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Holocene Stratigraphy and Geomorphology of Flintstone Hill, Lauder Sandhills, Glacial Lake Hind Basin, Southwestern Manitoba

Stratigraphie et géomorphologie holocène de la Flintstone Hill (Lauder Sandhills) dans le bassin du Lac glaciaire Hind, dans le sud-ouest du Manitoba

Estratigrafia y geomorfología holocena de la región de Flinstone Hills (Lauder Sandhills) en la cuenca del Lake glaciar Hind en el sudoeste de Manitoba, Canadá

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Article abstract

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HOLOCENE STRATIGRAPHY AND GEOMORPHOLOGY OF FLINTSTONE HILL, LAUDER SANDHILLS, GLACIAL LAKE HIND BASIN, SOUTHWESTERN MANITOBA

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ABSTRACT Sediments exposed at Flintstone Hill in a Souris River cutbank provide the most complete postglacial stratigraphic section in the Glacial Lake Hind Basin (GLHB), southwestern Manitoba. Four lithologic units, A-D, are observed: A1 (~2 m thick), glaciolacustrine silts and clays that grade upward to peat and record final regression of Glacial Lake Hind (~10 500-9300 BP); A2 (~1.5 m thick), low energy fluvial marl and silts grading to O-horizon(s) (by 6700 BP); B (1.5 m thick), dune sands that migrated from the southwest, contrary to the modern wind regime (after ~6700 BP); C (1.0 m thick), thin fluvial deposit between eolian sand sheets (~5500-3200 BP); D (up to 7 m thick), parabolic dune on the modern landscape oriented consistent with the modern wind regime, blowouts suggest episodic dune reactivation (~3200 BP to present). Overall, Flintstone Hill deposits record draining of Glacial Lake Hind, establishment of the Souris River channel through the GLHB, mid-Holocene eolian activity / landscape instability greater than present, and a return to nearly modern conditions by ~5400 BP. Native inhabitants in the GLHB focused on exploiting wetlands and wet meadows before 9300 BP and a landscape similar to the present thereafter.

RÉSUMÉ *Stratigraphie et géomorphologie holocène de la Flintstone Hill (Lauder Sandhills) dans le bassin du Lac glaciaire Hind, dans le sud-ouest du Manitoba.* Les sédiments à découvert de la Flintstone Hill, sur la berge escarpée de la rivière Souris, offrent la séquence stratigraphique postglaciaire la plus complète du bassin du Lac glaciaire Hind. Quatre unités lithologiques, de A à D, y sont observées : A1 (~2 m d'épaisseur), silts et argiles glaciolacustres au granoclassement vertical progressif jusqu'à la tourbe témoignent de la dernière régression du Lac glaciaire Hind (~10 500-9300 BP) ; A2 (~1,5 m d'épaisseur), marnes fluviatiles de faible énergie et silts jusqu'à un horizon O (vers 6700 BP) ; B (1,5 m d'épaisseur), sables dunaires en provenance du sud-ouest, contrairement au régime des vents actuel (après ~6700 BP) ; C (1,0 m d'épaisseur), dépôt fluviatile mince entre des couches de sable (~5500-3200 BP) ; D (jusqu'à 7 m d'épaisseur), dune parabolique faisant partie du paysage moderne et orientée selon le régime des vents actuel, avec des creux de déflation témoignant de réactivations dunaires épisodiques (~3200 BP à aujourd'hui). En résumé, les dépôts de la Flintsone Hill attestent d'abord de la vidange du Lac glaciaire Hind, puis de l'établissement du chenal de la rivière Souris à travers le bassin, d'une activité éolienne et d'une instabilité des paysages à l'Holocène moyen plus grande que maintenant et de l'établissement de conditions quasi contemporaines vers 5400 BP. Les premiers habitants du bassin ont d'abord exploité les terres humides et les prés humides avant 9300 BP, puis un paysage semblable à celui d'aujourd'hui par la suite.

RESUMEN *Estratigrafia y geomorfología holocena de la región de Flinstone Hills (Lauder Sandhills) en la cuenca del Lake glaciar Hind en el sudoeste de Manitoba, Canadá.* Los sedimentos expuestos en la zona de Flinstone Hills en la ribera del Souris River proporcionan el registro estratigráfico post-glaciar más completo de la cuenca del Lake Hind, al sudoeste de Manitoba. Se distinguen cuatro unidades litológicas: A-D. La unidad A1, de unos 2 m de grosor, está compuesta por limo y arcilla glaciolacustres, que pasan gradualmente a turba en la parte superior y evidencian la regresión final del Lake glaciar Hind hace unos 10 500 a 9300 años; la unidad A2 de alrededor 1.5 m de grosor, compuesta de marga de baja intensidad fluvial y de limo pasa gradualmente a un horizonte O hace unos 6700 años; la unidad B de aproximadamente 1.5 m de espesor, compuesta de dunas que migraron desde sudoeste, en dirección opuesta a la corriente eólica actual alrededor de unos 6700 años anteriores al presente; la unidad C de 1.0 m de espesor, compuesta por una capa fina de depósitos fluviales alternados con arenas datando de unos 5000 a 3200 años anteriores al presente; la unidad D que abarca mas de 7 m de grosor compuesta por la duna parabólica del paisaje actual orientada en la dirección del régimen eólico moderno. Las zonas de excavación eólica sugieren la reactivación de las dunas hace unos 3200 años. En conjunto, los depósitos provenientes de Flinstone Hills evidencian la canalización del Lake glaciar Hind y el establecimiento del cauce del Souris River a través de la cuenca. Además, a mediados del Holoceno, una actividad eólica y una inestabilidad del paisaje mayores a la época actual y el regreso a una condición similar al presente hace unos 5400 años. Hace aproximadamente 9300 años los habitantes de la cuenca del Lake glaciar Hind explotaron las tierras y praderas húmedas, posteriormente lo hicieron en un paisaje similar al actual.

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INTRODUCTION

It has been widely recognized by archeologists (Epp, 1984, 1986; Meyer and Epp, 1990) that throughout the Holocene human groups used distinct, identifiable locales within the Canadian prairies with greater frequency than the surrounding grasslands. As a result of Pleistocene glacial history and more recent geomorphic processes these locales are characterized by greater geomorphic complexity and topographic relief than surrounding grasslands. Examples of such locales include dune fields, deeply entrenched river valleys (including glacial meltwater channels), moraines, and glacially modified bedrock-controlled uplands. In turn, greater geomorphic complexity and topographic relief results in a local-scale landscape characterized by greater ecological complexity, including forest or parkland communities. Therefore, these ecologically diverse localities, characterized by complex mosaics of microhabitats, are endowed with a wider range of resources useful to human groups, as compared to the surrounding grasslands.

Several attempts have been made to model the observed occupation patterns of native inhabitants of the Canadian Prairies (Ray, 1972; Syms, 1977; Nicholson, 1988). However, these models are theoretical rather than empirical. The Study of Cultural Adaptations within the Prairie Ecozone (SCAPE) is a multidisciplinary project designed to test existing models and develop new models of human adaptation to changing environmental conditions, and to better understand human agency in environmental change within the Canadian prairies since deglaciation. The SCAPE approach is to reconstruct the natural and cultural landscapes of four ecologically diverse localities across Manitoba, Saskatchewan and Alberta (Fig. 1) through the Holocene, focusing on time intervals when Plains cultures exhibited major changes in lifeways and adaptive strategies.

