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POTENTIAL ABORIGINAL-OCCUPATION-INDUCED DUNE ACTIVITY, ELBOW SAND HILLS, NORTHERN GREAT PLAINS, CANADA

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ABSTRACT—Geomorphological and archeological evidence indicates potential linkages between Plains aboriginal occupation and dune activity in the Elbow Sand Hills of southern Saskatchewan, Canada. Vegetation encroachment has rapidly outpaced migration of an active dune complex over the last 65 years. Optical ages of stabilized dune remnants indicate that dune activity predates Euro-Canadian settlement (ca. AD 1900). Early Euro-Canadian explorers observed local occupation and exploitation of the sand hills by aboriginal groups for herding and impounding bison. Mapping of archeological sites in relation to physiography reveals that sand dunes, in close proximity to permanent water resources, were preferred areas of occupation. Collectively, these results support the hypothesis that aboriginal occupation disturbance may have perpetuated dune activity in the Elbow Sand Hills until the late 19th century, and that Euro-Canadian settlement and land use emphasizing conservation may have encouraged recent stabilization. We propose that similar aboriginal occupation disturbances may have been responsible for perpetuating dune activity in other dune fields in the Great Plains. To this end, climatic variability should not be considered exclusive of other drivers of dune activity in semivegetated inland dune fields of the Great Plains.

Key Words: aboriginal occupation, bison, disturbance, optical dating, sand dunes

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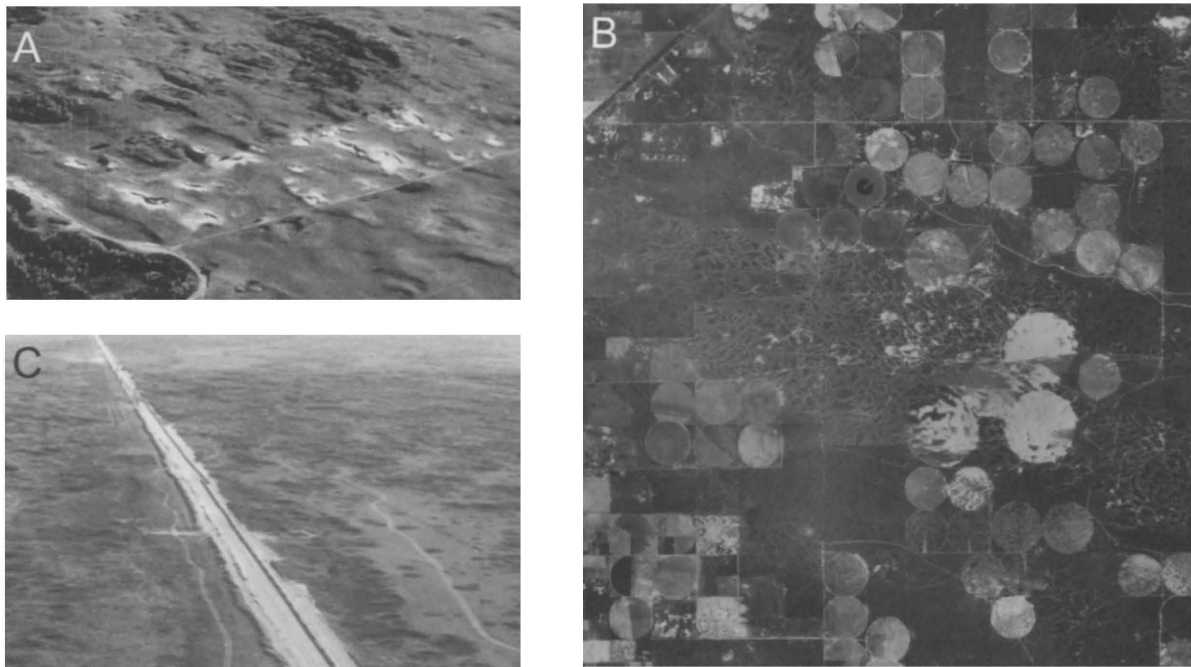


Figure 1. Examples of surficial disturbance and reactivation of eolian sands on the North American Great Plains. (A) Active blowouts caused by overgrazing during times of drought in the Dundurn Sand Hills, south of Saskatoon, Saskatchewan, November 2, 1937 (NAPL A-5850-33). (B) Active eolian sand caused by disturbance from center-pivot irrigation systems in three large circular fields at Portales, New Mexico, 1983 (Muhs and Maat 1993; USGS NAP361-103). (C) Removal of surface vegetation for pipeline installation in the Great Sand Hills, southwestern Saskatchewan, requiring reseeding to prevent reactivation of sand dunes, September 29, 1994 (photograph by S. Wolfe).

INTRODUCTION

On a global scale, sand seas and dune fields exist with different levels of activity or mobility. The level of activity is determined by the processes of surface sediment erosion and deposition by wind. It follows that active eolian landforms (e.g., dunes, sand sheets, blowouts, etc.) are those modified by contemporary surface eolian processes (Lancaster 1994). Like many geomorphic systems, dune activity occurs along a continuum, rather than in terms of distinct thresholds, with fully active dunes on one end and relict dunes on the other.

Increasingly, dune activity is used as an indicator of environmental change. This reflects the apparent sensitivity of sand dunes to changes in wind energy (which controls sediment transport capacity) as well as surface conditions (which control sediment supply and availability). Drought is commonly considered a prevalent form of disturbance in the North American Great Plains, and attempts have been made to correlate historical and geological records of dune activity to past episodes of drought (Forman et al. 2001; Miao et al. 2007). Direct correlations between drought events and dune activity

may be complicated, however, by the lag time between a given drought episode and the response and relaxation times of dune systems. Once activated, sand dunes may remain mobile for decades or centuries after the initial disturbance, particularly in arid environments and areas of high wind energy (Bullard et al. 1997; Hugenholtz and Wolfe 2005a).

Biogeomorphic and anthropogenic disturbances such as fire (Seppälä 1981; Filion 1984; Boyd 2002), overcultivation (Nickling and Wolfe 1994), logging (van Denack 1961; Lichter 1998), off-road vehicle traffic (Kotilainen 2004; Cordova et al. 2005), and overgrazing (Käyhkö and Pellikka 1994) have been observed to cause dune reactivation, as have climatic disturbances. In dryland environments, disturbances caused by overcultivation, livestock grazing, and tree cutting may lead to or intensify desertification (Fig. 1A and 1B; Nicholson et al. 1998). As a result, diligent management practices are often implemented to minimize initial disturbances and inhibit eolian activity subsequent to disturbance (Fig. 1C).

Dune fields are widespread in the northern Great Plains of North America (Fig. 2A). These areas consist of mostly stabilized sand dunes and sand sheets. However,

