University of Alberta

Geoarchaeology of the Bodo Archaeological Locality, Alberta

by

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ABSTRACT

Geoarchaeological investigations at the Bodo Archaeological Locality in east-central Alberta establish the first stratigraphic framework of the site. Stratigraphic analysis and radiocarbon dating demonstrate human occupation during three episodes of soil formation, at 2720-2350, 1070-920, and 270-200 cal. BP. Dates correlate with the Sandy Creek, Avonlea and Late Precontact Phases, respectively, in the Northwestern Plains cultural historical sequence. The sequence of aeolian sediments and palaeosols also document episodes of late Holocene landscape instability alternating with periods of soil formation that correlate with regional palaeoclimatic records.

Soil chemical and micromorphological analyses document bone, pottery and elevated nutrient levels (particularly phosphorus) as anthropogenic inputs during human occupation. Exploratory application of microbial phospholipid fatty acid (PLFA) analysis indicates that the microbial communities of onsite soils differ from the offsite control communities. Results of soils analyses indicate that human occupation of the site had a significant and lasting impact on the soil environment.

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CHAPTER 1: INTRODUCTION

Geoarchaeological investigations at the Bodo Archaeological Locality in east-central Alberta have revealed a cultural sequence and series of palaeosols[1]. Field and laboratory analyses of sediments and palaeosols establish the first stratigraphic framework at Bodo, and provide the basis for documenting and interpreting archaeological materials at the site. The cultural and environmental history at Bodo correlates with existing regional archaeological and palaeoclimatic chronologies.

The Bodo Archaeological Locality is situated in the Bodo Sand Hills and covers an area of at least 800 hectares, making it one of the largest Late Precontact sites on the northern Great Plains. Artifact typologies and concentrations indicate three episodes of human occupation at the site, during which the focus was bison procurement (Blaikie 2005; Gibson 2004b; Grekul 2007). Human occupation took place primarily during periods of landscape stability and soil formation.

Pedologists define soil as "the naturally occurring, unconsolidated, mineral or organic material at the earth's surface that is capable of supporting plant growth" (Soil Classification Working Group 1998: 5). This definition is useful in soil classification, however it does not account for soil formation processes. Soil formation involves a combination of various biogeochemical processes, such as nutrient cycling, leaching, oxidation, and reduction, which take place in sediments at the land surface, extending through to the depth of pedogenic alteration of soil parent material. Soil horizons develop as the result of soil formation processes, which include additions, losses, translocations and transformations[2] (Buol et al. 2003:110).

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[1] The term 'palaeosol' has several possible definitions (see discussion in Paleopedology Working Group 1990). However, in this thesis, 'palaeosol' refers to a buried soil.

[2] Additions (i.e. mineral and organic deposition), losses (e.g. leaching), translocations (i.e. movement of substances from one area to another within the soil profile) and transformations (e.g. microbial alteration of organics into humus) are discussed further in Simonson's (1959) model of soil formation.

Hans Jenny (1980: 6) recognized the importance of soil formation processes in his definition of a soil as "a body of nature that has its own internal organization and history of genesis." Since soil formation processes are inferred from observations of soil properties, documenting soil properties provides the basis for interpreting the environment of soil development.

Jenny's ecological approach to modeling soil formation recognizes five major factors in soil development: climate (cl; includes temperature and precipitation), organisms (ø; vegetation, fauna [Jenny uses a slash through the 'o' to avoid confusion with zero]), relief (r; slope, aspect, drainage), parent material (p; also influences drainage) and time (t) (Jenny 1980). In this thesis, the organism component (ø) is of special interest, because it includes humans as a soil-forming factor. However, ø refers only to the genetic makeup of the organisms; both genes and culture influence human behaviour. Therefore, Jenny (1980: 203) suggests that the symbols 'øh' are appropriate for acknowledging the role of humans as an additional factor in soil formation.

Any soil property (s) may thus be represented as a function (*f*) of the major factors of soil formation. The following equation is modified from Jenny's original to underscore the role of humans as a soil-forming factor and to emphasize the connection between culture and the environment:

$$s=f(cl,ø,øh,r,p,t,\ldots)$$

The dot factors (...) are included as a consideration of the unknown number of additional factors in soil formation, such as dust influxes or fire frequency (Jenny 1980).

This thesis answers two previously unresolved questions at the Bodo Archaeological Locality:

1. What does the stratigraphy suggest about cultural and environmental factors of soil formation at Bodo?

2. What methods can detect anthropogenic influences on soil properties?

The sediments and soils from four stratigraphic sections form the basis for this investigation; three sections are from within the Archaeological Locality, while the fourth is from an offsite area, serving as a control. I employ soil science methods, including soil profile description, chemistry and micromorphology to analyze and describe soil properties. In addition, I explore the archaeological applications of soil microbial phospholipid fatty acid (PLFA) analysis in a pilot study. Finally, I interpret and discuss the results of my investigations within the regional cultural historical and environmental contexts.

CHAPTER 2: BACKGROUND

The Bodo Archaeological Locality lies within the northern Great Plains, which has a complex geological, pedological and archaeological history. The topography surrounding the Archaeological Locality reflects sediment deposition and erosion by glacial, early postglacial and Holocene processes. During the Holocene, fluvial and aeolian processes dominated in the region, and climatic fluctuations contributed to recurring episodes of sediment erosion and redeposition. Soil development occurred during intervals of climate stability, with palaeosols resulting from sedimentation during unstable periods. People inhabited the Bodo Sand Hills during episodes of climate stability; archaeological evidence suggests that people have intermittently occupied the area during the past 5000 years. In this chapter, I review the geological, pedological and archaeological history of the Bodo Sand Hills region, to provide a basis for the interpretation of site stratigraphy.

Note that all radiocarbon dates in this thesis are uncalibrated unless otherwise stated, and dates should be read as 'radiocarbon years before present.' I discuss uncalibrated dates during most of this thesis for consistency with dates from existing archaeological and palaeoclimatic research. However, in some cases I present calibrated dates where the discussion is based on historical, instrumental or tree ring data. Also, in Chapter 6, I discuss the results of my analysis at Bodo using calibrated radiocarbon dates during comparison with the optical ages presented in the work of Wolfe and colleagues (2002a, 2002b, 2005, 2006).

2.1 PHYSICAL ENVIRONMENT

The hamlet of Bodo is located at 52°7' N, 110°6' W, approximately 687 m above sea level (asl). Bodo lies in east-central Alberta, less than 10 km from the Alberta-Saskatchewan border and about 400 km southeast of Edmonton (Figure 2.1). The Bodo Archaeological Locality is located in the Bodo Sand Hills, which is part of the Sounding Lake Sand Hills (Grekul 2007; Mulira 1986). The Eyehill Creek valley runs from Sounding Lake west of Bodo along the northern boundary of the Bodo Sand Hills at about 662 m asl, into Manitou Lake in Saskatchewan (Figure 2.2) (elevations from Department of Energy, Mines and Resources [NTS #73 D/1] 1977; Peter Heiler Ltd. 2000). To the southwest of the site lie the Neutral Hills, a topographic high ranging in elevation from 730-820 m asl, reaching a peak of about 850 m asl (Department of Energy, Mines and Resources [NTS #73 D/2] 1978).

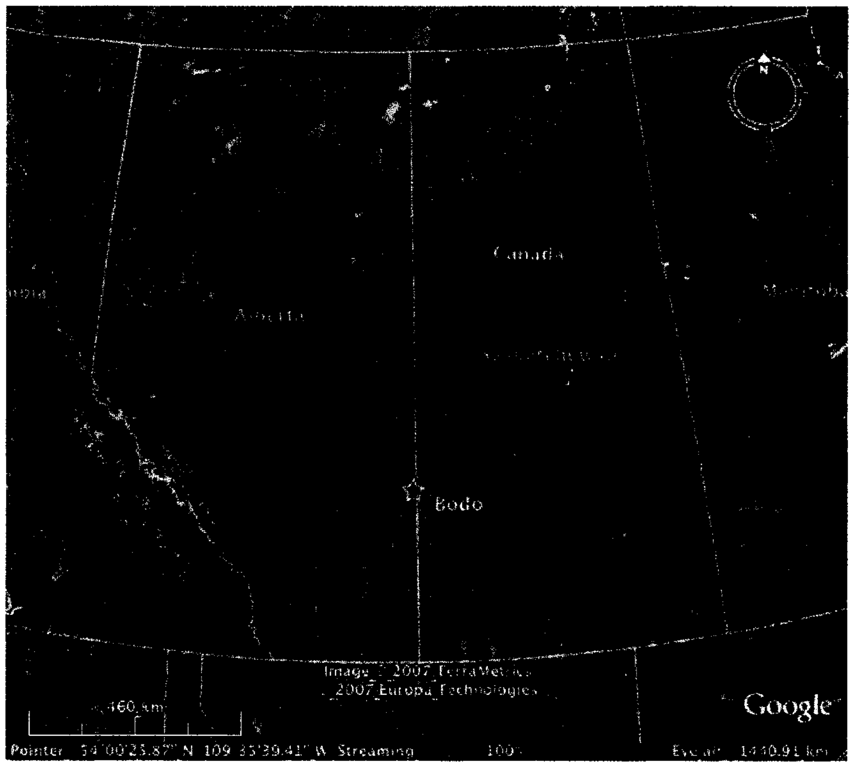

Figure 2.1. Location of Bodo, Alberta.
Satellite image.
(2007 Europa Technologies, Image 2007 TerraMetrics; accessed April 23, 2007)

2.1.1 Geology

2.1.1.1 Bedrock geology

The Bodo Sand Hills and surrounding region are underlain by two bedrock formations of Upper Cretaceous age. The Bearpaw Formation, composed of marine sediments, is the younger of the two. It consists of green, brown and grey shales, sands and bentonite, with occurrences of ironstone concretions and gypsum crystals. The Belly River Formation (also referred to as the Judith River Formation [Evans and Campbell 1995; McLean 1971]) is non-marine in origin, consisting of feldspar-rich sandstones, shales, clayey siltstone, mudstone and bentonite with concretionary ironstone and thin coal lenses. Both formations are soft and easily eroded; therefore they have been contorted in places by glacial movement. For example, the Neutral Hills lying southwest of Bodo consists of curved ridges of glacially contorted Bearpaw Formation bedrock, while the Mud Buttes south of the hamlet of Monitor, Alberta, illustrate the glacially contorted Belly River Formation (Figures 2.3 and 2.4) (Allan 1938; Copeland and Green 1982).

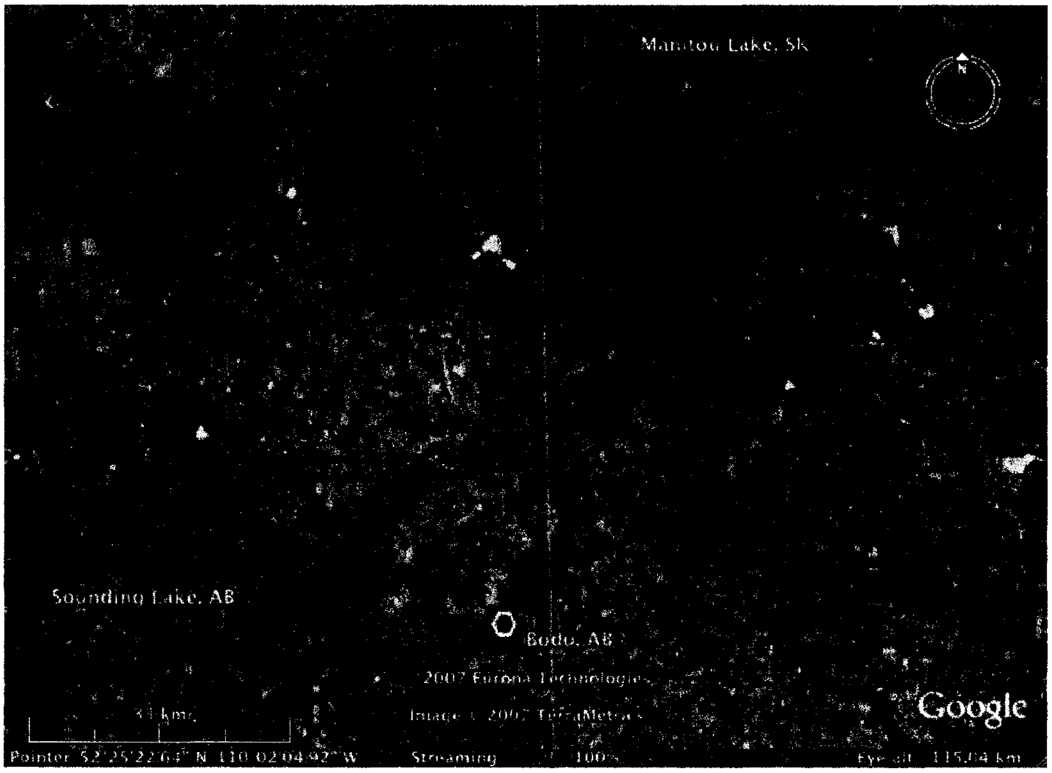

Figure 2.2. Location of Sounding and Manitou Lakes.

Eyehill Creek runs east and north from Sounding Lake, AB into Manitou Lake, SK.
(2007 Europa Technologies, Image 2007 TerraMetrics; accessed May 23, 2007)

The Belly River Formation underlies the Bodo Sand Hills region; however, Rippon and Moell (1982) have mapped a co-occurrence of the Belly River and Bearpaw Formations just south of the Bodo Archaeological Locality. Both formations are sources of the glaciogenic sediments that appear throughout the region; therefore they both influence the chemical composition of the local groundwater.

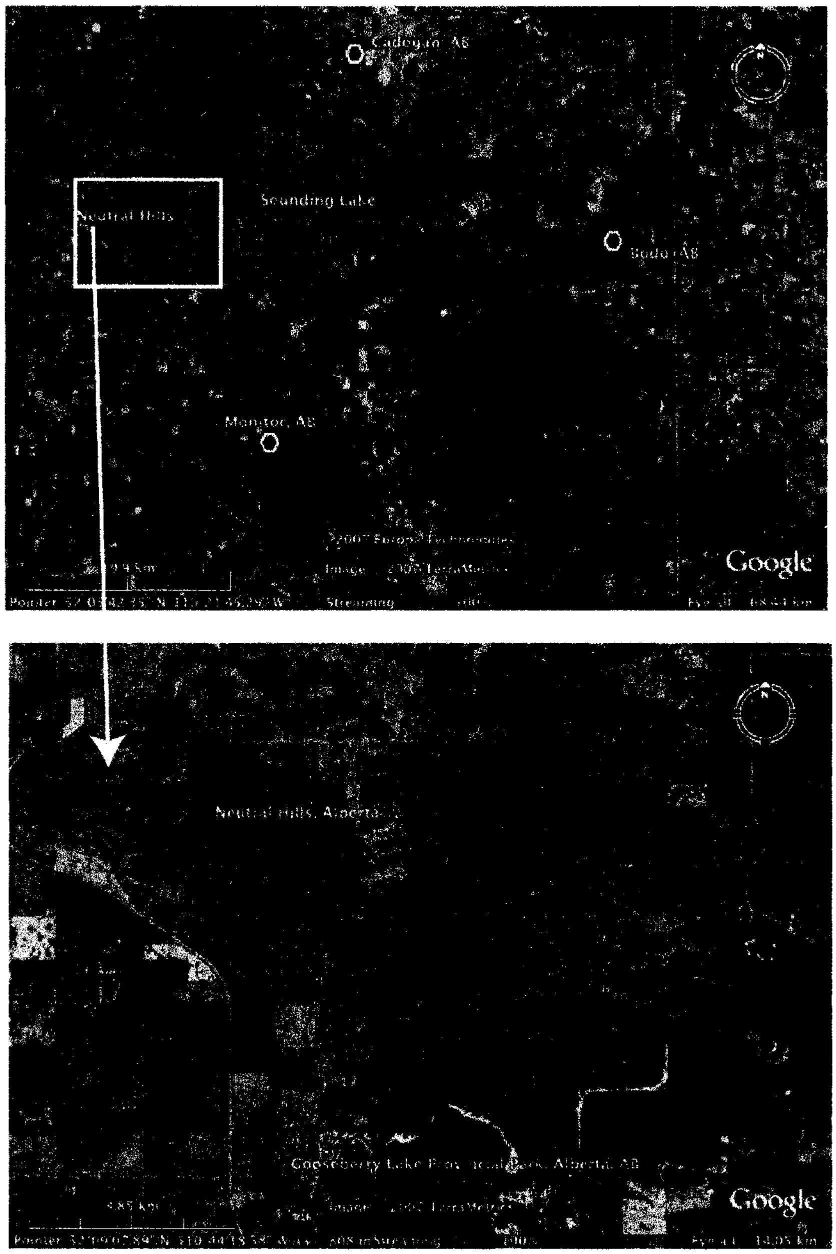

Figure 2.3. Location of Neutral Hills, Monitor, Sounding Lake and Cadogan

The Laurentide ice sheet contorted the Bearpaw Formation bedrock west of Sounding Lake, creating arcuate ridges that are now called the Neutral Hills. (2007 Europa Technologies, Image 2007 TerraMetrics; accessed May 23, 2007).


Photo: K. Gilliland

Figure 2.4. Mud Buttes, south of Monitor.

Glacial advance contorted the soft Belly River Formation bedrock in this area, demonstrated by the undulating bedrock layers in the photo, indicated by the arrow. June 5, 2006.

2.1.1.2 Surficial geology

Glaciers pulverized the relatively soft sandstones and shales as they moved, creating sediments ('till') rich in sand, silt, and clay. Gravels comprise less than five percent of the till, and are derived from the Precambrian Shield as well as the preglacial Saskatchewan Gravels[3]. Boulders in the till are also primarily derived from the Shield (Figure 2.5), as the local bedrock is too soft to have survived glacial movement as distinct clasts (Allan 1938; Bayrock 1967; Stalker 1961; Topp 1974). Till varies between 45-25 m thick in the Bodo region, but on hilltops it may be much thinner (Carlson and Topp 1971). Till was deposited as hummocky and ground moraine by

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[3] The Saskatchewan Gravels consist primarily of quartzite, chert, sandstone, clay, ironstone, shale, coal, carbonate and petrified wood derived from local bedrock and the Rocky Mountains, and do not contain rocks from the Shield (Allan 1938; Stalker 1961; Topp 1974). Evans and Campbell (1992, 1995) caution that fluvial sediments identified as the Saskatchewan Gravels and Sands may in fact have been deposited during interstadials or interglacials, or even postglacially. Careful attention to lithology and stratigraphy, as well as geochronological control will aid in resolving the period of deposition.

stagnating glaciers, creating undulating topography with frequent depressions that fill seasonally with runoff (Bayrock 1967).

Dyke and colleagues (2003) have reconstructed the timing of the North American deglaciation sequence using approximately 4000 radiocarbon dates. Their reconstruction indicates that the Keewatin sector of the Laurentide ice sheet had begun to separate from the Cordilleran ice sheet by about 18,000 yr BP (radiocarbon years before present) and that the Bodo region was still under ice or water at about 13 000 yr BP. Glaciers and proglacial lakes subsequently receded towards the northeast, and had disappeared from the Bodo region by 12 000-11 500 yr BP.

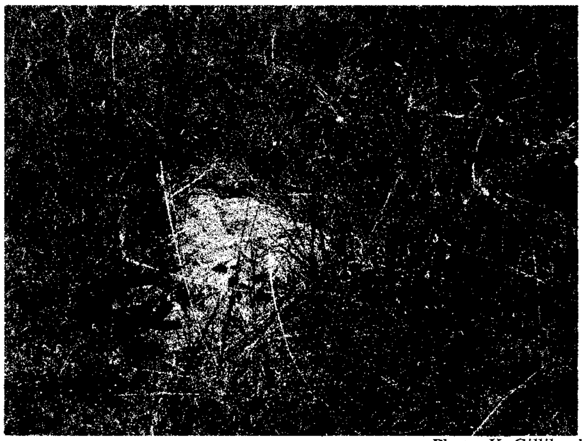


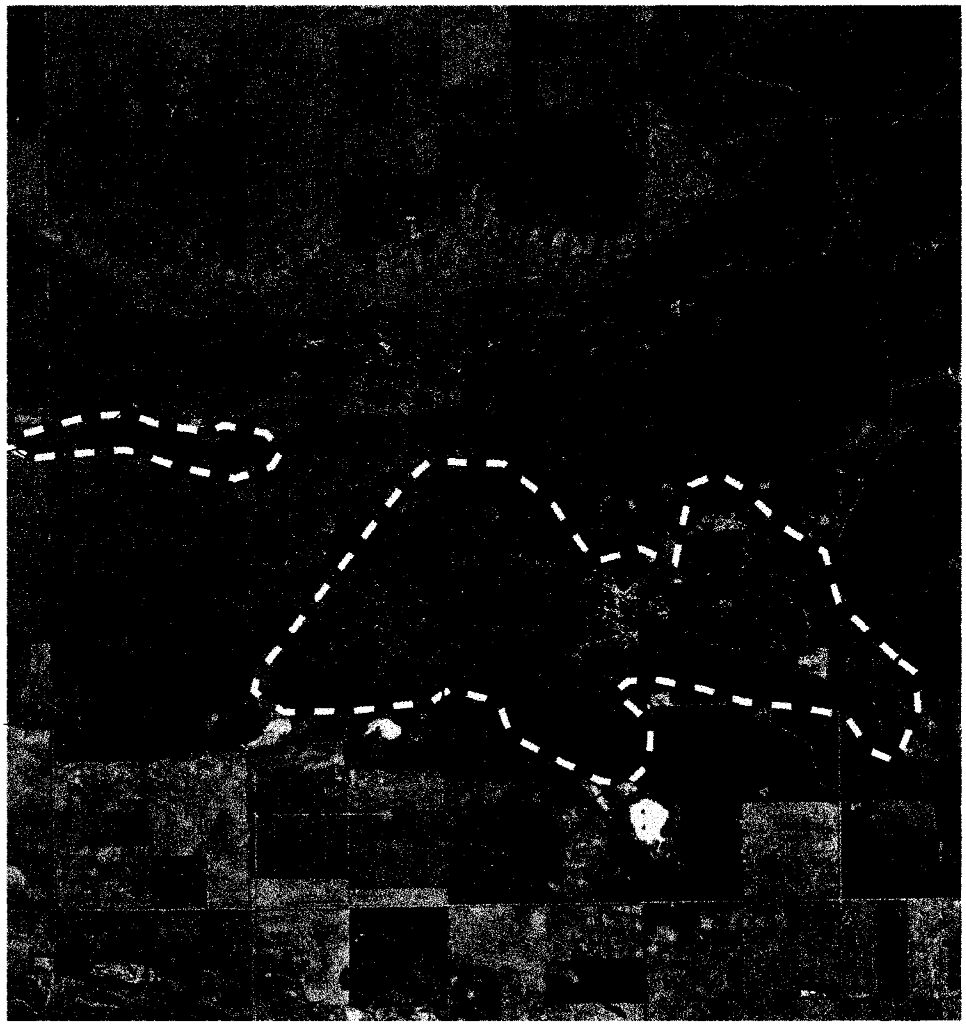
Photo: K. Gilliland

Figure 2.5. Boulder derived from the Precambrian Shield, exposed on Overlook Hill.

The nature of deglaciation may be inferred from sediments exposed in stratigraphic sections, roadcuts and natural exposures. Evans and Campbell (1992, 1995) reconstruct the preglacial, glacial and early postglacial hydrological history of Alberta south of the Red Deer River, using palaeoecological, sedimentological and stratigraphic analysis as well as geochronological dating. Laminated lacustrine sediments provide a record of the ice-dammed lakes that formed on the south and west margins of the retreating glacier. Glacial retreat was punctuated by relatively short episodes of glacial re-advance, inferred from ice-rafted coarser clasts within fine-grained lacustrine sediments (Evans and Campbell 1992). When the ice had melted sufficiently to release impounded water, proglacial lakes drained, eroding and reworking underlying sediments, sculpting spillway channels in the process. Cross-bedded fluvial gravels, sands and silts provide a sedimentary record of glaciofluvial drainage. However, cross-bedded sediments may also indicate fluvial deposition into proglacial lakes via supraglacial streams (Evans and Campbell 1992).

Gravels, sands and silts, which accumulated in supra- and pro-glacial lakes, or which were deposited in ice-walled streams, commonly sit on top of till in the Bodo region. (Bayrock 1967; Edwards and Scafe 1990; Shetshen 1990). Meltwater channel deposits, which were created when glaciers released large volumes of water, eroded and deposited sediment and formed channels, terraces and bars. Misfit streams or seasonal lakes within shallow depressions now occupy glacial meltwater channels; the Eyehill Creek valley is an example (Bayrock 1967; Edwards and Scafe 1990). Outwash is another type of glacial deposit formed when water containing sediment flows from beneath the ice surface onto the land, creating flat topography. Outwash deposits are also present in the region of the Bodo Archaeological Locality (Figure 2.6) (Bayrock 1967; Shetsen 1990).

Glacial retreat left large areas of exposed gravels, sands and silts, which served as the primary source for the earliest post-glacial dune-building period throughout Alberta. Aeolian sediments were deposited on top of glaciogenic deposits in the Bodo region. Dunes occur widely in Alberta and although some present-day forms may reflect early post-glacial formation, most aeolian deposits have been reworked during climatic fluctuations throughout the Holocene. For example, Mulira (1986) points out that many dunes in southern Alberta were formed during the late Holocene by winds blowing from the southwest. Near Hardisty west of Bodo, and at the Buffalo Park Sand Hills in the Wainwright region north of Bodo, late Holocene dunes were formed by winds from the northwest (David 1977; Mulira 1986).



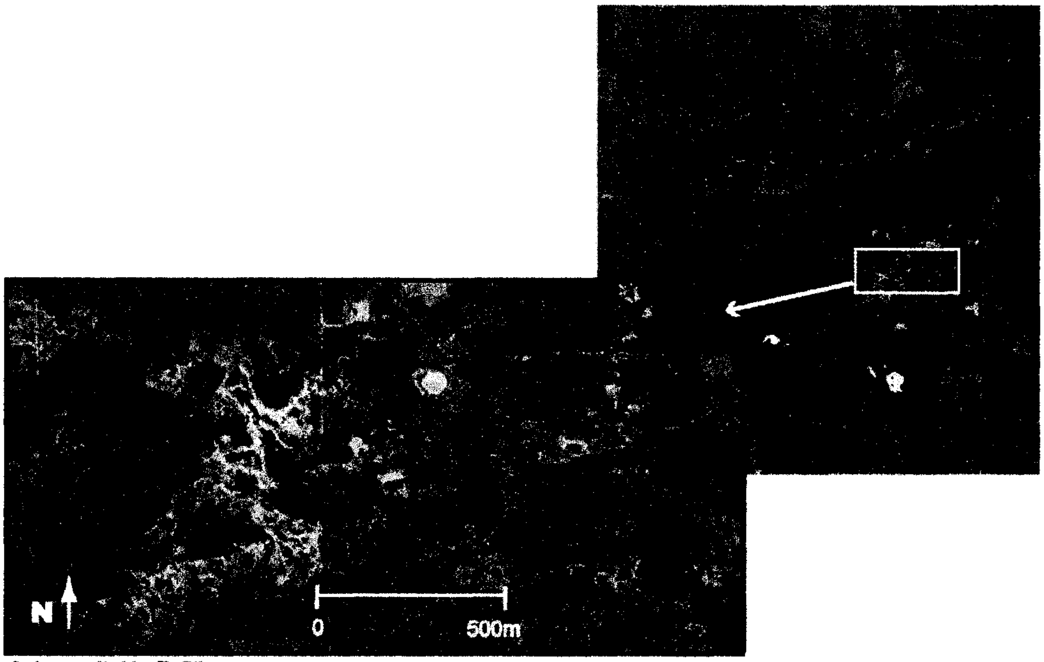
Ortho photo supplied by T. Gibson

Figure 2.6. Surficial Geology of the Bodo Region.

The two main areas of the Bodo Archaeological Locality are outlined in solid black. Dashed lines indicate boundaries of sand dune areas. GL1=Glaciolacustrine sediments; Pleistocene silt and clay. GL2-Glaciolacustrine sediments; Pleistocene sand and silt. O=Outwash deposits; Pleistocene gravel and sand. LA=Lacustrine and alluvial deposits; Holocene sand, silt and clay. A=Alluvial fan deposits; Holocene sand, silt and clay. E=Erosional scarp. G=Ground moraine, Pleistocene gravel, sand, silt, clay. Air photo interpretation by K. Gilliland, based on Bayrock (1967) and Shetsen (1990). Ortho photo flown by Geographic Air Survey, produced by Digital Environmental (Western Heritage Services, Inc.) May 18, 2004.

Air photo analysis (Figure 2.7) suggests that most of the dune forms within the Bodo Archaeological Locality are partially stabilized blowout dunes; however, remnants of parabolic and transverse dunes formed by winds blowing from the north, northeast and southeast are also present (identification of dune forms using Ritter 1986). Sands and coarse silts from the nearby outwash and meltwater channel deposits of the

Eyehill Creek valley were likely the source of aeolian sediments at Bodo (Bayrock 1967; Shetsen 1990; Townley-Smith 1980; Wolfe and Thorpe 2005). Dunes near the Archaeological Locality exhibit some destabilization that is at least partly due to recreational vehicle use and livestock grazing.



Ortho supplied by T. Gibson

Figure 2.7. Sand dune orientations, FaOm-1.

Dunes orientations shown by arrows, indicating that they were formed by winds blowing from the north, northeast, northwest and southeast. The chaotic nature of these dunes documents extensive blowout activity in this area (Wolfe et al. 2002a). Air photo interpretation by K. Gilliland. Ortho photo flown by Geographic Air Survey, produced by Digital Environmental (Western Heritage Services, Inc.) May 18, 2004.

2.1.2 Hydrology

Modern drainage networks in Alberta reflect a combination of bedrock topography, preglacial drainage patterns, glacial erosion and sediment deposition, and early postglacial hydrology. Glaciogenic sediments often bury preglacial river valleys, but these valleys continue to influence regional and local groundwater movement. In the Bodo region, for example, there are several buried preglacial channels that are tributaries to larger preglacial valleys. Regional and local groundwater flows northeast into the Battle River system, which intersects the preglacial Red Deer valley, also called the preglacial Battleford valley by Hackbarth (1975a) and the Wainwright valley by Carlson and Topp (1971) (Achuff 1992; Rippon and Moell 1982; Stalker 1961). Buried valleys mapped by Stalker (1961) indicate that, although most modern rivers in Alberta follow preglacial river courses, some portions of present-day river courses, such as the Red Deer and the South Saskatchewan Rivers, differ from their preglacial paths (Evans and Campbell 1995).

The Neutral Hills form a small drainage divide in the region; water north of the Neutrals flows into Ribstone Creek and the Battle River system, which is part of a drainage network ultimately connected to the Saskatchewan River system that drains east into Hudson Bay (Vance et al. 1995). However, water flowing to the south of the Neutral Hills summit flows into the Sounding and Gooseberry Lake basins, which are internal drainage systems. Internal drainage patterns are common in Alberta, and are a result of 'disorganized' drainage patterns created by glacial meltwater and sediment deposition (Achuff 1992).

Sounding Lake is a large, shallow ephemeral lake that may be completely dry to moderately saline, depending on moisture conditions (Figure 2.8) (Bradley and Bradley 1977; Department of Energy, Mines and Resources [NTS 73 D/1] 1977; Department of Energy, Mines and Resources [NTS 73 D/2] 1978; Hackbarth 1975b). However, the water within sloughs, lakes and streams in the Bodo region is relatively fresh, for several reasons. First, glaciogenic sands and gravels derived from the Belly River Formation sandstone comprise the aquifers in the Bodo region. Since these are relatively coarse, nonmarine sediments, the groundwater travels quickly through them, picking up less dissolved solids than the groundwater to the south, which is in the region of the slightly finer-grained, marine Bearpaw formation (Hackbarth 1975b). Second, most of the sloughs in the Bodo region are discharge sites[4] for local groundwater rather than for regional systems. Therefore, groundwater travels shorter distances through less saline sediments and is fresher. Finally, the dunes in the Bodo

[4] Discharge sites are outlets for groundwater at the land surface (e.g. springs, wetlands) (Ashley 2001).

Sand Hills are recharge sites[5] for water tables, contributing to relatively fresh local sloughs (Topp 1974). Water table levels vary from 1-17 m below surface, and therefore some may be easily accessible to humans (Hackbarth 1975b; Rippon and Moell 1982). Gooseberry Lake is the largest perennial lake basin in the region, and represents the region's largest freshwater source in the past (Allan 1938). Fresh water supports more plants than saline water and is an important resource for animals and humans.

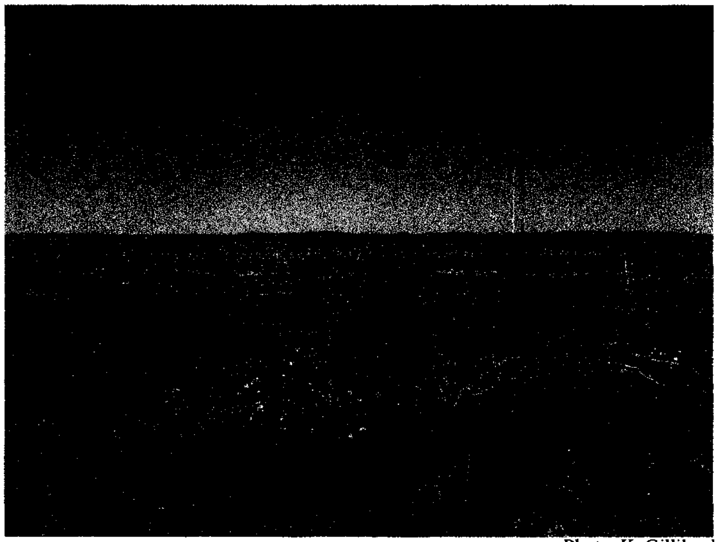


Photo: K. Gilliland

Figure 2.8. Sounding Lake, June 22, 2005.

In a visit to this spot in 2002, no water was seen in the lake; three years later, it is beginning to fill again.

2.1.3 Climate

Long, cold winters and warm summers are typical features of the Canadian Plains climate (Sauchyn and Beaudoin 1998). The Bodo region has a dry, cool climate, with a growing season from April-October, averaging 86 frost-free days. Annual precipitation is between 30-40 cm, with most falling in the summer months. The average annual temperature is about 2°C, although the area can experience extremes

[5] Recharge sites are areas on the landscape in which water is added to existing groundwater levels, for example, rainwater percolating through sand dunes to the water table (Goudie et al. 1994).

in excess of -40°C and 40°C. At the Bodo weather station, data from 2003-2006 record the mean temperature in January as -15°C and in July, 17.3°C. No long-term data are available for the Bodo weather station; however, at the nearby Cadogan weather station (52° 15' N, 110 ° 31' W, 665.3 m asl; Figure 2.3), data from1971-2000 record temperatures consistent with those recorded at Bodo. The average total annual precipitation recorded at Cadogan is 40-45 cm, 30-35 cm of that falling as rain between May-August. (Environment Canada 2004, 2006). Dry winds contribute to a potential evapotranspiration rate of 54 cm; therefore, the area has a moisture deficit and lies within a dry sub-humid moisture regime (see Wolfe and Thorpe 2005). Evidence of this moisture deficit is seen in salt crusts surrounding the many seasonal lakes and ponds in the area (Achuff 1994; Bradley and Bradley 1977; Hackbarth 1975b).

2.1.3.1 Palaeoclimate

Palaeoclimatic reconstructions rely on interpretations of numerous proxies, such as palaeolimnological data (including pollen, diatoms, algal pigments and sedimentation), soil formation, phytolith analysis, geomorphology and glacial movements combined with geochronological dating. However, different lines of proxy evidence within the same site or between sites can provide data that appears to conflict, and interpretations of the proxy data do not always agree. The following is a review of palaeoclimatic interpretations, from the late Pleistocene to the present, providing a general picture of climate fluctuations in Alberta over the past 12 000 years.

Late Pleistocene-Middle Holocene Palaeoclimate

In their reconstructions of late Pleistocene-early Holocene palaeohydrology, Schweger and Hickman (Hickman and Schweger 1993, 1996; Schweger and Hickman 1989) combine radiocarbon dating of organic lake sediments with analyses of diatoms, pollen and algal pigments from lake from central Alberta. The period immediately following deglaciation was dominated by freshwater conditions, after which lakes became more saline, suggesting a warmer and drier climate than in subsequent periods[6]. Most lake basins in central and southern Alberta were dry or saline until about 8000 yr BP, when many basins began to fill[7].

Pollen assemblages dominated by birch and spruce (*Betula* and *Picea*) in central Alberta also indicate a period of increased moisture in the late Pleistocene, as Boreal Forest vegetation had been established prior to 11 300 yr BP. Subsequent expansion of grassland into latitudes north and upslope of its current distribution prior to 6000 yr BP suggests that the early Holocene experienced prolonged aridity and evaporation. Schweger and Hickman (1989) attribute this peak in Holocene aridity to an interval of maximum summer insolation between 10 000-9000 yr BP. Also, the persistent presence of the Cordilleran glacier over the Rocky Mountains during the late glacial may have limited the transportation of moist air from the Pacific Ocean into central and east-central Alberta, contributing further to arid conditions in the late Pleistocene. As a result, in central Alberta, warmer, more arid summers and colder, drier winters prevailed from 12 000-6000 yr BP.

The grassland zone gradually retreated to its present distribution and was displaced following 6000 yr BP by Boreal Forest in northern Alberta and the Foothills, indicating the return of cooler, wetter conditions than previously. However, the climate continued to oscillate between arid and moist conditions until about 4000 yr BP. Lakes filled throughout the middle Holocene, although they were relatively shallow and warm compared to the present, reflecting a warmer, drier climate. Water levels were at similar depths to present by about 4000-3000 yr BP. Little change in diatom and pollen assemblages indicates that vegetation and moisture levels have remained relatively stable in Alberta for the past 3000 years.

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[6] However, diatoms from Goldeye Lake in the Rocky Mountain Foothills indicate an interval of freshwater dominated between 12 500-11 500 yr BP (Hickman and Schweger 1993), suggesting that the mountains may have experienced a different moisture regime than central and east-central Alberta.

[7] Moore Lake, a 30 m deep lake in east-central Alberta, is an exception. This lake contained relatively fresh water during the late Pleistocene and early Holocene (Hickman and Schweger 1996; Schweger and Hickman 1989)

Beaudoin and Oetelaar (2003) discuss the late Pleistocene-early Holocene climate of southern Alberta in a synthesis of primarily pollen and plant macrofossil data obtained from lake cores. The presence of large (now extinct) fauna in gravels of river valleys in southern Alberta, such as woolly mammoth (*Mammuthus primigenius*), helmeted musk-ox (*Bootherium bombifrons*) and extinct bison (*Bison bison antiquus*), suggests that the late Pleistocene supported a steppe-like vegetation that disappeared at the beginning of the Holocene. Thus, the late Pleistocene landscape was likely treeless and characterized by instability. Vegetation at the time of the early Holocene varied throughout southern Alberta, depending on regional moisture conditions. For example, the pollen assemblages at Toboggan Lake in the foothills of the Rocky Mountains reflect a vegetation suite that included grasses and shrubs with some willow (*Salix*) and birch (*Betula*) until about 9400 yr BP, after which the assemblage is dominated by spruce (*Picea*)[8]. However, pollen records from other lakes within the Foothills suggest that lodgepole pine (*Pinus contorta*) dominated Foothills vegetation during the late Pleistocene.

Waters and Rutter (1983) documented early Holocene soil development in southern Alberta using the Mazama tephra, deposited about 6800 yr BP, as a stratigraphic marker. Radiocarbon dating of regional palaeosols beneath the tephra suggests that soil development had occurred in southern Alberta by at least 8400-8030 yr BP. Phytoliths extracted from these palaeosols indicate that grasslands occupied greater areas of the Plains, Foothills and Rocky Mountains than at present, and thus a warmer, drier climate dominated in southern Alberta during the early Holocene prior to Mazama tephra deposition. Shortly before the tephra appears in the stratigraphic profiles, sedimentological evidence of renewed fluvial activity occurs at several sites, suggesting that landscape instability returned prior to tephra deposition. Waters and Rutter (1983: 220) state that "there appears to be no other widespread period of soil development in the postglacial floodplain sequences after Mazama ash deposition until the present." Beaudoin and Oetelaar (2003) argue that this period of soil

[8] Rapid vegetation change to spruce forest in the early Holocene may not be solely due to climate change but also the result of soil development and plant migration patterns (Beaudoin and Oetelaar 2003).

development took place during a relatively moist climate, under a landscape dominated by grassland mixed with woodland. Their evaluation is not supported by Schweger and Hickman's (1989) interpretation that a period of maximum aridity dominated during the early Holocene. However, Hickman and Schweger (1996) suggest an interval of relatively freshwater conditions is indicated at Moore Lake in central Alberta between 9100-8400 yr BP, which does correlate with the period of soil development in Waters and Rutter's (1983) study.

Lemmen and Vance (1999) offer another interpretation of early Holocene lake and moisture levels, based on palaeolimnological data. These researchers suggest that ground and surface water levels were recharged during the late Pleistocene and early Holocene, due to the vast amounts of water released by retreating glaciers. In addition, stagnant ice within hummocky and ground moraine may have continued to melt for thousands of years after deglaciation, contributing further to increased moisture levels. Thus, higher lake levels and freshwater conditions predominated from the early Holocene through to 7000 yr BP. However, Lemmen and Vance (1999) allow that higher groundwater levels could have masked the full effect of aridity brought on by the insolation maximum during the early Holocene. Therefore, the climate may have been arid, contributing to increased salinity in some lakes between 9800-8600 yr BP. Lemmen and Vance interpret the period of greatest aridity during the Holocene to have taken place during the middle Holocene between 7000-5000 yr BP. They agree, however, with Hickman and Schweger (1993, 1996) and Vance and colleagues (1995) that after about 5000 yr BP, lake levels began to rise and freshwater conditions continued to the present, with maximum lake and groundwater levels reached between 3000-2000 yr BP.

Vance and colleagues (1995) provide a synthesis of palaeolimnological, sedimentological and pedological proxy data, suggesting that the middle Holocene was a transition between the late Pleistocene-early Holocene interval of maximum aridity and the subsequently cooler, wetter late Holocene period. For example, Fiddler's Pond, in northern Alberta, is currently a year-round source of freshwater.

However, the presence of wormwood (*Artemisia*), Graminea, Chenopodiineae and cattail (*Typha latifolia*) pollen in the lake core by 6000 yr BP suggests that the lake was a seasonal pond during the middle Holocene, but it was completely dry during the early Holocene.

Increased influxes of pine pollen into Alberta lakes during the middle Holocene suggests increased fire frequency, which contributed to the migration of jack pine (*Pinus banksiana*) from the southeast between 6000-4500 yr BP (Vance et al. 1995). Diatom analysis suggests that, during the middle Holocene, water was fresher than during the early Holocene, but not as fresh as present. In the Rocky Mountains, plant macrofossils and pollen records document increased spruce (*Picea*) and fir (*Abies*) in areas above the present treeline, suggesting warmer temperatures during the middle Holocene than at present. Pollen from lakes within the Foothills and Plains indicate a northward expansion of grassland into the Foothills and Rockies, as well as into areas currently occupied by boreal forest about 6000 yr BP, suggesting increased dryness compared to today. Diatoms from alpine lakes also indicate warmer, drier conditions between 7000-5500 yr BP (Vance et al. 1995). Radiocarbon dates indicate that many lake basins in central Alberta were dry at 6000 yr BP, although Schweger and Hickman (1989) state that most lakes began to fill by 7500 yr BP.

Other lake cores discussed in the synthesis advanced by Vance and colleagues (1995) appear to contradict their reconstructed model of increased middle Holocene aridity compared to present. For example, Freefight Lake in southwestern Saskatchewan appears to have had water levels as high as today during the middle Holocene. Metiskow Lake in eastern Alberta is currently dry; however, it was a seasonal pond during the middle Holocene. These researchers point out that such apparently contradictory evidence could reflect fluctuations in local groundwater levels or simply the error margin for some conventional radiocarbon dates. They agree with Schweger and Hickman (1989) that cooler, wetter conditions began to prevail about 5000 yr BP, and the climate gradually achieved modern conditions by about 3000 yr BP.

Middle Holocene-Late Holocene Palaeoclimate

Sand dunes can serve as a proxy for environmental change, because they are very sensitive to climatic fluctuations and are often activated during periods of higher temperatures, increased fire frequency, lower humidity and reduced vegetation cover. Muhs and Wolfe (1999) combine geochronological methods with analysis of sand dune activity to provide an overview of Holocene climatic oscillations[9]. Although periods of dune formation took place during the early and middle Holocene (Wolfe et al. 2006), most dunes currently observed on the southern Canadian Plains were deposited during the late Holocene and are the result of the reworking of aeolian sands deposited during the early and middle Holocene. Aeolian activity fluctuated throughout the late Holocene, indicating periods of drought alternating with wetter conditions. Muhs and Wolfe (1999) also suggest that the middle Holocene, between 7000-5000 yr BP, was the period of maximum aridity during the Holocene, after which the climate began to approach a modern regime. For instance, Wolfe and colleagues (2006) have documented evidence of dune activity between 7600-4600 cal. yr BP (calendar years before present), indicating an interval of drought.

Based on dune activity, at least seven severe droughts have occurred within the southern Canadian Plains during late Holocene since 2500 yr BP. The timing and occurrence of dune activity, however, has varied between regions, suggesting that late Holocene dune activation depended on regional conditions such as groundwater fluctuations, and that activation was not widespread. Fluctuations in aeolian activity continued into historic times, and were documented in the eighteenth and nineteenth centuries by Euro-Canadian explorers entering the southern Canadian Plains. Sand dune areas were reported as active in Saskatchewan and Manitoba during the late nineteenth century, for example, and during the 1930s drought, some sand dunes in the Bodo region were active (Wyatt et al. 1938).

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[9] Dune activation occurs primarily as a response to environmental changes such as increased aridity and reduced vegetation cover, brought on by drought conditions (Wolfe et al. 2006).

Using multiple proxies such as palaeolimnological data, geomorphology, tree rings and historical and instrumental records, Sauchyn and Beaudoin (1998) provide a synthesis of climate change during the late Holocene. From about 3000 yr BP-present, conditions have generally been cooler and more humid than during the early and middle Holocene; however, proxy evidence suggests that climate fluctuations continued into the late Holocene. For example, Redwater Lake in Saskatchewan records increased salinity between 2500-1500 yr BP, while other lakes in closed basins on the Plains record higher water levels after 2000 yr BP. From about 1500 yr BP to present, a humid climate prevailed but was interrupted by warmer, drier intervals at 1000-900 cal. yr BP and 500-200 cal. yr BP (Sauchyn and Beaudoin 1998).

Recurring episodes of aridity characterize the last millenium, which can be divided into two main climatic periods (Sauchyn and Beaudoin 1998). The first represents an interval of recurring, prolonged, severe droughts, which caused higher lake salinity and lower lake levels between 1000-600 cal. yr BP, during the European Medieval Warm Period. From about 600 cal. yr BP to present, the climate has been relatively cooler and more humid; this period coincides with the onset of the Little Ice Age[10]. The southern Canadian Plains experienced generally higher lake levels and fresher water over the past 600 years, with some fluctuations in moisture and temperature conditions. For example, the last 800 years have experienced three episodes of sand dune reactivation brought on by drought conditions, but dunes stabilized and soil development took place during the Little Ice Age, between 560-220 cal. yr BP. However, Sauchyn and Beaudoin (1998) note that diatoms indicate relatively fresher water in lakes between 700-500 cal. yr BP, and a period of increased salinity prevailed between 500-100 cal. yr BP.

In addition to proxy data, instrumental records and early historical accounts by Euro-Canadian explorers provide a climatic record during the past 200-300 years that is

[10] The earliest Little Ice Age glacial advance in the Canadian Rockies occurred between 800-600 yr BP. The greatest extent of glacial advance during the Little Ice Age, however, took place between 300-200 yr BP. (Luckman et al. 1993).

more detailed and of higher resolution than for the rest of the Holocene. Sauchyn and Beaudoin (1998) suggest that the past 300 years on the Plains were characterized by periods of recurring severe drought, alternating with colder and wetter conditions. For example, the drought during the late 1700s AD was more severe than any drought subsequently recorded by instrumental records, including the 1930s drought. Severe droughts continued into the nineteenth century, which also experienced cooler temperatures than at present.