One of the SCAPE study localities is the Glacial Lake Hind Basin (GLHB) in southwestern Manitoba (Fig. 1), where numerous dune fields interrupt the plains topography (David, 1977; Wallace, 2001). A cutbank of the Souris River within the GLHB reveals a portion of the stratigraphy of a parabolic dune (Flintstone Hill) and underlying deposits. The oldest exposed deposits are associated with a radiocarbon age of 10 420 ± 70 BP (radiocarbon ages in text are uncalibrated; see Table I for calibrated ages), indicating that the stratigraphic sequence at Flintstone Hill potentially spans the Holocene. Wallace (2001) has shown that the stratigraphic sequence observed at the Flintstone Hill site is representative of the other dune fields within the GLHB. Moreover, the Flintstone Hill exposure is the only complete postglacial sequence known in the GLHB, and is therefore an archive for reconstruction of paleoenvironments and landscape evolution.

The purpose of this paper is to: 1) present a detailed description of the stratigraphy observed at Flintstone Hill, 2) provide a general model of Holocene paleoenvironmental change and landscape evolution for the GLHB, and 3) explain the geoarcheological significance of the Flintstone Hill section with respect to SCAPE investigations of human-environment interaction in the GLHB.

PHYSICAL SETTING

GEOLOGY, CLIMATE, VEGETATION

The GLHB is located in southwestern Manitoba, approximately 80 km southwest of Brandon (Fig. 1). The basin occupies a buried bedrock valley, a re-entrant into the Pembina Escarpment (a northeast-trending bedrock cuesta). This prominent escarpment separates the Manitoba Lowland to the east from the Saskatchewan Till Plain to the west (Dawson, 1875; Corkery, 1996; Holliday *et al.*, 2001). Relatively flat-lying Cretaceous shales underlie the GLHB that, in turn, disconformably overlie Paleozoic marine sedimentary rocks (Manitoba Mineral Resources, 1979).

Pleistocene glacial deposits overlie bedrock in the GLHB. Fine-grained glaciolacustrine deposits overlie ice-contact deposits. These fine-grained sediments act as a local aquiclude, perching water in overlying unconfined, sandy glaciodeltaic and glaciolacustrine sediments referred to as the Oak Lake aquifer. Sediments of the Oak Lake aquifer are overlain by a thin veneer of eolian silt and very fine sand east of the Souris River. West of the Souris River these sandy-textured glaciolacustrine and glaciofluvial deposits have been extensively reworked into eolian sand sheets and dune fields interspersed with interdunal wetlands. Soils in the GLHB are predominately sandy-textured Entisols, Inceptisols, and some Mollisols (Ellis, 1938; Erlich *et al.*, 1956; Eilers *et al.*, 1978).

The GLHB experiences a subhumid continental, drought-prone climate typical of the Canadian prairies (Environment Canada, 1993). Winds capable of mobilizing fine to medium sand (~6 m/s) are common year-round (Pfeiffer and Wolfe, 2002). The resultant sand transport direction is to the southeast (Fig. 1). Winds are west-northwesterly most of the year, with a secondary northeasterly peak during the late spring. Vegetation in the basin includes a complex mosaic of mesic and xeric grassland, aspen parkland, and oak savanna, interspersed with shallow wetland communities in interdunal areas, open grassland communities elsewhere in the basin, and riparian forest communities restricted to the Souris River valley (Boyd, 2000a). More extensive wetlands are present around Oak Lake (Oak Lake is in part the result of human impoundment), Maple Lake, and the Plum lakes.

GEOMORPHOLOGY

The GLHB was deglaciated between 12 000 and 11 000 BP (Sun and Teller, 1997). The basin evolved through a series of phases as described by Sun and Teller (1997). During phases 2 through 4, Glacial Lake Hind experienced through-flowing drainage at various times from the north, west and south, and drained eastward to Lake Agassiz via the Pembina, and later also the Assiniboine, spillways. Glacio-fluvial, –deltaic and –lacustrine sediments filled the basin. As the spillway outlets incised, lake level lowered until the basin was drained. Today, Oak Lake, Maple Lake, and the Plum Lakes and adjacent wetlands are the last remnants of the former glacial meltwater lake.