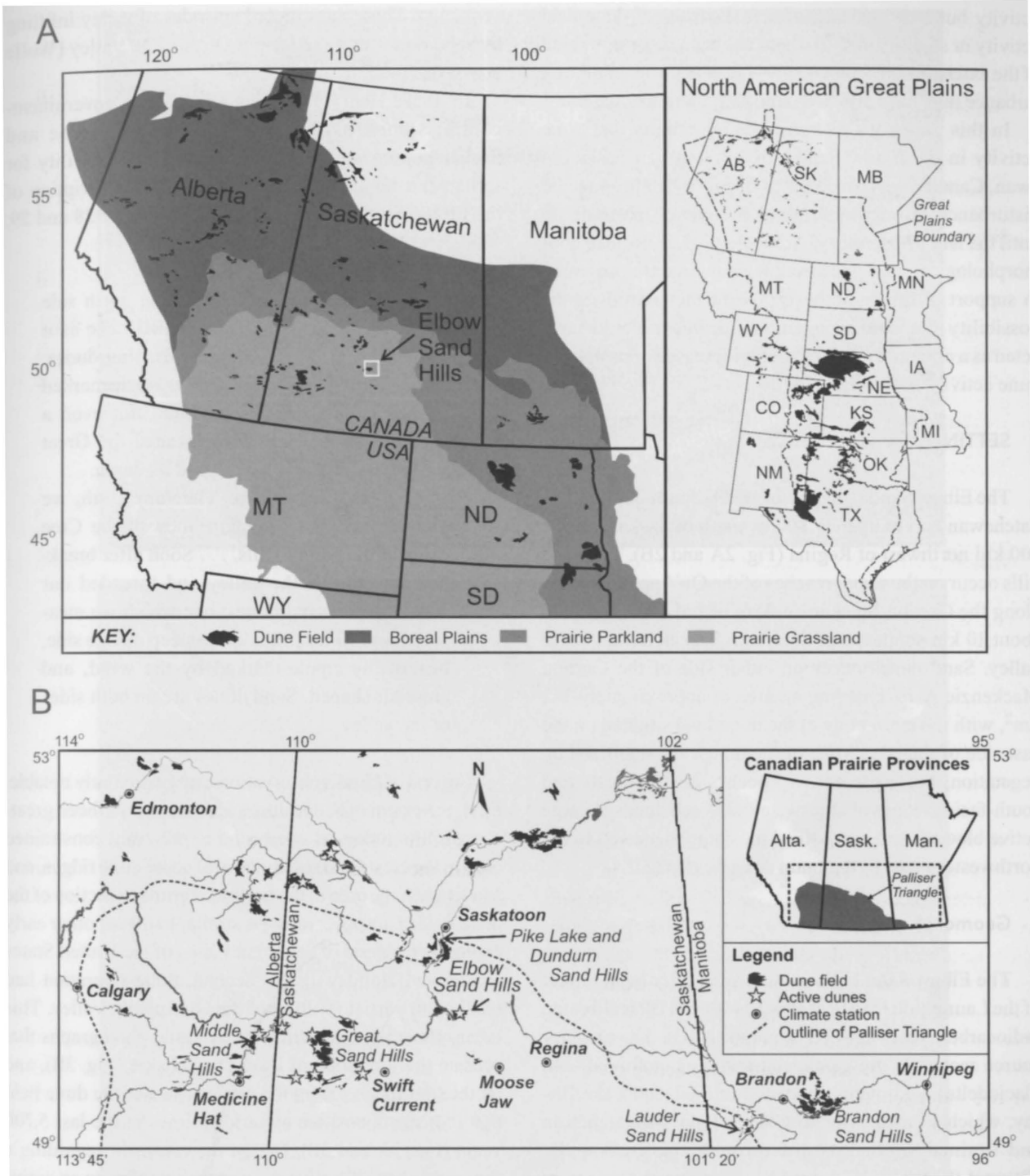


Figure 2. (A) Sand dune occurrences on the North American Great Plains, showing location of the study area (Elbow Sand Hills). (B) Elbow Sand Hills and other dune fields on the Canadian Prairies with climate stations in southern Saskatchewan from which drift potentials were derived.

localized dune activity in the form of blowouts, active dune crests, and a few large tracts of active dunes occur throughout the region. Investigations of dune activity in the northern Great Plains have focused on stratigraphic and

geochronologic evidence of former periods of activity and stability (David 1971; David et al. 1999; Wolfe et al. 2000, 2001, 2002; Running et al. 2002; Havholm and Running 2005). These studies contribute to the timing of past dune

activity but lack evidence of actual causes of dune-field activity or stability. As yet, there has been no examination of the extent to which biogeomorphic or anthropogenic disturbance may have affected dune activity in this region.

In this paper, we examine the hypothesis that dune activity in the Elbow Sand Hills of southern Saskatchewan, Canada, was perpetuated in part by anthropogenic disturbance through aboriginal occupation patterns up until the late 19th century. Archeological, historical, geomorphological, and geochronological data are presented in support of this hypothesis. We further introduce the possibility that anthropogenic disturbance could have acted as a potential mechanism for increased or prolonged dune activity in the Great Plains.

SETTING

The Elbow Sand Hills are located in south-central Saskatchewan approximately 80 km south of Saskatoon and 100 km northwest of Regina (Fig. 2A and 2B). The sand hills occur on the upper reaches of the Qu'Appelle Valley, along the Gordon Mackenzie Arm of Lake Diefenbaker, about 10 km southeast of the South Saskatchewan River valley. Sand dunes occur on either side of the Gordon Mackenzie Arm, covering an area of approximately 182 km², with the main body of the dune field situated on the east side of the lake. Most of the dunes are stabilized by vegetation, but some activity occurs on the crests and south-facing slopes of otherwise stabilized dunes. A large active blowout and parabolic dune complex occurs in the northwestern part of the main dune field (Fig. 3A).

Geomorphology

The Elbow Sand Hills were formed after local retreat of the Laurentide Ice Sheet about 14000 cal BP (calibrated radiocarbon years ago) (Dyke et al. 2003). The primary source materials are glaciolacustrine, glaciofluvial, and glaciodeltaic sediments deposited into Glacial Lake Birsay, which formed prior to Glacial Lake Saskatchewan and drained southeastward through the Qu'Appelle Channel (Scott 1971). A set of well-exposed sections in stabilized dunes on the western shoreline of Lake Diefenbaker record late Holocene dune activity (Fig. 3A; Lian et al. 2002; Wolfe et al. 2002). A 7 m section reveals a set of nine eolian sand units, separated by buried soils. Five optical ages bracketing most of this sequence indicate dune activity about 5700, 3000, 2000, 1500, and 200 years ago. An additional optical age from a depth of 2.5 m in an adjacent section indicates dune activity at about 145

years ago. These ages record episodes of valley infilling by sand dunes into the former Qu'Appelle Valley (Wolfe et al. 2002).

In 1858, Henry Hind led a Canadian government-commissioned exploration of the Assiniboine and Saskatchewan regions to document their suitability for settlement. Hind (1859:54-55) provides a description of the Elbow Sand Hills traversed between July 28 and 29, 1858:

The Sand Hills commence on the north side about two miles west of Sand Hill Lake as it appears in summer. They are drifting dunes, and many of them present a clear ripple marked surface without any vegetation, not even a blade of grass. They have invaded the Great Valley, and materially lessened its depth. . . .

On the morning of Thursday, 29th, we prepared to visit the main body of the Cree camp at the Sandy Hills. . . . Soon after breakfast we crossed the valley and threaded our way between sand dunes; one which we measured was 70 feet high, quite steep on one side, beautifully ripple-marked by the wind, and crescent-shaped. Sand dunes are on both sides of the valley.

Several of Hind's observations are particularly notable. First, the extent of active dunes appears to have been greater than it is today, as open sand is presently constrained only to the crests and south slopes of some dune ridges, and to a single large area in the northwesternmost section of the dune field. This observation is similar to that of other early explorers for parts of the Great Plains of the United States (Muhs and Holiday 1995). Second, dune migration had resulted in partial infilling of the Qu'Appelle Valley. This latter observation is confirmed by aerial photographs that predate the formation of Lake Diefenbaker (Fig. 3B), and by the optical ages from the western side of the dune field that indicate deposition at various times in the last 5,700 years (Fig. 3A and 3B). Lastly, the comment regarding a "crescent-shaped" active dune probably refers to an active parabolic dune or large blowout.

Climate and Vegetation

The present-day climate of the Elbow Sand Hills area is dry subhumid (dryland). Mean potential evapotranspiration (PE) at Outlook, Saskatchewan, approximately 35 km northwest of the sand hills, exceeds