Sauchyn and Beaudoin (1998: 339) state that "Euro-Canadian settlement of the Canadian Plains initiated the most significant environmental changes since the retreat of the Laurentide Ice Sheet." Soon after settlement in the late nineteenth century, lake cores in southern Alberta record increased sediment influxes due to land disturbance and erosion, likely the result of farming and ranching activities. Lake sediments also indicate anthropogenic effects such as increased algal biomass that may be due to agricultural practices or influxes of sewage. Pollen from lake cores in southern Alberta record the presence of exotic weeds such as Russian thistle (*Salsola kali*) or dandelion (*Taraxacum officinale*), related to the introduction of agriculture. Elimination of bison from the landscape, fire suppression, and overgrazing of the mixed grass prairie in southern Alberta has led to conversion to short grass prairie, or in some cases the development of trees in areas previously dominated by grassland. Sauchyn and Beaudoin (1998) state that vulnerable areas of the prairie landscape are less able to withstand droughts due to these anthropogenic changes, which may lead to increased erosion.

Palaeoclimate Summary:

The late Pleistocene-early Holocene palaeoenvironmental record of the Canadian Plains may be reconstructed from a variety of proxies, including palaeolimnological, geomorphological and pedological data, tree ring data and historical accounts by early Euro-Canadian explorers. However, limited data (particularly from the early Holocene), conflicting data and differences in interpretation of the data provide a complex, unresolved picture of Holocene palaeoclimate fluctuations.

Generally speaking, the late Pleistocene-early Holocene transition was characterized by a transition from relatively fresh water immediately following deglaciation to more saline conditions at 12 000 yr BP that persisted until 6000 yr BP. Warmer, drier summers and colder, drier winters were likely the result of the summer insolation maximum at 10 000-9000 yr BP[11]. Grassland expansion into latitudes north of its present distribution and into the Foothills and Rocky Mountains reflects this period of maximum aridity during the Holocene.

The middle Holocene was warmer and drier than at present, but cooler and wetter than in the early Holocene; therefore it may be considered to be a period of transition between the warmer, drier early Holocene and the cooler, more humid late Holocene. Many lakes began to fill by about 8000 yr BP, although some remained dry or saline until about 5000 yr BP.[12], after which surface and groundwater levels increased, reaching current levels by approximately 3000-2000 yr BP. Grasslands retreated towards the south during the middle Holocene, and vegetation on the Alberta Plains and in the Rocky Mountains achieved its present distribution by about 3000 yr BP.

Conditions continued to be relatively cooler and wetter than previously throughout the late Holocene. However, repeated severe droughts occurred, suggesting climatic oscillations have been the norm over the past 3000 years. During the European Medieval Warm Period, from about 1000-600 yr BP, groundwater and lake levels on the Northern Plains lowered and lakes became more saline. The climate became generally cooler and wetter about 600 yr BP, with the onset of the Little Ice Age, and conditions of higher lake levels and fresher water prevailed until the early twentieth century. During the eighteenth and nineteenth centuries in particular, however,

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[11] Insolation is calculated using astronomical data. Dates are based on calendar years, but are uncalibrated by climate modelers for compatibility with studies based on radiocarbon years BP(Charles Schweger, Department of Anthropology, University of Alberta, pers. comm.).

[12] A period of renewed glacial activity in the Canadian Rockies, called the Neoglacial, began about 5000-4000 yr BP, which coincides with increased groundwater levels on the Plains (Luckman et al. 2003).

fluctuations in temperature and moisture caused severe, extended droughts. During this time, aeolian deposits in the Great Sand Hills, Saskatchewan, southeast of Bodo, were reactivated (Sauchyn and Beaudoin 1998; Wolfe et al. 2002a, 2002b, 2006). Euro-Canadian settlement of the Canadian Plains during the late nineteenth century dramatically altered the landscape through farming and ranching activities, and lakes document increased sedimentation during this time, due to soil erosion and changes in vegetation cover. Anthropogenic landscape changes may therefore continue to increase the vulnerability of Plains landscapes to future climatic oscillations, especially to drought.

2.1.4 Resources

2.1.4.1 Soils

Wyatt and colleagues undertook the only formal soil survey of the Bodo area in 1938. This information was updated in the early 1990s and combined with landform information to become the *Physical Land Classification of Wainwright South District-NE Region* by S. Koagaclio (Harry Loonen, Alberta Sustainable Resource Development, Wainwright, pers. comm.). The following discussion extends from and builds on these two sources, to establish my research context.

Soils at the Archaeological Locality are developed primarily on glaciofluvial or glaciolacustrine sediments, aeolian sands and silts or till, mostly derived from the local Belly River Formation. Sediments range in texture from sandy loam to loamy sand, and so these soils are well-aerated, with good to excellent drainage, resulting in little erosion of the soils through runoff. The Bodo region is situated within the Dark Brown Chernozem soil zone, a soil type that is typically associated with semiarid grasslands. In addition, gleysols develop where the water table is close to the surface, such as near seasonal or permanent water sources, or in areas with fluctuating water tables (Figures 2.9-2.11). Regosols are common within the archaeological locality; these feature minimal horizon development and are formed on recently stabilized sediments following aeolian activity (Bradley and Bradley 1977; Fehr 1984). Although the region surrounding the Bodo Archaeological Locality has been farmed since the early 1900s, soils within the Locality are unsuited for agriculture (Borowitz 2007; Soil Research Institute 1970). Land within the Locality is used primarily for pasture, and most areas have never been cultivated due to the sandy nature of the soil, its sensitivity to disturbance and erosion, and the irregular topography of the Locality (Bradley and Bradley 1977; Koagaclio ca. 1990s; Soil Classification Working Group 1998; Wyatt et al. 1938).

Photo: K. Gilliland

Figure 2.9. Test Pit 25, Locality 71, FaOm-1, looking west.

This test pit is located on the west edge of an ephemeral water hole, in which a Gleysolic soil has developed. August 11, 2004.

Photo: K. Gilliland

Figure 2.10. Gleysolic soil, Test pit 25, Locality 71, FaOm-1.

The profile is about 50 cm deep, and contains a preserved bison bone with hair, seen on the right side of the photograph. Bluish-grey colors and mottling indicate reducing conditions due to continuous or recurring sediment saturation. August 17, 2004.

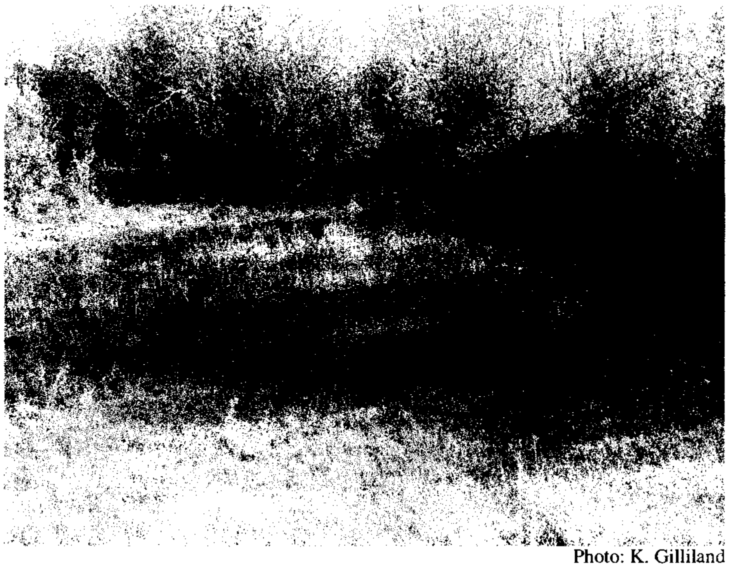


Photo: K. Gilliland

Figure 2.11. Test Pit 25, Locality 71, FaOm-1, looking south.

One year after the test pit was excavated, it lies under water. Arrow points to approximate location of test pit. September 2, 2005.

2.1.4.2 Vegetation

The Bodo Archaeological Locality hosts a unique combination of plant and animal communities due to the variety of habitats provided by the sand dunes and associated wetland areas. Positioned between the Aspen Parkland/Central Parkland and Northern Fescue Grassland natural regions (Achuff 1992, 1994), the Bodo area supports vegetation characteristic of both regions, contributing further to habitat diversity. The vegetation community is dominated by rough fescue (*Festuca scabrella*), along with a variety of other short grasses and shrubs such as rosebush, wolf willow, sage, Saskatoon berry, pin cherry and choke cherry. Small groups of aspen, poplar, birch and willow occupy wetter, low-lying areas, and include a dense understory of low shrubs and grasses. Creeping juniper, cacti, shrubs and prairie grasses stabilize most of the dunes, while sloughs and ponds support vegetation such as bulrushes, willows, sedges and herbs (Figures 2.12 and 2.13). Blowouts and interdune depressions are typically vegetated with grasses, lichens, and forbs. See Appendix I for a complete list of vegetation typical to the region (Epp and Johnson 1980; Fehr 1984; Hackbarth 1975b; Rippon and Moell 1982; Wallis and Wershler 1988; Wyatt et al. 1938).

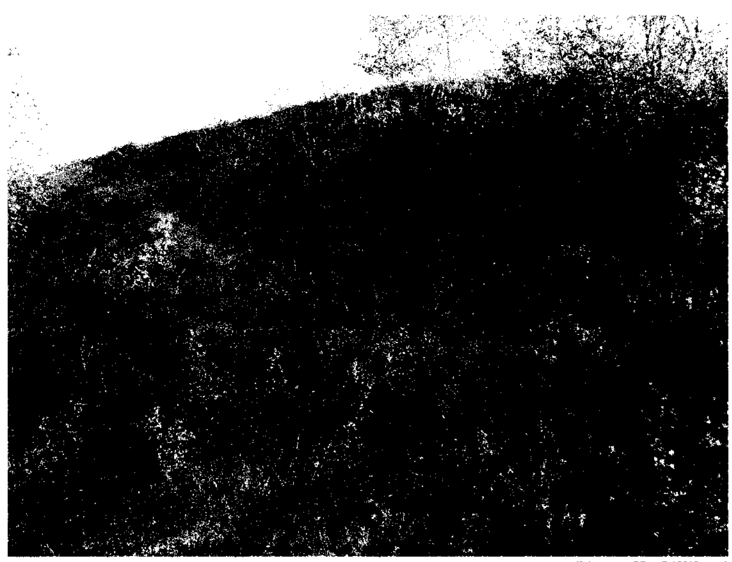


Photo: K. Gilliland

Figure 2.12. Dune vegetation, Bodo Sand Hills.

Interdune vegetation appears in the foreground; the exposed sand in the photograph likely represents disturbance by people and cattle. This dune is located approximately 500 m south of Locality 71, FaOm-1, and provided a sample for grain size analysis (Section 5.1.6). September 2, 2005.

Figure 2.13. Water hole vegetation, Locality 71, FaOm-1.

September 2, 2005.

2.1.4.3 Wildlife

Mule deer and white-tailed deer are currently the dominant large mammals in the Bodo region, although plains bison (*Bison bison*) and elk (*Cervus canadensis*) would historically have occupied the area in large numbers. Evidence of previously large numbers of bison at the Bodo Archaeological Locality appears in the work of Blaikie (2005) and Grekul (2007), in which almost 100 percent of identified faunal remains excavated from the Archaeological Locality were bison. Other mammals in the region include coyote, red fox, badger, and cougar, with small mammals such as ground squirrel, deer mouse, skunk, and jackrabbit also present. Numerous birds, such as the upland sandpiper and sage grouse, inhabit sandy and sagebrush areas. The golden eagle, prairie falcon and ferriginous hawk inhabit areas of rock outcrops and badland areas such as the north rim of the Eyehill Creek valley. Wetlands and ponds are home to migratory waterfowl such as Canada geese, snow geese and mallards (Achuff 1992).

Although many of the lakes in the area are saline, some of the larger, more permanent freshwater lakes may host fish such as burbot, Northern pike and yellow perch (Gibson 2001; Scott and Crossman 1973). In the past, fish could have inhabited several of the lakes in the region, including Gooseberry, Dillberry, Fleeinghorse, and perhaps Sounding Lakes. Muskrat and beaver may also be present in these lakes (Blaikie 2005). For a more complete list of animals typical to the area, see Appendix II.

2.2 HUMAN ACTIVITY

Anthony Henday was one of the first European explorers to enter south-eastern Alberta. Beaudoin and Pyszczyk (1998) suggest that Henday met with First Nations people (probably the Blackfoot) near Red Deer west of Bodo, as well as near the Battle River north of Bodo. Henday moved through this region during the 1750s AD, although Euro-Canadian settlers, primarily of Norwegian and German descent, arrived in the Bodo region more than a century later and began farming about 1895 AD (Borowitz 2007). Currently, land within the Bodo Sand Hills serves primarily as pasture for domestic livestock. Hydrocarbon extraction activities are also common. Recreational activities, such as the use of all-terrain vehicles (ATVs) and dirt bikes, contribute to dune destabilization, as does livestock grazing. Gooseberry and Dillberry Lakes represent the largest close permanent fresh water sources, providing locations for fishing and boating, although smaller spring-fed lakes such as Capt' Ayre Lake near Cadogan also contain fresh water and are recreational areas (Bradley and Bradley 1977; Fehr 1984; Hackbarth 1975b; Harry Loonen, Alberta Sustainable Resource Development, Wainwright pers. comm.).

2.2.1 Past use

The abundant plant and animal resources inhabiting sand hill environments have attracted humans for thousands of years. For example, the Great Sand Hills of Saskatchewan has archaeological evidence of human occupation beginning about 10 000 years BP (Epp and Johnson 1980). Within the Bodo Sand Hills region, humans were likely attracted to resources such as the accessible fresh water, abundant and varied plant and animal life, and wood from aspen and poplar groves for shelter or fuel (Gibson 2004b; Vickers and Peck 2004). However, oral histories, historical, and archaeological evidence suggest that the region was important to people of the

Northern Plains for socio-cultural reasons as well. According to Bradley and Bradley (1977), the Cree, Sarcee and Blackfoot all considered the nearby Neutral Hills, Nose Hill and Sounding Lake as part of their traditional neutral territory, and occasional communal gatherings of First Nations people took place near Sounding Lake until the 1970s (Terry Gibson, Alberta Western Heritage, pers. comm.). In 1879, over 5000 people of Cree, Metis and European descent attended the signing of the adhesion to Treaty 6 at Sounding Lake (King 1979). Although these events took place during recent historical times, archaeological evidence suggests that the Bodo area has been important habitation site for the past 5000 years.

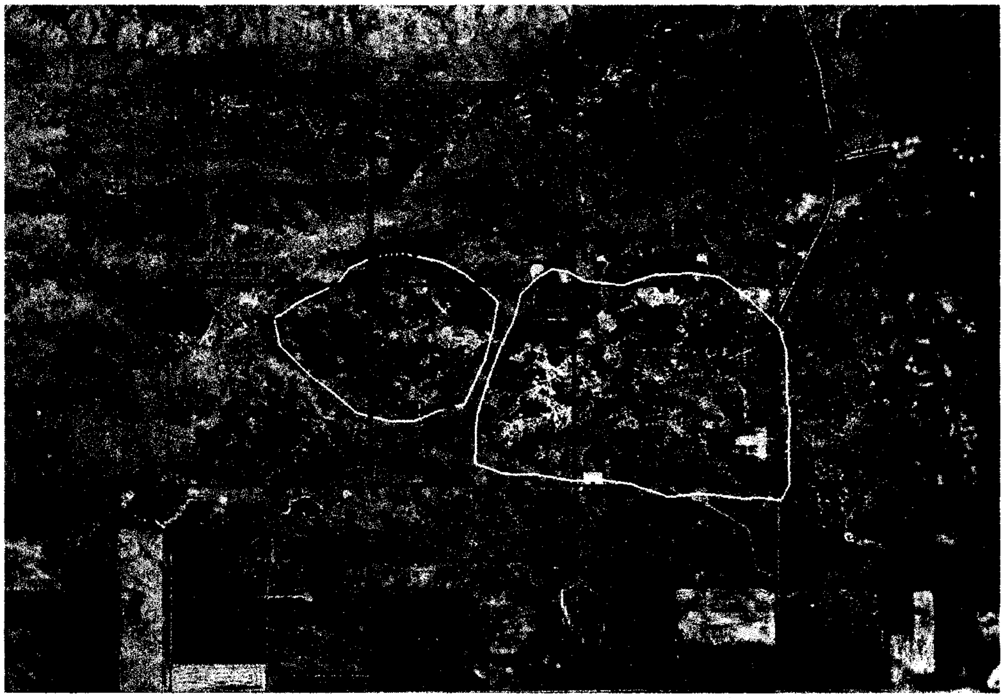
2.3 ARCHAEOLOGICAL INVESTIGATIONS

2.3.1 History of Research

Dr. Terry Gibson of Alberta Western Heritage first recorded the archeological locality in 1995 as FaOm-1, the Bodo Bison Skulls Site, during a cultural resource management (CRM) assessment (Gibson and McKeand 1996). The University of Alberta held its first archaeological field school at Bodo in 2002, and in 2003 Gibson recorded FaOm-22, the Bodo Overlook Site. Discoveries made during the four subsequent field schools and continued CRM work have considerably expanded knowledge about the locality, and the boundaries between FaOm-1 and FaOm-22 have almost merged. Gibson (pers. comm.) suggests that the sites be considered as two main areas within the larger Bodo Archaeological Locality, now estimated to cover 800-1000 hectares (Figure 2.14) (Gibson 2004b).

2.3.2 Archaeological Overview

Surface finds of diagnostic artifacts suggest that people first inhabited the region of the Bodo Archaeological Locality during the Middle Precontact (or Prehistoric) period. Projectile points that date to approximately 4600-3000 yr BP include Oxbow and Duncan types found on the land surface near a dugout in FaOm-1 in 2003, as well as a Hanna point (4200-3000 yr BP) found in a rodent disturbance on a pipeline right-of-way near the presumed northern boundary of FaOm-22 (Gibson 2004b). A buried component suggesting a Pelican Lake occupation (3300-2000 yr BP) was exposed during a test pit program in 2004 east of FaOm-22; however, there have been no other discoveries of the Pelican Lake typology at Bodo (Gibson 2004a; dates from Vickers 1986).



Ortho photo supplied by T. Gibson

Figure 2.14. Map of the Bodo Archaeological Locality.

Locations mentioned in the text are indicated as follows: WH=Water hole; PL1=Pipeline 1; CG=Well Pad 10-32, Area 5, focus of Grekul (2007) thesis research; KB=Well Pad 10-32, Area 7, focus of Blaikie (2005) thesis research. South L2, North L2, Locality 19 and Offsite refer to the profiles discussed in this thesis. Legal land descriptions are included in the boxes. Ortho photo flown by Geographic Air Survey, produced by Digital Environmental (Alberta Western Heritage) May 18, 2004.

Excavations at the Bodo Archaeological Locality suggest that there were three episodes of human habitation at the site. Artifacts from the most recent occupation are densely packed within a greasy black palaeosol (Soil 2) that appears at about 15 cm depth; this palaeosol has a continuous presence across the Locality. Diagnostic artifacts include Late Side-Notched points and fragments of Old Women's and Mortlach-style pottery, pointing to a Late Precontact occupation. In the northern Plains, Late Side-Notched points are present in sites that date between 1250-250 yr BP (Vickers 1986).

The second occupation at the Bodo Archaeological Locality is usually present within gray sand, at about 30 cm depth. Avonlea and Late Side-Notched points suggest that this layer is also of Late Precontact age. Northern Plains typology places the Avonlea point type between 1750-1150 yr BP, and the Late Side-Notched type a little later in time, between 1250-250 yr BP (Vickers 1986).

The oldest occupation appears sporadically across the Locality; when present, artifacts appear between 50-70 cm depth, usually within tan sand or a palaeosol. Many of the lithic and bone artifacts from this occupation layer appear to have rounded corners and angles, suggesting they have been ventifacted. A few points resembling the Oxbow typology have been found within the oldest occupation assemblage, suggesting that this occupation is of Middle Precontact age, dating between 4600-3000 yr BP. However, Gibson (pers. comm.) suggests that the points are of the Sandy Creek type, representing an early Besant Phase habitation, dated using northern Plains typology to between approximately 2500-2000 yr BP (Dyck and Morlan 1995: 389-405; Peck and Hudecek-Cuffe 2003; Vickers 1986; Wettlaufer 1955).

Spurious surface finds of more recent age include Euro-Canadian trade goods such as seed beads and a fragment of a metal projectile point found in 2000, suggesting that the area was occupied repeatedly into Protohistoric times[13] (Gibson 2004b). Faunal analysis in 2007 of previously excavated materials from PL1 (Figure 2.14) revealed domestic horse bones within the assemblage as well as a possible metal point fragment, further establishing a Protohistoric occupation (Gibson and Grekul 2007 forthcoming).

[13] The Protohistoric is characterized by the appearance of European trade goods at First Nations archaeological sites, before the arrival of Euro-Canadians into the region. This period dates to approximately 1700-1800 AD in Alberta (Peck and Hudecek-Cuffe 2003).

2.3.3. Previous Research

Graduate student research at the Bodo Archaeological Locality has resulted in two Master's theses[14]; Blaikie (2005) and Grekul (2007) analyzed artifacts from two areas within Well Pad 10-32 that were previously excavated during CRM investigations in 2000 (Figure 2.14). Blaikie (2005) analyzed materials recovered from a 5x5 m excavation called Area 7, containing several hearths and a diverse range of artifacts. Grekul (2007) analyzed a 2x2 m excavation called Area 5 that was interpreted to be a butchering discard area, containing primarily bison faunal remains.

The distribution of artifacts recovered from Well Pad 10-32, Area 7 suggested two possible occupations at first. However, based on stratigraphic evidence, Blaikie (2005) concluded that the upper layer had been disturbed. He therefore focused on the lower assemblage located within a palaeosol at 30-50 cm depth. This layer was described as a "palaeosol, within which was a well-defined living floor and a dense layer of lithic, ceramic and faunal artifactual material, and a number of features" (Blaikie 2005: 33). Projectile points of the Late Side-Notched variety suggested site use during the Late Precontact period, Old Women's Phase. Pottery sherds indicated the Saskatchewan Basin, Late Variant type, which is also characteristic of the Old Women's Phase. Faunal materials were primarily bison, although canid bones, representing wolf, domestic dog or fox were also recovered from Area 7 (Blaikie 2005). Rodents, such as the Richardson's ground squirrel, thirteen-lined ground squirrel and deer mouse, were also present, although Blaikie concluded that these likely represented intrusions. Ducks, geese, crow/magpie, golden eagle, and pike remains have been found in the faunal assemblage as well (Blaikie 2005). Blaikie interpreted radiocarbon dates of faunal materials and the absence of trade goods as indicating that the site was occupied about 1650 –1780 AD. Three hearths and a pit feature were noted and photographed during excavation; the combined archaeological materials provide the basis for Blaikie's interpretation that this area was likely a

[14] Borowitz (2007) has also produced a thesis related to the Bodo region, in which she documents farmers' experiences with agricultural drought and perceptions of climate variability in east-central Alberta.

location where secondary bison processing, habitation or food preparation took place. Based on his analysis and on historical accounts of early Euro-Canadian explorers, he concluded that the Late Precontact ancestors of modern Blackfoot people occupied the site. Using a number of lines of faunal evidence, as well as analysis of artifact density and interpretation of radiocarbon dates, Blaikie (2005) stated that that Area 7 represented multiple short-term occupations from late winter to mid summer. However, there is little stratigraphic evidence for this interpretation.

Grekul (2007) analyzed archeological materials recovered from Area 5, about 60 m northwest of Area 7 on Well Pad 10-32 (Figure 2.14). Archaeological materials from this area were located within a 20 cm-thick palaeosol at 10 cm depth. Artifacts included 62 complete and fragmented Late Side-Notched projectile points and Saskatchewan Basin: Late Variant pottery fragments distributed within a dense bone bed. Almost 100% of the bones were bison, although two unidentifiable bones and two bones identified as coyote (*Canis latrans*) were present. No features other than the bone bed were noted during excavation. Grekul interpreted Area 5 as a kill site, where primary bison butchering took place. She also suggested that the people occupying the site were ancestors of the modern Blackfoot people. Grekul interpreted the age and sex of identifiable elements to suggest that the area was in use during the summer months; however, she notes that the site could also represent multiple occupations, therefore seasonality is not resolved. Stratigraphy and radiocarbon dates suggest that occupation took place around 1450 AD.

CHAPTER 3: SOIL COMPONENTS

Soil formation processes may be inferred from observations of geomorphology as well as from soil properties documented in the field and laboratory (Birkeland 1999). The following is an introduction to aspects of sediment granulometry, soil chemistry, micromorphology and microbial phospholipid fatty acid analysis; these soil components provide a basis for inferences regarding the environment of soil formation at Bodo, discussed in Chapter 6.

3.1 SEDIMENT GRANULOMETRY

The observed grain size distribution of a sediment is a direct result of the environmental processes that transported and deposited that sediment (Davis 1992). In landscapes dominated by aeolian forces, wind speed and grain size are the two main controls on sediment mobilization during episodes of aeolian activity. The dominant grain size of aeolian sediment therefore provides an estimate of the relative wind velocity needed for transportation (David 1977). Generally speaking, strong winds transport coarser grains and larger quantities of sediment than gentler winds, and fine sediments travel farther than coarse ones (Allan 1938; Mulira 1986). Documenting variations in grain size distribution within a stratigraphic profile is thus a valuable tool for reconstructing fluctuations in aeolian activity over time.

3.2 SOIL CHEMISTRY

3.2.1 Carbon

Soil carbon (C) plays a crucial role in the global carbon cycle, and is present in soils primarily as carbonates or as organic matter. Soil organic matter includes the living biomass (plant and animal tissues and microbes), recognizable plant and animal remains (such as bones), and humus, which is a complex, relatively stable mix of humic and nonhumic substances[15] (Brady and Weil 2002). Within the soil system, soil organic matter provides sites for cation exchange, increases soil water-holding capacity, stores nitrogen and carbon for microbial metabolism, and is a primary influence on soil structure, stability and color. A balance is maintained in the soil between the loss of C through leaching and as carbon dioxide (CO_2) by microbial oxidation of organics, and the input of C into soil as plant and animal residues. However, C is also lost from the system due to disturbances such as fires and deforestation (Brady and Weil 2002).

3.2.2 Nitrogen

The nitrogen cycle is one of the driving forces for life on earth, because nitrogen (N) is an essential element for the production of amino acids, which form proteins. Nitrogen is also essential for the production RNA, DNA and plant chlorophyll, which is required for photosynthesis (Brady and Weil 2002).

Soil microbes play a pivotal role in the availability of soil nitrogen. For instance, organic compounds contain over 95% of soil N (Brady and Weil 2002), and although continuing research (e.g. Murphy et al. 2000) demonstrates that soluble organic N of low molecular weight is an important (if poorly understood) source of N for plants, current understanding is that plants take up mostly inorganic forms of N as ammonium (NH_4^+) and nitrate (NO_3^-). Microbes are essential to plant growth because they convert the N in organic matter to inorganic NH_4^+, through a process called ammonification. Subsequent microbial oxidation of NH_4^+ produces nitrate (NO_3^-) in a process called nitrification. Nitrogen mineralization includes both the

[15] Humic substances are very large, complex molecules, more resistant to microbial attack than other organic substances. They include fulvic acid (least resistant to microbial attack of all humic substances), humic acid and humin (most resistant to microbial attack). Nonhumic substances are derived from plant materials and from substances manufactured by soil microbes, including polysaccharides and polymers. Nonhumic substances are less complex organic molecules than humic substances and are therefore more easily modified by microbes (Brady and Weil 2002).

processes of ammonification and nitrification, which supply inorganic N to the soil solution, available for plant uptake (Brady and Weil 2002).

Another form of N unavailable for plant use is atmospheric N_2 gas. In the process of biological N-fixation, microbes convert the N_2 gas into ammonia (NH_3), which they subsequently synthesize to produce organic compounds, such as proteins. Only a limited number of microbes fix N, and several of these require a symbiotic relationship with legumes (e.g. alfalfa [*Medicago sativa*]) or certain other plants (e.g. alder [*Alnus*]) for biological N fixation to take place[16]. In these symbiotic relationships, plants supply the energy microbes require to fix atmospheric N, and in return, the microbes synthesize compounds containing N, which are accessible to the plant. However, if there is a sufficient amount in soil solution, inorganic N will be preferentially taken up by plants, and biological N fixation will not take place (Brady and Weil 2002).

Manufactured fertilizer and organic materials such as manure and urine also provide N to soils in the form of NH_4^+ and NO_3^-. Both NH_4^+ and NO_3^- are soluble and are available for plant uptake or can be lost through leaching. Soluble inorganic N may also be lost through denitrification, a process in which microbial conversion of NO_3^- into various gases, such as nitric oxide (NO), nitrous oxide (N_2O) or dinitrogen (N_2), results in losses of N to the atmosphere (Brady and Weil 2002).

Immobilization involves the microbial conversion of inorganic NH_4^+ and NO_3^- into organic forms of N, which are unavailable for plant use. Although the conversion of inorganic N into organic forms can take place during certain soil chemical reactions, incorporation of inorganic NH_4^+ and NO_3^- into microbial body structures is the main process of immobilization. Immobilization will commonly occur when microbes

[16] Some microbes (e.g. the bacteria *Azotobacter* as well as cyanobacteria) are able to fix N without a symbiotic association with plants (Brady and Weil 2002).

cannot obtain enough N from the decomposition of organic materials to sustain growth (i.e. in organic materials with high C:N ratios). The microbes are then forced to obtain N from the soil solution, which can result lower concentrations of N available for plant uptake. As microbes die, the N from their cellular structures is metabolized, and may be incorporated into other microbial structures, or enter the soil solution as inorganic forms during mineralization. Both mineralization and immobilization are simultaneously occurring within the soil environment, and the overall net balance between the two is controlled by the C:N ratio of soil organic matter (Brady and Weil 2002).

3.2.2.1 C:N Ratio

Soil microbes require a nutrient balance to build cells and obtain energy, and most soil microbes metabolize organic matter to obtain carbon for growth and energy. They also obtain nitrogen from organic matter to produce amino acids, enzymes, DNA, and other N-containing compounds. Organic material with a C:N ratio of about 24:1 is ideal for metabolism by soil microbes. Higher C:N ratios result in microbial incorporation of N from the soil solution (immobilization). The soil solution may then become depleted in N, resulting in adverse effects on plant growth. In addition, high C:N ratios slow down the rate of microbial organic decay. Manure and the A horizons of forest soils have an average C:N ratio of 20:1, while cultivated soils have an average C:N ratio of 12:1. (Brady and Weil 2002).

3.2.3 Phosphorus

Phosphorus (P) is required for the manufacture and operation of cell structures such as cell membranes, RNA, DNA and ATP (adenosine triphosphate, a requirement for cell energy systems). Processes such as N-fixation, photosynthesis and organism growth and development also rely on adequate P (Brady and Weil 2002).

The total P concentration in soils includes the inorganic and organic P fractions. Inorganic P is added to soils through the weathering of P-containing parent materials (e.g. apatite minerals) as well as during the microbial mineralization of organic P, which produces soluble inorganic phosphate ($H_2PO_4^-$). Organic P makes up 20-80% of total soil P, and is a component of all organic matter, including animal waste, plant tissues, and microbial cellular structures (Brady and Weil 2002).

In soils, P is present in soluble or insoluble forms; however, soluble P represents a very small percentage (about 0.01%) of the total soil P. Plant roots absorb soluble and labile P[17] from the soil solution, largely as the inorganic phosphate radicals HPO_4^{2-} and $H_2PO_4^-$, although some soluble organic P forms are also taken up. The soluble and labile portion of soil P is referred to as available or extractable P[18] (Brady and Weil 2002; Eidt 1977).

Soil pH is one of the most important controls on the availability and type of P present in soils. In acidic soils (i.e. pH<5.5), $H_2PO_4^-$ is the most common form of inorganic P. This P radical combines easily with iron (Fe^{3+}), aluminum (Al^{3+}) and manganese (Mn^{3+}) ions to form insoluble hydroxy phosphates (i.e. $FePO_4 \cdot 2H_20$, $AlPO_4 \cdot 2H_20$ and $MnPO_4 \cdot 2H_20$, respectively). Once formed, these P-containing compounds continue to undergo chemical reactions that decrease their solubility and availability for plant uptake. The conversion of soluble phosphates into insoluble forms is called P fixation or retention. As pH rises, Fe, Al and Mn hydroxy phosphates become soluble, and P available for plant uptake increases (Brady and Weil 2002).

In alkaline soils (i.e. pH≥8), HPO_4^{2-} is the most abundant form of soluble inorganic P. The soluble P easily reacts with calcium (Ca^{2+}) cations in alkaline soils to form

[17] Labile P is easily mobilized and readily available for plant uptake (Brady and Weil 2002).

[18] The term 'available P' refers to the soluble and labile P that is available for plant uptake in the soil. However, soil-plant interactions are very complex, and laboratory analysis is unable to accurately quantify available P resulting from these interactions. 'Extractable P' is the preferred term here, and is considered an estimate of available P (Eidt 1977; Dr. Jim Robertson, Department of Renewable Resources, University of Alberta, pers. comm.).

insoluble calcium phosphates[19] that become increasingly insoluble over time. Calcium phosphates are also a major constituent of bone, which is often deposited in significant quantities during human occupation of archaeological sites. As soil pH decreases, calcium phosphates become more soluble, and more soluble HPO_4^{2-} and $H_2PO_4^-$ is available for plant uptake or loss though leaching (Brady and Weil 2002).

In neutral or near-neutral soils (i.e. pH 5.5-7), both HPO_4^{2-} and $H_2PO_4^-$ are common forms of inorganic P that may be fixed by Fe^{3+}, Al^{3+}, Mn^{3+} or Ca^{2+} ions. However, P fixation is relatively low at near-neutral pH levels; therefore, more P is in solution, available for plant uptake (Brady and Weil 2002).

The amount of organic matter in soils also plays an important role in P availability. Microbial decomposition of organic matter releases organic acids, which decrease soil pH and increase the solubility of calcium phosphates in neutral or alkaline soils. Plant roots are then able to take up the soluble P. Organic acids also form complexes (called chelates) with Fe^{3+}, Al^{3+} and Mn^{3+} ions in solution; therefore, there are less of these ions combining with soluble HPO_4^{2-} and $H_2PO_4^-$ to form insoluble hydroxy phosphates, and more P remains in solution. In addition, organic compounds can stick to the surface of clays and other soil particles, blocking positively charged exchange sites on soil particles that would otherwise attract HPO_4^{2-} and $H_2PO_4^-$, so more P remains in the soil solution (Brady and Weil 2002).

P immobilization occurs when insoluble, inorganic Fe, Al and Mn hydroxy phosphates and Ca phosphates become soluble, forming Fe^{3+}, Al^{3+}, Mn^{3+} and

[19] Many different forms of calcium phosphates may be present in alkaline soils, including (in order from least to most soluble) fluorapatite ($[3Ca_3(PO_4)_2] \cdot CaF_2$), hydroxy apatite ($[3Ca_3(PO_4)_2] \cdot Ca(OH)_2$), and monocalcium phosphate ($Ca(H_2PO_4)_2 \cdot 2H_2O$). See Brady and Weil (2002) a more complete list of calcium phosphates commonly found in soils.

Ca^{2+}cations along with soluble P radicals (HPO_4^{2-} and $H_2PO_4^-$). Microbes subsequently immobilize the P through incorporation of P into cellular structures, converting soluble inorganic P into organic P (Brady and Weil 2002).

Losses of P from the soil environment occur when plants are harvested or grazed; unless grazing animals remain on the land to excrete the P, it is not returned to the soil. The other main loss of soil P is through erosion of soil particles after tilling, wildfires and tree harvesting. Leaching of soluble P can also occur, but this is generally minimal in natural soils due to the high rate of P fixation in most soils. (Brady and Weil 2002; Eidt 1977).

Human activities add significant amounts of P to the soil in the form of fertilizer, manure, bone deposits, excrement and other organics (Kuo 1996). Because only small amounts of P are lost through leaching or oxidation, unlike other soil nutrients such as C, N, Ca or S (sulfur), any anthropogenic addition of P to the soil results in accumulations over time. As P is fixed very quickly into the soil, there is very little horizontal or vertical movement of P through the soil profile; therefore, the distribution and concentration of P at archaeological sites reflects P deposited through human activities during site occupation (Eidt 1977; Parnell et al. 2001).

Many researchers (e.g. Dormaar and Beaudoin 1991; Eidt 1977; Lima et al. 2002; Parnell and Terry 2002; Parnell et al. 2001) have found strong correlations between areas of human activity and high total and extractable P levels at archaeological sites. Archaeologists have used P analysis as a prospection tool to identify features and site boundaries prior to excavation (Parnell et al. 2001). Phosphate analysis has also been used as a tool for interpreting human activities at archaeological sites, particularly in activity areas where low artifact concentrations limit archaeological inferences (Parnell and Terry 2002).

3.2.4 Cation Exchange

Soil nutrient cycling takes place primarily between plant roots, the soil solution and soil colloids[20]. Charged sites on colloid surfaces attract or repel soil substances such as water, metals and toxins. In addition, cations (such as calcium [Ca^{2+}], magnesium [Mg^{2+}], potassium [K^+], hydrogen [H^+], and sodium [Na^+]) as well as positively or negatively charged radicals are exchanged at colloid surfaces. Cation exchange occurs when a cation moves from a charged site on the colloid surface into the soil solution, and becomes available for uptake by plants and microorganisms. A cation of equal charge in the soil solution may then move onto the colloid surface at the abandoned site. A simple definition of the cation exchange capacity (CEC) is the total amount of positive charge per unit mass a soil can potentially hold (i.e. expressed as centimoles of charge per kilogram of soil [$cmol_c/kg$]). Exchangeable cations are those cations that have been adsorbed onto soil colloids and are available for exchange with cations in the soil solution, and are available for plant uptake (Brady and Weil 2002; Sumner and Miller 1996).

Cation exchange capacity depends on several conditions, including organic matter content, soil parent material (including type and amount of clay) and pH. Organic matter, along with silicate clays, provides charged sites for cation exchange. CEC is also determined by soil pH, as there is a significant amount of charged sites on soil colloids that are pH-dependant. For instance, in soils with a neutral or alkaline pH, more H^+ ions enter the soil solution to combine with the abundant OH^- radicals, creating negatively charged exchange sites on soil colloids, and increasing CEC. As pH decreases, the reverse reaction occurs, and CEC is lowered (Brady and Weil 2002).

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[20] Soil colloids are very small (<1-2 μm) clay, humus and sesquioxide particles with a negative net charge. Sesquioxides are oxides and hydroxides primarily of Fe, Al and Mn (Brady and Weil 2002).

In addition, as the pH of an acidic soil increases, aluminum hydroxy radicals, formerly occupying negatively charged sites on soil colloids, combine with OH^- in solution to produce aluminum hydroxide [$Al(OH)_3$], which is precipitated. As more exchange sites on soil colloids become available, the CEC increases. At neutral pH (of 7), almost all of the aluminum cations have been precipitated, and most of the pH-dependant charge has been realized (Brady and Weil 2002).

In soil science, CEC is a measure of a soil's fertility and behaviour, and is used for classification purposes (e.g. one of the diagnostic properties of a Chernozemic A horizon is that the base saturation[21] is more than 80% of the total CEC) (Brady and Weil 2002; Soil Classification Working Group 1998; Sumner and Miller 1996).

3.2.5 Soil pH

Soil pH is a measure of the hydrogen ion (H^+) concentration relative to hydroxide radicals (OH^-) in soil solution. It is influenced by several factors, including the type of materials present in the soil (i.e. humus and clay), the nutrient exchange properties of soil materials, amount of weathering, and the amount of precipitation inputs and soil leaching. Although the pH scale ranges from 0-14, most soils range in pH between 5-7 in humid regions and 7-9 in arid regions (Brady and Weil 2002). Soils with pH values near neutral (i.e. at 7) support larger and more diverse bacterial communities than soils with more acid or alkaline pH values. Bacterial activity decreases as pH falls below about 5.5; fungi are the dominant microbe in soils with low pH. The availability of soil nutrients such as N, K, Ca, Mg and P is at an optimum between the pH range of 5.5-7. Soil pH is generally lower in the upper soil horizons, near the surface, due to several possible factors that increase acidity, including decomposition of organic matter (see next paragraph) (Brady and Weil 2002).

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[21] The base saturation percentage is the percentage of the CEC that is occupied by nonacid cations such as Ca^{2+}, Mg^{2+}, K^+ and Na^+ (Brady and Weil 2002).

Soil acidity (lowering of pH) is increased through leaching of cations such as Ca^{2+}, Mg^{2+}, K^+ and Na^+ from the soil profile, resulting in replacement by H^+ into the soil solution. Soil pH is also lowered during microbial organic matter decomposition, which forms carbonic and other organic acids, resulting in release of H^+ ions into soil solution. Plant roots may release H^+ ions into solution during nutrient uptake, and microbial and chemical oxidization of soil N and S also releases H^+ ions; both processes lower the soil pH. Sulfuric and nitric acids, formed by forest fires, lightning or fossil fuel combustion, are added to the soil as acid rain. These acids break down into sulfate (SO_4^{2}) and nitrate (NO_3^-) radicals as well as H^+ cations, which lower pH and increase acidity. Human activities lower soil pH primarily by the addition of fertilizers and animal waste in agriculture and by creating acid rain. (Brady and Weil 2002; Thomas 1996).

In acidic soils, aluminum cations (Al^{3+}) are released from soil minerals into solution, increasing soil acidity, and causing plant and microbial toxicity and nutrient deficiency. The Al^{3+} ions combinine with OH^- radicals from water molecules, forming hydroxy aluminum radicals [$Al(OH)_x^{y-}$][22]. Hydroxy aluminum radicals can bind together to form compounds that take up much of the negatively charged sites on soil colloids, reducing the CEC. Nutrients such as Ca, K, P, and N are thus of limited availability in acidic soils, which can cause plant deficiencies. However, micronutrients such as Fe (iron), Zn (zinc), Cu (copper) and Mn (manganese) have increased solubility in acidic soils, and may be present in higher concentrations, to the point of being toxic to plants (Brady and Weil 2002).

[22] Hydroxy aluminum radicals can include $Al(OH)_2^+$ and $AlOH^{2+}$ (Brady and Weil 2002).

Alkaline soils are those with a pH above 7. These soils are caused by a buildup of nonacid cations such as Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} in the soil solution and at cation exchange sites in regions where leaching is limited and potential evapotranspiration[23] is relatively high. Fe, Zn, and other micronutrients have lower solubility in alkaline soils than in acidic soils, therefore plants may experience deficiencies in these micronutrients. P availability is also limited in alkaline soils, because phosphates form compounds with Ca^{2+} and Mg^{2+} ions at high pH, and P is immobilized (Brady and Weil 2002).

When the soil solution becomes saturated with Ca^{2+}, it precipitates as calcium carbonate ($CaCO_3$), usually between a soil pH of 7-8 (a calcareous soil). The buildup of salts in alkaline soils is a problem when Na^{+} dominates the cation exchange sites and soil solution, usually in soils with pH of 8.5 or higher (sodic soils). In this case, the soil structure breaks down, and soil pore space becomes clogged with colloids, preventing water infiltration (see discussion in 3.2.5) (Brady and Weil 2002).

3.2.6 Electrical conductivity

Soil salinity affects soil structure and nutrient balance, and can be a limiting influence on plant growth, especially in regions where potential evapotranspiration exceeds precipitation, or in areas with less than 500 mm of precipitation per year. Salt accumulations occur when they are released from rocks and sediments through weathering and insufficient leaching causes salts to build up. In addition, dissolved salts such as Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} as well as chloride (Cl^{-}) and sulfate (SO_4^{2-}) are transported in solution from areas of higher to lower elevations and from wetter to drier regions. When the water in solution evaporates, the salts remain, accumulating in the soil. If groundwater contains high concentrations of dissolved salts, salts may also accumulate in the soil profile through capillary rise of the water table. Salinity is

[23] Potential evapotranspiration is the combined amount of water loss from evaporation of water from the soil and from transpiration by plants living on the soil (Canarache et al. 2006).

indirectly measured using electrical conductivity (EC) (Brady and Weil 2002; Janzen 1993).

Saline soils contain elevated concentrations of soluble salts. Because the osmotic potential[24] of the water in the soil solution is lowered by the increased salt concentration, plants cannot take up soil water easily, and growth may be stunted. In young plants, the osmotic effect of salty soils may prevent growth or kill the plant, as the water in root cells moves into the soil solution. In saline soils, soil structure is maintained, and water infiltration and air movement throughout the profile is not affected, therefore salt-tolerant plants can survive. The pH of saline soils is below 8.5 (Brady and Weil 2002).

Sodic soils, on the other hand, have relatively high levels of Na^+ in soil solution and at cation exchange sites, and pH levels are 8.5 or higher. These soils are dominated by sodium carbonate ($NaCO_3$), which is more soluble than calcium or magnesium carbonate. In sodic soils, levels of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) in the soil solution are elevated, which buffers high H^+ concentrations and increases pH[25]. Relatively high levels of Na^+ adversely affect soil structure by disaggregating soil peds and creating blocked pore spaces, greatly reducing water infiltration and air movement throughout the profile. Plants are adversely affected, both by the toxic levels of Na^+, OH^- and HCO_3^- in soil solution, and by poor water infiltration and air movement within the profile (Brady and Weil 2002).

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[24] Osmotic forces are the result of the attraction of water molecules to solutes in soil solution. An increased concentration of salts in soil solution results in reduced movement of the water molecules and lower osmotic potential of the water. Water moves from areas of higher potential energy to areas of lower energy, therefore a lower osmotic potential in soil solution results in reduced uptake of water by young plants (causing stunted growth), or movement of water from the root cells (with higher osmotic potential) to soil solution, causing cell death (Brady and Weil 2002).

[25] Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) react with water to produce OH^-, which raises pH (Brady and Weil 2002).

3.3 SOIL MICROMORPHOLOGY

Soil micromorphology, or thin section analysis, has been used since the 1930s as a method to investigate soil formation and diagenesis. Undisturbed soil samples are taken using Kubiëna tins or comparable containers and are impregnated with resin. Once hardened, the samples are sliced to 30μm and are described using reflected and polarized light microscopy. Using a micromorphological approach, researchers are able to view soil particles in relation to each other, in order to identify soil parent materials, faunal activity, human disturbance, freeze-thaw processes (e.g. Sanborn and Pawluk 1989). Pedologists also use micromorphology in soil classification and in management studies (Stoops 2003). Archaeologists document soil micromorphological properties for use in combination with other techniques, such as chemical analyses, to investigate land use history and the nature of human activities at archaeological sites (e.g. Adderley et al. 2004; Lima et al. 2002; Simpson et al. 2000, 2006).

3.4 SOIL MICROBIAL PHOSPHOLIPID FATTY ACIDS

3.4.1 Soil Microbial Community

3.4.1.1 Microbial Community Function

The soil microbial community is of vital importance for global nutrient cycling, and has a major influence on soil properties and soil function. Microbes break down organic matter to form humus, a complex mix of relatively stable organic compounds that provides soil stability and structure. They convert essential nutrients such as N, P and Mg into useable forms for plant uptake, and facilitate interactions between roots and the soil. Finally, some microbes provide plants protection from environmental toxins and harmful microbial invasion. Microbial communities are sensitive indicators of soil environmental health, and soil microbiological studies can answer questions regarding soil contamination and the effects of agricultural practices (i.e. tilling, fertilizer applications) on soil fertility (Brady and Weil 2002; Horwath and Paul 1994; Yan et al. 2003).

3.4.1.2 Controls

Our understanding of the structure of microbial communities and their environmental controls is still developing. However researchers have identified several key factors influencing microbial community composition; these include substrate quality and quantity, temperature, moisture, pH, salinity, and competition and predation between microbes. Also, changes in the soil environment such as disturbance due to land use will affect the soil microbial habitat, thus changing the community structure (Bossio et al. 2006; Buckley and Schmidt 2001; Foster et al. 2003; Fraterrigo et al. 2006; Grayston et al. 2001; Hannam et al. 2006; Ibekwe and Kennedy 1999; Robertson, Crum and Ellis 1993). Within a single soil profile, a variety of microhabitats house different groups of organisms; for example, different communities inhabit the soil near the surface, around roots, near feces, near burrows, in waterlogged soils, and in areas of concentrated organic matter (Brady and Weil 2002; Buckley and Schmidt 2001; Grayston et al. 2001).

3.4.1.3 Diversity

Soil microbial communities are extremely diverse, with over one billion organisms in a single teaspoon of soil and more than 4000 different types of microbes in a single gram. The two main groups of microbes are fungi and bacteria; both play an integral role in the soil food web. Characterizing the microbial community structure provides a glimpse of the complex interplay between these organisms, and a view of overall soil ecology (Brady and Weil 2002; Buckley and Schmidt 2001; Kennedy 1994).

Soil fungi are organisms that are heterotrophic[26] eukaryotes[27]; and include yeasts (in anaerobic, waterlogged conditions), molds and mushrooms; they function to break down organic matter. Bacteria are prokaryotic organisms, and while some metabolize organic material as their carbon source (heterotrophs), others obtain it from

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[26] Microbial heterotrophs obtain their carbon from the breakdown of soil organic matter, while autotrophs obtain carbon from atmospheric CO_2 or carbonates (Canarache et al. 2006).

