GEOARCHAEOLOGY OF THE ELBOW SAND HILLS, SOUTH-CENTRAL SASKATCHEWAN

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By

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ABSTRACT

The Elbow Sand Hills and the adjacent South Saskatchewan and Qu'Appelle River valleys in south-central Saskatchewan have long been recognized as the locus of extensive precontact Plains cultural settlement throughout the post-glacial period. The objectives of this geoarchaeological investigation are to identify the extent to which 1) Holocene environmental changes and landscape evolution impacted precontact settlement patterns and archaeological site preservation and visibility, and 2) to investigate the relationship between archaeological site location and the environmental elements on a Northern Plains landscape using a Geographical Information System (GIS). The lithostratigraphic record suggests that this region experienced significant Holocene climatic changes with repetitive alternations between arid and humid climatic conditions over the past 5,000 years. Holocene climatic conditions influenced settlement patterns as indicated by extensive occupations of the study area, particularly in the aeolian sand dunes, during prolonged humid climatic intervals that are recorded by paleosols. Precontact cultural groups departed the Elbow Sand Hills and the adjacent uplands for the nearby South Saskatchewan and Qu'Appelle River spillways during extended arid climatic intervals characterized by aeolian activity and sand dune development.

GIS analyses reveal that precontact cultural settlement patterns were focused on certain environmental characteristics according archaeological site distribution. Precontact cultural groups apparently concentrated their settlement activities within the glacial meltwater spillways and aeolian sand dunes, which are topographically complex and situated in close proximity to water resources where natural resources were abundant and diverse. The glaciofluvial plains and glaciolacustrine plains are topographically subdued landforms, and along with the hummocky moraine, are distal to permanent water

resources. These landforms are characterized by a lower intensity of occupation because of a consequence of lower resource availability and diversity. Archaeological site visibility and preservation varies within the region with the hummocky moraine and glaciolacustrine plains displaying the greatest degree of site visibility and preservation. The aeolian sand dunes, meltwater spillways, and glaciofluvial plains were physiographic elements that exhibit the lowest site visibility and preservation potential. These landforms were more strongly influenced by post-glacial climatic conditions, geomorphic processes, and the recent formation of the Lake Diefenbaker reservoir.

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CHAPTER 1
INTRODUCTION

1.1 Statement of Problem

Geoarchaeology is the application of earth sciences concepts and methods in archaeological research (Waters 1992). The contribution of the earth sciences to archaeological investigations involves the integration of geomorphology, stratigraphy, sedimentology, pedology, geochronology, and geomatics with more traditional approaches of the study of cultural artifacts and features. This multi-disciplinary approach is fundamental to determining the temporal contexts of archaeological sites and their contents, understanding site formation processes, and reconstructing paleolandscapes during intervals of precontact cultural settlement (Renfrew 1976).

As a discipline, geoarchaeology has been pursued actively and comprehensively in archaeological research in the Middle East, the United States, and Europe for the past several decades. Until recently, archaeological research in the Canadian Plains was anthropological in orientation, focusing on cultural history, cultural evolution, and cultural processes (Artz 2000). There has been an increasing amount of collaboration between archaeologists and earth scientists during the past decade and the integration of geoarchaeology in archaeological investigations across the region (e.g., Walker 1992; Dyck and Morlan 1995). The quantity of completed geoarchaeological research undertaken in Saskatchewan is presently limited. However, the recently completed Study of Cultural Adaptations within the Prairies Ecozone (SCAPE), with research sites situated across the southern portions of all three prairie provinces (e.g., Robertson 2002; Boyd *et* *al.* 2003; Klassen 2004; Oetelaar 2004; Roskowski 2004; Havholm and Running 2005), has advanced our understanding of human-environment interactions in this region throughout the Holocene. The majority of geoarchaeological studies are aimed at comprehending precontact cultural settlement patterns and the preservation of archaeological artifacts in alluvial depositional environments (e.g., Robertson 2002; Klassen 2004; Oetelaar 2004; Roskowski 2004) and hillslope depositional environments (e.g., Rutherford 2004). In contrast, comparatively little geoarchaeological research has been undertaken in aeolian depositional environments on the Canadian Plains. The only published geoarchaeological research within aeolian sand dune environments is situated in the Lauder Sand Hills of southwestern Manitoba (Boyd 2000; Boyd *et al.* 2003; Havholm and Running 2005).

Aeolian sand dune landscapes in the Canadian Plains have long been recognized by archaeologists as the locus of extensive occupation by an array of precontact Plains cultural groups. Records of cultures occupying these landscapes are preserved at a number of significant archaeological sites in southern Saskatchewan. These sites include the Melhagen site in the Elbow Sand Hills (Ramsey 1991), the Fitzgerald site in the Dundurn Sand Hills (Hjermstad 1996), as well as the Tschetter site (Linnamae 1988) and the Harder site (Dyck 1970) in the Dunfermline Sand Hills. During historic times, early exploratory expeditions to the prairies (e.g., Hind 1860) have documented extensive precontact human activity in the Elbow Sand Hills in their journals.

Aeolian sand dune landforms, which are scattered across the prairie landscape, are highly sensitive to climate variability and change (Wolfe 1997). Studies on aeolian activity in Elbow Sand Hills (Wolfe *et al.* 2002a) and other surrounding sand dune complexes in southern Saskatchewan reveal repetitive, cyclic episodes of severe aridity throughout the Holocene, which promoted vegetation cover reduction, sand dune activity, and mobility. These arid intervals were frequently interrupted by cooler and moister climatic conditions that contributed to the establishment of vegetation, sand dune stability, and soil development. Fluctuating Holocene environmental conditions had a considerable influence on the distribution and nature of precontact cultural settlement on the prairie landscape of south-central Saskatchewan.

The study area for this project is situated in proximity to a region of substantial precontact human activity as evidenced by the quantity and variety of cultural artifacts and features recovered by archaeologists. Walker (1992) proposed that precontact peoples utilized the large river valleys as primary locations for their settlements as well as major corridors for migration on the Canadian Plains. The close proximity of the South Saskatchewan and Qu'Appelle River valleys to the Elbow Sand Hills permitted a diversity of precontact cultural groups to travel along these corridors and settle in the resource rich landscape in proximity to the Elbow Sand Hills. These hunter and gatherer groups extensively occupied the valleys but frequently moved out of the valleys and onto the surrounding uplands, particularly into the sand dunes, for short periods to procure the available natural resources there. These settlement patterns are recorded by several archaeological inventories and systematic excavations in the region (e.g., Ramsey 1991; Dyck and Morlan 1995; Himour 1997; Webster 2004; Neal 2006). The aeolian sand dune landscape, which is sensitive to environmental changes, provides a proxy environmental indicator of Holocene climates preserved in the sequence of aeolian sand deposits and intercalated paleosols. Comprehension of Holocene environmental conditions is critical to developing our understanding of cultural settlement patterns in the sand hills.

1.2 Objectives of Study

The present study is guided by two primary research objectives. The first objective is to examine the extent to which Holocene environmental changes and landscape evolution influenced precontact cultural settlement patterns and the preservation of sites and their cultural contents in the Elbow Sand Hills. This study incorporates an integrated investigation of the geomorphology, stratigraphy, sedimentology, and chronology of post-glacial sediments of the Elbow Sand Hills and the adjacent terrain. The second objective is to investigate the relationship between archaeological site location and environmental elements of the landscape surrounding the Elbow Sand Hills and the South Saskatchewan River and Qu'Appelle River valleys. This encompasses the application of a Geographical Information System (GIS) to examine the nature of the spatial and temporal distribution of archaeological sites in relation to the physiographic, hydrologic, and topographic elements of the prairie landscape.

CHAPTER 2
STUDY AREA

2.1 Location

The present study's focus is the examination of the terrain in the vicinity of archaeological site EgNo-23, which is situated at 51°20'15"N, 106°05'50"W in the centre of the study area, approximately 16 km east of the village of Elbow and 160 km south of the city of Saskatoon in south-central Saskatchewan (Fig. 2.1). The study area encompasses a 10 km radius from the EgNo-23 site comprising 400 km^2 in total (Fig. 2.2). The study area incorporates a large portion of the Elbow Sand Hills on the eastern shores of the Gordon McKenzie Arm on Lake Diefenbaker.

The study area is situated on the Saskatchewan Plain of the southern Interior Plains in western Canada. The Saskatchewan Plain is bounded by the Canadian Shield to the north, the Manitoba Plain to the east, the Alberta Plain to the west, and the United States border to the south (Klassen 1989) (Fig. 2.3). The southern Interior Plains generally slopes towards the east and north-east. The Saskatchewan Plain lies between 400 and 800 m above sea level (a.s.l.), and contains several upland areas such as the Touchwood and Allan Hills as well as Moose Mountain (Klassen 1989). Elevations within the study area range from 620 m a.s.l. in the northwest corner to 550 m a.s.l. in the southwest corner by the Lake Diefenbaker reservoir shoreline.

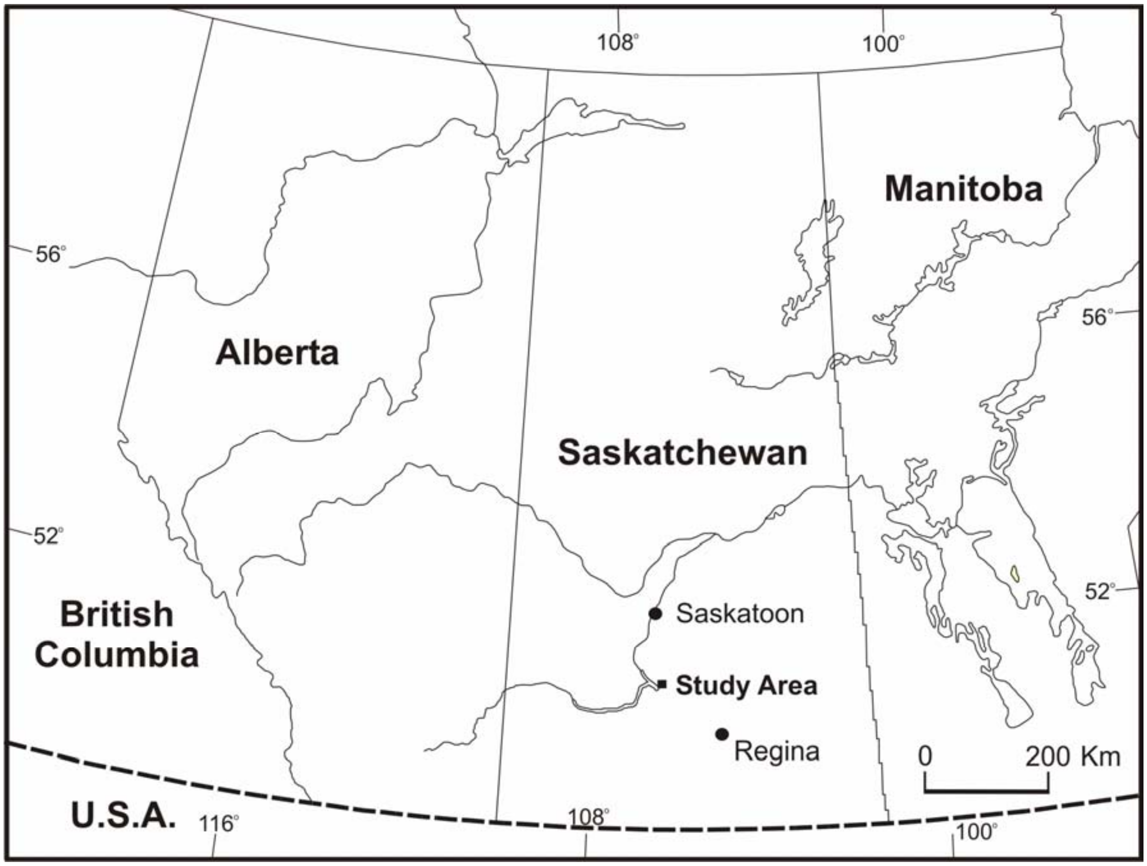


Fig. 2.1. Location of the study area in south-central Saskatchewan.

2.2 EgNo-23 Archaeological Site

EgNo-23 is a large multi-component archaeological site, located approximately 1 km north of the Elbow Sand Hills, with recorded evidence of several precontact cultural occupations spanning the past 5,000 years preserved at the site. Identified cultural remains recovered at the EgNo-23 site originate from the Middle and Late Prehistoric periods, which include materials from the Oxbow, McKean series (McKean, Duncan, and Hanna), Besant, Avonlea, and Plains-Side Notched cultural complexes. The EgNo-23 site was initially detected as a surface scatter in 1986 and buried components were excavated in 1999 and 2001 by archaeologists from Fedirchuk McCullough and Associates

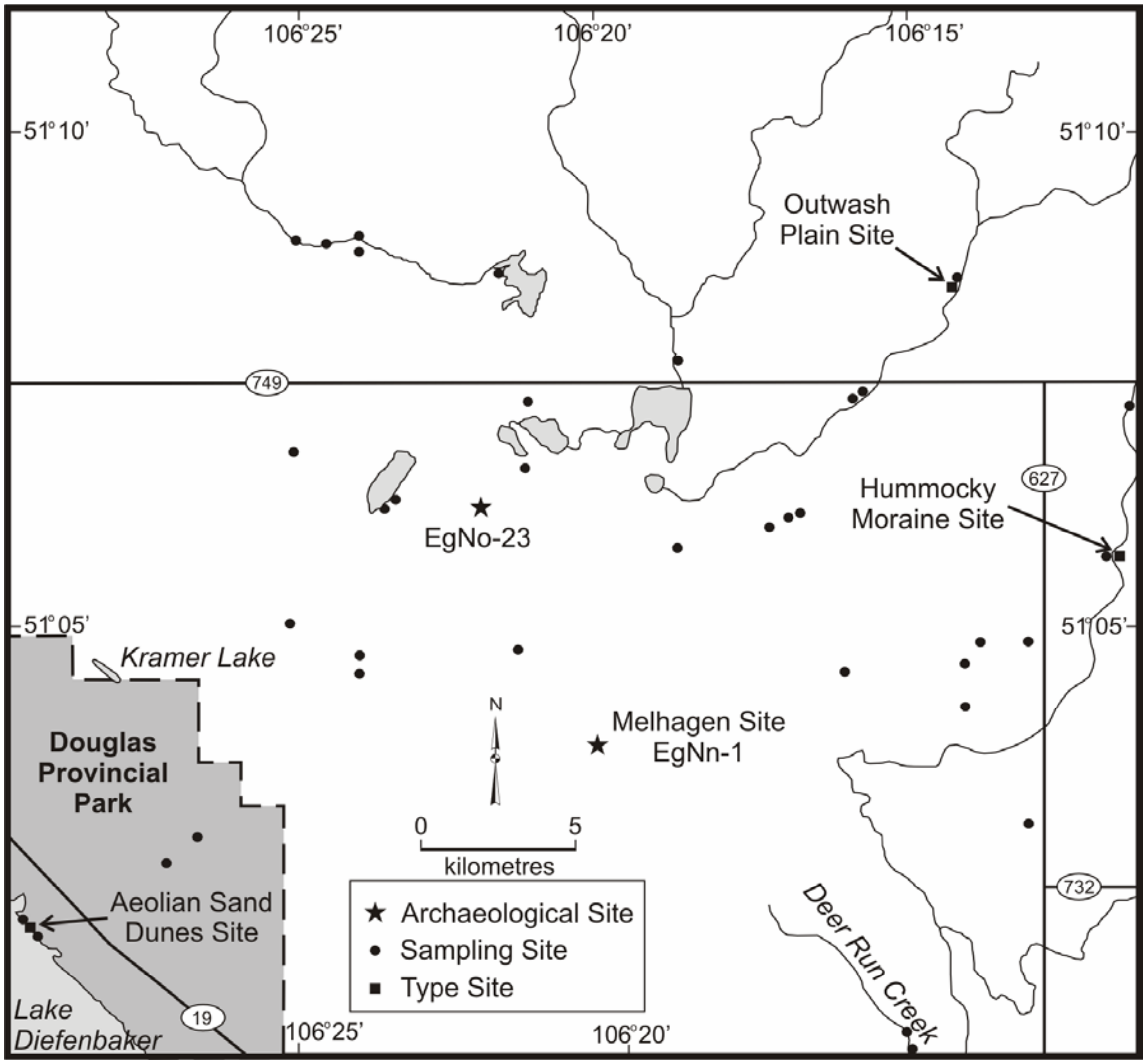


Fig. 2.2. The location of the EgNo-23 site, sampling sites, and the surrounding study area.

Resources Consultants Incorporated and the Department of Archaeology, University of Saskatchewan. During the two years of excavation, a total of 57 m² were investigated yielding 933 lithic artifacts, including 41 formed tools, and 22 expediency tools (FMA Heritage Resources Consultants Inc. 2002). Large quantities of modern Plains bison (*Bison bison*) bone were also collected at the EgNo-23 site with over 4000 specimens analyzed. The bone materials represent the butchering remains associated with a bison kill from two separate kill events (FMA Heritage Resources Consultants Inc. 2002).

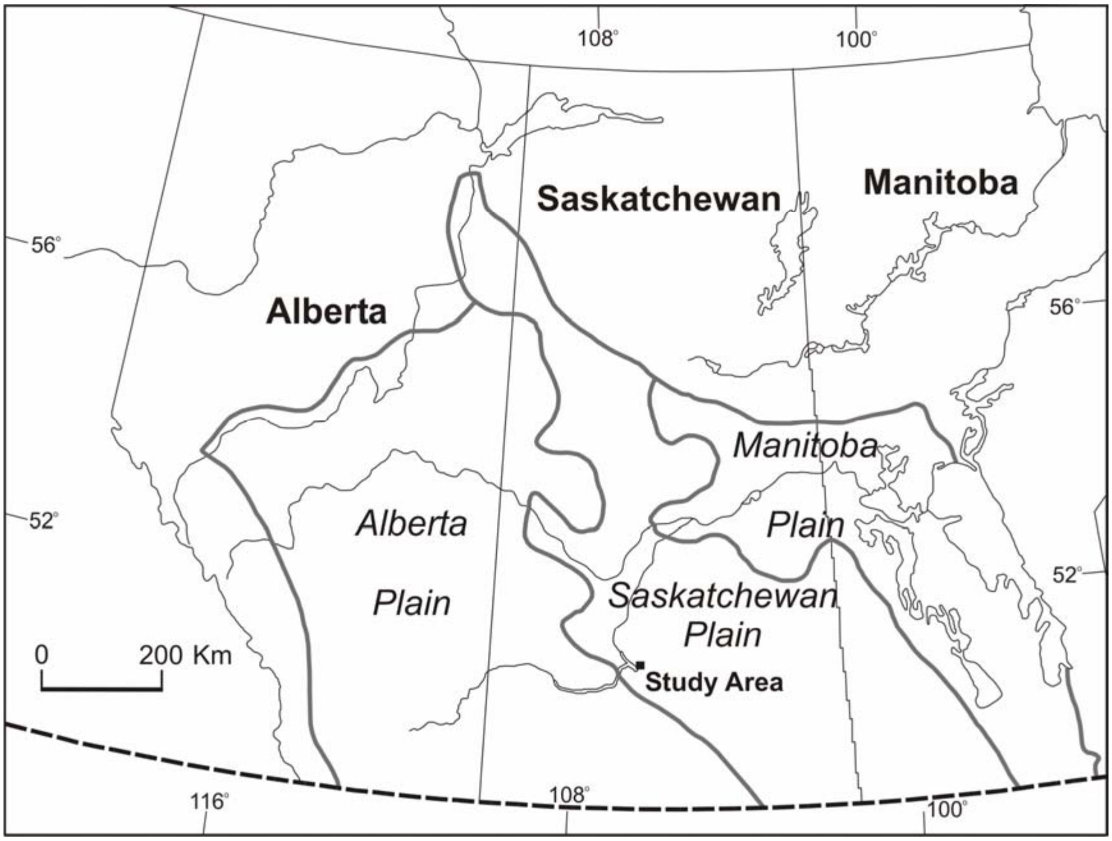


Fig. 2.3. Physiographic elements of the southern Interior Plains in western Canada. Adapted from Klassen (1989).

Archaeologists have interpreted the EgNo-23 site as a camp and bison kill site; it represents the first recognized McKean series bison kill site on the Canadian Plains (Webster 2004).

2.3 Geology

The bedrock geology of southern Saskatchewan is dominated by Cretaceous shales, siltstones, and sandstones, with outcrops of Tertiary siltstones and sandstones found in upland localities of the Touchwood, Bear, and Cypress Hills as well as Moose Mountain (Klassen 1989) (Fig. 2.4). Late Cenozoic drift covers the vast majority of the bedrock in southern Saskatchewan. Drift deposits vary spatially in thickness from 0 m to

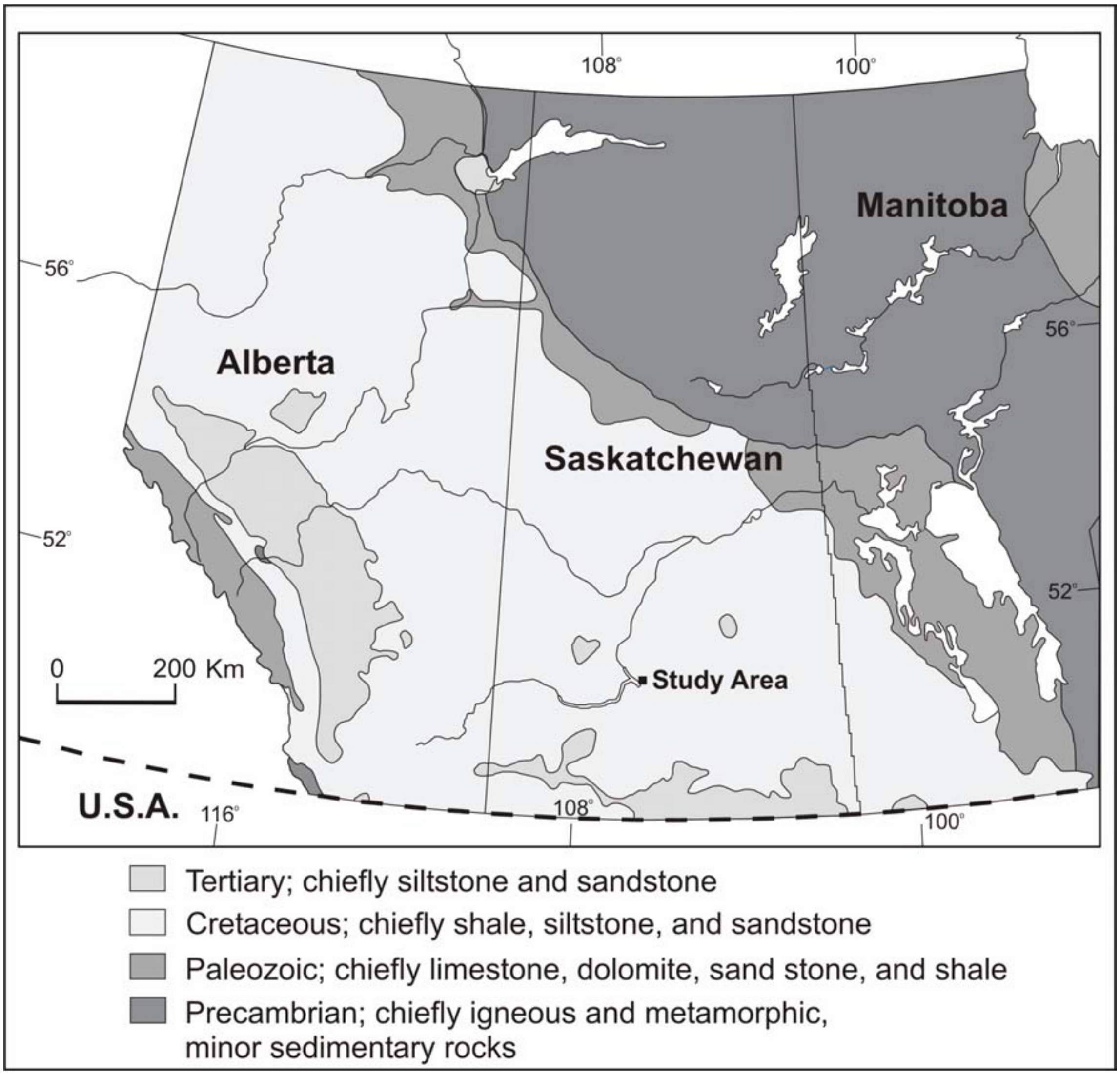


Fig. 2.4**.** Generalized bedrock geology of the southern Interior Plains in western Canada. Adapted from Klassen (1989).

greater than 120 m thick with the study area exhibiting drift thicknesses of less than 30 m (Klassen 1989). The established drift chronology for southern Saskatchewan consists of three primary lithostratigraphic groups: the Empress Group, the Sutherland Group, and the Saskatoon Group (Fig. 2.5). The Empress Group has been determined to date from the Late Tertiary to Early Quaternary and is composed of stratified gravel, sand, silt, and clay deposits of fluvial, lacustrine, and colluvial origins (Whitaker and Christiansen

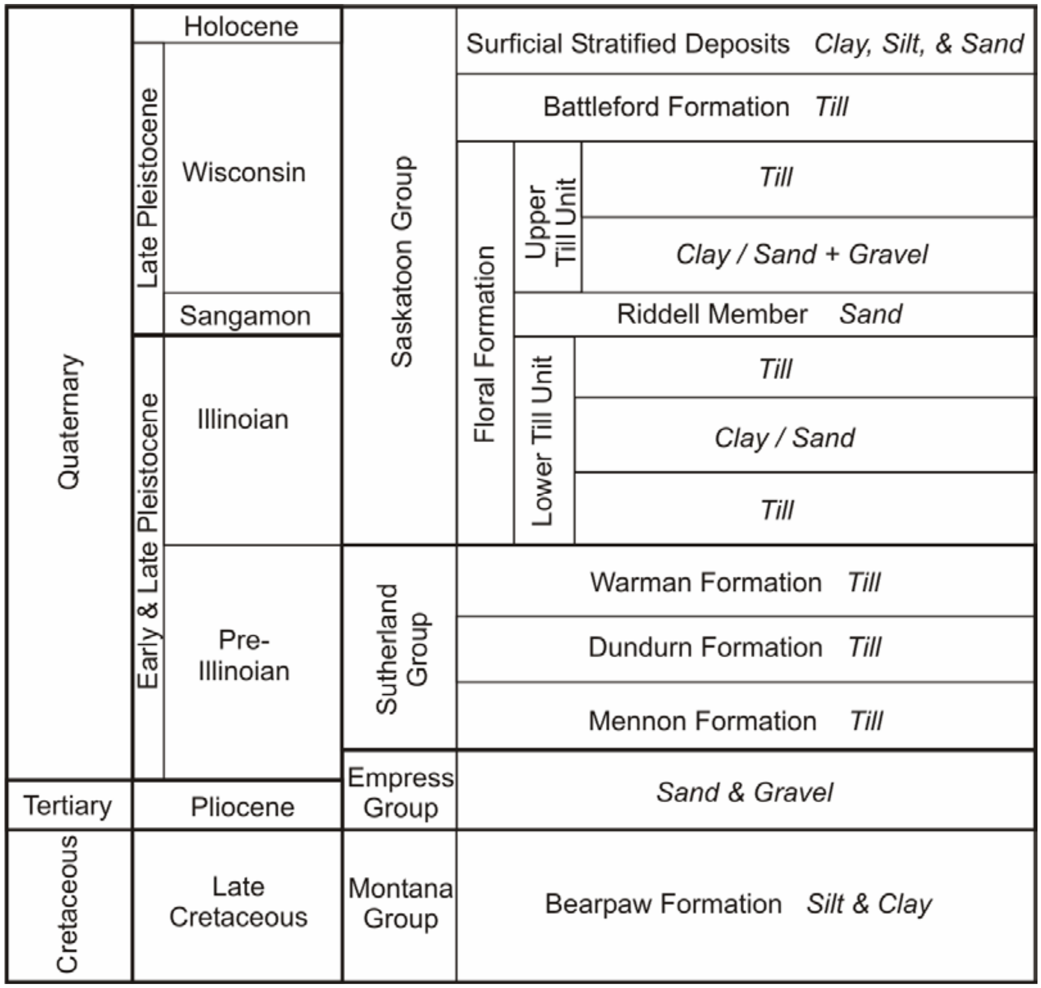


Fig. 2.5. Stratigraphic chart for south-central Saskatchewan. Adapted from Christiansen (1992).

1972). These sediments lie between the bedrock and the overlying Pleistocene glacial tills. The Pleistocene glacial tills consist of the Sutherland Group and the overlying Saskatoon Group. The Saskatoon Group is exposed at the surface within the study area and can be distinguished from the Sutherland Group based on the greater carbonate, calcite, dolomite, and sand contents as well as the lower clay contents (Christiansen 1992).

Surficial geological deposits in southern Saskatchewan comprise an assortment of sediments such as clay, silt, and sand derived from aeolian, alluvial, colluvial, glacial, glaciolacustrine, glaciofluvial, and glaciodeltaic origins. The study area is composed of three distinct surficial geological elements; aeolian sand dunes, an outwash plain, and hummocky moraine (Simpson 1999). The aeolian sand dunes occur within the southern half of the study area, and consist of blowout dunes, circular and parabolic dunes, and a few ridge-sided dunes (David 1977). These sand dunes are predominantly stabilized by vegetation, with the exception of one large, active parabolic dune in Douglas Provincial Park. The outwash plain lies north of the sand dunes and is characterized by level to gently undulating terrain, composed of fine- to coarse-grained glaciofluvial deposits (Scott 1971). The hummocky moraine is situated north of the sand dunes and the outwash plain and is distinguished by an undulating topography with closely spaced hummocks less than 3 m in relief and abundant in non-oriented, undrained depressions (Scott 1971). The grey coloured, massive, sandy glacial till observed in the hummocky moraine was deposited by the Laurentide Ice Sheet ca. 15 to 18 ka BP (Christiansen 1968).

2.4 Modern Climate and Hydrology

South-central Saskatchewan is situated within a semi-arid to sub-humid, continental climate according to Köppen's mid-latitude steppe (BSk) climate classification: short, warm summers (early June to early September) and long, cold winters (late October to early April) characterize this region. Saskatchewan lies in the zone of the westerlies, with weather systems moving in a general west to east direction. Cool, moist Pacific; cold, dry Arctic; and warm, dry continental air masses influence the region's climate (Phillips 1990).

The Tugaske meteorological station (50°53'N, 106°18'W) located approximately 20 km south of the EgNo-23 site is the nearest meteorological station that appropriately represents the modern climatic conditions of the study area. The climate at this station exhibits a mean annual temperature of 9.2°C, with daily mean temperature ranging from -9.9°C in January to 25.5°C in July (Environment Canada 2005). The annual extreme temperature range throughout the entire region varies from winter minimums colder than -40°C to summer maximums over 38°C (Hare and Thomas 1979). Mean annual precipitation recorded at Tugaske is 387.6 mm, divided between 292.1 mm of rain and 95.5 cm of snow (Environment Canada 2005). Evaporation rates throughout the region are high with annual moisture deficits greater than 30 cm/yr (Winter 1989).

The study area is situated along the drainage divide between the South Saskatchewan River and the Qu'Appelle River basins. The active sand dunes within Douglas Provincial Park act as a barrier between the two large drainage basins. Western sections of the study area are part of the South Saskatchewan River basin that drains towards the northeast. Eastern sections of the study area are incorporated within the Qu'Appelle River basin which flows towards the east. The southwest corner of the study area was once formerly part of the Qu'Appelle River valley, but was recently flooded with the creation of the Lake Diefenbaker reservoir. Lake Diefenbaker was formed in 1967 following the construction of the Gardiner and Qu'Appelle dams and inundation of sections of the South Saskatchewan and Qu'Appelle River valleys.

2.5 Modern Soils and Vegetation

Three primary soil orders occur within the study area and the distribution of these soils is influenced by the region's physiography and hydrologic drainage. Well drained, coarse to medium sand textured Orthic Regosols occur in association with the aeolian sand dunes (Ellis *et al*. 1970). Regosolic soils are distinguished by the presence of a thin A horizon overlying the parent material (Saskatchewan Land Resource Centre 1999). In the outwash plain and hummocky moraine, Orthic Dark Brown Chernozermic soils have developed. The Asquith Association dominates the outwash plain and is characterized by very fine sand loam to medium sand textures. The Elstow and Weyburn Associations dominate the hummocky moraine and are characterized as calcareous and loam textured with the presence of surface stones (Ellis *et al.* 1970). Chernozermic soils are recognized by dark-coloured A horizons and brownish-coloured B horizons underlain by light coloured (grayish) horizons with lime carbonate accumulations (Saskatchewan Land Resource Centre 1999). Clay loam textured gleysolic soils occur adjacent to sloughs and coulee bottoms in the outwash plain and hummocky moraine, which are water saturated soils subjected to oxidation and reduction chemical processes (Ellis *et al*.1970).