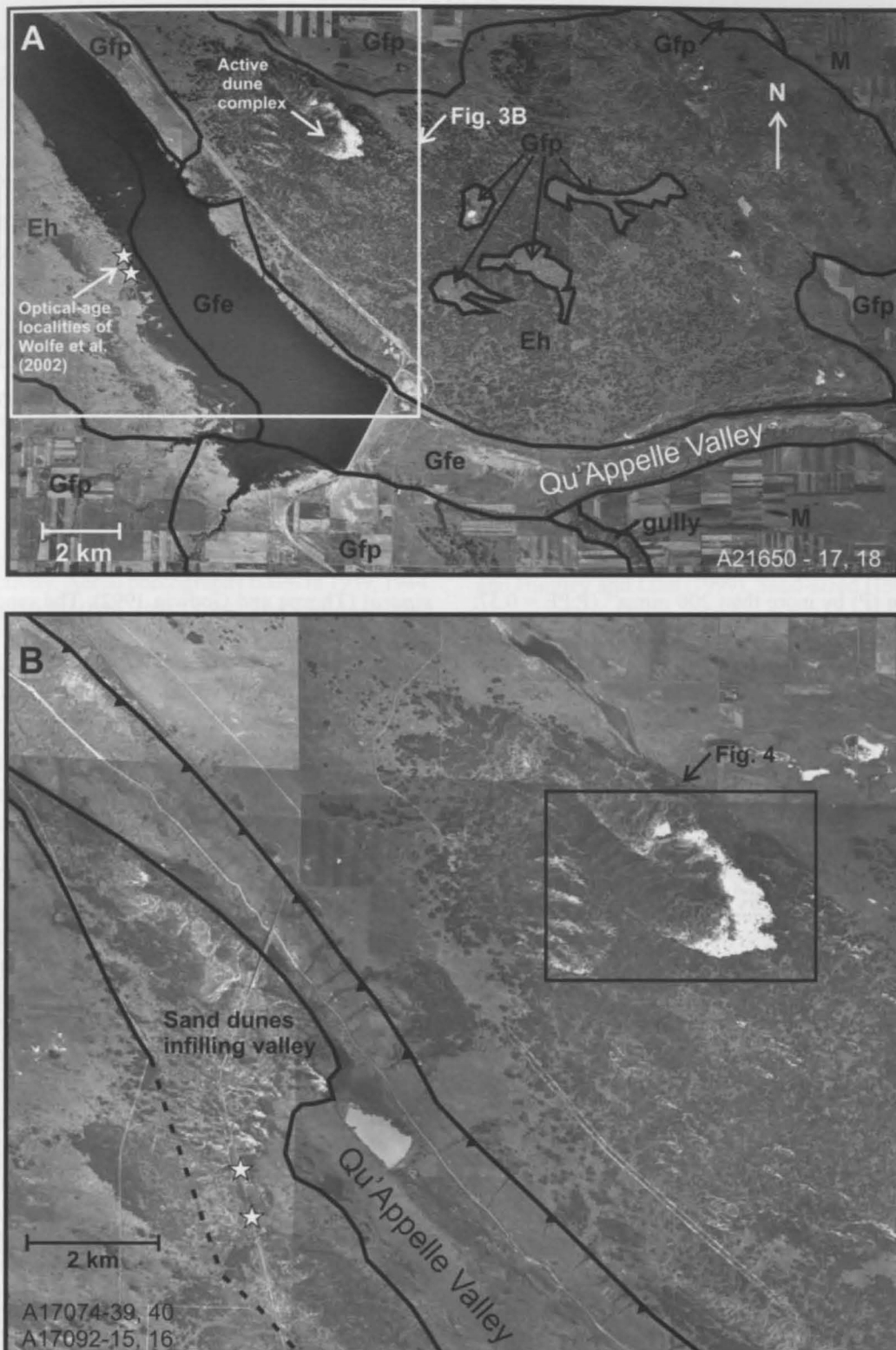


Figure 3. The Elbow Sand Hills at the junction of the Qu'Appelle Valley with the South Saskatchewan River. (A) Surficial geology: Eh = eolian hummocky; M = moraine; Gfp = glaciofluvial plain; Gfe = glaciofluvial eroded. (B) Enlargement showing Qu'Appelle Valley prior to flooding by Lake Diefenbaker. Note infilling of valley by sand dunes, and location of optical age locations (stars) by Wolfe et al. 2002.

TABLE 1
CLIMATIC VARIABLES FOR LOCATIONS IN SOUTH-CENTRAL SASKATCHEWAN

Location	Latitude, Longitude	Precipitation (mm)			PE (mm)	P:PE	Drift direction	W (%)	M
		Rain (mm)	Snow (cm)	Total P (mm)					
Saskatoon	52° 08', 106° 40'	253	105	347	547	0.63	SE	36	57
Outlook	51° 29', 107° 03'	239	84	323	562	0.57	SE [†]	36-42 [‡]	57-67 [‡]
Moose Jaw	50° 23', 105° 32'	257	122	356	572	0.62	ENE	42	67
Swift Current	50° 17', 107° 47'	248	128	367	546	0.67	NE	54	80
Regina	50° 27', 104° 37'	280	107	364	554	0.66	ENE	45	68

Note: Values derived for 1961-1990 from Environment Canada (1993), Walmsley and Morris (1992), and Wolfe (1997). P = precipitation; PE = potential evapotranspiration, calculated using method of Thornthwaite and Mather (1957); W = percentage of time winds exceed threshold of dry sand using data of Walmsley and Morris (1992); M = Lancaster's (1988) mobility index ($W\% / P:PE$).

[†]From measured orientations of active sand dunes.

[‡]W (%) and M range estimated from values for Saskatoon and Moose Jaw.

precipitation (P) by more than $200 \text{ mm}\cdot\text{a}^{-1}$ ($P:PE = 0.57$; Table 1) and approaches $300\text{-}350 \text{ mm}\cdot\text{a}^{-1}$ in drought years (Wolfe 1997). The mean annual air temperature is 3.2°C , with short hot summers and long cold winters. The monthly average air temperature in July (the warmest month) is 18.4°C , whereas the average in January (the coldest month) is -12.5°C . Detailed wind data for the Elbow Sand Hills or nearby Outlook are not available. However, winds in Saskatoon and Moose Jaw located north and south of the Elbow Sand Hills are above the threshold for transport of dry sand for approximately 36% and 42% of the time, respectively (Table 1). Thus, under present-day winds and aridity, the Lancaster (1988) dune mobility index value for the Elbow Sand Hills is in the range of 57-67, indicating that dunes with active crests may be present.

The sand hills occur within the moist-mixed grassland of the prairie ecozone and are situated along the eastern margin of the driest region of the province. Common graminoid species in the sand hills include obtuse sedge (*Carex obtusata*), prairie sandreed (*Calamovilfa longifolia*), sandbank sedge (*Carex siccata*), needle and thread grass (*Stipa comata*), and rough fescue (*Festuca scabrella*). Trees, shrubs, and cacti are locally abundant in the sand hills and include trembling aspen (*Populus tremuloides*), choke cherry (*Prunus virginiana*), western snowberry (*Symphoricarpos occidentalis*), wild rose (*Rosa* spp.), creeping juniper (*Juniperus horizontalis*), prairie sagebrush (*Artemisia frigida*), prickly pear cactus (*Opuntia fragilis*), and purple cactus (*Mamillaria vi-*

vipara) (Thorpe and Godwin 1992). The sand hills also contain the only known location in Saskatchewan of western spiderwort (*Tradescantia occidentalis*), a perennial flowering plant typically associated with areas of active, drifting sand where vegetation cover is relatively sparse (Thorpe 1999).

Land Use

The Elbow Sand Hills are co-managed by Douglas Provincial Park and the Elbow Pasture of Prairie Farm Rehabilitation Administration (PFRA). The park is classified as a "natural environment" park, with an emphasis on conservation of natural ecosystems and biodiversity. Resource uses such as grazing are considered mainly in terms of their role in achieving conservation goals of maintaining existing species diversity and habitats (Thorpe and Godwin 1992). Similarly, the main objective of the PFRA, which manages community pastures, is toward conservation-oriented land use (Thorpe and Godwin 1992).

The area was probably never cultivated as a consequence of the low soil fertility and the highly erodible nature of the sand dunes. Since Euro-Canadian settlement, the main land use has been cattle grazing. According to Thorpe and Godwin (1992), cattle probably first grazed in the area ca. 1898, prior to the main influx of homesteaders ca. 1905. Between 1914 and 1930, the sand hills were part of a forest reserve, during which conifer plantations were attempted in a few areas. Following the severe drought of

the 1930s, much of the area has been under management by the PFRA. Douglas Provincial Park was established in the late 1960s, following the creation of the Lake Diefenbaker reservoir with the construction of the Gardiner and Qu'Appelle dams. The Park became operational in 1973, and land for the park was taken from the Elbow pasture. Fencing to separate the two areas was completed in 1974. The large active dune complex and local surrounding area are contained entirely within Douglas Provincial Park and are presently protected from cattle grazing. However, between ca. 1898 and 1974 this area of active dunes was managed for cattle grazing.

METHODS

Historical Trend Analysis

Recent changes in the extent of active sand were assessed to quantify historical trends and estimate future and past activity. Aerial photographs taken in 1939, 1944, 1960, 1965, 1970, 1979, 1986, 1996, and a multispectral Quickbird satellite image (converted to grayscale) taken in 2004, were used to determine the extent of active sand.

The overall methodology is similar to that developed by Hugenholz and Wolfe (2005a). Aerial photographs were scanned in grayscale and, along with the satellite image, were geocoded and imported into a common geographic framework (UTM projection NAD83). Because the aerial photographs were obtained under slightly different lighting conditions, the grayscale values (0 to 255) were normalized between images before delineating the boundary between vegetation and active sand. The process, referred to as relative radiometric calibration, ensures that digital grayscale values representing open sandy areas are consistent between images, and that these values are clearly distinguishable from vegetated areas. Normalization was achieved by matching the histograms from each image to the 1996 image.

The normalized images were classified using a supervised classification scheme with a maximum likelihood classifier. Two classes were defined: (1) bare sand and (2) vegetation. The classification was facilitated by the fact that the bare sand surface on the dunes had significantly different grayscale values than the surrounding vegetation. A sample of no less than 200 training pixels for each class was used in each photograph. The classified images were rescaled to 1-bit (1 = sand and 0 = vegetation), and a Geographic Information System (GIS) was used to measure the total area of bare sand.

Optical Dating

Optical dating was used to determine the timing and extent of past dune activity upwind of the active dune complex. The sampling strategy for optical dating focused on determining the most recent episodes of past eolian activity upwind of the presently active dune. Samples were obtained from vegetated (i.e., stabilized) eolian terrain, progressively westward of the active dune. Three samples were collected from shallow pits at depths of 80 or 90 cm. Stratigraphy was described at each sample site, noting depth of pedogenesis and orientation of eolian bedding, if present. One surface sample of sunlight-exposed grains was collected as a reference "zero-age" test sample.

Optical dating measures the time elapsed since mineral grains were last exposed to sunlight. General descriptions of available techniques are found in *Radiation Measurements* (vol. 27, no. 5/6, 1997), Aitken (1998), and Huntley and Lian (1999). Sand-sized (180 to 250 μm diameter) K-feldspar grains were separated; equivalent doses were determined using 1.4 eV (infrared) excitation and measurement of the 3.1 eV (violet) emission, and an additive dose procedure. The preheat was 16 h at 120°C. The thermal transfer correction was made using an infrared/red bleach. A detailed description of the apparatus and methods used can be found in Ollerhead et al. (1994) and Huntley and Clague (1996).

Environmental beta and gamma dose rates were calculated from measured K, U, Th, and moisture contents (Table 2), using the conversion factors of Nambi and Aitken (1986), as updated by Adamiec and Aitken (1998), and the beta attenuation factors of Mejdahl (1979). Cosmic-ray dose rates were calculated using the formula of Prescott and Hutton (1988). Internal dose rates were calculated as explained in the footnotes to Table 2. The apparent ages were corrected for anomalous fading using the prescription of Huntley and Lamothe (2001). All analytical uncertainties shown are at $\pm 1\sigma$ (Table 3).