[27] Eukaryotes possess a nuclear membrane; prokaryotes do not (Canarache et al. 2006).

atmospheric CO_2 or from carbonates (autotrophs). Bacteria reduce and oxidize Fe, Mg and other nutrients, influencing soil color and the availability of nutrients for use by plants. Actinomycetes are prokaryotes that are usually heterotrophic, and along with fungi are particularly important in breaking down tough organic compounds like cellulose and chitin (Brady and Weil 2002).

3.4.2 Phospholipid Fatty Acids

Researchers measure the amount and types of microbes in a soil using a variety of techniques. For example, microbes are counted using culture techniques such as plate counts[28] or most probable number analysis[29]. To examine the morphology of microbes and their habitats, direct and scanning electron microscopy are employed. Microbial biomass is estimated using techniques such as fumigation-incubation[30], fumigation-extraction[31] and substrate-induced respiration[32].

Phospholipid fatty acid (PLFA) analysis is a method of assessing the total in situ microbial biomass and community structure of a soil. PLFAs are important components of almost all living cell membranes, and deteriorate quickly after cell death (Federle 1986; Guckert and White 1986; Kennedy 1994). While some PLFAs are specific to certain organisms, others occur in almost all members of the microbial

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[28] Plate counting involves culturing microbes in the laboratory for a specific period of time using a solid medium, and subsequently counting the resulting microbial colonies (Canarache et al. 2006).

[29] Most probable number (MPN) analysis is a culture technique that estimates microbial numbers by monitoring the presence or absence of microbes in increasingly diluted samples within a liquid medium (Canarache et al. 2006).

[30] Fumigation-incubation involves fumigating a soil sample with chloroform ($CHCl_3$) and subsequently incubating the sample. The surviving microbes consume the dead ones, producing CO_2 and NH_4^+, which are measured as an estimate of microbial biomass (Jenkinson et al. 2004).

[31] Fumigation-extraction is similar to fumigation-incubation in that the soil sample is fumigated with $CHCl_3$. However, once the samples have been fumigated, the soluble organic C and N are recovered from the dead microbes, as an estimate of microbial biomass (Jenkinson et al. 2004).

[32] Substrate-induced respiration involves measuring the amount of CO_2 released by soil microbes as they metabolize an added substrate, such as glucose. The amount of CO_2 measured is an estimate of the microbial biomass and activity (Anderson and Domsch 1978).

community. However, several PLFAs are considered biomarkers for functional groups of fungi and bacteria. PLFA analysis provides a profile of the soil microbial community structure, obtained through the identification and quantification of PLFAs present (Federle 1986; Frostegård and Bååth 1996; White and Ringelberg 1998). One of the primary applications of PLFA analysis in soil science is to assess soil fertility and nutrient status as a means of evaluating land management practices (Hannam et al. 2006; Ibekwe and Kennedy 1999; White and Ringelberg 1998).

3.4.3 PLFA Applications to Archaeology

3.4.3.1 Microbial Analysis

Researchers have used both microbial and fatty acid analysis to address archaeological problems. For example, Gearey and Caseldine (2006) undertook analyses of testate amoebae, pollen and plant macrofossils for the purpose of reconstructing water table fluctuations at the Derryville Bog, Co. Tipperary, Ireland. In another ongoing study at Wareham, Dorset, researchers assess microbial activities during the decomposition of buried archaeological materials (Lawson et al. 2000). Closer to home, Cook's (1969) analysis of multiple buried Ah horizons at the Head-Smashed-In Buffalo Jump archaeological site in Alberta provided evidence that archaeological layers continue to host large populations of microbes thousands of years after burial. Cook demonstrated that organic matter degredation continues in these horizons, although at a much slower pace because of limited soil moisture and oxygen.

3.4.3.2 Fatty Acid Analysis

Fatty acid analysis has been particularly useful for identifying residues on archaeological materials such as pottery and burnt rocks (Buonasera 2005; Eerkens 2005; Malainey et al. 1999). In addition, Dormaar and Beaudoin (1991) used a combination of soil chemistry and fatty acid analysis to interpret the soils at the Calderwood Buffalo Jump archaeological site in Alberta, as well as to identify an adjacent secondary butchering area.

PLFA analysis is distinct from microbial studies and fatty acid analysis in two ways. First, PLFA analysis provides a microbial community profile that aids in understanding the soil environment *at the time of sampling*, and does not provide an assessment of past microbial communities. However, the modern soil microbial community reflects the current soil habitat, which may be altered as a result of past environmental changes or human land use history. Second, unlike fatty acid analysis of archaeological residues, phospholipids are separated from the total lipid fraction prior to analysis. Therefore, although total fatty acid analysis and PLFA analysis may be complementary techniques when applied to archaeological materials, the data are not comparable (Jennifer Lloyd and Sylvie Quideau, Department of Renewable Resources, University of Alberta, pers. comm.; White and Ringelberg 1998).

3.4.3.3 Land Use History

Long-term studies suggest that land use history, particularly agricultural, grazing and logging practices, has a lasting influence on vegetation and soil properties, including physical (i.e. salinization, compaction, homogenized soil horizons) and chemical properties (Bossio et al. 2006; Foster et al. 2003; Fraterrigo et al. 2006; Robertson, Crum and Ellis 1993). Changes in vegetation and the soil environment due to land use can continue to impact the microbial community for centuries after land use has ceased. Microbes, soil and vegetation are parts of a feedback system within the entire soil ecosystem, therefore microbial activities affect soil characteristics and vegetation in turn (Foster et al. 2003; Fraterrigo et al. 2006).

The land use history of early indigenous peoples on the North American Plains is "easily overlooked" (Foster et al. 2003). However, First Nations people did alter the landscape and this may have significantly changed the soil environment. For example, to attract bison, people burned the prairies to promote new grass growth. Prairie burning and localized burning in hearths and cooking pits added charcoal to the soil, altering the soil environment. Pietikäinen and colleagues (2000) have shown that PLFA profiles differ based on the presence and type of charcoal in the soil (i.e. humus versus wood charcoal). It follows, therefore, that the various types of charcoal and ash produced by burning different materials at archaeological sites, such as grass, dung, wood, bone or vegetables, likely resulted in the emergence of distinct microbial community profiles.

Cooking residues, bone, viscera and other organics added to the soil during the course of human activity at archaeological sites probably provided substrates for microbial metabolization that differed from other areas. One would expect, therefore, that distinct microbial communities would appear at archaeological sites. Other human-imposed landscape changes could include clearing brush in preparation for habitation, causing vegetation changes that may also have had a lasting impact on the soil microbial community.

The development of the fur trade followed by the arrival of settlers from the east brought more changes in land use history. These include fire suppression, clearing vegetation for settlement, the introduction of agriculture and the replacement of bison with domesticated cattle as the dominating large herbivore (Knapp et al. 1999; Milchunas et al. 1998; Sauchyn and Beaudoin 1998).

3.5 SUMMARY: ARCHAEOLOGICAL APPLICATIONS

Land management practices including agriculture, grazing, burning and logging all impact the soil ecosystem and these effects can last hundreds or thousands of years after the activity has ceased (Foster et al. 2003). Chemical analysis and micromorphological techniques are valuable tools, by themselves or in combination with other techniques, for identifying anthropogenic sediments, past land management strategies, resource use and settlement construction techniques at archaeological sites (e.g. Adderley et al. 2000, 2004, 2006; Dormaar and Beaudoin 1991; Reeves 1978; Simpson et al. 2003, 2006). These methods can also help delineate site boundaries and identify areas of intensive use within the site (Dormaar and Beaudoin 1991; Eidt 1977; Lima et al. 2002; Parnell and Terry 2002; Parnell et al. 2001).

PLFA analysis is a relatively new technique in soil science, therefore it has had limited time to be applied in other fields such as archaeology. However, Ortega-Morales and colleagues (2000) applied PLFA analysis to a problem regarding the destruction of 1000-year-old Mayan limestone buildings by algae and bacterial films, which coated the buildings. These researchers characterized the microbial communities using a combination of techniques including PLFA analysis, and their work resulted in recommendations for remedial and preventative treatment through biocides, to preserve the buildings.

Because PLFA analysis has not yet been applied to archaeological soils, one can only speculate regarding the applicability of this technique to archaeological problems. However, human activities and land use have a long-lasting affect on vegetation distribution, soil properties, and substrate quality and quantity; these changes to the soil environment impact the microbial community structure. PLFA analysis is applied to soils in this thesis as a pilot study, to investigate the usefulness of this technique for documenting human activities and land use history at archaeological sites.

CHAPTER 4: RESEARCH METHODS

4.1 SITE SELECTION AND SAMPLING

4.1.1 Stratigraphic Profiles

A stratigraphic profile is a vertical exposure of sediment or rock that is a record of geological processes through time (definition adapted from Doyle et al. 1994); inferences can therefore be made regarding environments of the past through observations of stratigraphy. Soil properties within a stratigraphic profile are usually described to a depth of about 25 cm deeper than the observed influence of soil development (Soil Classification Working Group 1998). However, sediments situated below the soil profile are important for environmental interpretations, and are described to the extent that is possible.

Three stratigraphic profiles from within the Bodo Archaeological Locality were exposed for study; two profiles were from FaOm-22 Locality 2, and will be referred to as the South L2 and North L2 profiles, while the third comes from FaOm-22 Locality 19, referred to as the L19 profile. As a control for comparison, an offsite profile was also exposed. The data obtained from these stratigraphic profiles forms the basis for this thesis (Figure 2.14).

I described and photographed each profile in the field using guidelines set out by Day (1983). After laboratory work was completed, I determined the sedimentological units and designated the soil horizons after consultation with Dr. Peter Crown, Department of Renewable Resources, University of Alberta. Soil horizons[33] were assigned using guidelines from the *Canadian System of Soil Classification* (Soil

[33] Although there is a wide variety of soil types and horizons, there are three primary horizons in mineral soils. The A horizon is near the land surface and usually contains an accumulation of organic material. However, clays, organic material or sesquioxides may be translocated from the A horizon. In the B horizon, organic matter, clays, or sesquioxides accumulate. The C horizon represents the unaltered soil parent material, except for possible gleying (due to sediment saturation) or accumulations of carbonates and soluble salts. The three main horizons are subdivided according to horizon properties (e.g. a gleyed C horizon is a Cg horizon) (Soil Classification Working Group 1998).

Classification Working Group 1998). For the purposes of this thesis, I have numbered the soils in each of the stratigraphic profiles as Soil 1, Soil 2, etc., as they appear from the top of the profile. This is not the convention in soil science; however, as those reading this document may be from outside soil science, the soils are numbered for clarity during the discussion. Note that Soils 1 and 2 are the only soils that correlate between the four study profiles. Soil 3, if present, may not correlate between profiles.

Dr. Terry Gibson and I collected a small amount of elevation data within Locality 2 during September 2005 using a Total Station. Other elevations were obtained using the topographic map for the area (i.e. Department of Energy, Mines and Resources [NTS #73 D/1] 1977).

4.1.2 Site Selection

FaOm-22 Locality 2 is located on 12-31-36-1 W4M[34] at an elevation of 686 m asl (above sea level) on a series of low terrace-like landforms that gently descend north towards the Eyehill Creek valley (Figure 4.1) (Department of Energy, Mines and Resources [NTS #73 D/1] 1977). Locality 2 is a mostly stabilized aeolian landscape dominated by sandy soils that support deciduous trees, grasses and shrubs, and serves primarily as a grazing pasture for domestic livestock (Figures 4.2 and 4.3). Stratigraphic profiles were chosen from Locality 2 because the locality has been the focus of the University of Alberta field school excavations since 2003, and has provided the opportunity to observe stratigraphy within excavation pits. Each pit in Locality 2 was chosen based on observed stratigraphy during the summer of 2005.

4.1.2.1 South L2

The South L2 profile is located on a probable terrace about 676 m asl, within a grove of aspen, birch and poplar trees, with an understory of rosebush, willow and grass. A

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[34] This is the legal land description where the site is located. Within the township grid system, these numbers refer to legal subdivision (LSD) 12, section 31, township 36, range 1, west of the fourth meridian (Alberta Government 2005).

2x2 m excavation block was exposed during the summer of 2005, and dug to a depth of 95-100 cm, after which a hard sediment layer containing cobbles was encountered, halting excavation and precluding any auguring. The south wall of this excavation block is the South L2 profile (Figure 4.4).

4.1.2.2 North L2

The North L2 profile is located on a probable terrace about 674 m asl, 60 m to the north of the South L2 profile, and 2 m lower in elevation. It is in a relatively open area dominated by grass and shrubs, bordering on a grove of aspen, birch and poplar trees to the west. A block of excavations was begun during the 2003 field school at this location and subsequently expanded in 2005. Excavations reached approximately 200 cm depth, and the floor of the pit was subsequently hand augured to 268 cm, until the density of the sediment stopped further auguring. After auguring, the pit was backfilled to 130 cm depth for safety reasons, prior to profile description. The south wall of the 2005 field school excavation block is the North L2 stratigraphic profile (Figure 4.5).

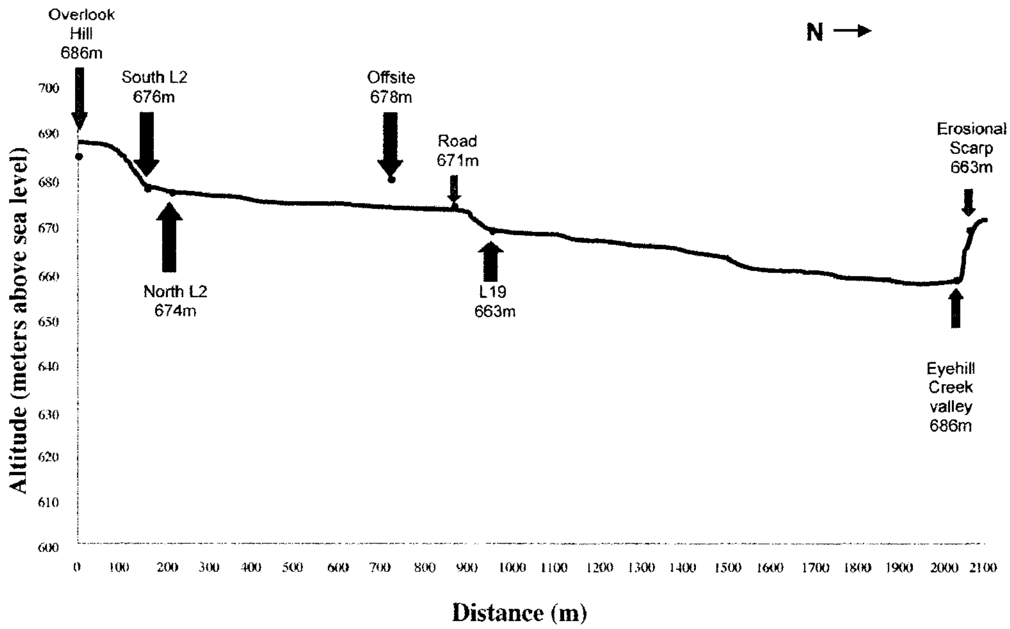

Figure 4.1. Location of Study Profiles in Cross-section.

Overlook Hill, is the highest point in the area immediately surrounding the Bodo Archaeological Locality, and is located approximately 250 m west of South L2. The Offsite profile is located about 700 m west of the archaeological site and at a higher elevation, indicated by the dot on the diagram. The thicker green arrows indicate study profiles. Elevations collected with the assistance of Terry Gibson using a Total Station, and from Department of Energy, Mines and Resources, NTS Map #73 D/1 (1977).

Photo: K. Gilliland

Figure 4.2. Terrain and vegetation, South L2 Profile.

This photo is taken looking towards the South L2 profile, located approximately 20 m south of where I am standing. The arrow indicates the approximate location of the South L2 profile. June 8, 2005.

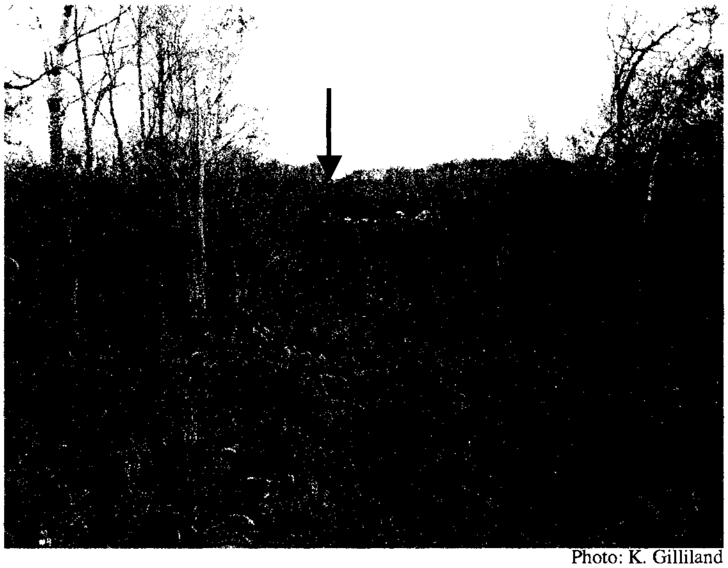

Photo: K. Gilliland

Figure 4.3. Terrain and vegetation, North L2 Profile.

This photo is taken looking towards the North L2 profile, located approximately 40 m north of where I am standing. The arrow indicates the approximate location of the North L2 profile, which is in the clearing, adjacent to the cooler seen in the distance. June 8, 2005.

Photo: K. Gilliland

Figure 4.4. South L2 Profile during excavation.

The south wall of the 2x2 m excavation pit, indicated by the arrow, provided the stratigraphic section for the South L2 profile. August 18, 2005.

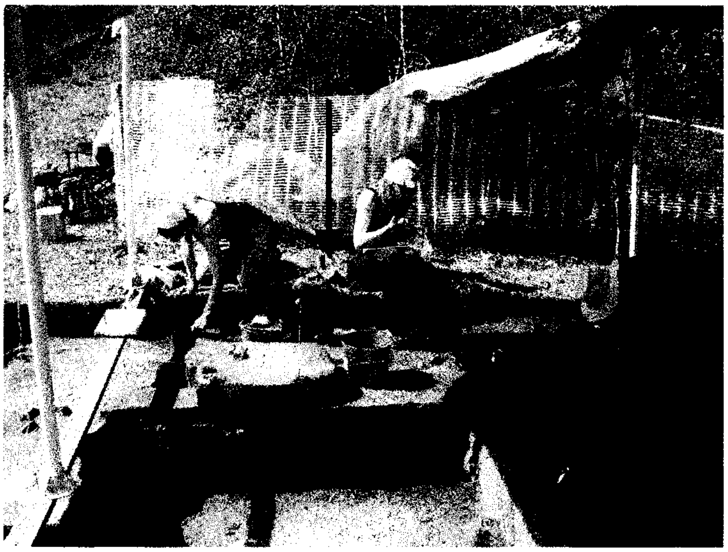

Photo: K. Gilliland

Figure 4.5. North L2 Profile during excavation.

The south wall of the excavation pit, indicated by the arrow, provided the stratigraphic section for the North L2 profile. July 1, 2005.

4.1.2.3 Locality 19

The L19 profile is located approximately 728 m north of North L2 at 4-6-37-1 W4M, at 663 m asl (Department of Energy, Mines and Resources [NTS #73 D/1] 1977). It is on a relatively flat area of land with a few low-lying dunes about 300 m to the east. Aspen, poplar and birch predominate with an understory of rosebush and grasses (Figure 4.6). This land currently serves as pasture for domestic livestock.

A 3x4 m excavation block was placed at this location during the 2006 archaeological field school. Although excavations were halted at 75 cm depth due to time constraints, Test Pit KG7, located less than 50 cm east of the excavation block, had similar stratigraphy and had been excavated earlier in the summer to 98 cm depth. The floor of the this pit was subsequently augured until the water table was reached at 186 cm depth, after which the sediment kept falling out of the augur. The north wall of Test Pit KG7 provided the stratigraphic profile for L19 (Figure 4.7).

Photo: K. Gilliland

Figure 4.6. Terrain and vegetation, L19 Profile.

This photo was taken during excavations of Test Pit KG9, located 10 m east of the L19 profile, and illustrates the vegetation of the excavation area. June 14, 2006.

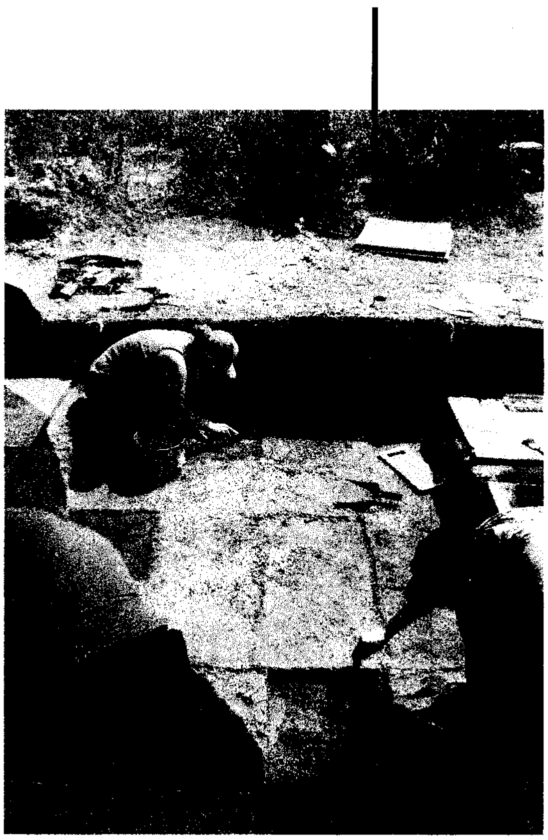

Photo: K. Gilliland

Figure 4.7. L19 Profile during excavation.

The north wall of Test Pit KG7, covered by wood for protection and indicated by the arrow, provided the stratigraphic section for the L19 profile. July 3, 2006.

4.1.2.4 Offsite

The Offsite soil profile is located about 700 m west of Locality 2 at 15-36-36-2 W4M at 678 m asl, (elevations from Department of Energy, Mines and Resources [NTS #73 D/1] 1977). This location was assessed in 2004 during CRM work and was designated of low historical resource value (Gibson 2004a), therefore it was chosen as a comparison with the archaeological profiles. Like the Locality 2 profiles, the Offsite profile is also located on a low terrace-like landform, however the vegetation at this location lacks trees, and is mostly grass with a few low rosebushes (Figure 4.8). Soil is occasionally exposed at the surface, which is dotted with boulders and cobbles. This land serves primarily as pasture, although there is some hydrocarbon extraction activity approximately 500 m to the west of the Offsite location. A 1.5x2 m pit was exposed during the summer of 2006, and the north and east walls comprise the Offsite profile.

Photo: K. Gilliland

Figure 4.8. Terrain and vegetation, Offsite Profile.

Photo taken during excavation of Offsite profile, indicated by arrow. June 16, 2006.

4.1.3 Sampling

Bulk sediment samples were collected from every soil horizon within each of the stratigraphic profiles during the summer of 2005 (South L2 and North L2) and 2006 (L19 and Offsite). Samples were also collected during auguring when sediment differences were observed. Bulk samples were stored in resealable plastic bags in the freezer for later soil mechanical and chemical analysis. Two sand dunes, located southeast of FaOm-1, Locality 71, provided samples for mechanical analysis in 2005, for comparison with the grain size of study profiles (see Figure 2.12).

Micromorphological samples were collected from the North L2 and South L2 profiles in 2005 using 8 x 6 cm Kubiëna tins according to FitzPatrick (1993), and subsequently wrapped in masking tape and placed in plastic resealable bags at room temperature; Vancouver Petrographics subsequently prepared standard 30μm-thick soil thin sections.

Dr. Sylvie Quideau of the Department of Renewable Resources, University of Alberta collected samples for soil PLFA analysis in late September 2005. The modern soil (Soil 1) and the most recent palaeosol (Soil 2) were sampled from the South L2 and North L2 profiles; samples were also taken from Test Pit L2-9, located halfway between the two profiles. Samples were collected from the offsite location also, however since the Offsite profile had not yet been excavated or described, sample provenience from this location are limited to the upper 5 cm of the profile, and may represent either Soil 1 or Soil 2. PLFA samples were immediately put on ice in plastic coolers, transported to the University of Alberta, and stored in a super freezer (-85°C) prior to analysis.

Six bone samples and one tooth from the South L2 and North L2 profiles were selected for radiocarbon dating after their provenience was documented and they were cleaned and catalogued. Two bone samples from immediately above and below Soil 3 in Test Pit L2-9 were also submitted. Soil 2 of the L19 profile contained adequate bone for radiocarbon dating, however since the occupation period associated with Soil 2 has been well dated (see discussion in Chapter 2), these were not submitted, and resources were spent on obtaining the other dates for this study. Therefore, there are no dates for L19 at present, nor are there any for the Offsite profile. Samples for dating were shipped to Beta Analytic in Miami, Florida, for accelerator mass spectrometry (AMS) radiocarbon analysis.

4.2 GENERAL PREPARATION

All bulk samples were weighed prior to drying in a 105°C oven for at least 12 hours and soil water content was subsequently calculated (Soil and Crop Diagnostic Center 1995: Method S032). Visible roots and bone fragments were removed before disaggregation and sieving to less than 2 mm size.

Soil mechanical analysis was performed using the hydrometer method followed by sieve analysis modified from McKeague (1981) and Soil and Crop Diagnostic Center (1995: Method S008). Samples with organic matter content exceeding 5% were pretreated with 30% hydrogen peroxide (H_2O_2) prior to hydrometer analysis (Lewis and McConchie 1994; Sheldrick and Wang 1993;). Organic matter and carbonate content were estimated using the loss-on-ignition method, with two replicates made of each sample (Beaudoin 2003; Bhatti and Bauer 2002; Boyle 2004; Heiri et al. 2001). Results are expressed as percentage of soil weight. I performed both mechanical analysis and loss-on-ignition in the Geoarchaeology Laboratory, Department of Anthropology, University of Alberta.

For total C, N and P analysis, samples were ground to fine powder using a ball-mill grinder. Chemical analyses took place at the Natural Resources Analytical Laboratory, Department of Renewable Resources, University of Alberta. Each chemical analysis included both laboratory standard and blank samples, and Natural Resources Analytical Laboratory staff monitored quality control.

4.3 CHEMICAL ANALYSIS

4.3.1 Total Carbon and Total Nitrogen

Total C and N were analyzed according to the Dumas dry combustion method using the Carlo Erba NA1500 elemental combustion system at the University of Alberta's Department of Renewable Resources (McGill and Figueiredo 1993). Using this method, samples are combusted in pure oxygen at temperatures in excess of 1000°C, ultimately oxidizing all C and N. All C is oxidized to produce CO_2 gas, and all forms of N are reduced to N_2 gas; both are separated from other elements with a gas chromatograph and subsequently quantified as percentage of the total original sample weight.

4.3.2 Total and Extractable Phosphorus

I prepared the samples for total P using the Kjeldahl digestion method, and they were subsequently analyzed using the automated Technicon Autoanalyzer II (Bremner and Mulvaney 1982; Technicon Industrial Systems 1977). Total P is expressed as a percentage of soil weight.

Extractable P is defined in this thesis as the measurable amount of P available for plant uptake, including the P in soil solution and the P loosely bound to soil particles (labile P) (Brady and Weil 2002; Eidt 1977). I first extracted P using the Kelowna method (Soil and Crop Diagnostic Center 1995: Method S023), and concentrations were subsequently determined using the Technicon Autoanalyzer II. Extractable P is expressed as milligrams per kilogram of soil (mg/kg), and it represents about 0.01% of total soil P (Brady and Weil 2002; Eidt 1977).

4.3.3 Cation Exchange Capacity and Available Cations

I measured both cation exchange capacity (CEC) and available cations, which can be measured in the same three-step procedure. In the first step, a 1 *M* solution of ammonium acetate (NH_4OAc) is poured into a filter containing the sample, to replace the cations currently attached to cation exchange sites in the soil with ammonium (NH_4^+). The filtrate contains the soil's exchangeable cations and is kept for later analysis of the major cations Ca^{2+}, Na^+, K^+ and Mg^{2+} using the Varian #880 Atomic Absorption Spectrometer. The sample is then washed with 125-150 mL of isopropanol, to eliminate the excess NH_4OAc, and this filtrate is discarded. In the final step, a 1 *M* KCl solution is gradually added to the samples to exchange K^+ for the NH_4^+ at cation exchange sites. The filtrate is removed and the NH_4^+ is quantified using the Technicon Analyzer II as a measure of the CEC (Hendershot et al. 1993; Thomas 1982). CEC and available cations are expressed as centimoles of charge per kilogram of soil ($cmol_c$/kg).

4.3.4 Soil pH and Electrical Conductivity

I performed the extraction for both soil pH and electrical conductivity (EC) using a soil to water ratio of 1:2[35]. Subsequent measurements were taken using an Accumet AR20 pH/conductivity meter, which was calibrated prior to measurement using

[35] 10g of soil to 20 mL of deionized water were used.

standard pH 4 and 7 buffer solutions. Conductivity is measured as microsiemens per centimeter (μS/cm) and soil pH is measured on a scale from 0 to 14, with 0 being the most acidic and 7 being neutral (McKeague 1981).

4.4 SOIL MICROMORPHOLOGY

One thin section from each of two palaeosols were described for this thesis; the South L2 Soil 3, from 63-69 cm depth, and the North L2 Soil 2 at 8-14 cm depth. I divided the slides into areas based primarily on organic matter concentration, and subsequently described and interpreted the slides according to FitzPatrick (1993) and Stoops (2003). Dr. Ian Simpson of the School of Biological and Environmental Sciences, University of Stirling provided assistance with thin section description and interpretation. I identified minerals using MacKenzie and Adams (1994); these identifications were approved by Dr. Christopher Herd of the Department of Earth and Atmospheric Sciences, University of Alberta.

4.5 SOIL MICROBIAL PHOSPHOLIPID FATTY ACID ANALYSIS

Soil microbial phospholipid fatty acids (PLFAs) were isolated using a method modified from Bligh and Dyer (1959), Frostegård and Bååth (1996) and White and Ringelberg (1998). Jennifer Lloyd of the Soil Biogeochemistry Laboratory, Department of Renewable Resources, University of Alberta performed the identification and analysis of the PLFAs, which were first extracted by Cherie Frantik. PLFA extraction and analysis involves several processes before meaningful results are obtained. The following is a brief summary of the process of extraction and analysis; see the above references for a full account.

4.5.1 PLFA Extraction and Identification

All lipids in the sample were isolated using the chloroform, methanol and citrate buffer method (Bligh and Dyer 1959; Frostegård et al. 1991). Phospholipids were then separated from neutral and glycolipids using silicic acid solid phase chromatography. In a third step, PLFAs were converted to phospholipid fatty acid methyl esters (PLFAMEs) through mild alkaline methanolysis (White and Ringelberg 1998). Samples were inserted into the Hewlett-Packard 6890N Gas Chromatograph (GC), which separated and quantified the PLFAMEs. The Microbial Identification (MIDI) Sherlock Protocol (MIDI Inc., Newark, DE) was used to identify the PLFAMEs through comparison with a reference collection. An internal standard (19:0) peak was used as a reference to allow quantification of sample PLFAMEs (Guckert and White 1986). See Appendix III for explanation of fatty acid nomenclature and a list of the PLFAs used as biomarkers for microbial functional group[36] identification.

4.5.2 PLFA Analysis

4.5.2.1 Ordination

Ordination is a multivariate method of organizing data along axes or dimensions to clearly summarize complex interrelationships. This method is ideal for describing patterns in ecological communities because it integrates environmental and historical data as well as community interactions. Ordination is also used to manage information that varies along a continuum. Ordination is often used in community ecology to explore or confirm suspected patterns or relationships in the data as well as to discover unexpected patterns. The goal of ordination is to simplify complex interrelationships between variables in as few dimensions or axes as possible. The results of ordinations are often used to generate or test hypotheses about variations within the community and to reveal the most important influences on it (McCune and Grace 2002).

4.5.2.2 Non-metric Multidimensional Scaling

Non-metric multidimensional scaling (NMS) is an ordination method that does not assume the data has a normal distribution or has any linear relationships, and it is commonly used for ecological data (Clarke 1993). As it can handle a wide range of

[36] Microbial functional groups include fungi and bacteria, which make up to the total microbial community profile.

variables of unequal importance, "NMS is the most generally effective ordination method for ecological community data and should be the method of choice, unless a specific analytical goal demands another method" (McCune and Grace 2002: 125). Patterns in soil PLFAs from Bodo were examined with the NMS technique (Kruskal 1964; Mather 1976) using PC-ORD software (version 4, MjM Software Design, Genenden Beach, OR). See Appendix IV for the list of microbial functional groups on which ordinations were run.

4.5.2.3 Statistical tests

The multi-response permutation procedure (MRPP) is a test of the statistical significance of the spread of the data in the ordination, and evaluates whether differences seen in the analysis reflect real differences in the data. MRPP is ideal for ecological data because it does not assume a normal distribution. MRPP generates several test statistics. The test statistic T describes the separation between groups; the more negative T is, the stronger the separation. A describes the homogeneity within groups, and is scored from 0-1, with 1 describing a group whose members are exactly the same. In community ecology, A is usually below 0.1. P represents the likelihood that the observed differences in the data are due to chance. A P value of 0.05 is usually considered significant. However, this study involves a small number of samples and is experimental, therefore a more conservative value of P=0.01 is the criteria for significance, (McCune and Grace 2002).

In addition to MRPP, NMS ordinations are evaluated using the Monte Carlo test. During the Monte Carlo test, ordinations are repeatedly run with randomized data; in some cases these are repeated in excess of 100 times. The Monte Carlo test evaluates whether the patterns expressed in the ordination could occur randomly (McCune and Grace 2002). The MRPP and Monte Carlo tests ensure that ordinations performed on a small number of samples are still meaningful, and that differences between groups are real and significant.

4.5.2.4 Indicator Species Analysis

Indicator species analysis is a statistical method commonly used in ecology to identify certain species that are characteristic of a particular habitat (Dufrêne and Legendre 1997). This method combines data regarding the abundance and frequency of a particular species within a group of samples, without comparison to other species in the group. Limiting measurements of species abundance to within-species comparisons means that measurements do not rely on the relative abundance of other species within the group.

The indicator value for each species is calculated using the following equation:

$$IndVal_{ij}\ (\%) = [Nindividuals_{ij}/Nindividuals_{i}] \times [Nsites_{ij}/Nsites_{j}].\ \times 100$$

Where $Nindividuals_{ij}$ is the mean number of individuals of species *i* throughout samples in group *j*, and $Nindividuals_{i}$ is the sum of the mean number of individuals of species *i* throughout all groups. $Nsites_{ij}$ is number of samples in group *j* where species *i* appears, and $Nsites_{j}$ is the total number of samples in $group_{j}$. $IndVal_{ij}$ is at 100% when species *i* is present in all samples of one particular group only (Dufrêne and Legendre 1997: 350). The significance of indicator values (IndVal) is assessed statistically using random arrangements of the sample data.

Hannam and colleagues (2006) applied indicator species analysis to PLFA data from various forest stand types and harvesting treatments. Results of the analysis allowed identification of specific PLFAs as indicators of aspen or spruce forest floors. These researchers also demonstrated that spruce forest and the associated understory have a particularly strong influence on the soil microbial community structure and result in high indicator values for several specific PLFAs. The study detected no significant difference in the total microbial community structure based on harvesting treatments.

CHAPTER 5: RESULTS

5.1 STRATIGRAPHY AND SOILS

Stratigraphic units in this thesis are identified in the order of deposition, following stratigraphic convention (e.g. Davis 1992). Identification of units is based on changes in grain size distribution as well as the presence of palaeosols, which represent depositional hiatuses in the sedimentary record (Davis 1992). Soil horizons are named beginning at the modern surface, as is conventional in soil science (Soil Classification Working Group 1998). Stratigraphic units and soils identified within each profile describe the stratigraphy of that particular profile (for correlations of stratigraphy, see discussion, Chapter 6).

5.1.1 South L2 Profile

Four stratigraphic units are present in the South L2 profile (Figures 5.1, 5.2; Tables 5.1, 5.2). Unit A, 101-95 cm, is a clay loam sediment containing rounded to subangular cobbles 10-20 cm in diameter. Unit B, 95-60 cm, consists of well-sorted loamy sand containing pebbles coarser than 0.5 mm. Soil 3, a palaeosol developed in the top of Unit B, indicates a depositional hiatus. Soil 3 resembles an Eluviated Dark Brown Chernozem (Soil Classification Working Group 1998).). Krotovinae[37] are present in Unit B, Soil 3, horizon IIIAhb2. Unit C, 60-8 cm, consists of well-sorted loamy sand, containing pebbles coarser than 0.5 mm from 60-55 cm. Soil 2, a palaeosol developed in the top of Unit C, indicates another depositional hiatus; Soil 2 is a Rego Dark Brown Chernozem (Soil Classification Working Group 1998). Krotovinae are present in all horizons of Unit C. Unit D, 8-0 cm, consists of well-sorted loamy sand. Soil 1 is the modern soil, formed on Unit D; the modern soil is not classified in any of the study profiles, as it represents a thickening of Soil 2, horizon IIAhb (Dr. Peter Crown, Department of Renewable Resources, University of Alberta).

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[37] A krotovina is an animal burrow that has been filled in with soil or sediment (Canarache et al. 2006).

Bone and lithic artifacts such as knives, scrapers and utilized flakes are present in the South L2 profile from 90-0 cm, however artifact concentrations are highest in Unit B, Soil 3, horizon IIIAhb2, and Unit C, Soil 2, horizon IIAhb. No diagnostic artifacts were recovered from the South L2 profile, although a few pieces of pottery were excavated from Unit C, horizon IICb1, between 25-15 cm depth.

One bison tooth was collected from Unit B, Soil 3, horizon IIIAeb, at 80-70 cm depth for AMS radiocarbon dating[38]. Three additional bone samples for AMS radiocarbon dating were taken from Unit B at depths of 60 cm (horizon IIIAhb2), 30 cm (horizon IICb1), and 15 cm (Soil 2, horizon IIAhb) (Table 5.2). One micromorphological sample was taken of Unit B, Soil 3, horizon IIIAhb2, at 69-63 cm depth. Samples for PLFA analysis were also taken of Unit C, Soil 2, horizon IIAhb, and Unit D, Soil 1, horizon Ah.

[38] All radiocarbon dates reported in this thesis have been submitted to the Canadian Archaeological Radiocarbon Database (CARD) (Morlan 2001).

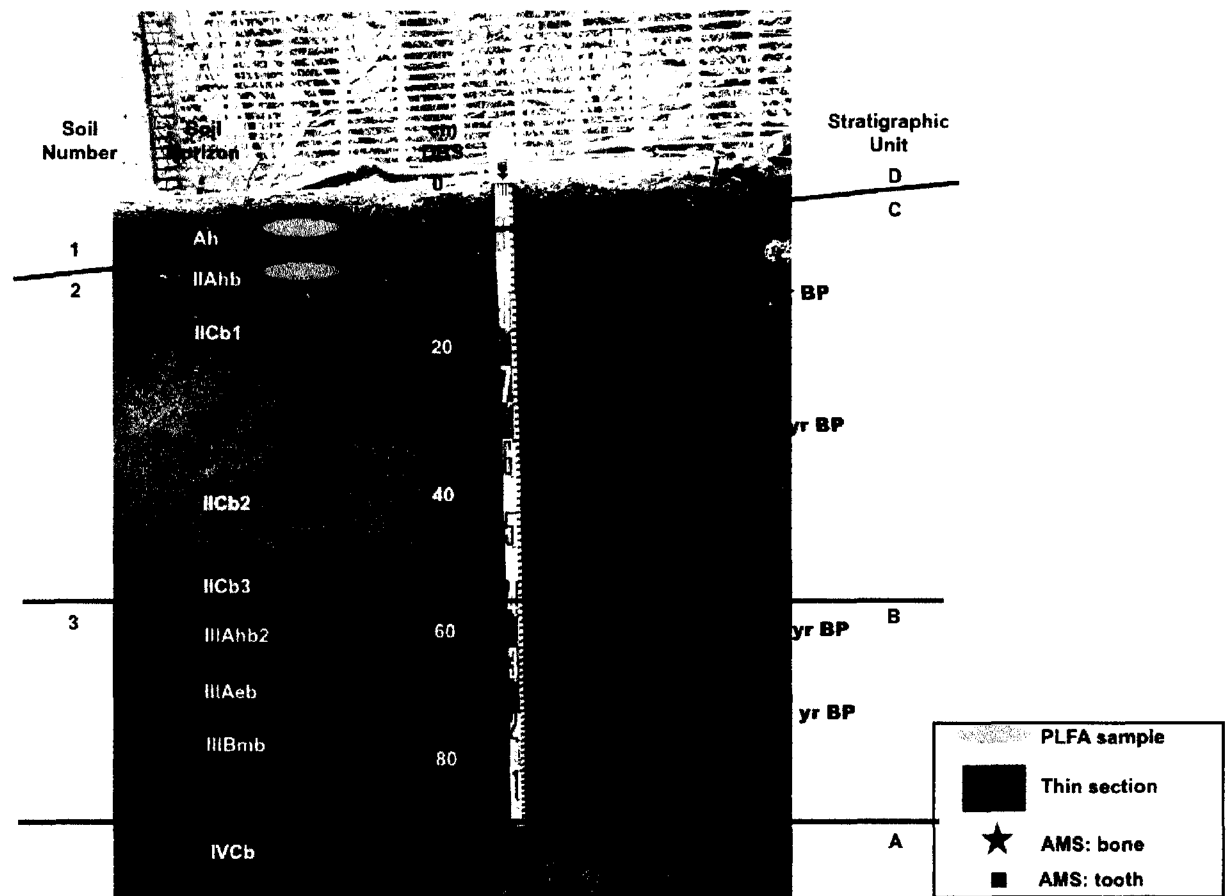

Photo: K. Gilliland

Figure 5.1. South L2 Stratigraphic Profile

Table 5.1. South L2 Profile Summary

Stratigraphic Unit	Soil Number	Soil Horizon	Depth below surface (cm)	Soil Description
Unit D	Soil 1	Ah	0-8	Black (10YR2/1, m) well-sorted loamy sand, single grain to coarse granular structure. Lower boundary clear to gradational and smooth. 10% HCL: weak.
Unit C	Soil 2	IIAhb	8-16	Black (10YR2/1, m) well-sorted loamy sand, single grain to coarse granular structure. Lower boundary clear to gradational, smooth to wavy. Charcoal dust and artifacts present (bone, lithics, pottery). 10% HCL: very weak.
		IICb1	16-39	Very dark gray (7.5YR3/1, d) well-sorted loamy sand, single grain to coarse granular structure. Lower boundary gradational and slightly irregular. 10% HCL: weak.
		IICb2	39-55	Brown (10YR4/3, d) well-sorted loamy sand, single grain to coarse granular structure. Lower boundary clear and slightly irregular. 10% HCL: weak.
		IICb3	55-60	Very dark grayish brown (10YR3/2, d) well-sorted loamy sand with 5% pebbles ~0.5mm diameter or coarser. Single grain to coarse granular structure. Lower boundary gradual and irregular. 10% HCL: weak.
Unit B	Soil 3	IIIAhb2	60-65	Very dark gray (10YR3/1, d) well-sorted loamy sand with 5% pebbles ~0.5mm diameter or coarser. Fine to medium granular structure. Lower boundary clear and smooth. Artifacts present (bone, lithics). 10% HCL: very weak to none.
		IIIAeb	65-70	Dark grayish brown (10YR4/2, d) well-sorted loamy sand with 5% pebbles ~0.5mm diameter or coarser. Single grain to medium granular structure. Lower boundary clear and slightly irregular. 10% HCL: very weak to none.
		IIIBmb	70-95	Very dark grayish brown (2.5Y3/2, m) well-sored loamy sand with 5% pebbles ~0.5mm diameter or coarser. Fine to medium granular structure. Lower boundary clear and wavy. 10% HCL: very weak to none.
Unit A		IVCb	95-101	Clay loam with rounded to subangular cobbles 10-20 cm in diameter. Blocky structure. Lower boundary not seen. 10% HCL: very weak.

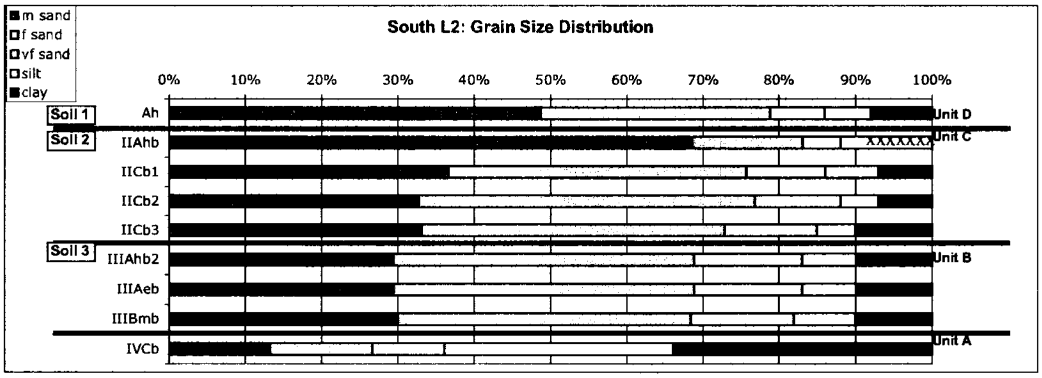

Figure 5.2. South L2 Grain Size Distribution

Hatched bar in Soil 2 (IIAhb horizon, Unit C) indicates laboratory error in measurement of silt and clay. Medium sand= >150μm; fine sand= 150-125μm; very fine sand= 125-63μm; silt= 63-3μm; clay= <3μm.

Table 5.2. AMS Radiocarbon Dates, South L2

Catalogue number	Beta Analytic	Depth (cm DBS)	C13/12 ratio (‰)	Conventional age (years BP)	Intercept with calibration curve (2 sigma, years BP)
41957	214251	15 UnitC Soil 2 IIAhb	-20.6	70 ± 40	270-210 140-20 0
45054	214253	30 Unit C IICb1	-20.1	930 ± 40	930-750
42613	214255	60 Unit B IIIAhb2	-19.3	620 ± 50	670-530
27470	209522	70-80 Unit B Soil 3 IIIAeb	-19.1	2430 ± 40	2720-2350

Calibration and mathematics applied by Beta Analytic using the Intcal 98 database (Stuiver and van der Plicht 1998; Stuiver et al. 1998; Talma and Vogel 1993).

5.1.2 North L2 Profile

Three stratigraphic units are present in the North L2 profile (Figures 5.3 and 5.4; Table 5.3). Unit A, 268-210 cm, is a clay loam, identified by auguring. Unit B, 210-11 cm, consists of finely bedded fine to very fine sands and silts from 210-189cm. These sediments grade upward into well-sorted medium to fine sand. Krotovinae are present in Unit B, horizons IIBmbgII, IIBmbgI and IIAhb, between 35-11 cm. Soil 2, a palaeosol developed in the upper portion of Unit B, indicates a depositional hiatus, and is a Gleyed Dark Brown Chernozem (Soil Classification Working Group 1998). Unit C, 11-0 cm, consists of well-sorted fine loamy sand. Soil 1 is the modern soil, formed on Unit C, and is not classified as it represents a thickening of Soil 2, horizon IIAhb (Dr. Peter Crown, Department of Renewable Resources, University of Alberta).

Three concentrations of artifacts occur in the North L2 profile. The first is between 65-50 cm, within Unit B, horizon IICbg2. Lithics such as debitage, utilized flakes and scrapers comprise the majority of the artifacts, however small bone fragments are also present. Many of the artifacts have rounded edges, suggesting that they have been ventifacted. Points resembling the Oxbow typology were excavated from this location during the 2003 field school (Gibson 2004b), however subsequent examination of the point type and associated stratigraphy suggests they may be associated with a Sandy Creek occupation (Dyck and Morlan 1995: 389-405).

The second artifact concentration in the North L2 profile occurs between 40-30 cm, within Unit B, horizons IICbg1 and IIBmbg2. Bison bone and lithics such as scrapers, as well as possible Avonlea and Late Side-Notched projectile points, comprise the artifacts within this concentration. During the 2005 field school, upright bison ulnar fragments were excavated, which may have served as a tie-down peg for a habitation structure (Dr. Terry Gibson, Alberta Western Heritage, pers. comm.).

The third and most dense concentration of artifacts in the North L2 profile occurs in Unit B, Soil 2, horizons IIBmbgI and IIAhb, between 20-10 cm. Artifacts include bison bone, Late Side-Notched projectile points, Old Women's Phase and Mortlach Phase pottery

(Dr. Terry Gibson, Alberta Western Heritage, pers. comm.), as well as numerous other lithic artifacts such as scrapers and flakes. Excavations during the 2005 archaeological field school revealed an intact hearth at this depth that contained two tiny fragments of iron as well as numerous identifiable bison bones and burnt lithic artifacts.