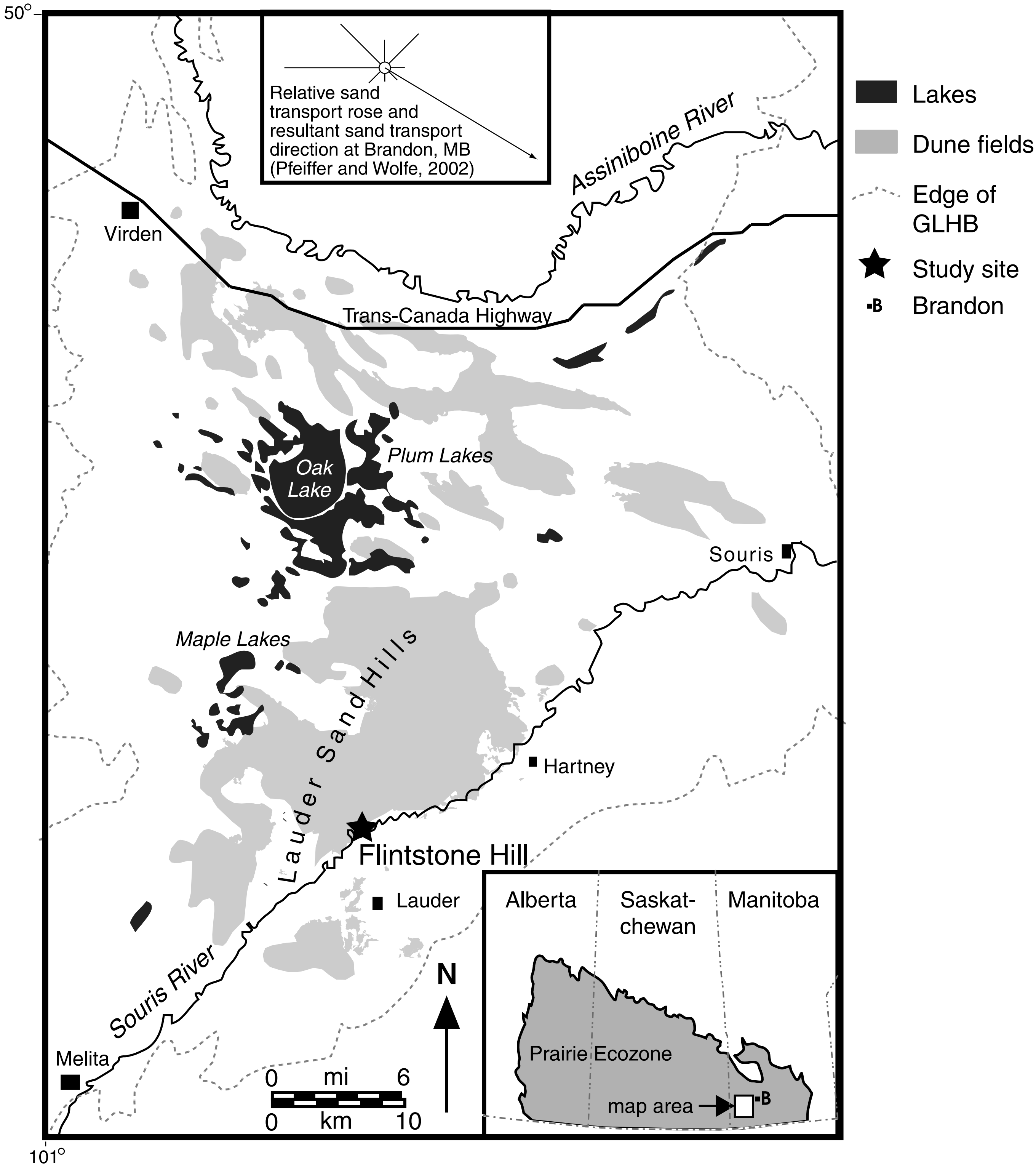

FIGURE 1. a) Location of study site in the Lauder Sandhills within the GLHB. Sand transport directions and relative magnitude at nearby Brandon, Manitoba, are shown. Dune field locations compiled from CANSIS (2001a, b), David, (1977), Fullerton *et al*. (2000), and Ollendick *et al*. (2001) after Wallace (2001).

Localisation des Lauder Sandhills, à l'intérieur du bassin du Lac glaciaire Hind. En carton : directions des vents (transport éolien) et direction résultante (Brandon, Manitoba). La localisation des champs de dunes résulte d'une compilation à partir de CANSIS (2001a, b), David, (1977), Fullerton et al. *(2000) et Ollendick* et al. *(2001) d'après Wallace (2001).*

TABLE I

Radiocarbon sample and age data

Unit	Stratigraphic location	Lab number	Material (pre-treatment)	Conventional age (BP)	*Calibrated age (cal BP)
D	Bottom of lowest blowout	Beta 111143	Bison skull (bone collagen extraction with alkali)	2500 ± 40	2741-2367
C2	Uppermost organic horizon	Beta 109529	Hearth soil (acid washes)	3250 ± 70	3638-3345
C2	Overbank silt	Beta 109900	Bison atlas bone (bone collagen extraction with alkali)	4090 ± 70	4924-4426
C1	Lowest organic horizon	Beta 109530 AMS	Large ungulate bone fragment (bone collagen extraction with alkali)	5350 ± 50	6278-5992
B	Foresets near base	Beta 165740	Charred material on foreset surface (acid/alkali/acid)	5780 ± 50	6680-6450
B	Foresets near base	Beta 165741	Charred material on foreset surface (acid/alkali/acid)	5760 ± 50	6670-6430
A2	Upper peat	Beta 111142	Wood (acid/alkali/acid)	6700 ± 70	7670-7434
A1	Top of basal peat	TO-7692 AMS	*Menyanthes trifoliata* seeds	9250 ± 90	10 670-10 225
A1	Bottom of basal peat	Beta 116994 AMS	*Menyanthes trifoliata* seeds	10 420 ± 70	12 809-11 951

*Calibrated ages according to Stuiver *et al.* (1998a, b). The calibrated range contains all probable dates within two standard deviations (2σ) from the mean.

Three distinct eolian landforms are widely observed in the GLHB west of the Souris River. These landforms are composed of the sandy component of glaciolacustrine and glaciofluvial deposits reworked by wind episodically throughout the Holocene. At least 18 dune fields are scattered throughout the basin and cover over 70 km^2. David (1977) collectively refers to these dune fields as the Oak Lake Dunes. More recently, Wolfe (2001) referred to dune fields in the northeast portion of the GLHB as the Souris Sand Hills, those in the northern portion as the Oak Lake Sand Hills, those in the northwest portion as the Routledge Sand Hills, and those in the southern portion of the basin as the Lauder Sand Hills.

The dunes in all of GLHB dune fields, like most dunes in the Canadian plains, are parabolic dunes that are currently vegetated and stabilized (David, 1977). Where preserved in the GLHB, dune arms are commonly 500-2 000 m long and up to 10 m high. Dune arms are oriented WNW-ESE (average orientations for 18 dune fields range from 96° to 134°; Ollendick *et al.*, 2001) roughly parallel to the modern average wind direction (resultant drift direction, Brandon, 126°; Pfeifer and Wolfe, 2002) (Fig. 1). Brandon, Manitoba experiences an obtuse bimodal, high-energy wind regime with intermediate directional variability (Pfeiffer and Wolfe, 2002). Low conical, irregular, or sinuous mound dunes (1-3 m high, 4-10 m diameter) are also present in association with the parabolic dunes. Eolian sand sheets (from ~1-3 m thick) occur among and between dune fields, and are commonly saturated (shallow interdunal wetlands and wet meadows).

Flintstone Hill is within the Lauder Sand Hills, which includes seven dune fields in the southwestern quadrant of the GLHB (after Wolfe, 2001). The hill represents the head of a dune that has been eroded to its current form by both eolian and fluvial processes. The remaining dune head deposits are up to 7 m higher than adjacent sand sheet deposits. The dune arms are up to 10 m high and 500 m (north arm) to 2 000 m (south arm) long. Orientation of the dune arms is consistent with the modern resultant drift direction (Ollendick *et al.*, 2001; Wallace, 2001) at Brandon, Manitoba.

METHODS

Cutbank profiles were excavated at Flintstone Hill during the 2000 to 2002 field seasons. Profiles were described, measured and correlated with one another across the exposure.