The use of an infrared/red bleach for the thermal transfer correction may not be optimum for these samples. Detailed measurements on dune samples from the Brandon Sand Hills, Manitoba (Wolfe et al. 2002), showed that this bleach led to a systematic error of the order of 0.1 Gy, corresponding to about 40 years. The equivalent dose and age obtained in the present work for the head of an active dune (SFU-O-253 in Table 3) are comparable to these. Therefore, there may be a systematic error in the present ages, and the true ages could be of the order of 40 years younger than those given in Table 3. However, such

TABLE 2
 SAMPLE LOCALITIES AND SAMPLE DEPTH, CONCENTRATIONS
 OF RELEVANT ELEMENTS USED FOR DOSIMETRY, AND WATER CONTENT

Lab number ^a	Location	Depth (cm) ^b	K (%) ± 5%		Th (µg·g ⁻¹) (±0.05)	U (µg·g ⁻¹) (±0.10)	Water content ^d
			Sample	Surroundings ^c			
SFU-O-253	Head of active dune	0	1.07	—	1.9	0.64	0.6
SFU-O-254	260 m west	80	1.24	1.14	2.1	0.68	1.7 ± 0.4
SFU-O-255	884 m west	80	1.15	1.15	1.7	0.66	1.4 ± 0.9
SFU-O-256	1317 m west	90	1.15	1.07	1.9	0.54	1.1 ± 0.2

Notes: Water content samples were obtained during the drought summer of 2001. Consequently, past average water content estimates also utilized values obtained at greater depths by Lian et al. (2002). K contents are from atomic absorption analyses, Th contents are from neutron activation analyses, U contents are from delayed neutron analyses. Rb contents were approximately 25 µg·g⁻¹. The effective dose rate from alpha particles emitted by U and Th within the grains was assumed to be 0.08 Gy·ka⁻¹ (following Huntley and Lian 1999). A condition of secular equilibrium is assumed for both the uranium and thorium decay chains.

^aSample field numbers were SAW01-11, -12, -13 and -14, respectively.

^bSample depth beneath the ground surface.

^cAverage of K content of samples collected 30 cm below and above the main sample.

^dWater content = 100% × (mass water)/(dry mineral mass); water contents are for the as-collected samples.

an error would have little effect on the interpretation of results.

Historical Records and Archeological Site Distribution Analysis

Historical texts by early Euro-Canadian explorers and surveyors were reviewed for documentation of land use and aboriginal occupation in the area. In addition, archeological and physiographic data within a 10,000 km² area surrounding the Elbow Sand Hills were compiled and analyzed in a GIS. Physiographic data (shape and attribute files) were obtained from the Geological Atlas of Saskatchewan (Saskatchewan Energy and Mines 2000). Archival archeological data were obtained from the Heritage Resources Unit of Saskatchewan Culture, Youth, and Recreation. The site attributes for these archeological data include the Borden Number (a Canadian archeological grid classification system for approximating site latitude and longitude), geographical coordinates, cultural components, and cultural affiliation. Cultural components are represented by identifiable artifacts, and

cultural affiliations represent specific cultural periods associated with the cultural components (i.e., artifacts).

Several categorization procedures were performed on the data prior to more detailed GIS analysis. First, the archeological site locations were converted to match the geographic framework of the physiographic data (UTM projection NAD83). Second, the physiographic data were classified into five dominant units, consisting of sand dunes, glaciofluvial plains, glaciolacustrine plains, hummocky moraine, and meltwater spillways (the latter being glacial meltwater drainage channels often occupied by "misfit" rivers or streams). Third, each archeological site was temporally categorized according to classification systems by Dyck (1983) and Walker (1992) of precontact cultural complexes and time periods in southern Saskatchewan (Table 4). Each cultural category was assigned a separate database file and converted into point data for further analysis.

Results of the GIS data analysis were statistically tested based on Kvamme's (1990) examination of standard statistical tests applied to GIS in archeological research. Chi-square goodness-of-fit and standardized residual tests

TABLE 3
TOTAL DOSE RATES (\dot{D}_T), EQUIVALENT DOSES (D_E), AND OPTICAL AGES

Laboratory number	\dot{D}_T (Gy/ka) ^a (± 0.08)	D_e (Gy)	Optical ages (a)	
			Uncorrected ^b	Corrected ^c
SFU-O-253	2.29	0.08 \pm 0.10	40 \pm 40	—
SFU-O-254	2.53	0.30 \pm 0.04	119 \pm 16	140 \pm 20
SFU-O-255	2.43	0.48 \pm 0.02	200 \pm 10	235 \pm 15
SFU-O-256	2.40	0.65 \pm 0.03	270 \pm 15	320 \pm 20

Notes: The past water content was assumed to be 4% \pm 1.5% for all samples, based on moisture contents obtained in this study and in Lian et al. (2002).

^aTotal dose rate, \dot{D}_T , is the dose rate due to α , β , and γ radiation and cosmic-ray radiation.

^bOptical ages, before AD 2001, *not* corrected for anomalous fading.

^cOptical ages, before AD 2001, corrected for anomalous fading (Huntley and Lamothe 2001) using a fading rate of 4.40% \pm 0.33%/decade for a dune sand sample (SFU-O-223) collected 3 km to the southwest (Lian et al. 2002; Wolfe et al. 2002). The delay time between irradiation and equivalent dose measurement was 14 days.

were applied to detect relationships present in the distribution of archeological sites with the physiographic units and distance to permanent water resources existing prior to creation of the Lake Diefenbaker reservoir (Evans 2006).

RESULTS

Historical Trends in Dune Activity

The active dune complex in the northern part of the dune field presently occupies an area of approximately 31 hectares (Fig. 4). The rate of dune migration between 1939 and 2004 has been highly variable along the lee side of the dune complex, with some areas migrating eastward, others unchanging, and still others stabilizing. The average lee side migration is about 22 m, or about 0.35 m·a⁻¹. In comparison, the average rate of vegetation encroachment along the stoss side of the dune complex is about 100 m, or about 1.6 m·a⁻¹. Consequently, vegetation encroachment has considerably outpaced dune migration over the last 65 years, and the dune complex has trended toward stabilization.

TABLE 4
CULTURAL CHRONOLOGY OF SOUTHERN SASKATCHEWAN

Time (ka BP)* ¹⁴ C BP Cal BP	Cultural Chronology	
	Cultural periods	Complexes and Projectile-point cultures
0	Historic	<i>Prairie Side-notched</i> <i>Plains Side-notched</i>
1	Late Prehistoric	<i>Besant</i> <i>Avonlea</i>
2		<i>Pelican Lake</i> <i>Sandy Creek</i>
3	Middle Pre-Historic	<i>Oxbow</i> <i>McKean series</i>
4		
5		
6	Early	<i>Mummy Cave series</i>
7		
8	Paleo-indian	<i>Agnostura</i> <i>Cody</i>
9		<i>Alberta</i> <i>Agate Basin & Hell Gap</i>
10		<i>Folsom</i> <i>Clovis</i>
11		
12		
13		
14		

Note: Derived from Dyck (1983) and Walker (1992).
* thousands of years before present.

Examination of aerial photographs and satellite imagery between 1939 and 2004 permits detailed assessment of the rate of stabilization of the dune complex. The area of active sand has declined from about 67 to 31 ha over 65 years, at an average rate of about 0.55 ha·a⁻¹, though the interannual rate of stabilization has varied (Table 5). The dune complex has also separated into several discrete patches of active sand areas (Fig. 4; Table 5).

Figure 5A shows the change in area of active sand with time. The rate of stabilization is extracted from these data using both a linear and an exponential regression model. Assuming a constant rate of stabilization, the dune complex will be fully stabilized by about AD 2060. However, previous studies demonstrate that the rate of stabilization of dune fields in the northern Great Plains is a nonlinear function of time (Wolfe et al. 2000; Hugenholtz and Wolfe 2005b), and that the active area is better represented by a logistic function, the latter portion of which is exponential (Hugenholtz and Wolfe 2005a). This exponential rate expresses the result of competing processes of vegetation colonization (stabilization) and dune migration/reactivation, and predicts long-term persistence of dune activity.