Three bone samples for radiocarbon dating were taken from Unit B at depths of 70 and 55 cm (horizon IICbg2) and 20 cm (top of horizon IIBmbg1)(Figure 5.4; Table 5.4). A micromorphological sample was taken of Unit B, Soil 2, horizon IIAhb, at 14-8 cm. Samples for PLFA analysis were also taken of Unit B, Soil 2, horizon IIAhb, and Unit C, Soil 1, horizon Ah.

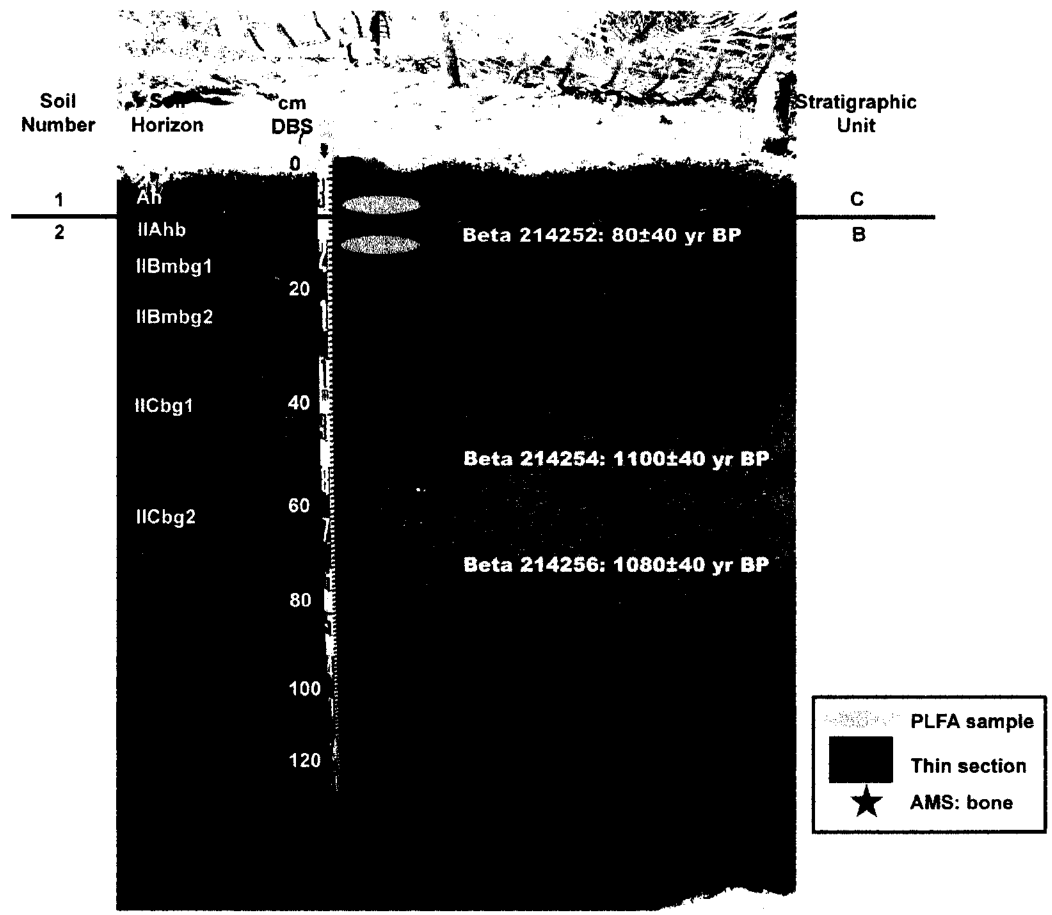

Photo: K. Gilliland

Figure 5.3. North L2 Stratigraphic Profile

Table 5.3. North L2 Profile Summary

Stratigraphic Unit	Soil Number	Soil Horizon	Depth below surface (cm)	Soil Description
Unit C	Soil 1	Ah	0-11	Very dark gray (10YR3/1, d), well-sorted fine loamy sand. Single grain to medium granular structure. Lower boundary clear and smooth. 10% HCL: weak.
Unit B	Soil 2	IIAhb	11-18	Very dark gray (10YR3/1, d), well-sorted fine loamy sand. Single grain to medium granular structure. Lower boundary clear and smooth. Dense concentration of charcoal and artifacts present(bone, pottery, lithics). 10% HCL: very weak.
		IIBmbg1	18-25	Dark grayish brown (10YR4/2, d) with faint Fe mottles. Well-sorted medium to fine sand. Single grain to coarse granular structure. Lower boundary transitional and smooth. Charcoal and artifacts (bone, lithics) present, hearth feature. 10% HCL: very weak.
		IIBmbg2	25-35	Brown (10YR4/3, d) with faint Fe mottles. Well-sorted medium to fine sand. Single grain to medium granular structure. Lower boundary gradual and smooth. Artifacts present (bone, lithics), vertical ulnar bison bone. 10% HCL: very weak
		IICbg1	35-50	Brown (10YR5/3, d) with faint Fe mottles. Well-sorted medium to fine sand. Single grain to coarse granular structure. Lower boundary gradual and smooth to irregular. 10% HCL: weak
		IICbg2	50-189	Light olive brown (2.5Y5/3, m) with 40% faint to distinct strong brown (7.5YR4/6) to yellowish brown (10YR5/6) Fe mottles. Well-sorted medium to fine sand. Single grain to medium granular structure. Gradually grades into finely bedded sands and silts. Artifacts present (mostly lithics, many ventifacted). 10% HCL: very weak
		-	189-210	Finely bedded fine to very fine sands and silts
Unit A		-	210-268	Clay loam

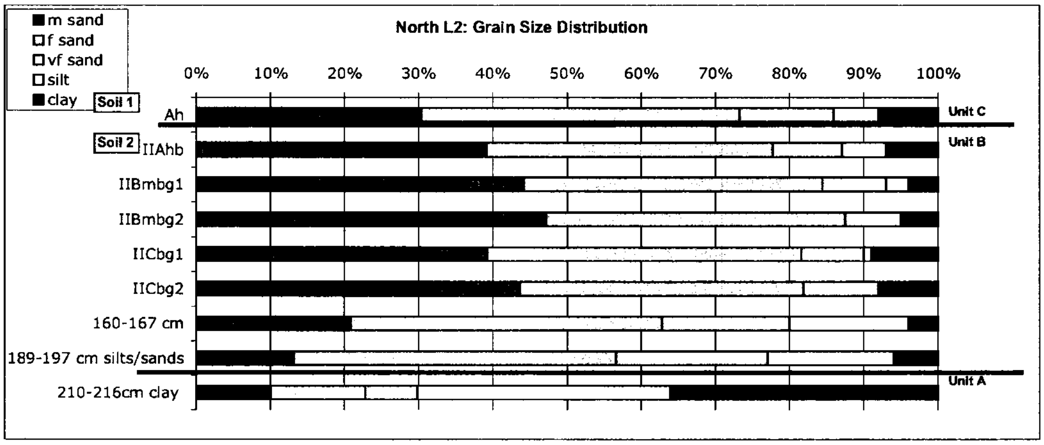

Figure 5.4. Grain Size Distribution, North L2 Profile

Medium sand= >150μm; fine sand= 150-125μm; very fine sand= 125-63μm; silt= 63-3μm; clay= <3μm.

Table 5.4. AMS Radiocarbon Dates, North L2

Catalogue number	Beta Analytic	Depth (cm DBS)	C13/12 ratio (‰)	Conventional age (years BP)	Intercept with calibration curve (2 sigma, years BP)
43590	214252	20 Unit B Soil 2 IIBmbg1	-20.7	80 ± 40	270-200 150-20 0
44934	214254	55 Unit B IICbg2	-18.9	1100 ± 40	1070-940
45098	214256	70 Unit B IICbg2	-19.4	1080 ± 40	1060-930

Calibration and mathematics applied by Beta Analytic using the Intcal 98 database (Stuiver and van der Plicht 1998; Stuiver et al. 1998; Talma and Vogel 1993).

5.1.3 Test Pit L2-9

The stratigraphy of Test Pit L2-9 was not described in detail; however this test pit consists of three stratigraphic units, inferred from the depositional hiatuses indicated by two palaeosols, Soils 3 and 2 (Figure 5.5). In the field, Soil 3 of Test Pit L2-9 was thought to be of the same age as Soil 3 in the South L2 profile, therefore two bone samples were taken from above and below Soil 3 in the test pit for AMS radiocarbon dating (Table 5.5). Samples for PLFA analysis were also taken of Soil 2 and Soil 1.

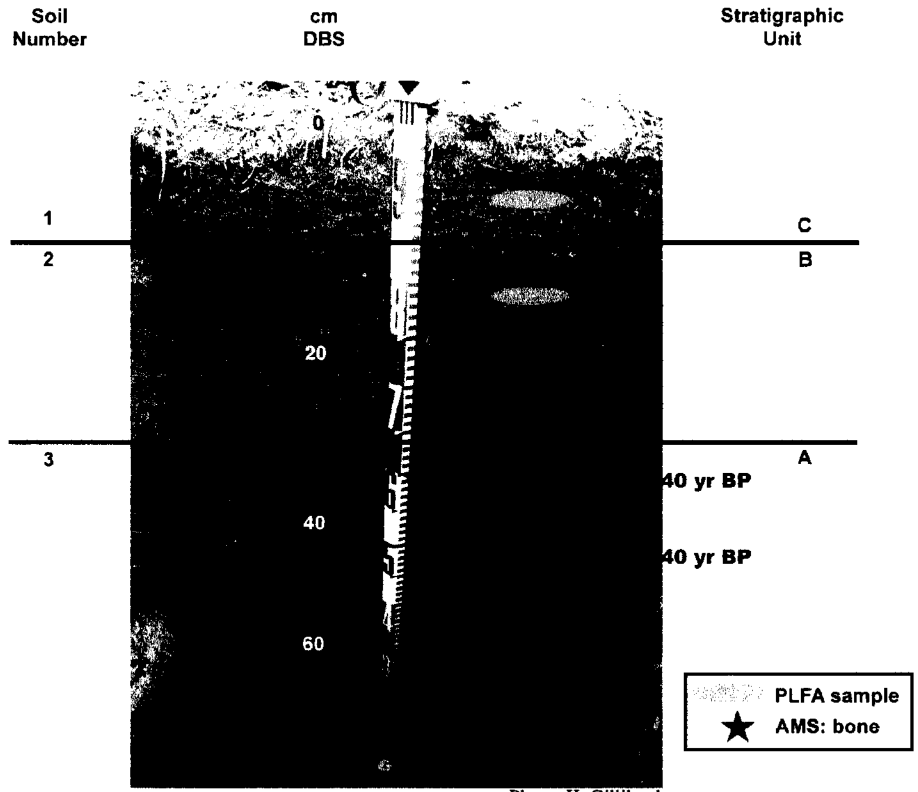

Photo: K. Gilliland

Figure 5.5. Test Pit L2-9 Stratigraphic Profile

The stratigraphy of this test pit was not described in detail, however inferences regarding the history of sediment deposition and soil formation are recorded here.

Table 5.5. AMS Radiocarbon Dates, Test Pit L2-9

Catalogue number	Beta Analytic	Depth (cm DBS)	C13/12 ratio (‰)	Conventional age (years BP)	Intercept with calibration curve (2 sigma, years BP)
26235	222510	30-40 top of Soil 3	-19.7	1040 ± 40	1040-1030 1000-920
26284	222511	40-50 bottom of Soil 3	-19.8	1100 ± 40	1070-940

Calibration and mathematics applied by Beta Analytic using the Intcal 98 database (Stuiver and van der Plicht 1998; Stuiver et al. 1998; Talma and Vogel 1993).

5.1.4 L19 Profile

Three stratigraphic units are present in the L19 profile (Figures 5.6 and 5.7, Table 5.6). Unit A, from the water table (reached by auguring) to 56 cm, consists of well-sorted medium to fine sand. Soil 3, a palaeosol developed in the upper portion of Unit A, indicates a depositional hiatus. Soil 3 resembles a Gleyed Rego Dark Brown Chernozem (Soil Classification Working Group 1998). Unit B, 56-8 cm, is a well-sorted medium and fine sand. Soil 2, a palaeosol developed in the upper portion of Unit B, indicates another depositional hiatus, and is also a Gleyed Rego Dark Brown Chernozem (Soil Classification Working Group 1998). A few krotovinae are present within Unit B, Soil 2, horizons IICbg1 and IIAhb, between 40-8 cm depth. Unit C, 8-0 cm, also consists of well-sorted medium and fine sand.

Bone fragments and lithic artifacts such as scrapers, utilized flakes and debitage are present throughout the L19 profile from 90-0 cm depth; however, two concentrations of artifacts occur. The first concentration of artifacts is within Unit A, Soil 3, horizon IIIAhbg, at about 65 cm. A few projectile points were found during the 2006 field school excavations, however they are of ambiguous affiliation and not diagnostic. Unburned bone was not preserved, however mineralized and calcined bone fragments were present. Lithic artifacts within this horizon consisted primarily of large flake and core tools of untreated Swan River Chert (Elizabeth Mann, Bodo Project Archaeologist, pers. comm.), black pebble chert scrapers and utilized flakes, and large, thermally-altered quartzite cobbles. All lithic artifacts within this lower concentration had sharp edges.

The second concentration of artifacts within the Localtiy 19 profile is located within Unit B, Soil 2, horizons IICbg1 and IIAhb, between 20-10 cm depth. Artifacts include bone fragments and lithics such as scrapers and debitage. Artifact concentrations in Soil 2 are lower compared to those in Soil 3.

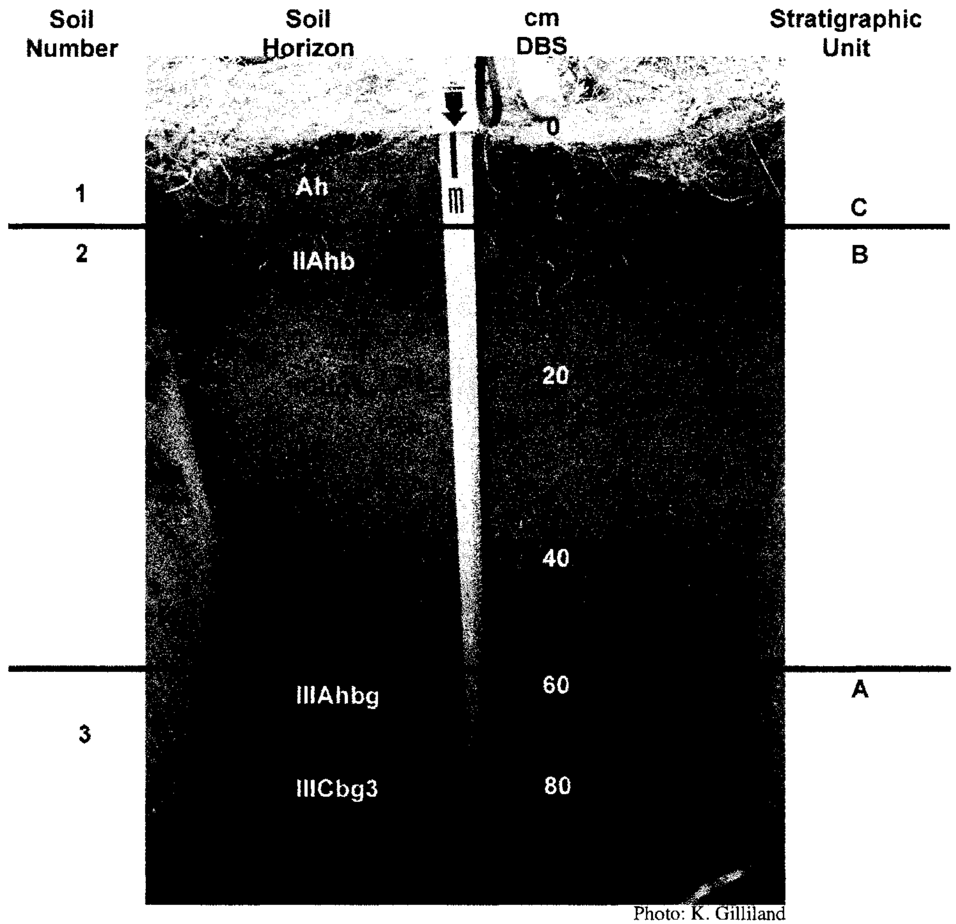

Figure 5.6. L19 Stratigraphic Profile

Table 5.6. L19 Profile Summary

Stratigraphic Unit	Soil Horizon	Soil Number	Depth below surface (cm)	Soil Description
Unit C	Ah	Soil 1	0-8	Very dark grayish brown (10YR3/2, d) well-sorted medium and fine sand. Single grain to medium granular structure. Lower boundary gradual and smooth. Charcoal dust present. 10% HCL: very weak.
Unit B	IIAhb	Soil 2	8-13	Very dark grayish brown (10YR3/2, d) well-sorted medium and fine sand. Single grain to medium granular structure. Weakly expressed. Lower boundary diffuse and smooth, transitional to IICbg1. Charcoal and artifacts present (bone, lithics). 10% HCL: very weak.
	IICbg1		13-40	Brown (10YR5/3, m) well-sorted medium and fine sand. Single grain to coarse granular structure. Lower boundary diffuse and smooth, transitional to IICbg2. 10% HCL: weak.
	IICbg2		40-56	Brown (10YR4/3, d) well-sorted medium and fine sand. Single grain to medium granular structure. 30% very faint yellowish brown (10YR5/4, m) Fe mottles. Lower boundary gradual, slightly irregular. 10% HCL: weak.
Unit A	IIIAhbg	Soil 3	56-68	Very dark grayish brown (10YR3/2, m) loamy sand with black to light gray mottling. Fine to coarse granular structure. Lower boundary clear and slightly irregular. Charcoal and artifacts present (bone, lithics). 10% HCL: weak.
	IIICbg3		68-186	Brown (10YR5/3, m) medium to fine grained sand. 10% brown (10YR4/3, m) Fe mottles that begin very faintly but become progressively more numerous and distinct, reaching 50% yellowish red (5YR4/6, m) mottles at depth. Very fine to coarse granular structure. Lower boundary not seen. Water table encountered at 186 cm. 10% HCL: very weak to none.

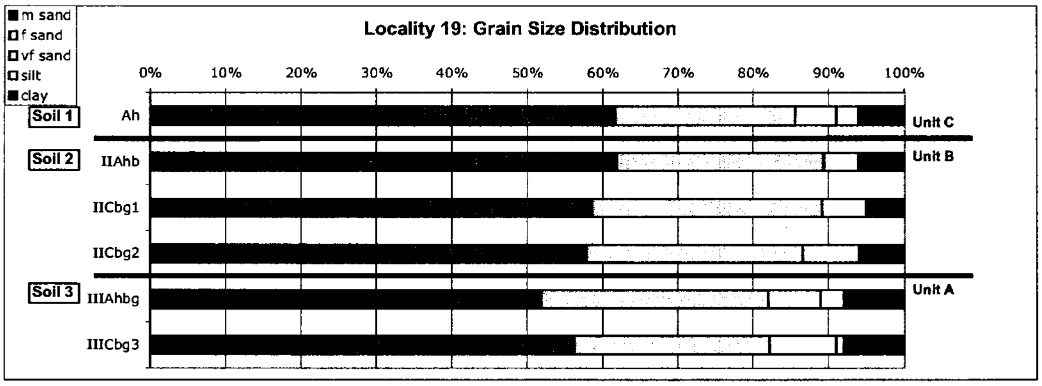

Figure 5.7. L19 Grain Size Distribution

Medium sand= >150μm; fine sand= 150-125μm; very fine sand= 125-63μm; silt= 63-3μm; clay= <3μm.

5.1.5 Offsite Profile

Three stratigraphic units are present in the Offsite profile (Figures 5.8 and 5.9; Table 5.7). Unit A, 83-40 cm, is a clay loam containing subangular pebbles larger than 1cm diameter and ironstone concretions. From 83-55 cm, $CaCO_3$ nodules were present, and application of 10% HCl solution to the sediment produced a strong fizzing reaction. Vertical cracks are present throughout Unit A, from below the floor of the pit to 40 cm depth. Unit B, 40-10 cm, is a well-sorted fine sandy loam containing rounded to subangular pebbles 0.5-4 cm in diameter. Soil 2, a palaeosol developed in the upper portion of Unit B, indicates a depositional hiatus, and is an Orthic Dark Brown Chernozem (Soil Classification Working Group 1998). A few krotovinae are present in Unit B, horizons IIBmb and IIBCb, between 40-16 cm depth. Unit C, 10-0 cm, is also a well-sorted fine loamy sand, containing rounded pebbles 1-2 cm in diameter. Samples for PLFA analysis were taken from Unit B, Soil 2, horizon IIAhb, and Unit C, Soil 1, horizon Ah.

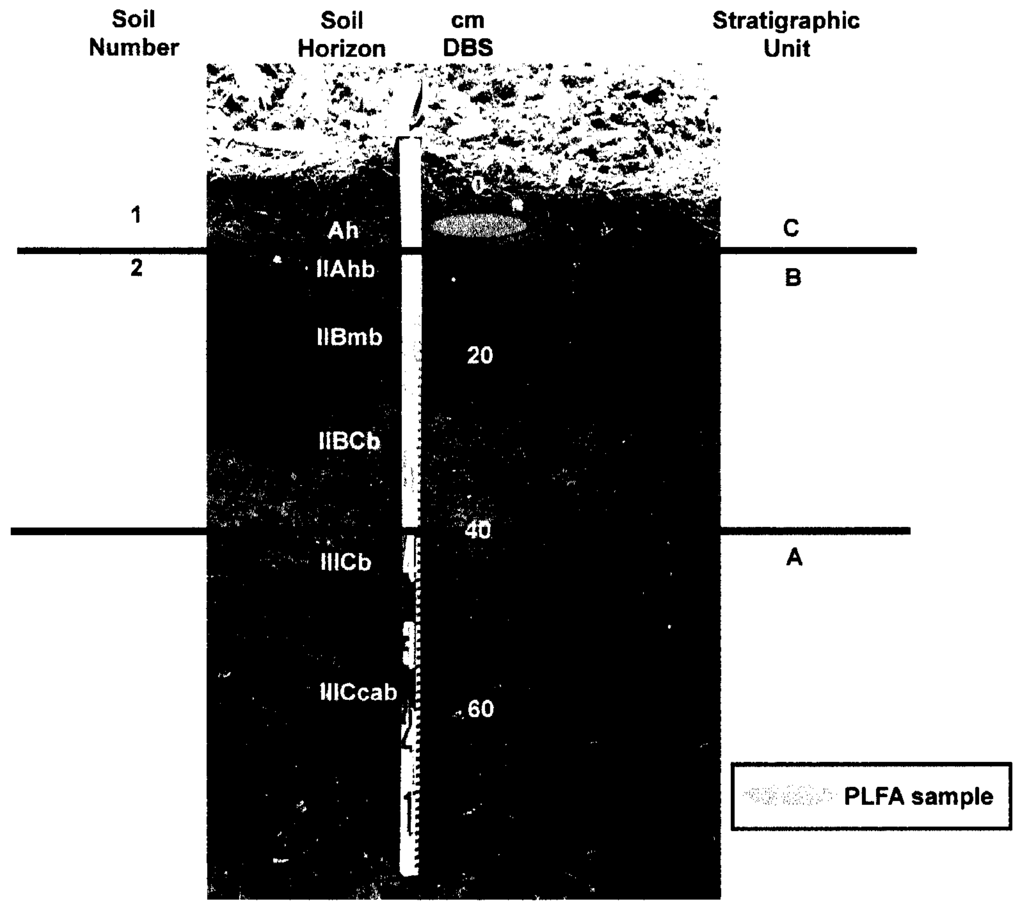

Photo: K. Gilliland

Figure 5.8. Offsite Stratigraphic Profile

Table 5.7. Offsite Profile Summary

Stratigraphic Unit	Soil Horizon	Soil Number	Depth below surface (cm)	Soil Description
Unit C	Ah	Soil 1	0-10	Very dark brown (10YR 2/2, m) well-sorted fine loamy sand with 5% rounded pebbles ~1-2 cm diameter. Fine crumb structure. Lower boundary clear and smooth. 10% HCL: very weak.
Unit B	IIAhb	Soil 2	10-16	Black (10YR 2/1, m) well-sorted fine sandy loam with 5-10% pebbles < 0.5 cm diameter and 2% rounded to subangular pebbles 3-4 cm diameter. Very fine granular structure. Lower boundary sharp and smooth. Charcoal dust present. 10% HCL: weak.
	IIBmb		16-25	Very dark brown (10YR 2/2, m) well-sorted fine loamy sand with 5-10% pebbles < 0.5 cm diameter and 2% rounded to subangular pebbles 3-4 cm diameter. Single grain structure. Lower boundary clear and slightly wavy. 10% HCL: moderate.
	IIBCb		25-40	Brown (10YR 4/3, d) fine sandy loam with 15-20% rounded to subangular pebbles 1 mm-1 cm diameter and 5% pebbles 3-4 cm diameter. Single grain and medium granular structure. Beginning of clay coatings on vertical cracks in profile. Lower boundary clear and irregular. 10% HCL: moderate to strong.
Unit A	IIICb		40-55	Dark yellowish brown (10YR 3/4, m) clay loam with 15% rounded to subangular pebbles and ironstone concretions >1cm. 2% reddish yellow to pale yellow (7.5YR 6/8 to 2.5Y 8/2) Fe nodules; 40% dark olive brown (2.5Y 3/3) mottles around cracks and rootlets. Medium angular blocky structure with gray (10YR 5/1) clay coatings on cracks and peds. Lower boundary indistinct and wavy. 10% HCL: weak.
	IIICcab		55-83	Light olive brown (2.5Y 5/4, m) clay loam with 15% rounded to subangular pebbles and ironstone concretions >1cm. 2-5% cobbles 10-20 cm in diameter. 5-50% $CaCO_3$ nodules. Coarse blocky structure with very dark gray (10YR 3/1) shiny clay coatings on cracks and peds. Lower boundary not seen. <1% charcoal or coal fragments 0.5-1mm diameter. 10% HCL: strong.

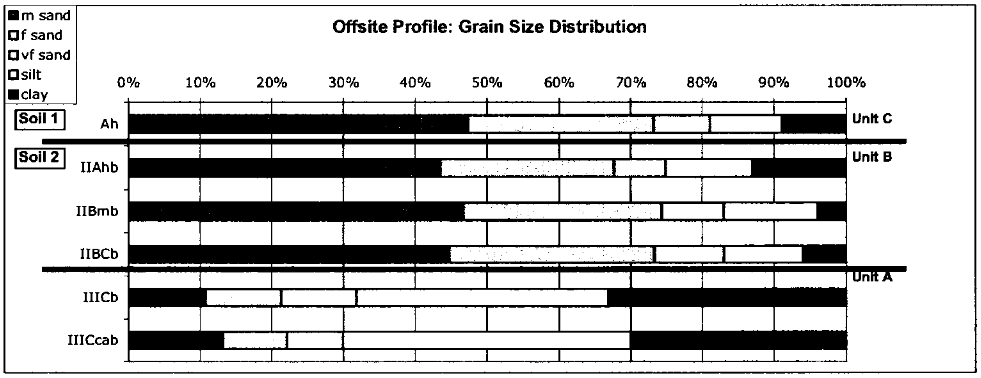

Figure 5.9. Offsite Profile Grain Size Distribution

Medium sand= >150μm; fine sand= 150-125μm; very fine sand= 125-63μm; silt= 63-3μm; clay=<3μm.

5.1.6 Dune Sand

The grain size distribution of samples from two sand dunes located within the Bodo Archaeological Locality, southeast of FaOm-1 are included as a reference (Figures 2.12 and 5.10). The grain size distribution of both of the dunes is almost identical, and consists of medium to fine sand.

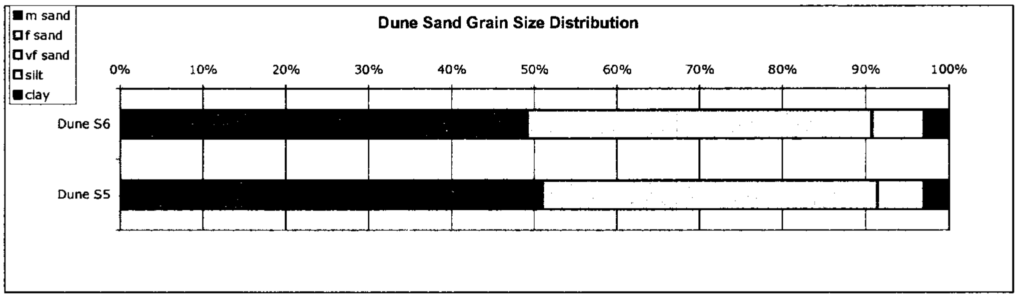

Figure 5.10. Dune Sand Grain Size Distribution

Medium sand= >150μm; fine sand= 150-125μm; very fine sand= 125-63μm; clay= <3μm.

5.2 CHEMISTRY

5.2.1 South L2

Organic content[39] ranges from a high of 7.49% in the surface soil (Unit D, Soil 1, horizon Ah), to a low of 0.39% in Unit C, horizon IICb2. Unit C, Soil 2, horizon IIAhb, is also relatively enriched in organics, with 4.35%. Unit B, Soil 3, horizon IIIAhb2 demonstrates a third peak in organics, at 1.89% (Figure 5.11, Appendix V).

$CaCO_3$ content is highest (1.88%) in Unit A, horizon IVCb, with lowest values (0.23%) in Unit C, horizon IICb2.

Total C peaks at 3.07% in Unit D, Soil 1, horizon Ah, with a low of 0.1% in Unit C, horizon IICb2. Unit C, Soil 2, horizon IIAhb and Unit B, Soil 3, horizon IIIAhb2 have secondary peaks of total C, with 2.08% and 0.93%, respectively.

Total N follows a similar pattern to total C; Unit D, Soil 1, horizon Ah, has the highest levels of total N, with 0.26%, while Unit C, horizon IICb2 has the lowest, with 0.01%. Unit C, Soil 2, horizon IIAhb and Unit B, Soil 3, horizon IIIAhb2 have secondary peaks of total N, with 0.21% and 0.08%, respectively.

C:N ratios in the South L2 profile range from 12:1 to 8:1, with the highest ratios in Unit D, Soil 1, horizon Ah and Unit B, Soil 3, horizon IIIAhb2, at 12:1. Lowest C:N ratios are in Unit C, horizon IICb2 and Unit A, horizon IVCb, at 8:1.

Total P ranges from a high of 0.065% in Unit C, Soil 2, horizon IIAhb, to a low of 0.02% in Unit C, horizon IICb2. Unit A, horizon IVCb also has elevated total P levels, with 0.057%. Unit B, Soil 3, horizon IIIAhb2 and Unit D, Soil 1, horizon Ah have similar total P levels, of 0.045% and 0.044%, respectively.

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[39] Estimated using loss-on-ignition (LOI).

Extractable P follows a similar pattern to total P; however, Unit B, Soil 3, horizon IIAhb2 has the highest concentration, at 121.27 mg/kg. The lowest concentration of extractable P, 43.48 mg/kg, is in Unit C, horizon IICb2. Unit C, Soil 2, horizon IIAhb and Unit B, Soil 3, horizon IIIAeb demonstrate secondary peaks in extractable P concentration, at 95.74 mg/kg and 94.68 mg/kg, respectively.

Unit A, Soil 1, horizon IVCb and Unit D, Soil 1, horizon Ah have the highest CEC, with values of 11.81 $cmol_c$/kg and 10.83 $cmol_c$/kg, respectively. Unit C, horizon IICb2 has the lowest CEC, at 1.32 $cmol_c$/kg. Unit C, Soil 2, horizon IIAhb and Unit B, Soil 3, horizon IIIAhb2 also have elevated levels of CEC, with 9.98 $cmol_c$/kg and 6.32 $cmol_c$/kg, respectively. Note that in all four profiles, total available cations are elevated relative to CEC; this is addressed in Chapter 6.

Ca^{2+} is the dominant exchangeable cation, with highest concentrations in Unit C, Soil 2, horizon IIAhb and Unit A, horizon IVCb, at 10.78 $cmol_c$/kg and 10.05 $cmol_c$/kg, respectively. The lowest Ca^{2+} concentration is in Unit C, horizon IICb2, with 1.55 $cmol_c$/kg. Unit D, Soil 1, horizon Ah and Unit B, Soil 3, horizon IIIAhb2 also have elevated concentrations of Ca^{2+}, with 9.97 $cmol_c$/kg and 6.91 $cmol_c$/kg, respectively.

Na^+ concentrations are highest in Unit A, horizon IVCb and Unit B, horizon IIBmb, with 0.14 and 0.12 and $cmol_c$/kg, respectively. Concentrations of Na^+ remain relatively similar throughout the remainder of the profile, with levels of 0.06-0.08 $cmol_c$/kg in Units D, C, and most of B.

K^+ concentrations are also highest in Unit A, horizon IVCb, at 0.74 $cmol_c$/kg, with lowest concentrations of K^+ in Unit C, horizon IICb2, at 0.18 $cmol_c$/kg. Unit D, Soil 1, horizon Ah, and Unit D, Soil 3 also have elevated levels of K^+, with 0.53 $cmol_c$/kg and 0.35 $cmol_c$/kg, respectively.

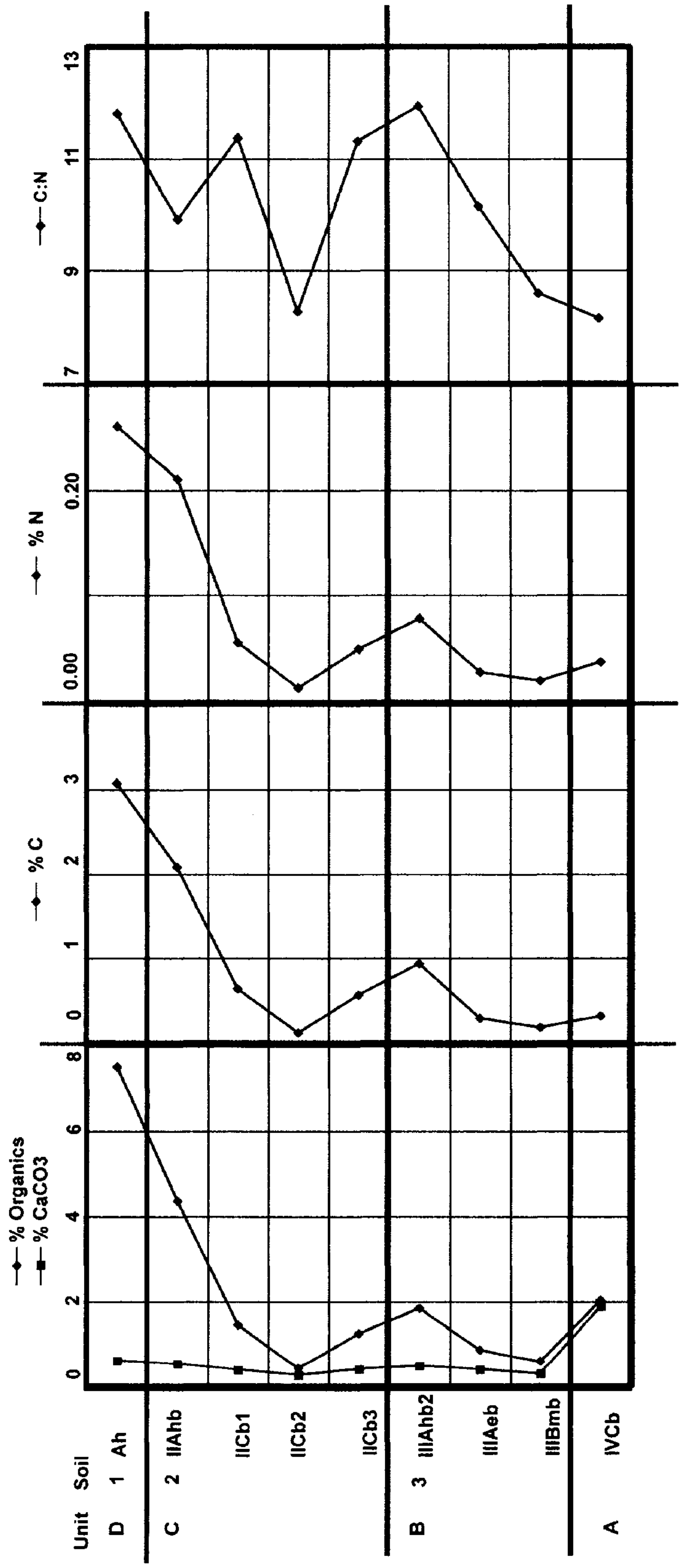

Figure 5.11a. Chemistry Results for South L2

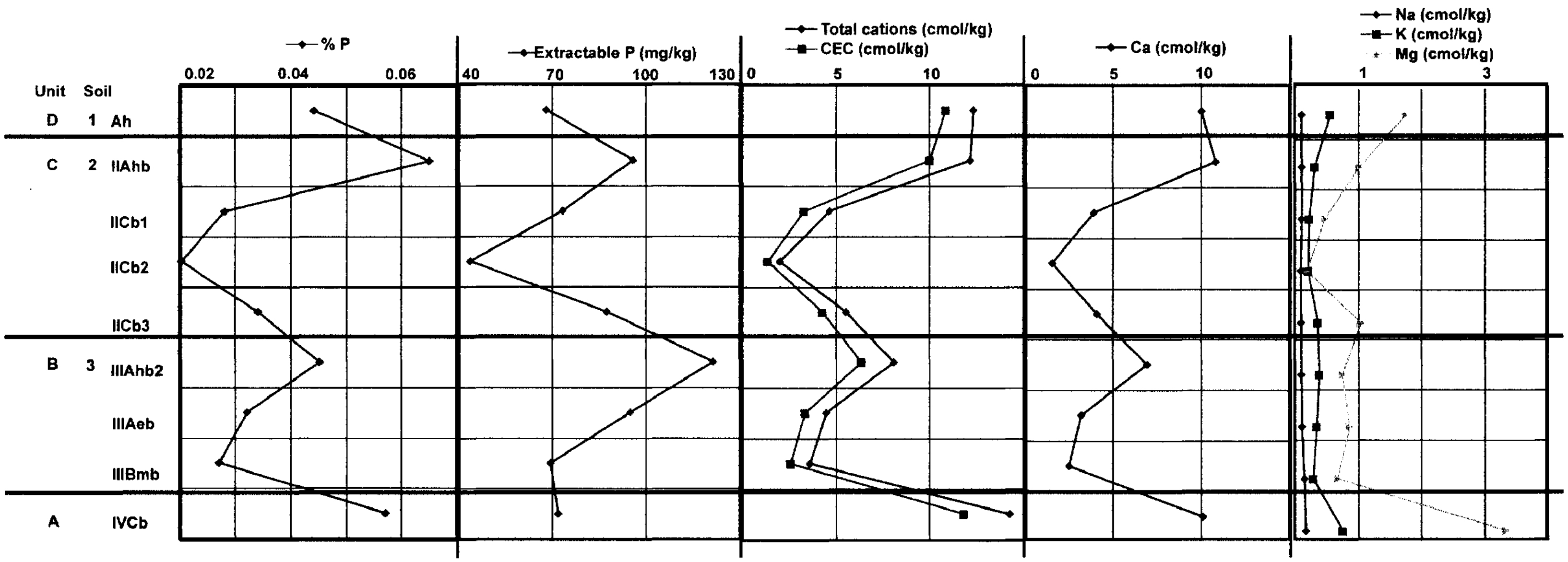

Figure 5.11b. Chemistry Results for South L2

Mg^{2+} ranges from 3.32 $cmol_c/kg$ in Unit A, horizon IVCb, to 0.16 $cmol_c/kg$ in Unit C, horizon IICb2. Unit D, Soil 1, horizon Ah also has elevated levels of Mg^{2+}, with 1.74 $cmol_c/kg$. Unit C, horizon IICb3 and Unit C, Soil 2, horizon IIAhb have similar levels of Mg^{2+}, with 1.02 $cmol_c/kg$ and 1.00 $cmol_c/kg$, respectively.

5.2.2 North L2

Organic content ranges from a high in Unit B, Soil 2, horizon IIAhb, at 3.43%, to a low of 0.5% in Unit B, horizon IICbg2. The surface soil (Unit C, Soil 1, horizon Ah) has an organic content of 2.71% (Figure 5.12, Appendix V).

$CaCO_3$ concentrations are relatively constant throughout the North L2 profile, ranging from a high of 0.37% in Unit B, Soil 2, horizon IIAhb to 0.23% in Unit B, horizon IICbg1.

Total C peaks at 2.35% in Unit C, Soil 1, horizon Ah, steadily declining down through the profile to 0.1% in Unit B, horizon IICbg2. Unit B, Soil 2, horizon IIAhb has a secondary peak of total C, at 1.54%.

Total N follows the same pattern at total C, with a peak in Unit C, Soil 1, horizon Ah, at 0.2%, and a low of 0.01% in Unit B, horizon IICbg2. Unit B, Soil 2, horizon IIAhb also has a relatively high concentration of total N, with 0.15%.

C:N ratios range from 12:1 to 7:1 in the North L2 profile; the highest ratio being in Unit C, Soil 1, horizon Ah and Unit B, horizon IIBmbg1, while the lowest ratio is in Unit B, horizon IICbg2 horizon.

Total P peaks at 0.177% in Unit B, Soil 2, horizon IIAhb, with a low of 0.03% in Unit B, horizon IICbg1. Unit C, Soil 1, horizon Ah has a relatively high concentration of total P, at 0.087%.

Extractable P follows the same pattern as total P, with highest levels in Unit B, Soil 2, horizon IIAhb, at 322.56 mg/kg, and a low of 80.84 mg/kg in Unit B, horizon IICbg1.

The CEC results range from 9.52 $cmol_c$/kg in Unit C, Soil 1, horizon Ah, to 1.77 cmolc/kg in Unit B, horizon IICbg1.

Ca^{2+} dominates the exchangeable cations, with highest levels in Unit C, Soil 1, horizon Ah at 10.44 $cmol_c$/kg, with a low of 2.19 $cmol_c$/kg in Unit B, horizon IICbg1. Unit B, Soil 2, horizon IIAhb and Unit B, horizon IIBmbg1 have secondary peaks of Ca^{2+}, with 7.3 $cmol_c$/kg and 6.24 $cmol_c$/kg, respectively.

Na^+ remains relatively constant throughout the North L2 profile, at 0.05-0.06 $cmol_c$/kg.

K^+ ranges from 0.48 $cmol_c$/kg in Unit C, Soil 1, horizon Ah, to 0.18 $cmol_c$/kg in Unit B, horizon IICbg1. Unit B, horizon IIBmbg1 shows a secondary peak in K^+ concentration, with 0.35 $cmol_c$/kg.

Mg^{2+} also peaks in Unit C, Soil 1, horizon Ah, at 1.04 $cmol_c$/kg, with a low of 0.30 $cmol_c$/kg in Unit B, horizon IICbg1. Unit B, horizon IICbg2 has a secondary peak in Mg^{2+} concentration, with 0.67 $cmol_c$/kg.

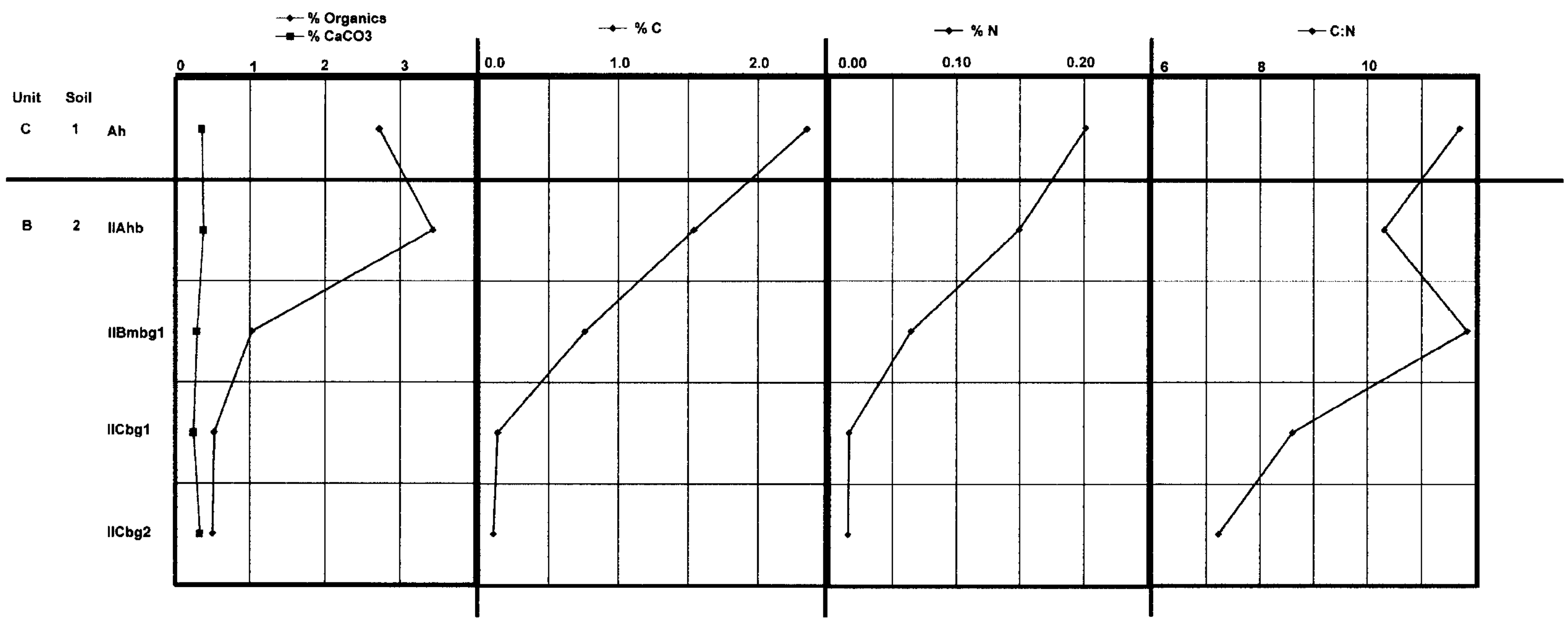

Figure 5.12a. Chemistry Results for North L2

Note that there are no data for the IIBmbg2 horizon.

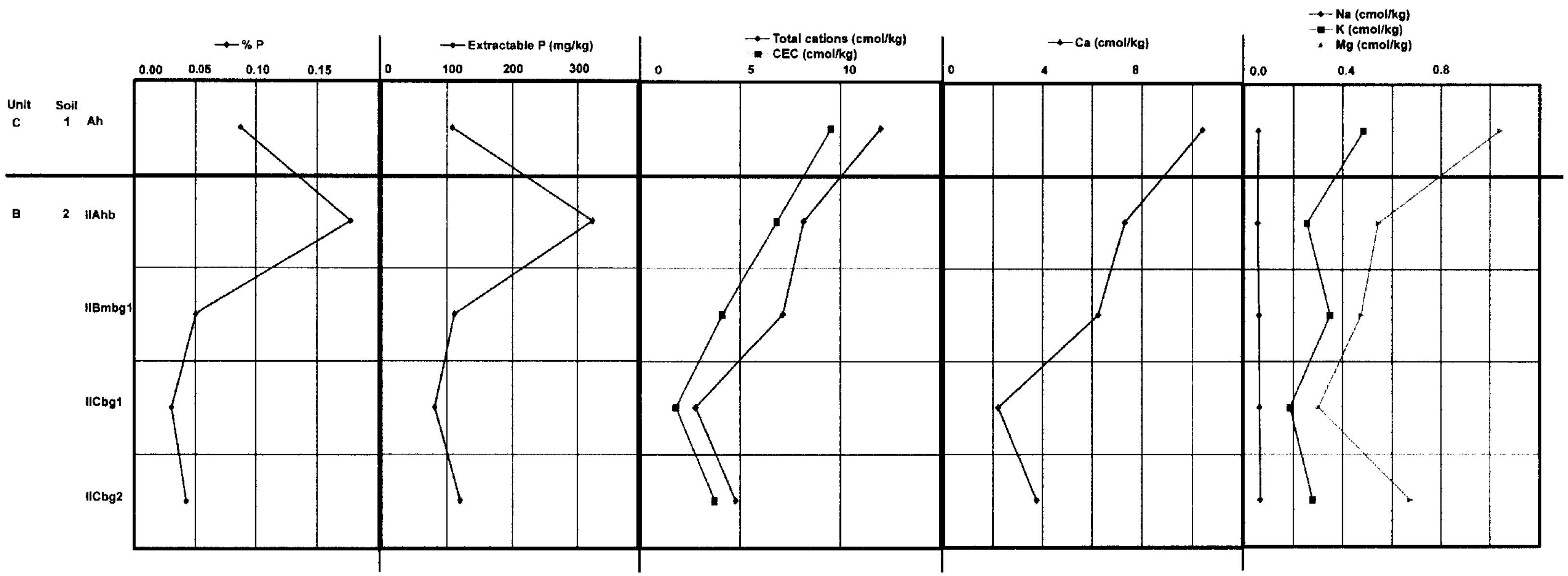

Figure 5.12b. Chemistry Results for North L2

Note that there are no data for the IIBmbg2 horizon.

