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ARTICLE

Late Holocene temporal constraints for human occupation levels at the Bodo archaeological locality, east-central Alberta, Canada using radiocarbon and luminescence chronologies

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The Bodo Archaeological Locality in east-central Alberta is one of the largest precontact (prehistoric) archaeological sites in the Canadian Prairie

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Ecozone. Situated at the transition between the aspen parkland and fescue grassland regions within a postglacial eolian dune landscape, the site has the potential to add to existing understandings of cultural–environmental dynamics as they relate to late Holocene hunter-gatherer settlement and subsistence patterns in the region. To that end, we present a composite stratigraphy for the locality constructed from five separate sampling pits, obtaining chronological control using accelerator mass spectrometry radiocarbon and luminescence ages. We identify three main periods of landscape stability and associated human occupation during the late Holocene: 750 to 400 cal B.C., 750 to 1000 cal A.D., and 1450 to 1750 cal A.D. Early Holocene eolian activity is documented, but the mid-Holocene stratigraphic record is absent, suggesting extensive sediment reworking. Evidence also exists of major cultural landscape changes that coincide with the arrival of Euro-Canadians.

KEYWORDS Bodo, eolian, northern Great Plains, Prairie Ecozone, radiocarbon, luminescence

Throughout the Holocene, ecologically diverse environments in the Prairie Ecozone of western Canada (Figure 1) have provided a broad spectrum of exploitable resources (food, water, and fuel), which sustained human populations during environmentally productive periods as well as during times of stress (Nicholson and Wiseman 2006; Vickers and Peck 2004). Abundant archaeological sites in the region bear testimony to this human presence (Peck 2011; Running et al. 2007; Wiseman and Graham 2007). The Bodo archaeological locality, located in the Bodo Sand Hills at the transition between the Aspen/Central Parkland and Northern Fescue Grassland regions in east-central Alberta (Achuff 1992, 1994) is among these ecologically rich, geomorphologically diverse locales, featuring a range of readily exploitable resources that undoubtedly made it an ideal location for human habitation (e.g., Boyd et al. 2006; Running et al. 2002; Townley-Smith 1980). However, as Boyd et al. (2006) point out, cultural–environmental dynamics as they relate to late Holocene hunter-gatherer settlement and subsistence patterns in the Prairie Ecozone are relatively poorly understood, and there are few well-documented sites with associated chronometric ages in the published literature. Interdisciplinary research through the SCAPE project (Study of Cultural Adaptations within the Prairie Ecozone; Nicholson 2011; Nicholson and Wiseman 2006) has attempted to address this lacuna for much of the Prairie region in southern Alberta, Saskatchewan, and Manitoba. Accordingly, a study of human–environmental dynamics in the Bodo Sand Hills region situated at the northern boundary of the Prairie Ecozone would provide valuable data for comparison with the SCAPE sites.

The first archaeological site identified in the Bodo area (FaOm-1; Figure 1) was recorded when excavation work for petroleum pipeline development in the Bodo Sand Hills resulted in the discovery of the Bodo Bison Skulls site in 1995 (Gibson et al. 1998). Subsequent work in 2000 in areas adjacent to the initial find (McKeand and Gibson 2000) led to the realization that the artifact distribution