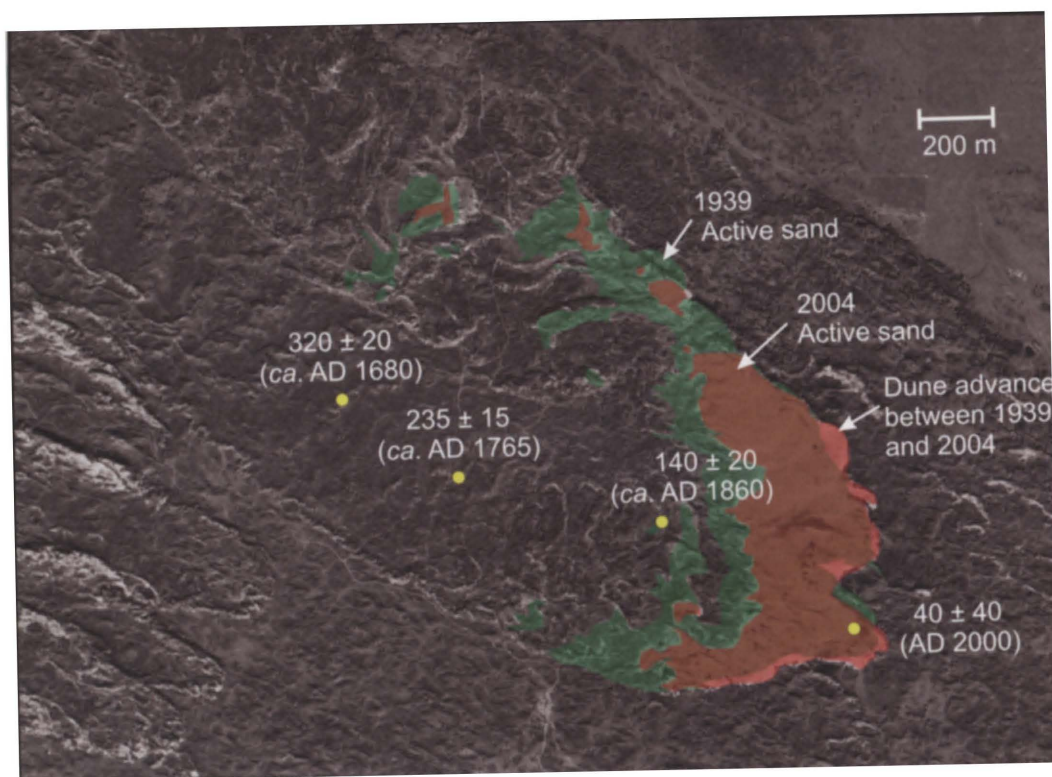


Figure 4. Areas of active sand in 1939 and 2004 at the active dune complex in the northwestern portion of the Elbow Sand Hills. Also shown are optical ages of surface and subsurface samples.

TABLE 5
TOTAL AREA OF ACTIVE SAND (HECTARES),
STABILIZATION RATES, AND PATCH SIZES FOR
YEARS BETWEEN 1939 AND 2004

Year	Area (ha)	Rate (ha/year)	Patch size (>0.5 ha)
1939	66.7	—	2
1944	62.3	0.88	2
1960	50.5	0.74	3
1965	47.9	0.52	4
1970	42.2	1.14	4
1979	40.2	0.22	4
1986	40.0	0.03	4
1996	38.5	0.15	4
2004	31.3	0.90	4

Note: Derived from aerial photographs and satellite imagery.

The best-fit exponential stabilization model (Fig. 5A) is statistically significant ($r^2 = 0.99$, $p \leq 0.001$) and indicates a historical rate of stabilization of about 10% per decade. This model predicts that the dune will remain active, assuming the relevant geomorphic controls remain approximately constant, well after AD 2100, although the amount of active sand remaining will be small (Fig. 5A).

The historical rate of stabilization of the dune complex is comparable to, but less than, the rates for other dune fields on the Canadian prairies that demonstrate more-or-less constant rates of stabilization. In the Brandon Sand Hills, Manitoba, for example, two dune complexes have historically stabilized at rates of approximately 15% and 40% per decade (Hugenholtz and Wolfe 2005a). The greater rates of stabilization in these Manitoba sand dunes are probably due to greater overall moisture (resulting in more vigorous vegetation colonization) and lower overall wind strength (resulting in slower rates of dune migration), than for the Elbow Sand Hills. Figure 5B compares the area of active sand in the Elbow Sand Hills to that in the Brandon (North) dune complex (Hugenholtz and Wolfe 2005a). The Brandon North complex, stabilizing at a rate of about 47% per decade in historical times, demonstrates a persistence, or base level, of dune

activity in more recent decades at a constant base-level of about 10 ha (Fig. 5B). This persistence is the result of small isolated blowouts on dune crests and south-facing slopes that tend to remain active long after the majority of the dune complex has stabilized. For the purposes of estimating the time to reach a base level of dune activity in the Elbow Sand Hills, extrapolation of the historical rate of stabilization leads to an area of about 10 ha by ca. AD 2100 (Fig. 5B). However, the higher aridity and strong wind regime in the Elbow Sand Hills, compared to the Brandon Sand Hills, will probably lead to a larger area of persistent dune activity occurring sooner than AD 2100.

Extrapolating the constant stabilization rates to an earlier time provides an estimate of the former size of the dune complex. The validity of such extrapolation is limited in time to the period during Euro-Canadian settlement. Wolfe et al. (2001) extrapolated the Brandon North dune complex back to an area of about 212 ha in ca. AD 1920 based on the morphology of that dune field (Fig. 5B). Extrapolating the Elbow Sand Hills dune complex back to the early period of Euro-Canadian settlement, ca. AD 1900, indicates that the active dune area may have been about 94 ha, or about 50% larger than the area covered in 1939 (Fig. 5B).

Optical Ages

At each of the three optical-dating sites upwind of the active dune, the soils were orthic regosols characterized by O/A/C horizons. The A-horizons increased in thickness away from the active dune from about 2, to 5, to 10 cm, respectively. Subsurface stratigraphy was most visible at the site nearest the active dune (288 m upwind) and consisted of finely bedded parallel laminations dipping approximately 4° to the west, likely formed by migrating ripples. The other two sections contained predominantly discontinuous subhorizontal structure indicative of vegetation-disturbed sedimentation, and also contained abundant modern roots to a depth of about 60 cm. All of the sands were fine- to medium-grained and well sorted.

The optical ages provide estimates of the timing of past eolian activity. The ages are shown in Figure 4 along with the historically active dune area. The optical age of 140 ± 20 years (ca. AD 1860 \pm 20 years) falls near the limit of historically active sand, indicating that the dune surface was probably active here in historical times. This is a reasonable interpretation, given that the optical sample comes from a depth of about 80 cm below the modern surface. It should be further noted that, because of the infrared/red bleach, the sample age may be too old by about

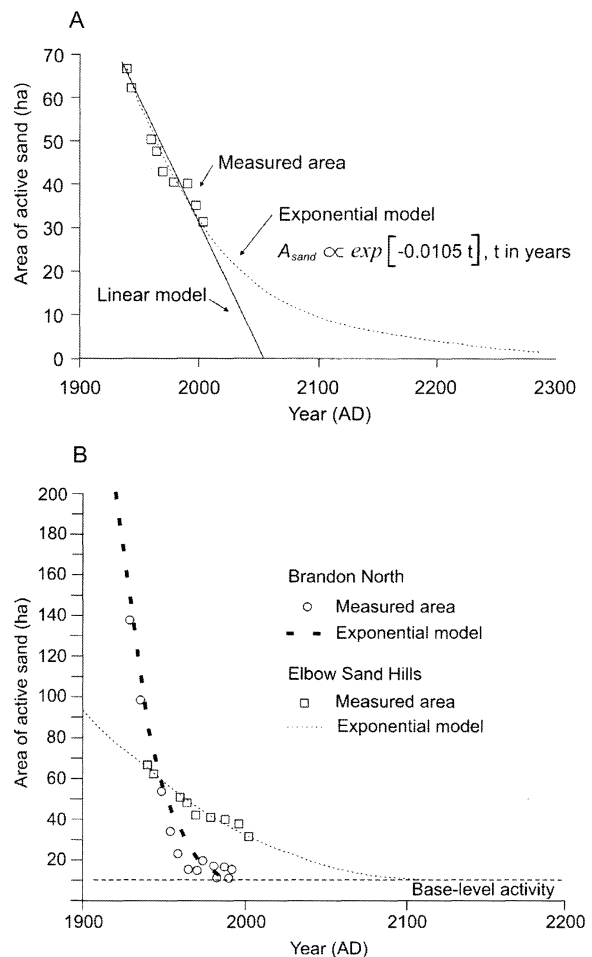


Figure 5. Change in area of active sand in the active dune complex with time. (A) Measured area of active sand from aerial photographs with exponential and linear model projections of future change in area. (B) Comparison of areas of active sand in the active dune complexes at the Elbow and Brandon North sand hills with exponential model projections of past and future activity.

40 years. Thus, the true optical age may be closer in time to that of early Euro-Canadian settlement (ca. AD 1900). The remaining optical ages lie outside the area of historically active dune sand. Nevertheless, they are relatively young, confirming that active sand occurred upwind of the present area in recent precontact times.