5.2.3 L19

Organic content ranges from 1.43% in Unit B, Soil 2, horizon IIAhb, to a low of 0.43% in Unit B, horizon IICbg2. Unit C, Soil 1, horizon Ah, and Unit A, Soil 3, horizon IIIAhbg also have elevated levels of organic content, with 1.38% and 0.96%, respectively (Figure 5.13, Appendix V).

$CaCO_3$ levels range from a high of 0.39% in Unit A, Soil 3, horizon IIIAhbg to a low of 0.24% in Unit B, horizons IICbg1 and IICbg2.

Total C is highest in Unit C, Soil 1, horizon Ah and Unit B, Soil 2, horizon IIAhb, with 0.64% and 0.62%, respectively. The lowest levels of total C (0.1%) are in Unit A, horizon IIICbg3 and Unit B, horizon IICbg1. Unit A, Soil 3, horizon IIIAhbg has a total C level of 0.38%.

Total N is highest in Unit C, Soil 1, horizon Ah, and Unit B, Soil 2, horizon IIAhb, with 0.06% and 0.05%, respectively. Lowest levels of total N (0.01 %) are in Unit B, horizon IICbg1 and Unit A, horizon IIICbg3.

The C:N ratio is highest in Unit B, horizon IICbg2, at 18:1. Unit B, Soil 2, horizon IIAhb and Unit A, Soil 3, horizon IIIAhbg have ratios of 13:1 and 12:1, respectively. Lowest C:N ratios (8:1) are in Unit B, horizon IICbg1 and Unit A, horizon IIICbg3.

Total P concentrations are highest in Unit A, Soil 3, horizon IIIAhbg, at 0.035%, with lowest concentrations in Unit A, horizon IIICbg3, at 0.015%. Total P levels remain relatively constant throughout the rest of the profile, at about 0.02%.

Extractable P concentrations are also highest in Unit A, Soil 3, horizon IIIAhbg, at 48.24 mg/kg. Lowest levels of extractable P are in Unit C, Soil 1, horizon Ah, and in Unit A, horizon IIICbg3, at 21 mg/kg and 24.2 mg/kg, respectively.

CEC peaks at 4.53 $cmol_c/kg$ in Unit A, Soil 3, horizon IIIAhbg, while the lowest CEC is in Unit B, horizon IICbg1, at 1.26 $cmol_c/kg$. Unit C, Soil 1, horizon Ah and Unit B, Soil 2, horizon IIAhb have secondary peaks in CEC at 2.81 and 2.68 $cmol_c/kg$, respectively.

Ca^{2+} dominates the exchangeable cations, and peaks in Unit A, Soil 3, horizon IIIAhbg, with 4.86 $cmol_c/kg$. Secondary peaks in Ca^{2+} concentration also occur in Unit B, Soil 2, horizon IIAhb and Unit C, Soil 1, horizon Ah, with 2.57 $cmol_c/kg$ and 2.01 $cmol_c/kg$, respectively; Unit A, horizon IIICbg3 has a Ca^{2+} concentration of 2.11 $cmol_c/kg$. Lowest levels of Ca^{2+} are in Unit B, horizon IICbg1, with1.32 $cmol_c/kg$.

Na^{+} levels are constant throughout the profile, from 0.05 $cmol_c/kg$ to 0.06 $cmol_c/kg$.

K^{+} concentrations are highest in Unit A, Soil 3, horizon IIIAhbg and Unit C, Soil 1, horizon Ah, with 0.27 $cmol_c/kg$ and 0.24 $cmol_c/kg$, respectively. Unit B, horizon IICbg1 has lowest concentrations of K^{+} , with 0.13 $cmol_c/kg$.

Mg^{2+} concentrations are also highest in Unit A, Soil 3, horizon IIAhbg, with 1.03 $cmol_c/kg$. Lowest concentrations of Mg^{2+} are in Unit B, horizon IICbg1, with 0.27 $cmol_c/kg$.

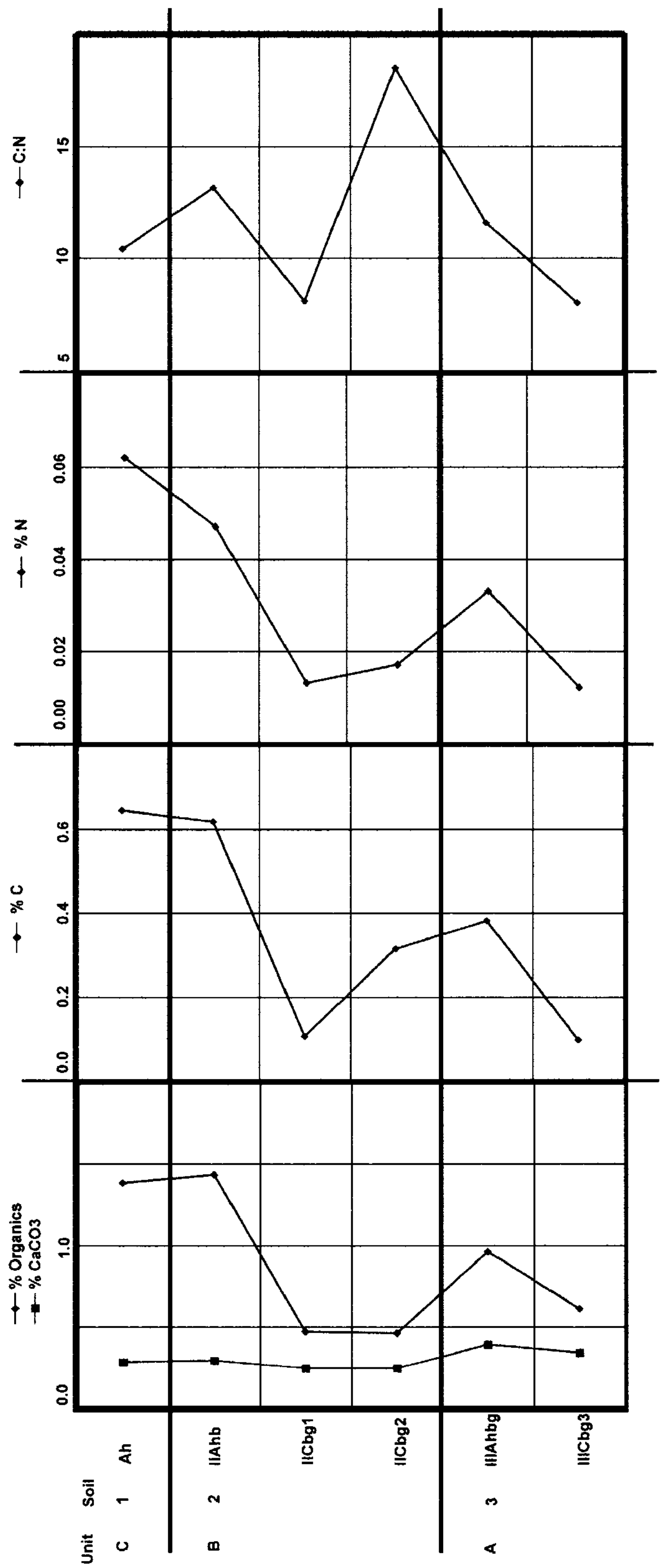

Figure 5.13a. Chemistry Results for L19

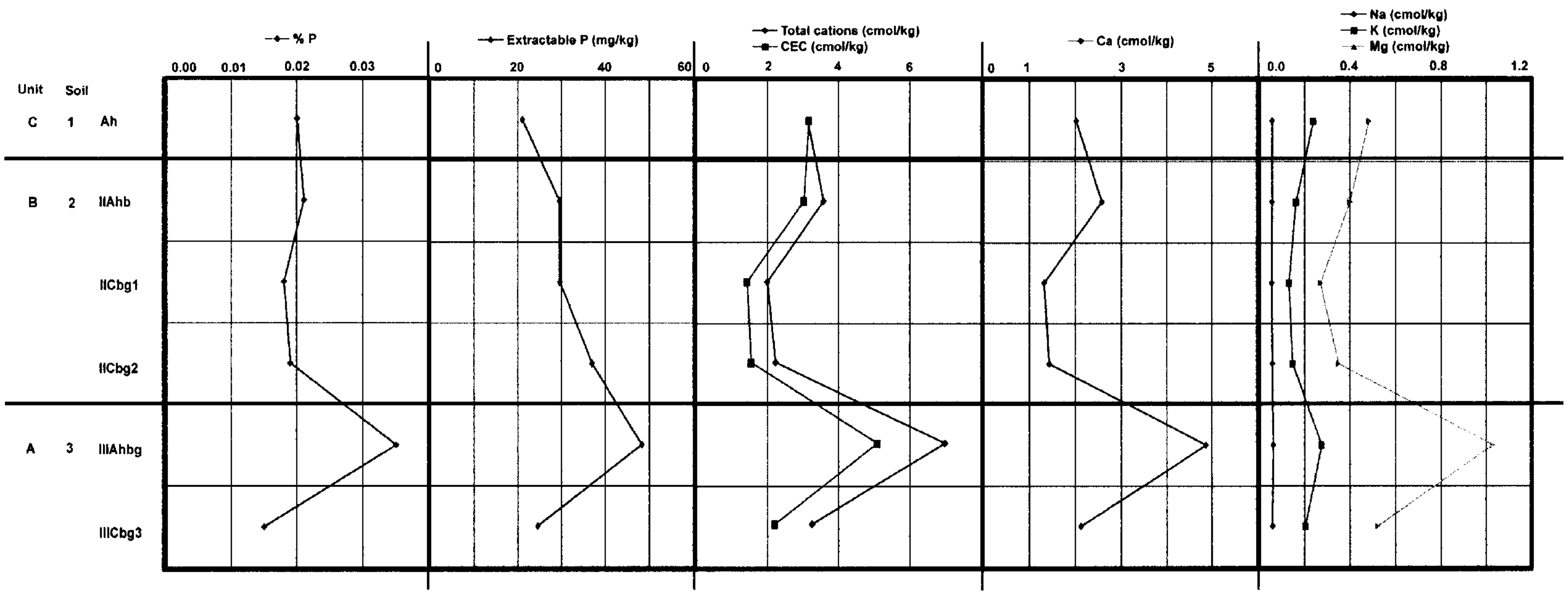

Figure 5.13b. Chemistry Results for L19

5.2.4 Offsite

Organic content ranges from 5.11% in Unit B, Soil 2, horizon IIAhb to 1.79% in Unit B, horizon IIBCb. Unit A, horizons IIICb and IIICcab also have relatively elevated levels of organics, at 4.31% and 3.91%, respectively. Unit C, Soil 1, horizon Ah has an organic content of 3.48% (Figure 5.14, Appendix V).

$CaCO_3$ content is highest in Unit A, with levels of 4% and 1.61% in horizons IICcab (which had a strong reaction to 10% HCl in the field) and IICb, respectively. $CaCO_3$ levels are relatively constant throughout Units B and C, with Unit B, Soil 2, horizon IIAhb having the highest level, at 0.84%. Unit B has the lowest concentration in horizon IIBCb, with 0.51%.

Total C is highest in Unit B, Soil 2, horizon IIAhb and Unit C, Soil 1, horizon Ah, at 2.17% and 1.53%, respectively. Lowest total C concentrations are in Unit A, horizon IIICb, with 0.57%. Unit A, horizon IIICcab and Unit B, horizon IIBmb also have relatively elevated levels of total C, with 1.1% and 1%, respectively.

Total N is highest in Unit B, Soil 2, horizon IIAhb and Unit C, Soil 1, horizon Ah, at 0.19% and 0.14%, respectively. Unit A, horizon IIICcab has the lowest total N, at 0.04%.

The C:N ratio is highest in Unit A, horizon IIICcab, with 27:1; however the rest of the horizons throughout the profile range between 9:1 (Unit A, horizon IIICb) and 12:1 (Unit B, Soil 2, horizon IIAhb).

Total P is highest in Unit A, horizon IIICcab, with 0.05%. Throughout the rest of the profile, total P ranges between 0.034% (Unit B, Soil 2, horizon IIAhb) and 0.027% (Unit B, horizon IIBCb).

Extractable P is highest in Unit C, Soil 1, horizon Ah and Unit B, Soil 2, horizon IIAhb, with 14.41 mg/kg and 13.34 mg/kg, respectively. Extractable P levels are lowest in Unit A, horizon IIICcab, at 0.83 mg/kg. Unit B, horizon IIBCb shows a secondary peak in extractable P, with 10.68 mg/kg.

CEC is highest in Unit A, horizons IIICb and IIICcab, at 15.07 $cmol_c/kg$ and 13.09 $cmol_c/kg$, respectively. The CEC in Units B and C range from 3.68 $cmol_c/kg$ (Unit B, horizon IIBCb) to 9.08 $cmol_c/kg$ (Unit B, Soil 2, horizon IIAhb).

Ca^{2+} dominates the exchangeable cations throughout the Offsite profile, with the highest levels in Unit A, horizons IIICcab and IIICb, at 27.64 $cmol_c/kg$ and 11.07 $cmol_c/kg$, respectively. Units B and C have Ca^{2+} concentrations that range from 3.23 $cmol_c/kg$ (Unit B, horizon IIBCb) to 8.16 $cmol_c/kg$ (Unit B, Soil 2, horizon IIAhb).

Na^+ concentrations are also highest in Unit A, horizons IIICcab and IIICb, with 0.25 $cmol_c/kg$ and 0.21 $cmol_c/kg$, respectively. Na^+ concentrations remain relatively constant throughout Units B and C, at about 0.06-0.07 $cmol_c/kg$.

K^+ is highest in Unit A, with concentrations in both horizons at about 0.7 $cmol_c/kg$. Unit B, Soil 2, horizon Ahb and Unit C, Soil 1, horizon Ah also have relatively elevated concentrations of K^+, with 0.65 and 0.62 $cmol_c/kg$, respectively. Lowest concentrations of K^+ are in Unit B, horizon IIBCb, with 0.43 $cmol_c/kg$.

Mg^{2+} is highest in Unit A, horizons IIICb and IIICcab, with 7.75 and 6.73 $cmol_c/kg$, respectively. Units B and C range in concentration from 1.03 $cmol_c/kg$ (Unit B, horizon IIBmb) to 1.51 $cmol_c/kg$ (Unit B, Soil 2, horizon IIAhb).

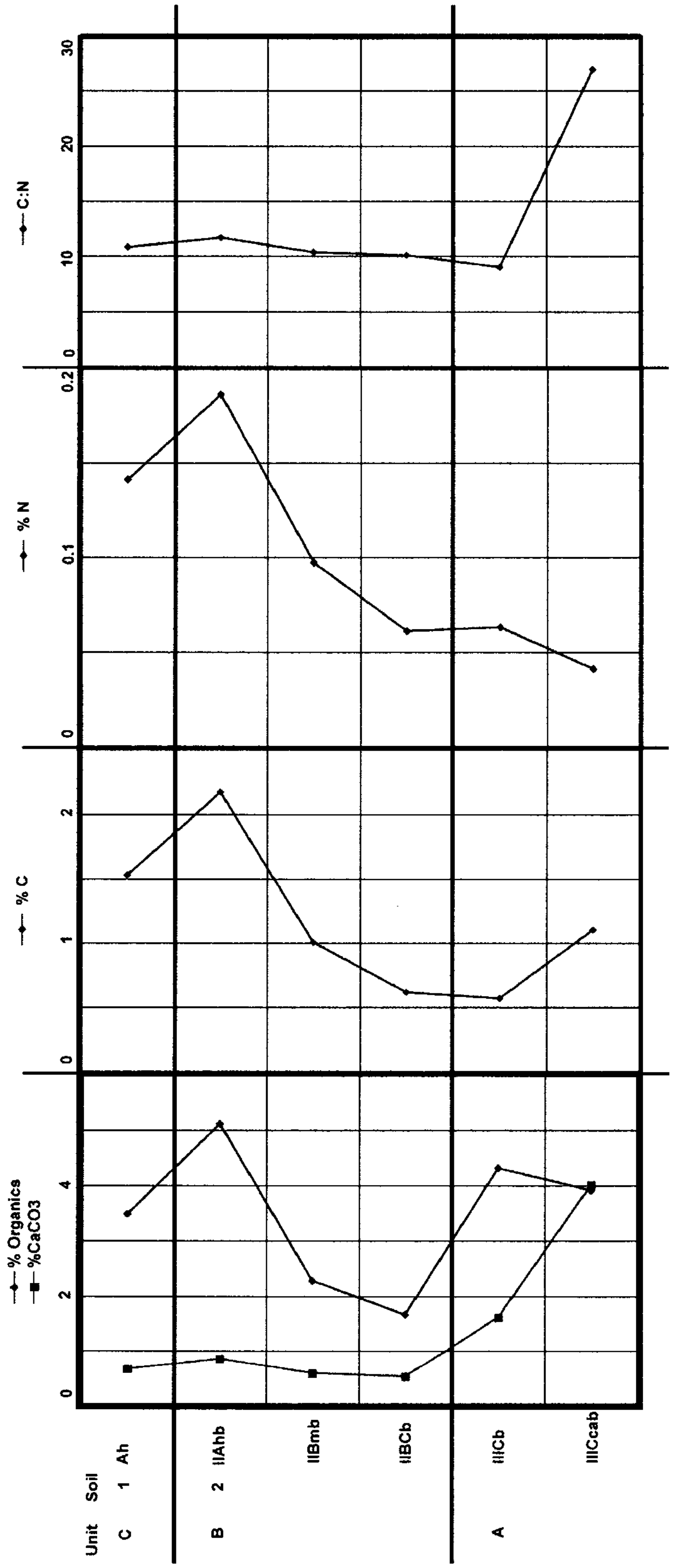

Figure 5.14a. Chemistry Results for Offsite

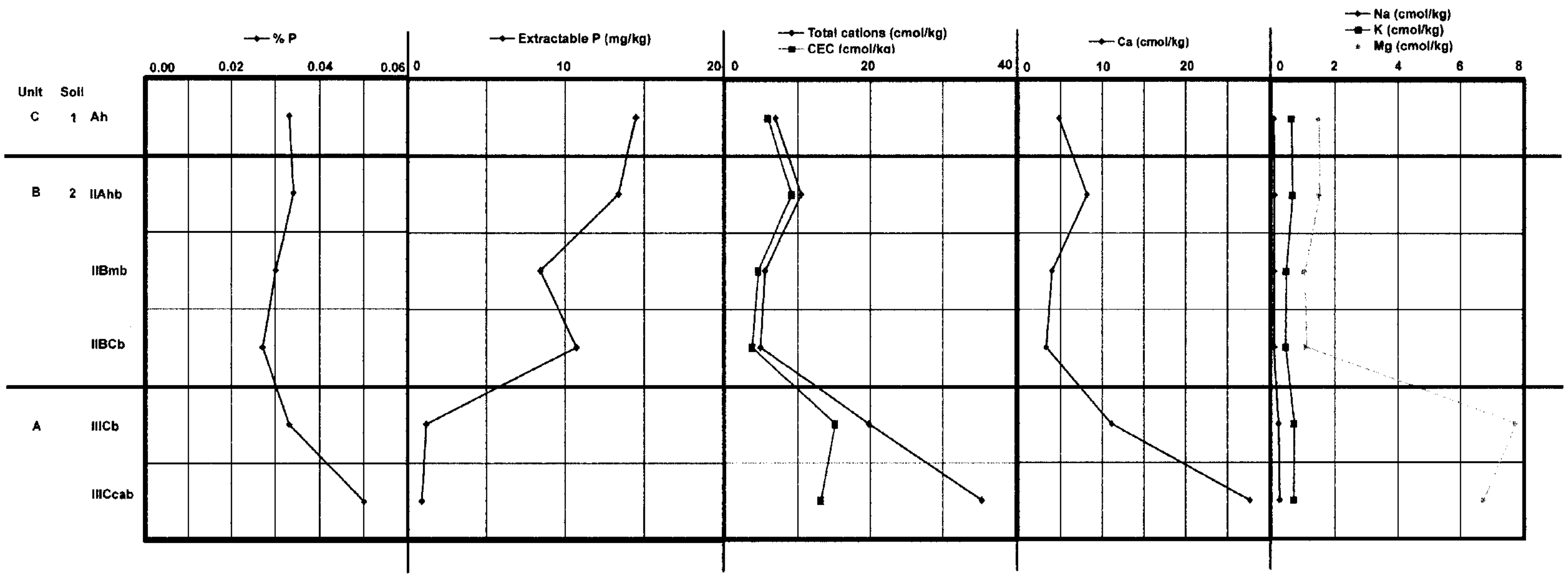

Figure 5.14b. Chemistry Results for Offsite

5.2.5 Soil pH and Conductivity

5.2.5.1 Soil pH

As expected, soil horizons near the land surface have lower pH than more deeply buried horizons (see Section 3.2.4). All study profiles are slightly acidic, with average pH values ranging from 6.1-6.5. The South L2 and L19 profiles have average pH values of 6.1 and 6.2, respectively; both are slightly more acidic than the North L2 profile, which has an average pH of 6.5. The Offsite profile also has and average pH of 6.2, however Unit A, horizon IIICcab has the highest pH of all, with 7.3; again, as expected (Table 5.8).

5.2.5.2 Electrical Conductivity

Average electrical conductivity ranges from 310 µS/cm (South L2 profile) to 105 µS/cm (L19 profile). The Offsite and North L2 profiles have average values at 219 and 232 µS/cm, respectively. Within each profile, higher conductivity levels are generally found in the Ah horizons of all soils, as well as in Unit A of the Offsite and South L2 profiles (Table 5.8).

Table 5.8. Results of pH and Conductivity

Profile	Stratigraphic Unit	Soil Number	Horizon	pH	Conductivity (µS/cm)
South L2	D	1	Ah	5.5	650
	C	2	IIAhb	6	382
			IICb1	6	349
			IICb2	6.3	196
			IICb3	6.3	304
	B	3	IIIAhb2	6.4	325
			IIIAeb	6.2	292
			IIIBmb	6.2	185
	A		IVCb	6.2	255
	Average value			6.1	310
North L2	C	1	Ah	6.4	334
	B	2	IIAhb	6.2	274
			IIBmbg1	6.8	210
			IIBmbg2	-	-
			IICbg1	6.8	166
			IICbg2	6.5	177
	Average value			6.5	232
L19	C	1	Ah	5.6	124
	B	2	IIAhb	5.8	140
			IICbg1	6.5	80.7
			IICbg2	6.8	78.5
	A	3	IIIAhbg	6.2	122
			IIICbg3	6.2	85.6
	Average value			6.2	105
Offsite	C	1	Ah	5.5	208
	B	2	IIAhb	5.9	278
			IIBmb	6	187
			IIBCb	6.1	187
	A		IIICb	6.4	191
			IIICcab	7.3	262
	Average value			6.2	219

5.3 SOIL MICROMORPHOLOGY

5.3.1 South L2 Profile: Unit B, Soil 3, Horizon IIIAhb2

One third of the total sample consists of randomly oriented organic matter, the majority of which is composed of amorphous fine materials with opaque black punctuations and a crumb structure (Figures 5.15 and 5.16) (FitzPatrick 1993; Stoops 2003). There are very few fresh or humified plant tissues present. The mineral fraction of the South L2 sample consists of well-sorted medium sand, primarily of rounded to subangular quartz and chert grains. Quartz grains are very dominant, making up 70-80% of the coarse mineral fraction. 10-20% of the mineral grains are coated with reddish yellow to black iron and amorphous organic coatings; these primarily appear on chert and quartz aggregate grains. The sample also contains a few silt-sized organo-mineral accumulations[40] that increase near the bottom of the slide. Appendix VI provides complete micromorphological descriptions of both the South L2 and North L2 samples. In both samples, poor slide preparation limited the area examined.

5.3.2 North L2 Profile: Unit B, Soil 2, Horizon IIAhb

One third of the sample consists of randomly oriented organic matter, the majority of which consists of amorphous fine organic material with opaque black punctuations and a crumb structure (Figures 5.17-5.19) (FitzPatrick 1993; Stoops 2003). 10% of the total sample is composed of humified and relatively fresh plant tissues. The mineral fraction of the North L2 sample consists of well-sorted medium sand, primarily of subrounded to subangular quartz and chert grains. Although quartz grains still dominate the coarse mineral fraction, the North L2 sample consists of 60-70% quartz, slightly lower than the South L2 sample. About 15% of the mineral grains are coated with yellow to brown iron and amorphous organic coatings, appearing primarily on chert and quartz aggregate grains.

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[40] Organo-mineral accumulations are formed when organic matter bonds with clay minerals or other materials such as Al and Fe hydroxides inside soil aggregates, creating complexes that render the organic matter unavailable for microbial decomposition (Brady and Weil 2002).

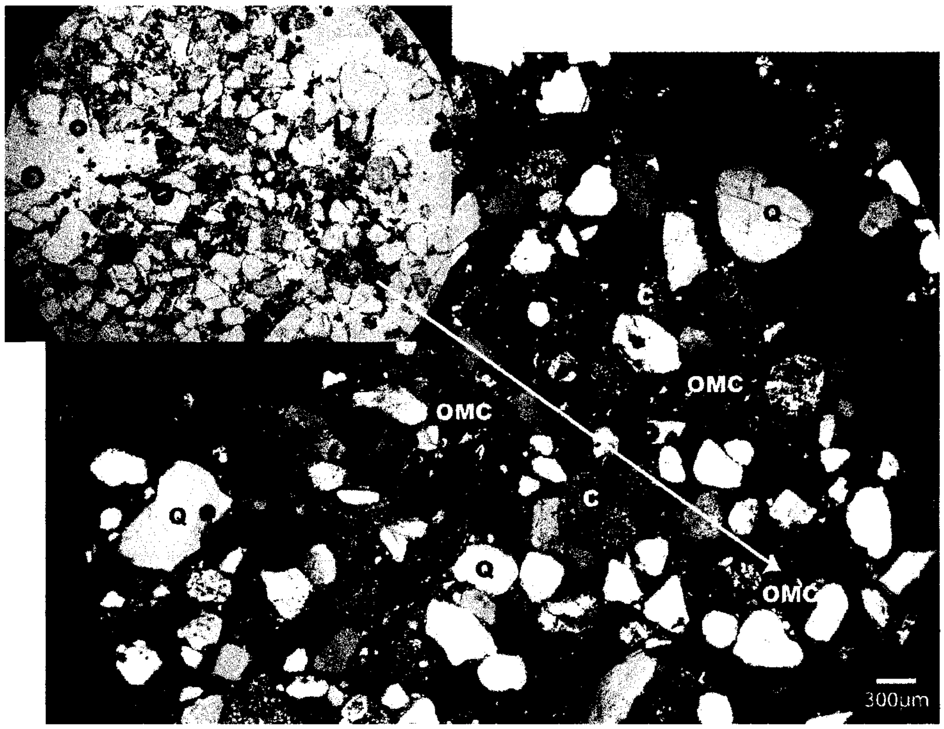
Photo: K. Gilliland

Figure 5.15. Distribution of Minerals and Organics

South L2 Profile, Unit B, Soil 3, Horizon IIIAhb2.

PT=plant tissue; Ao=amorphous organic material; C=iron and amorphous organic coating on mineral grains; Q=quartz grains. Black circles are air bubbles in the resin. Scale is approximate.
Photo: PPL[41] 40x.

[41] Plane polarized light



Photos: K. Gilliland

Figure 5.16. Organo-mineral Accumulations

South L2 Profile, Unit B, Soil 3, Horizon IIIAhb2

OMC=organo-mineral accumulations; Ch=chert grains; Q=quartz grains; C=iron and amorphous organic coatings on mineral grains. Black circles are air bubbles in the resin Scale is approximate. Top photo: 40x PPL; bottom photo: 40x XPL[42].

[42] Cross polarized light

Photo: K. Gilliland

Figure 5.17. Distribution of Minerals and Organics

North L2 Profile, Unit B, Soil 2, Horizon IIAhb.

Ao=amorphous organic material; B=bone; Q=quartz grains; C=iron and amorphous organic coating on mineral grains; Hb=hornblende grain. Black circles are air bubbles in the resin. Scale is approximate. Photo: PPL 40x.

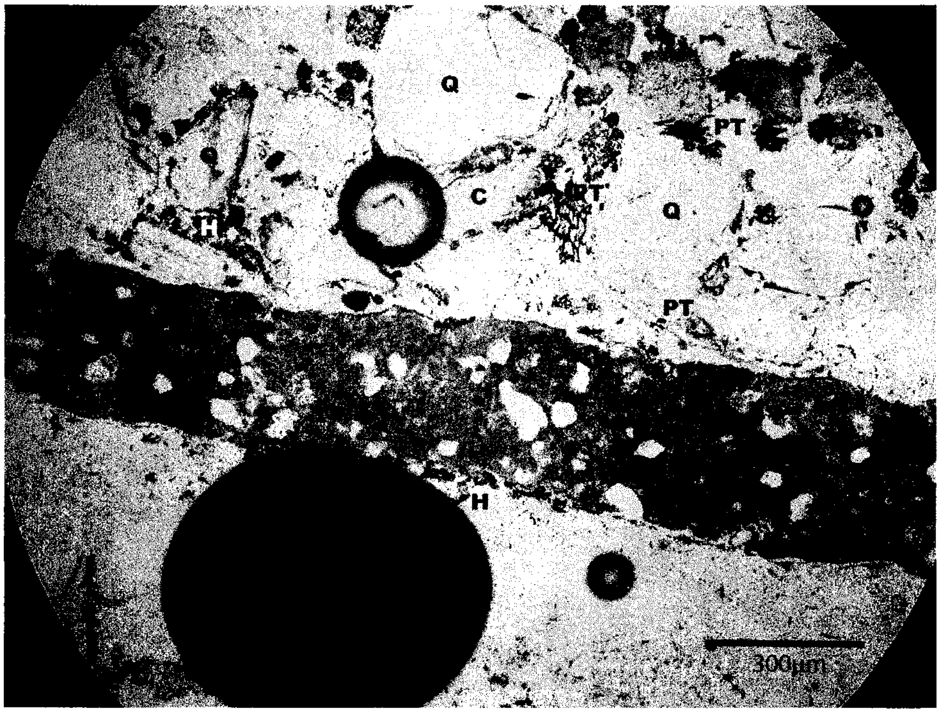


Photo: K. Gilliland

Figure 5.18. Vesicular Lithic

North L2 Profile, Unit B, Soil 2, Horizon IIAhb.

H=humified organics; PT=plant tissue; Q=quartz grains; C=iron and amorphous organic coating on mineral grains. Black circles are air bubbles in the resin. Scale is approximate. Photo: PPL 100x.

The North L2 sample contains charcoal, one pottery fragment (Figure 5.19) and several angular bone fragments, about 30% of which are stained with iron. The sample also contains one subangular fragment of a very fine-grained vesicular mudstone or chert, or possibly a devitrified obsidian (Figure 5.18) (Dr. John Waldron, Department of Earth and Atmospheric Sciences, University of Alberta, pers. comm.).

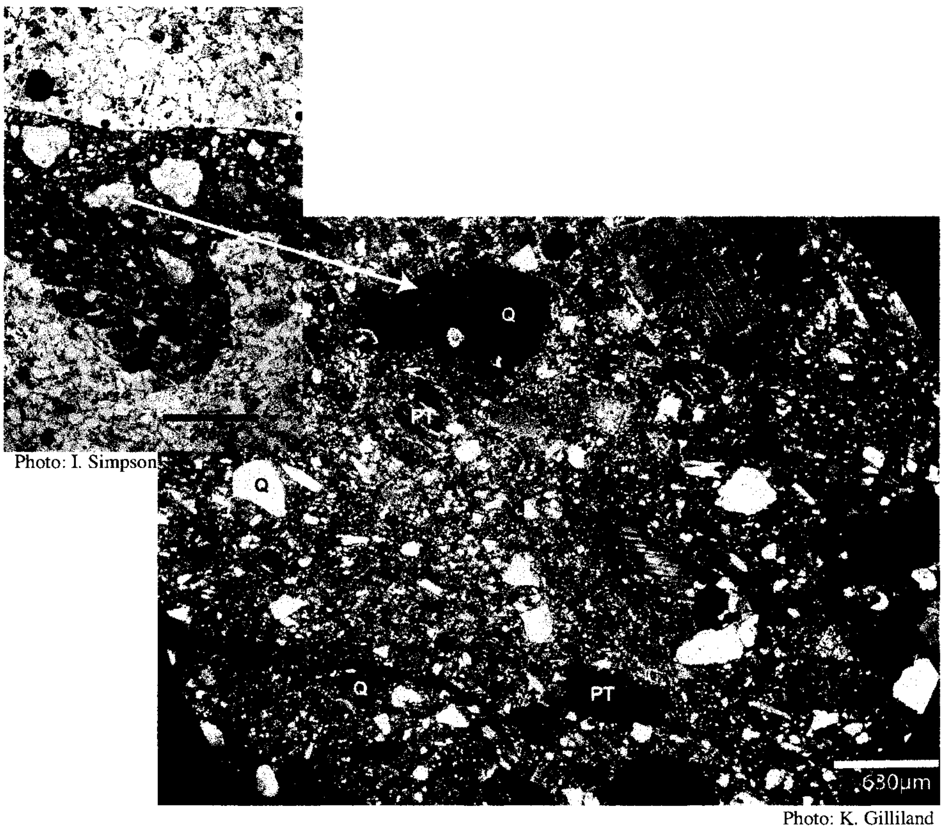


Figure 5.19. Pottery

North L2 Profile, Unit B, Soil 2, Horizon IIAhb.

PT=plant tissues; Q=quartz; Ch=chert; F=feldspar. Scale is approximate. Top photo: PPL 20x(?); Bottom photo: XPL 100x.

5.4 SOIL MICROBIAL PLFA ANALYSIS

Due to the high sand content of the study soils, soil samples needed to be relatively large for sufficient extraction of PLFAs. For two of the samples,[43] not enough soil was submitted for extraction, therefore the extracted PLFA concentration was too low in these samples for detection by the gas chromatograph (Jennifer Lloyd, Department of Renewable Resources, University of Alberta). These two samples were present as outliers in the initial ordination results, however these were removed on the advice of Dr. Sylvie Quideau, Renewable Resources, University of Alberta. Because only the

[43] Both outliers were surface Ah samples from the east and west walls of Test Pit L2-9.

upper 5cm of the Offsite profile was sampled, it is not known whether the Offsite samples represent Soil 1 or Soil 2. Therefore, to reduce confusion in the following discussion, I refer to samples from Soils 1 and 2 of the Locality 2 profiles simply as Soil 1 and Soil 2. The Offsite samples are referred to as such.

5.4.1 Total Microbial Analysis

The ordination for the total microbial PLFAs (Figure 5.20) indicates that PLFAs from Soil 1 of the South L2, North L2 and Test Pit L2-9 profiles are distinct from Soil 2 and the Offsite PLFAs. MRPP analysis of the ordination comparing the Soil 1, Soil 2 and Offsite PLFA profiles demonstrates that the separation between the three groups is significant ($T= -8.14$, $P= 0.000021$). In addition, MRPP analysis (Table 5.9) demonstrates that the total PLFAs in Soil 1 samples are significantly different from the Soil 2 and Offsite samples ($T= -6.81$, $P= 0.00012$ and $T= -8.632$ and $P= 0.000052$, respectively)[44]. The Soil 2 and Offsite samples have total PLFA profiles that are not significantly different from each other ($T= 2.538$ and $P= 0.03$).

Table 5.9. MRPP results for total PLFA analysis comparing Soil 1, Soil 2 and Offsite samples, excluding outliers.

	T	*A*	*P*
All 3 groups	-8.14	0.19	0.000021
Soil 1 and Soil 2	-6.81	0.146	0.00012
Soil 1 and Offsite	-8.632	0.237	0.000052
Soil 2 and Offsite	2.538	0.067	0.03

[44] T describes the separation between groups; the more negative T is, the stronger the separation. A describes the homogeneity within groups, and is scored from 0-1, with 1 describing a group whose members are exactly the same. P represents the likelihood that the observed differences are due to chance. A P value of 0.05 is usually considered significant; however in this study, a more conservative value of P=0.01 is the criteria for significance (see section 4.5.2.3) (McCune and Grace 2002).

5.4.2 Analysis of Gram (+) Community

Ordinations performed on microbial functional groups revealed significant differences (T= -6.47, P=0.000022) in the Gram (+)[45] communities between the Soil 1, Soil 2 and Offsite samples (Figure 5.21). MRPP analysis of the ordination results (Table 5.10) demonstrates that the Gram (+) PLFAs are most significantly different between the Soil 1 samples and the Soil 2 and Offsite samples (T= -4.197, P= 0.0018 and T= -6.134, P= 0.000078, respectively). However, the Gram (+) PLFAs in the Soil 2 and Offsite samples are also significantly different (T= -3518, P= 0.0083).

Table 5.10. MRPP results for Gram (+) PLFA analysis comparing Soil 1, Soil 2 and Offsite samples, excluding outliers.

	T	*A*	*P*
All 3 groups	-6.47	0.124	0.000022
Soil 1 and Soil 2	-4.197	0.0866	0.0018
Soil 1 and Offsite	-6.134	0.0128	0.000078
Soil 2 and Offsite	-3.518	0.0777	0.0083

[45] Differences in microbial cell wall structure can be detected in some organisms using the Gram test, in which cell structures are stained, resulting in identification of Gram (-) or Gram (+).

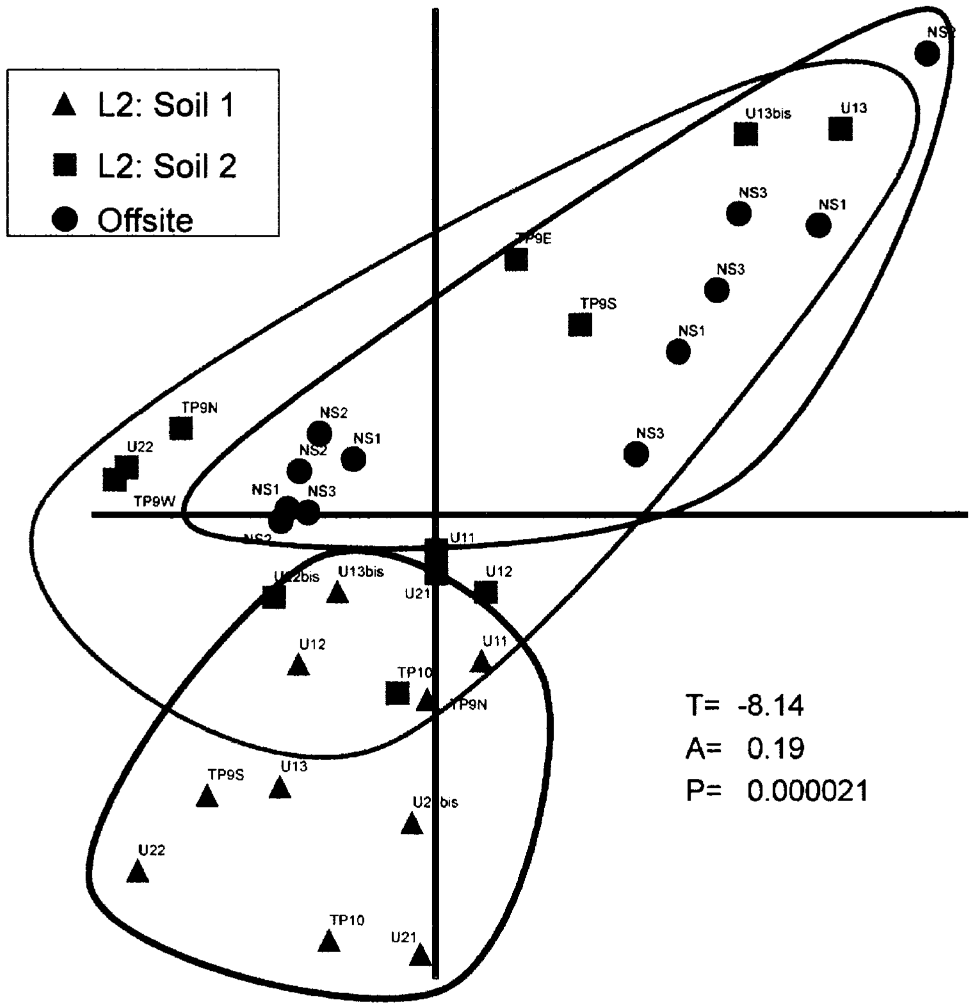


Figure 5.20. Total Microbial PLFAs.

The triangles and squares represent PLFAs from the surface soil (Soil 1, Ah horizons) and Soil 2 (Ahb horizons), respectively, in the South L2, North L2 and Test Pit L2-9 profiles. The circles represent PLFAs from the upper 5 cm of the Offsite profile samples.

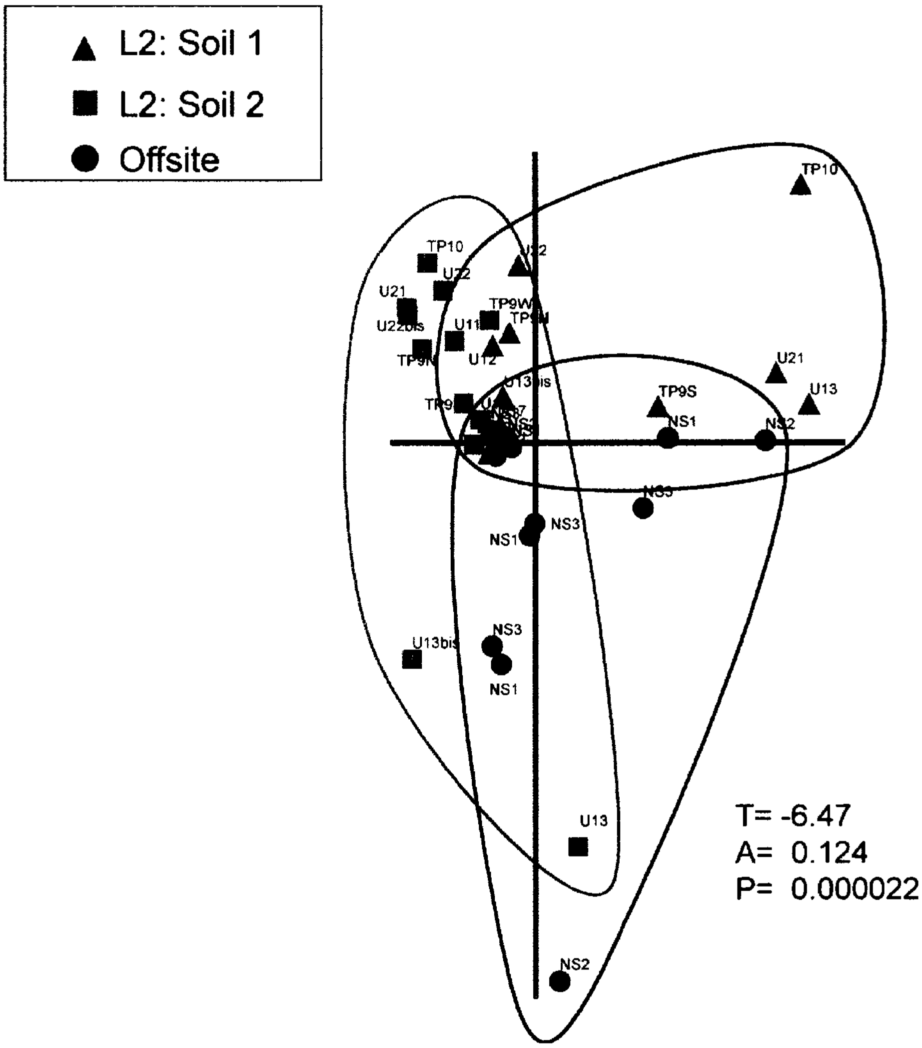


Figure 5.21. Gram (+) PLFAs.

The triangles and squares represent PLFAs from the surface soil (Soil 1, Ah horizon) and Soil 2 (Ahb horizons), respectively, in the South L2, North L2 and Test Pit L2-9 profiles. The circles represent PLFAs from the upper 5 cm of the Offsite profile samples.

5.4.3 Indicator Species Analysis

Indicator analysis of PLFA data detected eight PLFAs indicative of Soil 1 and one PLFA indicative of Soil 2 (Table 5.11). Two of the indicator PLFAs (15:1 ω6c and 14:1 ω5c) are biomarkers for Gram (-) microbes, however the rest of the indicator PLFAs are not considered biomarkers for any microbial functional group (DeGrood et al. 2005). Indicator analysis of the data did not identify any PLFA indicative of the Offsite soil.

Table 5.11. Indicator values of specific PLFAs associated with Soil 1, Soil 2, and Offsite samples at the Bodo Archaeological Site, excluding outliers.

PLFA	Observed indicator values (%)[46]			Indicator value from randomized tests[47]	
	Soil 1	Soil 2	Offsite	Mean (std. dev.)	*P*
13:0	56	1	0	16.5 (6.9)	0.001
12:0 2OH	40	0	0	13 (6.5)	0.001
12:0 3OH	50	0	0	14.1 (6.8)	0.001
*14:1 ω5c	64	1	0	17.7 (7.2)	0.001
*15:1 ω6c	74	4	0	22.5 (7.2)	0.001
15:0 ISO 3OH	69	0	3	22.6 (7.2)	0.001
16:0 2OH	73	0	3	23.5 (7.4)	0.001
18:1 2OH	67	0	0	18.2 (7.4)	0.001
16:1 ISO H	0	47	1	16.7 (6.7)	0.001

* biomarkers for Gram (-) microbes (DeGrood et al. 2005)

[46]Indicator value is at 100% when the specific PLFA is present in all samples of only one soil group (i.e. Soil 1, Soil 2 or Offsite) (Dufrêne and Legendre 1997: 350).

[47]The significance of observed indicator values is assessed statistically using random arrangements of the sample data. *P* is the proportion of randomized runs that are equal to or greater than the observed values of the samples. Low *P* values such as those shown in Table 5.11 demonstrate that the observed indicator values are unlikely to be achieved by chance.

CHAPTER 6: DISCUSSION

Sand dune destabilization occurs during periods of higher temperatures, increased fire frequency, lower humidity and reduced vegetation cover[48]. On the other hand, climatic episodes of increased humidity and cooler temperatures promote dune stability, increased vegetation cover, and soil formation (Wolfe et al. 2002b). The sequence of sediments and soils within a sand dune environment, such as the Bodo Sand Hills, thus provides a record of climactic fluctuations over time. Soil chemical, micromorphological and microbial properties also provide information about climate and other soil forming factors, including anthropogenic influences and land use history (see Chapter 3). In this chapter, I discuss the stratigraphy, radiocarbon chronology and properties of sediments and soils at the Bodo Archaeological Locality within the regional environmental and archaeological context. A schematic diagram of the stratigraphy is shown in Figure 6.1, and will be explained at length during discussion of results (see Figures 6.5-6.7).

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[48] Human activity can also activate sand dunes through disturbances such as farming or recreational activities (e.g. the use of all-terrain vehicles).