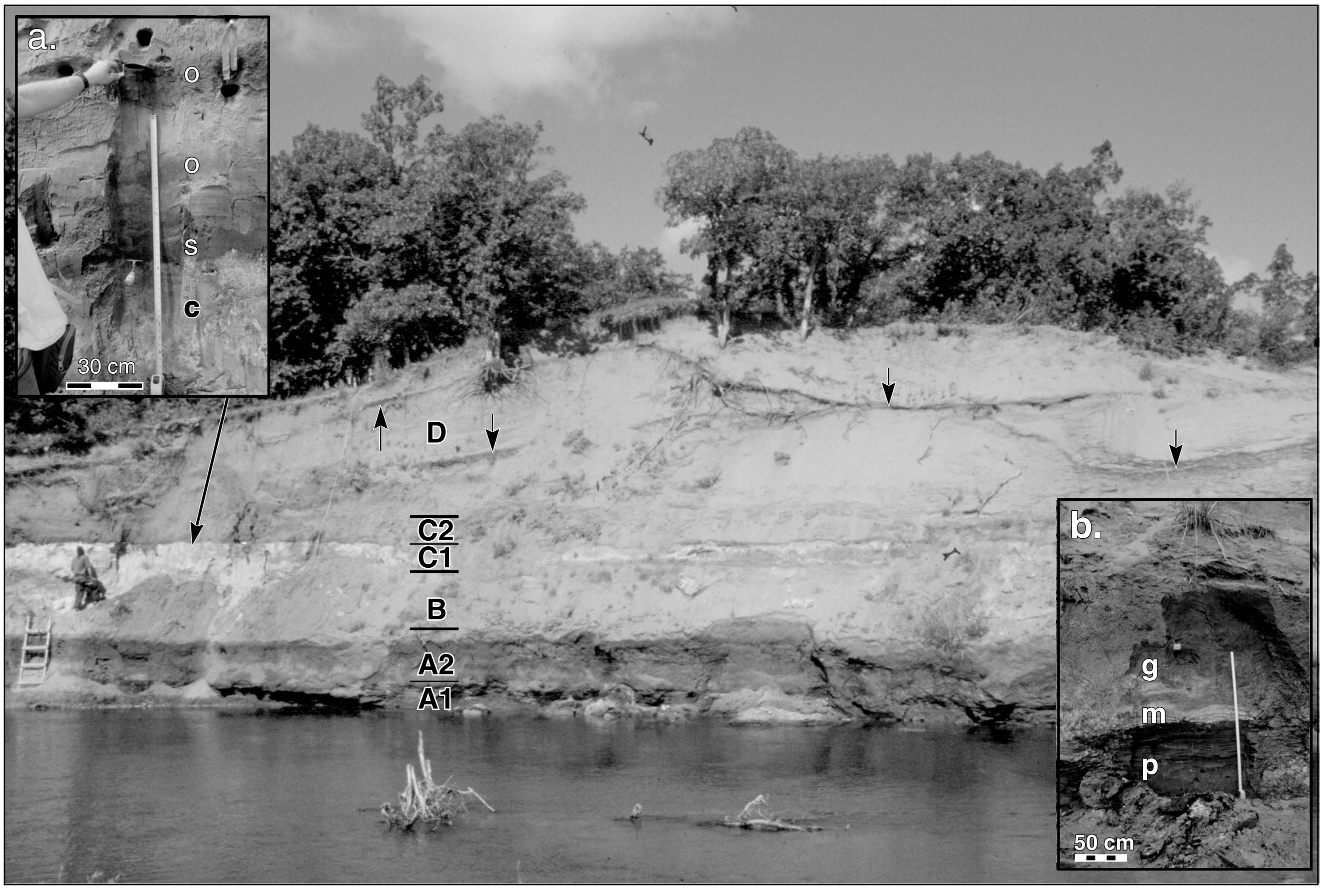

FIGURE 2. Cutbank exposure at Flintstone Hill. A through D are units described in text. Arrows indicate A-horizons of buried soils that formed during periods of stability of the late-Holocene dune. Photo inset a. shows details of unit C. Carbonate-enriched sediment of unit C1 (c) is capped by a silt loam (s). Two sand horizons enriched in finely disseminated organic matter and silt (o) in unit C2 lie above. Two trowels indicate base and top of unit C2. Photo inset b. shows some detail of unit A. Peat of A1 (p) is overlain by marl (m) and coarsening-upward gleyed sand (g).

L'affleurement de la Flintstone Hill, sur la berge escarpée de la rivière Souris. Les unités A à D sont décrites dans le texte. Les flèches montrent les horizons A de sols enfouis qui se sont formés pendant les périodes de stabilité dunaire, à l'Holocène supérieur. Le carton a donne les détails de l'unité C. Le sédiment enrichi de carbonate de l'unité C1 (c) est surmonté d'un limon silteux (s). Deux horizons enrichis dans une matière organique et un silt finement disséminé (o) dans l'unité C2 le recouvrent. Les deux truelles montrent le sommet et la base de l'unité C2. Le carton b montre quelques détails de l'unité A. La tourbe de A1 (p) est surmontée par la marne (m) et un sable à gley plus grossier vers le haut (g).

Samples of bone, hearth charcoal, soil organics and macrobotanical materials were collected for phytolith and radiocarbon analysis (first reported in Boyd, 2000a and b; see also Boyd, 2002; Boyd *et al.*, 2003). Flintstone Hill was mapped using Trimble ProXRS differentially corrected global positioning systems and a TopCon total station (Running *et al.*, 2002). Analysis of ground penetrating radar (GPR) data collected along and across the Flintstone Hill dune ridges, and data from 3 Geoprobe cores collected from well away from the cutbank confirmed the aerial extent of lithologic units exposed in the cutbank (Havholm *et al.*, 2003). Additional samples of some lithologic units were collected to support a variety of specialized microfossil, macrofossil, mineralogical, and isotopic analyses. Preliminary results of some of these analyses are included in this paper. Sand grain size distribution was determined by inspection in the field, and confirmed with a Malvern Mastersizer grain-size analyzer. Laboratory methods to determine carbonate and organic content by loss on ignition followed Singer and Janitzky (1986).

RESULTS AND INTERPRETATION

Four distinct lithologic units are identified based on sedimentary facies distinguished in the cutbank exposure (Fig. 2). A schematic representation of the units is shown in Fig. 3 and indicates a changing depositional environment at the Flintstone Hill site through the Holocene (Table II).

UNIT A

The basal unit (A, Figs. 2 and 3) is at least 2 m thick and is divisible into two sub-units. The lower sub-unit (A1) extends below the river level. That portion of unit A1 observed in the field grades from a gleyed, massive to planar-bedded clay to

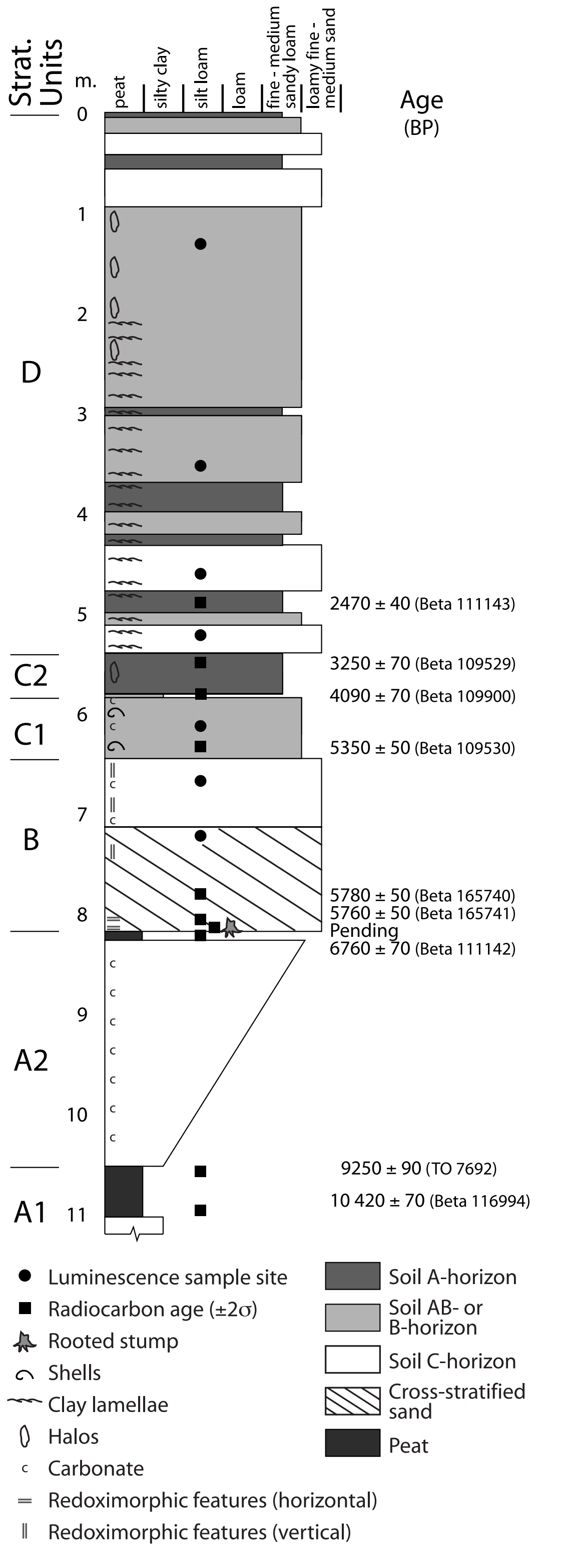

FIGURE 3. Schematic representation of lithostratigraphic Units A through D exposed at Flintstone Hill. Uncalibrated radiocarbon ages shown (see Table I for details).