The study area is located within the moist mixed grassland ecozone of the prairie ecoregion and the vegetation cover is characterized by a mixture of midgrass and shortgrass vegetation communities. Sandy regosolic soils within the aeolian sand dunes have vegetation communities of needle-and-thread (*Stipa comata*), sand reed grass (*Calamovilfa longifolia*), northern wheat grass (*Agropyron dasystachyum*), and western wheat grass (*Agropyron smithii*), as well as forbs such as pasture sage (*Artemisia frigida*), golden-bean (*Thermopsis rhombifolia*), hairy golden aster (*Chrysopsis villosa*), and lance-leaved psoralea (*Psoralea lanceolata*) (Thorpe 1999). Needle-and-thread and blue grama (*Bouteloua gracilis*) are the dominant vegetation within the loamy textured chernozermic soils situated on the outwash plain and hummocky moraine. Woody vegetation communities can be found within the sand dunes, adjacent to prairie potholes (or sloughs), and in small riverine valleys. These communities include shrub species such as chokecherry (*Prunus virginiana*), wolf willow (*Elaeagnus commutate*), Woods' rose (*Rosa woodsii*), and western snowberry (*Symphoricarpos occidentalis*) as well as tree species, in particular trembling aspen (*Populus tremuloides*), and water birch (*Betula occidentalis*) (Thorpe 1999).

CHAPTER 3
LITERATURE REVIEW

3.1 Post-glacial Geomorphology

3.1.1 Deglaciation

The geomorphology of south-central Saskatchewan has been greatly influenced by the Late Pleistocene advance and retreat of the Laurentide Ice Sheet. The stagnation and collapse of the continental ice sheet had a dominant influence on the modern landform assemblages and the timing of human settlement on the Canadian Plains. Christiansen (1979) proposed a model of the nature and chronology of deglaciation in southern Saskatchewan based on the association and radiocarbon age of ice marginal landforms, proglacial lake basins and meltwater spillways, post-glacial drainage patterns and radiocarbon-dated bone, carbonaceous silt, gastropod shells, gyttja, and organic silt and clay sediments (Fig. 3.1). Ice sheet recession, initiated ca. 17 ka BP, was associated with the release of enormous quantities of meltwater and rock debris that supplied an extensive network of proglacial lakes (such as Glacial Lake Saskatchewan, Regina, and Birsay), connected by glacial meltwater spillways (such as the South Saskatchewan River, Qu'Appelle River, and Blackstrap spillways). Kehew and Lord (1986) argue that these ice-contact lakes periodically drained catastrophically with high meltwater discharges through the spillways as marginal barriers of ice or sediment failed, entrenching broad, deep valleys presently occupied by meandering and braided, underfit streams.

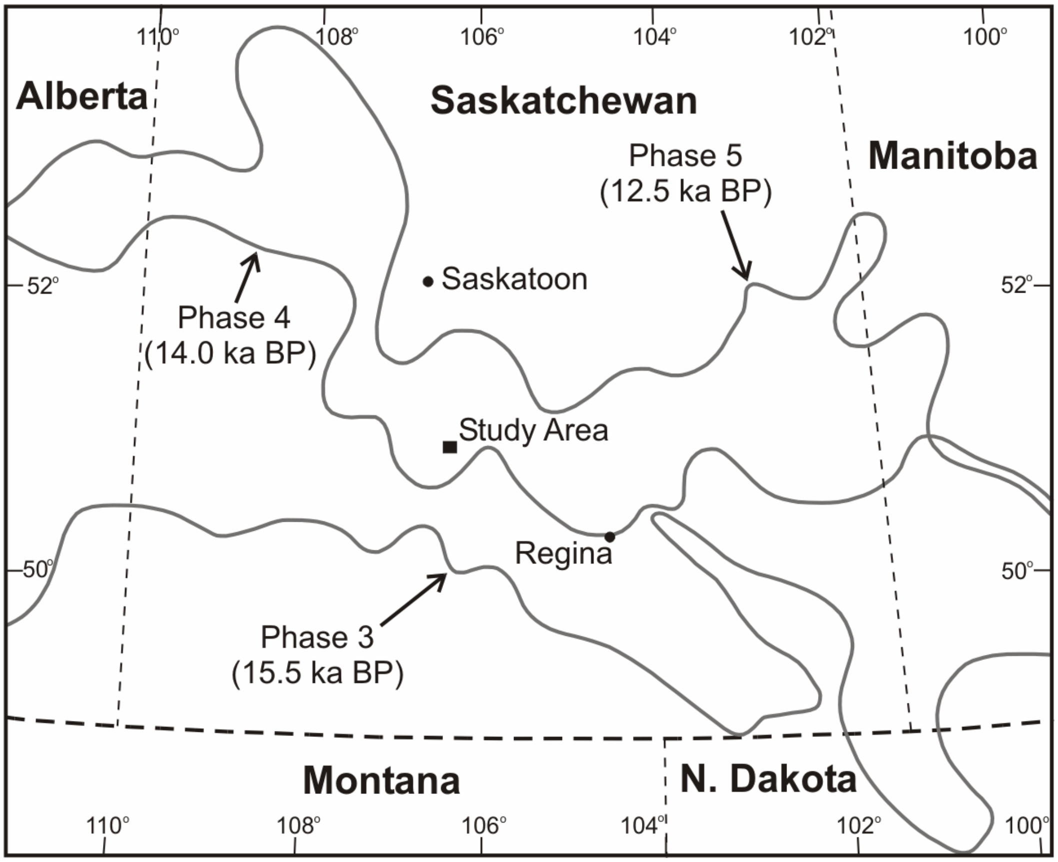


Fig. 3.1. Laurentide Ice Sheet margins between 15.5 and 12.5 ka ^{14}C BP. Adapted from Christiansen (1979).

By ca. 13.0 ka, the ice sheet retreated northeast of the Elbow Sand Hills leaving this area ice-free. Accompanying ice sheet recession, proglacial Lake Birsay inundated the region between 13.0 and 12.0 ka (Kehew and Teller 1994) (Fig. 3.2). As the ice margin retreated further to the northeast, Glacial Lake Birsay drained to the southeast through the Qu'Appelle River spillway towards Glacial Lake Agassiz situated in southern Manitoba.

The early post-glacial environment available for human settlement consisted of a hummocky landscape derived from moranic and aeolian deposits. David (1977) noted that the development of aeolian landforms (such as parabolic dunes, blowout features,

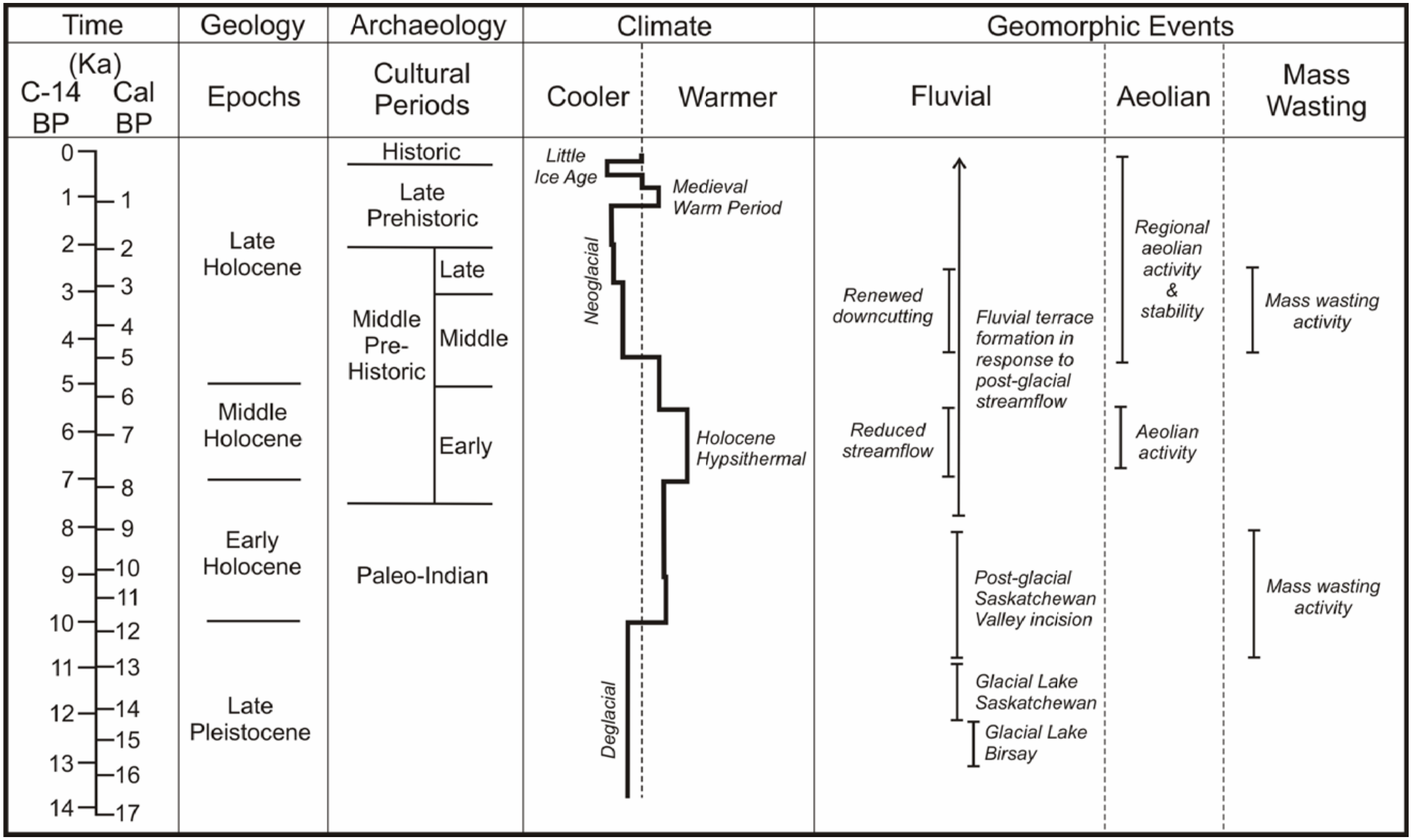


Fig. 3.2. Chronology of post-glacial climatic and geomorphic events in south-central Saskatchewan. Adapted from Walker (1992); Kehew and Teller (1994); Vance *et al.* (1995); Lemmen *et al.* (1998); Lemmen and Vance (1999).

and sand sheets) on the Canadian Plains transpired almost immediately after deglaciation. Aeolian deposits were initially derived from the exposure of fine-grained glaciofluvial, glaciolacustrine, and glaciodeltaic sediments reworked by strong katabatic winds (David 1977; Muhs and Wolfe 1999). The Late Pleistocene and Early Holocene periods were additionally characterized by the initial vertical and lateral incision of the South Saskatchewan and Qu'Appelle Rivers as evidenced by river terrace sequences within the glacial meltwater spillways (Fig. 3.2). Early post-glacial river degradation coincided with an interval of elevated regional groundwater tables fully charged from deglaciation and cool, moist climatic conditions. These environmental conditions were contributors to slope instability promoting extensive mass wasting activity depositing colluvium sediments within the river valleys (Lemmen *et al.* 1998; Lemmen and Vance 1999). Sloughs are also common features throughout this landscape. These features began their history as kettle lakes within hummocky moraine formed as large blocks of stagnant glacial ice were abandoned and subsequently melted in proglacial environments.

3.1.2 Holocene Aeolian Activity

Throughout the Holocene, aeolian landforms on the Canadian Plains experienced repetitive, climatically-induced episodes of re-activation. These periods of aeolian activity coincided with arid climatic intervals of prolong moisture deficits when the local vegetation cover was reduced substantially by drought. Several episodes of Middle and Late Holocene dune activity have been recorded across the Canadian Plains, including the Elbow Sand Hills (Wolfe *et al.* 2002a), as well as surrounding sand dune fields such as the Brandon Sand Hills (Wolfe *et al.* 2000), the Burstall Sand Hills (Wolfe *et al.* 2001), the Duchess Sand Hills (Wolfe *et al.* 2002b), the Dundurn Sand Hills (Wolfe *et al.*

2002a), the Great Sand Hills (Wolfe *et al.* 2001), and the Lauder Sand Hills (Running *et al.* 2002; Havholm and Running 2005) (Fig. 3.2). The sand dune activity cycle incorporates phases of aeolian erosion and deposition separated phases of complete dune stabilization (David *et al.* 1999) (Fig. 3.3). The cycle commences with stabilized sand dunes (P_s) during cool, moist climatic conditions when grassland vegetation is established and immobilizes aeolian deposits. Extensive vegetation colonization and pedogenesis on aeolian landforms correlates with periods of landscape stability (Birkeland 1999). Landscape stability has been described as a measure of the temporal and spatial distributions to resisting and disturbing geomorphic processes (Brunsden and Thornes 1979). During stable landscape conditions, landforms demonstrate the high ability to absorb climatically-induced perturbations (such as drought climatic conditions) under broad geomorphic thresholds or the high ability a landscape can prevent extensive

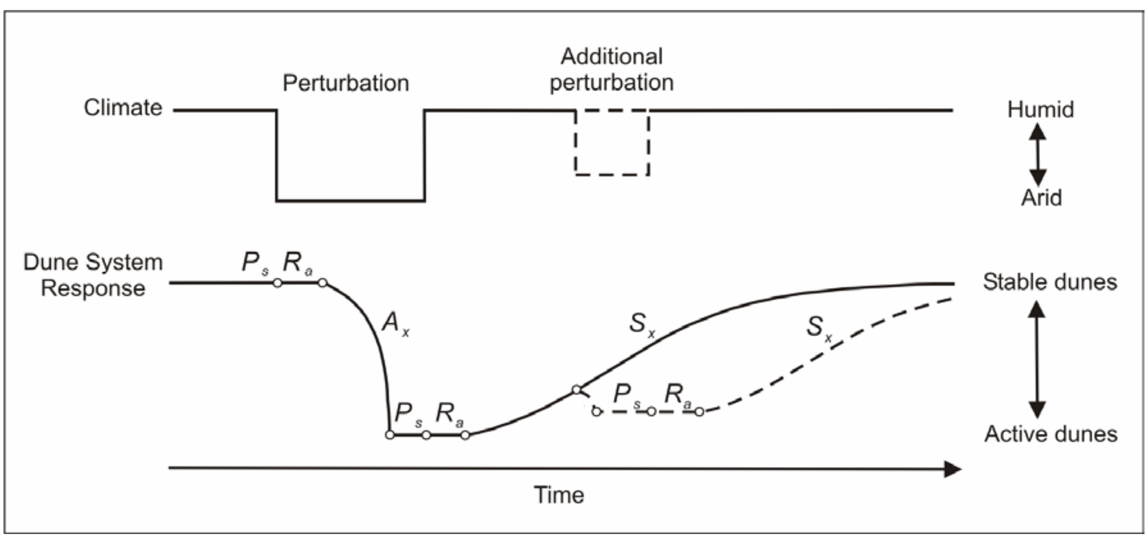


Fig. 3.3. The biogeomorphic model of aeolian sand dune activity on the Canadian Plains with (P_s) persistence interval, (R_a) reaction lag, (A_x) activation interval, and (S_x) stabilization interval. Adapted from Hugenholtz and Wolfe (2005a).

geomorphic processes to the accelerated modification of landforms (Schumm 1979). Extended intervals of humid climatic conditions and landscape stability are preserved in the post-glacial stratigraphy as buried soils (or paleosols). A climatic perturbation through severe arid climatic conditions initiates an adjustment (A_x) to an active sand dune phase, which persists for an extended interval (P_s). Arid climatic conditions associated with prolonged periods of moisture deficits and the reduction of grassland vegetation cover, permitted extensive aeolian sediment deflation and deposition and contributed to landscape instability. Landscape instability pertains to landforms or components of landforms that are sensitive to geomorphic change, which are significantly modified by substantial infrequent events (Schumm 1979). Landscapes exhibiting unstable conditions are distinguished by low geomorphic thresholds. These geomorphic conditions are characterized by the inability for a landform to absorb climatically-induced perturbations (such as extended severe arid climatic conditions) and subjected to experience long intervals of accelerated geomorphic modification in response to these perturbations. The last portion of the cycle incorporates the decline of the climatic perturbation with the cessation of arid climatic conditions and an adjustment to a stabilization phase (S_x). The last stabilization phase is initiated during the onset of extended humid climatic conditions which coincides with the gradual re-colonization of grassland vegetation, soil development, and landscape stability on aeolian landforms.

3.1.3 Cultural Occupation Patterns within the Prairie Landscape

Comprehension of the post-glacial landscape is critical for this study, because it is during the early post-glacial period that humans initially migrated into south-central Saskatchewan and developed adaptive strategies for the cool, moist climate that characterized this period. Understanding the nature of the post-glacial drainage network is particularly significant, for Walker (1992) argues that water resources were an important consideration for precontact human populations on the Canadian Plains. Precontact cultural groups utilized river valleys, particularly the glacial meltwater spillways, as corridors for movement into new territories, as well as focus points for their occupation proximity to food, fuel, and shelter. Nicholson *et al.* (2002) further recognized that river valleys, as well as wetlands, hummocky glacial uplands, and aeolian sand dune complexes are features that were extensively settled by Plains cultural groups. These physiographic elements contained a diversity of resources within proximity of major river valleys and permanent sources of potable water (Hamilton and Nicholson 1999; Nicholson *et al.* 2002). These inhabitants departed frequently from the valley bottoms and moved onto the adjacent plains for short durations, notably into the sand dunes to procure the abundant resources, especially large game, vegetal foods, and wood at these localities. Cultural remains situated in these landscape features may contain evidence regarding resource acquisition strategies in the form of cultural artifacts and features preserved in their occupation sites.

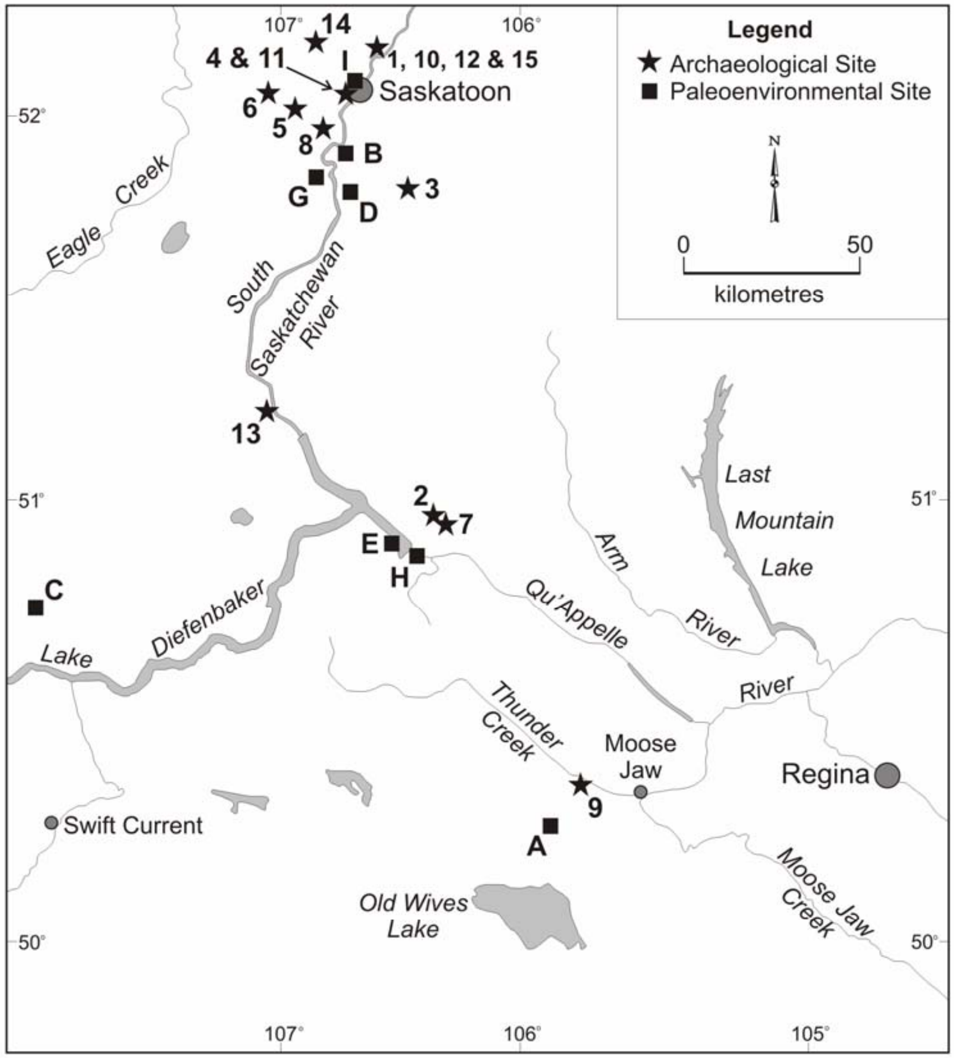
3.2 Holocene Climatic Conditions

3.2.1 Proxy Environmental Indicators

The reconstruction of Holocene climatic conditions in south-central Saskatchewan has been facilitated by proxy environmental indicators derived from paleolimnologic, paleopedologic, and aeolian geomorphic investigations. Paleolimnologic studies of prairie lakes and sloughs in the region such as the Andrews site located 75 km southeast (Yansa 1998; Aitken *et al.* 1999; Yansa and Basinger 1999), Clearwater Lake located 115 km northwest (Last *et al.* 1998; Wilson and Smol 1999), and Oro Lake located 160 km southeast of site EgNo-23 (Last and Vance 2002) provide data on past environmental conditions of the landscape surrounding these lake basins (Fig. 3.4). These investigations examine stratigraphic variations in the quantities of plant pollen, algal pigments, the stable isotope composition of organic matter, mineralogy, and the physical properties of lacustrine sediments to assess paleoenvironmental conditions. Paleolimnologic studies can be integrated with investigations of paleosols situated within aeolian sand deposits to develop a more comprehensive reconstruction of Holocene environmental conditions. Paleopedologic and aeolian geomorphic studies offer stratigraphic information regarding intervals of moist and arid climatic conditions throughout the Holocene (Forman *et al.* 2001) (Fig. 3.5). Although these environmental proxies reflect changes in different environmental parameters, they reveal similar general climatic trends and contribute absolute ages of paleoclimatic events. Understanding post-glacial environmental conditions are critical to the study of cultural settlement patterns throughout the Holocene in south-central Saskatchewan.

3.2.2 Holocene Climatic Chronology

Pollen and plant macrofossil remains preserved in lacustrine sediments have yielded a proxy record of Late Pleistocene and Early Holocene climate variations. These records indicate the presence of an open white spruce (*Picea glauca*) parkland community covering southern Saskatchewan landscapes during the early post-glacial period ca. 12.1 to 11.5 ka BP (Yansa 2006). The occurrence of this biotic community in the region suggests the existence of a cool, moist, climatic regime during the Late Pleistocene (Fig. 3.2). Spruce woodlands were succeeded by a deciduous parkland community dominated by balsam popular (*Populus balsamifera*), trembling aspen (*Populus tremuloides*), and water birch (*Betula occidentalis*). The gradual transition towards a grassland ecozone by ca. 10 ka BP (Mott, 1973) signifies the onset of warmer



Archaeological Sites

1 Amisk site (FbNp-17) (Amundson 1986)
2 EgNo-23 site (Webster 2004; Neal 2006)
3 Fitzgerald site (ElNp-8) (Hjermstad 1996)
4 Gowen I & II sites (FaNq-25 & FaNq-32) (Walker 1992)
5 Grandora site (FaNr-2) (Dyck 1972)
6 Harder site (FbNs-1) (Dyck 1970)
7 Melhagen site (EgNr-1) (Ramsey 1991)
8 Moon Lake site (FaNq-5) (Dyck 1970)
9 Mortlach site (EcNl-1) (Wettlaufer 1955)
10 Newo Asiniak site (FbNp-16) (Kelly 1986)
11 Norby site (FbNq-56) (Zurberg 1991)
12 Redtail site (FbNp-10) (Ramsey 1993)
13 Sjovold site (EiNs-4) (Dyck and Morlan 1995)
14 Tschetter site (FbNr-1) (Linnamae 1988)
15 Thundercloud site (FbNp-25) (Mack 2000)

Paleoenvironmental Sites

A Andrews site (Yansa 1998; Yansa and Basinger 1999)
B Beaver Creek (Turchenek *et al.* 1974)
C Clearwater Lake (Last *et al.* 1998; Wilson and Smol 1999)
D Dundurn Sand Hills (Wolfe *et al.* 2002a)
E Elbow Sand Hills (Wolfe *et al.* 2002a)
F Oro Lake (Last and Vance 2002)
G Pike Lake (Morlan *et al.* 2001)
H Qu'Appelle site (Klassen 1971)
I Saskatoon site (Morlan *et al.* 2001)

Fig. 3.4. Locations of significant post-glacial paleoenvironmental and Middle and Late Prehistoric archaeological sites in south-central Saskatchewan.

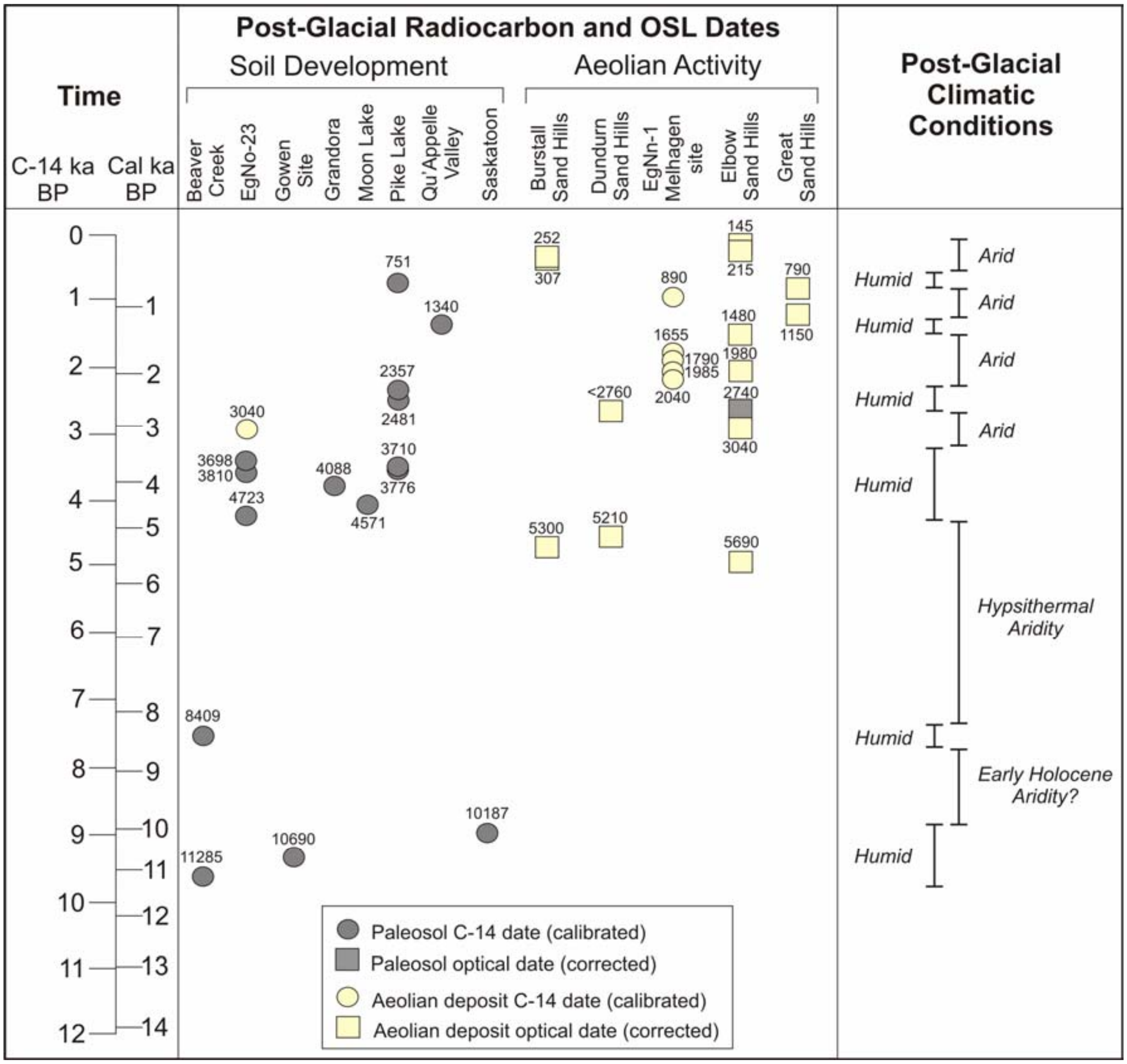


Fig. 3.5. Post-glacial climatic conditions in south-central Saskatchewan based on radiocarbon and optical luminescence dating techniques of soil horizons and aeolian deposits. Adapted from Morlan *et al.* (2001); Wolfe *et al.* (2002a); Webster (2004).

and drier climatic conditions in the early Holocene. Cool and moist climatic conditions persisted throughout the Early Holocene as indicated by the occurrence of high lake levels detected in the lacustrine sediments surrounding the study area at Clearwater Lake, Oro Lake, and the Andrews site, and the presence of Orthic Black Chernozermic soils developed on aeolian sediments dated ca. 10 to 8 ka BP in the region (Turchenek *et al.* 1974). This relatively cool and moist period was briefly interrupted by a warm and arid climatic interval revealed by shallower lake levels and higher lake salinities at Clearwater Lake between 9.65 to 9.4 ka BP and 9.2 to 8.6 ka BP (Wilson and Smol 1999), at the Andrews site between 8.8 and 7.7 ka BP (Aitken *et al.* 1999), and at Oro Lake approximately 8.3 ka BP (Last *et al.* 2002). Humid climatic conditions returned for a brief period immediately following this interval with higher lake levels and lower lake salinities at these localities.

Anderson *et al*. (1989) denoted the interval from ca. 8.0 to 6.0 ka BP as an interval distinguished by peak aridity referred to as the Holocene Hypsithermal Interval in southern Saskatchewan. The Middle Holocene period was marked by increasingly warmer and arid climatic conditions characterized by reductions in effective moisture (Vance *et al.* 1995), surface area of sloughs and lakes (Lemmen *et al.* 1997), stream discharges (Lemmen *et al.* 1998), regional water tables (Remenda and Birks 1999), and ecological resource abundances from declines in grassland vegetation foliage yield and density, and bison herd populations (Reeves 1973; Frison 1975; Meltzer 1999). These changes in the regional climate were associated with increases of aeolian activity, geomorphic erosion, and resource patchiness from reductions in resource availability, as well as declines in sediment weathering (Meltzer 1999). This climatic interval has been attributed to an increase in summer radiation between 12.0 and 9.0 ka BP controlled by the Milankovitch earth-sun orbital variations (Barnosky *et al.* 1989). The timing of the Hypsithermal lags behind this period of maximum solar radiation and it is time transgressive in western Canada, emerging earlier in Alberta (ca. 9.2 to 5.8 ka BP (Anderson *et al.* 1989)) than in Manitoba (ca. 5.5 to 3.5 ka BP (Patterson *et al.* 1997)). In southern Saskatchewan during this period, mean summer temperatures were 2ºC warmer and growing season precipitation was 15% lower than the present (Vance *et al.* 1995). Confirmation of these dry climatic conditions is recorded from several prairie lakes in the region: for example, low water levels at Oro Lake between 7.3 and 4.0 ka BP, and desiccation at Clearwater Lake, resulting in limited or no lacustrine deposits from this time interval. Charred wood and abundant charcoal flakes recovered at the Andrews site suggest the extensive occurrence of prairie fires, which can be associated with the onset of a severe arid interval between 8.8 and 7.7 ka BP (Yansa and Basinger 1999). Regosolic soils developed on aeolian sediments, dated between 8.0 to 3.0 ka BP, provide further indication of an extended interval of prolonged arid climatic conditions (Turchenek *et al.* 1974). This period of severe aridity is also characterized by the widespread mobilization and deposition of aeolian sediments throughout the North American Great Plains (e.g., Holliday 1989; Stokes and Gaylord 1993; Olsen *et al.*1997; Stokes and Swinehart 1997; Wolfe *et al.* 2002a; Havholm and Running 2005). However, only a few Middle Holocene aeolian deposits are preserved in southern Saskatchewan, perhaps because of being reworked by subsequent intervals of extensive aeolian activity during the Late Holocene (Wolfe *et al.* 2002a).