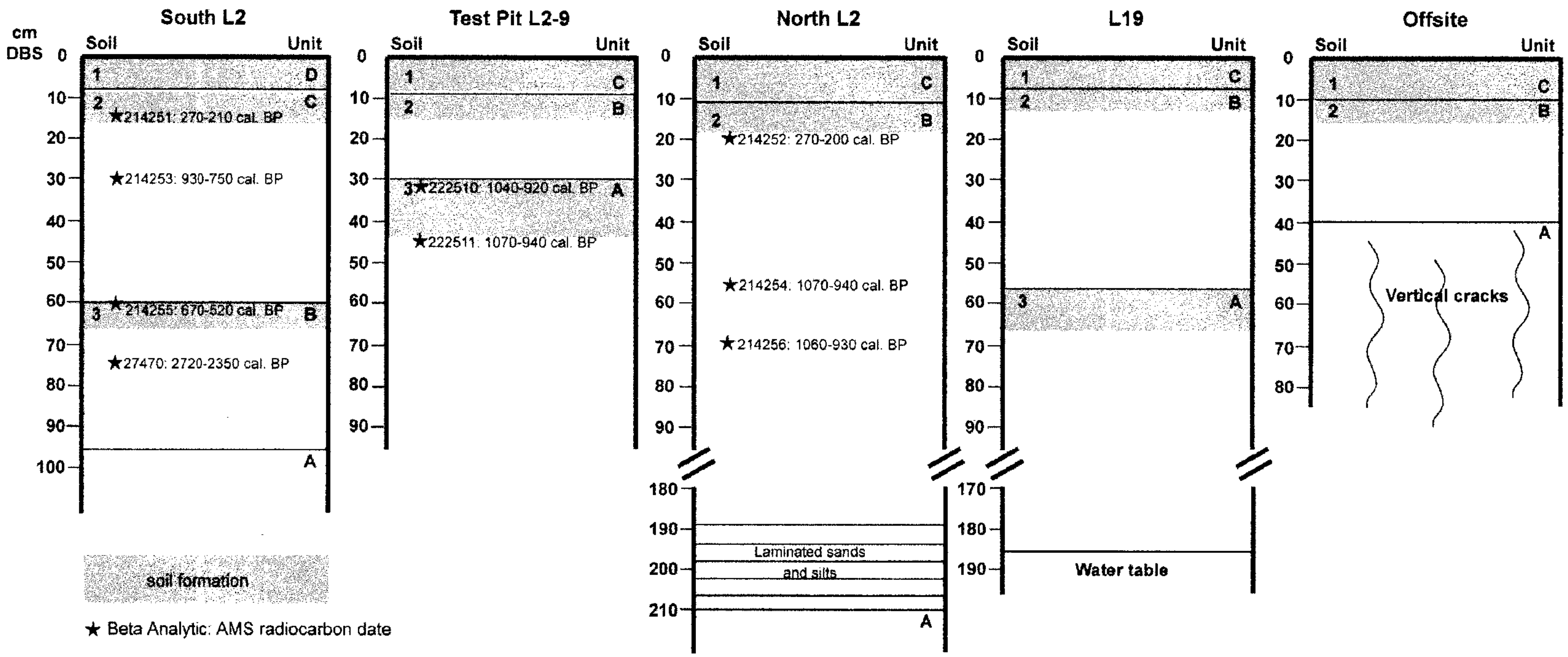

Figure 6.1. Summary of Stratigraphic Profiles

6.1 STRATIGRAPHY AND SOIL DEVELOPMENT

6.1.1 Clay Loam

Unit A of the South L2 and Offsite profiles is composed of clay loam sediment containing pebbles and boulders, that likely represents glacial till or glaciogenic sediments deposited in the near ice environment during the late Pleistocene (Bayrock 1967). The vertical cracks throughout Unit A of the Offsite profile reflect expansion and contraction of the clay in response to freeze/thaw episodes.

Limited exposure of the clay loam sediment comprising Unit A of the North L2 profile prevented observation of any pebbles or cobbles included in the sediment. Although it is probable that Unit A of the North L2 profile correlates with Unit A of the South L2 and Offsite profiles, more stratigraphic work is needed prior to making that conclusion. In the South L2, North L2 and Offsite profiles, the contacts between Units A and B are geological unconformities, representing an interval of erosion or sediment non-deposition.

6.1.2 Aeolian Sediment

The Bodo Archaeological Locality is on a slope that declines to the north, towards the Eyehill Creek valley (Figure 4.1), therefore slopewash must be considered as a possible process responsible for sediment accumulation in the study profiles. Slopewash involves transportation of sediment across the land surface and downslope by runoff. Slopewash sediments are typically poorly sorted and massively to poorly bedded, constituting a type of colluvium (Rapp and Hill 1998; Schiffer 1987).

Colluvium may be difficult to distinguish from aeolian sediments at the Archaeological Locality, as aeolian deposits may also exhibit massive bedding (Huckleberry 2001: 67). However, three lines of evidence indicate that aeolian processes are responsible for the deposition of the sandy sediments at the Bodo Archaeological Locality. First, due to the sandy nature of the sediments, the study area is very well drained. During three seasons of fieldwork, I observed no instances of substantial runoff, during or immediately after intense and prolonged precipitation. Second, slopewash transports surface sediments such as organic material and soils from higher elevations, depositing these sediments downslope. The North L2 and L19 profiles should therefore exhibit layers of sediments mixed with organics; they do not. In addition, areas of higher elevation should demonstrate erosion of surface soils, but the South L2 profile does not. Third, the grain size distribution of the two sampled dunes southeast of FaOm-1 (Figure 5.10) may be considered as averages for aeolian sediments in the Bodo area. The grain size distributions of the study profiles (Figures 5.2, 5.4, 5.7 and 5.9) are consistent with those of the dune sand, although with added silt. Aeolian activity is therefore the dominant geomorphological force responsible for sediment deposition in the Bodo Archaeological Locality.

With the exception of the clay loam, discussed above, all study profiles are composed primarily of aeolian sediments that exhibit variations in grain size, indicating that sediments were deposited during fluctuations in aeolian intensity.

6.1.2.1 South L2

Unit B

Unit B of the South L2 profile has near-uniform grain size distribution (Figure 5.2), indicating that sediments were deposited during a climatic interval that experienced few fluctuations in wind speed or strength. Freeze/thaw processes forced pebbles up from Unit A into Unit B.

Soil 3, formed in Unit B, exhibits distinct horizon development, indicating that intense or prolonged weathering took place during this period of soil formation compared to subsequent periods of pedogenesis. The bison tooth from Unit B, Soil 3, horizon IIIAeb produced an AMS date of 2430±40 yr BP providing a minimum age of 2720-2350 cal. BP for Soil 3 of the South L2 profile.

A small bone fragment was also collected from Unit B, Soil 3, horizon IIIAhb2, which produced an AMS date of 620±50 yr BP (670-530 cal. BP). This date requires further consideration, as this bone is located between two larger bones from Units B and C, which date to 2340 yr BP and 930 yr BP, respectively (see below). However, as numerous krotovinae are present throughout Unit B, Soil 3 as well as Unit C (see Section 5.1.1), the bone fragment could have been transported downward through burrowing fauna. Therefore, this date is rejected.

Unit C

The proportion of medium and fine sands increases from the bottom of Unit C to the top, where Soil 2 contains the highest percentage of medium sand of all four of the study profiles. The higher proportion of medium sand may be due to the erosion of finer materials from Soil 2 as a result of disturbance during human occupation. Alternatively, the increase in medium sands throughout Unit C may reflect increasing intensity of winds or a closer sediment source, or both.

A bison calcaneus was found in anatomical position along with other bones from the left hind limb at 30 cm depth, within Unit C, horizon IICb1, and was dated to 930±40 yr BP (930-750 cal. BP). The bone could have moved down from upper horizons, or moved up from lower horizons by bioturbation, cryoturbation or other disturbance mechanisms. However, these types of disturbance are unlikely to be responsible for the bone's stratigraphic position, given that the calcaneus is a large bone, and it was found in anatomical position with other hind limb bones. The bone therefore likely represents an in situ deposit, although it could also represent a lag deposit from an eroded land surface. However, no other evidence of a lag deposit, such as a stone line or other bones or artifacts, was seen at this level. An alternative explanation for is that humans deposited the bone while occupying the Bodo area during a period of landscape instability, at a time of active aeolian deposition.

AMS radiocarbon dates of bone collected from Soil 2 at 15 cm depth produced a conventional age of 70±40 yr BP. This date has three intercepts with the radiocarbon calibration curve (see Table 5.2). However, the 270-200 cal. BP intercept is the most likely, for three reasons.

First, the samples were collected from within Soil 2, which is continuous across the Archaeological Locality, including at the North L2 profile, where Soil 2 contained Late Precontact pottery types and Late Side-Notched projectile points. There is therefore congruence with the 270-200 cal. BP date and the artifact typologies associated with the AMS sample. Previous research focusing on the Late Precontact occupation in other areas of the Bodo Archaeological Locality has produced dates between 520-120 cal. BP for this occupation period (Blaikie 2005; Grekul 2007); again, there is congruence with the Soil 2 date obtained in the South L2 profile (Figure 6.2).

Second, two small iron pieces comprise the only Euro-Canadian trade goods found among the thousands of artifacts excavated from Soil 2 of the North L2 profile area in 2005. The small amount of trade goods in the artifact assemblage indicates that the Late Precontact occupation took place during the Protohistoric period, prior to European settlement of the area, after European goods were available in abundance on the continent.

Finally, although bison populations were almost completely gone from the Great Plains by the mid-1800s (Knapp et al. 1999), dense bone deposits within Soil 2 throughout the Archaeological Locality indicate that bison were still abundant at the time of the Late Precontact occupation. Given that artifact typology, radiocarbon dates from previous research and abundant bison remains all support a pre-1850s AD date for Soil 2 sample, the 270-200 cal. BP intercept is most likely correct. This age provides a minimum age for formation of Soil 2.

Unit D

The surface soil (Soil 1) is formed on Unit D and exhibits no apparent horizon differentiation, indicating that surface sediments have undergone minimal weathering.

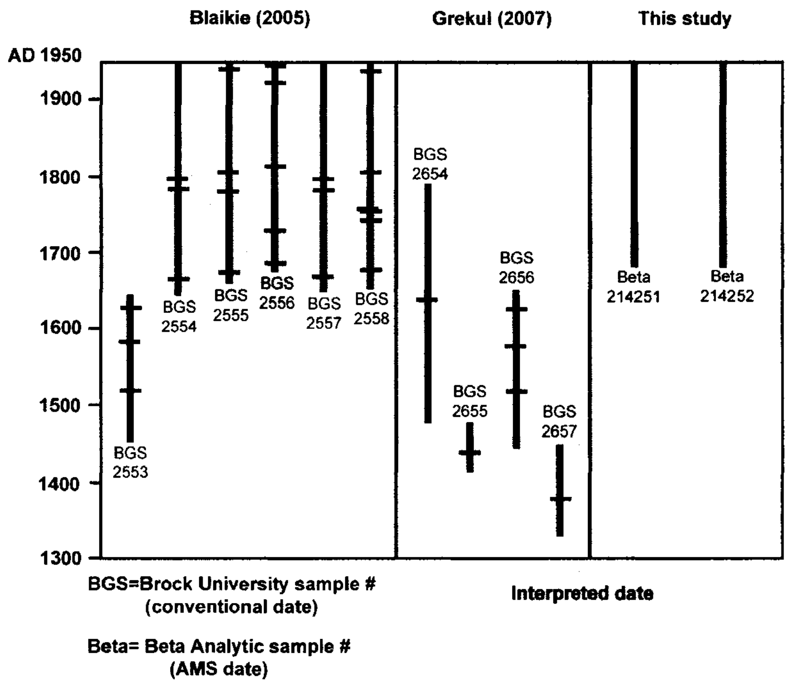

Figure 6.2. Summary of Radiocarbon Dates, Late Precontact Occupation, Bodo Archaeological Locality

Short horizontal lines indicate reported intercepts with the radiocarbon calibration curve. In this study, the only intercepts with the curve were at AD 1950. Vertical lines indicate the maximum and minimum calibrated age ranges at 2 sigma. Shaded areas represent the interpreted date of Late Precontact occupation, as reported in Blaikie (2005), Grekul (2007), and this study.

6.1.2.2 Test Pit L2-9

Unit A

Bone from just below Soil 3 of Test Pit L2-9 (about 45 cm depth) produced an AMS date of 1100±40 yr BP (1070-940 cal. BP). Bone from the top of Soil 3 at 35 cm depth, produced an AMS date of 1040±40 yr BP, which has two intercepts with the calibration curve; one at 1040-1030 cal. BP, and one at 1000-920 cal. BP. The calibrated ranges of this sample are very close to each other; therefore, they are both included in the age estimate of the bone. The radiocarbon dates provide the minimum age of formation of Soil 3, Test Pit L2-9, between 1070-920 cal. BP.

6.1.2.3 North L2

Unit B

The bottom of Unit B consists of laminated fine sand and silt, which gradually grades upward, from contact with Unit A at 210 cm to about 84 cm depth. I have observed similarly laminated sand and silt within a stratigraphic profile surrounding a perennial waterhole in FaOm-1 (see Figures 2.14, 6.3 and 6.4). The waterhole sediments may have been transported into the area by wind and subsequently deposited into a pond or wetland, where they settled, creating laminations (Rapp and Hill 1998). The clay loam of Unit A provides a relatively dense substrate that inhibits water infiltration and may contribute to ponding. During deposition of Unit B, the moist land surface near Unit A could have trapped aeolian sands and silts in fine layers similar to those seen at the waterhole. Water would have continued to be drawn up into the accumulating sediments, wetting the land surface until Unit B had built up out of the reach of capillary action.

10 cm

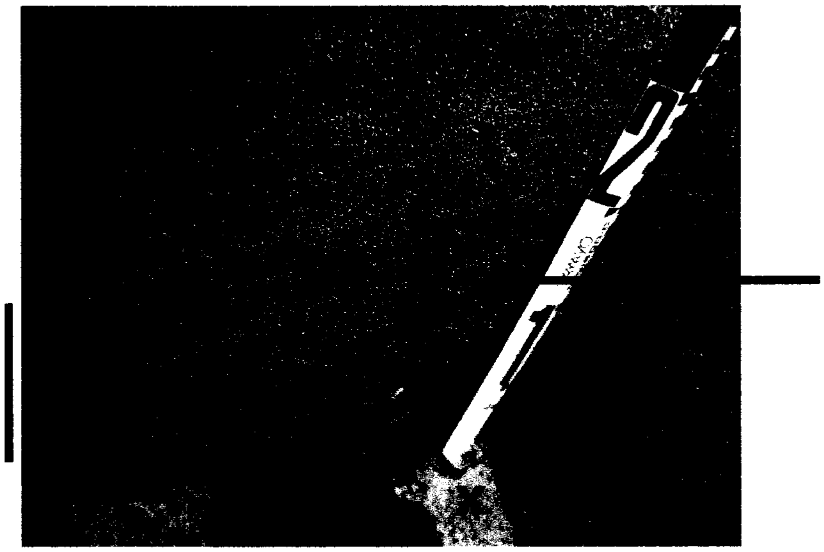

Photo: K. Gilliland

Figure 6.3. Laminated Sediments near the base of Unit B, North L2 Profile

Unit A, the clay loam sediment, is indicated by the 'X'; laminations are indicated by the arrow. Scale is approximate.


Photo: K. Gilliland

Figure 6.4. Laminations in Soil Profile near Waterhole, FaOm-1, Locality 71

Gley colors and iron mottling appear throughout Unit B, up to 20 cm depth, indicating that sediments have been subject to repeated episodes of wetting and drying. Sediment saturation was probably a combination of infiltration and groundwater ponding on top of Unit A, with capillary rise up into Unit B. As the North L2 profile is a topographic low relative to the South L2 profile, water flowing downslope from South L2 in the form of throughflow[49] may have periodically accumulated in the North L2 sediments or at the base of Unit B, also contributing to sediment saturation.

Two small bone fragments from 70 cm and 55 cm of Unit B, horizon IICbg2 of the North L2 profile produced AMS dates of 1080±40 and 1100±40, respectively (1060-930 cal. BP and 1070-940 cal. BP). Krotovinae were only observed in the top 35 cm of the profile, therefore although it is possible that burrowing activity transported the bone fragments, this cannot be confirmed. Other possibilities are that the bones have been moved out of context by cryturbation, or that they represent in situ deposits. However, as they were

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[49] Throughflow is the flow of water downslope, within the soil (Birkeland 1999).

ventifacted and associated with ventifacted lithics, these bone fragments likely represent lag deposits and are not in situ.

Unit B, Soil 2 has developed a IIBmbg horizon, indicating a prolonged period of stability relative to the development of the surface soil, perhaps as much as a few hundred years (Brady and Weil 2002). Radiocarbon dating of bone from 20 cm depth, Unit B, Soil 2, horizon Bmbg1 produced a conventional age of 80±40 yr BP, providing a minimum age of formation of Soil 2 of 270-200 cal. BP (see discussion in Section 6.1.2.1).

6.1.2.4 L19

Units A, B and C

The proximity of the water table to the modern land surface at the L19 profile suggests that the aeolian sands sit on top of a clay-rich substrate, which inhibits infiltration and allows water to pond. Gley colors and iron mottles throughout the L19 profile indicate that sediments are regularly saturated due to fluctuations in the water table and capillary action.

On average, Units A, B and C of the L19 profile have a higher proportion of medium sands than the other three study profiles (Figure 5.7), indicating that the L19 sediments were deposited by higher velocity winds, or were from a closer source, or both. Sand dune morphology suggests that winds from the north have been a significant geomorphological factor in the past, in addition to winds from the southeast and northwest (see Figure 2.7). The grain size distribution of L19 sediments probably reflects the proximity of L19 to the Eyehill Creek valley, the original source of aeolian sediments during the late Pleistocene. The grain size distribution of the L19 sediments remains relatively constant throughout the profile, indicating that sediments were deposited by similar aeolian processes through time.

6.1.2.5 Offsite Profile

The Offsite profile is located on an exposed, elevated area of the landscape with no protection from the wind. Boulders and cobbles at the land surface provide evidence that there is little opportunity for sediments to accumulate at this location, and that significant erosion of sediments may occur during landscape destabilization.

Units B and C

Freeze/thaw processes are responsible for the occurrence of pebbles in Unit B, which were forced up from the underlying clay loam of Unit A. The grain size distribution of Units B and C remains relatively constant throughout the profile, indicating that sediments were deposited by relatively similar aeolian processes through time (Figure 5.9). However, the Offsite profile is in an exposed area of the landscape, providing little opportunity for sediments to accumulate.

Unit B, Soil 2, horizon IIAhb has a sharp lower contact with horizon Unit B, horizon IIBmb. Dr. Scott Hamilton of Lakehead University and Dr. Terry Gibson of Alberta Western Heritage have both suggested that Soil 2 may represent a cultivated layer; however, the land has never been cultivated (Alan Akre, landowner, communication with T. Gibson). The sharp lower contact may therefore indicate an erosive surface, on which very little sediment accumulated, followed by formation of Soil 2 (Figures 5.8, 6.6 and 6.7).

Land west of the Offsite profile has been cultivated, and Unit C may have accumulated as the result of sediment deposition by prevailing westerly winds subsequent to Euro-Canadian settlement of the area (Dr. Terry Gibson, Alberta Western Heritage).

6.1.3 Stratigraphic Interpretation

In non-coastal sand dune environments, there is a finite amount of sand; therefore, sediment deposition in one area requires erosion and transportation of sediments from another, resulting in discontinuous buried soil horizons. Fluctuations in aeolian activity at Bodo during the late Holocene resulted in recurring periods of sediment erosion and redeposition; therefore, there may be episodes of soil development that have no record in the study profiles. The discontinuous nature of Soil 3 in the South L2, Test Pit L2-9, and L19 profiles provides evidence of these cycles of aeolian erosion and sediment deposition at Bodo. The stratigraphy at Bodo suggests several possible scenarios regarding late Holocene local environmental conditions; three possibilities are illustrated in Figures 6.5-6.7.

Interpretation 1

Figure 6.5 depicts an interpretation (Interpretation 1) of the study profiles, based on what was observed in the field. Soils 1 and 2 are correlated between all five profiles, based on the observation that Soil 2 is consistently black, continuous, and is buried by Soil 1 at a relatively uniform depth across the Locality. Soil 3 is correlated between the South L2, Test Pit L2-9 and L19 profiles. The discontinuous nature of Soil 3 suggests that either aeolian erosion took place in the North L2 and Offsite profiles, or that Soil 3 simply did not form at these locations. A depositional hiatus, indicating landscape stability, is inferred where soils are observed in the study profiles. Otherwise, relatively continuous aeolian sediment accumulation in the profiles is assumed, indicating landscape instability.

Interpretation 2

Interpretation 2 (Figure 6.6) is similar to Interpretation 1, but with added radiocarbon dates. Soils 1 and 2 are again assumed to correlate throughout all of the study profiles. However, radiocarbon dates indicate that Soil 3 in the South L2 profile and Soil 3 in the Test Pit L2-9 profile do not correlate; the study profiles therefore document four episodes of soil formation at Bodo during the late Holocene. Soil 3 of the L19 profile may thus correlate with Soil 3 of either the South L2 or Test Pit L2-9 profiles. However, because they appear at similar depth (i.e. about 60-70 cm; Figures 5.1, 5.6, and 6.1), Soil 3 of the L19 and South L2 profiles are assumed in Interpretation 2 to be of the same age.

As noted in Section 6.1.2.5, Soil 2 of the Offsite profile has a sharp lower contact with the underlying sediments. The sharp contact indicates an erosive surface, where soil development previously took place (indicated by horizon IIBmb; Figure 5.8). As there are no dates associated with this erosive surface, the eroded soil (i.e. Soil 3 of the Offsite profile) could be of any age. However, the most parsimonious explanation is that the eroded soil is of the same age as Soil 3, Test Pit L2-9 (1070-920 cal. BP), the documented period of soil formation at Bodo that preceded the formation of Soil 2.

Interpretation 3

Interpretation 3 (Figure 6.7) correlates all sediment types and periods of soil formation documented in all of the study profiles. The glaciogenic clay loam (Stratigraphic Unit A) is only observed in the South L2, North L2 and Offsite profiles. However, Test Pit L2-9 (Figure 5.5) and the L19 profile (Figure 5.6) demonstrate gleying or mottling, which indicates repeated episodes of sediment saturation. A dense, fine-grained substrate, such as the clay-rich Unit A, is necessary to inhibit water infiltration, promote ponding, and saturate sediments in these profiles. Therefore, Unit A is inferred at the Test Pit L2-9 and L19 profiles, although this unit is located at depths beyond the reach of the augur.

The in situ bone from Unit C, South L2 profile (930-750 cal. BP) and the ventifacted bone fragments from Unit B, North L2 profile (1070-930 cal. BP) produced dates that roughly correspond with those obtained from artifacts within Soil 3 in the Test Pit L2-9 profile (1070-920 cal. BP). These dates, and the close proximity of the three study profiles in which they appear (i.e. within 60 m of each other), suggest that the period of soil formation documented by Soil 3 in the Test Pit L2-9 profile likely occurred at least throughout Locality 2. In addition, Soil 3 in the L19 profile (Figure 5.6) resembles Soil 3 of Test Pit L2-9 (Figure 5.5) in that it has no B horizon (unlike Soil 3 of the South L2 profile [Figure 5.1]); therefore, Soil 3 of the L19 profile may be the same age as that of Test Pit L2-9. Soil 3 is thus correlated between all of the study profiles (Figure 6.7).

Soil 4 (Figure 6.7) appears in the South L2 profile only. However, since Soil 4 dates to a period of regional soil formation (see Section 6.5.2.2 and Figure 6.10) and is the only palaeosol at Bodo with a B horizon, Soil 4 probably reflects a relatively prolonged, widespread episode of soil formation that was followed by a period of aeolian activity.

Soil 4 is correlated between all of the study profiles in Interpretation 3, to reflect this regional episode of soil formation (Figure 6.7).

Interpretation Summary

Stratigraphic Interpretation 1 illustrates the conclusions that can be drawn from field observations of the study profiles, and indicates three episodes of soil formation at Bodo. However, the addition of radiocarbon dates in Interpretations 2 and 3 reveals that four episodes of soil formation are recorded by the study profiles.

Interpretation 2 depicts the observable episodes of soil formation and radiocarbon dates associated with each of the profiles, and does not illustrate any assumptions regarding the regional extent of soil formation at Bodo. When limited to making interpretations based solely on data from the study profiles, Stratigraphic Interpretation 2 is the most parsimonious of the three interpretations presented in this thesis.

However, regional episodes of soil formation in the southern Canadian Plains are documented at approximately 2500 cal. BP and 1000 cal. BP (Section 6.5.2.2 and Figure 6.10), which correlate to Soils 3 and 4 (illustrated in Interpretation 3, Figure 6.7). Because the study area is relatively small (i.e. covers an area of about 1 km^2), it is unlikely that soil formation occurred in one area of the study and not another. In addition, discontinuous palaeosols are common in dune environments due to cycles of landscape stability and instability (Townley-Smith 1980; Wolfe et al. 2002a). The ventifacted artifacts in the North L2 profile and the sharp lower contact of Soil 2 of the Offsite profile are evidence of repeated episodes of erosion at Bodo. Therefore, erosion is the probable cause of the discontinuous nature of Soils 3 and 4, not an absence of soil formation at specific locations in the study area. Using a regional palaeoclimatic perspective, Stratigraphic Interpretation 3 correlates Soils 3 and 4 between all of the study profiles, and is thus the most likely of the three interpretations presented here.

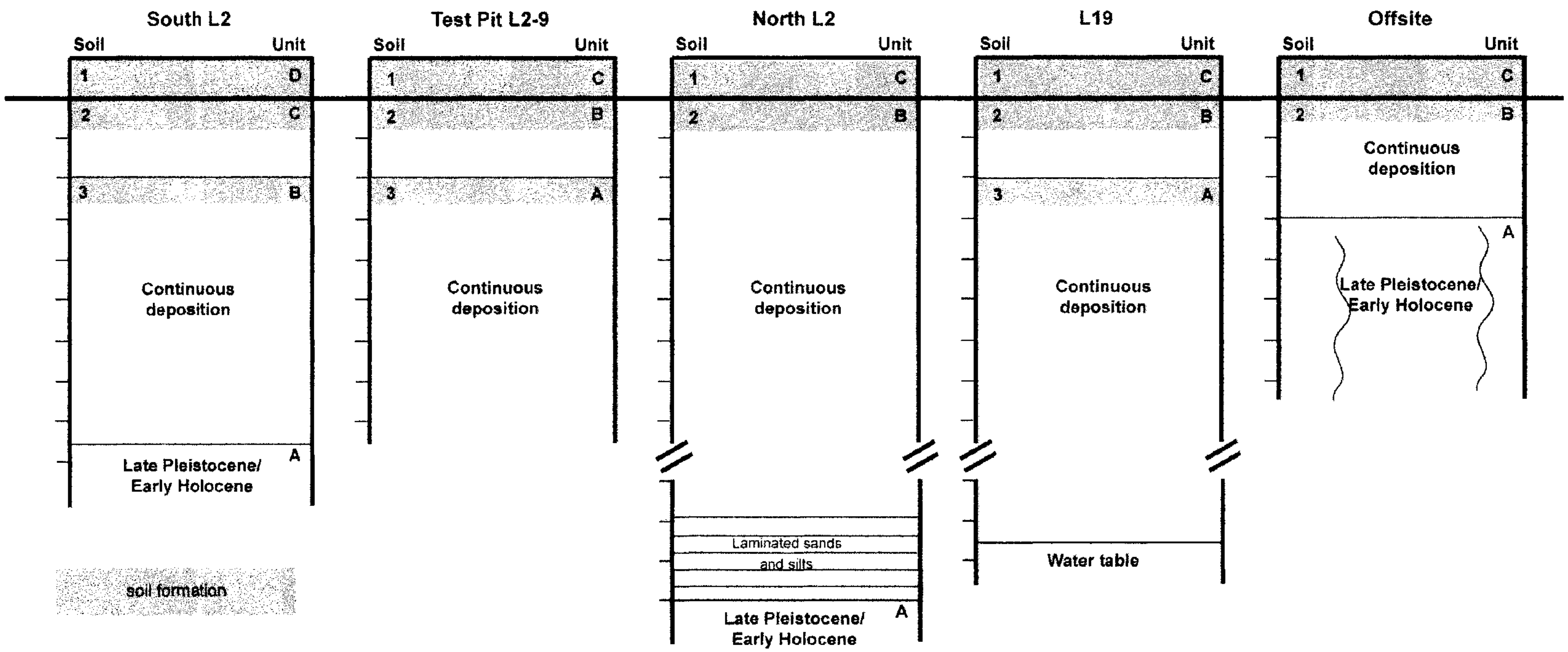

Figure 6.5. Stratigraphic Interpretation 1

Interpretation is based on what was observed in the field. Soils 1 and 2 are correlated between all five profiles, based on horizon morphology and uniformity of depth. Soil 3 is correlated between the South L2, Test Pit L2-9 and L19 profiles. Soil 3 is assumed to have either eroded from the North L2 and Offsite profiles, or not formed at these locations. A depositional hiatus (indicating landscape stability) is inferred where soils are observed in the study profiles; otherwise, relatively continuous aeolian sediment accumulation (landscape instability) in the profiles is assumed. Diagram not to scale.

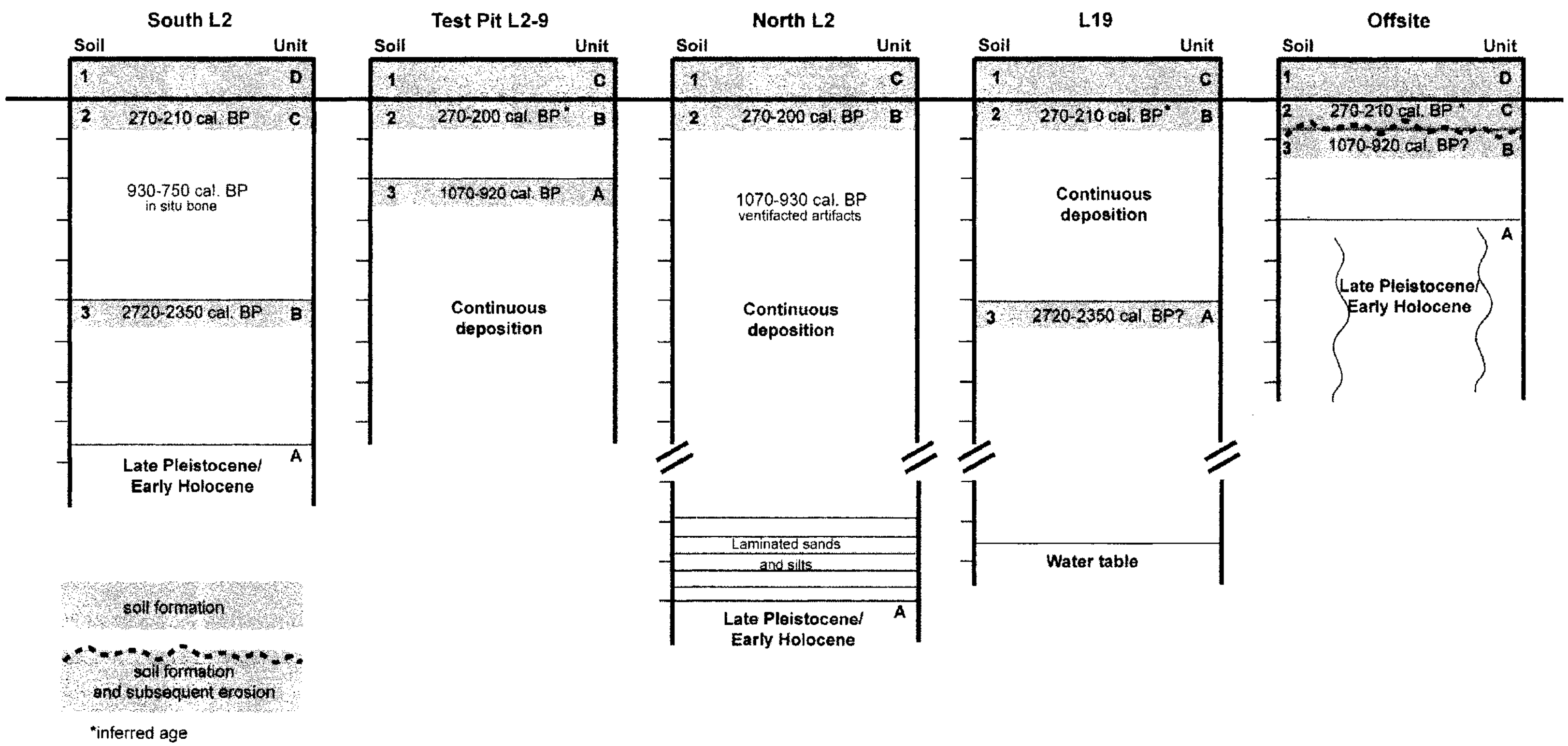

Figure 6.6. Stratigraphic Interpretation 2

Although Soils 1 and 2 correlate throughout all of the study profiles, radiocarbon dates indicate that Soil 3 in the South L2 profile and Soil 3 in the Test Pit L2-9 profile <u>are different</u>; the study profiles therefore document <u>four</u> episodes of soil formation at Bodo. Soil 3 of the L19 profile is interpreted to be of the same age as Soil 3 of the South L2 profile, based on their similar depths. The eroded soil (Soil 3) underlying Soil 2 of the Offsite profile is interpreted as being of the same age as Soil 3 of Test Pit L2-9 (1070-920 cal. BP). Diagram not to scale.

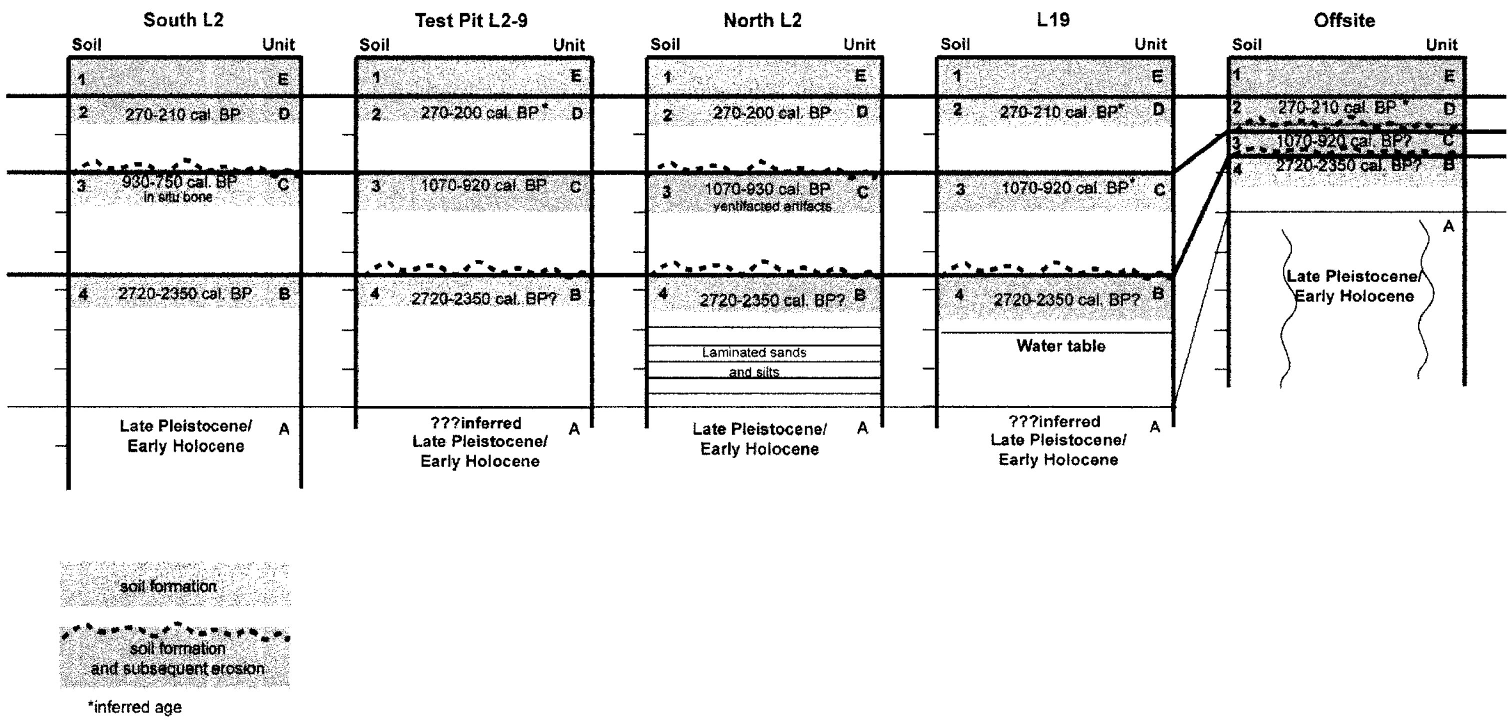

Figure 6.7. Stratigraphic Interpretation 3

All sediment types and periods of soil formation are correlated in all of the study profiles. The glaciogenic clay loam (Unit A) is inferred in Test Pit L2-9 and the L19 profiles, because sediment gleying and mottling in these profiles indicate that they have been repeatedly saturated, suggesting they are underlain by a dense, fine-grained substrate. As the in situ bone and ventifacted bones in the South L2 and North L2 profiles, respectively, have produced dates that roughly correspond to Soil 3 in Test Pit L2-9, Soil 3 is correlated between the three Locality 2 profiles. In addition, Soil 3 in the L19 profile lacks a B horizon and is morphologically similar to (and therefore correlated with) Soil 3 in Test Pit L2-9. Soil 4 appears in the South L2 profile only. However, Soil 4 dates to a period of regional soil formation (Figure 6.10); therefore, it was likely present at all study locations but was eroded in a subsequent episode of aeolian activity. Thus, Soil 4 is also correlated between all of the study profiles. Diagram not to scale.

6.2 SOIL CHEMISTRY

6.2.1 Organic Carbon and Carbonates

Levels of organic matter tend to decline rapidly down the profiles of sand dune soils (Epp and Johnson 1980), and this is also the case with the study profiles at Bodo. Organic content is highest in Soil 1 and Soil 2 of all four profiles, with secondary peaks in Soil 3 of the South L2 and L19 profiles.

The higher organic content of Soils 1, 2 and 3 likely reflects higher surface vegetation inputs. However, organic content of the palaeosols may also reflect anthropogenic inputs of bone, vegetable material and waste during human occupation of the site.

In the South L2 profile, Soil 1 shows increased organic content relative to Soil 2, probably because Soil 1 contains more unhumified plant tissues. All other profiles exhibit higher levels of organic carbon in Soil 2 relative to Soil 1. In the North L2 and L19 profiles, higher organic levels in Soil 2 could reflect anthropogenic inputs of bone, vegetable material and waste during occupation of the site. However, since the Offsite profile also shows increased organic content in Soil 2 relative to Soil 1, it is possible that Soil 2 supported denser vegetation throughout the study area, which explains the increased organic concentration. A colder climate during formation of Soil 2 may also explain the increased levels of organics, due to slower microbial decomposition. Organic matter may also be translocating from Soil 1 and accumulating in Soil 2 in the North L2, L19 and Offsite profiles.

The L19 profile has the lowest organic content of all the study profiles, probably because the coarser nature of the sediments allows better drainage, resulting in translocation of soluble organics through the profile, with increased losses to groundwater. In addition, the coarser sediments enhance aeration, increasing oxidation of organic matter, which may also explain lower levels of organics in the L19 profile.

Unit A of the South L2 and Offsite profiles also demonstrates elevated levels of organics. However, I experimented with clay firing temperatures during loss-on-ignition of the study profile sediments, and clay-rich sediment had lower amounts of organic content when fired at 375°C than at 550°C. The apparent elevated levels of organics in Unit A are therefore at least partially the result of water extruded from clay lattice during firing at 550°C. (see Boyle 2004; Heiri et al. 2001).

All stratigraphic units feature carbonate levels below one percent and are considered non-calcareous, except for Unit A of the South L2 and Offsite profiles. As Unit A consists of clay loam partly derived from marine bedrock (enriched in carbonates), the elevated levels of carbonates are expected. The slight rise in carbonate concentration in Unit A of the L19 profile is likely due to groundwater deposition and capillary action.

6.2.2 Total Carbon and Total Nitrogen

Carbon and nitrogen levels are closely linked to organic content because of their importance for the manufacture and maintenance of living cells. Total C levels reflect the combined carbonate and organic carbon concentrations in soil horizons, therefore increased levels of total C in all of the study profile soils relative to other horizons are due to increased organic input at the soil surfaces. Total N levels follow a pattern similar to total C.

The C:N ratio is based on the relative amounts of total C and total N in the soil. All of the study profiles average C:N ratios slightly lower than 12:1. C:N ranges are within the range of the average agricultural soil, and are within the optimal range for microbial decomposition of organic material (i.e. below 25:1). Therefore, with the exception of Unit A, horizon IIICcab (27:1), there is enough nitrogen in the soil to meet the needs of both microbes and plants (Brady and Weil 2002).

The C:N ratio is elevated in Unit B, horizon IICbg2 of the L19 profile, correlating with higher total C levels in this horizon, which may represent increased groundwater deposits and a capillary effect drawing carbon up from the lower palaeosol. Unit A, horizon IIICcab of the Offsite profile has an elevated C:N (27:1), due to the high levels of carbonates (4%) in the horizon.

6.2.3 Total and Extractable Phosphorus

The Offsite profile has low amounts of total and extractable P relative to other profiles, except for the L19 profile, discussed below. Soils 1 and 2 of the Offsite profile exhibit higher levels of total and extractable P than other horizons within the profile, reflecting increased inputs of P from vegetation. The dramatic drop in extractable P relative to total P in Unit A of the Offsite profile is probably due to the higher pH and increased presence of Ca^{2+}, which fixes soluble P compounds, making them unavailable for plant uptake (see Section 3.2.3) (Brady and Weil 2002).

Total and extractable P levels are elevated in Soil 2 of the South L2, North L2 and L19 profiles, reflecting increased anthropogenic inputs, especially of bison bone. Soil 2 of the North L2 profile contains a dense bone deposit, which is the likely cause of elevated total and extractable P levels relative to Soil 2 of the other study profiles.

In this study, variations in total and extractable P concentrations within and between profiles do not follow the same pattern (Figures 6.8 and 6.9). For instance, extractable P levels are consistently higher throughout the archaeological profiles relative to the Offsite profile (Figures 5.11-5.14 and Figure 6.9). However, total P levels are elevated in the South L2 and North L2 profiles relative to the L19 profile, which on average has lower total P than the Offsite profile (Figure 6.8). One possible explanation is that the archaeological profiles are located in areas with denser and more varied vegetation than the Offsite profile, and are naturally enriched in extractable P through increased organic inputs. A more likely explanation is that anthropogenic inputs of P during occupation of the site effectively saturated all

P-fixation sites. The resulting excess of P in solution was then distributed P throughout the archaeological profiles. The situation at L19 supports this explanation, as it has lower levels of total P, but higher levels of extractable P than the Offsite profile. However, L19 also has very low levels of carbonates and Ca^{2+} compared to the Offsite profile, therefore there is less opportunity in the L19 profile for Ca^{2+} to combine with soluble P to produce insoluble P compounds. Lower levels of total P in the L19 profile relative to the other three profiles may therefore also reflect the lower carbonate and Ca^{2+} content of the L19 sediments.

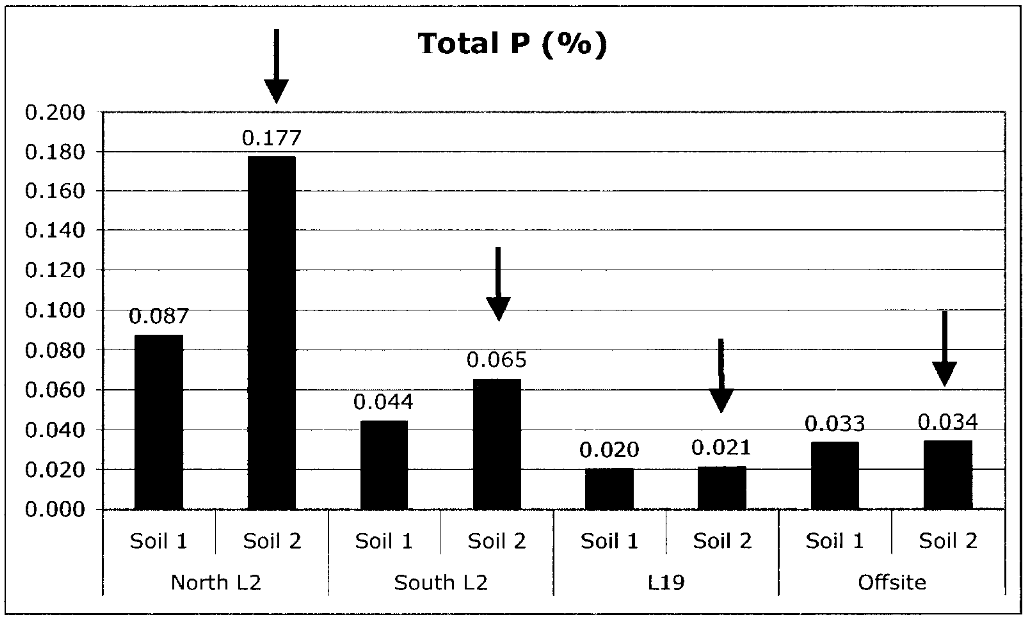

Figure 6.8. Total Phosphorus Results for Soils 1 and 2

In the North L2 and South L2 profiles, total P is significantly elevated in Soil 2 (indicated by the arrows) relative to Soil 1, reflecting anthropogenic inputs to Soil 2. However, the L19 profile does not demonstrate elevated total P levels in Soil 2 relative to Soil 1. In addition, the L19 profile has lower levels of total P relative to the Offsite profile, therefore total P is not a reliable indicator of human occupation at Bodo.

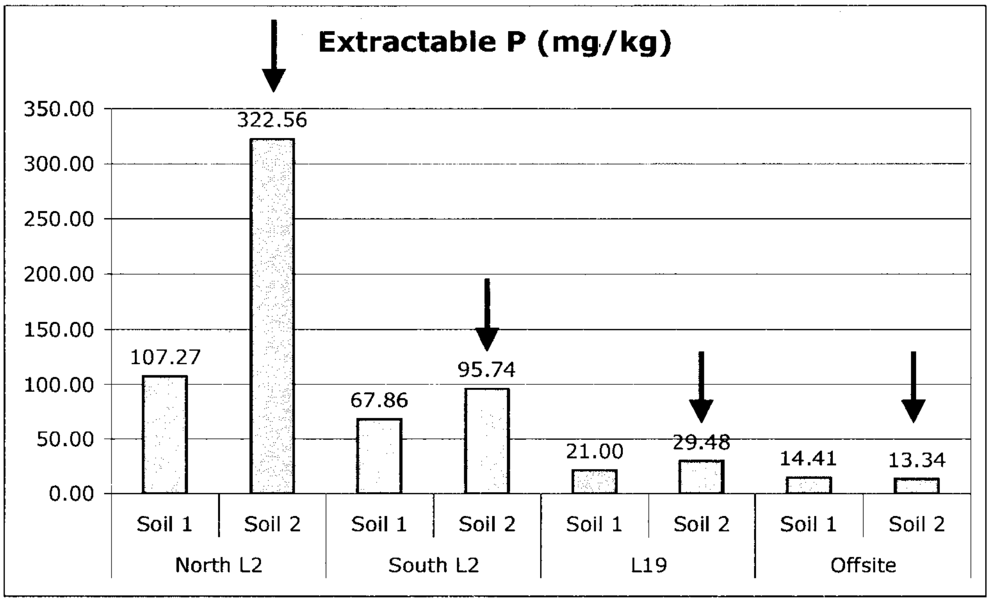

Figure 6.9. Extractable Phosphorus Results for Soils 1 and 2

Extractable P is consistently elevated in the archaeological profiles (i.e. North L2, South L2 and L19) relative to the Offsite profile. In addition, Soil 2 (indicated by the arrows) demonstrates elevated extractable P relative to Soil 1 in all archaeological profiles, reflecting anthropogenic inputs to Soil 2. In the Offsite profile, Soils 1 and 2 have similar levels of extractable P. Extractable P is therefore a better indicator of human occupation at Bodo than total P.

6.2.4 CEC and Available Cations

The South L2, North L2 and L19 profiles all exhibit increased CEC levels in the Ah horizons of all soils relative to other horizons. This is expected, because soil Ah horizons contain higher organic concentrations, which enhances CEC. CEC is highest in Unit A of the South L2 and Offsite profiles, probably due to the high clay content of the sediment, which also increases CEC. The remaining horizons of all units within all profiles have a CEC of approximately 2 $cmol_c/kg$; this is consistent with the CEC of quartz and feldspars, which form most of the sediment at the site (Birkeland 1999).

As expected, Ca^{2+} is the most abundant cation throughout all profiles[50]. Na^{+} is the least abundant and variable cation analyzed, and the slightly elevated levels occurring in Unit A of the South L2 and Offsite profiles are likely due to concentrations inherited from the till. Ca^{2+}, K^{+} and Mg^{2+} levels tend to fluctuate more throughout the South L2, North L2 and L19 profiles compared to the Offsite profile. Increased levels of these three cations are present in the soils of all three archaeological profiles, which may partially reflect anthropogenic inputs of bone and other organic deposits. However, as the Offsite profile also shows an increase in Ca^{2+} in Soil 2 relative to Soil 1, the more probable cause for fluctuations in available cations throughout the archaeological profiles is simply that these horizons have higher CEC due to increased organic content, therefore they have increased levels of exchangeable cations.

In this study, the sum of the total available cations is consistently elevated compared to CEC. There are two possible explanations for this:

1. Some non-exchangeable soil elements such as $CaCO_3$ and $CaS0_4$ (calcium sulfate) may have dissolved in the solutions used during CEC analysis, resulting in increased measurement of available cations relative to CEC (Dr. Jim Robertson, Department of Renewable Resources, University of Alberta, pers. comm.).

2. The final KCl solution may not have displaced all of the NH^{4+} from the cation exchange sites during analysis, resulting in measurement of only part of the total CEC (Dr. Jim Robertson, pers. comm.).