Représentation schématique des unités lithostratigraphiques A à D de la Flintstone Hill. Les dates au radiocarbone non étalonnées sont présentées (voir le tabl. I).

silty clay upward into a 30 cm-thick peat layer with alternating silty clay and detrital organic laminations. Buckbean (*Menyanthes trifoliata*) seeds from the bottom and top of this peat provide ages of 10 420 ± 70 BP and 9250 ± 90 BP respectively (Boyd, 2002; Boyd *et al.*, 2003).

Unit A2 is composed of interbedded fine sand, silt, clay and marl, with an overall higher carbonate content than unit A1, and abundant gastropod and bivalve shells. This unit coarsens upward to a second, thinner, discontinuous peat layer(s) up to 15 cm thick in a fine sand matrix. In places, multiple (up to 4) thin (1-10 cm thick) peat layers weld to a single layer. Wood fragments are commonly observed within this peat and tree stumps with roots in life position are locally preserved indicating the peat formed in a wooded wetland. One such stump has been identified as a willow (*Salix* spp.) (A.B. Beaudoin, personal communication, 2002). A conventional radiocarbon age on wood from the upper peat places it at 6760 ± 70 BP (Table I).

Unit A1 is interpreted as representing the transition from deep to shallow glacial lake conditions in the basin as Glacial Lake Hind drained through the Pembina and Assiniboine spillways (Phase 4, Sun and Teller, 1997). Studies of pollen and other proxies by Boyd (2000a, b) and Boyd *et al.* (2003) indicate the peat developed in a wetland environment during and after the final recession of Glacial Lake Hind, and that the decline of white spruce during this time indicates an overall warming of the regional climate. Plant macrofossils from the same deposit also suggest that wetland plant succession during the Pleistocene-Holocene transition was largely the result of climate-forced fluctuations in groundwater levels (Boyd *et al.*, 2003).

Unit A2 represents the early Souris River prior to incision that established its present channel through the GLHB. Previously, this unit was interpreted as a closed-basin lacustrine environment with fluctuating lake levels (*e.g.*, Running *et al.*, 2002; Havholm *et al.*, 2003). However, the observed distribution of marl, grain sizes and bedding that generally coarsen upward, and greater carbonate content as compared to unit A1 below, are consistent with a low-energy lateral accretion facies, likely deposited in a position away from the thalweg of the channel (near the channel margin). As the thalweg of this early Holocene Souris River channel migrated away from the site and/or incised to its present position, eolian sand encroached toward the channel, and localized wetlands formed (Boyd *et al.*, 2003). This interpretation is supported by the gastropod and bivalve shell assemblage recovered from unit A2 deposits at Flintstone Hill and in other cutbank exposures along the Souris River (A. Aitken, personal communication, 2002). Vertical accretion facies of unit A2, associated with cumulic A-horizons instead of peat, are locally observed in other cutbank exposures.

UNIT B

Unit B is a cross-stratified, subangular to well-rounded, moderately sorted, fine- to medium-grained sand up to 3 m thick that conformably overlies the upper peat of unit A2. In some profiles, a single set of angle-of-repose eastward-dip-

TABLE II

The sequence of events indicated by the sedimentary sequence observed at the Flintstone Hill site, a cutbank exposure along the Souris River, in the Glacial Lake Hind Basin, southwestern Manitoba

Age (BP)	Environment of deposition
Prior to 10 400	Glacial Lake Hind (unit A1)
10 400 - 9300	wetland with fluctuations in water table greater with time
9300 - 6700	ancestral Souris River, thalweg migrating across the site, then incising to current position, then wooded wetland
6700 - 5400	parabolic dune(s) migrate(s) in from the southwest (unit B) and bury wetland
5400 - 4100	sand sheet deposition and soil/wetland formation alternate twice (unit C1) depositing on a planed surface of unit B
4100 - 3250	stream flood; partial erosion of flood deposit and unit C1; sand sheet deposition and soil/wetland formation alternate twice (unit C2)
3250 - present	parabolic dune migrates in from the northwest with at least 6 periods of stability during formation, dune experiences localized deflation (blow-outs) and deposition (unit D), clay lamellae develop in units D and C2

ping cross-strata (69° to 107° dip azimuths) comprises most of the unit. Strata fade upward into massive sand with similar grain characteristics. In other profiles, the entire unit is massive up to the overlying unit (unit C). Sand in the basal half of the unit exhibits leached or gley colours, presumably the result of groundwater perched in the unit by finer-textured units underlying it. Iron-oxide mottles, and to a lesser extent manganese oxide stains, occur in the unit with concentrations at the top and locally at the base. Horizontally oriented iron-oxide mottles in the basal 50 cm are common, very coarse (up to 5 cm), distinct to prominent, mottles that cut across stratification. Locally, thin, faint to distinct, vertically oriented iron-oxide (and manganese oxide mottles at depth) that follow root traces and, in some instances, cross-strata, are present toward the top of the unit. In addition, few, thin, faint, vertically oriented carbonate stringers and grain coatings exhibiting moderate reaction to 10 % hydrochloric acid (HCl) extend down into the upper 10-30 cm of this unit from above. These carbonate bodies become more extensive upward and progressively obscure iron-oxide mottles toward the top of unit B.

Cross-strata in the basal 10-20 cm of unit B contain wood fragments in gleyed toe-sets where they merge with peat that marks the contact with unit A2. Cross-strata that grade conformably into the unit A2 peat contain finely disseminated organic matter and charcoal along two foresets. Analysis of charcoal from these cross-strata yielded conventional radiocarbon ages of 5790 ± 50 BP and 5800 ± 50 BP, respectively (Table I). A large ungulate (likely bison) leg bone (collagen) from the base of the overlying unit (unit C), with a radiocarbon age of 5350 ± 50 BP (Table I), provides a minimum age for the unit.

Unit B, at least where cross-strata can be seen, represents migration of the slipface of an eolian dune migrating eastward into a wooded wetland. Eolian dune sands conformably overlie unit A2. Textural similarity of the two deposits and the presence of the occasional tree stump associated with unit A2 extending upward into unit B suggest that dunes encroached and buried the wetland. Analysis of unit B at Flintstone Hill and in other Souris River cutbanks in the GLHB indicates unit B represents more than one parabolic dune actively migrating into the Souris River valley from the southwest (Bergstrom *et al.*, 2002).