By 6 ka BP, the Hypsithermal interval of peak aridity had waned, and climatic conditions gradually shifted towards a cooler and moister environment (Vance *et al.* 1995). These climatic conditions are demonstrated by paleolimnologic proxy parameters distinguished by rising lake levels, an increase in the abundance of tree pollen, a decrease in the quantity of algal pigments, and the ^{18}O-enrichment of carbonate minerals in lake sediments throughout south-central Saskatchewan. Humid climatic conditions during this interval promoted renewed river downcutting in the South Saskatchewan and Qu'Appelle

River spillways and raised regional groundwater table levels, which contributed to slope instability along river valleys sides (Lemmen *et al.* 1998; Lemmen and Vance 1999).

The aeolian stratigraphic record of the Late Holocene period was punctuated by brief intervals of severe aridity. Wolfe *et al.* (2002a) have documented repeated episodes of extensive aeolian activity, based on optical luminescence dating of sand grains, coinciding with arid climatic conditions at 215 ± 17, 1480 ± 60, 1980 ± 80, 3040 ± 140, and 5690 ± 240 years BP in the Elbow Sand Hills (Fig. 3.5). The radiocarbon dates of bison bone within aeolian deposits, implying burial by wind blown sand at the EgNo-23 site with normalized ages of 2900 ± 40 years BP (Webster 2004) and at the Melhagen site of 890 ± 205, 1655 ± 115, 1790 ± 55, 1985 ± 55, 1985 ± 110, 1990 ± 75, and 2040 ± 90 years BP (Ramsey 1991) in the study area. These periodic, arid intervals alternated with cooler and moister climatic conditions that contributed to soil genesis as suggested by the preservation of paleosols within the aeolian stratigraphy of the region. Establishing the chronology of paleosol horizons through radiocarbon dating of bison bone in paleosol horizons aged 3520 ± 40, 3537 ± 55, and 4240 ± 50 years BP (Webster 2004) and optical luminescence dating of paleosol sand grains aged 2740 ± 120 years BP (Wolfe *et al.* 2002a) have denoted of intervals of Late Holocene humid climatic conditions (Fig. 3.5).

3.2.3 Caveats with Proxy Environmental Indicators

Several complications arise in utilizing these proxy environmental indicators to reconstruct Holocene climatic change in south-central Saskatchewan. One of these complications is the absence of a single environmental indicator that offers a complete, accurate record throughout the entire Holocene. The examination of environmental change requires the observation of a multitude of proxy indicators to attain a continuous, reliable chronology. The problem in using these proxy indicators also lies with the nature of prairie lakes in the region. These lakes tend to be ephemeral and highly saline, permitting discontinuous sedimentary records and a limited range of biological proxy indicators (Lemmen *et al.* 1997). In aeolian geomorphic and paleopedologic studies, the thickness of aeolian sediments and preservation of paleosols varies laterally, reflecting spatial and temporal discontinuities in aeolian activity and pedogenesis (Forman *et al*. 2001). Furthermore, paleoenvironmental sites on the Canadian Plains frequently suffer from a lack of dateable material for radiocarbon dating, and sites are separated by great distances (Beaudoin 2002). This situation makes it difficult to reconstruct post-glacial paleoclimatic conditions, notably establishing Late Pleistocene and Early Holocene environmental conditions due to the limited number of sites with proxy indicators extending back to the Early Holocene. Paleoenvironmental sites that contribute the most precise, continuous chronology of climatic change are situated well outside of the study area. For example, Sauchyn's (1990) study of Harris Lake provides the most detailed and complete sedimentologic and palynologic record in the Canadian Plains over the past 9,300 years. Harris Lake poorly represents the Holocene climatic and environmental conditions in south-central Saskatchewan poorly, however, as a consequence of the lake's geographic and altitudinal location in the Cypress Hills in southwestern Saskatchewan.

3.3 South-Central Saskatchewan Archaeology

3.3.1 Precontact Cultural Chronology

Archaeological evidence of precontact human settlement in the province extends back 13,000 years. A number of significant archaeological sites that have contributed greatly to the understanding of precontact cultural groups in the Canadian Plains are situated in south-central Saskatchewan (Fig. 3.4). The archaeological record in southern

Saskatchewan can be categorized into three primary, precontact cultural periods according to Dyck's (1983) and Walker's (1992) classification system; the Paleo-Indian period (or Early Prehistoric period) prior to 7.5 ka BP, the Middle Prehistoric period from 7.5 to 2.0 ka BP, and the Late Prehistoric period from 2.0 to 0.17 ka BP (Fig. 3.5). The Middle Prehistoric and Late Prehistoric periods are of greatest interest for this investigation since the EgNo-23 site preserves evidence of human settlement during these cultural intervals. These humans were exclusively hunter and gatherers that were extensively involved in the procurement of large game, particularly bison. These intervals

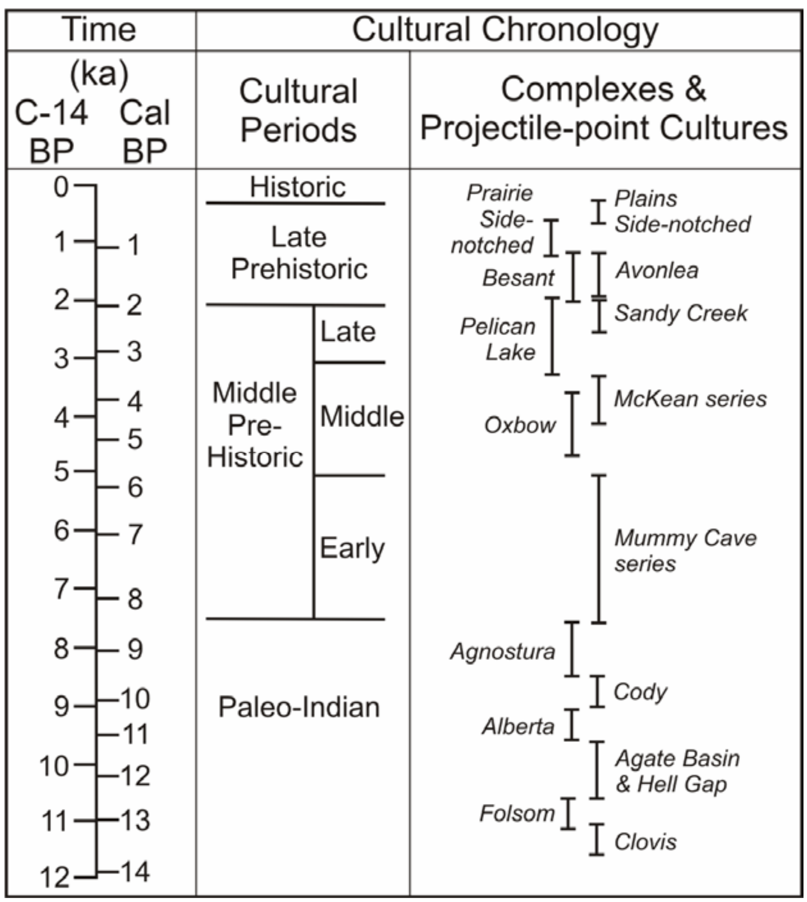


Fig. 3.6. Precontact cultural chronology of south-central Saskatchewan. Adapted from Dyck (1983); Linnamae *et al*. (1988); Walker (1992).

were periods of frequent and significant environmental changes in south-central Saskatchewan.

3.3.1.1 Middle Prehistoric Period

The Middle Prehistoric period is marked by a technological shift from the use of lanceolate spear points to side-notched dart tips associated with the use of the atlatl or spear thrower (Linnamae *et al.* 1988). This modification in projectile point technology could be the result of an expansion of the dietary breadth of precontact populations to incorporate a variety of large and small game (such as bison, pronghorn, and canids) as well as plants (such as saskatoonberry, chokecherry, and gooseberry) to cope with diminished food and potable water resources during this period (Meltzer 1999). The beginning of this period coincides with the Holocene Hypsithermal Interval, when a warmer and drier climatic regime than the present existed. The climate gradually returned to cooler and moister conditions in the latter part of the Middle Prehistoric period. The Middle Prehistoric period is further subdivided into three divisions according to contrasting technologies, population increases and mobility, and cultural characteristics (Walker 1999).

The Early Middle Prehistoric period (7.5 to 5.0 ka BP) represents an interval distinguished by the presence of various cultural groups occupying the Canadian Plains. This is signified by the large series of different, side-notched projectile points discovered throughout the region. These inhabitants were hunting extinct early varieties of the modern Plains bison (i.e., *Bison bison occidentalis*) that exhibited larger body and horn sizes. Succeeding bison forms gradually declined in body mass and increased in population numbers throughout the Holocene (Wilson 1978). The Mummy Cave series are represented in the Saskatoon area by the Norby bison kill site (Zurburg 1991) and the

Gowen camp sites (Walker 1992). The significance of these sites, particularly the Gowen sites, is that they support Hurt's (1966) and Reeves' (1973) concepts that precontact peoples extensively inhabited the Canadian Plains during the Hypsithermal Interval. Previous researchers in the 1950s and 1960s postulated the existence of a cultural hiatus during this prolonged arid climatic interval (e.g., Mulloy 1958), where humans abandoned the Great Plains for more humid climates situated in the aspen woodlands at the periphery of the plains and/or upland refuges such as the Cypress Hills. Walker (1992) observed that the number of archaeological sites associated with the Mummy Cave series increases after 6.5 ka BP, possibly indicating population expansions in response to the gradual shift to cooler, moister climatic conditions.

The middle part of the Middle Prehistoric period (5.0 to 3.5 ka BP), experienced conditions that continued the transition towards cooler, moister climatic conditions according to proxy paleoclimatic indicators. The Oxbow complex (4.7 to 3.5 ka BP) and the McKean series complex (4.1 to 3.5 ka BP) were the two dominant technological complexes that co-existed in the Canadian Plains during this interval. The typical Oxbow projectile point is side-notched with a concave base and projections between the base and notches. The McKean series complex is composed of a variety of projectile points including McKean, Duncan, and Hanna. McKean projectile points are unnotched and basally concave, Duncan points are broadly notched, and Hanna points are side-notched (Dyck 1983). Cultural artifacts originating from the Oxbow complex can be detected at the Moon Lake camp site in the Pike Lake Sand Hills and the Harder camp site in the Dunfermline Sand Hills (Dyck 1970). Evidence for the McKean series complex are encountered at the Redtail (Ramsey 1993) and the Thundercloud sites (Mack 2000) within Wanuskewin Heritage Park, north of Saskatoon.

Succeeding the Oxbow and McKean complexes, the Pelican Lake cultural complex (3.3 to 1.85 ka BP) emerged on the Canadian Plains with two associated variations of straight-sided, corner notched projectile points during the Late Middle Prehistoric period. Dyck (1983) indicates that the first point variant composed of a straight base is detected early in the Pelican Lake sequence, whereas the second variant is composed of a concave based point recovered in the middle and late sequences. The small size of mainly dart-sized points of Pelican Lake components seems to imply that the bow and arrow may have been utilized here for the first time (Dyck 1983). The Mortlach site (Wettlaufer 1955) and the Sjovold site (Dyck and Morlan 1995) are multi-component camp sites that date to the Late Middle and Late Prehistoric periods and include artifacts from the Pelican Lake complex and other late side-notched varieties.

3.3.1.2 Late Prehistoric Period

The Late Prehistoric period has been portrayed as an interval characterized by a transition to contemporary climatic conditions, with several episodic fluctuations between warm, arid and cool, moist climatic intervals. This cultural interval is also recognized by the introduction of pottery, the widespread use of the bow and arrow, and increased sophistication in communal bison hunting techniques on the Canadian Plains (Walker 1999). The Besant complex (2.0 to 1.15 ka BP) employed both dart-type projectile points and arrow points, and was probably the first group in the region to utilize pottery. Frison (1991) proposed that the Besant complex represents a climax in bison procurement strategies on the Plains, where these peoples used a series of topographic traps (particularly vertical cliffs and sand dunes) as well as corrals (or pounds) for large scale communal bison kills with associated processing areas. Cultural artifacts originating from the Besant complex are relatively common in south-central Saskatchewan with a number of large bison kill and processing sites such as the Melhagen site in the Elbow Sand Hills (Ramsey 1991) and the Fritzgerald site in the Dundurn Sand Hills (Hjermstad 1996), as well as habitation sites such as the Mortlach site (Wettlaufer 1955) and the Grandora site (Dyck 1972). The Avonlea complex (1.8 to 1.15 ka) co-existed with the Besant complex, but is distinguished by the use of small, delicate side-notched points (Walker 1999). Artifacts from the Avonlea complex are located at the Amisk (Amundson 1986) and Newo Asiniak multi-component sites (Kelly 1986) within the Wanuskewin Heritage Park.

The latter portion of the Late Prehistoric period is characterized by an array of cultural groups utilizing a series of side-notched arrow points, involved with considerable population increases and movement, and new adaptation strategies (Walker 1999). The Prairie Side-notched complex (1.2 to 0.55 ka BP) is distinguished by a small, side-notched arrow point with the placement of the notches close to the basal corners (Dyck 1983). Ceramics are commonly recovered at Prairie Side-notched sites with globular pottery representing an important component of their technology (Linnamae *et al.* 1988). The Plains Side-notched complex (0.55 to 0.17 ka BP) co-existed with and eventually replaced the Prairie Side-notched complex (Dyck 1983). Plains Side-notched projectile points are small and triangular with narrow side-notches positioned higher from the basal corner than the Prairie Side-notched style (Linnamae *et al.* 1988). This cultural complex is recognized as the builders of a quantity of cultural features, particularly medicine wheels and boulder effigies throughout southern Saskatchewan. Excavated sites depicting these two cultural complexes in south-central Saskatchewan include the upper levels of the Amisk (Amundson 1986) and Newo Asiniak sites (Kelly 1986). The Tschetter bison kill site in the Dunfermline Sand Hills (Linnamae 1988) reveals the procurement strategies associated with the Prairie Side-notched complex.

The significance in examining the precontact archaeology of south-central Saskatchewan for this investigation is to attempt to comprehend the subsistence, procurement, and habitation patterns of precontact humans. Studying the evolution of different precontact cultural complexes indicates the variety of adaptive strategies cultural groups employed to endure variations in environmental conditions and landscape processes throughout the Holocene.

3.4 GIS in Archaeological Research

The majority of the data archaeologists recover is spatial in nature or has an important spatial component, and frequently involves a vast quantity of information at a variety of scales (Wheatley and Gillings 2002). Spatial information, its collection, manipulation, and examination are the primary concern for archaeological theory, methods, and practice. It is a fundamental premise in archaeology that human behaviour is patterned and, therefore, spatial behaviour reflected by sites, settlements, or organization across the landscape should exhibit non-random tendencies (Brandt *et al.* 1992). The introduction of Geographical Information Systems (GIS) has been an important technological development in archaeology as a valuable research tool to aid in the investigation of spatial distributions and patterns of precontact human populations. GIS is a set of computer tools for collecting, storing, retrieving, transforming, and displaying spatial data from the real world for a particular range of purposes (Burrough and McDonnell 1998). GIS integrates digital spatial data at a variety of scales, times, and formats. These systems are particularly valuable for data structures dealing with measuring and mapping environmental parameters, determining change through time, and modeling (Rapp and Hill 1998). Since the application of GIS in archaeology was initiated in the early 1980s, archaeologists have been increasingly integrating GIS as a fundamental component of archaeological research. Advances in microcomputer and GIS software technology in storage, power, and accessibility over the past three decades have drastically improved the ability to regularly utilize GIS in archaeology. GIS have permeated all aspects of archaeology, revolutionizing research by permitting easy access to vast quantities of information, new techniques of data visualization that promote insight through pattern recognition, and unique methodologies that permit new approaches to the study of the past (Kvamme 1999). Recent GIS research has been directed towards an array of archaeological approaches such as modeling population settlement patterns (Anderson and Gillam 2000), determining ancient land uses (Hill 2004), reconstructing paleoenvironmental conditions (Spinkins 2000; Periman 2005; Fyfe 2006), illustrating stratigraphic and site contents (Spinkins *et al.* 2002; Nigro *et al.* 2003), and examining landscape settings of site locations (Bevan and Conolly 2002; Bauer *et al.* 2004; Fry *et al.* 2004).

Archaeological GIS has been broadly established and practiced in European and American archaeology, but it has not been applied so comprehensively in Canada (Ebert 2004). To date, several studies have been published in Canada, which have been concentrated on predictive archaeological modeling approaches in the context of cultural heritage management (e.g., Dalla Bona and Larcombe 1996; Dalla Bona 2000; Hamilton

2000), but only a few studies have been completed in the Canadian Plains (e.g., Dalla Bona 1993; Friesen 1998; Hamilton and Nicholson 1999). The limited number of GIS-based archaeological investigations in Canada is progressively improving, with several projects still in progress and broader in scope, particularly research associated with the SCAPE project on the Canadian Plains. Research projects such as these explore the application of GIS technology to better comprehend the spatial distribution and patterns of human settlement, as well as the extent to which environmental factors influence precontact human settlement.

CHAPTER 4
METHODS

4.1 Field Methods

Field work was performed to record observations of the physical properties and stratigraphy of the surficial sediments, and to obtain samples for further analysis in the laboratory. These data were utilized to reconstruct post-glacial sedimentary environments and their relation to archaeological site preservation and visibility. Prior to commencing field work, an examination of the geomorphic features within the study area was performed using a topographic map and aerial photographs of the Elbow Sand Hills and the surrounding terrain. This analysis was used to identify landscape features of interest as well as potential sampling locations to acquire samples of the surficial sediments.

The field season took place in August 2003, and 342 sediment samples were collected from 77 logged stratigraphic sections at 42 sampling sites (Fig. 2.2). The sampling site distribution was designed to examine the sedimentary characteristics of each dominant physiographic element (i.e., aeolian sand dunes, an outwash plain, and hummocky moraine) and the spatial variations in the physical properties of the surficial sediments (see Fig. 2.2). Sediment samples were acquired from natural and anthropogenic exposures situated within the study area such as lakeshore cliffs, road cuts, sand and gravel pits, and dugouts. A hand auger was used to sample the surficial sediments at sites where exposures of the underlying deposits were absent. The hand auger was capable of extracting a 0.05 m diameter core in 0.2 m sections to a maximum depth of 2 m. The geographical location of each sampling site was obtained using a handheld Global Positioning System (GPS). Site elevations were measured with the use of an altimeter. A topographic profile was constructed at each sampling site using a clinometer, measuring tape, and ranging rod.

The physical properties of the post-glacial sediments and stratigraphy were examined at all sampling sites. Visual observations included sediment texture, colour (according to the Munsell colour system), the depth of the strata and the nature of their bounding surfaces, the presence of pedogenic or organic horizons (according to the Canadian System of Soil Classification (Soil Classification Working Group 1998)), and the occurrence of any primary and secondary sedimentary structures. Clasts encountered within the sediment sequences were examined according to their sphericity, orientation, and lithology. Azimuth measurements were performed on profiles where dipping sedimentary bedforms and organic horizons were present. Organic materials found within the stratigraphic sections, such as charcoal and well-developed paleosol horizons, were sampled for bulk radiocarbon dating to establish the chronology of the depositional environments within the study area. Samples were extracted from exposed outcrops and auger holes at intervals that reflect the vertical and lateral changes in sediment characteristics.

4.2 Laboratory Methods

Laboratory analyses were performed to understand the nature of the depositional environments represented in the sediment samples and to identify distinct sedimentary facies within the study area. Laboratory analyses for this study include the use of the loss-on-ignition procedure for the determination of organic and inorganic carbon contents percentages and particle size distributions via sieving and pipette techniques.

4.2.1 Sediment Sample Selection

A variety of field data including sediment texture and colour, and primary and secondary sedimentary structures observed in outcrop, were used to develop a preliminary set of sedimentary facies represented in the logged stratigraphic sections. Sedimentary facies are distinctive bodies of sediments which differ from bodies above, below, and laterally adjacent that were formed under certain sedimentation conditions reflecting a particular process, set of conditions, or environment (Reading 2003). Facies are distinguished according to colour, bedding, composition, texture, and sedimentary structures, and are categorized in this study according to Miall's (1977) and Eyles *et al.*'s (1983) lithofacies notations (Table 4.1). The number of samples selected for further analysis was established based on the relative importance of each facies within the logged stratigraphic profiles and auger samples. Of the 342 sediment samples collected in the field, 160 samples were selected for further analysis. The sample selection for detailed analysis represents the full spectrum of depositional environments in the study area.

Type sites were established at sampling sites that depicted the chronology and characteristics of depositional environments exposed in outcrop for each of the three dominant physiographic elements (aeolian sand dunes, outwash plain, and hummocky moraine) situated in the study area. These type sites are locations where stratigraphic sequences revealed representative characteristics of the nature and variation of post-glacial sediments and lithofacies units detected within each of the physiographic elements. Furthermore, these type sites preserve a depositional record throughout the post-glacial period.

Table 4.1. Lithofacies code and sedimentary structures for late Cenozoic sedimentary deposits Adapted from Miall (1977); Eyles *et al.* (1983).

Diamict, D		**Sands, S**	
Dm	matrix supported	Sr	rippled
Dc	clast supported	St	trough crossbeds
D-m	massive	Sp	planar crossbeds
D-s	stratified	Sh	horizontal lamination
D-g	graded	Sm	massive
Gravel, G		Sg	graded
Gms	massive, matrix supported	Sd	soft sediment deformation
Gm	massive	S-e	aeolian deposits
Gt	trough crossbeds	**Fine-grained (mud), F**	
Gp	planar crossbeds	Fl	lamination
Genetic interpretation		Fm	massive
---(r)	resedimented	F-d	with dropstones
---(c)	current reworked		
---(s)	sheared		

4.2.2 Organic and Inorganic Carbon Percent Determination

The organic and inorganic carbon content in the sediment samples were determined using a modified loss-on-ignition procedure derived from Dean (1974), Lee (1980), and Lewis and McConchie (1994) with the use of a Leco CR-12 carbon analyzer in the Department of Soil Science laboratory at the University of Saskatchewan. Approximately 0.15 – 0.20 g of air-dried sample were weighed to 0.0001 g prior to placing the sample into the carbon analyzer with furnace temperatures set at 840ºC for organic carbon and 1100ºC for total carbon percentage determination. The carbon analyzer reported both organic and inorganic carbon percentages to 0.001%. The detailed procedure and calculations for organic and inorganic carbon percent determination are described in Appendix A. These analyses were undertaken to examine the nature and fluctuation of organic and inorganic carbon contents through the post-glacial sediments to aid in paleoenvironment construction, particularly to recognize pedologic horizons where cultural artifacts are frequently recovered *in situ*.

4.2.3 Particle Size Analysis

Particle size analysis was based upon a combination of two techniques. The gravel and sand fractions were analyzed according to standard dry sieving procedures, and the silt and clay fractions according to standard pipette procedures derived from Day (1965), Gee and Bauder (1982), Kunze and Dixon (1982), and Lewis and McConchie (1994). Each sample was pre-treated with 30% hydrogen peroxide to remove organic material. The samples were treated additionally with a dilute hydrochloric acid solution (10-15%) to remove carbonate cement, which was observed in many of the samples. Procedures and calculations involved with particle size analysis for this study are described in Appendix B.

Grain size data were classified according to the logarithmic Udden-Wentworth scale (Udden 1914; Wentworth 1922), which is a fixed ratio between successive size class boundaries, each size being twice as large as the previous class (Prothero and Schwab 1996). To facilitate graphical and statistical manipulation of the grain size distributions, the data were organized according to Krumbein's (1934) grade scale. Krumbein's (1934) application of the phi (Φ) value from the expression $\Phi = -\log_2 d$, where d is the grain diameter in millimeters, calculates the logarithmic particle diameter. The diameters and corresponding phi notations used in this study are presented in Table 4.2.

Grain size data were subsequently entered into Gradistat software version 4.0 (Blott and Pye 2001). This software is capable of calculating and plotting grain size statistics from any standard measuring techniques and reporting particle size and

Table 4.2. Grain diameter in millimetres (*d*) and corresponding phi (Φ) values of class units applied in particle size analysis.

d	Φ	*d*	Φ
4.000	-2.0	0.180	2.5
2.800	-1.5	0.125	3.0
2.000	-1.0	0.900	3.5
1.400	0.5	0.630	4.0
1.000	0.0	0.020	5.5
0.710	0.5	0.005	7.5
0.500	1.0	0.002	9.0
0.355	1.5	0.001	10.0
0.255	2.0		

statistics from any standard measuring techniques and reporting particle size and distribution statistics based on measures of moments and Folk and Ward graphical methods. The measures of moments method (Krumbein 1936) is the most commonly applied set of formulae and is used in this study. Particle size analysis was performed on sediment samples to provide information regarding the nature and origins of post-glacial sediments as well as the paleoenvironmental conditions during their deposition.

4.3 Geographical Information Systems (GIS) Methods

4.3.1 Data Acquisition

The development of the GIS to examine precontact cultural settlement patterns in relation to landscape features involved a larger study area. The GIS covers an expanded study area spanning a 50 km radius from the elbow of the South Saskatchewan River, encompassing approximately 10,000 km² in total. The elbow of the South Saskatchewan River (51º06'45"N, 106º37'30"W) was selected as a focal point for this study because of the location's established reputation as the location of extensive precontact cultural settlement in the southern Saskatchewan and because it is in close proximity of the Elbow

Sand Hills. The construction of the GIS involved acquiring digital data from several sources. Surficial geology and surface hydrology polygon shape and attribute files were derived from the Geological Atlas of Saskatchewan CD-ROM (Saskatchewan Energy and Mines 2000). Topographic data were obtained through the application of raster digital elevation models (DEM), which were downloaded from the Canadian Council on Geomatics through the GeoBase internet website (Canadian Council on Geomatics 2005). In total, 38 DEMs at a scale of 1:50,000 were acquired and merged into a single mosaic covering the entire study area through the use of the mosaic function in ArcToolbox software within ESRI ArcGIS version 9.0. Documented archival archaeological data were obtained from the Heritage Resources Unit of Saskatchewan Culture, Youth and Recreation in a Microsoft Excel spreadsheet format. The database records identified all of the archaeological sites within the study area, and included site attributes (e.g., Borden Number, geographical location, cultural affiliation, and site contents).

Several difficulties involving the archaeological database emerged from the limited amount of information relating to site locations, cultural affiliations, and contents. The geographical locations of sites in the database are based largely on the legal land survey grid, where sites were identified to the quarter section (1.6 km X 1.6 km area) to sub-quarter section (0.8 km X 0.8 km area). A large number of archaeological sites in the database also have Universal Transverse Mercator (UTM) grid units, derived from the North American Datum of 1927 (NAD27) associated with them. The exclusive use of legal land survey grid units in the database to identify geographical site locations provided imprecise locations for a significant proportion of sites.

The lack of sufficiently detailed description of the cultural affiliation and contents associated with sites were an addition hindrance to database development. A large quantity of sites were identified as having unknown cultural affiliations, and a relatively low number of sites were designated with cultural affiliations, which are based primarily on diagnostic cultural artifacts, notably projectile points. The inadequate description of site contents and types (e.g., camp sites, bison kill or processing sites, and bison drive lanes) further contributed to difficulties as it was problematic to infer the nature of site activities based on the poor quality of the data. The limited amount of detailed documentation of sites in the study area presented challenges in determining the nature of precontact settlement activities in relation to the environmental elements.

4.3.2 Data Categorization

A number of data categorization procedures were undertaken to prepare the data for analysis. The surficial geology shape file initially divided the study area into 11 separate physiographic elements. To simplify the study area's surficial geology, the dissolve function in ArcMap software was applied to combine the surficial geological polygon shape elements into 5 dominant physiographic elements. These physiographic elements include: aeolian sand dunes, glaciofluvial plains, glaciolacustrine plains, hummocky moraine, and glacial meltwater spillways.

The geographical locations of sites were converted from NAD27 to the North American Datum of 1983 (NAD83) through the use of ArcMap software. Archaeological sites designated exclusively by legal land survey grid units were manually assigned UTM grid units using NAD83 using topographic maps, allowing for the archeological sites to be plotted in the GIS software. All subsequent shape files were adjusted to the to UTM grid system in the NAD83 projection. The archaeological database was further organized using Microsoft Excel prior to entering into ArcMap. Furthermore, each archaeological site was categorized according to Dyck's (1983) and Walker's (1992) classification system of precontact cultural complexes and time periods in southern Saskatchewan (Fig. 3.3), as well as the nature of the cultural components recovered at each site. Site type categorization was based on the occurrence of cultural contents as defined by the Saskatchewan Heritage Resource Unit: artifact scatter, artifact find, single feature, artifact/feature combination, alignment/configuration, recurrent features, midden, or burials. Each cultural and component category was assigned a separate Excel spreadsheet file. These files were converted into a database (DBF IV) spreadsheet file to allow the point data to be imported into the GIS software.

4.3.3 GIS Analysis

The database spreadsheet files were imported into the ArcMap software as XY point data subsequent to the categorization of the data. The archaeological point data were then converted to point shape files using ArcMap. The surficial geology and DEM data were overlaid and combined with the archaeological site data based on culture and site type by using the join function. This was performed to illustrate the relationship between site distribution and site type and the surficial geology and topography. With the archaeological point data plotted in ArcMap, a raster site density surface was constructed using the density function from the spatial analyst extension. This task was performed in conjunction with the surficial geology layer to generate a contour site density raster file. The site density surface was used to determine the variances in distribution and concentration of sites in relation to the environmental elements in the study area.

The surface hydrology shape file containing the post-1967 surface hydrology with the modern Lake Diefenbaker reservoir was imported into ArcMap. A polyline shape file was created based on the post-1967 surface hydrology so that only the pre-1967 drainage of the original permanent, surface water resources were present, which included the Arm, South Saskatchewan, and Qu'Appelle Rivers, Beaver and Thunder Creeks, and Lucky Lake for analysis. The buffer function was applied to the polyline surface hydrology layer at 1 kilometre intervals to calculate archaeological site distances from permanent water resources. The software's join function was used to merge the archaeological site data with the distance to water data. This was performed to determine the distance sites are situated from water resources.

Results of the GIS data analysis were tested based on Kvamme's (1990) examination of standard statistical tests for various tasks utilizing GIS in archaeological research. The chi-square goodness-of-fit and standardized residual tests were noted to be valuable non-parametric statistical tests to detect differences and contributing variables in the archaeological site distribution with the physiographic elements and site distances to permanent water resources. The chi-square goodness-of-fit test was applied in this study based on its power for analyzing categorical variables: the test distinguishes if the observed frequencies of events differ significantly from expected frequencies of the hypothesized proportions (or null hypothesis) (Madrigal 1998). The single sample chi-square goodness-of- fit (χ^2) test is defined by the expression:

$$\chi 2 = \sum \frac{(f_o - f_e)}{f_e} \qquad [4.1]$$

In the chi-square test formulae, f_o represents the frequency of observed sites; and f_e represents the frequency of expected sites. The frequency of expected sites is calculated as an even distribution of archaeological sites in relation to surface area for each dominant physiographic element and the distance from permanent water resources. The null hypothesis for this investigation is that there are no relationships present in the distribution of archaeological sites with the physiographic elements and distance to water resources. The alternate hypothesis is that relationships are present in the distribution of archaeological sites with the physiographic elements and distances to water resources. The calculated chi-square test value was compared with the minimum requirements to reject or accept the null hypothesis at the determined level of significance. Chi-square tests alone are insufficient to determine the strength of a relationship or the significance of the related variables (Sheenan 1988).