Henry Hind's Account of Aboriginal Occupation and Land Use

In 1858, Hind encountered several Cree camps along the Qu'Appelle Valley, including the "main body of the Crees at the Sandy Hills" residing along the northwestern margin of the Elbow Sand Hills. At the time of Hind's encounter, the Cree were in the process of moving their

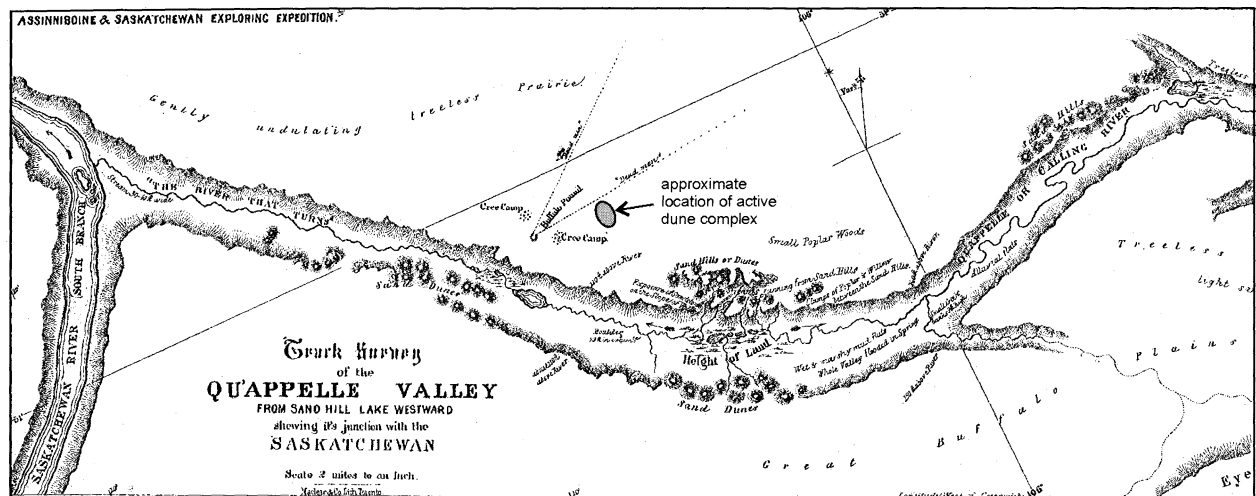


Figure 6. A portion of Henry Hind's survey of the Qu'Appelle Valley showing location of Cree camps and buffalo pound (Hind, 1859). Also shown is the approximate location of the active dune area in the northern part of the Elbow Sand Hills.

camp due to the overpowering odor of decay from a wooden impoundment used for trapping and slaughtering bison. Hind (1859:55-56) provides an account of bison impoundment in the Elbow Sand Hills:

They were about constructing a new pound, having literally filled an old one with buffalo, and being compelled to abandon it on account of the stench which arose from the putrifying bodies. . . .

. . . [T]he Chief's son asked me, through the interpreter, if I would like to see the old buffalo pound, in which they had been entrapping buffalo during the past week. With a ready compliance I accompanied the guide to a little valley between sand hills, through a lane of branches of trees, which are called "dead men" to the gate or trap of the pound. A sight most horrible and disgusting broke upon us as we ascended a sand dune overhanging the little dell in which the pound was built. Within a circular fence 120 feet broad, constructed of trunks of trees, laces with withes together, and braced by outside supports, lay tossed in every conceivable position over two hundred dead buffalo. . . . In all, 240 animals had been killed in the pound, and it was its offensive condition which led . . . [them] to construct a new one.

This was formed in a pretty dell between sand hills, about a half mile from the first, and leading from it in two diverging rows, the

bushes they designate dead men, and which serve to guide the buffalo when at full speed, were arranged. The dead men extended a distance of four miles in the prairie, west of and beyond the Sand Hills. They were placed about 50 feet apart, and between the extremity of the rows might be a distance of from one and a half to two miles.

In addition to this account, Hind includes a survey map of the Qu'Appelle Valley with the location of the Cree camps and buffalo pound (Fig. 6). The camps and pound were located along the margins of the Elbow Sand Hills, about 3 km west of the presently active dune area.

Precontact Culture Affiliations

A total of 387 precontact archeological sites are documented in the study area, the majority of which are surface finds. Ninety-five sites have recognized cultural affiliations, of which 47 are multicomponent sites (i.e., associated with two or more cultural complexes). Only a few detailed archeological investigations on excavation sites have been completed, including the Melhagen site (Ramsey 1991), the Sjøvold site (Dyck and Morlan 1995), site EgNn-9 (Neal 2006), and site EgNo-23 (Webster 2004; Neal 2006). Nevertheless, all cultural complexes occurring in southern Saskatchewan are represented by artifacts found within the study area (Fig. 7). A large number of sites originate from the Late Prehistoric to Middle Middle Prehistoric cultural periods (0.2-5.7 cal

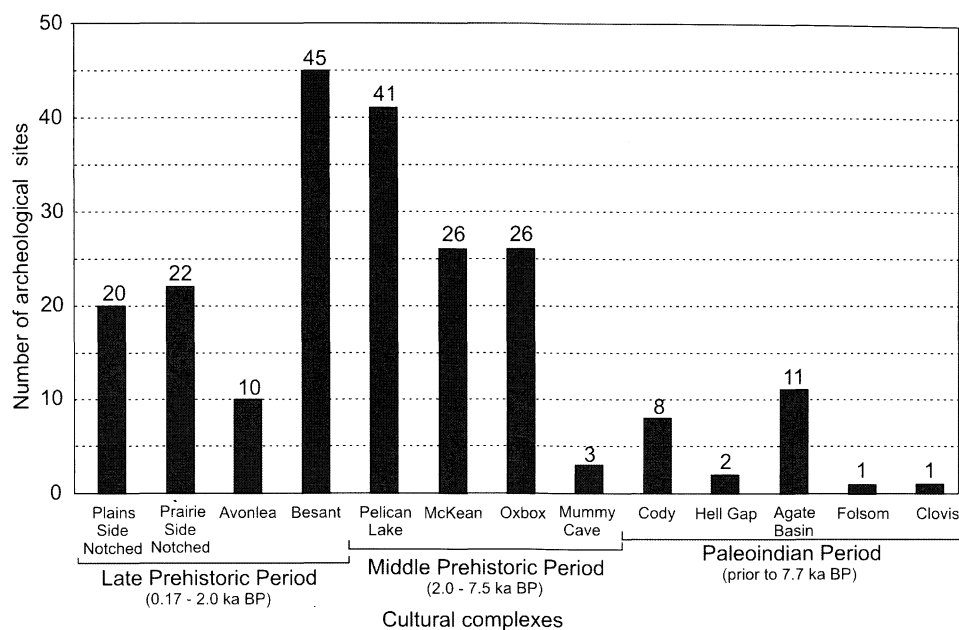


Figure 7. Number of archeological sites affiliated with particular cultural complexes in the Elbow Sand Hills area.

ka BP), with McKean, Pelican Lake, and Besant cultural complexes well represented by artifacts. A small number of sites originate from between the Early Middle Prehistoric to Paleoindian cultural periods (5.7-13.8 cal ka BP), with artifacts from Clovis, Folsom, and Mummy Cave series complexes occurring in small quantities.

Mapping archeological sites in relation to physiography (Fig. 8) reveals several important associations. First, over two-thirds of sites occur within 5 km of permanent water sources, and most are in close proximity to the South Saskatchewan River (Fig. 9). Potential exists for an even greater number of archeological sites within the South Saskatchewan and Qu'Appelle River valleys. A substantial number of sites were inundated by Lake Diefenbaker, prior to extensive archeological surveys and investigations (Himour 1997). Within the study area, 76 archeological sites are submerged by waters stored in the Lake Diefenbaker reservoir. Second, of the total archeological sites, about 25% occur both within meltwater spillways and hummocky moraines, 20% both on sand dunes and glaciolacustrine plains, and 10% on glaciofluvial plains. With the exception of the hummocky moraines, which cover most of the study area (57%), a greater number of sites occur on the remaining physiographic units than statistically expected (Evans 2006). In particular, the quantity of sites occurring on sand dunes is most notable given the comparatively small area occupied by dunes (3.3% of the area).

With respect to archeological sites with known cultural affiliations, most occur within meltwater spillways and sand dunes ($n = 45$ sites in each case), with considerably fewer sites within hummocky moraine, glaciofluvial plains, and glaciolacustrine plains ($n = 20$, 17, and 14 sites, respectively). The standardized residuals of a chi-square test reveal that these differences are statistically significant (at $p \leq 0.001$). This preferential association of archeological sites with meltwater spillways and sand dunes persists throughout the mid- to late Holocene and most of the cultural chronology (Fig. 10). The standardized residual values for each cultural period reveal that meltwater spillways and sand dunes have significant positive values (at $p \leq 0.001$), with significantly greater numbers of archeological sites occurring in these physiographic units than expected (Evans 2006).

