lake Agassiz receded from the area for the last time, less than 9500 years ago, the ancestral Assiniboine River extended its route across the flat lacustrine plain of the Red River valley. Deltaic and lacustrine sediments previously deposited near the mouth of the valley between Brandon and Portage la Prairie, as well as fluvial deposits to the west, were entrenched at this time. The initial route of the Assiniboine River across the newly exposed lake floor has been obscured by later alluviation and may have been northward toward Lake Manitoba or eastward toward the Red River, roughly along the route of the modern La Salle River or Assiniboine River. An alluvial fan, the Portage la Prairie fan, was progressively built eastward from the mouth of the entrenched valley (Fig. 2).

The oldest recognizable major paleochannel on the Portage la Prairie fan is Willowbend Channel. Like the younger Flee Island and Blind River channels to the east, Willowbend is oriented northward from the fan apex and carried water into the Lake Manitoba basin. Alluviation along the northern side of the fan eventually forced the Assiniboine River to assume an easterly course across the Lake Agassiz plain toward the Red River, bypassing Lake Manitoba.

The initial link to the Red River appears to have been along the present course of the La Salle River south of the modern route of the Assiniboine, joining with the Red River 14 km south of Winnipeg (Fig. 2). It is possible, however, that flow through the Long Lake – High Bluff paleochannels preceded the La Salle River route. Continued aggradation on the fan caused the Assiniboine River to shift its course again, establishing first the Mill Channel, then the Curtis Ridge Channel, and, finally, the modern course of the Assiniboine River (Fig. 5).

The oldest recognizable channel on the fan was forming by 7030 BP, based on a radiocarbon date of that age (Table 2). However, because this date is from shell subject to contamination by the hard-water effect, it is possible that the channel is somewhat younger than is implied by that date. A shell date of 4520 ± 60 BP (TO-330) from Blind Channel, the youngest of the drainageways leading into the Lake Manitoba basin, indicates that the northward Assiniboine River continued until at least this time. By about 3000 years ago, the river had established its eastward course to the Red River. This change is bracketed by wood dates of 3375 ± 250 BP (I-1255) from Blind Channel and 2980 ± 70 BP (TO-242) from La Salle Channel. Further shifts are recorded by dates of 1330 ± 100 BP (BGS-1078) and 700 ± 70 BP (BGS-1079) from the Mill and Curtis Ridge channels, respectively. Although the lower reaches of these two channels coincide with the modern Assiniboine River channel, the present course of the latter across the Portage fan to the Red River was not established before 700 years ago.

Conclusions

Construction and abandonment of alluvial ridges by the lower Assiniboine River have produced a succession of distinctly different river courses that, in combination, form an unusual alluvial fan with its apex near Portage la Prairie. The morphologies of the paleochannels suggest that channel-forming discharges were similar to those of the modern Assiniboine despite clear paleobiological evidence that the Holocene climate of the region was warmer and drier until about 3500 years ago. This discrepancy is attributed to the dominance of snowmelt and the importance of the Manitoba uplands in peak-discharge formation. The sediment loads of these ancestral channels were probably also similar to that of the modern Assiniboine River.

The cross-cutting relations, maturity of associated soils, and radiocarbon dates indicate that paleochannels that carried water northward across the fan into the Lake Manitoba basin are the oldest. This phase had been established about 6000 years ago and ended about 3000 years ago. An earlier channel phase, no longer morphologically identifiable, either followed a similar route to the Lake Manitoba basin or directed flow eastward to the Red River. After 3000 years ago, the Assiniboine River abandoned its route into Lake Manitoba and produced a succession of channels between Portage la Prairie and Winnipeg. By about 1300 years ago, the river had established its present course, except on the higher western part of the Portage fan, where avulsion continued to develop new channels until about 700 years ago.

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