The standardized residual test was applied additionally to the GIS data in order to determine the strength of contributing variables to differences in the chi-square test. The standardized residual (R) test is defined by the expression:

$$R = \frac{f_o - f_e}{\sqrt{f_e}} \qquad [4.2]$$

In the standardized residual test formulae, f_o represents the frequency of observed sites and f_e represents the frequency of expected sites. The standardized residual test value for a category establishes if the category was a significant factor (or contributor) to the departure from the expected and observed frequencies in the chi-square test. Standardized residual test values are interpreted to be significant contributors when calculated values are greater than 2.00 in absolute value. A positive significant standardized residual test value indicates that a greater quantity of archaeological sites are observed within a category than expected; a negative significant standardized residual test value indicates that fewer sites are observed within a category than expected.

CHAPTER 5
RESULTS

5.1 Late Quaternary Geomorphology, Stratigraphy, and Sedimentology of the Elbow Sand Hills and Vicinity

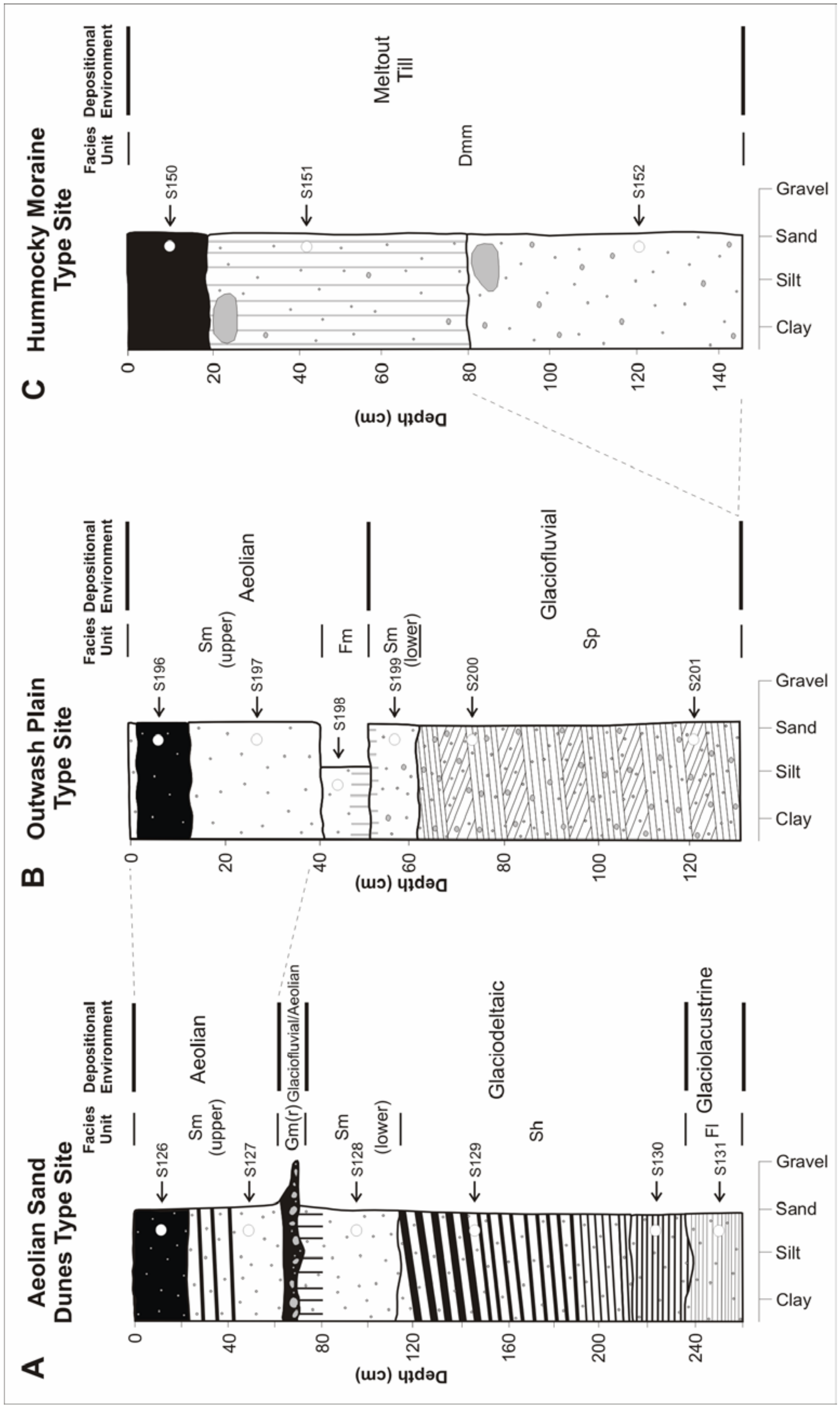
5.1.1 Aeolian Sand Dunes Type Site

The aeolian sand dunes physiographic element incorporates a variety of aeolian landforms, particularly hummocky parabolic sand dunes and associated blowout features (Fig. 5.1). The aeolian sand dunes type site is located at 51º1.998'N, 106º29.622'W along the Lake Diefenbaker shoreline cliff in the southwest corner of the study area (Fig. 2.2).

Fig. 5.1. Field photograph of landforms associated with the aeolian sand dunes physiographic element.

The cliff base has an elevation of 550 m a.s.l., where a 2.6 m tall exposure in the cliff base is oriented towards the southwest (Fig. 5.2). Five primary lithofacies units were recorded in the profile, and 8 sediment samples were acquired from this site (Fig. 5.3). The bottom unit consists of a 25 cm thick Fl facies unit of rhythmically laminated, moderately sorted, very fine sand deposits alternating between olive brown (2.5Y 4/4) clay and light yellowish brown (2.5Y 6/4) fine sand (Fig. 5.4 & Table 5.1). Overlying these sediments is a 145 cm Sh unit of massive, light yellowish brown (2.5Y 6/4) well to moderately sorted, fine sand, interbedded with black (10YR 2/1) organic detritus beds rich in charcoal flakes. The lower portions 37 cm of Sh unit contains an abundance of strong light olive brown (2.5Y 5/4) iron oxide stained mottles and lenses with thin organic detritus beds that gradually increase in thickness and dip angles upwards with organic layers dipping up to 9º towards the south. A 40 cm thick lower Sm unit consisting of a buried B_h soil horizon of moderately sorted, massive, dark brown (10YR 3/3) medium sand overlies the Sh unit. Coarser grains of the lower Sm unit consist of occasional sub-angular to sub-rounded gravel to small cobbles of a mixed foreign lithologies. At other sampling locations within the aeolian sand dunes, notably along exposures along the Lake Diefenbaker reservoir shoreline, calcium carbonate accumulations that appear as discrete nodules have been recognized within the lower Sm unit, demonstrating a weakly developed calcic (or C_{ca}) horizon. The deposits of the Fl, Sh, and lower Sm facies units coarsen upwards reflecting a decline in the clay and silt content and an increase in the sand content. The degree of sorting along with organic and inorganic carbon contents fluctuates throughout these sediments with the greatest degree of sorting and inorganic carbon contents detected in sediments proximal to the top

Fig. 5.2. Field photograph of the aeolian sand dunes type vertical profile. Note: field notebook in the photograph has the dimensions of 17.7 cm X 11.0 cm.



A
Aeolian Sand Dunes Type Site
B
Outwash Plain Type Site
C
Hummocky Moraine Type Site
Depth (cm)
Facies Unit
Depositional Environment
Clay
Silt
Sand
Gravel
S126
S127
S128
S129
S130
S131
Sm (upper)
Gm(r)
Sm (lower)
Sh
Fl
Aeolian
Glaciofluvial/Aeolian
Glaciodeltaic
Glaciolacustrine
S196
S197
S198
S199
S200
S201
Fm
Sp
Glaciofluvial
S150
S151
S152
Dmm
Meltout Till

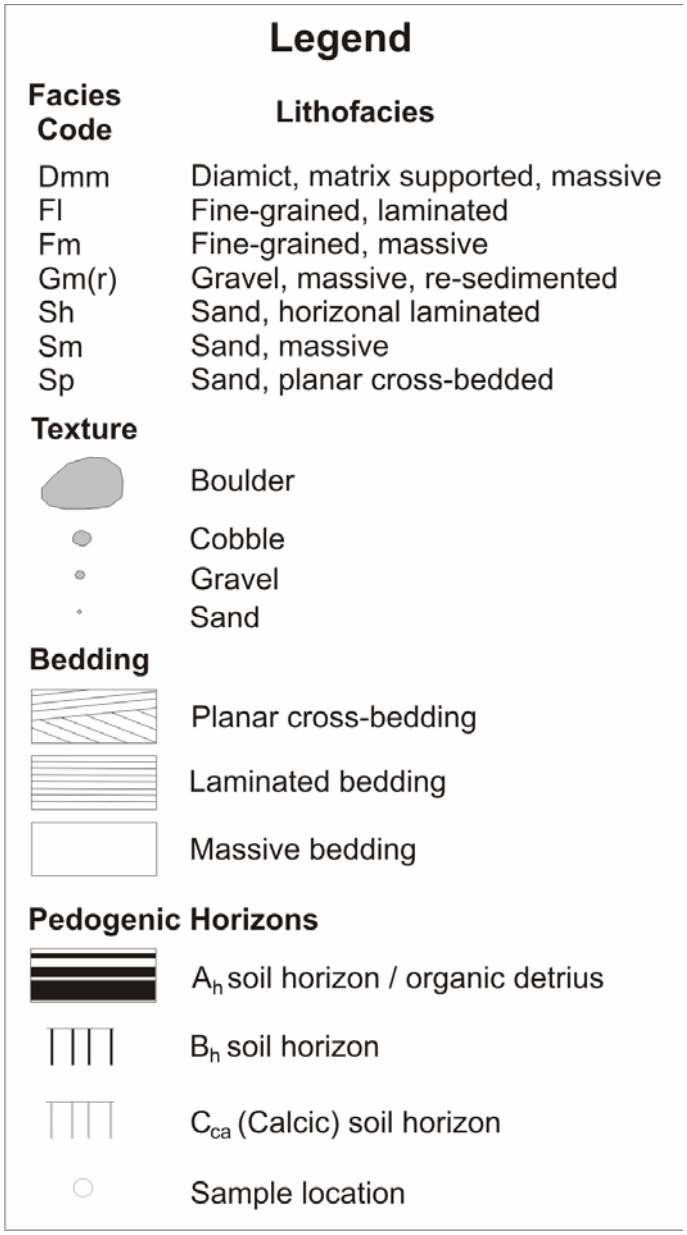


Fig. 5.3. Vertical profiles for the (A) aeolian sand dunes, (B) outwash plain, and (C) hummocky moraine type sites, depicting lithofacies units and inferred paleoenvironments within the study area.

Table 5.1. Physical properties of sediment samples collected from the aeolian sand dunes type site vertical profile.

Sample Number	S126	S127	S128	S129	S130	S131
Facies Unit	Sm	Sm	Sm	Sh	Sh	Fl
Gravel (%)	0.0	0.0	0.1	0.1	0.0	0.0
Sand (%)	73.7	85.2	94.8	91.2	97.7	89.4
Silt (%)	21.6	11.8	4.1	8.8	1.8	9.2
Clay (%)	4.6	3.0	1.0	0.0	0.4	1.4
Mean (Φ)	3.330	2.735	2.009	2.243	2.336	3.367
Standard Deviation (Φ)	2.320	2.004	1.234	1.101	0.813	1.126
Organic Carbon (%)	1.248	0.327	0.094	2.992	0.028	0.000
Inorganic Carbon (%)	0.047	0.118	0.938	0.569	0.096	0.598

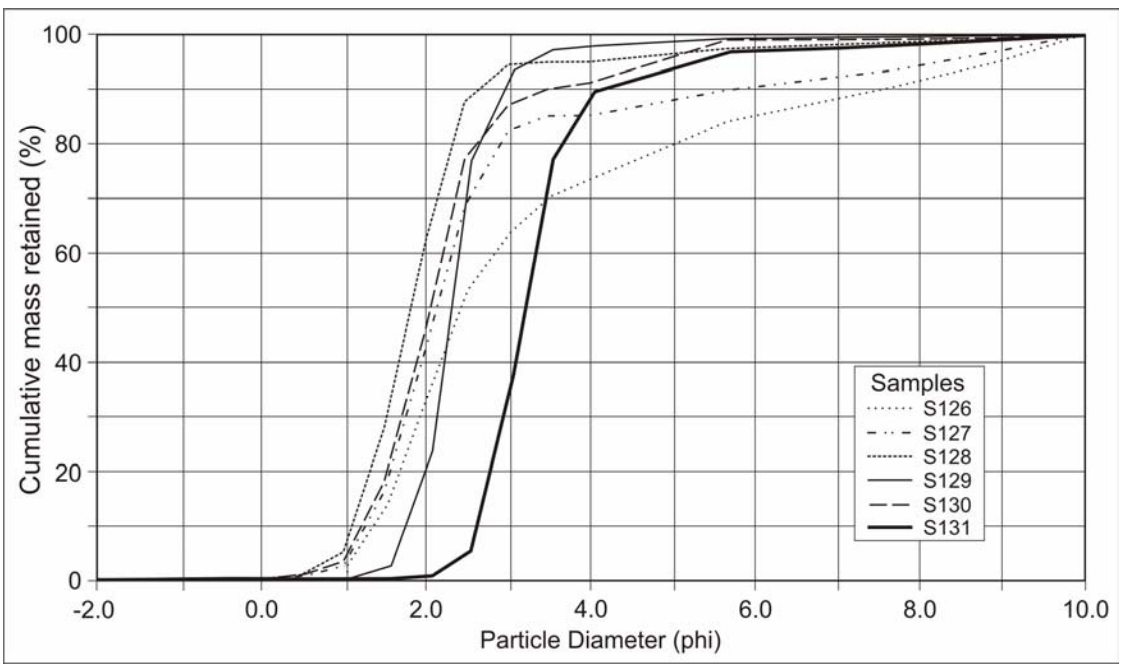


Fig. 5.4**.** Plot of particle size distribution for samples collected at the aeolian sand dunes type site vertical profile.

and bottom boundaries of the sediments. The greatest organic carbon content occurs within the Sh facies unit. A 19 cm thick very dark brown (10YR 2/2) buried A_h soil horizon overlies these sediments consisting of fine sand containing gravel to small cobble particles (Gm(r)). Coarser grains in this lithofacies unit comprise sub- to well-rounded clasts of a mixed foreign lithologies. Overlying the Gm(r) unit is a 63 cm thick upper Sm facies unit of massive olive brown (2.5Y 4/4), poorly to moderately sorted, very fine to medium sand. The upper Sm facies unit incorporates several pedogenic horizons with three poorly to moderately developed very dark grayish brown (10YR 3/2) A_h horizons. These paleosol horizons are thin, approximately 3 cm each and discontinuous throughout the upper Sm unit. In the top 23 cm of the upper Sm unit lies a moderately developed dark brown (10YR 3/3) A_h paleosol horizon at 50 cm below the top of the profile and at the top of the type site's vertical section. Sediments acquired from the upper Sm unit fines upwards as reflected by the increase of clay and silt contents and decline in sand contents. The upper Sm unit is further characterized by an upwards decline in the degree of sorting and inorganic carbon contents, in addition to the increase in organic carbon contents of the sediments.

5.1.2 Outwash Plain Type Site

The outwash plain physiographic element is distinguished by level to gently undulating topography (Fig 5.5). The outwash plain type site is located at 51º7.986'N, 106º14.790'W within a sand and gravel pit in the northeast portion of the study area (Fig. 2.2). The type site is situated 736 m a.s.l. at the base of the exposure, with the profile oriented to the southeast at a depth of approximately 125 cm below the surface (Fig. 5.6). Four lithofacies units are recognized based on field observations and 6 sediment samples were collected from the profile (Fig. 5.3). The Sp facies unit is 51 cm thick and characterized by the presence of light olive brown (10YR 5/4) planar cross-bedded sands and gravels with abundant strong brown (7.5YR 5/8) iron stained lenses and mottles in the finer grain fractions. The coarser grains present within these facies units display sub-

Fig. 5.5. Field photograph of the landforms associated with the outwash plain physiographic element.

angular to well-rounded clast morphologies of mixed foreign lithologies. Sediments in the Sp facies unit are composed of very poor to poorly sorted, medium sand (Table 5.2 & Fig. 5.7). Mean grain size declines upwards in the Sp unit with declines in gravel, silt, and clay contents, and an increase in sand contents. A 10 cm thick lower Sm unit, consisting of light olive brown (2.5YR 5/4) massive, poorly sorted medium sand, lies above the Sp unit. The top 2 cm of the lower Sm consists of a marked accumulation of white (10YR 8/1) calcium carbonate mottles, signifying the lower boundary of a C_{ca} horizon, and occasional calcium carbonate staining throughout the remainder of the facies unit. A decline in the mean grain size and gravel contents, in addition to increases in sand and silt contents, distinguish these sediments from the Sp unit. The presence or absence

Fig. 5.6. Field photograph of the outwash plain type vertical profile. Note: field notebook in the photograph has the dimensions of 17.7 cm X 11.0 cm.

Table 5.2. Physical properties of sediment samples collected in the outwash plains vertical profile.

Sample Number	S196	S197	S198	S199	S200	S201
Facies Unit	Sm	Sm	Fm	Sm	Sp	Sp
Gravel (%)	0.1	0.2	0.1	0.9	11.0	16.2
Sand (%)	53.6	68.7	38.7	86.4	82.0	74.3
Silt (%)	43.3	29.9	55.4	12.7	6.9	8.6
Clay (%)	3.1	1.2	5.8	0.0	0.0	0.9
Mean (Φ)	3.930	3.256	4.671	2.165	1.320	1.322
Standard Deviation (Φ)	2.143	1.773	2.363	1.431	1.727	2.290
Organic Carbon (%)	2.626	0.610	0.762	0.238	0.095	0.124
Inorganic Carbon (%)	0.398	0.078	0.226	0.637	1.308	1.707

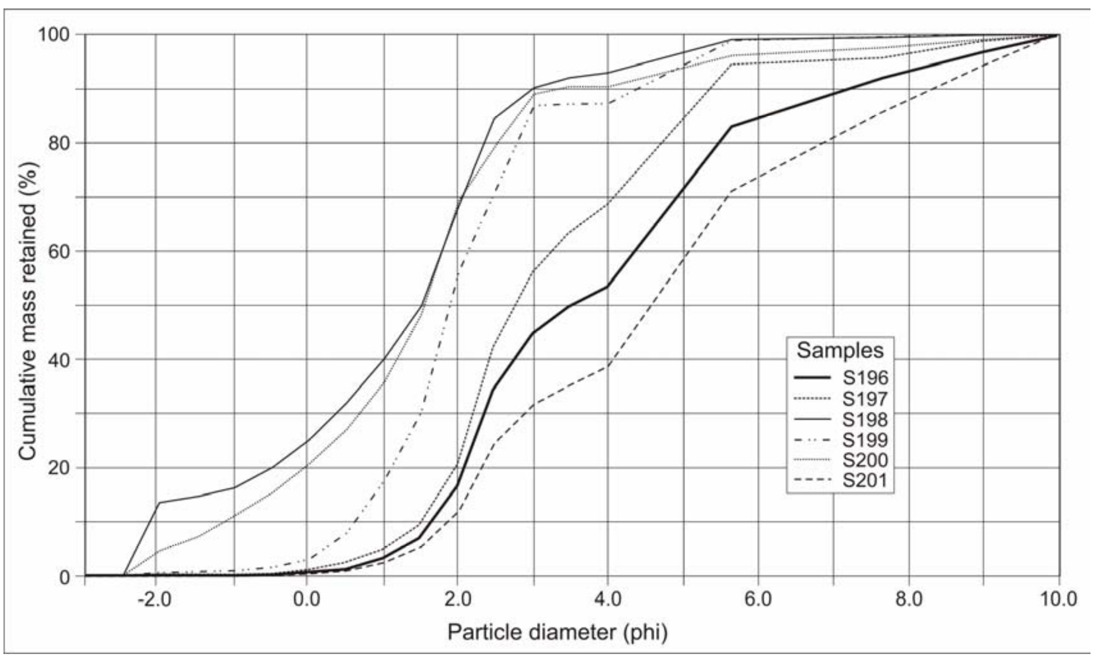


Fig. 5.7. Plot of particle size distribution for samples collected from the outwash plain type site vertical profile.

of the lower Sm unit varies within the outwash plain; this unit is missing at a number of outwash sampling site profiles. The Sp and lower Sm units are characterized by low organic carbon contents and high inorganic carbon contents, which decline within in these units.

Deposits of the Sp and lower Sm units are overlain by a Fm facies unit composed of a 25 cm thick dark brown (10YR 3/3) massive, very poorly sorted, coarse silt (Table 5.2 & Fig. 5.7). The lower 3 cm of the Fm unit is characterized by an abundance of white (10YR 8/1) calcium carbonate forming a cemented horizon, which signifies the upper boundary of a C_{ca} horizon. This unit has been identified to be the stratigraphic position for illuviation of silts and clays from the overlying units. Above the Fm, lies a 41 cm thick upper Sm facies unit composed of yellowish brown (10YR 5/4) massive, very poor to poorly sorted, very fine sand that resembles the upper Sm in the aeolian sand dunes type site vertical profile. Sand percentages decline and silt percentage increase upwards in the unit, with an 11 cm thick dark brown (10YR 3/3) well developed A_h horizon between 2 and 13 cm from the profile top. The uppermost 2 cm of this unit is a very dark grayish brown (10 YR 3/2) massive, fine sand surficial A_h horizon. In the Fm and upper Sm units, organic carbon increases upwards from 0.7% at the bottom to the buried A_h paleosol horizon exhibiting 2.6 % organic carbon. Inorganic carbon contents fluctuate in the unit with the pedologic horizons demonstrating low inorganic carbon contents ranging from 0.2 to 0.4% with trace amounts between these horizons.

5.1.3 Hummocky Moraine Type Site

The hummocky moraine physiographic element comprises of a gently non-oriented undulating topography of diamicton (Fig. 5.8). The hummocky moraine type site is situated at 51º5.767’N, 106º11.574’W along a road cut on the western crest of a coulee (Fig. 5.9). The profile is locate at approximately 707 m a.s.l. at the exposure base,

Fig. 5.8. Field photograph of landforms associated with the hummocky moraine physiographic element.

oriented northwards, and extending about 122 cm below the surface, where 3 sediment samples were acquired. The hummocky moraine consists of a single lithofaces unit, the Dmm facies (Fig. 5.3). The top 19 cm of this vertical profile consist of a well developed surficial dark brown (10YR 3/3) A_h horizon with an associated well developed light grey (10 YR 6/2) C_{ca} horizon between 19 to 81 cm below the profile top. These horizons consist of very poor to poorly sorted, very fine to fine sand. A unit of dark brown (10YR 3/3) massive, poorly sorted, medium-grained sand occurs beneath these pedogenic horizons (Table 5.3 & Fig. 5.10). The Dmm facies unit contains of unsorted sub-angular to sub-rounded gravel to small boulder size clasts of mixed, foreign lithologies. A_h soil

Fig. 5.9. Field photograph of the hummocky moraine type vertical profile. Note: field notebook in the photograph has the dimensions of 17.7 cm X 11.0 cm.

Table 5.3. Physical properties of sediment samples collected at the hummocky moraine type site vertical profile.

Sample Number	S150	S151	S152
Facies Unit	Dmm	Dmm	Dmm
Gravel (%)	33.4	1.1	24.4
Sand (%)	28.4	46.6	40.6
Silt (%)	34.2	51.3	35.0
Clay (%)	4.0	1.1	0.0
Mean (Φ)	2.273	3.731	2.129
Standard Deviation (Φ)	3.772	1.705	2.963
Organic Carbon (%)	4.925	0.435	0.128
Inorganic Carbon (%)	0.416	2.263	2.353

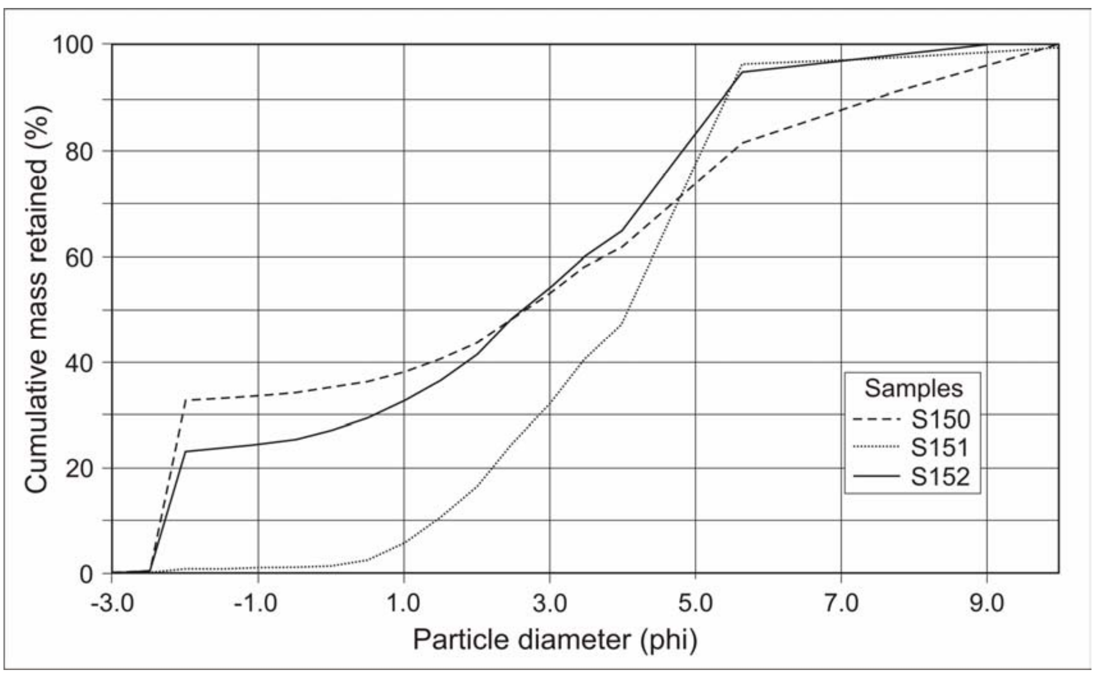


Fig. 5.10. Plot of particle size distribution of samples collected at the hummocky moraine type site vertical profile.

horizon organic carbon contents are high at 5.0 %, but the quantity of organic carbon decreases downwards through the C_{ca} and C horizons from 0.4 and 0.1%, respectively. Inorganic carbon contents are low at the A_h horizon of 0.4%, but increases downwards through the C_{ca} and C horizons at 2.3 and 2.4 % respectively. Detailed sediment sampling locations and characteristics are described in Appendix C.

5.1.4 Radiocarbon Dating

Four bulk radiocarbon samples of wood, charcoal, and a paleosol were collected from the aeolian sand dunes and outwash plain type sites' profiles to attempt to obtain a chronology for the depositional environments. Results from the Brock University Radiocarbon Laboratory provided dates for only two of the samples that are described in Appendix D. The radiocarbon laboratory failed to supply accurate dates for the other two organic samples. The two samples where radiocarbon dates were obtained from charcoal and a paleosol were acquired from the aeolian sand dunes type site near the bounding surfaces of the lower Sm and upper Sm facies units with calibrated dates of 18,435 ± 100 years BP (BGS 2497) and 30,660 ± 470 years BP (BGS 2498), respectively. These radiocarbon dates are significantly greater than anticipated, based on their situation in the post-glacial stratigraphy, indicating contamination from ancient carbon sources and for these reasons are rejected for this study. A potential contributor to contamination by 'old' carbon is the Cretaceous shale that underlies the study area and was introduced into surficial deposits by Pleistocene glacial dynamics.

5.2 Environmental Characteristics of Archaeological Site Distributions

5.2.1 Archaeological Database

A total of 387 archaeological sites have been identified within the Elbow Sand Hills and the surrounding South Saskatchewan River valley study area: 95 of these sites have recognized cultural affiliations, and 47 sites are multi-component sites. The majority of these sites are surface finds: only a few detailed investigations on excavation sites have been completed, including the Melhagen site (Ramsey 1991), the Sjovold site (Dyck and

Morlan 1995), the EgNn-9 site (Neal 2006), and the EgNo-23 site (Webster 2004; Neal 2006). All cultural complex phases and periods are represented by recovered artifacts at archaeological sites in varying quantities (Fig. 5.11). Large quantities of sites originating from the Middle Middle Prehistoric to the Late Prehistoric cultural periods (5.0 – 0.17 ka BP) have been recorded in the study area. Cultural complex phases including McKean, Pelican Lake, and Besant were observed to have particularly large amounts of recovered artifacts within the region. Low quantities of sites with artifacts dating from the Paleo-Indian to the Early Middle Prehistoric cultural periods (12.0 – 5.0 ka BP) have been recorded. Cultural artifacts derived from the Clovis, Folsom, and Mummy Cave series complex phases been recovered in small quantities.

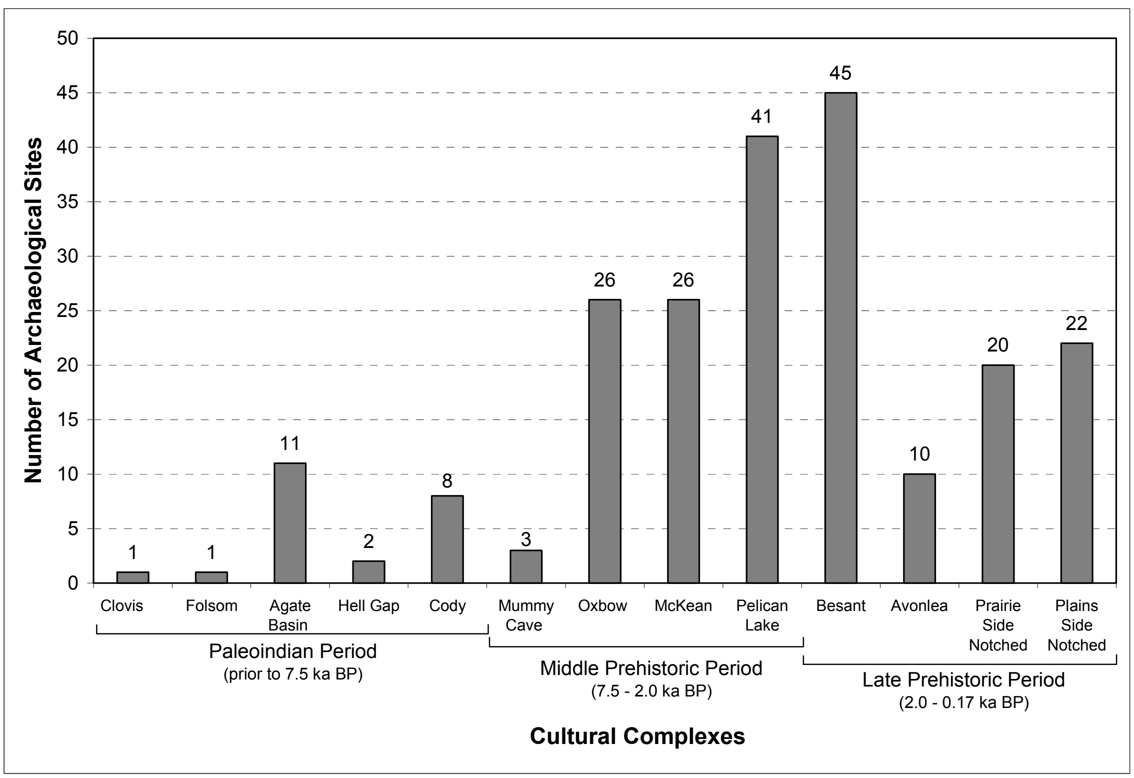


Fig. 5.11**.** Number of archaeological sites derived from each cultural complex phase in the study area.

Distinct settlement patterns were observed in relation to physiographic, surface hydrologic, and topographic elements. Cultural contents and site types, however, were noted to exhibit no apparent spatial distribution patterns according to any of these environmental characteristics. This could be a consequence of the poor description and categorization of site contents and types within the archival archaeological database.