The archeological analysis signifies that sand dunes, in close proximity to meltwater spillways and permanent water resources in this area, were a preferred area for Plains aboriginal groups. The availability of fresh water close to the Elbow Sand Hills was noted by Hind (1859:55), as "springs and small streams, a foot or two broad, issuing from the Sandy Hills". The known archeological sites within and immediately surrounding the Elbow Sand Hills include several precontact bison kill sites and camp-sites. The Melhagen site (Fig. 8) is a Besant bison kill site, dating to about 1,900 years BP, and has evidence of multiple kill events (Ramsey 1991). Similarly, site EgNo-

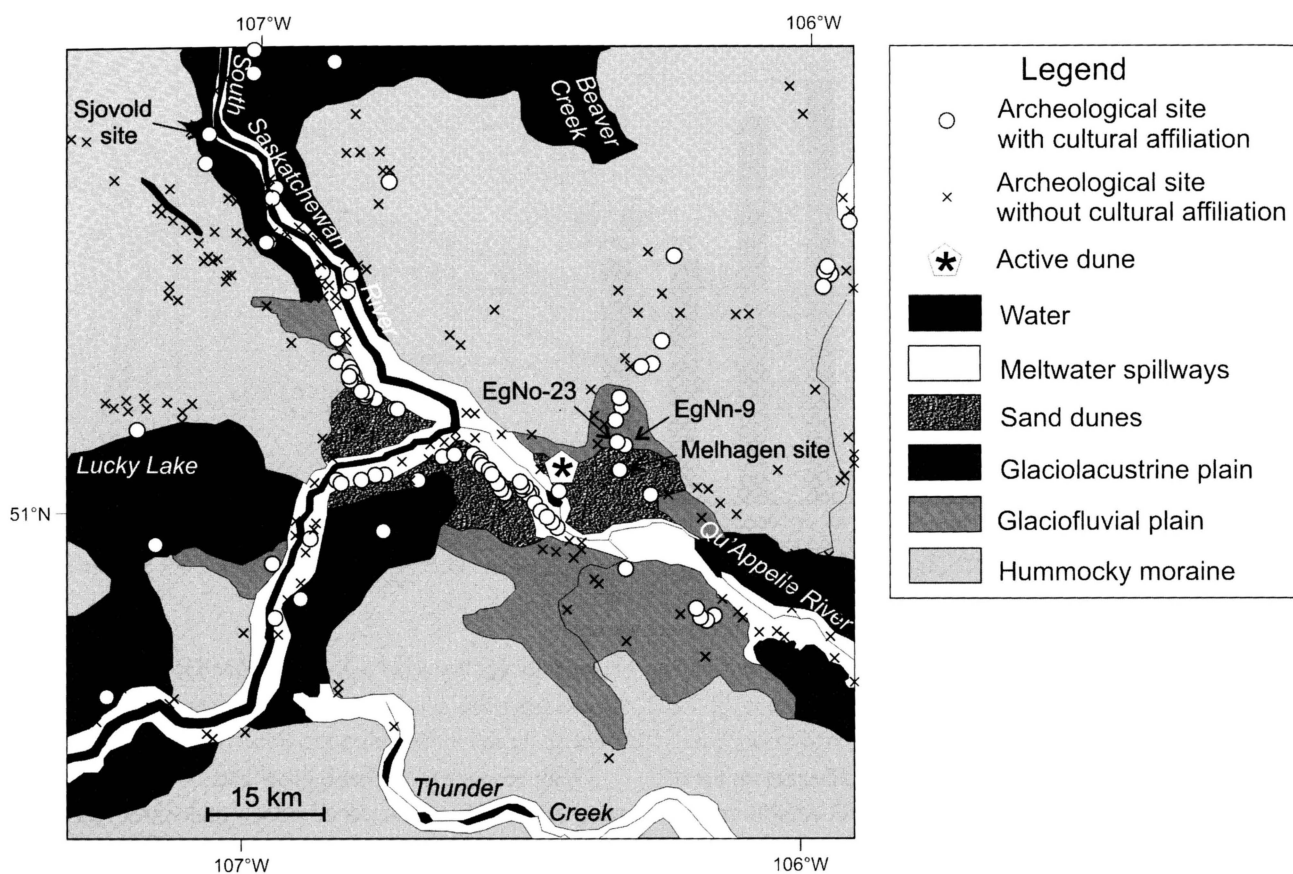


Figure 8. Map of archeological sites with selected cultural affiliations in relation to different physiographic units and configuration of rivers prior to damming of South Saskatchewan River and formation of Lake Diefenbaker. Location of active dune area in the Elbow Sand Hills is also shown.

23 (Fig. 5) depicts a McKean complex camp and bison kill site with artifacts dating from the past 5,000 years; also represented at the site are Oxbow, Besant, Avonlea, and Plains Side-Notched Cultural Complexes (Webster 2004). EgNn-9 is a multicomponent Besant and Pelican Lake campsite (Neal 2006). Several other suspected bison kill and campsites are recorded within the Saskatchewan Archaeological Resource Record but have not been investigated in significant detail. These archeological sites indicate that not only were sand dunes a preferred area for habitation, but aboriginal groups utilized the dunes for procurement of resources including bison.

DISCUSSION AND CONCLUSIONS

The distribution of archeological sites illustrates the affinity local aboriginal groups had for the sand dunes in the Elbow Sand Hills. Similar results have been reported for the nearby Lauder Sand Hills in southwestern Manitoba (Running et al. 2002), the Great Sand Hills in

southwestern Saskatchewan (Epp and Johnson 1980), and the Harris Sand Hills in west-central Saskatchewan (Epp 1986). The working hypothesis is that geomorphically complex terrain and topographic relief (both characteristics synonymous with dune fields) result in a landscape of greater ecological heterogeneity and complexity (Swanson et al. 1992). These ecologically diverse landscapes, characterized by a mosaic of microhabitats, are endowed with a wide range of resources useful to support aboriginal populations (Running et al. 2002). In the Elbow Sand Hills, these ecological communities include aspen woodlands, grasslands, and wetlands.

Access to potable water resources provided essential elements for Plains aboriginal occupation (Walker 1992). Sufficient water occurs in the Elbow Sand Hills as a result of highly permeable eolian sediment, with a semi-impermeable substrate promoting the development of high and stable groundwater aquifers (Saskatchewan Museum of Natural History 1973). Seepage springs contributed sources of fresh water, along with riparian woodlands,

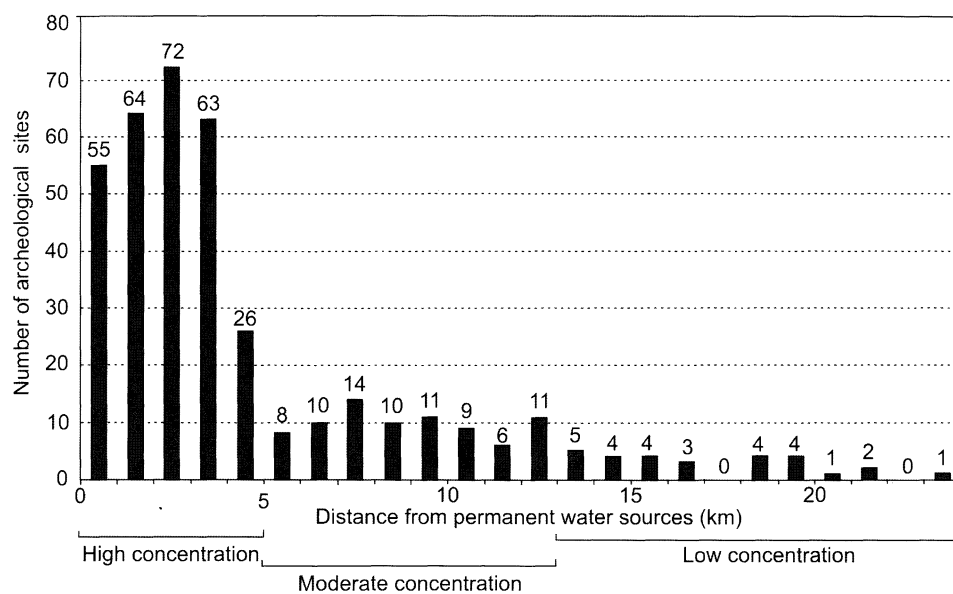


Figure 9. Distribution of the total number of archeological sites with distance from surface water in the study area.

wetlands and lakes in the adjacent Qu’Appelle River valley. The proximity to the Qu’Appelle and Saskatchewan river valleys were probably also beneficial for Plains aboriginal groups utilizing these as natural corridors for movement.

Activities of aboriginal cultural groups within and surrounding the Elbow Sand Hills may have caused sufficient disturbance, by means of tree cutting, trampling (from the driving of large bison herds into traps), and fire, to initiate or perpetuate sand dune activity along the margins. It has been suggested that fire disturbance was frequent and purposely used in dune fields on the northern Great Plains (e.g., Boyd 2002). Examining paleoecological data within eolian sediments, Boyd (2002) found evidence of an apparent peak in fire frequency shortly after 2,500 ¹⁴C years BP in the Lauder Sand Hills. This peak was attributed to deliberate burning of the prairie by aboriginal farmers and hunter-gatherers. Fire was used strategically “to turn the buffalo” (Hind 1859:52) in the immediate vicinity of the Elbow Sand Hills. As well, extensive use of the dunes by aboriginal groups for campsites close to kill and processing sites probably caused a reduction in vegetation cover in the dunes and greater susceptibility to erosion.

From Hind’s account, it is clear that aboriginal groups utilized the sand hills for timber resources in the construction of bison pounds. This preference has also been noted in other sand hills areas from archeological

evidence in southern Saskatchewan (Linnamae 1988; Hjernstad 1996). The margins of the sand hills were likely preferred locations for bison kill sites because these provided natural topographic traps for empoundments, abundant timber resources for the construction of pounds and drive lanes, and a transition to the prairie grasslands where bison herds were abundant. Aboriginal groups may also have preferred the sand dunes for habitation sites, as evidenced by Hind’s account as well as archeological investigations in other surrounding sand hills areas, including the Grandora site in the Dunfermline Sand Hills (Dyck 1972) and the Harder and Moon Lake sites in the Pike Lake Sand Hills (Dyck 1970).