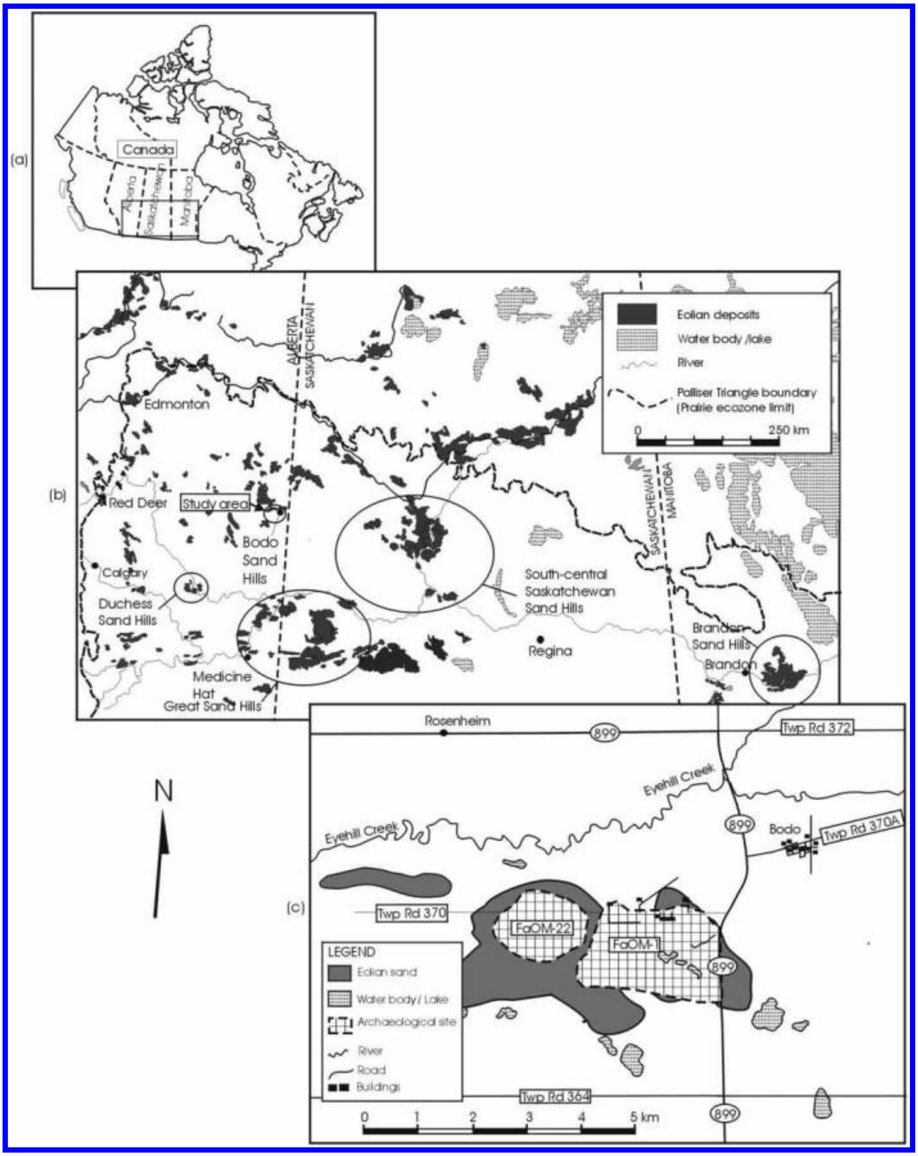

FIGURE 1 The Prairie Ecozone in western Canada. (a) Location of the Prairie Ecozone; (b) limits of the Palliser Triangle covering parts of east central and southeastern Alberta, southern Saskatchewan and southwestern Manitoba (Muhs and Wolfe 1999), and (c) the Bodo region including the sites FaOm-1 and FaOm-22.

was extensive, exhibiting a range of archaeological finds that included bison bones, pottery, and numerous projectile points. After detailed excavation in 2001 yielded evidence of a dense occupation living floor located hundreds of meters from the excavations undertaken in 2000 (Gibson and Grekul 2010), the University of Alberta was urged to consider the site's potential as a teaching and research locality. As a result, the University initiated its archaeological field school at the Bodo