5.2.2 Physiographic Elements

5.2.2.1 Archaeological Sites

Five dominant physiographic elements were recognized within the study area: 1. aeolian sand dunes, 2. glaciofluvial plains, 3. glaciolacustrine plains, 4. hummocky moraine, and 5. glacial meltwater spillways (Fig. 5.12). Mapping the distribution of the archaeological sites revealed that particular physiographic elements exhibited greater quantities of sites located within their boundaries than others. The largest quantities of archaeological sites were observed to be situated within the meltwater spillways and hummocky moraine (Fig. 5.13). Smaller quantities of archaeological sites were detected within the aeolian sand dunes, glaciofluvial plains, and glaciolacustrine plains. Chi-square test results indicate significant statistical differences between the expected and observed archaeological site quantities within the physiographic elements, where the null hypothesis can be rejected and the alternate hypothesis can be accepted (Table 5.4). The standardized residual test values indicate that thefive physiographic elements were significant contributors to settlement densities in the physiographic elements. The glaciofluvial plains, meltwater spillways, glaciolacustrine plains, and aeolian sand dunes were significant contributors to differences in the chi-square test value, where a greater number of sites occurred within these physiographic elements than what were expected. This is particularly evident for the aeolian sand dunes according to this physiographic

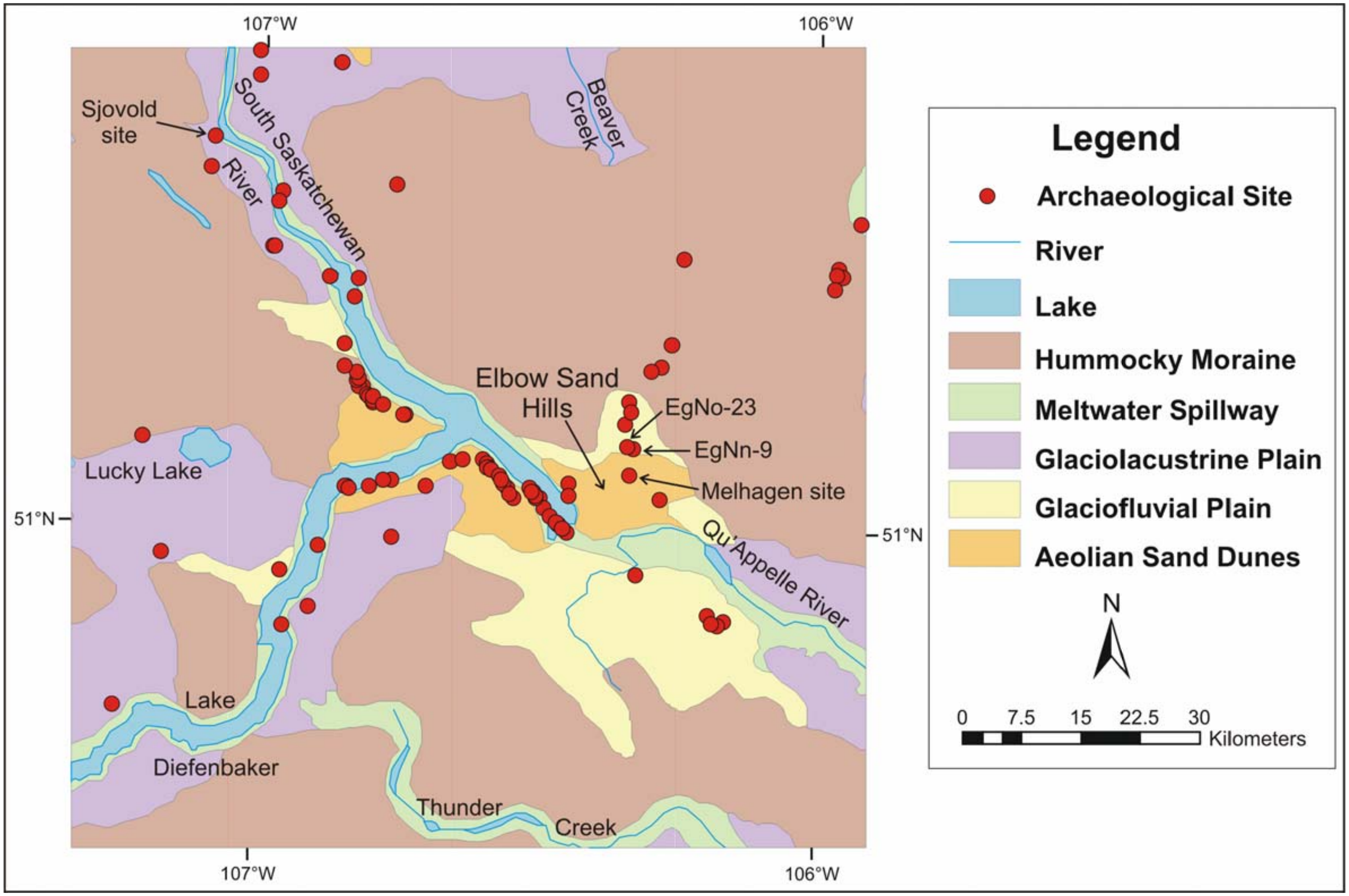


Fig. 5.12. Archaeological site distribution with cultural affiliations according to the physiographic elements in the Elbow Sand Hills and surrounding South Saskatchewan River valley study area.

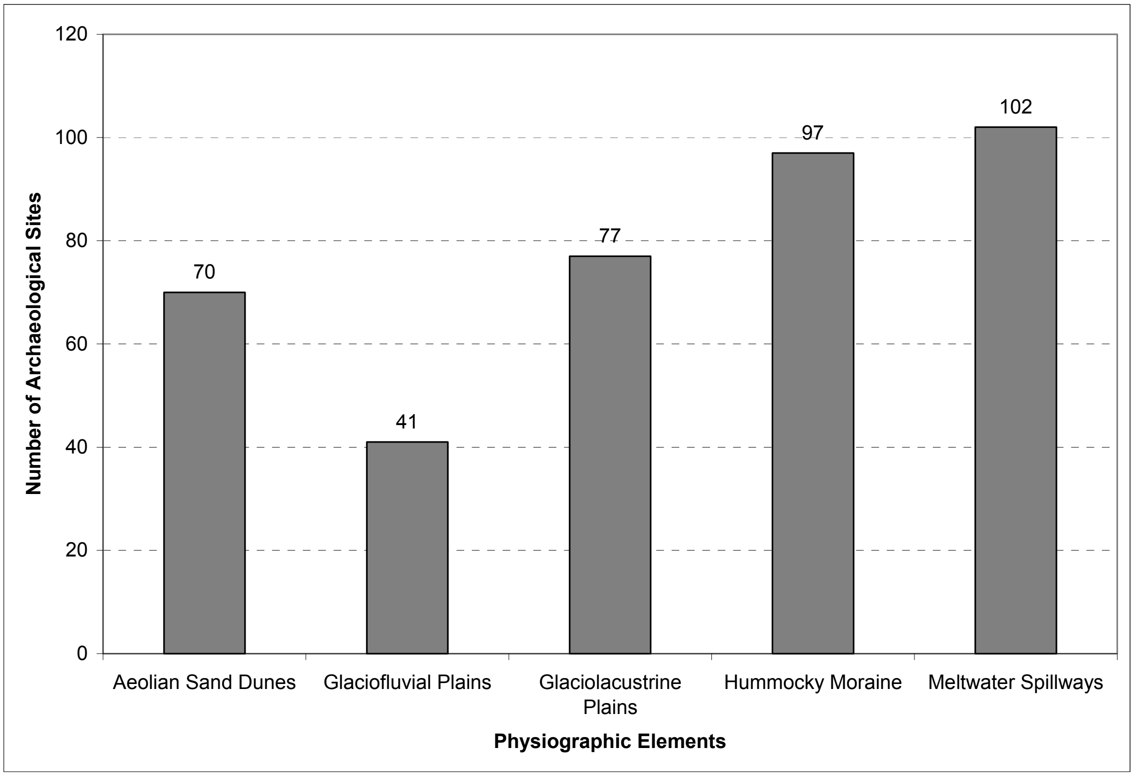


Fig. 5.13. Distribution of the total number of archaeological sites according to the physiographic elements in the study area.

element's large quantity of sites in relation to its surface area and high standardized residual test value as compared to the other physiographic elements. The hummocky moraine demonstrated a large significant negative standardized residual value, which signifies that the moraine was a significant contributor to lower site quantities occurring than expected.

5.2.2.2 Archaeological Sites with Cultural Affiliations

A similar distribution pattern emerges from the examination of the locations of archaeological sites with cultural affiliations. More archaeological sites with cultural affiliations were situated within the glacial meltwater spillways and aeolian sand dunes

Table 5.4. Chi-square and standardized residual tests results for archaeological site distributions according to the physiographic elements in the study area.

A) Total Number of Archaeological Sites

Physiographic Elements	Percent of Area	Actual Sites	Expected Sites	Chi-Square	Standardized Residual
Aeolian Sand Dunes	3.3	70	12.8	256.453	16.0 [a]
Glacial Meltwater Spillways	14.9	102	57.7	34.091	5.8 [a]
Glaciofluvial Plains	7.1	76	27.5	85.689	9.3 [a]
Glaciolacustrine Plains	17.7	97	68.5	11.859	3.4 [a]
Hummocky Moraine	57.0	42	220.6	144.587	-12.0 [a]
Total	100.0	387	387.0	$\chi^2 = 523.343$ *	

B) Archaeological Sites with Cultural Affiliations

Physiographic Elements	Percent of Area	Actual Sites	Expected Sites	Chi-Square	Standardized Residual
Aeolian Sand Dunes	3.3	30	3.1	230.216	15.2 [a]
Glacial Meltwater Spillways	14.9	27	14.2	11.656	3.4 [a]
Glaciofluvial Plains	7.1	13	6.7	5.801	2.4 [a]
Glaciolacustrine Plains	17.7	11	16.8	2.011	-1.4
Hummocky Moraine	57.0	14	54.2	29.770	-5.5 [a]
Total	100.0	95	95.0	$\chi^2 = 279.454$ *	

* Significant at $p \leq 0.001$

[a] Major contributor to the significant chi-square value

(Figs. 5.12 & 5.14), relative to archaeological sites with cultural affiliations that were recorded in the hummocky moraine, glaciofluvial plains, and glaciolacustrine plains. This pattern of site distributions within various physiographic elements is confirmed on the site density map (Fig. 5.15). The greatest site densities are recorded in the meltwater spillways and aeolian sand dunes in addition to other localities in close proximity to permanent water resources, notably the South Saskatchewan and Qu'Appelle Rivers, with site densities demonstrated to be frequently greater than 0.300 per 5000 km^2. The lowest site densities are observed in the hummocky moraine, glaciofluvial plains, and glaciolacustrine plains, as well as other localities distal from permanent water resources, with site densities demonstrated to be frequently less than 0.300 per 5000 km^2.

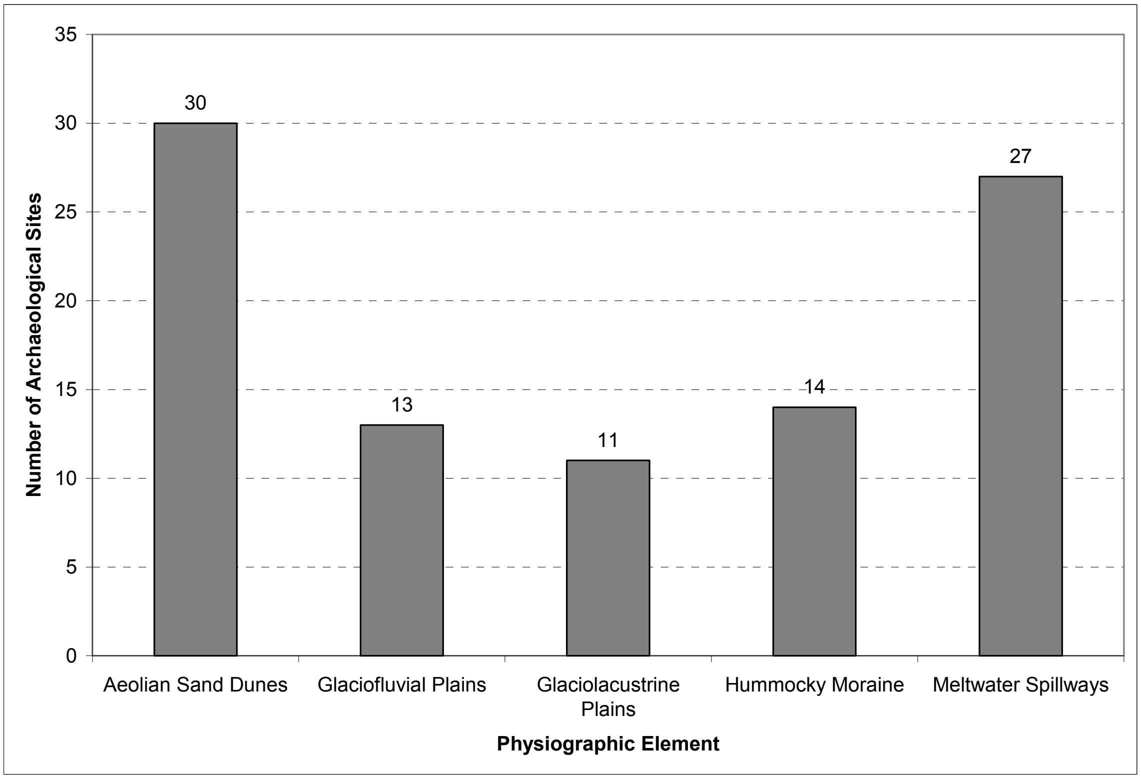


Fig. 5.14. Number of archaeological sites with cultural affiliations located within each physiographic element in the study area.

Distribution of archaeological sites with cultural affiliations in relation to the physiography demonstrated a significant chi-square test value, indicating statistical differences between the expected and observed site numbers, which permits the rejection of the null hypothesis and acceptance of the alternate hypothesis (Table 5.4). The positive significant standardized residual test values calculated for the glaciofluvial plains, meltwater spillways, and aeolian sand dunes signify that these elements were significant contributors to differences in the chi-square test, where a greater quantity of sites than expected occurred within these landforms. The aeolian sand dunes were a particular contributor to an increased quantity of sites based on the larger standardized residual

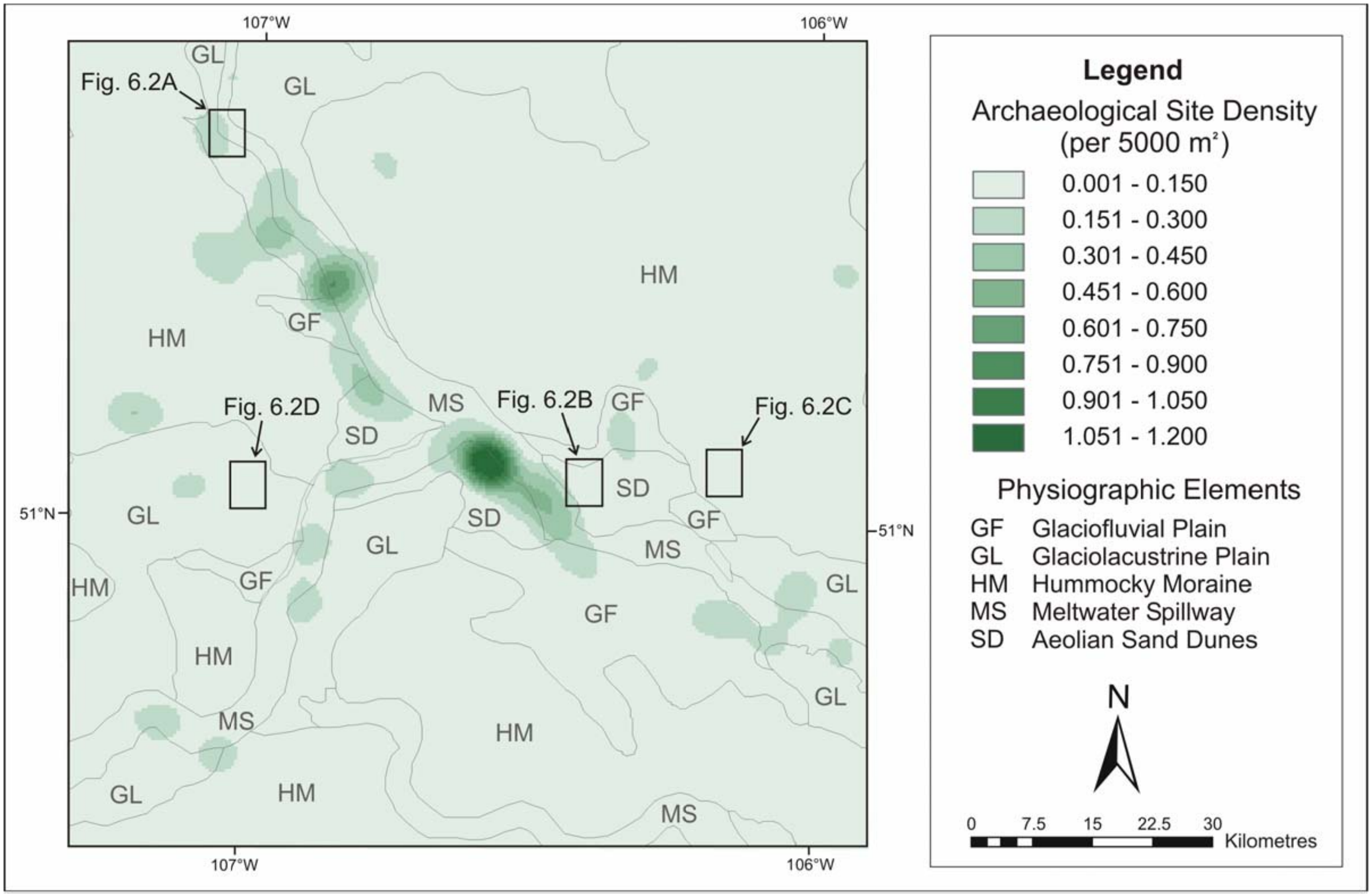


Fig. 5.15. Archaeological site density map in relation to the physiographic elements in Elbow Sand Hills and the surrounding South Saskatchewan River study area.

value in relation to the remainder of the physiographic elements. The hummocky moraine physiographic element was a major negative contributor to the chi-square test, where significantly fewer sites were present within the moraine than expected. The glaciolacustrine plains were determined not to be a contributing factor in the chi-square test.

The clustering of archaeological sites with cultural affiliations within the glacial meltwater spillways and aeolian sand dunes persists throughout the cultural chronology (Fig. 5.16). The number of sites dating from each cultural period fluctuates in relation to the various physiographic elements. Low site quantities located in the hummocky moraine, glaciofluvial plains, and glaciolacustrine plains persisted throughout each cultural period. The glaciolacustrine plains and hummocky moraine display approximately equal proportions of sites from each cultural period with small differences between periods. Large differences in the proportions of sites among the three cultural periods were detected in the aeolian sand dunes, glaciofluvial plains, and hummocky moraine. Chi-square test values for each cultural period suggest significant differences between the observed and the expected number of sites within the physiographic elements, where the null hypothesis can be rejected and the alternate hypothesis can be accepted (Table 5.5). Standardized residual test values for each cultural period reveal that the meltwater spillways and aeolian sand dunes demonstrate significant positive standardized residual test values and are significant contributors to greater quantities of sites occurring in these physiographic elements than expected. The hummocky moraine exhibited significant negative standardized residual test values for each cultural period

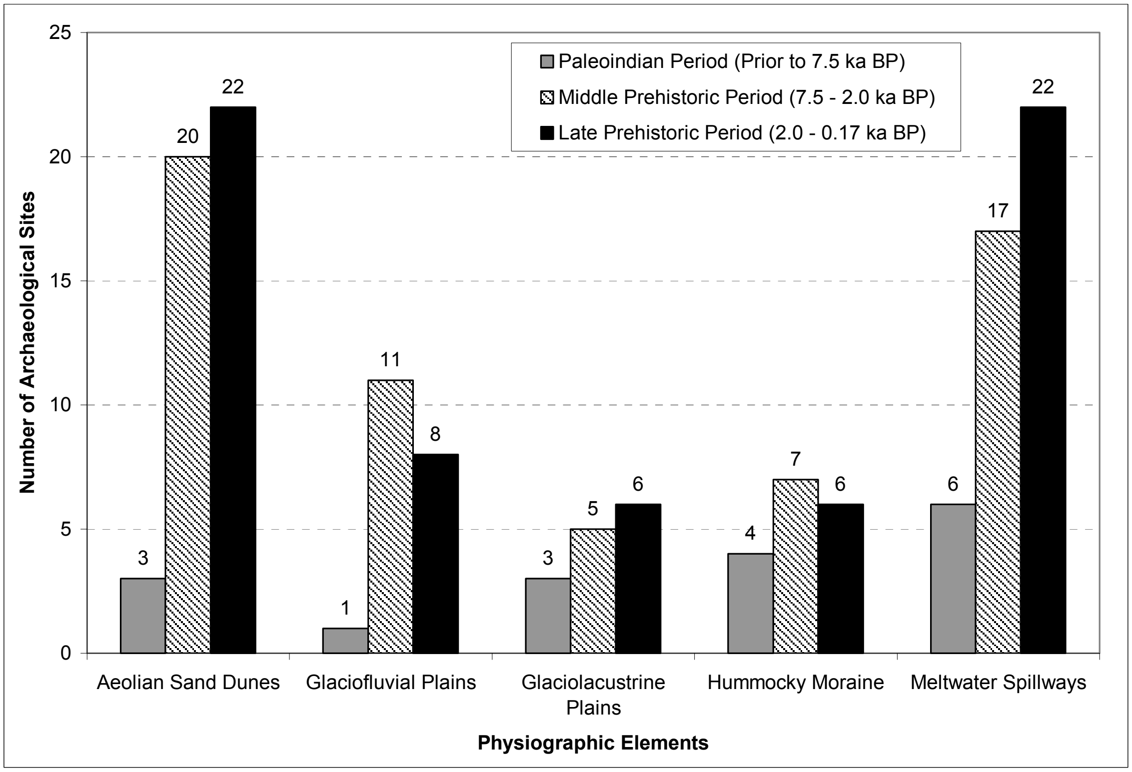


Fig. 5.16. Number of archaeological sites originating from each cultural period situated in the physiographic elements represented in the study area.

and was a significant contributor to lower quantities of sites. The glaciofluvial plains and glaciolacustrine plains demonstrated insignificant standardized residual test values during each cultural period indicating that these physiographic elements were not significant contributors to settlement patterns. An exception occurs with the glaciofluvial plains during the Middle Prehistoric period, where the physiographic element exhibited a significant positive standardized residual test value. This suggests that the glaciofluvial plains were a significant contributor towards a greater number of sites occurring in the physiographic element than expected during the Middle Prehistoric period.

The high concentration of precontact settlement activities within the meltwater

Table 5.5. Chi-square and standardized residual tests results for archaeological site distribution according to the physiographic elements for the three cultural periods in the study area.

A) Paleoindian period

Physiographic Elements	Percent of Area	Actual Sites	Expected Sites	Chi-Square	Standarized Residual
Aeolian Sand Dunes	3.3	3	0.6	40.641	3.3 [a]
Glacial Meltwater Spillways	14.9	6	2.5	4.789	2.2 [a]
Glaciofluvial Plains	7.1	1	1.2	0.162	-0.2
Glaciolacustrine Plains	17.7	3	3.0	0.138	0.0
Hummocky Moraine	57.0	4	9.7	5.307	-1.8
Total	100	17	17.0	$\chi^2 = 51.037$ *	

B) Middle Prehistoric period

Physiographic Elements	Percent of Area	Actual Sites	Expected Sites	Chi-Square	Standarized Residual
Aeolian Sand Dunes	3.3	19	1.9	152.524	12.4 [a]
Glacial Meltwater Spillways	14.9	16	8.6	6.265	2.5 [a]
Glaciofluvial Plains	7.1	11	4.1	11.501	3.4 [a]
Glaciolacustrine Plains	17.7	5	10.3	2.701	-1.6
Hummocky Moraine	57	7	33.1	20.542	-4.5 [a]
Total	100	58	58.0	$\chi^2 = 193.534$ *	

C) Late Prehistoric period

Physiographic Elements	Percent of Area	Actual Sites	Expected Sites	Chi-Square	Standarized Residual
Aeolian Sand Dunes	3.3	22	2.1	187.279	13.7 [a]
Glacial Meltwater Spillways	14.9	22	9.5	16.291	4.0 [a]
Glaciofluvial Plains	7.1	8	4.5	2.629	1.6
Glaciolacustrine Plains	17.7	6	11.3	2.506	-1.6
Hummocky Moraine	57	6	36.5	25.467	-5.0 [a]
Total	100	64	64.0	$\chi^2 = 234.171$ *	

* Significant at $p \leq 0.001$

[a] Major contributor to the significant chi-square value

spillways and aeolian sand dunes, and to a lesser degree in the hummocky moraine, is exhibited throughout all of the cultural complex phases (Table 5.6). The majority of the cultural complex phases originating from the Paleo-Indian and Early Middle Prehistoric periods were detected to have exhibit insignificant chi-square and standardized residual test values. The chi-square test values for the Paleo-Indian and Early Middle Prehistoric cultural complex phases indicate of insignificant differences between the observed and expected number of sites, where the null hypothesis can be accepted and the alternate hypothesis can be rejected. These outcomes are realized because of the low site quantities from these cultural complex phases in the study area. Agate Basin and other cultural complex phases originating from the Middle Middle to Late Prehistoric periods were found to exhibit significance differences between the observed and expected number of sites, where the null hypothesis can be rejected and the alternate hypothesis can be accepted. The meltwater spillways and aeolian sand dunes were physiographic elements that demonstrated positive significant standardized residual test values and were significant contributors to greater site quantities than expected for these cultural complex phases. The hummocky moraine for the Agate Basin and other cultural complex phases during the Middle Middle Prehistoric to Late Prehistoric periods were noted to have negative significant standardized residuals and were a significant contributor to a lower number of sites than expected.

5.2.3 Permanent Water Resources

The distribution of archaeological sites in relation to distances from permanent water resources (i.e., major rivers, streams, and lakes) can be divided into three

Table 5.6. Chi-square and standardized residual tests results for archaeological site distribution according to the physiographic elements for individual cultural complexes in the study area.

Cultural Complexes	**Chi-Square Test Values**	**Standardized Residual Test Values**				
		Aeolian Sand Dune	Meltwater Spillways	Glaciofluvial Plains	Glaciolacustrine Plains	Hummocky Moraine
Clovis	0.754	-0.2	-0.4	-0.3	-0.4	0.6
Folsom	4.650	-0.2	-0.4	-0.3	2.0 [a]	-0.8
Agate Basin	31.261 *	4.4 [a]	2.6 [a]	-0.9	0	-2.1 [a]
Hell Gap	2.233	-0.3	1.3	-0.4	-0.6	-0.1
Cody	4.606	1.4	0.7	0.6	0.5	-1.2
Mummy Cave	17.134 **	-0.3	3.8 [a]	-0.5	-0.7	-1.3
McKean	137.166 *	10.9 [a]	1.6	1.6	-1.7	-3.1 [a]
Pelican	122.541 *	9.2 [a]	2.8 [a]	3.6 [a]	-2.0 [a]	-3.8 [a]
Besant	187.966 *	12.7 [a]	2.8 [a]	0.5	-1.1	-4.1 [a]
Avonlea	13.401 *	2.9 [a]	0.4	1.5	0.2	-1.5
Prairie Side-notched	54.650 *	6.6 [a]	1.7	1.3	-1.3	-2.2 [a]
Plains Side-notched	83.808 *	7.4 [a]	2.1 [a]	3.6 [a]	-2.0 [a]	-3.0 [a]

* Significant at $p \leq 0.001$

** Significant at $p \leq 0.01$

[a] Major contributor to the significant chi-square value

categories. The greatest quantities of sites were situated within the first 5 kilometres from major permanent water resources (category 1) (Figs. 5.17 & 5.18); approximately 72 % of the archaeological sites are positioned between 0 and 5.0 km from permanent water resources. Category 2 contains all of the sites located between 5.1 to 13.0 km from permanent water resources; 20 % of sites are situated within this interval. Few sites were recorded at distances between 13.1 to 24.0 km (category 3), which consists 8 % of sites. Chi-square test results indicates a significance in the distribution of sites in relation to the distance from water resources, where the null hypothesis can be rejected and the alternate hypothesis can be accepted. Distance intervals associated with category 1 were observed to be significant contributors to greater than expected site quantities, based on the standardized residual tests values (Table 5.7). The standardized residuals test values further suggest that distance intervals associated with category 3 as well as intervals 11.1 – 12.0 km and 13.1 – 14.0 km were significant contributors to greater than expected site quantities, based on the standardized residual tests values (Table 5.7). The standardized residuals test values indicates that distance intervals associated with category 3 as well as intervals 11.1 – 12.0 km and 13.1 – 14.0 km were significant contributors to lower site quantities than expected. Distance intervals within category 2 were noted to have generally insignificant standardized residual tests values, and were not significant contributors to the differences in the chi-square test.

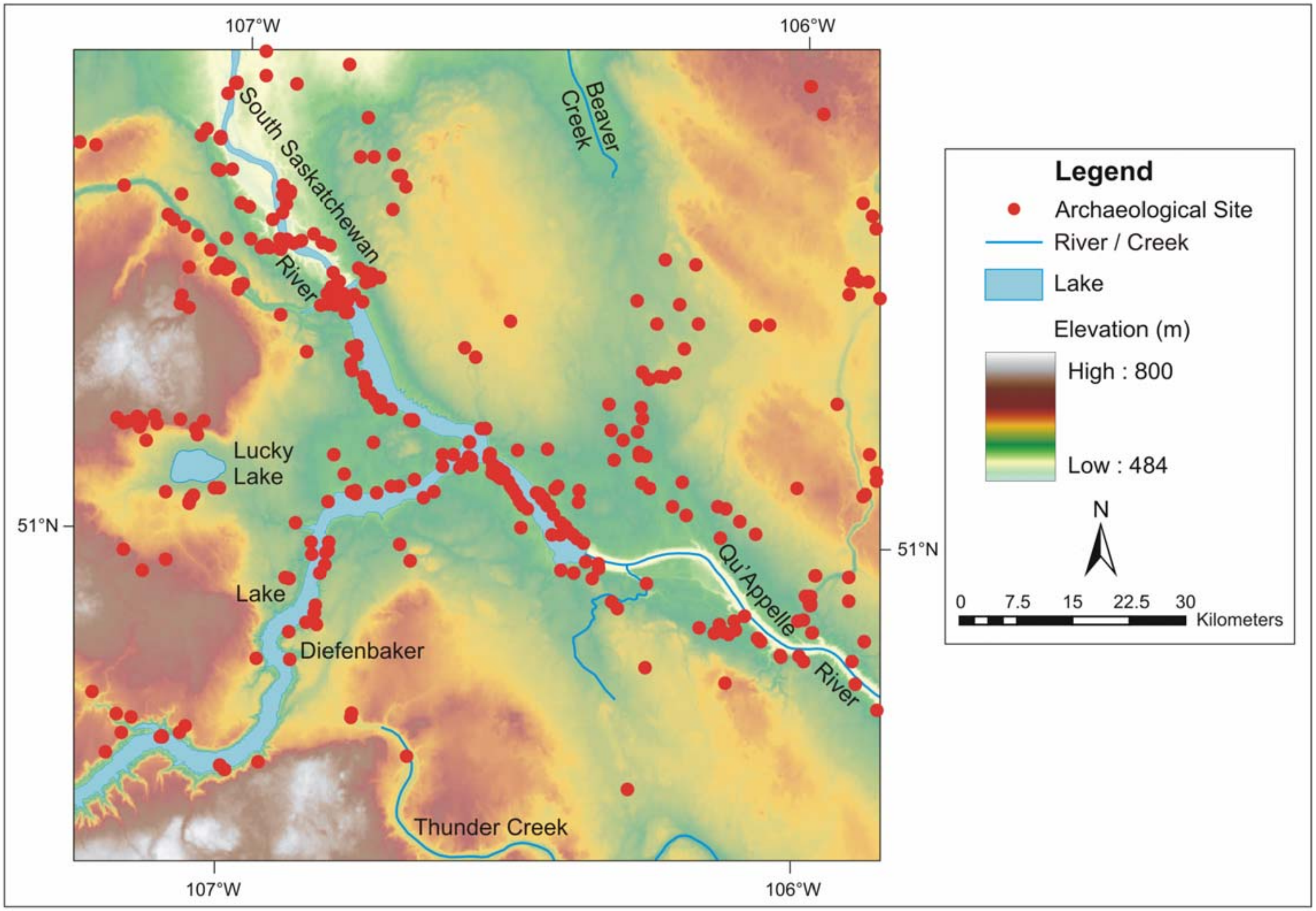


Fig. 5.17. Distribution of archaeological sites in relation to the topography in the Elbow Sand Hills and the surrounding South Saskatchewan River valley study area.