UNIT C

Even where preserved in its entirety, unit C is relatively thin (about 1 m thick), yet it is the most complex lithologic unit observed at Flintstone Hill. Evidence of a variety of depositional environments, post-depositional diagenetic and pedogenic processes, and erosional disconformities are observed in this unit. We subdivide the unit into lower (C1) and upper (C2) sub-units, as follows.

Unit C1 is composed of tan to white (10YR5-7/2-4), fine to medium sandy loam to loamy sand. The entire sub-unit is overprinted with calcium carbonate, the most conspicuous morphological characteristic of the sub-unit. Carbonate content, based on colour and reaction to hydrochloric acid, increases upward. Gastropod shells are present throughout. Unit C1 is only preserved in its entirety in the west end of the Flintstone Hill exposure.

Two 10-15 cm thick horizontally oriented layers within unit C1 exhibit darker colour and a slight increase in silt and clay content (fine to medium loamy sand to sandy loam). The darker colour indicates enrichment in finely disseminated organic matter. Carbonate overprint is particularly pronounced in these layers owing in part to their slightly finer texture and in part to the proclivity of carbonate to complex with finely disseminated organic matter. Both layers vary laterally from moderate to strong, fine to medium, granular structure to massive (no pedogenic structure). These layers are typically separated from each other by up to 15 cm of lighter colour, slightly coarser sand, but in some places weld into a single layer. Locally, where not eroded, the upper organic-enriched layer exhibits 1-2 cm of very strong carbonate enrichment (strong, fine to medium, platy structure) at its upper contact.

The lower organic-enriched layer locally contains archeological material. Fragments of disarticulated, calcined bone (presumably bison or other large ungulates) dated at 5350 ± 50 BP (Table I) and flakes of Knife River Flint (an important material for stone tool manufacture in the northern Great Plains) are observed. The carbonate overprint in this layer is sufficient to obscure the contact with unit B below it and it remains unclear if the basal layer enriched in finely disseminated organic matter formed in the upper few centimetres of unit B or in the basal sediments that unconformably overlie the unit B contact.

Unit C1 is separated from unit C2 by an erosional disconformity. Locally, the disconformity is overlain by up to 7 cm of massive, carbonate-free, dark brown silt loam (sand fraction is very fine sand) observed only in the west end of the exposure. A bison bone recovered from this layer yielded a radiocarbon age of 4090 ± 70 BP (Table I). Unit C1 and the lens of silt loam are increasingly truncated towards the east by a second unconformity, so that unit C2 rests directly on unit B at the eastern end of the exposure. The unconformity and lens of silt loam suggest an overbank flood where local fluvial erosion was followed by deposition.

Unit C2 is similar to unit C1 except no carbonate enrichment is observed. Two darker and finer layers are comparable to those in unit C1 below. The layers are separated from each other and the underlying deposits by up to 15 cm of lighter colour, slightly coarser sand but locally the two layers weld to a single layer and in some places rest directly on unit C1 deposits. Unit C2 is preserved in its entirety across the exposure. Archeological charcoal from a hearth in the upper organic-enriched layer of unit C2 yielded a radiocarbon age of 3250 ± 70 BP (Table I).

Both darker, horizontally oriented layers exhibit prominent 1-3 cm diameter, botryoidal-shaped discolorations. The discolorations ("halos") exhibit lower chroma, gley colours on the inside and higher chroma, "mottle-like" colours toward their outside edges. Their edges are 0.5-1.0 cm thick and slightly enriched in clay content. The origin of the botryoidal-shape bodies is unknown but their colour pattern (gley inside, oxidized edges) suggest they may, in part, be redoximorphic features.

Prominent clay lamellae are also observed throughout the thickness of unit C2. The lamellae, where best expressed, are 1-2 cm thick, slightly enriched in clay content, exhibit prominent high chroma colours, and are continuous across the exposure. The lamellae are horizontally oriented and extend upward into the overlying unit D where they become progressively thinner, less distinct, less continuous, and more widely spaced. The clay lamellae "zone" is 1.0-1.5 m thick and lamellae cross-cut darker and finer layers in both unit C2 and unit D across the entire Flintstone Hill exposure. Therefore, clay lamellae must have formed post-depositionally.

The sand component of unit C is interpreted as sand sheet deposits, suggesting an eolian environment in which the presence of vegetation, or a high water table limited the ability of wind to develop dunes (Kocurek and Nielson, 1986). The four layers of the unit enriched in finely disseminated organic matter (two in C1 and two in C2) are interpreted as buried A-horizons. These layers gently undulate across the exposure. Massive structure observed at slightly lower elevations but absent elsewhere, suggests formation in a sedge meadow environment. We interpret the carbonate and iron oxide overprint in unit C1 as indicative of a period of high water table. Upward groundwater flow to the surface and evaporative concentration of solutes near the surface within unit C1 (carbonate and iron oxide) and in the top of unit B (iron oxide only) prior to about 4090 ± 70 BP (Table I) (Morrell *et al.*, 2000; Boyd, 2000b). Carbonate, iron oxide, and the presence of gastropod shells observed in unit C1 are consistent with that observed in prairie Calciaquolls that typically form in association with interdunal sedge meadows. Therefore, unit C records a period during the mid-Holocene when water table fluctuations occurred and deposition of sand sheets (lower water table) alternated with soil formation and wetland development (higher water table). Overall, unit C represents a time (about 2000 years) of greater variability in the depositional environment at Flintstone Hill than do the units above and below it.

UNIT D

The uppermost unit is a mostly massive, subangular to rounded, fine- to medium-grained sand, loamy sand, or sandy loam. Low-angle wind-ripple cross-strata are preserved locally. Darker layers enriched in finely disseminated organic matter and silt are ubiquitous in unit D. These sloping layers are 5-15 cm thick and either mimic the modern dune form or are present on concave-up reactivation surfaces within the unit. Concave-up surfaces truncate other soil-capped surfaces. "Halos" as described in unit C are also locally observed in or directly below darker layers. Clay lamellae extend into the base of the unit from below. A bison skull associated with the lowest concave-up surface yielded a radiocarbon age of 2470 ± 40 BP (Table I). The top of unit D is the modern surface of the Flintstone Hill parabolic dune.

This unit was deposited in a parabolic dune that migrated over the site as part of a field of parabolic dunes that constitute the modern surface topography of Flintstone Hill and its surroundings. Darker layers are interpreted as buried A-horizons. All of the buried A-horizons are associated with thin, A-C soil profiles. Sloping surfaces within which the A-C soil profiles formed and that mimic, in a subdued fashion, the modern surface represent positions of dune growth during which the dune was stable and vegetated. Concave-up surfaces are the result of scour in blow-outs within the dune head.

Since its formation, the Flintstone dune has experienced multiple events of localized eolian deflation alternating with deposition (blow-out and fill events) that slightly modified its parabolic dune morphology. Based on the number of buried A-horizons observed in unit D, periods of eolian activity alternated with at least 6 periods of stability during which the buried soil profiles observed in the unit were formed. Clay lamellae, which cross-cut bedding and pedogenic horizons in units C2 and D, including the basal buried A-horizon in unit D that yielded a radiocarbon age of 2470 ± 40 BP, must have formed more recently. Using criteria of Rawling (2000), lamellae appear to be pedogenic features formed by illuviation. However, their environmental significance is not clear.