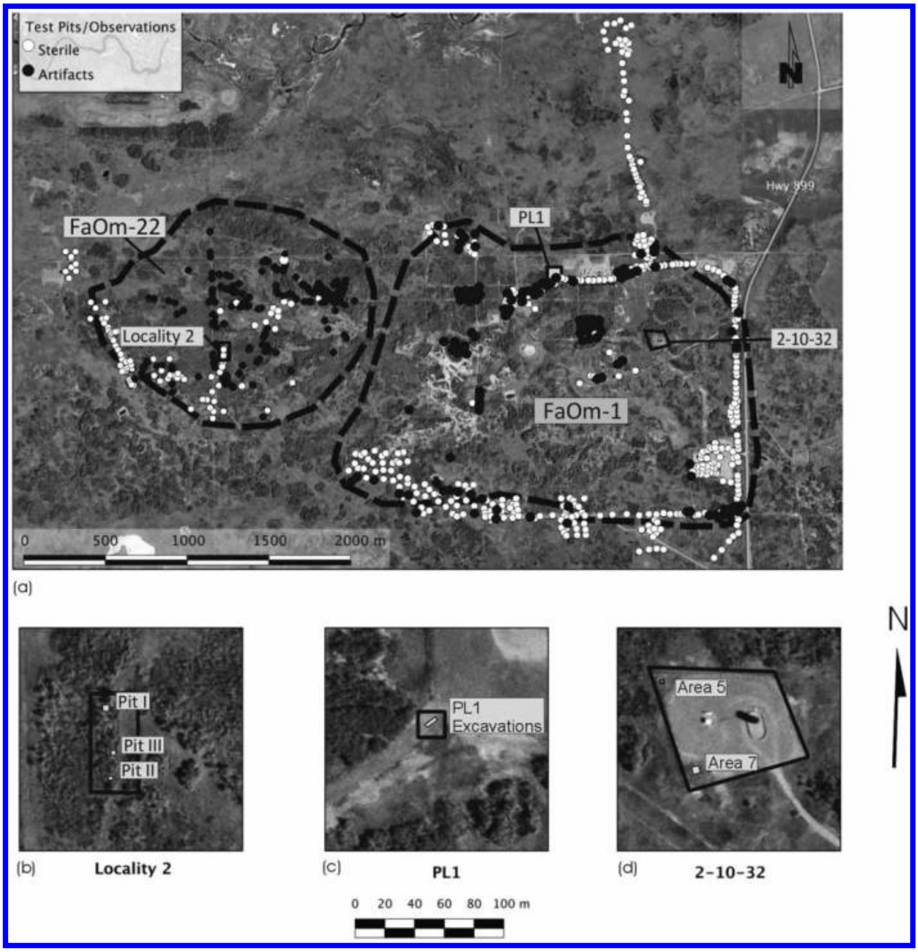

FIGURE 2 The Bodo archaeological locality. (a) Shovel tested areas with artifact recoveries in FaOm-1 and FaOm-22. (b–d) Location of sites selected for excavation in this study. Pits I–III (b) are located in FaOm-22 (Gilliland 2007). PL1 (c), Areas 7, and 5 (d) in FaOm-1 were excavated by Gibson in 2000 and 2001. Areas 7 and 5 at 2–10–32 were analyzed in detail by Blaikie (2005) and Grekul (2007), respectively. PL1 was analyzed in detail by Grekul et al. (2009) and Gibson and Grekul (2010).

archaeological locality in 2002. The increased archaeological activities at the site resulted in the discovery of the Bodo Overlook Site (FaOm-22) adjacent to FaOm-1 (Figures 1 and 2). Surface finds at FaOm-22 suggested the presence of more deeply buried artifacts diagnostic of older occupations.

Additional excavations between 2004 and 2005 in areas adjacent to FaOm-1 and at FaOm-22 led to the tentative identification of three main occupation levels at Bodo. The uppermost of these is a cultural level identified at both FaOm-1 and FaOm-22. Diagnostic projectile points and pottery fragments suggest a late pre-Euro-Canadian contact period (hereafter prehistoric) occupation (850 to 1700 cal A.D.) consistent with the Old Women's and Mortlach phases in the northern Plains cultural sequence (Dyck and Morlan 1995; Vickers 1986). In isolated places, a middle occupation level is also present and was initially thought to be compatible with the Oxbow phase of the northern Plains typology (about 2550 to 2150 cal B.C.; Dyck 1977). However, subsequent analysis of associated points suggests they represent a Sandy Creek occupation, about 550 cal B.C. (Dyck and Morlan 1995; Wettlaufer 1955). Surface finds suggested a third occupation level, with artifacts initially identified as of Oxbow and Duncan typology (2650 to 1050 cal B.C.; Vickers 1986). However, this tentative occupation has yet to be identified in a stratigraphic context at FaOm-1 or at FaOm-22. When recovered in stratigraphic context, artifacts are frequently associated with buried soils representing periods of past stability; these are intercalated with accumulations of eolian sands pointing to intervening periods of landscape instability.