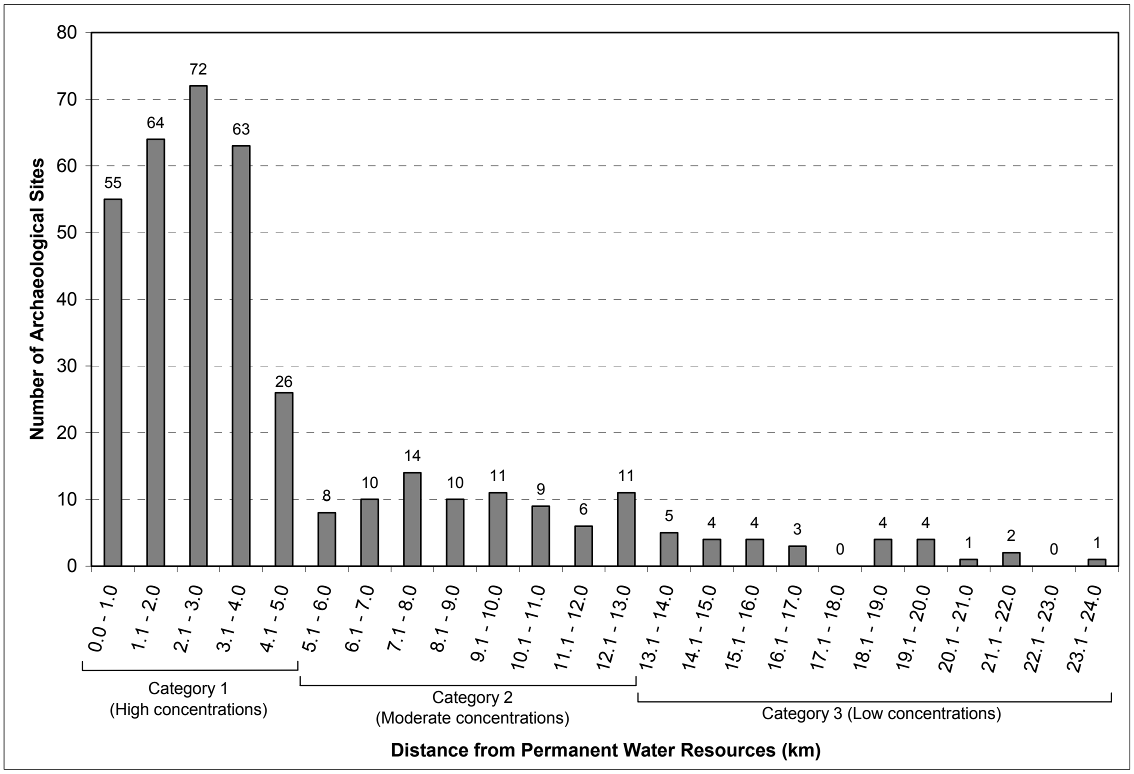


Fig. 5.18. Distribution of the total number of archaeological sites according to the distance from surface water in the study area.

Table 5.7. Chi-square test results for the total number of archaeological sites according to distances from permanent water resources in the study area.

Total Number of Archaeological Sites

Distance from Water	Percent of Area	Actual Sites	Expected Sites	Chi-Square	Standardized Residual
0.0 - 1.0	2.9	55	11.2	170.759	13.1 [a]
1.1 - 2.0	3.0	64	11.6	236.409	15.4 [a]
2.1 - 3.0	3.0	72	11.6	314.122	17.7 [a]
3.1 - 4.0	3.1	63	12.0	216.830	14.7 [a]
4.1 - 5.0	3.2	26	12.4	14.971	3.9 [a]
5.1 - 6.0	3.3	8	12.8	1.782	-1.3
6.1 - 7.0	3.5	10	13.5	0.928	-1.0
7.1 - 8.0	3.6	14	13.9	0.000	0.0
8.1 - 9.0	3.7	10	14.3	1.303	-1.1
9.1 - 10.0	3.8	11	14.7	0.934	-1.0
10.1 - 11.0	3.9	9	15.1	2.460	-1.6
11.1 - 12.0	4.0	6	15.5	5.806	-2.4 [a]
12.1 - 13.0	4.2	11	16.3	1.698	-1.3
13.1 - 14.0	6.0	5	23.2	14.297	-3.8 [a]
14.1 - 15.0	2.3	4	10.1	3.652	-1.9
15.1 - 16.0	4.3	4	16.6	9.602	-3.1 [a]
16.1 - 17.0	4.4	3	17.0	11.557	-3.4 [a]
17.1 - 18.0	4.5	0	17.4	17.415	-4.2 [a]
18.1 - 19.0	4.6	4	17.8	10.701	-3.3 [a]
19.1 - 20.0	4.6	4	17.8	10.701	-3.3 [a]
20.1 - 21.0	4.6	1	17.8	15.858	-4.0 [a]
21.1 - 22.0	4.7	2	18.2	14.409	-3.8 [a]
22.1 - 23.0	4.8	0	18.6	18.576	-4.3 [a]
23.1 - 24.0	4.8	1	18.6	16.630	-4.1 [a]
24.1-25.0	4.9	0	19.0	18.963	-4.4 [a]
Total	100.0	387	387.0	$\chi^2 = 1130.361$*	

* Significant $p \leq 0.001$

[a] Major contributor to the significant chi-square value

CHAPTER 6
DISCUSSION

6.1. Paleoenvironmental Reconstruction

6.1.1 Late Pleistocene Environment

The Elbow Sand Hills and the adjacent landscape have endured significant environmental changes since deglaciation. The diamicton (Dmm facies) exhibits sedimentologic properties similar to the Battleford Formation till described by Christiansen (1968) and (1971); consists of massive, poorly sorted, medium sand with sub-angular to sub-rounded clast morphologies of mixed, foreign lithologies (Fig. 5.9). The Dmm facies is distinguished from older Floral and Sutherland tills by the coarser grain size distribution, the absence of iron and manganese oxide staining, and the dark brown to dark gray colours that are characteristics of the Battleford Formation till. Researchers have contributed a number of geomorphic models towards the development of the hummocky moraine landscape on the Canadian Plains (e.g., Gravenor and Kupusch 1959; Munro and Shaw 1997; Eyles *et al*. 1999)). This diamicton is interpreted as supraglacial meltout till deposited by the stagnation and collapse of the Laurentide Ice Sheet ca. 15 to 18 ka BP. Hummocky moraine is derived from meltout till (or ablation till) deposited through the gradual release of debris originating from the upper surface of stagnant glacial ice (Whiteman 2002). The massive structure and the low clay content in the Dmm facies reflect rapid sedimentation of coarse-grained tills through the release of meltwater in a supraglacial environment. The occurrence of irregular, non-orientated knob and kettle topography (see Fig. 6.2D), and the absence of streamlined glacial landforms (such as drumlins and flutings) in this low-lying region (c.f., Scott 1971) indicate of supraglacial origins of the Dmm facies and the hummocky moraine rather than formation through subglacial meltwater erosion (Munro and Shaw 1997) or ice sheet deformation processes (Eyles *et al.* 1999). Physiographic elements associated with ice sheet stagnation include the hummocky moraine and outwash plains. The Dmm facies occurs at the surface within the hummocky moraine physiographic element, but lies beneath thick aeolian, glaciofluvial, glaciodeltaic, and glaciolacustrine deposits in the surrounding physiographic elements.

Immediately following deglaciation ca. 13.0 ka BP, the retreating ice sheet released large volumes of glacial meltwater through glaciofluvial channels in front of the ice sheet into proglacial Lake Birsay, inundating large sections of the study area between 13.0 to 12.0 ka BP. The rounded clast morphologies observed in Sp facies unit indicate a glaciofluvial origin for these sediments. The preservation of massive and planar cross-bedded sand and gravel observed in the lower Sm and Sp facies units at the field sampling sites throughout the outwash plain (Fig. 5.6) are generated in proglacial braided river environments (Maizels 2002). The poorly sorted nature of sediments in the Sp and lower Sm lithofacies units at outwash plain sampling sites are indicative of rapid sedimentation in ice-proximal environments (Church and Gilbert 1975). Primary sedimentary structures in these units record the migration of bar and dune bedforms under a high discharge flow regime. The massive structure of the lower Sm unit is indicative of high sedimentation rates occurring across the outwash plain at this site. These braided channels flowed from the ice sheet terminus towards Glacial Lake Birsay, where glaciofluvial channel orientation can be implied by the spatial decline in the gravel fraction and mean grain size of the outwash sediments in a general southwest direction. The rate of downstream decrease in grain size and increase degree of sorting is significantly related to the rate of decline in channel gradient attributed to an increase in abrasion and the selective sorting of sediments (Maizels 2002).

Rhythmically laminated, moderately sorted, fine-grained sand and silt deposited as the Fl unit at the aeolian sand dunes type site (Fig. 5.2) have been interpreted to be associated with Glacial Lake Birsay (c.f., Scott 1971). The lower portions of the Fl unit record the intermittent deposition of fine sand (during the summer) and silts and clays (in the winter) couplets, as a result of varying seasonal sedimentary accumulation conditions in deep water, low energy glaciolacustrine environment distal from the ice sheet terminus, typically below the lake's thermocline (Ashley 2002). The upward increase in the thickness of alternating massive sand and organic detrius beds as well as grain size in the Sh and lower Sm facies units reflects a shift to a near-shore glaciolacustrine environment. These changes in sedimentologic properties mark the increase in sedimentation rates from a prograding delta into Glacial Lake Birsay. Deltas in a glacial environment are formed at stagnating ice sheet termini, which are fed by meltwater streams that originate in active ice and discharge into the glacial lake (Ashley 2002). The organic detritus beds rich with charcoal flakes were reworked from the surrounding landscape into near-shore, high energy glaciodeltaic environments. The preservation of charcoal flakes within the organic detritus beds in the upper glaciodeltaic deposits of the Sh facies unit imply extensive fire regimes on the adjacent landscape of Late Pleistocene age proximal to the final stages of Glacial Lake Birsay. These latter stages of Glacial Lake Birsay correlate to the onset of the early open spruce parkland interval signifying of abundant wood supply in the landscape during this period. The Sh facies unit does not correspond to the nearby Andrews site zone IV (Yansa 1998; Yansa and Basinger 1999) or unit L2 (Aitken *et al.* 1999) despite the similar sedimentary characteristics of these units: the Andrews site's sandy clay unit abundant in charcoal flakes (zone IV or unit L3) has been dated between 8.8 and 7.7 ka BP, significantly later than the Sh unit which was deposited between 13.0 and 12.0 ka BP. The earlier age of the Sh unit suggests the occurrence of frequent, extensive Late Pleistocene fires transpiring within the open spruce woodlands that contributed to charcoal flakes preserved within the upper portions of the Sh unit. The lower Sm unit of massive, moderately sorted, medium sand indicates the final stages of the glaciodeltaic environment preserved under rapid sedimentation conditions in a shallow, high energy delta depositional environment. The occurrence of proglacial deltas is significant in south-central Saskatchewan since these geomorphic features are recognized as a primary contributing sediment source for post-glacial sand dune development (David 1977; Muhs and Wolfe 1999). Glaciofluvial and aeolian sediments in the aeolian sand dunes landscape cap these glaciodeltaic deposits.

The catastrophic drainage of Glacial Lake Birsay at 12.0 ka BP through the Qu'Appelle River spillway proposed by Kehew and Teller (1994) permitted outwash channels to cover briefly the desiccated lake basin prior to the major downcutting of the floor of Glacial Lake Birsay as represented by the gravel-cobble lag concentrates established within the Gm(r) unit at the aeolian sand dunes type site and certain locations in the outwash plain sites (Kehew 2005, personal communication). Aeolian activity initially occurred during the Late Pleistocene with strong katabatic winds from the proximal ice sheet deflating the exposed glaciodeltaic deposits. Deflation of these fine-grained sediments left a coarse-grained gravel to cobble concentrate lag in the Gm(r) unit from the outwash deposits at the basal contact of aeolian sands. Immediately, following this event, cool, moist climatic conditions ensued as indicated by the presence of well developed A_h and associated B_h horizon at the aeolian sand dunes type site at the Gm(r) and upper portions of the lower Sm unit. The Late Pleistocene interval is characterized by the presence of an open, white spruce parkland and the initial opportunity for precontact peoples to migrate in the Elbow Sand Hills region, as detected by the recovery of fluted Paleo-Indian projectile points in the surrounding terrain.

6.1.2 Holocene Environment

The Holocene environment is marked by a shift to a grassland ecosystem with frequent alternations between arid and humid climatic conditions. Landscape stability commenced during extended cool, moist climatic intervals; these intervals are preserved in the lithostratigraphy as paleosol horizons. Buried A_h soil horizons, identified by their dark brown to black colour and high organic carbon contents, were observed in the upper Sm unit of the aeolian sand dunes and outwash plain type sections and sampling sites (Figs. 5.2, 5.3, & 5.6). At these locations, multiple moderately to well developed A_h paleosol horizons have been detected within the aeolian deposits. Paleosol formation during cooler and moister climatic conditions records intervals of pedogenesis associated with an increase in grassland vegetation cover on the landscape and stabilization of aeolian landforms. The occurrence and depth of C_{ca} horizons in the aeolian sand dunes, outwash plains, and hummocky moraine reflects the upward movement of calcium carbonates from the calcareous parent materials, notably the Battleford Formation. Calcic horizons in this semi-arid landscape developed in response to high evapotranspiration conditions, particularly during Holocene arid climatic intervals.

Extensive aeolian activity and landscape instability during prolonged severe arid intervals are preserved in the lithostratigraphy within upper Sm facies units as massive, very fine to fine sand deposits (Fig. 5.3). These sediments reflect the frequent episodes of landscape instability the sand dunes experienced, when deflation and deposition of silts and sands occurred in both the aeolian sand dunes and outwash plain. Both the aeolian sand dunes and outwash plain are physiographic elements with low geomorphic thresholds that exhibited landscape sensitivity, as defined by Brunsden (2001), and were unable to absorb perturbations in environmental conditions.

Aeolian activity was focused in the vicinity of the sand dunes, as evidenced by the occurrence of metres thick, very fine to medium-grained sand deposits, and the presence of aeolian landforms, particularly blowout, circular, and parabolic sand dunes in addition to sand sheets (Figs. 5.1 and 6.2B). The presence of silt and fine sand and the poorly sorted nature of the aeolian deposits (Table 5.1 and Fig. 5.4) are a consequence from aeolian dust and mineral disaggregation, and the eluviation of clay from soil development (Pye and Tsoar 1990). Furthermore, Muhs and Wolfe (1999) indicate that aeolian sand dune fields on the Northern Plains are characterized as closed systems with a limited quantity of sand available for transportation and deposition. The frequent aeolian reworking of sands throughout the post-glacial period without a renewed sediment source have permitted the gradual abrasion of sand grains and the increased influx of fine grained particles within aeolian deposits in the region.

David (1993) suggested that precontact cultural groups may have been a particular contributor to aeolian activity and landscape instability events in sand dune locales via frequent disturbances associated with large scale bison procurement practices.

Elongated parabolic sand dunes served as efficient large game traps for precontact human hunters. The unvegetated sand dune backslope which exhibits gentle slopes were utilized to drive bison herds into these topographic traps. The loose sand impedes the movement for large, split-hoofed animals, particularly bison, with the steep side slopes of the sand dune forming a perpendicular barrier that inhibits the escape of the large game, maintaining a definite advantage for hunters (Frison 2004). The seasonality of large scale bison kill sites within sand dune locales seems to be focused within the late autumn to early spring months. This situation is recorded by faunal remains recovered at the Melhagen site in the Elbow Sand Hills (Ramsey 1991), in addition to extensive historical and archaeological evidence at a number of large bison kill sites in southern Saskatchewan (e.g., Walker 1974; Walker 1979; Hjermstad 1996; Malainey and Sherriff 1996). The optimal period for bison hunting coincides with low potential for aeolian erosion and deposition, which is limited by extensive snow cover and interstitial ice on the landscape surface (Wolfe and Lemmen 1999). The utilization of these locales for bison kills during the late fall to early spring would permit these precontact hunting practices to have minimal impacts on the regional re-activation of sand dunes.

Short arid climatic events possess limited capacity to initiate regional re-activation of aeolian deposits. These events only have a local influence, forcing small-scale landscape elements towards activation and an unstable phase. Examples of these perturbations were observed during intense drought conditions in the 1920s, 1930s, 1980s, and early 2000s on the Canadian Plains, which failed to promote wide-spread re-activation of the Elbow Sand Hills and surrounding sand dune fields (Wolfe 1997; Hugenholtz and Wolfe 2005b). Only the most sensitive aeolian landscapes experienced local expansion of parabolic dunes in response to climatically and/or anthropologically-induced perturbations. Intervals of severe aridity with durations measured in decades and centuries (e.g., Holocene Hypsithermal Interval) may have been sufficiently vigorous perturbations to serve as effective agents in promoting regional re-activation of aeolian sand dunes.

The aeolian sand dunes and outwash plains were localities of aeolian deposition during the Holocene with sand sheets varying in thickness from several centimeters to greater than a metre represented by the upper Sm facies unit at the aeolian sand dunes and outwash plains type sections (Figs. 5.2, 5.3, & 5.6). Sand sheets develop in aeolian environments where conditions do not favour the development of dunes with slip faces. Kocurek and Nielson (1986) attribute extensive vegetation cover and the coarse grain size of surficial sediments as primary factors promoting sand sheet formation. Extensive vegetation cover and coarse grained surficial sediments protect fine grained sediments from entrainment by the wind and limits the wind transport capacity of available sand allowing for vertical accumulation (Kocurek and Nielson 1986). Furthermore, the distal, downwind location of the outwash plains in relation to the active aeolian sand dunes provided a vicinity of the deposition of wind transported fine grained silts and sands developing spatially extensive sand sheets. Sand sheets provide an accurate indicator of the depositional environment as these aeolian sediments have the greater potential to be preserved in the lithostratigraphy (Kocurek 1981).

Researchers working in the study area have developed a chronology of paleoenvironmental conditions in the region through radiocarbon dating of organic materials in paleosol horizons and optical luminescence dating of aeolian sand grains.

Fluctuations between humid and arid climatic conditions, reflected by paleosol and sand dune development, respectively (Fig. 6.1), in the Elbow Sand Hills and surrounding landscape have been recorded in the lithostratigraphy over the past 5,000 years. This interval overlaps with the cultural occupation of the EgNo-23 site. Humid climatic conditions contributed to an increased grassland vegetation cover as well as the ensuing landscape stability and pedogenesis recorded by the preservation of paleosol horizons, between 5.0 to 3.3 ka BP, 2.9 to 2.2 ka BP, and 1.5 to 1.1 ka BP in the Elbow Sand Hills region (Klassen 1971, Ramsey 1991, Wolfe *et al.* 2002a, Webster 2004). Arid climatic conditions resulted in extensive landscape instability characterized by sand dune mobility associated with the Holocene Hypsithermal prior to 5.0 ka BP, as well as shorter intervals between 3.3 to 2.9 ka BP, 2.2 to 1.5 ka BP, and 1.1 to 0.1 ka BP. The absence of Early and Middle Holocene sediments preserving paleoenvironmental conditions in the region can be attributed to the repeated reworking of surficial sediments by aeolian processes (Wolfe *et al.* 2002a).

Hummocky moraine landscapes were only slightly modified by aeolian erosion and deposition. The scarcity of aeolian deposits in hummocky moraine is a consequence of its distal location and greater elevation relative to the aeolian sand source, which inhibited extensive aeolian sand deposition. The hummocky moraine appears to have experienced persistent stability throughout the Holocene as demonstrated by the thick and well developed chernozermic A_h horizon at the type site section and a number of field sampling sites within this physiographic element (Fig. 5.9). The advanced development of pedogenic horizons on the moraine surface signifies that this physiographic element was an insensitive landform that was able to absorb disturbances with broad geomorphic

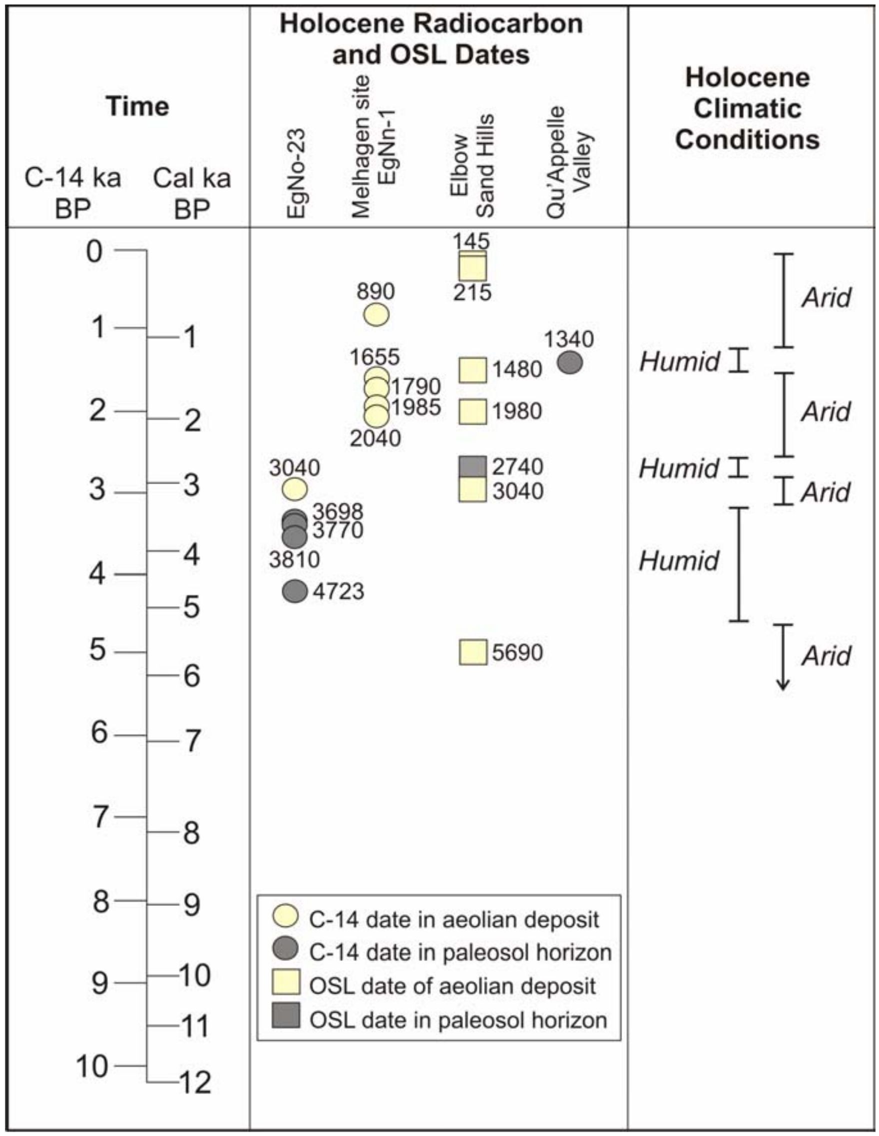


Fig. 6.1. Holocene climatic conditions in the Elbow Sand Hills and the surrounding landscape based by radiocarbon and optical simulated luminescence (OSL) dates. Note: all radiocarbon dates are corrected and OSL dates are calibrated. Adapted from Klassen (1971); Ramsey (1991); Wolfe *et al.* (2002a); Webster (2004).

thresholds.

6.2 Precontact Human Settlement Patterns

Precontact human populations extensively occupied the landscape within the study region with the aeolian sand dunes, and glacial meltwater spillways physiographic elements exhibiting the greatest archaeological site densities (Fig. 5.15 & Table 5.4). The glaciofluvial plains, glaciolacustrine plains, and hummocky moraine physiographic elements demonstrated lower site densities. The meltwater spillways and aeolian sand dunes physiographic elements are characterized by topographic complexity expressed as a broad range of topographic relief over a small area (Fig. 6.2A & B). These topographically complex landforms influence the pattern of ecotones, so that ecological heterogeneity increases with topographic complexity (Swanson *et al.* 1992). Ecological heterogeneity occurs on a landscape that comprises an array of non-uniform biotic spatial elements (Huggett 2004). The glacial meltwater spillway valleys and aeolian sand dunes are examples of landscapes demonstrating high ecological heterogeneity through the presence of a variety of ecological communities. In the spillways, riparian woodlands of aspen and willow as well as mixed grasslands of spear grass and wheat grass occur along the valley slopes and bottom (Saskatchewan Museum of Natural History 1973). Riparian habitats adjacent to the active river channel, in addition to wetlands and oxbow lakes formed from the abandonment of former river channels, are the locations for diverse communities of grasses, sedges, rushes, and shrubs. The aeolian sand dunes are characterized by the absence of vegetation or small grassland vegetation communities within active, unstable aeolian landforms. Mixed grassland communities of needle-and-thread and wheat grass occur on stabilized aeolian landforms. Aspen woodlands are

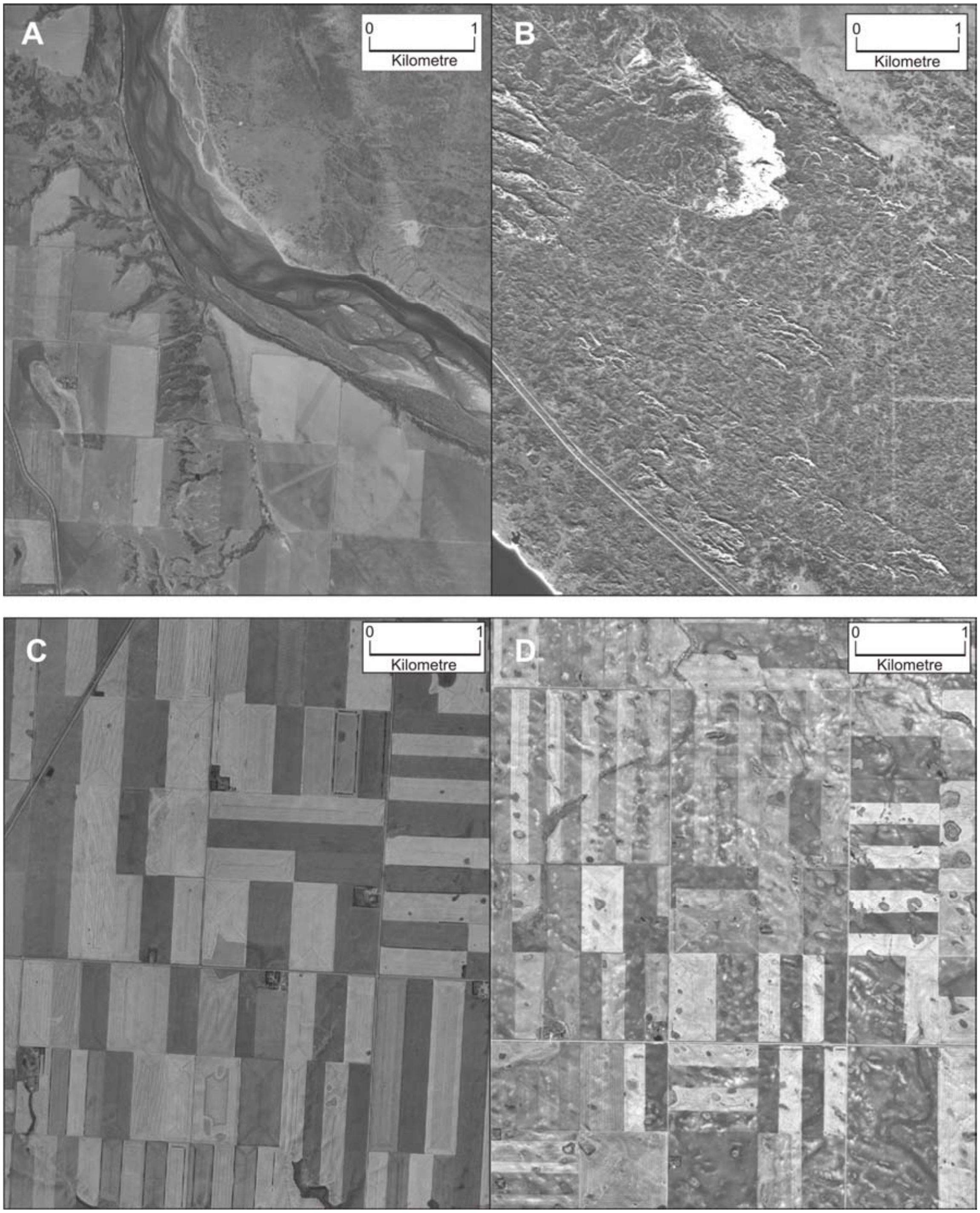


Fig. 6.2. Air photos of physiographic elements within the study area.(A) South Saskatchewan River meltwater spillway (966675-10 #220). (B) Elbow Sand Hills (A25126-113). (C) Glacial Lake Birsay plain (A25316-40). (D) Hummocky moraine. A25316-40). Source: Information Service Corporation and Saskatchewan Ministry of Transportation and Highways.

common in areas in the sand dunes where the groundwater table is in close proximity to the surface. Interdune wetlands are characterized by the presence of diverse communities of submergence and moisture tolerant vegetation (Saskatchewan Museum of Natural History 1973).

Localities with high levels of ecological heterogeneity are focal areas for precontact Plains cultural occupations, as revealed by high site densities. These landscapes are distinguished by a diverse array of natural resources, and are situated in close proximity to permanent freshwater resources, offering attractive habitats capable of supporting extensive precontact cultural settlements (Epp and Johnson 1980; Epp 1986). The glaciofluvial plains and glaciolacustrine plains are landforms that are topographically subdued and, along with the hummocky moraine, are typically situated considerable distances from permanent freshwater sources (Fig. 6.2C & D). Ecological heterogeneity associated with these landforms is lower, and these landforms offered a lower level of resource diversity for human populations to exploit as indicated by the lower sites densities.

The data confirm that various precontact cultural groups occupied sites within the glacial meltwater spillways and frequently moved over the crests of the spillways onto the adjacent uplands to procure floral and faunal resources, particularly in the sand dunes. These cultural groups resided primarily within the first 5 km of major permanent water resources in low-lying areas, as demonstrated by high site densities. These precontact groups appeared to have infrequently traveled greater than 5 km, and rarely greater than 13 km from major water resources towards greater elevations into the morainic uplands, as indicated by lower site densities in hummocky moraine (Fig. 5.17 & 5.18).

The glacial meltwater spillways and aeolian sand dunes were preferred localities for cultural groups, providing environmental conditions with abundant natural resources in proximity to potable water resources. Sand dune locales deserve particular scrutiny during archaeological investigations of high site density and increase site visibility associated with these physiographic elements. These heterogeneous landforms are ecological islands that are quite distinctive based on the combination of resource productivity and/or predictability that differentiates these locales from the surrounding landscape. The sand dunes contribute an element of complexity and ecological diversity that attracted precontact human populations to such features and the natural resources associated with them (Osborn and Kornfield 2003). A number of ecological communities are found in the sand dunes, including grasslands, aspen woodlands, and wetlands. Sufficient water exists in the sand dunes as a result of highly permeable aeolian sediment and thick semi-impermeable glacial tills beneath, promoting the development of high and stable groundwater aquifers (Saskatchewan Museum of Natural History 1973). Seasonal or annual fluctuations in precipitation and surface water levels are buffered by the gradual release of shallow aquifer water, which permits droughts to have a less impact on sand dunes ecosystems than they do at other localities on the Plains (Koch and Bozell 2003).

The presence of high and stable groundwater aquifers is of critical importance because they sustain waterfowl and mammal species otherwise not locally available. Woody vegetation located in the sand dunes is of particular significance because it provides a source of shelter, construction material, and firewood for human populations. In addition, precontact groups had access to an array of berries and other vegetal foods (such as saskatoonberry, buffaloberry, and chokecherry), and a range of large game (such as bison, deer, and antelope) in the sand dunes. The undulating, partially treed topography of the sand dunes offered favourable situations for viewing, stalking, trapping, and killing a variety of game, in particular the communal hunting of bison (Epp and Johnson 1980). In the study area, the Melhagen site (Ramsey 1991) is a prime example of a bison kill and processing site within the aeolian sand dunes. Localities possessing such a variety of environmental characteristics are scarce on the low relief plains and the hummocky moraine surrounding the sand dunes. These ecological islands play an important role in the settlement strategies of precontact human populations by permitting occupation year-round and during times of environmental stress.