The radiocarbon age associated with the underlying buried A-horizon at the top of unit C2 suggests that initial migration of the Flintstone Hill parabolic dune occurred around 3250 BP. In the Brandon Sand Hills, about 100 km northeast of Flintstone Hill, a phase of dune activity occurred around 3500-3300 BP (Wolfe *et al.*, 2000), suggesting that unit D may have formed during a regional period of dune activity.

DISCUSSION

IMPLICATIONS FOR CLIMATE CHANGE STUDIES

Unit A1, observed at Flintstone Hill and in other cutbank exposures along the Souris River, provides a record of the terminal stages of Glacial Lake Hind. Low-water levels were established throughout much of the basin by 10 400 BP. Based on macrobotanical evidence derived from the peaty portion of unit A1, Boyd (2000b) and Boyd *et al.* (2003) identified three sequential wetland plant assemblages established in the basin from prior to 10 400 BP to about 9100 BP. In part, this sequence reflects local plant community succession. However, the shift to a *Menyanthes-Equisetum* association between 9800 BP and 9100 BP is interpreted as evidence of more pronounced fluctuations in local water tables. Establishment of this shallow-wetland plant community in the basin is coincident with the decline of *Picea* on surrounding uplands and reflects the onset of substantial, regional-scale postglacial warming.

Unit A2, interpreted as a fluvial deposit, is restricted to the floodplain of the Souris River. Unit A2 equivalent deposits elsewhere in the basin are not to be expected. Indeed, none were observed in cores recovered from sites investigated by Wallace (2001). As such, unit A2 provides a record of local environmental conditions within the riparian zone of the Souris River Valley, rather than regional-scale climatic variability.

At Flintstone Hill, dune sediments dominate the mid-Holocene (unit B) and the late-Holocene (unit D), interspersed with fluvial, wetland and sand sheet sediments (unit C). Eolian units B through D may reflect regional-climatic variability because landscape response in eolian systems has been linked to climate (Clayton *et al.*, 1976; Muhs *et al.*, 1996, 1997; Running, 1997; David *et al.*, 1999; Muhs and Wolfe, 1999; Wolfe *et al.*, 2000; Hopkins and Running, 2000). In general, these climate-landscape response models indicate greatest landscape stability occurs during climatic episodes characterized by moist, cool, relatively drought-free conditions when water tables are high and vegetation cover is abundant. Conversely, greatest eolian activity occurs during warmer/drier (higher growing season potential evapotranspiration and lower water tables, *e.g.*, Laird *et al.*, 1996a, b; Fritz *et al.*, 2000; Hopkins and Running, 2000), and more drought-prone climatic episodes when high-magnitude, low-frequency droughts and storms are more common and more severe (Katz and Brown, 1992). In addition, for climatic conditions near the intrinsic instability/stability threshold for dunes, minor changes in drought frequency and magnitude may reactivate or stabilize dunes (Rosensweig and Reibseme, 1990; Muhs and Maat, 1993; Wolfe *et al.*, 1994; Lemmen *et al.*, ed., 1998; Lemmen and Vance, 1999; Hopkins and Running, 2000). These authors and others have proposed that the comparatively warm, dry and, perhaps, drought-prone mid-Holocene (about 8000 to 5000 BP) was characterized by the greatest rates of eolian activity. During the late Holocene similar eolian response has occurred due to increased aridity (Muhs and Holliday, 1995; Laird *et al.*, 1996a, b; Sauchyn and Beaudoin, 1998) and to increased aridity accompanied by increased drought frequency/magnitude, (Wolfe *et al.*, 1994; Muhs and Holiday, 1995; Muhs *et al.*, 1997; Hopkins and Running, 2000; Wolfe *et al.*, 2001).

Unit B parabolic dune deposits at Flintstone Hill and other cutbank exposures along the Souris River are some of the oldest known parabolic dune deposits in the Canadian Prairies. Orientation of cross-strata preserved in unit B indicate parabolic dunes migrated from the southwest (Bergstrom *et al.*, 2002). This dune orientation indicates a southwesterly resultant drift direction and paleowind regime that are not consistent with the modern wind regime. The southwesterly paleowind regime suggests zonal flow was more significant when the unit B parabolic dunes were actively migrating (at least from about 6700 BP to 5400 BP). In general, zonal flow in the Great Plains of North America is associated with warmer/drier, and droughty climatic conditions (Borchert, 1950) and many consider these conditions to be characteristic of the mid-Holocene. However, the paleowind regime inferred from mid-Holocene dune deposits in the Nebraska Sand Hills is northwesterly, inconsistent with zonal flow (Stokes *et al.*, 1999). We restrict our discussion of the climatic implications of dune orientation inferred from unit B parabolic dune deposits to the GLHB until more details of stratification style and orientation can be studied.

The eolian sequence at Flintstone Hill (units B through D) and its timing essentially conform to the emerging regional picture of mid– and late Holocene dune formation followed by periods of dune reactivation and dune stabilization. However, the modern GLHB landscape is composed of a mosaic of landforms that are modern analogs for the depositional environments that resulted in the formation of lithologic units B through D and associated buried soils at Flintstone Hill. Relatively minor lateral shifts of these sub-environments could result in the vertical sequence observed. Minor changes in anthropogenic fire regimes may yield similar landscape responses (Hamilton and Nicholson, 1999, 2000; Boyd 2000a, b, 2002). Therefore, we recognize that the sedimentary sequence at Flintstone Hill considered alone does not necessarily reflect regional-scale climatic variability. However, the similarity of the mid- and late Holocene eolian sequences at Flintstone Hill to those observed nearby in Manitoba (elsewhere in the GLHB, Wallace, 2001; the Brandon Sand Hills, David, 1971; Wolfe *et al.*, 2000), and North Dakota (the Minot Dune Field, Muhs *et al.*, 1997; the Sheyenne Delta, Running, 1997; Hopkins and Running, 2000) does suggest that regional-scale climate variability is the likely causal mechanism.

GEOARCHEOLOGICAL SIGNIFICANCE

SCAPE archeologists are developing prehistoric land-use models based on their investigations in the GLHB. The contribution by SCAPE geoscientists is to provide the Holocene local-scale environmental context for human use of the basin.

The peat deposit in unit A1 represents plant communities coincident with edges of small, isolated wetlands. Of particular importance to archeologists, these wetlands and associated plant communities were likely to have been widely distributed throughout the recently drained glacial lake basin. The basin may not have been attractive to human groups as a place to live. However, Boyd *et al.* (2003) argue that Folsom Complex people practiced seasonal bison resource extraction in the basin during this period. Such plant communities would have provided suitable forage for bison. These communities would have attracted bison to the basin, and associated wetlands would have provided locations suitable for their acquisition by human hunters. Bison kill sites, rather than occupation sites are likely associated with unit A1. Unit A1, where observed, is buried well below the depth of traditional archaeological surveying methods. Except where exposed in cutbanks, unit A1 is only accessible to archeologists via cores or deep trenches.