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[50]The clay loam till is enriched in Ca^{2+}, therefore sediments derived from till will have Ca^{2+} as a major component. Also, the Bodo Archaeological Locality is in the Dark Brown Chernozemic soil zone, indicating that most soils in the region will have Ca^{2+} as the dominant cation (Soil Classification Working Group 1998).

Both situations may be responsible for the discrepancy, however given that Ca^{2+} concentrations are almost always higher than CEC levels in the samples, the most likely explanation is that some of the small amount of $CaCO_3$ present in the samples dissolved in the analyzing solutions, resulting in increased measurement of exchangeable cations relative to CEC. The effect is particularly pronounced in the IIICcab horizon of Unit A of the Offsite profile.

6.2.5 pH and Electrical Conductivity

The pH of Soils 1 and 2 of all profiles but the North L2 is slightly acidic, at 6 or below. These pH levels likely reflect the acidic nature of the quartz sand, as well as organic acid production during humification processes in the upper soil horizons. The release of H^+ ions during N oxidation and cation exchange may also contribute to slightly acid pH values in Soils 1 and 2 (Birkeland 1999). Ash from a hearth within Soil 2 of the North L2 profile may be responsible for the elevated pH of the palaeosol relative to other profiles (Brady and Weil 2002; Glaser et al. 2002). Unit A, horizon IIICcab of the Offsite profile has the highest pH at 7.3, due to the increased presence of $CaCO_3$ in the parent material, which has an alkaline effect.

Electrical conductivity results demonstrate that Soil 1 of the South L2 profile has the highest average concentration of dissolved salts in solution. These salts have accumulated in Soil 1, probably as a result of insufficient leaching down through the South L2 profile (Brady and Weil 2002). L19 likely has the lowest levels of conductivity because of losses to groundwater due to the coarse, well-drained nature of the sediments. All soil profiles are classified as non-saline based on their electrical conductivity values (Canarache et al. 2006: 737).

6.2.6 Summary

The potential for loss of C and N through leaching in soil solution make these soil components unreliable detectors of past human activities, and because total P varies from profile to profile, it is best used for within-profile comparisons. However, extractable P is a particularly sensitive tool for detecting occupation layers within soil profiles as well as detecting archaeological versus non-archaeological areas. There is therefore potential for use of extractable P as a prospecting tool when determining archaeological site boundaries, or as a prospecting tool when looking for site activity areas.

6.3 MICROMORPHOLOGY

Sanborn and Pawluck (1989) examined the micromorphological properties of Chernozemic Ah horizons[51] from Alberta and British Columbia. These Ah horizons feature humus forms that differ from the spongy mull humus[52] typical of many European Chernozems. In particular, Sanborn and Pawluck (1989) found that Ah horizons formed on sandy loam sediments in Alberta had a 'silicate moder' type of humus[53]. Silicate moder is characterized by minimal formation (or a complete lack) of organic aggregates, and is composed primarily of microfaunal excrements, unhumified and partially humified plant tissues, and mineral grains (Kubiëna 1970).

6.3.1 Soil 3, South L2 Profile

Soil 3 of the South L2 profile features occasional randomly distributed aggregates composed of humified plant material, microfaunal excrements and mineral grains

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[51] Properties of Chernozemic A horizons include the following: a thickness of at least 10 cm; organic C content between 1-17%; C:N ratio less than 17; neither massive or single-grained structure when dry; Ca is the predominant exchangeable cation; and restricted to regions dominated by a drier than humid moisture regime, in which the mean annual temperature is higher than 0°C (Soil Classification Working Group 1998).

[52] Mull is a form of humus in which the organic and mineral fractions have been bound together by soil microfauna, especially earthworms. The organic matter is very stable because it has been well-humified, and there is little to none left for transformation into humus. Earthworms are essential in creating the spongy structure of mull, which appears as loose aggregates of mineral and organic material with many pores and interconnected voids (Canarache et al. 2006; Kubiëna 1970).

[53] Moder is a form of humus that contains incompletely humified organic matter, which has not been completely incorporated with the mineral fraction as in mull. Moder is usually the product of the decomposition of organic material by soil fauna such as arthropods, and fungi (Canarache et al. 2006).

These aggregates resemble Kubiëna's (1970) silicate moder humus, although some aggregates approach a 'mull-like moder' form[54].

Soil 3 has developed organo-mineral accumulations, which are stable complexes of clay, organics, and Al and Fe hydroxides (Brady and Weil 2002). Organo-mineral accumulations are formed during intense (e.g. under warmer, wetter climatic conditions) or prolonged periods of pedogenesis. Therefore, Soil 3 of the South L2 profile formed under different conditions or over a longer period of time than Soil 1 or Soil 2 (Ian Simpson, School of Biological and Environmental Sciences, University of Stirling, pers. comm.).

6.3.2 Soil 2, North L2 Profile

The distribution and loose arrangement of microfaunal excrements, plant tissues and quartz and chert grains in Soil 2 of the North L2 profile is consistent with Kubiëna's (1970) silicate moder humus (Sanborn and Pawluk 1989). Soil 2 contains a higher proportion of fresh plant tissues and less humified organic material than Soil 3 of the South L2 profile; this difference reflects the more recent formation of Soil 2 of the North L2 profile.

The most noticeable features in the Soil 2 thin section are the anthropogenic charcoal, bone fragments, pottery and lithic. The pottery fragment in the sample contains approximately the same amount of fine clay and silt as it does fine to coarse quartz grains. Quartz grains and fresh plant tissues were added to the clay and silt as clay temper. The vesicular chert, mudstone or obsidian fragment is a unique lithological type in the groundmass, and is obviously foreign to the sample. Given its very fine-grained nature, this lithic type is ideal for stone tool manufacture and the fragment probably represents microdebitage from flintknapping activities at this location.

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[54] Mull-like moder is characterized by the formation of aggregates, however humification of plant materials is incomplete, and the organic and mineral fractions have not been bound together as intimately as in mull. Decomposition of organic material is largely due to soil fauna such as arthropods (Canarache et al. 2006; Kubiëna 1970).

6.3.3 Summary

The distribution and composition of the mineral and organic fractions of Soil 3 of the South L2 profile and Soil 2 of the North L2 profile are almost identical. In addition, both samples have silicate moder humus, and a similar distribution of coatings on mineral grains. These properties demonstrate that the soils were formed in similar parent materials and had comparable inputs of organics, aside from the anthropogenic charcoal and bone in Soil 2 of the North L2 profile. However, Soil 3 of the South L2 profile contains organo-mineral accumulations, which indicate that different pedogenic processes have acted on the two soils.

6.4 MICROBIAL PLFA ANALYSIS

Microbial PLFA analysis was performed on samples from the surface soil (Soil 1) and Soil 2 of the South L2, North L2 and Test Pit L2-9 profiles, as well as on samples taken from the upper 5 cm of soil from the Offsite location.

It was expected that the total microbial community in Soil 2 would be unique and distinct from the microbial communities in Soil 1 and the Offsite samples, due to anthropogenic inputs and disturbance during the Late Precontact occupation. However, the total PLFA distribution demonstrates that the Soil 1 microbial community is distinct from that of Soil 2 and the Offsite samples, which are similar to each other. in addition, Soil 2 of the North L2 profile incorporated dense deposits of bone and had a greasy texture, such that the microbial community at the North L2 profile was expected to be unique, compared to Soil 2 in the other study profiles. However, the total microbial community of Soil 2, North L2 was similar to Soil 2, South L2; therefore, the bone bed and greasy-feeling soil had a minor effect on the microbial community structure.

The significant differences between the Soil 1 and Soil 2 total microbial PLFAs may be due to the fact that Soil 2 is a buried horizon. Soil 2 therefore experiences environmental conditions, such as soil temperature, air, or moisture conditions, which provide a different habitat for microbes than Soil 1 (Dr. Sylvie Quideau, Department of Renewable Resources, University of Alberta, pers. comm.). However, the microbial community of Soil 1 is also significantly different from the Offsite soil, from which samples were taken at or near the surface. Differences between Soil 1 and the Offsite samples therefore cannot be due to burial of the Offsite soil, but may reflect other environmental conditions, such as the increased elevation and exposure of the Offsite soil to aeolian forces.

The Gram (+) communities of the samples show significant differences between Soil 1, Soil 2 and the Offsite samples. The Gram (±) community is particularly sensitive to land use disturbance, which may explain variations in the Gram (+) community between samples (Fraterrigo et al. 2006). Examples of disturbance at the archaeological site during occupation include clearing brush in preparation for occupation construction or as fuel in food preparation, or sediment trampling during daily activities.

Of the nine PLFAs with high indicator values, eight were found predominantly in the Soil 1 samples, suggesting that the microbial community in Soil 1 is strongly influenced by specific soil properties or environmental conditions, which have yet to be determined (Table 5.11). Two of the PLFAs with high indicator values for Soil 1 are biomarkers for Gram (-) microbes, which are sensitive to land disturbance; the Gram (+) communities are also significantly different between all three soils. Therefore, patterns of disturbance in the study area may exert a considerable influence on the microbial community at the site.

6.4.1 Summary

PLFA analysis is a potential tool for detecting areas of disturbance (and therefore human activity) within archeological sites. However, more research needs to be done, comparing microbial PLFA characteristics in controlled archaeological samples with characteristics of non-archaeological samples, in order to determine whether this method is of use for addressing archaeological questions.

6.5 INTERPRETATION OF RESULTS

Radiocarbon dates and archaeological dating through pottery and projectile point typologies indicate that the stratigraphy of the study profiles largely reflects late Holocene geological, pedological and archaeological processes. A regional Holocene palaeoclimatic summary is constructed from a variety of published proxy data (Figure 6.10), to provide the basis for discussion of the history of the archaeological site within the late Holocene.

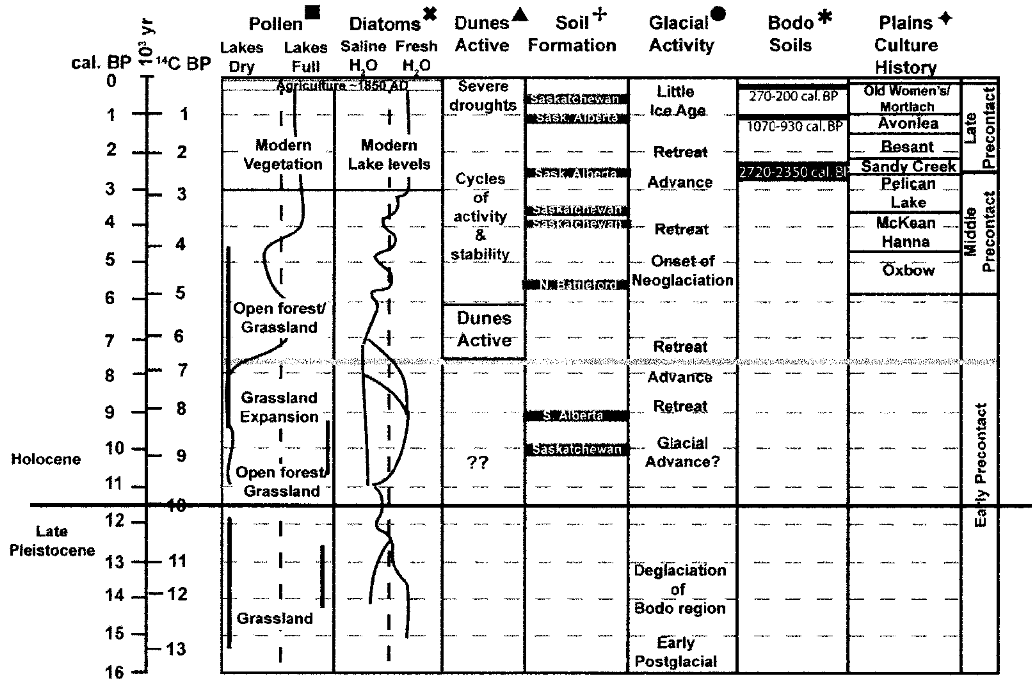


Figure 6.10. Regional Palaeoclimatic Summary

Several lines within the pollen and diatom categories represent evidence from multiple studies. These data point to different palaeoenvironmental conditions, influenced by local and regional climatic fluctuations. Light grey line indicates Mazama tephra deposition, approximately 6800 ^{14}C yr BP. Only the phases in Plains culture history mentioned in the text are illustrated here. Compiled from the following previously published sources: ■=Beaudoin and Oetelaar 2003; Hickman and Schweger 1993, 1996; Sauchyn and Beaudoin 1998; Schweger and Hickman 1989; Vance et al. 1995 ✖= Beaudoin and Oetelaar 2003; Hickman and Schweger 1993, 1996; Muhs and Wolfe 1999; Sauchyn and Beaudoin 1998; Schweger and Hickman 1989; Vance et al. 1995 ▲=Sauchyn and Beaudoin 1998; Wolfe et al. 2002a, b; 2006 ✢=Hopkins and Running 2000; Waters and Rutter 1983; Wolfe et al. 2002a, b, 2006 ●=Dyke et al. 2003; Luckman et al. 1993 ✱=this study ✦=Dyck and Morlan 1995; Peck and Hudecek-Cuffe 2003; Vickers 1986; Wettlaufer 1955.

6.5.1 Regional Climatic History

6.5.1.1 Early and Middle Holocene

Very little geomorphological evidence of early Holocene dune activity survives on the northern Great Plains. However, Wolfe et al. (2006) have documented dune activity at the Nisbet and Fort à la Corne Sand Hills in south-central Saskatchewan to before 11,000 cal. BP. This dune activity was followed by a stable period, indicated by palaeosol development, between 9500-7500 cal. BP. Dune activity resumed during the middle Holocene between 7500-4800 cal. BP, in many cases reworking early Holocene aeolian sediments. Local and regional environmental conditions influenced landscape stabilization, and soil development occurred at different times in different regions. For example, a palaeosol indicating an interval of middle Holocene stability developed on the North Battleford Sand Hills, Alberta about 5600 cal. BP. Middle Holocene soil development occurred between 4600-3300 cal. BP in south-central Saskatchewan (Wolfe et al. 2002b).

6.5.1.2 Late Holocene

Aeolian activity during the late Holocene reworked early and middle Holocene sediments, obliterating most of that early palaeoclimatic record. The late Holocene was characterized by alternating periods of landscape stability and instability, controlled by a combination of local and regional climatic fluctuations. These fluctuations are often preserved in the stratigraphic record, however correlating regional aeolian chronologies can be difficult, as horizons are often missing or discontinuous (Townley-Smith 1980; Wolfe et al. 2002a).

Vegetation patterns had reached their modern distribution in Alberta by about 3000 cal. BP (Sauchyn and Beaudoin 1998; Hickman and Schweger 1993, 1996; Schweger and Hickman 1989). The period between 3000-2000 cal. BP was also characterized by increased humidity, in which groundwater levels reached their peak and freshwater lakes were at optimum levels (Sauchyn and Beaudoin 1998). The 3000-2000 cal. BP interval was also a period of widespread regional soil development, documented in palaeosols throughout the northern Great Plains (see Hopkins and Running 2000; Wolfe et al. 2002a, b, 2006).

Landscape instability and aeolian activity increased in east-central Alberta and west-central Saskatchewan following 2000 cal. BP, interrupted by an episode of soil development between 1400-1000 cal. BP. Over the past 1000 years, recurring severe and prolonged droughts have resulted in repeated cycles of landscape instability and aeolian activity alternating with periods of local and regional soil formation. A period of widespread soil development between 980-400 cal. BP indicates a significant episode of landscape stability at the beginning of the Little Ice Age advance in the Canadian Rockies (Hopkins and Running 2000; Luckman et al. 1993; Wolfe et al. 2002a, b, 2006).

6.5.2 Holocene Climate and Human Occupation of the Bodo Sand Hills

6.5.2.1 Early and Middle Holocene

Sand hill environments on the northern Great Plains are characteristically abundant in resources, which have attracted humans since the early Holocene (Epp and Johnson 1980). Especially during more humid climatic episodes, the environment in and around sand hills provides habitats for a diverse array of plant and animal species, such as herbs, berries, wood for shelter and fuel, and game animals like bison, elk, antelope and deer. Wooded areas in sand hills and nearby parklands provide shelter and wintering grounds for antelope. In the past, these would have hosted bison as well, and the animals may have been available almost year-round (Epp and Johnson 1980; Vickers and Peck 1994). Stabilized sand hill environments provide relatively well-drained sites for habitation, while the interdune low-lying areas host permanent or ephemeral ponds and wetlands that fill rapidly during humid periods. The low concentrations of dissolved solids in the groundwater means that water in these areas is relatively fresh. In addition, the undulating topography of the sand hills provides excellent opportunities for surveying the plains below for bison herds, and for trapping the animals in communal kills (Epp and Johnson 1980; Vickers and Peck 1994).

Surface finds of Oxbow, McKean and Hanna projectile points indicate the first human occupation of the Bodo Archaeological Locality took place during the middle Holocene. However, stratigraphic analysis at Bodo suggests that repeated episodes of aeolian activity during the late Holocene have resulted in reworking of early and middle Holocene sediments. As only a small portion of the site has been explored, more stratigraphic work is needed at the Bodo Archaeological Locality for the discovery of in situ early and middle Holocene deposits.

6.5.2.2 Late Holocene

The stratigraphic record of the study profiles within the Bodo Archaeological Locality reflects regional late Holocene climatic patterns tempered with local conditions. The soil numbers (i.e. Soil 1, 2 or 3) and stratigraphic units in this discussion refer to the observed soils and sediments in the study profiles as illustrated in Stratigraphic Interpretation 2 (Figure 6.6).

The bison tooth from Unit B, Soil 3 of the South L2 profile provides a minimum date of soil formation to between 2720-2350 cal. BP, which corresponds to a period of widespread soil development throughout the northern Great Plains (Figure 6.10). The tooth is associated with the earliest in situ evidence of human occupation at Bodo. This human occupation occurred during a period of increased humidity and elevated groundwater levels, and the Bodo region likely featured abundant surface water resources as well as flourishing vegetation and animal species. Artifacts Unit B in the South L2 profile are not diagnostic; however, projectile points found within Unit B of the North L2 and L19 profiles suggests a Sandy Creek occupation, which would be congruent with the South L2 Unit B, Soil 3 date (Dyck and Morlan 1995; Dr. Terry Gibson, Alberta Western Heritage, pers. comm.; Wettlaufer 1955).

Warmer, drier climatic conditions increased in the region after 2400 cal. BP, resulting in declining lake and groundwater levels, reduced vegetation, and landscape instability due to increased aeolian erosion. There is no geochronological or stratigraphic evidence of either soil development or human occupation at the Bodo Archaeological Locality between approximately 2400-1100 cal. BP, either because people did not occupy the area or because subsequent erosion has erased evidence of human habitation.

The L19 profile has no associated chronometric dates; however, Soil 3 can tentatively be assigned to the same soil-forming period as Soil 3 of the South L2 profile, given that both soils are located at a similar depth and are formed on aeolian sediments (Figure 6.6). However, the observable properties of Soil 3 in the L19 profile resemble Soil 3 in Test Pit L2-9, and therefore may date to about 1000 cal. BP (Figure 6.7). Bone in Soil 3 of the South L2 and L19 profiles is unsuitable for radiocarbon dating, and future research should focus on alternative geochronometric techniques, such as optical dating of sediments (Huntley and Lian 1999; Lian et al. 2002).

Artifacts in Soil 3 of Test Pit L2-9 provide evidence for human occupation of Bodo between 1070-920 cal. BP, near the end of a period of widespread regional landscape stability (Figure 6.10) (Wolfe et al. 2002b, 2006). Bone fragments from Unit B of the North L2 profile are also dated to 1070-930 cal. BP; however, they are likely out of primary context, and may represent natural inputs of bone (see section 6.1). In addition, in situ bone dated from the South L2 profile roughly correlates with the formation of Soil 3 in Test Pit L2-9 (930-750 cal. BP), although aeolian activity has since obliterated the soil record from the South L2 profile. Avonlea and Prairie Side-Notched projectile points have been recovered from Unit B of the North L2 profile, providing typological evidence of human occupation between 1500-250 cal. BP (Peck and Huducek-Cuffe 2003). Over the past 1000 years, recurring severe droughts caused local and regional landscape instability, which left behind only a remnant of the 1000-year-old palaeosol in Test Pit L2-9 (Figures 6.6 and 6.7).

Bone from Soil 2 of the South and North L2 profiles provides a minimum date of soil formation of 270-200 cal. BP, coinciding with maximum Little Ice Age advance in the Canadian Rockies (Luckman et al. 1993). These artifacts and others dated during previous research indicate soil formation and human occupation of the Bodo Archaeological Locality between 500-200 cal. BP (Blaikie 2005; Grekul 2007). Plains Side-Notched projectile points and pottery support Old Women's and Mortlach Phase occupations during this time. The dense concentration of artifacts within Soil 2 suggests that a relatively large population inhabited the area repeatedly or for a prolonged period (Gibson 2004b). The presence of horse bones and iron point fragments at PL1, FaOm-1, as well as other early historic artifacts such as trade beads suggests that human occupation of the Bodo Archaeological Locality extended into the Protohistoric period of Alberta Plains prehistory.

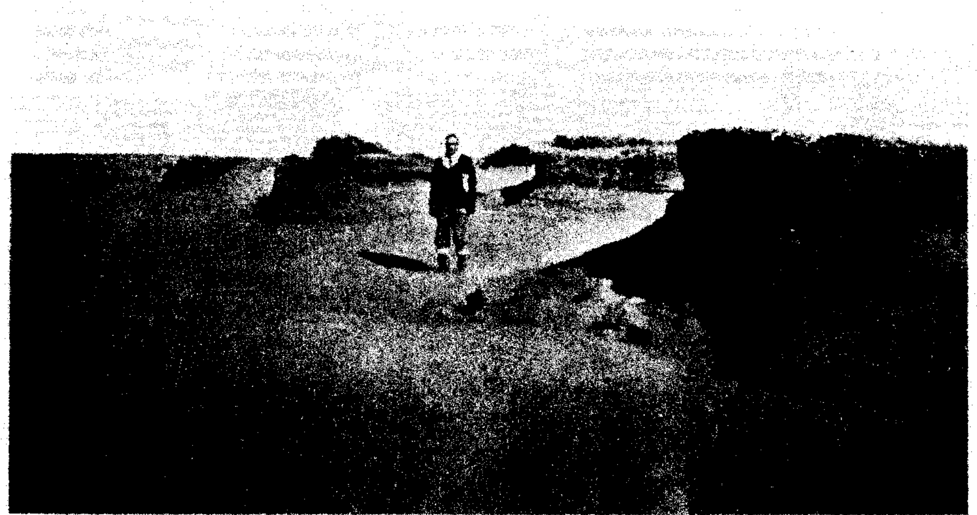
The intact, continuous nature of Soil 2 throughout the archaeological site suggests that the sediments burying Soil 2 were not eroded and transported from local sources, but were transported from outside the boundaries of the Bodo Archaeological Locality. Regional landscape destabilization occurred in some areas of the northern Great Plains during the severe drought in the late 1700s AD, destabilizing sand dune areas and exposing sediment for transport. For example, the Great Sand Hills of Saskatchewan southeast of Bodo were activated during the late 1700s AD, and may have been the source of aeolian sediment that buried Soil 2 (Wolfe et al. 2002a).

An alternative explanation is that agricultural practices in the Bodo region during the late 1800s and early 1900s AD induced land destabilization (Wyatt et al. 1938). Tilling and removal of vegetation through grazing destabilized land surfaces, and subsequent droughts in the early 1900s further increased the susceptibility of the sediments to aeolian erosion. Sauchyn and Beaudoin (1998) have suggested that the conversion of Prairie grasslands to farmland on the southern Canadian Plains drastically affected the ability of formerly stable land surfaces to withstand drought and erosion. Cores from Prairie lakes record increases in sedimentation following the introduction of agriculture into the area, about 1880 AD (Sauchyn and Beaudoin

1998). In addition, the Sullivan Lake soil survey (Wyatt et al. 1938) documents extreme erosion of sediment and soils southwest of Bodo, near the plains surrounding the Neutral Hills (Figure 6.11) (Tony Brierley, Alberta Soil Survey, pers. comm.). As most of the Bodo Archaeological Locality and associated Offsite profile area have never been tilled, Soil 2 was likely protected by vegetation during this most recent period of aeolian activity. Soil 1 at Bodo thus could represent an historic accumulation of sediment, of anthropogenic origin.

Archaeological evidence of sedimentation within the Bodo Archaeological Locality during the historic period exists in Test Pit L71-04-5, located in an interdune area containing a perennial water hole in FaOm-1 Locality 71 (Figure 2.14). This test pit revealed a tin can buried approximately 10 cm below the modern surface (Figures 6.12 and 6.13).

The stratigraphy of FaOm-1 Locality 71 is slightly different from the study area that is the focus of this thesis; however, the tin can was excavated from 10-15 cm depth, and was situated above a palaeosol located at 15-20 cm depth. Archaeological and stratigraphic evidence from the test pit suggests that at least the top 10 cm of sediment in Locality 71 accumulated during the 20th century, and that the surface soil is not only anthropogenic in origin, it contains historic artifacts. The conversion of the prairie surrounding the Archaeological Locality into farmland during the early part of the 20th century is a probable cause for landscape instability and subsequent aeolian activity, which ultimately resulted in deposition of the surface sediments at Bodo.



Wyatt et al. (1938: Figure 3)

Figure 6.11. Soil Erosion near the Neutral Hills, circa 1935.

This field was once cultivated. Reproduced with permission, Tony Brierley, Alberta Soil Survey. From Wyatt et al. (1938).

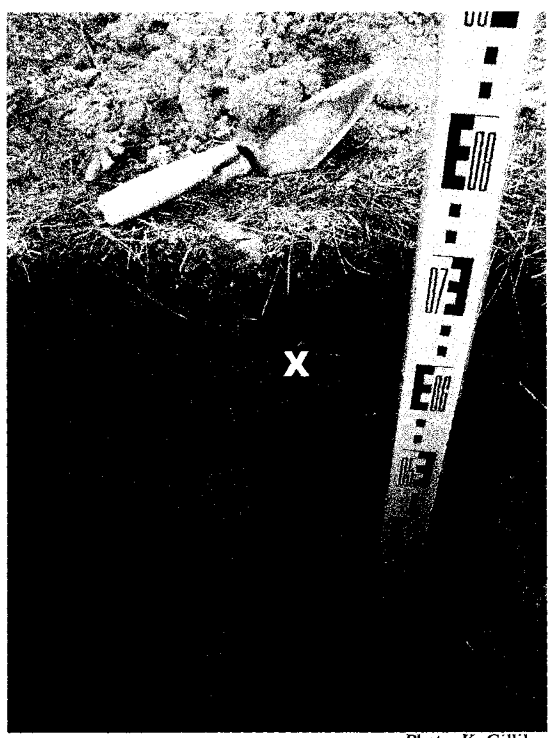


Photo: K. Gilliland

Figure 6.12. Stratigraphy of Test Pit L71-04-5, Locality 71, FaOm-1

The tin can was located approximately 10 cm below the modern surface, as indicated by the 'X'. Squares on the scale indicate centimeters.

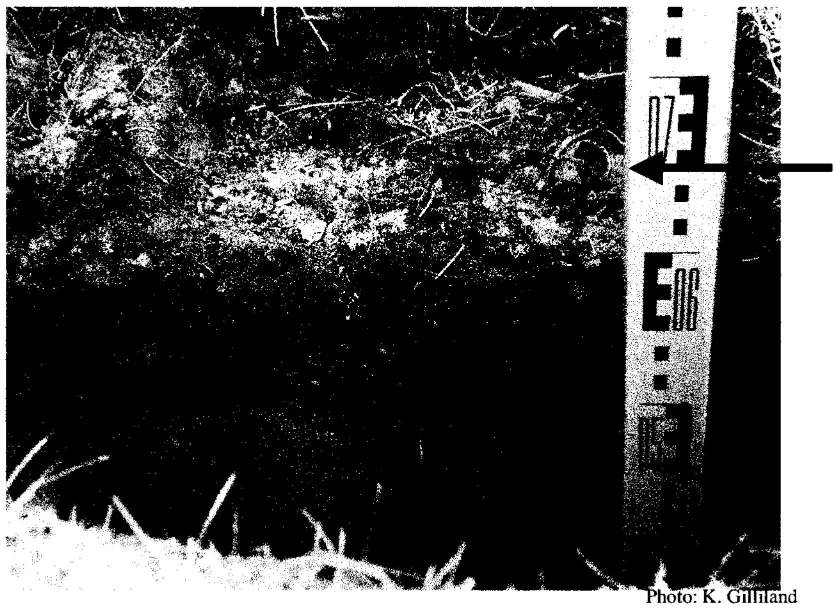


Photo: K. Gilliland

Figure 6.13. Historic Artifacts in Test Pit L71-04-5, FaOm-1

The tin can indicated by the arrow is buried approximately 10 cm below the modern surface, suggesting that at least the top 10 cm of sediments accumulated during the 20th century. Squares on the scale indicate centimeters.

CHAPTER 7: CONCLUSION

The sediments and soils investigated as part of this thesis provide a record of the geological, pedological and archaeological history of the Bodo Archaeological Locality since the late Pleistocene. Documenting the properties of the sediments and soils therefore provides a detailed picture of environmental fluctuations during the period of human occupation.

This thesis answers the following two questions:

1. What does the stratigraphy suggest about cultural and environmental factors of soil formation at Bodo?

The North L2, South L2 and Offsite profiles are composed primarily of aeolian sediments, which sit unconformably on till. The high water table, gley colors and iron mottling in the L19 profile indicates that water infiltration at this location is prevented by a clay-rich substrate, therefore the aeolian sediments in the L19 profile are also likely underlain by till.

Stratigraphic analysis documents the key role of local and regional climatic oscillations in soil formation and preservation since the late Pleistocene. Early and middle Holocene sediments were reworked by recurring cycles of aeolian activity during the late Holocene, resulting in discontinuous pockets of palaeosols, which are seen in the South L2, Test Pit L2-9 and L19 profiles.

The study profiles document four episodes of soil formation at Bodo during the late Holocene. The oldest soil (Soil 3, South L2) formed by at least 2400 cal. BP, and is associated with a Sandy Creek occupation. The next period of soil formation occurred by 1100 cal. BP (Soil 3, Test Pit L2-9), and is associated with an Avonlea occupation. Soil 2 is widespread throughout the Bodo Archaeological Locality and had formed by about 270 cal. BP. It is associated with a Late Precontact occupation.

Soil 1 (the modern soil) is also continuous across the Archaeological Locality, is formed in sediments that have accumulated since about 200 cal. BP, and occasionally contains historic artifacts. Soil 1 sediments are likely anthropogenic, and may be the result of landscape destabilization and sediment mobilization due to the introduction of agriculture during the late 19th and early 20th centuries.

2. What methods can detect anthropogenic influences on soil properties?

As expected, chemical analyses reveal that all of the soil Ah horizons in the study profiles are enriched in C, N, P and major cations, relative to the underlying B and C horizons. However, the archaeological profiles (i.e. South L2, North L2 and L19) demonstrate significantly elevated nutrients compared to the Offsite profile. In particular, extractable P levels are consistently elevated in all of the archaeological profiles, relative to the Offsite profile (Section 6.2.3 and Figure 6.9). Soil chemistry thus not only reflects nonanthropogenic soil formation processes (e.g. organic additions to soil surface Ah horizons, nutrient cycling), but also documents anthropogenic inputs to the soils in the archaeological profiles (i.e. phosphorus).

Although humans may have occupied the Bodo Archaeological Locality during episodes of active sediment deposition, the chemical properties of the soils within the archaeological site demonstrate that human occupation took place primarily during periods of landscape stability. While a full chemical analysis can be performed on sediments and soils, it is time-consuming, costly and is not necessary for detecting anthropogenic soil characteristics. This study found that extractable P is a sensitive indicator of human activity that can be used to detect human occupation periods in the Bodo region.

Micromorphological comparison of Soil 2 of the North L2 profile and Soil 3 of the South L2 profile demonstrates that the soils have similar properties. However, the organic matter in Soil 2 has undergone less humification than Soil 3, and contains more anthropogenic inputs. In addition, organo-mineral accumulations in Soil 3 of the South L2 profile indicate that the soil formed under different pedogenic processes than Soil 2. Micromorphological analysis can thus describe details regarding anthropogenic and non-anthropogenic soil properties. It can therefore be applied to specific questions about human activities and soil formation (e.g. Adderley et al. 2004; Simpson et al. 2000, 2003, 2006). At Bodo, for example, micromorphology could be applied to the question of whether a kill site represents more than one kill episode (e.g. as in Grekul 2007), or whether a hearth has been reused over time.

Soil microbial PLFA analysis demonstrates that the total microbial communities of Soil 1 differ significantly from the microbial communities of Soil 2 and the Offsite samples. In addition, PLFA analysis of the Gram (+) community documents significant differences in the microbial communities between all three soils. It is too early to conclude what cultural and environmental factors influenced soil microbial PLFA properties at the Bodo Archaeological Site. However, indicator species analysis and examination of the Gram (+) data suggests that patterns of land disturbance at the archaeological site have a considerable impact on the microbial communities. Microbial PLFA analysis therefore has the potential to be able to identify and provide details about human activity areas at archaeological sites.

Research Directions

Given the extent of the archaeological site, further research is required to more fully document interactions between culture and the environment at Bodo. Below are suggestions for future work that will assist in recording the geological, pedological and archaeological history of the Bodo Archaeological Locality:

1. Extractable P analysis can be employed to aid in defining site boundaries, which are at present still unclear. In addition, soil samples can be taken during field school or CRM excavations for subsequent analysis, to examine the relationship between extractable P and the type and density of associated artifacts and features. However, before the sampling program is put in place, there are three caveats. First, meaningful interpretation of results requires documentation of the sample's stratigraphic position

in the field. Second, as pH is a major influence on P fixation, soil pH must also be measured (Section 3.2.3). Finally, a comparable offsite control sample is imperative for evaluation of results.

Extractable P may be measured in the field or laboratory using several different methods (Kuo 1996). For example, Dormaar and Beaudoin (1991) assessed the rapid ring chromatography field test for phosphates and found that this qualitative method correlated well with laboratory measurements of available P. Eidt (1977) also recommended use of the field ring chromatography test, in conjunction with measurement of extractable P in the lab. In addition, Eidt (1977) recommended phosphate fractionation, to determine whether extractable P levels were the result of human activity or natural processes. Parnell and colleagues (2001) have developed another relatively simple quantitative method of extractable phosphate analysis that may be performed in a field laboratory situation (method in Terry et al. 2000). Regardless of which field technique is chosen, it is also prudent to analyze samples for extractable P in the laboratory, to assess the accuracy of the field test.

2. Wolfe and colleagues (2002b, 2006) point out that the stratigraphic records of middle Holocene dune activity are likely to be preserved in areas that are transitional between grassland and parkland, such as the Bodo area. As grasslands migrated north of their present range during the Holocene peak in aridity[55], sand dunes on the northern Great Plains were activated. Cooler, moister conditions following the Holocene aridity maximum resulted in the northern extent of the grassland boundary being replaced by parkland vegetation, and a stabilized landscape. These stabilized areas, which were formerly grassland during the early to middle Holocene but are now parkland, may record middle Holocene aeolian activity. At Bodo, surface finds indicate human occupation during the middle Holocene, therefore there are probably areas of the site in which the middle Holocene stratigraphic record is preserved. These areas may be located under the sand dunes near the south edges of the

[55] Researchers disagree on whether the peak in aridity occurred in the early or middle Holocene; see Hickman and Schweger (1993); Schweger and Hickman (1989); Wolfe et al. (2002b).

archaeological site, furthest away from the northerly winds that prevailed during late Holocene dune formation. Optical dating of the sand dunes (e.g. Huntley and Lian 1999; Lian et al. 2002) would aid in reconstruction of the timing of dune activation, and may suggest whether excavation of the dunes to gain access to middle Holocene deposits is worthwhile.

3. The sandy nature of the soils at Bodo promotes oxidation and leaching of organic matter from palaeosols. Therefore, unless adequate quantities of well-preserved, in situ bone are present, radiocarbon dating is often not feasible. Optical dating of sands is useful tool in building a chronology of climatic events at sites dominated by aeolian activity (e.g. Wolfe et al. 2002a, b, 2006). This chronometric method can be applied to sand dunes, as discussed above, but also to the aeolian sediments and soils within stratigraphic profiles, which will aid in reconstructing the timing of aeolian and pedogenic events.

4. Mapping the distribution and thickness of sand throughout the archaeological site using a Geoprobe could be another useful prospection tool when looking for middle or early Holocene deposits and palaeosols. For example, thicker deposits may indicate a local depositional basin, in which older sediments have been preserved. Geoprobe survey and sediment analysis, along with collection of geochronological data will greatly aid documentation of the palaeosol sequence at Bodo.

5. Stable carbon isotope analysis of dune palaeosols can result in identification of the types of vegetation growing on the soils. For example, vegetation consisting predominantly of C_3 plants (e.g. all trees and most grasses that thrive in cooler environments) may indicate a relatively short growing season and cool summer temperatures. If C_4 plants predominate (i.e. grasses that grow in warm temperatures), longer growing seasons and warmer summer temperatures are indicated (Muhs and Wolfe 1999). Tracking changes in vegetation over time using stable isotope analysis can thus provide climatic information regarding episodes of soil formation and human occupation at the Bodo Archaeological Locality.

6. Knowledge regarding the relationship between the soil microbial community and human activity areas at archaeological sites is still developing. Experimental archaeology combined with PLFA analysis could address question such as: What is the impact on the soil community in areas where bone is processed for grease extraction? What types of microbes can survive repeated use of a hearth? Are microbes significantly affected by repeated trampling of an area? How does the microbial community change over time in areas where specific human activity takes place? The results of archaeological experiments using PLFA analysis may be used to make inferences regarding human activities at the archaeological site. In addition, within the Bodo Archaeological Locality, PLFA analysis of human activity areas (i.e. within a charcoal concentration, hearth or bone bed [e.g. Grekul 2007]) combined with experimental results will aid in understanding the long-term impact these activities have on the microbial community. Also research design should incorporate PLFA analysis of samples from a number of offsite areas with similar environmental conditions to the archaeological site, to control for known variables such as vegetation, slope and soil parent materials.

The study profiles at the Bodo Archaeological Locality document local and regional late Holocene climatic oscillations, during which humans repeatedly occupied the site. Incorporating stratigraphic analysis, optical dating, and interpretations of archaeological materials will result in more accurate, detailed reconstructions of environmental fluctuations and human activities at Bodo. The density of archaeological deposits, the size of the Bodo Archaeological Locality and the ongoing research at the site through CRM, field school and graduate research activities makes this location ideal for exploring the relationship between the environment and culture. In addition, by involving soil science in their research designs, archaeologists can make substantial contributions to understanding the long-term impact of human activities on the soil environment.

REFERENCES CITED

Achuff, P. L.

1992 *Natural Regions and Subregions of Alberta: A Revised Classification for Protected Areas Management.* Alberta Tourism, Parks and Recreation, Edmonton.

—— 1994 *Natural Regions, Subregions and Natural History Themes of Alberta.* Parks Service, Alberta Environmental Protection, Edmonton.

Adderley, W. P., I. A. Simpson, M. J. Lockheart, R. P. Evershed and D. A. Davidson

2000 Modeling Traditional Manuring Practice: Soil Organic Matter Sustainability of an Early Shetland Community? *Human Ecology* 28(3):415-431.

Adderley, W. P., I. A. Simpson, H. Kirscht, M. Adam, J. Q. Spencer and D. C. W. Sanderson

2004 Enhancing Ethno-pedology: Integrated Approaches to Kanuri and Shuwa Arab Definitions in the Kala-Balge Region, Northeast Nigeria. *Catena* 58:41-64.

Adderley, W. P., I. A. Simpson and D. A. Davidson

2006 Historic Landscape Management: A Validation of Quantitative Soil Thin-section Analyses. *Journal of Archaeological Science* 33(3):320-334.

Alberta Government

2005 *Agricultural Land Resource Atlas of Alberta-Township Grid System of Alberta.* Web page, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex10302, accessed September 1, 2006.

Allan, J. A.

1938 The Relation of the Geology to the Soils in the Sullivan Lake Sheet. In *Soil Survey of Sullivan Lake Sheet* by F. A. Wyatt, J. D. Newton, W. E. Bowser and W. Odynsky, pp. 89-102. University of Alberta, Edmonton.

Anderson, J.P.E. and K.H. Domsch
1978 A Physiological Method for the Quantitative Measurement of Microbial Biomass in Soils. *Soil Biology and Biochemistry* 10:215-221.

Ashley, G. M.
2001 Archaeological Sediments in Springs and Wetlands. In *Sediments in Archaeological Context*, edited by J. K. Stein and W. R. Farrand, pp.183-210. University of Utah Press, Salt Lake City.

Bayrock, L. A.
1967 *Surficial Geology of the Wainwright Area (East Half), Alberta.* Research Council of Alberta, Edmonton.

Beaudoin, A.
2003 A Comparison of Two methods for Estimating the Organic Content of Sediments. *Journal of Paleolimnology* 29:387-390.

Beaudoin, A. B, and H. P. Pyszczyk
1998 Where was Anthony Henday and What did He See? *Alberta Archaeological Review* 28:25-31.

Beaudoin, A. B. and G. A. Oetelaar
2003 The Changing Ecophysical Landscape of Southern Alberta during the Late Pleistocene and Early Holocene. *Plains Anthropologist* 48(187):187-207.

Bhatti, J. S. and I. E. Bauer
2002 Comparing Loss-on-ignition with Dry Combustion as a Method for Determining Carbon Content in Upland and Lowland Forest Ecosystems. *Communications in Soil Science and Plant Analysis* 33(15-18):3419-3430.

Birkeland, P. W.
1999 *Soils and Geomorphology.* Oxford University Press, New York.

Blaikie, K.
2005 Archaeological Investigations of FaOm-1: The Bodo Bison Skulls Site. Unpublished Master's thesis, Department of Anthropology, University of Alberta, Edmonton.

Bligh, E. G. and W. J. Dyer
1959 A Rapid Method of Total Lipid Extraction and Purification. *Canadian Journal of Biochemistry and Physiology* 37(8):911-917.

Borowitz, M.
2007 Cultural Meaning of Climate: Agricultural Drought in East-Central Alberta. Unpublished Master's thesis, Department of Anthropology, University of Alberta, Edmonton.

Bossio, D. A., J. A. Fleck, K. M. Scow and R. Fujii
2006 Alteration of Soil Microbial Communities and Water Quality in Restored Wetlands. *Soil Biology & Biochemistry* 38:1223-1233.

Boyle, J.
2004 A Comparison of Two Methods for Estimating the Organic Matter Content of sediments. *Journal of Paleolimnology* 3(1):125-127.

Bradley, L. and C. Bradley
1977 *Aspen Groveland Resource Assessment: Neutral Hills Area.* Alberta Recreation, Parks and Wildlife, Edmonton.

Brady, N. C. and R. R. Weil
2002 *The Nature and Properties of Soils.* Prentice Hall, Upper Saddle River.

Bremner, J. M. and C. S. Mulvaney
1982 Nitrogen-Total. In *Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties*, edited by A. L. Page, R. H. Miller and D. R. Keeney, pp. 595-599. American Society of Agronomy and Soil Science Society of America, Madison.

Buckley, D. H. and T. M. Schmidt
2001 The Structure of Microbial Communities in soil and the Lasting Impact of Cultivation. *Microbial Ecology* 42:11-21.

Buol, S. W., R. J. Southard, R. C. Graham and P. A. McDaniel
2003 *Soil Genesis and Classification.* 5th ed. Iowa State Press, Ames.

Buonasera, T.
2005 Fatty Acid Analysis of Prehistoric Burned Rocks: A Case Study from Central California. *Journal of Archaeological Science* 32:957-965.

Canarache, A., I. Vintila and I. Munteanu
2006 *Elsevier's Dictionary of Soil Science: In English (with definitions), French, German and Spanish.* Elsevier, Amsterdam.

Carlson, V. A. and L. M. Topp
1971 *Bedrock Topography of the Wainwright Map-Area NTS 73D, Alberta*, edited by. A. Badry. Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa.

Clarke, K. R.
1993 Non-parametric Multivariate Analyses of Changes in Community Structure. *Australian Journal of Ecology* 18:117-143.

Cook, F. D.
1969 Significance of Microorganisms in Paleosols, Parent Materials, and Ground Water. In *Pedology and Quaternary Research*, edited by S. Pawluk, pp. 53-61. University of Alberta, Edmonton.

Copeland, F. L. and R. Green
1982 *Geological Map of Alberta.* Alberta Geological Survey, Alberta Research Council, Edmonton.

David, P. P.
1977 *Sand Dune Occurrences of Canada: A Theme and Resource Inventory Study of Eolian Landforms of Canada.* Contract No.74-230. Indian and Northern Affairs, National Parks Branch, Ottawa.

Davis, R. A.
1992 *Depositional Systems. An Introduction to Sedimentology and Stratigraphy.* 2nd ed. Prentice Hall, Englewood Cliffs.

Day, J. H. (editor)
1983 *The Canada Soil Information System (CanSIS) Manual for Describing Soils in the Field.* Rev. ed. LRRI contribution no. 82-52. Expert Committee on Soil Survey, Canada Committee on Land Resource Services, Ottawa.

DeGrood, S. H., V. P. Claassen and K. M. Scow
2005 Microbial Community Composition on Native and Drastically Disturbed Serpentine Soils. *Soil Biology & Biochemistry* 37:1427-1435.

Department of Energy, Mines and Resources
1977 *Bodo 73 D/1 Alberta-Saskatchewan.* Canada NTS Series, 1:50,000. Surveys and Mapping Branch, Ottawa.

—— 1978 *Neutral Hills 73 D/2 Alberta.* Canada NTS Series, 1:50,000. Surveys and Mapping Branch, Ottawa.

Dormaar, J. F. and A. B Beaudoin
1991 Application of Soil Chemistry to Interpret Cultural Events at the Calderwood Buffalo Jump (DkPj-27), Southern Alberta, Canada. *Geoarchaeology* 6(1):85-98.

Doyle, P., M. R. Bennett and A. N. Baxter
1994 *The Key to Earth History*. John Wiley & Sons, Chichester.

Dufrêne, M. and P. Legendre
1997 Species Assemblages and Indicator Species: The Need for a Flexible Asymmetrical Approach. *Ecological Monographs* 67(3):345-366.

Dyck, I., and R. E. Morlan
1995 *The Sjovold Site. A River Crossing Campsite in the Northern Plains.* With contributions by E. A. Christiansen, H. E. Hendry, D. W. Anderson and J. G. Ellis. Mercury Series, Archaeological Survey of Canada Paper 151. Canadian Museum of Civilization, Hull.

Dyke, A. S. A. Moore and L. Robertson
2003 *Deglaciation of North America.* 1:15,000,000. Geological Survey of Canada Open File 1574. Geological Survey of Canada, Ottawa.

Edwards, W. A. D. and D. W. Scafe
1990 *Sand and Gravel Resources of the East Half of the Municipal District of Provost, Number 52.* Alberta Environmental Protection, Edmonton.

Eerkens, J. W.
2005 GC-MS Analysis and Fatty Acid Ratios of Archaeological Potsherds from the Western Great Basin of North America. *Archaeometry* 47(1):83-102.

Eidt, R. C.
1977 Detection and Examination of Anthrosols by Phosphate Analysis. *Science* 197(4311):1327-1333.

Environment Canada
2004 *Climate Data Online: Cadogan, Alberta, 1980-2000.* Web page, http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html, accessed June 7, 2007.

——
2006 *Climate Data Online: Bodo AGDM, 2003-2006.* Web page, http://www.climate.weatheroffice.ec.gc.ca/climateData/monthlydata_e.html, accessed June 7, 2007.

Epp, H. T. and K. E. Johnson
1980 Archaeological Resources in the Great Sand Hills. In *The Great Sand Hills of Saskatchewan*, edited by H. T. Epp and L. Townley-Smith, pp. 90-133. Saskatchewan Environment, Regina.

Evans, D. J. A. and I. A. Campbell
1992 Glacial and Postglacial Stratigraphy of Dinosaur Provincial Park and Surrounding Plains, Southern Alberta, Canada. *Quaternary Science Reviews* 11:535-555.

——
1995 Quaternary Stratigraphy of the Buried Valleys of the Lower Red Deer River, Alberta, Canada. *Journal of Quaternary Science* 10(2):123-148.

Federle, T. W.
1986 Microbial Distribution in Soil-New Techniques. In *Perspectives in Microbial Ecology. Proceedings of the Fourth International Symposium on Microbial Ecology*, edited by F. Megusar and M. Gantar, pp. 493-498. Slovene Society for Microbiology, Ljubljana.

Fehr, A. W.
1984 *Wainwright Study Area: A Biophysical Inventory*. Alberta Energy and Natural Resources, Public Lands Division, Edmonton.

FitzPatrick, E. A.
1993 *Soil Microscopy and Micromorphology*. John Wiley & Sons, Chichester.