Settlement of the uplands surrounding the meltwater spillways was most extensive during cool, moist post-glacial climatic conditions. Precontact groups probably traveled greater distances from the major river valleys during humid climatic conditions with greater access to potable water available to support human populations distal from the major watercourses. During prolong intervals of severe arid climatic conditions, humans probably returned to sites in proximity to primary water resources as a consequence of the decline in surface and groundwater levels, the reduction of vegetation cover, and landscape instability in upland vicinities of the aeolian sand dunes and glaciofluvial plains. The broad, deep glacial meltwater spillways provided localities of persistent environmental stability. The riverine corridors of the South Saskatchewan and Qu'Appelle Rivers are exceptionally diverse and support high biological richness, frequently one of the highest in the landscape (Forman 1995), and are capable of sustaining extensive human populations. These patterns are revealed at the Sjovold site

(Dyck and Morlan 1995) in the South Saskatchewan River valley study area, as well as the Gowen sites (Walker 1992) and sites within the Wanuskewin Heritage Park (Amundson 1986; Kelly 1986; Walker 1988; Ramsey 1993; Mack 2000) in the Saskatoon area. These multi-component archaeological sites are locales where large quantities of cultural artifacts and features have been detected, exhibiting a variety of precontact human activities. These sites record repeated use for shelter, social/religious gatherings, and food procurement as indicated by the numerous of habitation sites, medicine wheels, as well as large game kill and associated processing sites situated within the major riverine valleys and immediate surroundings.

6.3 Archaeological Visibility and Preservation

The distribution of archaeological sites with cultural affiliations within the Elbow Sand Hills and the South Saskatchewan River valley study area demonstrates that site visibility and preservation varies among the physiographic elements. Archaeological visibility refers to the degree of ease with which archaeological artifacts can be recovered in a specific location (Feder 2004). The approximately equal proportions of sites from the three cultural periods observed in the glaciolacustrine plains and hummocky moraine signify that archaeological site visibility and preservation are high in these physiographic elements (Fig. 5.16). These physiographic elements are characterized by having a high capability to absorb disturbance, permitting little geomorphic change and extensive landscape stability, where limited erosion and deposition of sediments occurred within these landscapes. This is supported by field observations of well developed surficial soils and the absence of extensive Holocene sedimentation and erosion in hummocky moraine landscapes. These geomorphic conditions permit archaeological sites situated in close proximity to the surface to be well preserved and highly visible.

The aeolian sand dunes, glacial meltwater spillways, and glaciofluvial plains are physiographic elements situated at lower elevations in close proximity to permanent water sources. These landforms demonstrated low geomorphic thresholds and a low ability to absorb disturbance, and experienced frequent intervals of significant landscape instability of erosion-deposition events, which influenced the visibility and preservation of cultural artifacts and sites. The aeolian sand dunes, glaciofluvial plains, and glacial meltwater spillways exhibited widespread aeolian, fluvial, and mass wasting geomorphic processes that eroded and deposited post-glacial sediments (Klassen 1972; Lemmen *et al.* 1998; Lemmen and Vance 1999; Wolfe *et al.* 2002a). Field observations within the aeolian sand dunes and outwash plains physiographic elements indicated extensive Holocene aeolian deflation and deposition, with sediments contributing to accumulations several metres thick (Figs. 5.2 & 5.6). Many archaeological sites in these physiographic elements are potentially deeply buried underneath post-glacial sediments and/or eroded from their original stratigraphic contexts and transported to other localities by associated geomorphic processes. These conditions are particularly apparent with the low number of recorded sites originating from early in the cultural chronology during the Paleo-Indian and Early Middle Prehistoric cultural periods (Fig. 5.11). Blowout features in the aeolian sand dunes represent localities of extensive aeolian deflation that contribute high degrees of archaeological visibility in these landscapes. These aeolian landforms exhibit a high potential for cultural artifacts and features to be present on or near the non-vegetated surface, notably sites originating from younger occupations during Prehistoric cultural periods.

Oscillations in post-glacial climatic conditions further affected site visibility and preservation. Intervals of extensive paleosol development and landscape stability correspond to high site densities associated with the Middle Middle Prehistoric to Late Prehistoric cultural periods, particularly from the McKean, Pelician Lake, and Besant complexes (Fig. 6.3). Extensive paleopedogenesis during intervals of landscape stability between 5.0 and 0.17 ka BP permitted the preservation of archaeological sites. The period between 12.0 and 5.0 ka BP was distinguished by significant environmental change and landscape instability in south-central Saskatchewan, where extensive post-glacial river incision by the South Saskatchewan and Qu'Appelle Rivers (Fig. 3.2) and subsequent valley slope landsliding from the valley sides contributed to widespread erosion and deposition within the major river valleys in the region (Lemmen *et al.* 1998). Prolonged arid climatic conditions during the Early Holocene and Hypsithermal intervals characterize these periods which intensified aeolian geomorphic processes within the sand dunes and adjacent physiographic elements. The extensive landscape instability within the glacial meltwater spillways and aeolian sand dunes correspond to low site densities from the Paleo-Indian and Early Middle Prehistoric periods, particularly from the Clovis, Folsom, and Mummy Caves series cultural complexes (Fig. 6.3). Deep burial beneath aeolian, alluvial, and colluvial deposits and/or erosion from initial stratigraphic contexts have contributed to poor site preservation, the diminished physical integrity of artifacts, and lower site visibility. These circumstances have been exacerbated at sites affected by flooding during the formation of the modern Lake Diefenbaker reservoir (see

Figs. 5.12 & 5.17). A substantial number of sites were inundated prior to extensive archaeological surveys and investigations being conducted (Himour 1997). Within the study area, 76 archaeological sites were identified as being submerged by the waters stored within the Lake Diefenbaker reservoir and unavailable for further examination by future archaeological investigations.

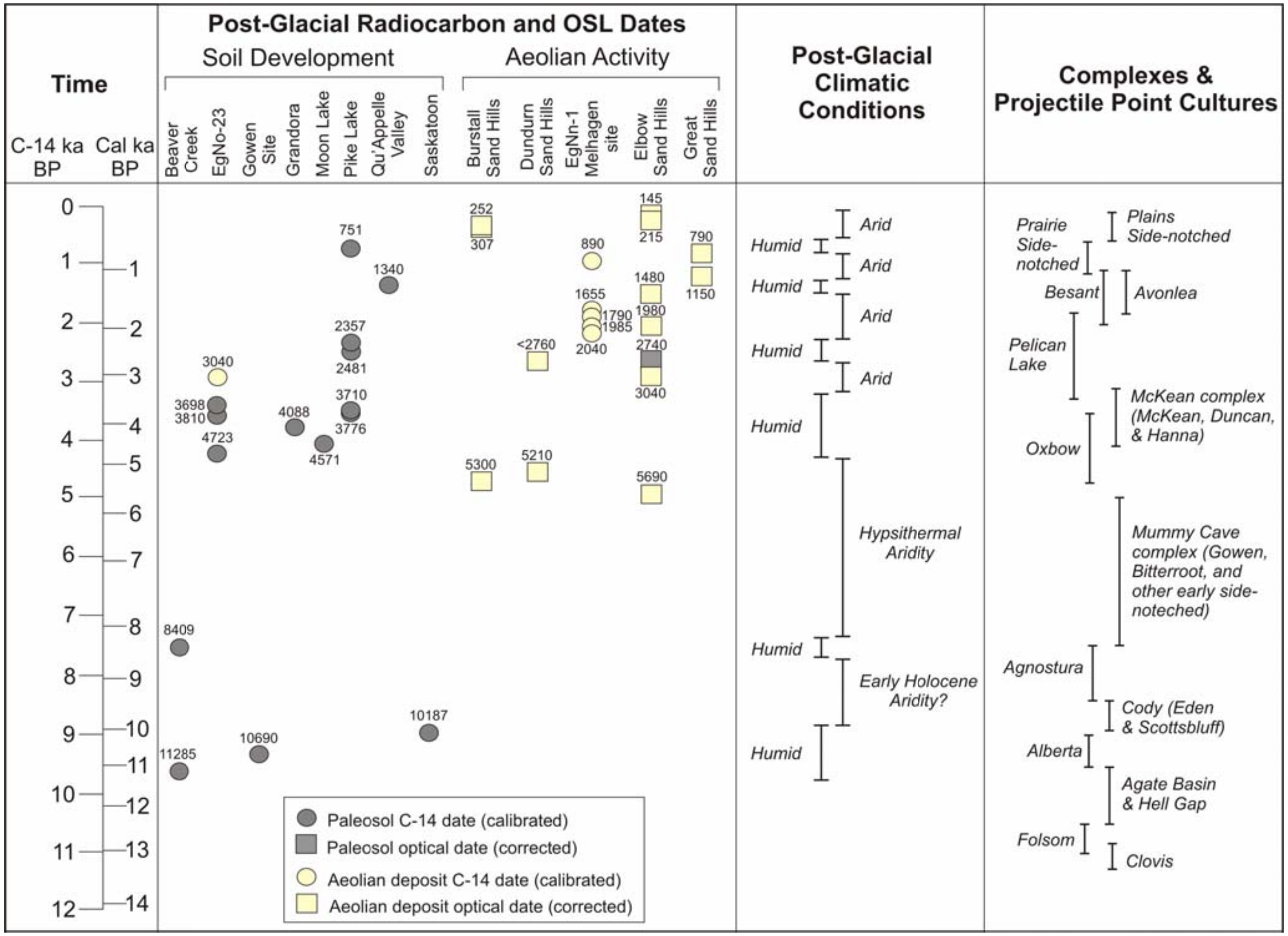


Fig. 6.3. Post-glacial climatic conditions and precontact cultural complexes in south-central Saskatchewan based on radiocarbon and optical simulated luminescence (OSL) dates. Adapted from Klassen (1971); Ramsey (1991); Morlan *et al.* (2001); Wolfe *et al.* (2002a); Webster (2004).

CHAPTER 7
SUMMARY AND DIRECTIONS FOR FUTURE RESEARCH

7.1 Summary

The first opportunity for precontact humans to migrate into the Elbow Sand Hills and vicinity occurred ca. 12.0 ka BP following the drainage of Glacial Lake Birsay and during the initial development of the aeolian sand dunes. Throughout the Holocene, the sand dunes experienced repetitive episodes of extensive aeolian activity associated with intervals of severely arid climates. These arid intervals were interspersed with intervals of cool, moist climates that permitted the stabilization of aeolian sand deposits through vegetation colonization and ensuing pedogenesis. These alternating episodes of humid and arid climatic conditions were accompanied by extensive human settlements in the study area. Cool, moist climatic conditions over the past 5,000 years are evidenced by paleosol horizon development in aeolian deposits and subsequent landscape stability between 5.0 to 3.3 ka BP, 2.9 to 2.2 ka BP, and 1.5 to 1.1 ka BP. During humid climatic conditions, precontact cultural groups occupied the river valleys extensively and temporarily expanded onto the surrounding uplands landscapes, particularly the aeolian sand dunes to exploit natural resources such as large game, vegetal foods, and wood supplies. These sand dune locales are ecological islands that accommodated a high biological diversity contributing abundant and stable resources for humans to exploit. Climatic intervals of prolonged, severe aridity transpired prior to 5.0 ka, 3.3 to 2.9 ka BP, 2.2 to 1.5 ka BP, and 1.1 to 0.1 ka BP over the past 5,000 years, permitted the mobilization of sand dune deposits and landscape instability. Arid climatic conditions compelled humans to abandon the sand dunes and adjacent uplands such as the glaciofluvial plains and hummocky moraine for other resource abundant and environmentally stable localities in close proximity to permanent water resources such as the nearby South Saskatchewan and Qu'Appelle Rivers spillways.

These precontact settlement patterns are confirmed by the examination of the temporal and spatial distribution of archaeological site location in the Elbow Sand Hills and surrounding South Saskatchewan River and Qu'Appelle River valleys study area. The quantity and patterning of archaeological sites within the various physiographic elements indicate that certain landscape settings experienced a greater degree of precontact human activity by a variety of Plains cultural groups. These groups seem to have concentrated their settlement activities within the glacial meltwater spillways and aeolian sand dunes that were situated in topographically low and complex localities in the proximity of permanent water resources. These landscapes demonstrate a high degree of ecological heterogeneity, and act as ecological islands, where greater flora and fauna species diversities transpired that contributed an abundant array of resources for human populations to exploit. Topographically subdued landscapes such as the glaciofluvial plains and glaciolacustrine plains as well as other localities such as the hummocky moraine, are located at greater distances from permanent freshwater resources exhibited lower concentration of precontact cultural settlement. These landscapes possessed a lower degree of ecological heterogeneity and did not sustain a broad diversity of resources to support a variety of precontact cultural groups. This research project confirms that precontact humans focused their settlement patterns within the major glacial meltwater spillways of the South Saskatchewan and Qu'Appelle Rivers from which they frequently departed to the surrounding uplands, particularly to the aeolian sand dunes as a source of shelter and resource procurement.

Visibility and preservation of archaeological sites differ within the study region. High site visibility and preservation based on equal site proportions over the major cultural periods are associated with the hummocky moraine and glaciolacustrine plains. Low site visibility and preservation based on unequal site proportions over the major cultural periods are associated with the aeolian sand dunes, glaciofluvial plains, and glacial meltwater spillways. Varying post-glacial climatic conditions, geomorphic processes, and the formation of the modern Lake Diefenbaker reservoir were primary contributors to the dissimilarity for archaeological site visibility and preservation in the region.

7.2 Directions for Future Research

Several approaches could be explored for future research within the study area that would improve and extend the results of this project and advance the understanding of post-glacial climatic changes and human-environment interactions on the Canadian Plains. One approach involves the comprehensive application of dating techniques to establish a precise chronology of landscape evolution, climate change, and human settlement. The integration of radiocarbon dating of organic materials enclosed in the paleosols and optical luminescence dating of aeolian sand deposits would further our understanding of post-glacial climatic fluctuations and associated geomorphic and human responses to these environmental conditions.

A comprehensive paleopedology investigation to examine the nature and characteristics of pedogenic horizons frequently recognized in the aeolian stratigraphy also is needed. The aim of this approach is to improve the understanding of the intervals of humid paleoclimates and landscape stability during which precontact human populations extensively occupied the landscape, leaving large quantities of cultural artifacts remaining in buried soil horizons. Accompanying this approach is a need for a greater amount of proxy paleoenvironmental research within the Elbow Sand Hills and the surrounding landscape. Existing studies consist of discontinuous and limited aeolian geomorphic, limnologic, and paleopedogic chronologies, and are frequently considerable distances from the study area. More research is necessary to understand post-glacial environmental conditions, particularly during the Late Pleistocene to Middle Holocene where detailed data relating to the climatic, ecological, and geomorphic systems occurring during this interval on the Canadian Plains is currently very limited.

The improvement of the archival archaeological database would facilitate the analysis of the spatial and environmental distributions of archaeological sites and settlement patterns in southern Saskatchewan through the application of GIS technology. The present study was hampered by the inadequate descriptive contexts and categorization of cultural artifacts and features at each site. Improvement of the database could advance the understanding of the variety of land use practices precontact populations employed. Furthermore, the geographical location referencing system needs to be refined. Legal land surveying units must be consistently accompanied by UTM references to identify site locations precisely.

The quantity of geoarchaeological research in southern Saskatchewan is still relatively limited compared to other surrounding geographic regions on the Northern and Northwestern Plains such as North Dakota, South Dakota, Wyoming, and Alberta. There is a need for interdisciplinary projects such as the SCAPE project where archaeologists, geographers, soil scientists, and geologists work collaboratively to examine post-glacial landscape evolution, climate change, and human interactions with the prairie environment. The Elbow Sand Hills and the surrounding South Saskatchewan River and Qu'Appelle River valleys region has long been recognized as a focal point of extensive precontact cultural settlement on the Canadian Plains and has substantial potential for undetected archaeological sites. These sites have the capacity to further our understanding of the nature and strategies of precontact cultural groups utilized to adapt to the prairie landscape, particularly multi-component sites with cultural artifacts dating to the Middle Prehistoric cultural period. Examination of Middle Prehistoric cultural sites will advance our understanding of human populations and their response to substantial post-glacial climate change on the Canadian Plains.

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APPENDIX A

MODIFIED LOSS ON IGNITION PROCEDURE AND CALCULATIONS

The following loss on ignition method in the determination of percent organic and inorganic carbon is obtained from Dean (1974), Lee (1980), and Lewis and McConchie (1994).

Laboratory Procedures

Sample Treatment Techniques

1. Air-dry sample in a clean laboratory.
2. If necessary, gently grind the sample with a porcelain mortar and pestle. Break up clods to less than 2mm.

Instructions for use of LECO CR-12

3. Turn on oxygen tank and turn on secondary valve on oxygen tank to 40 PSI.
4. Press RESET on Leco Pad, make sure printer is turned on.
5. Push GAS button on Leco Pad (Make sure red light is on).
6. Push DATA XMITT button on Leco Pad (Make sure red light is on).
7. Select temperature (840ºC for organic carbon; 1100ºC for total carbon).
8. Press SYSTEM UPDATE on the Leco pad and press NO under display constrants.
   Press NO to Calibrate System. Press NO to stack routines. Press YES to set furnace temperature. Enter the desired temperature and press ENTER.
   Note: If temperature has to be raised or lowered, it will take a few minutes for the furnace to adjust. Check temperature by pressing MONITOR.
9. Weigh out calibration standard into four crucibles (~0.15g sucrose for organic carbon; ~0.15g calcium carbonate for total carbon). Place crucibles on ledge by the furnace opening, keeping them in order. Press MANUAL WEIGHT, enter weight using numeric keys and press ENTER on the Leco pad.
   Note: Make sure the manual weight for each sample is entered. If you miss one, all the following carbon percentages will be incorrect.
10. When the desired furnace temperature has been reached, the calibration samples can be processed. Press ANALYZE on the Leco pad and wait for the LOAD FURNACE light to come on. Push crucible completely into the oven with a rod while simultaneously pressing ANALYZE again. Analysis will be complete in about 2 minutes for sucrose and about 4 minutes for calcium carbonate. Remove crucible from oven and repeat procedure.
11. When all standards have been analyzed, the carbonator can be calibrated.
12. Press SYSTEM UPDATE on the Leco pad and press NO under display constraints. Press YES to Calibrate System. Press YES to Calibrate by standard? Enter the number of calibration standards under Select from __ results. Under Carbon Std% enter 42.10 for sucrose or 12.00 for calcium carbonate. You will now be promoted to include or exclude each calibration result. Answer YES unless it is really a bad result. Carbonator will then print out a new calibration equation.

13. Weigh out your samples in the same fashion as for the standards (e.g.,~0.15g soil for organic carbon; ~0.15g soil for total carbon).
14. Press MANUAL WEIGHT, enter weight and press ENTER. Weigh out your samples and place crucibles on ledge by furnace opening, keeping them in order. New samples may be entered while analysis is proceeding. Make sure the manual weight for each sample is entered. If you miss one, all of the following carbon percentages will be incorrect.
    Note: Most analyzes will be completed in 1-2 minutes. When analyzing for organic carbon it is important that analysis be completed in 120 seconds or less. The duration of each analysis takes longer than 120 seconds, it indicates that inorganic carbon is being combusted. This is a fairly uncommon occurrence and is typically associated with samples containing significant amounts of both organic and inorganic carbon. Should this happen, simply rerun the sample using a lower sample weight.
15. To logoff the carbonator when finished, turn furnace temperature down to 840ºC. Push gas button on Leco pad (make sure the red light is off). Push the X-MITT button on Leco pad (make sure the red light is off). Turn off main valve at oxygen tank, and the bleed gas line. The valves will drop to "zero" and then turn off secondary valve. A PRINT ALARM STACK message will appear on the screen. Ignore it.

Calculations

Inorganic carbon percentage
% inorganic carbon = % total carbon - % organic carbon

(Appendix A.1)

APPENDIX B

MODIFIED PARTICLE SIZE ANALYSIS PROCEDURE

The following particle size analysis method were obtained from Day (1965), Gee and Bauder (1982), Kunze and Dixon (1982), Lewis and McConchie (1994), and Rutherford (2004).

Laboratory Procedures
Sample Treatment Techniques

Drying

1. Air-dry sample in a clean laboratory.
2. Record dry Munsell colour.

Physical Disaggregration

3. If necessary, gently grind the sample with a porcelain mortar and pestle. Break up clods to less than 2 mm.

Sample Splitting

4. Subsample the sediment by pouring the sample onto a flat sheet of glazed paper. Use a knife to split the cone of sediment into quarters. Carefully move the quarters apart and combine opposite quarters to produce two equivalent subsamples. Continue to split the subsamples until an approximately 100 g subsample is produced.

Removal of Organic Material

5. Place sample in a 1-L beaker.
6. Just cover sample with distilled water.
7. Add 5 mL of 30% hydrogen peroxide (H_2O_2).
8. Stir the suspension and allow time for any strong frothing to subside.
9. Continue adding H_2O_2 in small quantities until the sample ceases to froth. Transfer to sample to a hot plate and heat slowly to 65 to 70ºC. Do not heat samples in excess of 70ºC, as it will result in the decomposition of the H_2O_2.
10. During heating, watch the sample closely for 10 to 20 minutes or until danger of any further strong reaction has passed. Continue heating the sample until most of the water has evaporated. Do not take sample to dryness.
11. Continue the H_2O_2 and heat treatment until most of the organic matter has been destroyed. The reaction of soil with H_2O_2 is essentially complete when the soil loses its dark colour or when conspicuous frothing ceases.
12. Following H_2O_2 treatment, add warm dilute hydrochloric acid (HCl) (10 – 15%) to remove calcium carbonates.
13. Continue HCl treatment until calcium carbonates have been removed. The reaction of soil with HCl is completed when the soil loses its white or light grey colour or when conspicuous frothing ceases.
14. Use distilled water to transfer the sample to centrifuge tubes. Make sure to remove all particles from the sides of the beaker.

15. Balance pair of tubes and centrifuge the tubes at 1600 to 2200 for 10 to 15 minutes.
16. Decant and discard the supernatant (yellowish to brownish) liquid.
17. Fill the tubes with distilled water and stir until the sample is completely mixed.
18. Balance pairs, centrifuge, and decant the supernatant liquid.
19. If the supernant liquid is relatively clear use distilled water to transfer the sample to a 250-mL beaker and cover with a watch glass. Otherwise, repeat the centrifuge procedures. If H_2O_2 is present in the sample at the time of the centrifuge procedure, the continuous decomposition of the H_2O_2 will make it difficult to obtain a clear supernant liquid. It may be necessary to destroy the excess peroxide by boiling the samples for a few minutes.

Calgon Solution

20. Prepare a soil sodium hexametaphosphate (calgon) stock solution. The concentration of the stock solution is 50 g of calgon per 1000 L of distilled water.
21. Cover the sample with a small quantity of distilled water plus 10 mL of the calgon solution. Use (rubber-gloved) fingers to gently break up the sample. Rinse mud off the gloves back into the beaker.

Sieve Analysis

Wet Sieving

22. Separate the gravel and sand fractions from the silt and clay fractions by wet-sieving the sample through a 63-µm sieve. This is accomplished by pouring the sample through a 63-µm sieve placed in a large funnel above a 1-L column. Wash all fines into the column using as little distilled water as possible.
23. Transfer (using distilled water) the entire gravel and sand fractions retained on the sieve to a tared beaker.
24. Dry the sand and gravel at approximately 55ºC, leave to cool for 1 hour, and weight to 0.001 g. Drying at temperatures greater than 60ºC can cause the formation of aggregates which cannot be easily dispersed during later analyses. In addition, cooling should be conducted in a desiccator chamber.

Dry Sieving

25. Transfer the dried sand and gravel to a nest of sieves arranged from top to bottom with decreasing size and in the following order: 4.0-mm, 2.8-mm, 2.0-mm, 1.4-mm, 1.0-mm, 710-µm, 500-µm, 355-µm, 250-µm, 180-µm, 125-µm, 90-µm, 63-µm. It is best to divide the sieves in half and run two separate nests of sieves. The coarser nest includes the 4.0-mm, 2.8-mm, 2.0-mm, 1.4-mm, 1.0-mm, 710-µm, and 500-µm sieves and the finer nest include the 350-µm, 250-µm, 125-µm, and 63-µm sieves as well as the pan fraction.
26. Place the sieves on a sieve shaker and run the shaker for 10 minutes and at a speed of 4-5.
27. Weigh each gravel and sand fraction as well as the residual silt and clay that passed through the 63-µm sieve (pan fraction). Record the weight to 0.001 g and add the pan fraction to the silt and clay already in the 1-L column.

28. If greater than 5% of the sample is lost during sieving operations, the whole process must be repeated.

Pipette Analysis

29. Add exactly 10-mL of the calgon stock solution to each 1-L cylinder.
30. Later calculations require that the exact weight of calgon added to each sample be known, Therefore, add exactly 20 mL of calgon (the total added to each sample) to a tared beaker, dry the beaker and record the weight of the calgon to 0.001g.
31. Thoroughly stir the cylinder with a brass stirring rod and top the column up to 1-L with distilled water.
32. Place the cylinder containing the silt and clay suspension in a water bath.
33. Cover the cylinder with a watch glass and let it stand overnight to equilibrate with the water temperature.
34. Label and weight to 0.001 g, five small beakers per sample (total suspension (time zero), 20 µm, (~4 min), 5 µm (~1 hr), 2 µm (~7 hr), and 1µm (~30 hr)).
35. Take the temperature of the water in the water bath and look up the corrected sampling times (Table B.1). Monitoring and adjust for any temperature changes during the pipette analysis.
36. Mark a line exactly 10 cm from the bottom of the 20-mL pipette.
37. Have a large beaker of distilled water ready for rinsing.

Table B.1. Pipetting times according to the temperature. Adapted from Gee and Bauder (1982).

Temperature (ºC)	20 µm	5 µm	2 µm	1 µm
20	4 min 48 sec	1 hr 16 min 48 sec	8 hr 0 min	31 hr 51 min
21	4 min 42 sec	1 hr 15 min	7 hr 49 min 12 sec	31 hr 10 min
22	4 min 36 sec	1 hr 13 min 12 sec	7 hr 37 min 48 sec	30 hr 28 min
23	4 min 30 sec	1 hr 11 min 30 sec	7 hr 27 min 36 sec	29 hr 18 min
24	4 min 24 sec	1 hr 9 min 54 sec	7 hr 16 min 48 sec	28 hr 18 min
25	4 min 18 sec	1 hr 8 min 18 sec	7 hr 7 min 12 sec	28 hr 18 min

38. Starting at 1 min 30 sec before the initial withdrawal time, begin to stir the sample with a brass stirring rod. Start with short, quick strokes at the bottom and then proceed to long vigorous strokes. While stirring the sample, be careful not to mix

air in with the suspension. Stir for 1 min, withdraw the stirrer, lower the pipette to 10 cm, and at precisely time zero extract a 20 mL sample.

39. Empty the pipette into the respective tared beaker. Rinse the pipette with distilled water and empty the rinse water into the same beaker. Repeat the rinse procedure and wash the outer part of the pipette.
40. With the exception of stirring, repeat the above pipette sampling techniques for all subsequent withdrawals. Stirring only occurs prior to the time zero extraction and during the remaining withdrawals it is important to avoid creating turbulence.
41. Between withdrawals, cover the 1-L column with a watch glass.
42. Over-dry the samples at 105ºC. No further analysis is required so the samples may be dried at a higher temperature.
43. Remove dry beakers from the oven, cool for 1 hr in a desiccator chamber, and record weight to 0.001g.

Calculations

Pipette Analysis

Pipette analysis calculations are to be complete in conjunction with Table B.2.

Table B.2. Spreadsheet for pipette analysis calculations.

extraction time	mass sample and calgon	mass sample	mass	percent still in suspension	percent change	percent of original sample
zero time				100		
4 mins						
1 hour						
7 hours						
29 hours						
colloidal clay						

Mass of sample and calgon.

Mass sample and calgon = mass beaker and extraction – mass beaker

(Appendix B.1)

Mass of sample alone.

Mass sample = mass sample and calgon – mass calgon

(Appendix B.2)

Mass of sample multiplied by 50.

Mass of sample = mass sample X 50

(Appendix B.3)

Percent of silt and clay still in suspension at n time.

$$\% \text{ in suspension at n time} = \frac{\text{mass at n time}}{\text{mass at zero time}} \text{ X } 100$$

(Appendix B.4)

Percent change from previous reading.

$$\% \text{ change} = \frac{\text{previous \% in suspension}}{\text{at n time reading}} - \frac{\text{\% in suspension}}{\text{at n time}}$$

(Appendix B.5)

Percent of original sediment sample at this size.

$$\% \text{ original sample} = \frac{\text{\% change X \% silt and clay}}{100}$$

(Appendix B.6)

Percent of colloidal clay

% colloidal clay = % silt and clay – (%4 min + %1 hour + % 7 hours + % 29 hours)

(Appendix B.7)

Percent of silt

% silt = % 4 min + % 1 hour

(Appendix B.8)

Percent of clay

% clay = % 7 hours + % 29 hours + % colloidal clay

(Appendix B.9)

Calgon solution

Mass of calgon in 1000 mL cylinder

Mass in cylinder = mass of beaker and calgon – mass of beaker

(Appendix B.10)

Mass of calgon in 20 mL pipette sample.

$$\text{Mass of calgon} = \frac{\text{mass calgon in cylinder}}{1000} \text{ X } 20$$

(Appendix B.11)

APPENDIX C

SURFICIAL SEDIMENT SAMPLING LOCATIONS AND CHARACTERISTICS

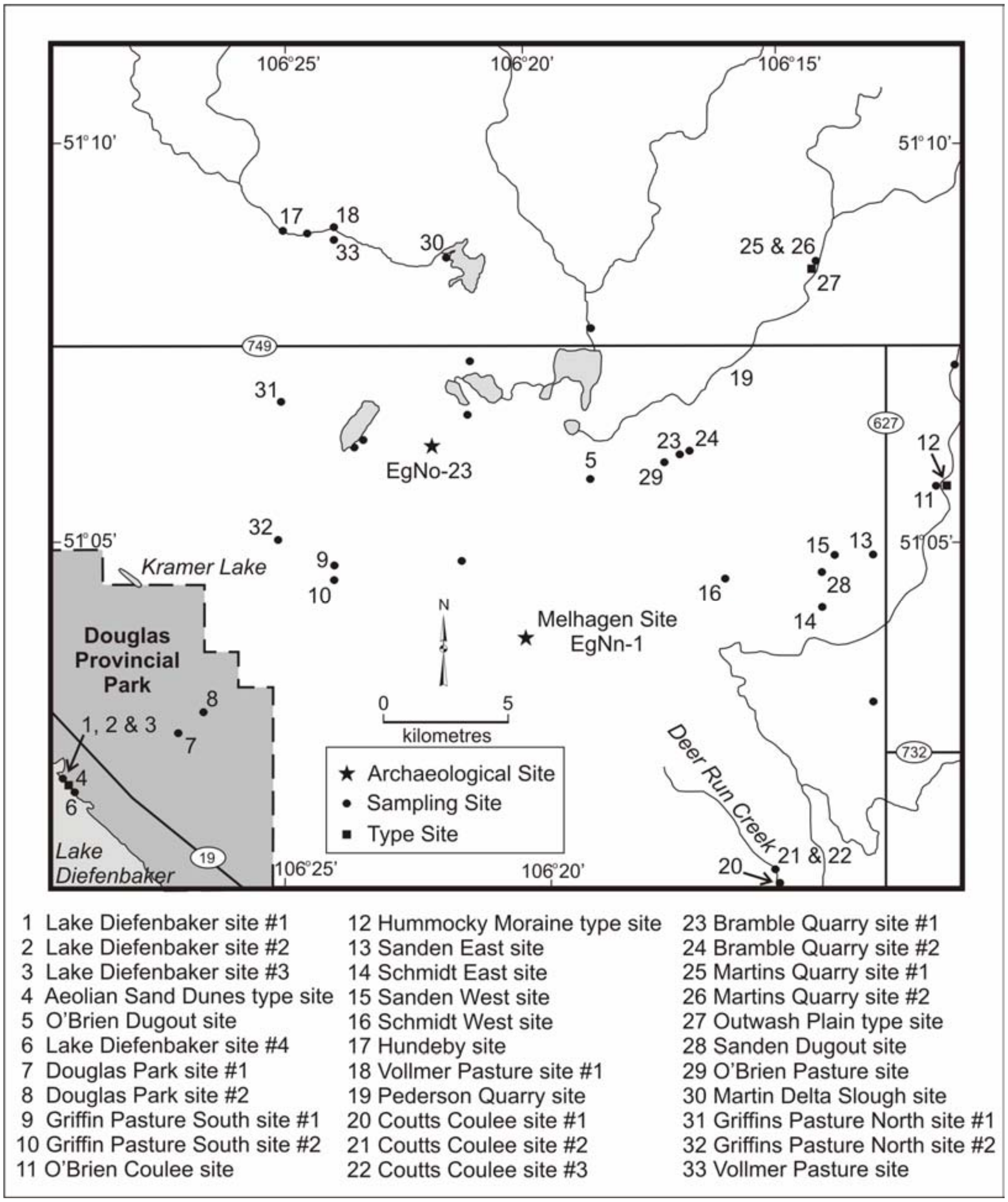

Fig. C.1. Map of sampling locations of surficial sediments. Labeled locations have been sampling sites that have undergone extensive examination.