Unit A2 is likely to be particularly significant archeologically. It is well known that past human groups were attracted to floodplain settings, and that archeological sites are often encountered in fluvial deposits. Presumably this is because riparian forests and other floodplain vegetation communities provide a wide variety of resources useful to humans. Unit A2 fluvial deposits are widespread in the Souris River Valley and both vertical accretion and lateral accretion facies have been observed in numerous cutbank exposures along the Souris River. Well-stratified archeological sites are often preserved within vertical accretion deposits. Indeed, one such site has recently been identified by SCAPE archeologists (B.A. Nicholson, personal communication, 2002). Preliminary results of macrobotanical, pollen, and other proxies in lateral accretion facies deposits at Flintstone Hill indicate the vegetation community associated with the thin peat at the upper contact of unit A2 is consistent with woody wetland communities (Kasstan, 1999; A. Aitken, personal communication, 2002; A.B. Beaudoin, personal communication, 2002). Similar communities are widely observed in similar settings on the modern floodplain landscape suggesting that the extant mosaic of riparian communities in the Souris River Valley is likely to be a reasonable analog for riparian communities in the past. At another cutbank archeological evidence suggests unit A2 is time-transgressive (B.A. Nicholson, personal communication, 2002), owing to the meandering character of the Souris River. Therefore, though often deeply buried by younger deposits, unit A2 is widespread in the Souris River Valley, formed over much of the Holocene in a setting attractive to past human groups, and is at least partly composed of fluvial deposits where preservation of well-stratified archeological sites is expected.

Units B and D are both parabolic dune deposits. SCAPE archeologists working in the GLHB area suggest human settlement of the GLHB focused on parabolic dunes adjacent to interdunal wetlands extant on the modern landscape (Hamilton and Nicholson, 1999; B.A. Nicholson, personal communication, 2002). Human groups were attracted to these settings by the ecological complexity that characterizes them. Whether this land-use pattern extends back in time to include parabolic dunes represented by unit B remains an important archeological question. However, where unit B deposits are observed in the GLHB this land-use model should be applicable from at least 6700 BP to European contact.

Unit B deposits are not likely to be as areally extensive as are unit C and D deposits. Unit B deposits are only observed in cutbank exposures along the Souris River near the centre of the GLHB. In general, parabolic dunes are progressively younger westward across the GLHB and have not been observed toward the margins of the basin (Wallace, 2001).

Researchers working in parabolic dune-dominated landscapes identify several lines of evidence that strongly suggest parabolic dunes may have been present in their study areas during the mid-Holocene yet parabolic dune deposits from the mid-Holocene are rare (Muhs *et al.*, 1996, 1997; Running, 1997; David *et al.*, 1999; Muhs and Wolfe, 1999; Wolfe *et al.*, 2000). Complete reactivation of these deposits during intense mid-Holocene and later episode(s) of dune activity is considered the most likely reason that mid-Holocene parabolic dune deposits are not preserved. This scenario is likely in the western margins of the GLHB as well, where sandy deposits are thicker, and higher on the landscape and better drained (Ellis, 1938; Erlich *et al.*, 1956) (and more prone to water table fluctuations in the Oak Lake Aquifer). Fluctuation of the Oak Lake Aquifer water table toward the higher elevation basin margin, perhaps in response to regional-scale climatic change, are likely to have been more frequent allowing greater deflation and reworking of dune sediments. However, evidence suggests mid-Holocene dunes are preserved toward the centre of the GLHB, such as at Flintstone Hill and nearby cutbank exposures, where the water table appears to have been more stable. Therefore, archeological investigations focused on the mid-Holocene should be restricted to the center of the GLHB. Deeply buried sites should be expected.

Sand sheets and parabolic dunes that exhibit characteristics similar to units C and D, respectively, are ubiquitous over much of the modern GLHB landscape west of the Souris River. Sand sheets, sometimes subaqueous (interdunal wetlands and wet meadows) are widely observed within and between parabolic dune fields. Multiple, thin, buried soil or shallow wetland horizons are common in these sand sheets. Indeed, the uppermost buried soil in unit C2 at Flintstone Hill welds to the surface soil near the margins of the exposure. Stratified archeological sites may be preserved in these buried soils, particularly in landscape positions at the base of parabolic dunes adjacent to interdunal wetlands.

Parabolic dunes in the GLHB are oriented in a manner consistent with the modern wind regime. Buried soils, morphologically similar to those observed at Flintstone Hill, that mimic the modern surface topography are often observed in parabolic dunes as are complex cut-and-fill sequences. The morphology of buried soils and surface soils formed on both dunes and sand sheets on the modern surface are consistent with grassland vegetation. That locally the GLHB is now heavily wooded is an artifact of recent Euro-Canadian fire suppression rather than climatic change.

There is a strong temptation to interpret the unit C to unit D transition as an indicator of some change in environmental conditions; a landscape dominated by sand sheets (unit C), replaced by a landscape dominated by parabolic dunes (unit D) is implied. Instead, we argue that beginning about 5400 BP both sand sheets and parabolic dunes, like those that characterize the modern landscape, were present in the GLHB. Intensity of eolian activity was, at times during this period, greater than the present. Relative positions of parabolic dunes and intervening sand sheets certainly changed through time. However, units C and D represent a period during which local-scale conditions were broadly similar to those that characterized the GLHB at the time of Euro-Canadian settlement. Archeologists can assume humans operated during this period in a landscape that included parabolic dunes and intervening sand sheets and interdunal wetlands.

CONCLUSION

Four lithologic units, spanning the entire postglacial period are observed at Flintstone Hill site (Table II). Glacial Lake Hind drained from much of the basin by about 10 400 BP. The ancestral Souris River flowed through the basin, and isolated shallow wetlands dominated the landscape from 10 400 BP until 9300 BP. Macrobotanical evidence indicates composition of wetland plant communities established along the margins of these wetlands changed during this time. These changes coincided with changes in vegetation communities in the surrounding uplands. At least in part, these changes were in response to postglacial warming and drying. Regardless, wetland plant communities present in the basin throughout this period provided fodder suitable to attract bison, in locations suitable for Folsom-Complex hunters to trap them.

The GLHB was characterized by a mosaic of landforms and vegetation broadly similar to the present during the remainder of the Holocene. By 6700 BP the Souris River established its current course. Resources associated with riparian and other vegetation communities would have been available in the Souris River Valley from 9300 BP to the present.

Parabolic dunes, sand sheets, and interdunal wetlands were present in the centre of the basin by 6700 BP. Unit B represents one of the oldest mid-Holocene parabolic dune deposits (6700 BP to 5400 BP) known in the Canadian prairies and adjacent parts of the Great Plains in the United States. Sedimentary features preserved in unit B deposits indicate a southwesterly paleowind regime during this period. This paleowind regime indicates greater zonal flow, suggesting the mid-Holocene was warmer, drier, and more drought-prone than the modern regional climate. However, riparian vegetation would still have been present within the Souris River Valley throughout this period. Parabolic dunes, sand sheets, and interdunal wetlands like those that characterize the modern landscape were established over much of the GLHB by 5400 BP.

SCAPE archeologists working in the GLHB area suggest human groups were attracted to dune-dominated landscapes within the basin. Based on the results of our investigations at Flintstone Hill, their model of prehistoric land-use and settlement patterns can be applied over much of the GLHB from 6700 BP to the time of Euro-Canadian settlement.

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