Foster, D., F. Swanson, J. Aber, I. Burke, N. Brokaw, D. Tilman and A. Knapp
2003 The Importance of Land-use Legacies to Ecology and Conservation. *BioScience* 53(1):77-88.

Fratterigo, J. M., T. C. Balser and M. G. Turner
2006 Microbial Community Variation and its Relationship with Nitrogen Mineralization in Historically Altered Forests. *Ecology* 87(3):570-579.

Frostegård, Å., A. Tunlid and E. Bååth
1991 Microbial Biomass Measured as Total Lipid Phosphate in Soils of Different Organic Content. *Journal of Microbiological Methods* 14:151-163.

Frostegård, Å. and E. Bååth

1996 The Use of Phospholipid Fatty Acid Analysis to Estimate Bacterial and Fungal Biomass in Soil. *Biology and Fertility of Soils* 22:59-65.

Gearey, B. R. and C. J. Caseldine

2006 Archaeological applications of testate amoebae analyses: A case study from Derryville, Co. Tipperary, Ireland. *Journal of Archaeological Science* 33(1):49-55.

Gibson, T. H.

2001 *Management Summary of Archaeological Work Undertaken in the South Bodo Oilfield (FaOm-1) for Murphy Oil Company in 2000.* Permit 2000-116. Report on file, Heritage Resource Management Branch, Alberta Community Development, Edmonton.

—— 2004a *An Historical Resources Impact Assessment of New Century Wellpads 3A1 (3-1-37-2 W4M), 2B (15-36-36-2 W4M) and 9C (9-36-36-2 W4M) in the Bodo District.* Permit 04-226. Report on file, Heritage Resource Management Branch, Alberta Community Development, Edmonton.

—— 2004b An Overview of the Archaeology of the Bodo Sites Locality: 1995-2004. Draft Version 1. Report on file with T. Gibson, Alberta Western Heritage, Inc., St. Albert, Alberta.

Gibson, T. and P. McKeand

1996 *Heritage Resources Impact Assessment of a Fletcher Challenge Petroleum Pipeline in the Eyehill Creek Locality, Bodo, Alberta.* Permit 95-101. Report on file, Heritage Resource Management Branch, Alberta Community Development, Edmonton.

Glaser, B., J. Lehmann and W. Zech

2002 Ameliorating Physical and Chemical Properties of Highly Weathered Soils in the Tropics with Charcoal-A Review. *Biology and Fertility of Soils* 35:219-230.

Goudie, A., B. W. Atkinson, K. J. Gregory, I. G. Simmons, D. R. Stoddart and D. Sugden, editors

1994 *The Encyclopedic Dictionary of Physical Geography.* 2nd ed. Reprint, Blackwell Publishers, Oxford, 1997.

Grayston, S. J., G. S. Griffith, J. L. Mawdsley, C. D. Campbell and R. D. Bardgett

2001 Accounting for Variability in Soil Microbial Communities of Temperate Upland Grassland Ecosystems. *Soil Biology & Biochemistry* 33:533-551.

Grekul, C. P.

2007 A Zooarchaeological Analysis of a Late Precontact Bison Kill Site in the Bodo Sand Hills of Alberta. Unpublished Master's thesis, Department of Anthropology, University of Alberta, Edmonton.

Guckert, J. B. and D. C. White

1986 Phospholipid, Ester-Linked Fatty Acid Analysis in Microbial Ecology. In *Perspectives in Microbial Ecology. Proceedings of the Fourth International Symposium on Microbial Ecology*, edited by F. Megusar and M. Gantar, pp. 455-459. Slovene Society for Microbiology, Ljubljana.

Haack, S. K., H. Garchow, D. L. Odelson, Forney L. J. and Klug M. J.

1994 Accuracy, Reproducibility and Interpretation of Fatty Acid Methyl Ester Profiles of Model Bacterial Communities. *Applications of Environmental Microbiology* 60:2483-2493.

Hackbarth, D. A.

1975a *Hydrogeology of the Wainwright Area, Alberta.* Alberta Research Council, Edmonton.

—

1975b *Regional Chemistry of Groundwater in the Wainwright Area, Alberta.* Alberta Research Council, Edmonton.

Hannam, K. D., S. A. Quideau and B. E. Kishchuk

2006 Forest Floor Microbial Communities in Relation to Stand Composition and Timber Harvesting in Northern Alberta. *Soil Biology & Biochemistry* 38:2565-2575.

Heiri, O., A. F. Lotter and G. Lemcke

2001 Loss on Ignition as a Method for Estimating Organic and Carbonate Content in Sediments: Reproducibility and Comparability of Results. *Journal of Paleolimnology* 25:101-110.

Hendershot, W. H., H. Lalande and M. Duquette
1993 Ion Exchange and Exchangeable Cations. In *Soil sampling and Methods of Analysis*, edited by M. R. Carter and the Canadian Society of Science, pp. 167-175. Lewis Publishers, Boca Raton.

Hickman, M. and C. E. Schweger
1993 Late Glacial-Early Holocene Palaeosalinity in Alberta, Canada-Climate Implications. *Journal of Paleolimnology* 8:149-161.

———
1996 The Late Quaternary Palaeoenvironmental History of a Presently Deep Freshwater Lake in East-central Alberta, Canada and Palaeoclimate Implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 123:161-178.

Hopkins, D. G. and G. L. Running
2000 Soils, Dunes, and Prairie Vegetation: Lessons from the Sandhills of North Dakota. In *Changing Prairie Landscapes*, edited by T. A. Radenbaugh and P. C. Douaud, pp. 39-57. Canadian Plains Research Center, University of Regina, Regina.

Horwath, W. R. and E. A. Paul
1994 Microbial Biomass. In *Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties*, edited by R. W. Weaver, S. Angle and P. Bottomley, pp. 753-773. SSSA book series no. 5. Soil Science Society of America, Madison.

Huckleberry, G.
2001 Archaeological Sediments in Dryland Alluvial Environments. In *Sediments in Archaeological Context*, edited by J. K. Stein and W. R. Farrand, pp. 67-92. University of Utah Press, Salt Lake City.

Huntley, D. J. and O. B. Lian
1999 Using Optical Dating to Determine When a Sediment was Last Exposed to Sunlight. In *Holocene Climate and Environmental Change in the Palliser Triangle: A Geoscientific Context for Evaluating the Impacts of Climate Change on the Southern Canadian Prairies*, edited by D. S. Lemmen and R. E. Vance, pp. 211-221. Geological Survey of Canada, Ottawa.

Ibekwe, A. M. and A. C. Kennedy
1999 Fatty Acid Methyl Ester (FAME) Profiles as a Tool to Investigate Community Structure of 2 Agricultural Soils. *Plant and Soil* 206:151-161.

Janzen, H. H.
1993 Soluble salts. In *Soil Sampling and Methods of Analysis*, edited by M. R. Carter and the Canadian Society for Soil Science, pp. 161-166. Lewis Publishers, Boca Raton.

Jenkinson, D.S., Brooks, P.C. and Powlson, D.S.
2004 Measuring Soil Microbial Biomass. *Soil Biology and Biochemistry* 36:5-7.

Jenny, H.
1980 *The Soil Resource: Origin and Behavior*. Springer-Verlag, New York.

Kennedy, A. C.
1994 Carbon Utilization and Fatty Acid Profiles for Characterization of Bacteria. In *Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties*, edited by R. W. Weaver, S. Angle and P. Bottomley, pp. 543-556. Soil Science Society of America, Madison.

King, A.
1979 After 100 Years Thunderchild Remembers. *Saskatchewan Indian* 9(6):10, June. Electronic document, http://www.sicc.sk.ca/saskindian/a79jun10.htm, accessed June 7, 2007.

Knapp, A. K., J. M. Blair, J. M. Briggs, S. L. Collins, D. C. Hartnett, L. C. Johnson and E. G. Towne
1999 The Keystone Role of Bison in North American Tallgrass Prairie. *BioScience* 49(1):39-50.

Koagaclio, S.
ca. 1990s *Physical Land Classification of Wainwright South District-NE Region*. 1:100 000 scale. Map on file at Alberta Sustainable Resource Development, Rangeland Mgt. Branch, Wainwright Provincial Building, Wainwright.

Kruksal, J. B.
1964 Nonmetric Multidimensional Scaling: A Numerical Method. *Psychometrika* 29:115-129.

Kubiëna, W. L.
1970 *Micromorphological Features of Soil Geography*. Rutgers University Press, Brunswick.

Kuo, S.
1996 Phosphorus. In *Methods of Soil Analysis, Part 3. Chemical Methods*, edited by J. M. Bartels, pp. 869-919. Soil Science Society of America and American Society of Agronomy, Madison.

Lawson, T., D. W. Hopkins, J. A. Chudek, R. C. Janaway and M. G. Bell
2000 The Experimental Earthwork at Wareham, Dorset after 33 years: 3. Interaction of Soil Organisms with Buried Materials. *Journal of Archaeological Science* 27:273-285.

Lemmen, D. S. and R. E. Vance
1999 An Overview of the Palliser Triangle Global Change Project. In *Holocene Climate and Environmental Change in the Palliser Triangle: A Geoscientific Context for Evaluating the Impacts of Climate Change on the Southern Canadian Prairies*, edited by D. S. Lemmen and R. E. Vance, pp. 7-22. Geological Survey of Canada Bulletin 534. Geological Survey of Canada, Ottawa.

Lewis, D. W. and D. M. McConchie
1994 *Analytical Sedimentology*. Chapman & Hall, New York.

Lian, O. B., D. J. Huntley, and S. A. Wolfe
2002 Optical Dating of Eolian Dune Sand from the Canadian Prairies. *Géographie physique et Quaternaire* 56(2-3):191-202.

Lima, H. N., C. E. R. Schaefer, J. W. V. Mello, R. J. Gilkes and J. C. Ker
2002 Pedogenesis and Pre-Columbian Land Use of "Terra Preta Anthrosols" ("Indian black earth") of Western Amazonia. *Geoderma* 110:1-17.

Luckman, B. H. G. Holdsworth and G. D. Osborn
1993 Neoglacial Glacier Fluctuations in the Canadian Rockies. *Quaternary Research* 39:144-153.

McCune, B. and J. B. Grace
2002 *Analysis of Ecological Communities*. With contributions by D. L. Urban. MjM Software Design, Glenenden Beach.

McGill, W. B. and C. T. Figueiredo
1993 Total Nitrogen. In *Soil Sampling and Methods of Analysis*, edited by M. R. Carter and the Canadian Society of Science, pp. 201-211. Lewis Publishers, Boca Raton.

McKeague, J. A. (editor).

1981 *Manual on Soil Sampling and Methods of Analysis*. 2nd ed. Prepared by the Subcommittee on Methods of Analysis. Canadian Society of Soil Science, Ottawa.

MacKenzie, W. S. and A. E. Adams

1994 *Color Atlas of Rocks and Minerals in Thin Section*. John Wiley & Sons, New York.

McLean, J. R.

1971 *Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Great Plains,* edited by R. G. Arnold. Saskatchewan Research Council Geology Division, Saskatoon.

Malainey, M. E., R. Przybylski and B. L. Sherriff

1999 The Fatty Acid Composition of Native Food Plants and Animals of Western Canada. *Journal of Archaeological Science* 26:83-94.

Mather, P. M.

1976 *Computational Methods of Multivariate Analysis in Physical Geography*. Wiley, London.

Milchunas, D. G., W. K. Lauenroth and I. C. Burke

1998 Livestock Grazing: Animal and Plant Biodiversity of Shortgrass Steppe and the Relationship to Ecosystem Function. *Oikos* 83:65-74.

Morlan, R.E.

2001 Canadian Archaeological Radiocarbon Database. Canadian Museum of Civilization. Electronic document. http://www.canadianarchaeology.ca/radiocarbon/card/card.htm, accessed July 3, 2007.

Muhs, D. R. and S. A. Wolfe

1999 Sand Dunes of the Northern Great Plains of Canada and the United States. In *Holocene Climate and Environmental Change in the Palliser Triangle: A Geoscientific Context for Evaluating the Impacts of Climate Change on the Southern Canadian Prairies*, edited by D. S. Lemmen and R. E. Vance, pp. 183-197. Geological Survey of Canada, Ottawa.

Mulira, J. E.

1986 *Eolian Landforms of Alberta.* Alberta Forestry, Lands and Wildlife, Resource Evaluation and Planning and Public Lands Divisions, Edmonton.

Murphy, D. W., A. J. Macdonald, E. A. Stockdale, K. W. T. Goulding, S. Fortune, J. L. Gaunt, P. R. Poulton, J. A. Wakefield, C. P. Webster and W. S. Wilmer

2000 Soluble Organic Nitrogen in Agricultural soils. *Biology and Fertility of Soils* 30:374-387.

Ortega-Morales, O., J. Guezennec, G. Hernandez-Duque, C. C. Gaylarde and P. M. Gaylarde

2000 Phototrophic Biofilms on Ancient Mayan Buildings in Yucatan, Mexico. *Current Microbiology* 40:81-85.

Paleopedology Working Group

1990 Field Recognition, Description and Spatial Relationships of Paleosols. *Quaternary International* 6:1-95.

Parnell, J. J. and R. E. Terry

2002. Soil Chemical Analysis Applied as an Interpretive Tool for Ancient Human Activities in Piedras Negras, Guatemala. *Journal of Archaeological Science* 29:379-404.

Parnell, J. J., R. E. Terry and C. Golden

2001 Using In-field Phosphate Testing to Rapidly Identify Middens at Piedras Negras, Guatemala. *Geoarchaeology* 16(8):855-873.

Peck, T. R. and C. R. Hudecek-Cuffe

2003 Archaeology on the Alberta Plains: The Last Two Thousand years. In *Archaeology in Alberta: A View to the New Millennium*, edited by J. W. Brink and J. F. Dormaar, pp. 72-102. Archaeological Society of Alberta, Medicine Hat.

Peter Heiler Ltd.

2000 *Alberta.* 1:1,250,000. MapMEDIA Corp, Oshawa, Ontario.

Pietikäinen, J., O. Kiikkila and H. Fritze

2000 Charcoal as a Habitat for Microbes and its Effect on the Microbial Community of the Underlying Humus. *Oikos* 89:231-242.

Rapp, G. and C. L. Hill
1998 *Geoarchaeology*. Yale University Press, New Haven.

Reeves, B. O. K.
1978 Head-Smashed-In: 5500 Years of Bison Jumping on the Alberta Plains. *Plains Anthropologist* 23:151-174.

Rippon, R. E. and C. E. Moell
1982 *Hazardous Waste Project Preliminary Hydrogeological Site Investigation, N 1/2 7-36-1-W4*. Department of Environment, Earth Sciences Division, Edmonton.

Ritter, D. F.
1986 *Process Geomorphology*. 2nd edition. Wm. C. Brown Publishers, Dubuque.

Robertson, G. P., J. R. Crum and B. G. Ellis
1993 The Spatial Variability of Soil Resources Following Long-term Disturbance. *Oecologia* 96:451-456.

Sanborn, P. and S. Pawluk
1989 Microstructure Diversity in Ah Horizons of Black Chernozemic Soils, Alberta and British Columbia (Canada). *Geoderma* 45:221-240.

Sauchyn, D. J. and A. B. Beaudoin
1998 Recent Environmental Change in the Southwestern Canadian Plains. *The Canadian Geographer* 42(4):337-353.

Schiffer, M. B.

1987 *Formation Processes of the Archaeological Record*. University of Utah Press, Salt Lake City.

Schweger, C. E. and M. Hickman

1989 Holocene Paleohydrology of Central Alberta: Testing the General-Circulation-Model Climate Simulations. *Canadian Journal of Earth Sciences* 26:1826-1833.

Scott, W.B. and E.G. Crossman

1973 *Freshwater Fishes of Canada*. Bulletin 184. Fisheries Research Board of Canada, Ottawa.

Sheldrick, B. H. and C. Wang

1993 Particle Size Distribution. In *Soil Sampling and Methods of Analysis*, edited by M. R. Carter and the Canadian Society of Science, pp. 499-511. Lewis Publishers, Boca Raton.

Shetsen, I.

1990 *Quaternary Geology, Central Alberta.* 1:500,000. Alberta Research Council, Natural Resources Division, Edmonton.

Simonson, R. W.

1959 Outline of a Generalized Theory of Soil Genesis. *Soil Science Society of America Proceedings* 23:152-156.

Simpson, I. A., S. Perdikaris, G. Cook, J. L. Campbell and W. J. Teesdale

2000 Cultural Sediment Analyses and Transitions in Early Fishing Activity at Langenesvaeret, Vesterålen, Northern Norway. *Geoarchaeology* 15(8):743-763.

Simpson, I. A., O. Vesteinsson, W. P. Adderley and T. H. McGovern

2003 Fuel Resource Utilisation in Landscapes of Settlement. *Journal of Archaeological Science* 30:1401-1420.

Simpson, I. A., E. B. Guttmann, J. Cluett and A. Shepherd

2006 Characterizing Anthropic Sediments in North European Neolithic Settlements: An Assessment from Skara Brae, Orkney. *Geoarchaeology* 21(3):221-235.

Soil and Crop Diagnostic Center

1995 *Standard Operating Procedures Manual*, part 2. Alberta Agriculture, Edmonton.

Soil Classification Working Group

1998 *The Canadian System of Soil Classification.* Agriculture and Agri-food Canada Publication 1646. Rev. ed. NRC Research Press, Ottawa.

Soil Research Institute

1970 *Soil Capability for Agriculture: Wainwright, Alberta: West of Fourth Meridian.* 1:250,000. Canada Land Inventory, Ottawa.

Stalker, A. M. S.

1961 *Buried Valleys in Central and Southern Alberta.* Geological Survey of Canada paper 60-32. Geological Survey of Canada, Ottawa.

Stoops, G.

2003 *Guidelines for Analysis and Description of Soil and Regolith Thin Sections.* Soil Science Society of America, Inc, Madison.

Stuiver, M. and J. van der Plicht

1998 Calibration Database Editorial Comment. *Radiocarbon* 40(3):xii-xiii.

Stuiver, M., P. J. Reimer, E. Bard, J. W. Beck, G. S. Burr, K. A. Hughen, B. Kromer, G. McCormac, J. van der Plicht and M. Spurk

1998 INTCAL 1998 Radiocarbon Age Calibration. *Radiocarbon* 40(3):1041-1083.

Sumner, M. E. and W. P. Miller.

1996 Cation Exchange Capacity and Exchange Coefficients. In *Methods of Soil Analysis, Part 3. Chemical Methods*, edited by J. M. Bartels, pp. 1201-1229. Soil Science Society of America and American Society of Agronomy, Madison.

Talma, A. S. and J. C. Vogel

1993 A Simplified Approach to Calibrating C14 Dates. *Radiocarbon* 35(2):317-322.

Technicon Industrial Systems

1977 Individual/simultaneous Determination of Nitrogen and/or Phosphorus in BD Acid Digests. In *Methods of Analysis, Technicon Autoanalyzer II.* Rev. ed. Industrial method No. 334-74A/A, 1-7. Technicon Industrial Systems, Tarrytown.

Terry, R. E., P. J. Hardin, S. D. Houston, M. W. Jackson, J. Carr and J. J. Parnell

2000 Quantitative Phosphorus Measurement: A Field Test Procedure for Archeological Site Analysis at Piedras Negras, Guatemala. *Geoarchaeology* 15:151-166.

Thomas, G. W.

1982 Exchangeable Cations. In *Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties*, edited by A. L. Page, R. H. Miller and D. R. Keeney, pp. 159-165. American Society of Agronomy and Soil Science Society of America, Madison.

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1996 Soil pH and Soil Acidity. In *Methods of Soil Analysis, Part 3. Chemical Methods*, edited by J. M. Bartels, pp. 475-490. Soil Science Society of America and American Society of Agronomy, Madison.

Topp, L. M.

1974 *Hydrogeology: Wainwright Study Area.* Alberta Environment, Edmonton.

Townley-Smith, L.

1980 Physical Environment of the Great Sand Hills. In *The Great Sand Hills of Saskatchewan*, edited by H. T. Epp and L. Townley-Smith, pp. 10-29. Saskatchewan Environment, Regina.

Vance, R. E., A. B. Beaudoin and B. H. Luckman

1995 The Paleoecological Record of 6 ka BP Climate in the Canadian Prairie Provinces. *Géographie physique et Quaternaire* 49(1):81-98.

Vickers, J. R.

1986 *Alberta Plains Prehistory: A Review.* Archaeological Survey of Alberta Occasional Paper No. 27. Alberta Culture, Edmonton.

Vickers, J. R. and T. R. Peck

2004 Islands in a Sea of Grass: The Significance of Wood in Winter Campsite Selection on the Northwestern Plains. In *Archaeology on the Edge: New Perspectives from the Northern Plains*, edited by B. Kooyman and J. Kelley, pp. 95-124. Canadian Archaeological Association Occasional Paper no. 4. University of Calgary Press, Calgary.

Wallis, C. and C. Wershler

1988 *Rare Wildlife and Plant Conservation Studies in Sandhill and Sand Plain Habitats of Southern Alberta.* Alberta Forestry, Lands and Wildlife, Alberta Recreation and Parks, Edmonton.

Waters, P. L. and N. W. Rutter

1983 Utilizing Paleosols and Volcanic Ash in Correlating Holocene Deposits in Southern Alberta. In *Correlation of Quaternary Chronologies*, edited by W. C. Mahaney, pp. 203-223. GeoBooks, Norwich.

Wentworth, C. K.

1922 A Scale of Grade and Class Terms for Clastic Sediments. *Journal of Geology* 30:377-392.

Wettlaufer, B. N.

1955 *The Mortlach Site in the Besant Valley of Central Saskatchewan.* Anthropological Series no.1. Department of Natural Resources, Regina.

White, D. C. and D. B. Ringelberg

1998 Signature Lipid Biomarker Analysis. In *Techniques in Microbial Ecology*, edited by R. S. Burlage, R. Atlas, D. Stahl, G. Geesey and G. Sayler, pp. 255-272. Oxford University Press, New York.

Wolfe, S. A., J. Ollerhead, D. J. Huntley and C. Campbell

2002a *Late Holocene Dune Activity in the Duchess Dune Field, Alberta.* Current Research 2002-B3. Geological Survey of Canada, Natural Resources Canada, Ottawa.

Wolfe, S. A., J. Ollerhead, and O. B. Lian

2002b Holocene Eolian Activity in South-central Saskatchewan and the Southern Canadian Prairies. *Geographie physique et Quaternaire* 56(2-3):215-227.

Wolfe, S. A. and J. Thorpe

2005 Shifting Sands: Climate Change Impacts on Sand Hills in the Canadian Prairies and Implications for Land Use Management. In *Managing Changing Prairie Landscapes*, edited by T. A. Radenbaugh and G. C. Sutter, pp. 117-134. Canadian Plains Research Center, University of Regina, Regina.

Wolfe, S. A., J. Ollerhead, D. J. Huntley and O. B. Lian

2006 Holocene Dune Activity and Environmental Change in the Prairie Parkland and Boreal Forest, Central Saskatchewan, Canada. *The Holocene* 16(1):17-29.

Wyatt, F. A., J. D. Newton, W. E. Bowser and W. Odynsky
1938 *Soil Survey of Sullivan Lake Sheet.* Alberta Soil Survey Report no. 8. University of Alberta, Edmonton.

Yan, T., L. Yang and C. D. Campbell
2003 Microbial Biomass and Metabolic Quotient of Soils under Different Land Use in the Three Gorges Reservoir area. *Geoderma* 115:129-138.

APPENDIX I: VEGETATION IN THE BODO SAND HILLS REGION

Grasses	
Common name	**Scientific name**
Bearded wheat grass	*Agropyron trachycaulum*
Rough fescue	*Festuca scabrella*
Hooker's oatgrass	*Helictotrichon hookeri*
Prairie junegrass	*Koeleria cristata*
False melic grass	*Schizachne purpurascens*
Western porcupine grass	*Stipa curtiseta*
Forbs/herbs	
Baneberry	*Actaea rubra*
Prairie crocus	*Anemone patens*
Sarsaparilla	*Aralia nudicaulis*
Prairie sagewort	*Artemisia ludoviciana*
Lindley's aster	*Aster ciliolatus*
Harebell	*Campanula rotundifolia*
Mouse-ear chickweed	*Cerastium arvense*
Fairy bells	*Disporum trachycarpum*
Fireweed	*Epilobium angustifolium*
Fleabane	*Erigeron glabellus*
Northern bedstraw	*Galium boreale*
Old man's whiskers	*Geum triflorum*
Cream-colored peavine	*Lathyrus ochroleucus*
Wild blue flax	*Linum lewisii*
Dewberry	*Rubus pubescens*
Star-flowered Solomon's seal	*Smilacina stellata*
American vetch	*Vicia Americana*
Trees	
Green alder	*Alnus crispa*
Balsam poplar	*Populus balsamifera*
Aspen	*Populus tremuloides*
Shrubs	
Saskatoon berry	*Amelanchier alnifolia*
Bunchberry	*Cornus canadensis*
Red osier dogwood	*Cornus stolonifera*
Beaked hazel	*Corylus cornuta*
Silverberry	*Elaeagnus commutata*
Twining honeysuckle	*Lonicera dioica*
Bracted honeysuckle	*Lonicera involucrata*

Bluebell	*Mertensia paniculata*
Pin cherry	*Prunus pensylvanica*
Choke cherry	*Prunus virginiana*
Pink wintergreen	*Pyrola asarifolia*
Northern gooseberry	*Ribes oxyacanthoides*
Rosebush	*Rosa* spp
Pussy willow	*Salix discolor*
Snowberry	*Symphoricarpos albus*
Western snowberry	*Symphoricarpos occidentalis*
Low-bush cranberry	*Viburnum edule*

compiled from Achuff 1992, 1994.

APPENDIX II: FAUNA OF THE BODO SAND HILLS REGION

Land Mammals	
Large Ungulates	
Common name	**Scientific name**
Moose	*Alces alces*
Pronghorn antelope	*Antilocapra americana*
Plains bison◆	*Bison bison*
Elk◆	*Cervus canadensis*
White-tailed deer	*Odocoileus hemionus*
Mule deer	*Odocoileus virginianus*
Carnivores	
Coyote	*Canis latrans*
Wolf◆	*Canis lupus*
Porcupine	*Erethizon dorsatum*
Cougar	*Felis concolor*
Badger	*Taxidea taxus*
Black bear	*Ursus americanus*
Grizzly bear◆	*Urus horribilis*
Red fox	*Vulpes vulpes*
Small Mammals	
Ord's kangaroo rat*	*Dipodomys ordii*
White-tailed jackrabbit	*Lepus townsendii*
Striped skunk	*Mephitis mephitis*
Deer mouse	*Peromyscus maniculatus*
Richardson's ground squirrel	*Spermophilus richardsonii*
Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*
Nuttall's cottontail	*Sylvilagus nuttallii*
Water Mammals	
Beaver	*Castor canadensis*
Muskrat	*Ondatra zibethicus*
Birds	
Sage grouse	*Centrocercus urophasiaanus*
Sharp-tailed grouse	*Tympanuchus phasianellus*
Migratory Birds	
Baird's sparrow	*Ammodramus bairdii*
Sprague's pipit	*Anthus spragueii*
Golden eagle	*Aquila chrysaetos*
Upland sandpiper	*Bartramia longicauda*
Various hawks	*Buteo* spp.
Ferruginous hawk	*Buteo regalis*
McCown's longspur	*Calcarius mccowni*
Chestnut-collared longspur	*Calcarius ornatus*

Nighthawk	*Chordeilus minor*
Northern flicker	*Colaptes auratus*
Horned lark	*Eremophila alpestris*
Prairie falcon	*Falco mexicanus*
Yellow-breasted chat	*Icteria virens*
Northern oriole	*Icterus galbula*
Rock wren	*Salpinctes obsoletus*
Mountain bluebird	*Sialia currucoides*
Meadowlark	*Sturnella neglecta*
Brown thrasher	*Toxostoma rufum*
House wren	*Troglodytes aedon*
Mourning dove	*Zenaida macroura*
Migratory Waterfowl	
Canada geese	*Branta canadensis*
Snow geese	*Chen hyperborean*
Mallard	*Anas platyrhynchos*
Fish	
Longnose sucker	*Catostomus catostomus*
White sucker	*Catostomus commersoni*
Lake herring	*Coregonus artedii*
Northern pike	*Esox lucius*
Burbot	*Lota lota*
Shorthead redhorse	*Moxostoma macrolepidotum*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum*
Amphibians	
Tiger salamander	*Ambystoma tigrinum*
Chorus frog	*Pseudacris triseriata*
Northern leopard frog	*Rana pipiens*
Plains spadefoot*	*Spea bombifrons*
Reptiles	
Plains hognose snake*	*Heterodon nasicus*
Garter snake	*Thamnophis sirtalis*

compiled from Achuff 1992; Blaikie 2005; Epp and Johnson 1980; Fehr 1984; Gibson 2001; Grekul 2007.

* denotes rare or endangered species
◆ indicates species historically present on southern Canadian Plains

APPENDIX III: FATTY ACID NOMENCLATURE AND FUNCTIONAL GROUP IDENTIFICATION

FATTY ACID NOMENCLATURE

Microbial PLFAs typically have chain lengths between 10-20 carbons long (Haack et al. 1994; Hannam et al. 2006). Fatty acids are named using the basic form A:BωC, where A is the number of carbons in the molecule chain; B is the number of double bonds; and C is distance of the closest double bond from the methyl end (CH_3^-, indicated by [ω]) of the molecule. Other prefixes and suffixes may be added to this basic structure; these represent various configurations and branching of the fatty acid molecule (DeGrood et al. 2005; Federle 1986).

For example, the unsaturated fatty acid 16:1ω7 indicates a Gram (-) bacteria. The fatty acid consists of a chain of 16 carbons with one double bond occurring after the seventh carbon from the methyl end of the chain. Saturated fatty acids indicate Gram (+) bacteria, for example 17:0 ANTE. In this example, a chain of 17 carbons makes up the fatty acid. It has no double bonds, therefore it is saturated, and the 'ANTE' signifies a methyl group (CH_3^-) occurring at the third carbon from the methyl end of the chain.

PLFAs USED AS BIOMARKERS FOR FUNCTIONAL GROUP IDENTIFICATION
(after DeGrood et al. 2005)

Gram (-) bacteria (monounsaturated fatty acids)	A:1ωC
Gram (+) bacteria (saturated fatty acids)	A:0 (ISO, ANTEISO, 10 methyl)
Fungi	18:3 ω6c (6, 9, 12) 18:2 ω6,9c
Actinomycetes	16:0 10 methyl 18:0 10 methyl

APPENDIX IV: MICROBIAL FUNCTIONAL GROUP CALCULATIONS

(from DeGrood et al. 2005)

Total biomass	Sum of all fatty acids
% Gram (-)	A:1ωC / total biomass
% Gram (+)	A:0(ISO, ANTEISO, 10 methyl) / total biomass
% Fungi	[18:3ω6c (6,9,12) + 18:2ω6,9c] / total biomass
% Actinomycetes	16:0 10 methyl + 18:0 10 methyl / total biomass
Fungal/Bacterial biomass	18:2ω6,9c / 15:0 ISO + 15:0 ANTEISO + 15:0 + 16:0 ISO + 16:1ω5c + 17:0 ISO + 17:0 ANTEISO + 17:0 CYCLO + 17:0 + 18:1ω7c
Gram (-) / Gram (+):	A1ωC / A:0(ISO, ANTEISO, 10 methyl)

APPENDIX V: CHEMICAL DATA FOR SOIL PROFILES

Results for South L2

Unit	Soil	Horizon	Depth (cm)	% Organics	% $CaCO_3$	% C	% N	C:N
D	1	Ah	0-8	7.49	0.58	3.07	0.26	12
C	2	IIAhb	8-16	4.35	0.50	2.08	0.21	10
		IICb1	16-39	1.43	0.35	0.63	0.06	11
		IICb2	39-55	0.39	0.23	0.10	0.01	8
		IICb3	55-60	1.22	0.37	0.55	0.05	11
B	3	IIIAhb2	60-65	1.83	0.45	0.93	0.08	12
		IIIAeb	65-70	0.83	0.36	0.27	0.03	10
		IIIBmb	70-95	0.55	0.26	0.16	0.02	9
A		IVCb	95-101	2.02	1.88	0.30	0.04	8

Unit	Soil	Horizon	Depth (cm)	% P	Extractable P (mg/kg)	Total cations ($cmol_c$/kg)	CEC ($cmol_c$/kg)
D	1	Ah	0-8	0.044	67.86	12.31	10.83
C	2	IIAhb	8-16	0.065	95.74	12.13	9.98
		IICb1	16-39	0.028	73.05	4.60	3.22
		IICb2	39-55	0.020	43.48	1.95	1.32
		IICb3	55-60	0.034	87.27	5.49	4.22
B	3	IIIAhb2	60-65	0.045	121.27	8.05	6.32
		IIIAeb	65-70	0.032	94.68	4.42	3.28
		IIIBmb	70-95	0.027	69.18	3.53	2.50
A		IVCb	95-101	0.057	71.68	14.25	11.81

Unit	Soil	Horizon	Depth (cm)	Na ($cmol_c$/kg)	K ($cmol_c$/kg)	Mg ($cmol_c$/kg)	Ca ($cmol_c$/kg)
D	1	Ah	0-8	0.07	0.53	1.74	9.97
C	2	IIAhb	8-16	0.08	0.28	1.00	10.78
		IICb1	16-39	0.07	0.19	0.44	3.89
		IICb2	39-55	0.06	0.18	0.16	1.55
		IICb3	55-60	0.07	0.34	1.02	4.06
B	3	IIIAhb2	60-65	0.07	0.35	0.73	6.91
		IIIAeb	65-70	0.08	0.32	0.84	3.18
		IIIBmb	70-95	0.12	0.26	0.65	2.50
A		IVCb	95-101	0.14	0.74	3.32	10.05

Results for North L2

Unit	Soil	Horizon	Depth (cm)	% Organics	% $CaCO_3$	% C	% N	C:N
C	1	Ah	0-11	2.71	0.35	2.35	0.20	12
B	2	IIAhb	11-18	3.43	0.37	1.54	0.15	10
		IIBmbg1	18-25	1.02	0.28	0.76	0.06	12
		IIBmbg2	25-35	-	-	-	-	-
		IICbg1	35-50	0.52	0.23	0.13	0.02	9
		IICbg2	50-189	0.5	0.32	0.10	0.01	7

Unit	Soil	Horizon	Depth (cm)	% P	Extractable P (mg/kg)	Total cations ($cmol_c$/kg)	CEC ($cmol_c$/kg)
C	1	Ah	0-11	0.087	107.27	11.98	9.52
B	2	IIAhb	11-18	0.177	322.56	8.14	6.83
		IIBmbg1	18-25	0.050	110.46	7.12	4.10
		IIBmbg2	25-35	-	-	-	-
		IICbg1	35-50	0.030	80.84	2.74	1.77
		IICbg2	50-189	0.042	119.30	4.75	3.69

Unit	Soil	Horizon	Depth (cm)	Na ($cmol_c$/kg)	K ($cmol_c$/kg)	Mg ($cmol_c$/kg)	Ca ($cmol_c$/kg)
C	1	Ah	0-11	0.06	0.48	1.04	10.40
B	2	IIAhb	11-18	0.05	0.25	0.54	7.30
		IIBmbg1	18-25	0.06	0.35	0.47	6.24
		IIBmbg2	25-35	-	-	-	-
		IICbg1	35-50	0.06	0.18	0.30	2.19
		IICbg2	50-189	0.06	0.28	0.67	3.74

Note: no data are available for the IIBmbg2 horizon.

Results for L19

Unit	Soil	Horizon	Depth (cm)	% Organics	% $CaCO_3$	% C	% N	C:N
C	1	Ah	0-8	1.38	0.28	0.64	0.06	10
B	2	IIAhb	8-13	1.43	0.29	0.62	0.05	13
		IICbg1	13-40	0.47	0.24	0.11	0.01	8
		IICbg2	40-56	0.46	0.24	0.31	0.02	18
A	3	IIIAhbg	56-68	0.96	0.39	0.38	0.03	12
		IIICbg3	68-186	0.61	0.34	0.10	0.01	8

Unit	Soil	Horizon	Depth (cm)	% P	Extractable P (mg/kg)	Total cations ($cmol_c$/kg)	CEC ($cmol_c$/kg)
C	1	Ah	0-8	0.020	21.00	2.79	2.81
B	2	IIAhb	8-13	0.021	29.48	3.18	2.68
		IICbg1	13-40	0.018	29.54	1.77	1.26
		IICbg2	40-56	0.019	36.94	1.97	1.36
A	3	IIIAhbg	56-68	0.035	48.24	6.22	4.53
		IIICbg3	68-186	0.015	24.52	2.89	1.95

Unit	Soil	Horizon	Depth (cm)	Na ($cmol_c$/kg)	K ($cmol_c$/kg)	Mg ($cmol_c$/kg)	Ca ($cmol_c$/kg)
C	1	Ah	0-8	0.05	0.24	0.48	2.01
B	2	IIAhb	8-13	0.05	0.16	0.40	2.57
		IICbg1	13-40	0.05	0.13	0.27	1.32
		IICbg2	40-56	0.06	0.15	0.35	1.42
A	3	IIIAhbg	56-68	0.06	0.27	1.03	4.86
		IIICbg3	68-186	0.06	0.20	0.52	2.11

Results for Offsite

Unit	Soil	Horizon	Depth (cm)	% Organics	%$CaCO_3$	% C	% N	C:N
C	1	Ah	0-10	3.48%	0.65%	1.53	0.14	11
B	2	IIAhb	10-16	5.11%	0.84%	2.17	0.19	12
		IIBmb	16-25	2.27%	0.57%	1.00	0.10	10
		IIBCb	25-40	1.66%	0.51%	0.62	0.06	10
A		IIICb	40-55	4.31%	1.61%	0.57	0.06	9
		IIICcab	55-83	3.91%	4.00%	1.10	0.04	27

Unit	Soil	Horizon	Depth (cm)	% P	Extractable P (mg/kg)	Total cations ($cmol_c$/kg)	CEC ($cmol_c$/kg)
C	1	Ah	0-10	0.033	14.41	6.91	5.85
B	2	IIAhb	10-16	0.034	13.34	10.39	9.08
		IIBmb	16-25	0.030	8.43	5.51	4.55
		IIBCb	25-40	0.027	10.68	4.83	3.68
A		IIICb	40-55	0.033	1.12	19.73	15.07
		IIICcab	55-83	0.050	0.83	35.30	13.09

Unit	Soil	Horizon	Depth (cm)	Na ($cmol_c$/kg)	K ($cmol_c$/kg)	Mg ($cmol_c$/kg)	Ca ($cmol_c$/kg)
C	1	Ah	0-10	0.06	0.62	1.48	4.76
B	2	IIAhb	10-16	0.07	0.65	1.51	8.16
		IIBmb	16-25	0.07	0.46	1.03	3.95
		IIBCb	25-40	0.06	0.43	1.10	3.23
A		IIICb	40-55	0.21	0.70	7.75	11.07
		IIICcab	55-83	0.25	0.69	6.73	27.64

APPENDIX VI: THIN SECTION MICROMORPHOLOGY DESCRIPTION

South L2 Profile, Unit B, Soil 3
Horizon IIIAhb2

Thin Section: TS7 H7 U22
Depth: 63-69 cm DBS
Vertical thin section
Size: about 29 cm^2
Thickness: about 30 μm

Microstructure and porosity
Intergrain microaggregate crumb microstructure; randomly arranged; nonaccommodating complex packing voids dominant.

Groundmass:
$c/f_{60\mu m}$ ratio: varies from 1/1 to 3/1; c/f-related distribution pattern: single spaced fine chito-enaulic.

Coarse material:
<u>*Mineral:*</u> well-sorted polymyctic sand with randomly distributed constituents: subangular quartz grains very dominant (m.s., 70-80% of coarse fraction); few subrounded chert grains (m.s., 10-15%); few rounded to subrounded quartz aggregates (m.s.-c.s., 5-10%); very few rounded to subrounded feldspar grains (m.s., 1-2%); very few subrounded hornblende grains (m.s., 1-2%); rare subrounded microcline grains (m.s., <1%); rare chalcedony grains (m.s., <1%); 1 rounded grain of calcareous sandstone (f.g.); 1 possible earthworm biospheroid (m.s.)
<u>*Organic:*</u> very few randomly distributed fresh roots and plant tissues (c.s.-v.c.s., 1-2% of coarse fraction); very few moderately humified plant tissues and root fragments (m.s., 1%); rare well-humified plant tissues (m.s.-c.s., <1%)

Micromass: randomly oriented polymorphic amorphous organic material (s.s.-m.s.), very dark gray to very dark brown and black, with opaque black punctuations, crumb microstructure and undifferentiated to stipple-speckled b-fabric.

Pedofeatures

♦Dusty, nonlaminated, discontinuous Fe and amorphous organic coatings (s.s.) on mineral grains common(10-20% of total minerals). Coatings predominantly on chert and quartz aggregate grains (30-40% are coated). Color ranges from reddish yellow to reddish brown and black.

♦Few organo-mineral accumulations (5-12 μm) near top of slide, increasing to frequent near middle and bottom of slide.

♦Red (10R 4/8) Fe coating on mineral grain (v.c.s.), lower right corner (area 5).

♦Large subrounded quartz aggregate (f.g.) with intermineral crack (25-30 μm wide), lined with dusty clay coating up to 10 μm thick.

North L2 Profile, Unit B, Soil 2
Horizon IIAhb

Thin Section: TS19 H3 U12
Depth: 8-14 cm DBS
Vertical thin section
Size: about 30 cm^2
Thickness: about 30 μm

Microstructure and porosity
Intergrain microaggregate crumb microstructure; randomly arranged; nonaccommodating complex packing voids dominant.

Groundmass
c/f $_{50\mu m}$ratio: varies from 3/1 to 7/1; c/f-related distribution pattern: single spaced fine chito-enaulic.

Coarse material:

Mineral: well-sorted polymyctic sand with randomly distributed constituents: dominated by subangular grains of quartz (m.s., 60-70% of coarse fraction); frequent subrounded chert grains (m.s., 20-30%); very few subangular quartz aggregates (m.s., 1-2%; c.s. 1-2%); very few subrounded grains of feldspar (m.s., 1-2%); very few subrounded grains of hornblende (m.s., 1-2%); rare subrounded grains of microcline (c.s., <1%); rare subrounded grains of chalcedony (m.s., <1%);

1 piece of very fine-grained subangular vesicular chert, mudstone or devitrified obsidian (2 mm x .319 mm size; rounded vesicles 0.029-0.1 mm size).

Angular bone fragments (c.s.-f.g., 10%; f.s.-m.s., 4%), 30% of which are stained to varying degrees with Fe; bone presence increases near middle and bottom of slide.

1 angular pottery fragment (approx. 8.8 x 3.4 mm) lower left of slide:

c/f $_{60\mu m}$ (pottery): 1/1; c/f-related distribution pattern: double spaced porphyric; primary constituents are clays, silts, dominant quartz grains (f.s.-c.s., 50-60%); few grains of subrounded chert (m.s., 10%); few grains of quartz aggregate (m.s., 5%); few unhumified angular plant remains (c.s., 5%); rounded voids (f.s., 10%)) and planar voids (v.c.s., 15%)) common.

<u>Organic</u>: Randomly distributed fresh plant tissues (m.s.-f.g., 5-10% of coarse fraction); reddish brown to brown humified plant remains (m.s., 1-2%). Charcoal (f.s.-m.s.) increases from 0% at top to 5% at bottom of slide.

Micromass: randomly oriented polymorphic amorphous fine organic material (s.s.-v.f.s.), black to dusty red, with opaque black punctuations, crumb structure and undifferentiated b-fabric.

Pedofeatures

♦dusty, nonlaminated, discontinuous Fe and amorphous organic coatings (s.s.) on mineral grains (15% of total minerals), predominantly on chert grains and quartz aggregates. Color ranges from strong brown to dark reddish brown to yellow.

Table VIIa. Size Classes Used in Micromorphological Description

Abbreviations	Size class	Size limits (mm)
c.	Clay	<0.002
s.s.	Silt	0.002-0.063
v.f.s.	Very fine sand	0.063-0.1
f.s.	Fine sand	0.1-0.2
m.s.	Medium sand	0.2-0.5
c.s.	Coarse sand	0.5-1
v.c.s.	Very coarse sand	1-2
f.g.	Fine gravel	>2

adapted from Stoops (2003), Wentworth (1922)

Note: all colors described in oblique incident light (OIL)

Figures VIIa and VIIb are maps of each of the thin sections, referred to in tables VIIb and VIIc, respectively, which provide summaries of the micromorphological properties of these samples.

Figure VIIa. Map of Thin Section, South L2: Unit B, Soil 3, Horizon IIIAhb2

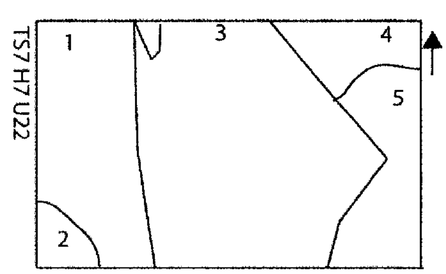

Table VIIb. Summary of Micromorphological Properties, South L2: Unit B, Soil 3, Horizon IIIAhb2

South L2 Profile: Unit B, Soil 3, Horizon IIIAhb2

	Coarse mineral material										Coarse organic material			Fine organic material	Pedofeatures					
Area	Quartz	Chert	Quartz aggregate grains	Feldspar	Hornblende	Microcline	Chalcedony	Other lithic	Animal bone	Pottery	Humified organic material	Roots	Charcoal	Amorphous (black to very dark brown)	Fe coatings on mineral grains	Textural (clay coatings)	Microstructure	Coarse material arrangement	Groundmass B fabric	Related distribution
1	******	**	**	*	*	.	.	–	–	–	.	.	–	****	**	?	crumb	random	?	single-spaced fine chito-enaulic
2	******	**	**	*	*	.	.	–	–	–	.	.	–	****	**	?	crumb	random	?	single-spaced equal chito-enaulic
3	******	**	**	*	*	.	.	.	–	–	*	*	–	**	***	**	crumb	random	undifferentiated to stipple-speckled	chitonic and single spaced equal chito-enaulic
4	******	**	**	*	*	.	.	–	–	–	.	.	–	****	**	?	crumb	random	?	chitonic and single spaced fine enaulic
5	******	**	**	*	*	.	.	.	–	–	.	.	–	****	**	?	crumb	random	?	single-spaced equal chito-enaulic

Abundance classes (adapted from Stoops [2003]): ******Very dominant (.70%); *****Dominant (50-70%); ****Frequent (30-50%); ***Common (15-30%); **Few (5-15%); *Very few (<5%); . Rare (<1%); ? Unable to determine due to quality of slide

Figure VIIb. Map of Thin Section, North L2: Unit B, Soil 2, Horizon IIAhb

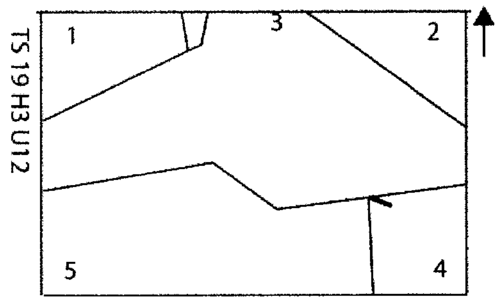

Table VIIc. Summary of Micromorphological Properties, North L2: Unit B, Soil2, Horizon IIAhb

North L2 Profile: Unit B, Soil 2, Horizon IIAhb

	Coarse mineral material									Coarse organic material			Fine organic material	Pedofeatures					
Area	Quartz	Chert	Quartz aggregate grains	Feldspar	Hornblende	Microcline	Chalcedony	Other lithic	Animal bone	Pottery	Humified organic material	Roots	Charcoal	Amorphous (black to dusty red)	Fe coatings on mineral grains	Textural (clay coatings)	Microstructure	Coarse material arrangement	Groundmass B fabric	Related distribution
1	*****	****	*	*	*	.	.		.		*	*		**	**	-	crumb	random	-	single-spaced fine chito-enaulic
2	*****	****	*	*	*	.	.		*		*	*		**	**	-	crumb	random	-	single-spaced fine chito-enaulic
3	*****	****	*	*	*	.	.		**		*	*	*	*	**	***	crumb	random	-	single-spaced fine chito-enaulic
4	*****	****	*	*	*	.	.	*	*		*	*	**	**	**	-	crumb	random	-	single-spaced fine chito-enaulic
5	*****	****	*	*	*	.	.		*	*	*	*	*	**	**	-	crumb	random	-	single-spaced fine chito-enaulic

Abundance classes (adapted from Stoops [2003]): ******Very dominant (.70%); *****Dominant (50-70%); ****Frequent (30-50%); ***Common (15-30%); **Few (5-15%); *Very few (<5%); . Rare (<1%)