Table C.1. Characteristics of surficial sediment samples selected for laboratory analyses in this study.

Site No.	Sample Number	Depth (m)	Munsell Colour	Composition (%) Gravel	Sand	Silt	Clay	Organic Carbon	Inorganic Carbon	Mean (Φ)	Standard Deviation (Φ)	Facies Code
1	**Aeolian Sand Dunes Physiographic Element**											
	Site: Lake Diefenbaker Beach Profile #1 Location: 51°1.998'N, 106°29.622'W Elevation: 652 m asl											
	DB-S95-080803	0.0-0.62	2.5Y 4/4 & 10YR 2/2	0.0	93.9	6.1	0.0	0.294	0.330	2.538	1.089	Sm
	DB-S96-080803	0.62-0.96	10YR 2/1 & 2.5Y 5/4	8.6	72.6	16.6	2.3	3.557	0.062	2.485	2.478	Sm
	DB-S97-080803	0.96-1.00	10YR 4/3	1.0	80.2	16.0	2.8	1.481	0.051	3.027	2.091	Gm(r)
	DB-S98-080803	1.00-1.11	10YR 2/2	0.3	81.0	15.7	3.1	0.750	0.351	2.923	2.119	Sm
	DB-S99-080803	1.11-1.22	10 YR 5/3 & 2.5Y 4/4	0.0	92.7	6.1	1.2	0.129	0.208	2.574	1.350	Sm
	DB-S100-080803	1.22-1.57	10YR 4/3 & 10YR 3/3	0.0	79.9	16.3	3.8	0.732	0.397	2.943	2.219	Sm
	DB-S101-080803	1.57-2.21	10YR 3/3	0.0	85.0	13.1	1.8	0.286	0.299	2.673	1.884	Sm
	DB-S102-080803	2.21-2.27	2.5YR 4/4	0.0	82.9	15.0	2.1	0.254	0.323	2.767	2.015	Sm
	DB-S103-080803	2.27-2.43	10YR 4/4	1.3	88.3	9.9	0.5	0.156	0.289	2.360	1.526	Sm
	DB-S104-080803	2.43-2.63	10YR 2/2	0.0	94.9	5.1	0.0	0.782	0.838	1.831	1.107	Sm
	DB-S105-080803	2.63-2.72	2.5Y 4/4	0.0	94.7	4.8	0.5	0.176	0.772	1.819	1.207	Sm
	DB-S106-080803	2.72-2.94	7.5YR 2/0	0.0	90.6	8.9	0.5	1.870	0.317	2.116	1.513	Sm
2	**Site: Lake Diefenbaker Beach Profile #2 Location: 51°1.998'N, 106°29.622'W Elevation: 652 m asl**											
	DB-S112-100803	0.0-0.95	2.5Y 5/4	0.0	93.1	6.0	0.9	0.116	0.240	2.517	1.425	Sm
	DB-S113-100803	0.95-1.19	10YR 3/3	0.1	78.5	17.8	3.5	1.185	0.271	3.132	2.137	Gm(r)
	DB-S114-100803	1.19-1.34	10YR 2/2	1.0	81.7	14.8	2.5	3.691	0.085	2.697	2.076	Sm
	DB-S115-100803	1.34-2.26	10YR 3/2 & 10YR 2/2	0.9	86.0	12.6	0.5	5.559	2.508	2.334	1.427	Sm
	DB-S116-100803	2.26-2.45	2.5 Y 6/4 & 10YR 2/1	0.1	89.5	8.6	1.8	1.262	0.340	2.435	1.721	Sh
	DB-S117-100803	2.45-2.81	10YR 7/2 & 10YR 4/1	0.0	88.3	10.7	0.9	0.060	0.123	3.228	1.233	Fl
3	**Site: Lake Diefenbaker Beach Profile #3 Location: 51°1.998'N, 106°29.622'W Elevation: 652 m asl**											
	DB-S118-110803	0.0-0.60	10YR 4/3	0.0	82.4	15.4	2.2	0.271	0.388	2.814	2.051	Sm
	DB-S119-110803	0.60-0.74	10YR 3/2	1.0	91.5	7.1	0.5	0.668	0.146	2.130	1.419	Gm(r)
	DB-S120-110803	0.74-1.00	10YR 4/3 & 10YR 3/3	0.3	90.9	8.3	0.4	0.187	0.676	2.195	1.441	Sm
	DB-S121-110803	1.00-1.19	10YR 2/2	0.1	86.0	13.4	0.5	2.758	0.690	2.328	1.379	Sm
	DB-S122-110803	1.19-1.36	10YR 3/3	0.3	94.8	4.5	0.5	0.214	0.986	1.986	1.063	Sm
	DB-S123-110803	1.36-2.05	10YR 2/2 & 2.5Y 5/4	0.1	84.4	14.6	0.9	1.891	1.070	2.670	1.738	Sh
	DB-S124-110803	2.05-2.43	10YR 5/4 & 10YR 2/1	0.0	99.0	1.0	0.0	0.035	0.244	2.231	0.494	Sh
	DB-S125-110803	2.43-2.68	2.5Y 4/4 & 2.5Y 6/4	0.0	85.7	12.7	1.5	0.019	0.760	3.443	1.256	Fl
4	**Site: Aeolian Sand Dunes Type Site Lake Diefenbaker Beach Profile# 4 Location: 51°1.998'N, 106°29.622'W Elevation: 652 m asl**											
	DB-S126-110803	0.0-0.23	10YR 3/3	0.0	73.7	21.6	4.6	1.248	0.047	3.330	2.320	Sm

	DB-S127-110803	0.23-0.73	2.5Y 4/4 & 10YR 3/2	0.0	85.2	11.8	3.0	0.327	0.118	2.735	2.004	Sm
	DB-S128-110803	0.73-1.13	10YR 2/2 & 10YR 3/3	0.1	94.8	4.1	1.0	0.094	0.938	2.009	1.234	Sm
	DB-S129-110803	1.13-2.0	10YR 2/1 & 2.5Y 6/4	0.1	91.2	8.8	0.0	2.992	0.569	2.243	1.101	Sh
	DB-S130-110803	2.0-2.45	2.5Y 2/0 & 2.5Y 6/4	0.0	97.7	1.8	0.4	0.028	0.096	2.336	0.813	Sh
	DB-S131-110803	2.45-2.60	2.5Y 4/4 & 2.5Y 6/4	0.0	89.4	9.2	1.4	0.000	0.598	3.367	1.126	Fl
5	**Site: O'Brien Dugout Location: 51º5.765'N, 106º16.862'W Elevation: 690 m asl**											
	SH-S162-130803	0.0-0.40	10YR 3/3	0.0	82.7	14.5	2.8	1.125	0.125	3.576	1.713	Sm
	SH-S163-130803	0.40-0.80	2.5YR 4/4 & 2.5Y 4/4	0.0	81.7	15.0	3.3	0.130	0.503	3.613	1.738	Sm
	SH-S164-130803	0.80-1.00	10YR 3/2 & 2.5Y 5/4	0.0	47.7	48.8	3.5	0.561	0.247	4.898	2.443	Sm
	SH-S165-130803	1.00-1.17	10YR 5/3	0.0	78.4	21.1	0.5	0.341	0.536	3.501	1.218	Sm
	SH-S166-130803	1.17-1.35	2.5Y 6/4 & 2.5Y 7/2	0.0	46.6	52.2	1.2	0.307	2.600	4.028	1.460	Sm
	SH-S167-130803	1.35-1.60	2.5Y 5/4	0.0	32.8	66.1	1.1	0.340	2.564	4.222	1.472	Sm
6	**Site: Lake Diefenbaker Beach Profile #4 Location: 51º5.765'N, 106º16.862'W Elevation: 690 m asl**											
	DB-S303-250803	0.0-0.40	2.5Y 4/4	0.7	67.7	26.4	5.2	0.638	0.188	3.630	2.460	Sm
	DB-S304-250803	0.40-0.50	10YR 4/3	7.6	73.1	15.4	3.9	0.672	0.152	2.755	2.546	Gm(r)
	DB-S305-250803	0.50-0.74	2.5Y 5/4	0.0	93.4	5.7	0.9	0.083	0.645	2.566	1.185	Sm
	DB-S306-250803	0.74-1.49	2.5Y 6/2	0.0	93.9	5.2	0.9	0.021	0.619	2.595	1.134	Sm
	DB-S307-250803	1.49-2.04	2.5Y 6/4 & 10YR 2/1	0.0	90.8	8.3	0.9	0.195	0.301	2.648	1.286	Sh
7	**Site: Douglas Park #1 Location: 51º2.785'N, 106º26.829'W Site: 646 m asl**											
	SH-S310-260803	0.0-0.77	2.5Y 5/6	0.0	96.6	2.9	0.5	0.011	0.048	1.727	1.132	Sm
8	**Site: Douglas Park #2 Location: 51º2.783'N, 106º26.777'W Elevation: 648 m asl**											
	SH-S311-260803	0.0-1.20	2.5Y 5/6	0.0	96.3	3.2	0.4	0.055	0.102	1.920	1.144	Sm
	SH-S312-260803	1.20-1.45	10YR 2/2	0.0	82.5	14.7	2.8	0.300	0.348	2.821	2.082	Sm
	SH-S313-260803	1.45-1.80	2.5Y 5/6	0.0	92.5	5.8	1.7	0.067	0.082	2.352	1.537	Sm
9	**Site: Griffin Pasture South #1 Location: 51º4.882'N, 106º22.610'W Elevation: 732 m asl**											
	GF-S330-270803	0.0.0-0.55	10YR 3/3	0.0	68.3	27.2	4.6	1.721	0.239	4.065	2.073	Sm
	GF-S331-270803	0.55-0.80	2.5Y 4/4	0.0	75.0	20.0	5.0	0.436	0.517	3.879	2.034	Sm
	GF-S332-270803	0.80-1.80	2.5Y 5/4	0.0	88.9	10.1	1.0	0.377	0.841	3.151	1.152	Sm
10	**Site: Griffin Pasture South #2 Location: 51º4.687'N, 106º22.779'W Elevation: 734 m asl**											
	GF-S333-270803	0.0-0.60	10YR 3/3	0.0	80.7	16.7	2.5	0.789	0.347	3.499	1.742	Sm
	GF-S334-270803	0.60-1.00	2.5Y 5/4	0.0	82.6	14.5	3.0	0.174	0.213	3.467	1.767	Sm
	GF-S335-270803	1.0-1.5	10YR 3/3	0.0	85.9	13.6	0.5	0.423	0.138	3.123	1.091	Sm
	Hummocky Moraine Physiographic Element											
19	**Site: Pederson Quarry Location: 51º7.443'N 106º15.735'W Elevation: 708 m asl**											
	GF-S24-020803	0.0-1.70	10YR 4/2	6.7	53.5	39.4	0.4	0.150	1.058	3.060	2.078	Dmm
11	**Site: O'Brien Coulee Location: 51º5.766'N 106º11.768'W Elevation: 706 m asl**											
	HM-S144-120803	0.0-0.13	10YR 3/3	2.0	38.8	57.4	1.8	2.458	0.507	4.409	2.475	Dmm

	HM-S145-120803	0.13-0.48	10YR 7/2	2.7	44.0	52.8	0.6	0.684	1.623	3.545	1.824	Dmm
	HM-S146-120803	0.48-0.86	10YR 3/3	10.4	87.3	2.2	0.1	0.138	1.444	2.027	1.748	Dmm
12	**Site: Hummocky Moraine Type Site O'Brien Coulee Location: 51°5.767'N 106°11.574'W Elevation: 707 m asl**											
	HM-S150-120803	0.0-0.19	10YR 3/3	33.4	28.4	34.2	4.0	4.925	0.416	2.273	3.772	Dmm
	HM-S151-120803	0.19-0.81	10YR 6/2	1.1	46.6	51.3	1.1	0.435	2.263	3.731	1.705	Dmm
	HM-S152-120803	0.81-1.38	2.5Y 6/4	24.4	40.6	35.0	0.0	0.128	2.353	2.129	2.963	Dmm
11	**Site: O'Brien Coulee Location: 51°5.767'N 106°11.574'W Elevation: 707 m asl**											
	HM-S156-120803	0.0-0.15	10YR 3/3	2.4	41.0	51.6	5.0	2.566	0.317	4.431	2.564	Dmm
	HM-S157-120803	0.15-0.62	10YR 7/1	5.7	48.1	46.2	0.0	0.308	1.912	3.186	2.003	Dmm
	HM-S158-120803	0.62-1.35	10YR 3/3	6.8	49.5	42.6	1.1	0.156	1.238	3.083	2.203	Dmm
13	**Site: Sanden East Location: 51°4.777'N, 106°13.137'W Elevation: 673 m asl**											
	HM-S233-210803	0.0-0.20	10YR 4/3	1.3	47.9	45.0	5.8	0.780	0.637	4.398	2.543	Sm
	HM-S234-210803	0.20-0.60	10YR 5/4	1.5	51.6	45.2	1.6	0.387	0.923	3.773	1.772	Sm
	HM-S235-210803	0.60-0.80	10YR 6/2	0.6	55.1	41.6	2.8	0.293	1.840	3.719	2.004	Sm
14	**Site: Schmidt East Location: 51°2.937'N, 106°12.906'W Elevation: 670 m asl**											
	HM-S236-210803	0.0-0.60	10YR 4/3	0.0	26.6	65.1	8.3	1.773	0.234	5.539	2.058	Sm
	HM-S237-210803	0.60-0.80	2.5Y 5/6	0.0	55.4	43.3	1.4	0.494	0.306	4.182	1.235	Sm
	HM-S238-210803	0.80-1.40	10YR 7/2	0.5	30.2	65.8	3.5	0.328	2.445	4.570	1.762	Sm
15	**Site: Sanden West Location: 51°4.778'N, 106°13.701'W Elevation: 683 m asl**											
	HM-S239-210803	0.0-0.60	10YR 3/3	0.3	24.7	66.8	8.2	1.696	0.542	5.477	2.181	Sm
	HM-S240-210803	0.60-0.70	10YR 4/4	0.6	31.7	63.1	4.7	0.828	0.454	5.034	2.094	Sm
	HM-S241-210803	0.70-1.10	12YR 6/3	0.7	62.7	35.0	1.6	0.344	1.648	3.386	1.875	Sm
16	**Site: Schmidt West Location: 51°5.470'N, 106°15.743'W Elevation: 683 m asl**											
	HM-S244-210803	0.0-0.60	10YR 3/3	0.0	62.7	33.3	4.0	1.521	0.585	4.242	2.001	Sm
	HM-S245-210803	0.60-0.75	2.5Y 4/4	0.0	79.3	19.7	1.0	0.348	0.321	3.385	1.268	Sm
	HM-S246-210803	0.75-0.85	2.5Y 4/4	0.0	83.7	15.5	0.9	0.363	0.006	3.314	1.364	Sm
	HM-S247-210803	0.85-1.60	2.5Y 4/4	0.3	60.1	36.5	3.1	0.273	1.967	3.933	1.832	Dmm
17	**Site: Hundeby Farm Location: 51°9.041'N, 106°25.356'W Elevation: 782 m asl**											
	HM-S265-230803	0.0-0.20	10YR 4/3	0.3	51.0	46.7	2.0	1.697	0.808	3.655	2.024	Dmm
18	**Site: Vollmer's Pasture Location: 51°9.043'N, 106°24.038'W Elevation: 770 m asl**											
	HM-S272-230803	0.0-0.30	10YR 4/3	0.3	35.4	57.5	6.8	1.296	0.487	4.893	2.411	Dmm
	HM-S273-230803	0.30-0.60	10YR 5/3	0.1	44.7	51.7	3.4	0.821	1.962	4.128	1.917	Dmm
	HM-S274-230803	0.60-0.90	10YR 5/3	1.1	42.5	53.4	3.1	0.293	1.615	4.109	1.993	Dmm
	HM-S275-230803	0.90-1.05	10YR 3/3	2.2	61.6	33.9	2.3	0.112	1.043	3.348	2.076	Dmm
	Outwash Plain Physiographic Element											
19	**Site: Pederson Quarry Location: 51°7.443'N 106°15.735'W Elevation: 708 m asl**											
	GF-S13-010803	0.0-0.04	10YR 5/3	1.4	36.6	57.1	4.8	1.375	0.106	4.470	2.492	Sm

	GF-S14-010803	0.04-0.21	2.5Y 3/2	1.1	22.6	66.3	9.9	1.964	0.109	5.387	2.548	Sm
	GF-S16-010803	0.56-0.72	10YR 6/2	0.0	48.4	48.9	2.7	0.709	2.486	4.013	1.814	Sm
	GF-S17-010803	0.72-1.12	10YR 5/3	55.4	36.5	8.0	0.0	0.282	2.485	-0.307	2.323	St
	GF-S18-010803	1.12-1.31	10YR 5/3	80.3	16.0	3.6	0.0	0.092	1.567	-1.393	1.802	St
20	**Site: Coutts Coulee #1 Location: 51º0.529'N 106º14.991'W Elevation: 611 m asl**											
	GF-S40-030803	0.0-0.38	10YR 3/3	0.3	86.0	12.0	1.8	0.523	0.352	3.040	1.737	Sm
	GF-S41-030803	0.38-0.50	10YR 3/3	1.2	79.4	19.4	0.0	0.784	0.265	3.171	1.802	Gm(r)
	GF-S42-030803	0.50-0.80	2.5Y 7/2	0.0	56.9	42.2	0.9	0.629	2.230	4.109	1.797	Sm
	GF-S43-030803	0.80-1.20	2.5Y 5/4 & 2.5Y 6/6	19.6	56.7	23.3	0.5	0.142	1.824	1.798	2.446	Sm
21	**Site: Coutts Coulee #2 Location: 51º0.529'N 106º14.991'W Elevation: 611 m asl**											
	GF-S44-050803	0.0-0.20	10YR 3/3	0.7	77.2	18.5	3.6	0.580	0.513	3.431	2.127	Sm
	GF-S45-050803	0.20-0.60	10YR 6/4	0.4	83.9	14.7	0.9	0.503	0.541	3.069	1.423	Sm
	GF-S46-050803	0.60-0.80	10YR 6/3	1.1	80.5	17.5	0.9	0.241	1.278	3.128	1.516	Sm
	GF-S47-050803	0.80-0.100	2.5Y 6/4	0.0	75.2	23.6	1.2	0.245	1.355	3.423	1.392	Fm
	GF-S48-050803	0.100-1.15	10YR 4/1	1.0	46.2	50.0	2.8	0.208	1.768	3.967	1.986	Sm
	GF-S49-050803	1.15-1.20	2.5Y 5/2	0.9	54.0	43.4	1.7	0.165	1.362	3.929	1.680	Sm
	GF-S50-050803	1.20-1.30	2.5Y 5/4	0.4	64.7	32.4	2.5	0.136	0.843	3.895	1.616	Sm
	GF-S51-050803	1.30-1.50	2.5Y 4/4	13.0	77.1	9.5	0.4	0.041	0.908	1.064	1.974	Sm
22	**Site: Coutts Coulee #3 Location: 51º0.611'N, 106º15.186'W Location: 616 m asl**											
	GF-S60-050803	0.00-0.20	10YR 4/3	0.0	75.2	20.0	4.8	0.925	0.541	3.620	2.158	Sm
	GF-S61-050803	0.20-1.50	2.5Y 4/4	0.2	78.2	17.8	3.8	0.312	0.276	3.504	2.105	Sm
23	**Site: Bramble Quarry #1 Location: 51º6.582'N, 106º16.943'W Elevation: 668 m asl**											
	GF-S68-060803	0.0-0.10	10YR 4/2	40.3	39.5	18.8	1.4	1.399	0.670	0.732	3.128	Sm
	GF-S69-060803	0.10-0.16	10YR 8/1	39.5	52.8	7.2	0.5	0.265	2.393	-0.068	2.195	Sm
	GF-S70-060803	0.16-0.21	2.5Y 3/2	15.0	56.7	27.8	0.5	1.507	0.478	1.825	2.638	Sm
	GF-S71-060803	0.21-0.28	10YR 5/4	35.3	40.9	22.9	1.0	0.406	0.406	1.164	3.160	Sm
	GF-S72-060803	0.28-0.32	2.5Y 3/2	7.6	57.4	31.2	3.7	0.697	0.103	2.695	3.099	Sm
	GF-S73-060803	0.32-0.77	10YR 5/1 & 10YR 7/1	4.8	42.3	52.2	0.6	2.711	0.247	3.144	2.287	Sm
	GF-S74-060803	0.77-1.16	2.5Y 5/4	31.5	45.2	21.7	1.5	0.000	2.355	1.030	3.001	Sp
	GF-S75-060803	1.16-1.57	7.5YR 4/6 & 2.5Y 8/0	44.4	52.6	2.5	0.5	0.111	2.781	-0.429	1.845	Sp
	GF-S76-060803	1.57-1.69	7.5 YR 4/6	4.2	82.0	11.7	2.1	0.044	1.883	1.432	2.258	St
24	**Site: Bramble Quarry #2 Location: 51º6.719'N 106º16.546'W Elevation: 670 m asl**											
	GF-S81-070803	0.0-0.12	10YR 4/3	5.2	59.9	33.3	1.7	1.009	0.757	2.980	2.248	Sm
	GF-S82-070803	0.12-0.25	2.5Y 4/4	0.0	26.0	67.0	6.9	0.981	0.314	5.522	2.089	Sm
	GF-S83-070803	0.25-0.82	2.5Y 7/2 & 2.5Y 6/2	0.0	69.7	29.6	0.6	0.224	1.770	3.692	1.102	Sm
	GF-S84-070803	0.82-1.21	10YR 6/8 & 10YR 5/8	44.9	46.8	7.6	0.8	0.069	0.094	-0.024	2.474	Gp
	GF-S85-070803	1.21-1.33	10YR 6/8	13.4	71.5	14.6	0.4	0.046	0.082	1.201	2.092	Sp
	GF-S86-070803	1.33-1.53	10YR 6/8	70.5	19.4	8.8	1.3	0.057	3.238	-0.759	2.635	Gm

25	**Site: Martins Quarry site #1 Location: 51º8.043'N 106º17.650'W Elevation: 736 m asl**											
	GF-S176-170803	0.0-0.45	10YR 4/3	0.5	72.7	26.3	0.5	0.238	0.686	3.009	1.611	Sm
	GF-S177-170803	0.45-0.74	10YR 7/2	0.7	53.1	41.2	4.9	0.435	2.430	4.160	2.129	Sm
	GF-S178-170803	0.74-1.00	2.5YR 5/4, 10YR 8/1, & 7.5YR 5/8	7.4	74.8	15.3	2.5	0.075	0.341	2.236	2.339	Sm
	GF-S179-170803	1.00-1.52	10YR 8/7 & 7.5 YR 5/8	9.2	77.3	12.6	0.9	0.077	0.169	1.943	2.026	Sp
26	**Site: Martins Quarry site#2 Location: 51º8.043'N 106º17.650'W Elevation: 736 m asl**											
	GF-S183-180803	0.0-0.25	10YR 4/3 & 2.5Y 5/6	60.6	32.6	6.3	0.4	0.549	0.667	-0.597	2.248	Gm
	GF-S184-180803	0.25-0.87	2.5Y 5/6 & 10YR 5/6	0.0	73.3	26.0	0.8	0.134	0.137	3.398	1.617	Sm
	GF-S185-180803	0.87-1.28	10YR 7/1 & 2.5Y 4/4	0.0	91.8	7.1	1.0	0.000	0.159	2.339	1.440	Sm
26	**Site: Martins Quarry#2 Location: 51º8.043'N 106º17.650'W Elevation: 736 m asl**											
	GF-S186-180803	0.0-0.19	10YR 4/3 & 10YR 5/6	54.0	34.7	10.5	0.8	0.205	0.666	0.019	2.751	Gm
	GF-S187-180803	0.19-0.30	10YR 3/3	8.7	59.5	29.1	2.7	1.633	0.344	3.002	2.733	Sm
	GF-S188-180803	0.30-1.10	2.5Y 5/4 & 10YR 8/2	0.0	83.1	16.4	0.5	0.091	0.067	2.938	1.244	Sm
	GF-S189-180803	1.10-1.38	10YR 7/1 & 2.5 4/2	0.0	93.9	4.9	1.2	0.117	0.068	2.686	1.221	Sm
27	**Site: Outwash Plain Type Site Martin Quarry Location: 51º7.986'N 106º14.790'W Elevation: 732 m asl**											
	GF-S196-180803	0.0-0.11	10YR 3/2 & 10YR 3/3	0.1	53.6	43.3	3.1	2.626	0.398	3.930	2.143	Sm
	GF-S197-180803	0.11-0.39	10YR 5/4	0.2	68.7	29.9	1.2	0.610	0.078	3.256	1.773	Sm
	GF-S198-180803	0.39-0.64	10YR 3/3	0.1	38.7	55.4	5.8	0.762	0.226	4.671	2.363	Fm
	GF-S199-180803	0.64-0.74	2.5Y 5/4 & 10YR 8/1	0.9	86.4	12.7	0.0	0.238	0.637	2.165	1.431	Sm
	GF-S200-180803	0.74-0.94	10YR 6/3, 10YR 8/1, & 10YR 5/8	11.0	82.0	6.9	0.0	0.095	1.308	1.320	1.727	Sp
	GF-S201-180803	0.94-1.25	10YR 5/4 & 7.5YR 5/8	16.2	74.3	8.6	0.9	0.124	1.707	1.322	2.290	Sp
28	**Site: Sanden Dugout Location: 51º4.623'N, 106º14.475'W Elevation: 702 m asl**											
	SH-S221-200803	0.0-0.09	10YR 3/3	0.1	38.7	53.3	7.9	3.070	0.130	4.968	2.443	Sm
	SH-S222-200803	0.09-0.22	10YR 3/1	0.2	35.8	56.8	7.2	2.115	0.290	5.021	2.339	Sm
	SH-S224-200803	0.57-0.97	2.5Y 5/4, 10YR 7/2, & 10YR 5/8	0.0	51.6	47.8	0.6	0.248	1.994	3.718	1.540	Sm
	SH-S225-200803	0.97-1.71	2.5Y 6/4 & 10YR 3/3	0.1	93.7	5.3	0.9	0.076	0.039	1.831	1.454	Sp
29	**Site: O'Brien Pasture Location: 51º6.419'N, 106º17.195'W Elevation: 714 m asl**											
	GF-S248-220803	0.0-0.35	10YR 4/3	1.5	47.0	45.0	6.5	0.983	0.494	4.166	2.892	Sm
	GF-S249-220803	0.35-0.60	10YR 7/2	4.7	65.3	27.3	2.7	0.815	2.151	2.556	2.515	Sm
	GF-S250-220803	0.60-1.00	2.5Y 5/4 & 7.5 YR 6/8	11.3	81.5	67.0	0.5	0.093	1.376	1.104	1.836	Gm
30	**Site: Martin Delta Slough Location: 51º8.537'N, 106º21.612'W Elevation: 738 m asl**											
	GF-S259-220803	0.0-0.25	10YR 2/2	0.0	33.2	57.1	9.7	5.485	0.663	5.142	2.685	Sm
	GF-S260-220803	0.25-0.40	10YR 4/2	0.0	47.9	49.1	2.7	1.088	2.562	4.108	2.176	Sm
	GF-S261-220803	0.40-0.60	10YR 6/8 & 10YR 7/2	0.0	41.7	51.7	6.6	0.419	4.274	4.356	2.299	Sm
	GF-S262-220803	0.60-0.75	2.5Y 5/4, 10YR 7/2, & 10YR 6/8	1.4	62.3	32.4	3.9	0.608	1.033	3.364	2.342	Sm
	GF-S263-220803	0.75-0.90	2.5Y 5/4 & 10YR 6/8	0.3	81.8	16.9	1.0	0.201	0.197	2.570	1.998	Sm
	GF-S264-220803	0.90-1.15	10YR 5/8	1.1	84.5	11.6	2.8	0.066	0.128	2.276	2.228	Sm
	GF-S265-220803	1.15-1.50	2.5Y 4/4 & 10YR 5/8	1.6	61.2	36.7	0.5	0.109	0.580	3.236	1.688	Sm

31	**Site: Griffin Pasture North Location: 51º7.291'N, 106º21.351'W Elevation: 757 m asl**												
	HM-S276-230803	0.0-0.30	10YR 3/3 &10YR 6/3	0.0	64.3	30.2	5.5	0.732	0.624	4.423	2.086	Sm
	HM-S277-230803	0.30-0.50	10YR 6/3 & 10YR 6/3	0.0	66.6	30.8	2.6	0.558	1.812	4.044	1.477	Sm
	HM-S278-230803	0.50-1.60	2.5Y 5/4	0.0	84.5	14.4	1.1	0.156	1.033	3.487	1.163	Sm
32	**Site: Griffin Pasture South Location: 51º6.659'N, 106º21.259'W Elevation: 733 m asl**												
	GF-S326-270803	0.0-0.40	10YR 3/3 & 10YR 8/1	0.0	67.8	27.3	4.8	0.711	0.573	4.164	2.091	Sm
	GF-S327-270803	0.40-0.70	2.5Y 5/2 & 10YR 6/8	0.0	64.8	28.2	7.1	0.340	1.047	4.351	2.262	Sm
	GF-S328-270803	0.70-0.80	2.5Y 4/4 & 10YR 8/1	0.0	80.7	17.3	2.0	0.121	0.671	3.484	1.435	Sm
	GF-S329-270803	0.80-1.80	2.5Y 5/4 & 10YR 5/8	0.0	77.4	22.1	0.5	0.070	0.714	3.593	1.423	Sm
33	**Site: Vollmer's Pasture Location: 51º8.517'N, 106º24,014'W Elevation: 685 m asl**												
	GF-S339-280803	0.0-0.40	10YR 3/3	0.1	58.6	40.4	0.9	1.171	0.259	3.435	2.116	Sm
	GF-S340-280803	0.40-0.60	10YR 4/6	1.2	81.5	16.4	0.9	0.384	0.456	2.246	1.803	Sm
	GF-S341-280803	0.60-0.70	2.5Y 5/4 & 10YR 6/8	2.8	78.0	16.7	2.5	0.325	0.316	2.679	2.352	Sm
	GF-S342-280803	0.70-1.80	10YR 6/4 & 7.5YR 5/8	2.3	83.5	13.3	0.9	0.053	0.403	1.972	1.832	Sm

APPENDIX D
RADIOCARBON DATES ACQUIRED IN THIS STUDY

Sample Number: DB-O96-080803

Geographic Location: 51º01’50”N, 106º29’30”W

Site Description: Lake Diefenbaker cliff face.

Depth Below Surface: 65 cm

Sediments Characteristics: Massive, fine black (10YR 2/1) sand.

Facies Unit: Sm (upper)

Sample Number: DB-O106-080803

Geographic Location: 51º01’50”N, 106º29’30”W

Site Description: Lake Diefenbaker cliff face.

Depth Below Surface: 275 cm

Sediment Characteristics: Massive, fine black (10YR 2/0) sand, rich in charcoal.

Facies Unit: Sm (lower)

Table D.1. Radiocarbon dates collected for this study.

Sample Number	Lab Number	Dated Sample	Calculated Age	Calibrated Age
DB-O96-080803	BGS 2497	Paleosol	15,435 ± 100 yrs BP	18,435 ± 100 yrs BP
DB-O106-080803	BGS 2498	Charcoal flakes in paleosol	30,660 ± 470 yrs BP	35,660 ± 100 yrs BP