The construction of a single pound required a significant number of trees, though the exact amount is difficult to estimate. Based on Hind’s estimate of the diameter of the bison pound (120 feet), and assuming a log (*Populus tremuloides*) diameter of about 7 inches (Linnamae 1988), it is thought that a single pound required in excess of 100 (and possibly up to 600) logs for an enclosure (circumference of 375 feet with a single opening of about 20 feet), depending on the spacing of the logs. Branches and brush were also used to secure the logs and to construct the “dead men” (two rows of brush piles at 50-foot intervals and extending up to two miles from the pound). Timber would also have been procured locally for shelter, fire, and construction materials.

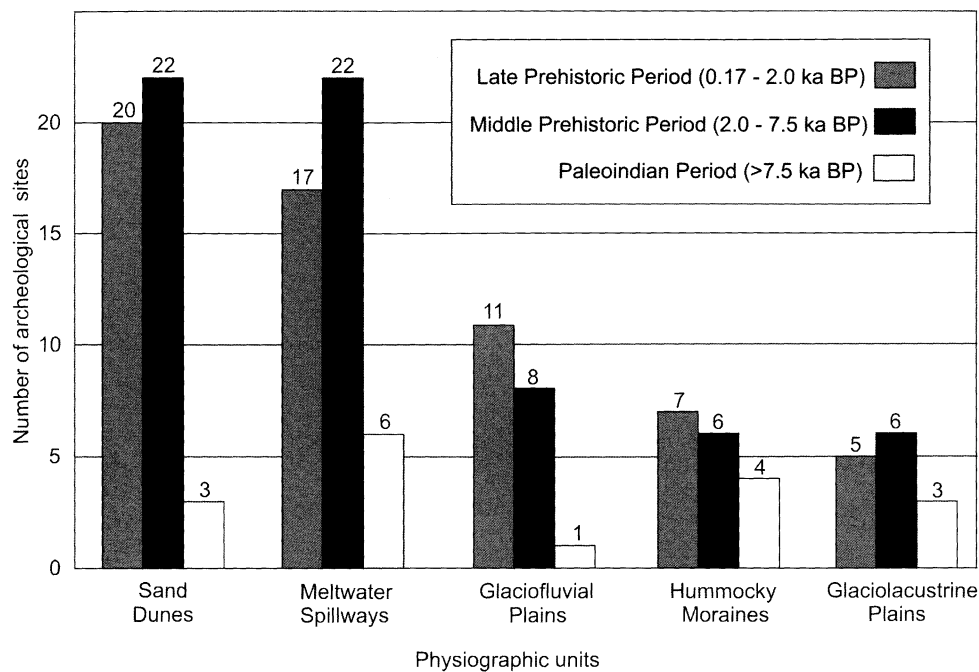


Figure 10. Number of archeological sites in different cultural periods associated with various physiographic units.

The net effect of the timber utilization along the margins of the sand hills would have been localized clearing of trees and brush. The sand hills margins were potentially further subjected to intensive trampling by people, in the procurement of timber and other resources, and by bison, which occasionally escaped en masse from the pounds (Hind 1859). Fire probably had a significant impact along the margins of the sand hills, whether intentional or inadvertent.

Comparison of recent aerial photographs to the first Dominion Land Surveys indicate that the wooded margins of the Elbow Sand Hills are in a similar position today as they were in 1883 (Thorpe and Godwin 1992). A noted exception is along the northwestern periphery of the sand hills, where the area was mapped as undulating prairie in 1883, but has subsequently become more wooded. The comparison of aerial photographs between 1939 and present indicate recent expansion of tree cover in the northwestern part of the sand hills. If aboriginal groups cut or burnt the woodland, then the observed expansion may be a return to former positions along the sand hills margin. Thorpe and Godwin (1992) further note that throughout the Elbow Sand Hills, aspen stands presently appear to be "overmature," as signified by the common presence of standing and fallen dead trees. The general overmaturity of aspen in the sand hills suggests a

uniformity of age and indicates that the area has not been affected by fire or tree cutting for at least 70 to 80 years.

Trend analysis of aerial photographs and satellite imagery (1939-2004) indicates that dune stabilization has far outpaced dune migration and reactivation in historical times, and that the dune may be nearly stabilized by the end of this century. Back-calculations signify that the active area was about three times larger at the time of early Euro-Canadian settlement than it is today. This is further supported by early explorer accounts of greater activity in the mid-19th century (Hind 1859). Optical ages also indicate that active sand occurred upwind of the present dune complex in the relatively recent past. As with the increase in woodland cover and the overmaturity of aspen stands in the sand hills, the trend of dune stabilization in historic times may be attributed in part to reduced disturbance following Euro-Canadian settlement in the region.

The active dune complex in the Elbow Sand Hills was not activated by drought in the 1930s, and was probably more active prior to this period. Other dune areas in the northern Great Plains have similarly been shown to be active prior to the 1930s, including the Brandon Sand Hills, Manitoba, and several dune areas in southwestern Saskatchewan (David et al. 1999; Wolfe et al. 1995, 2000). In the Great Sand Hills, Saskatchewan, Wolfe et al. (2001) suggest that drought in the 1700s may have been severe

enough to have caused widespread dune activity, and that dunes in that area have been recovering historically from that event. Hugenholz and Wolfe (2005a) have further shown that dune stabilization rates (including the Elbow Sand Hills) are broadly related to decadal-scale changes in aridity, but because only part of the variability is explained by aridity, the regional historical decline in dune activity may be largely a response to recent climate variations superimposed on a longer-term trend toward stabilization, possibly in place since the late 1700s. In these cases, the effects of the 1930s drought may have been to briefly slow the rate of dune stabilization, thereby prolonging the period of activity (Hugenholz and Wolfe 2005b). Thus, as with the Great Sand Hills (Wolfe et al. 2001), it is possible that drought during the precontact period contributed to an increased potential for dune activity. The optimal condition for increasing and prolonged dune activity would be met if anthropogenic disturbance and drought occurred contemporaneously.

The integration of the archeological and geomorphological evidence presented lends support to the hypothesis that anthropogenic disturbance, through aboriginal occupation patterns up until the late 19th century, perpetuated dune activity in the Elbow Sand Hills. Therefore, past levels of dune activity may not reflect climate forcing exclusively. It is further notable that, because of the glaciofluvial origin of most sand dunes on the northern Great Plains, many dune fields occur in close proximity to major river systems. Consequently, the potential for past aboriginal-disturbance-induced dune activity is high in other areas such as the Brandon and Lauder Sand Hills, Manitoba, the Pike Lake and Dundurn Sand Hills, Saskatchewan, and the Middle Sand Hills, Alberta (Fig. 2B).

Periods of increased bison procurement activities had the potential for increased amounts of disturbance in sand dunes. The Late Prehistoric period (1.9-0.2 cal ka BP) was a cultural period characterized by increases in bison procurement activities on the northern Plains, particularly with the Besant cultural complex (1.9-1.0 cal ka BP). Frison (1978) argues that the Besant complex represents a climax in bison procurement strategies in the Plains, based on the discovery of a number of very large-scale communal bison kill and processing sites. It has been further suggested that during the Late Prehistoric period up to the 19th century, groups occupied sites adjacent to these large-scale bison kill and processing sites for extended intervals (up to several months) in very large groups (in the order of up to 3,000 individuals) (Arthur 1975; Walde 2006). In comparison, eolian chronology in

the southern Canadian prairies reveals intermittent dune activity in the late Holocene, after about 3.5 cal ka BP, with successive activity partially reworking underlying sediments (Wolfe et al. 2002). In addition, notable increases in dune activity are recorded throughout the prairies within the last 260 years, which have previously been attributed primarily to drought (Wolfe et al. 2001, 2002). However, periods of intensive bison procurement and extensive site occupation could significantly contribute to disturbance and increased eolian activity in dune fields.

This raises issues about paleoclimatological interpretations of geochronological records of dune activity and stability, because climate may not be the sole driver of past activity levels. In fact, many studies from the Great Plains demonstrate some regional disagreement with respect to the timing of major episodes of dune activity and soil formation, particularly in the last 5,000 years (Forman et al. 2001:20). Lepper and Scott (2005) suggest that the regional disparities reflect environmental or climatic "noise." Though they do not define the term, we suggest that one form of this so-called noise may be anthropogenic disturbance (Hugenholz and Wolfe 2005b), which reactivates dunes and/or perpetuates their mobility. Forman et al. (2001) recognized that widespread irrigation, the lack of open rangeland affected by bison herds, and the suppression of fires reduce landscape disturbance factors necessary to reactivate dunes under present climate conditions. Correspondingly, reduced disturbance in modern times may explain why most dunes across the northern Great Plains have trended rapidly toward stabilization since the early 1900s (Hugenholz and Wolfe 2005a).

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