Despite the considerable early work at Bodo and the emergence of the locality as one of the largest prehistoric archaeological sites in western Canada, the stratigraphic context at the sites remains poorly defined and the cultural levels identified hitherto are still to be dated precisely. To address this deficit, our study carries out a detailed analysis of the stratigraphy at Bodo and develops a radiocarbon and luminescence-based chronology for the geomorphic evolution of the landscape. In doing so, we establish the environmental and temporal context of human occupation at the site and help shed better insights on human–environment interactions in the Prairie Ecozone. In particular, our work addresses questions relating to the environmental conditions during periods of occupation at Bodo, as well as the timing of the occupations. It also looks at how the record of cultural–environmental interactions at the site compares with the other records for the Prairie Ecozone. Furthermore, the research has broader implications regarding interpreting past environmental changes and cultural activities in eolian dune environments on the Northwestern Plains and outlines protocols that could be employed in developing chronological frameworks in eolian settings.

To help contextualize the archaeological terminology used in this paper, Table 1 outlines the culture-historical model used for classifying material cultures in the

TABLE 1

CULTURE HISTORICAL MODELS FOR ALBERTA AND THE NORTHWESTERN PLAINS (AFTER PECK 2011)

Period	Phase(s)		Cal years B.P.	Cal years B.C./A.D.
Protohistoric	Old Women's	Mortlach	250–0	1700–1950 A.D.
Late			600–250	1350–1700 A.D.
	Old Women's		1100–600	850–1350 A.D.
	Avonlea		1350–1100	600–850 A.D.
Middle	Besant		2100–1500	150 B.C.–450 A.D.
	Pelican Lake/Bracken		2800–2100	850–150 B.C.
		Outlook/Sandy Creek	ca. 2500	ca. 550 B.C.
	Pelican Lake		3600–2800	1650–850 B.C.
	McKean		4200–3500	2550–1550 B.C.
	Oxbow		4500–4100	2550–2150 B.C.
	Mummy Cave		7500–4500	5550–2550 B.C.

While humans are known to have been in Alberta since about 11,000 cal years B.P., for purposes of this study, Table 1 only presents cultures from the last 7,500 years.

southern Canadian Plains region. This model is organized into phases based on projectile point morphology, the rationale being that hunting technology (interpreted from point morphology) changed over time. An absolute scale gives the temporal equivalents.

Study area

The Bodo archaeological locality lies within the Bodo Sand Hills region of east-central Alberta, Canada (Mulira 1986). The locality is situated about 1.5 km southwest of the settlement of Bodo (Figure 1C). Physiographically, the region is part of the northern Great Plains of North America and it is located within confines of the Palliser Triangle, a region that delineates the subhumid and semiarid Prairie Ecozone of central southern Canada (Wolfe et al. 2002b). Soils at the archaeological locality are developed primarily on late Pleistocene glaciofluvial and glaciolacustrine sediments and associated eolian sands originally derived primarily from the local late Cretaceous Belly River Formation. Sediments range in texture from sandy loam to loamy sand, and drainage is good to excellent, resulting in little erosion due to runoff. The Bodo region is situated within the Dark Brown Chernozem soil zone, which is typically associated with semiarid grasslands. Gleysols develop in areas between dunes and where the water table is high (i.e., around seasonal or semi-permanent sloughs). Regosols featuring minimal horizon development are also commonly observed within the locality. Although Euro-Canadian settlers (primarily of Norwegian and German descent) settled in the Bodo region around 1895 A.D. and began cultivation shortly afterward (Borowitz 2007), the area in which the Bodo Archaeological Locality is situated has never been tilled, as it is unsuitable for agriculture due to its irregular topography, sandy nature, and sensitivity to disturbance and erosion (Soil Research Institute 1970). Currently, the Bodo Sand Hills area is used primarily for grazing livestock. Hydrocarbon extraction activities are also common, and recreational activities, such as the use of all-terrain vehicles and dirt bikes, contribute to contemporary destabilization of the landscape.

The archaeological site lies in a basin that forms part of a broad east–west trending depression occupied by the Eyehill Creek, a stream that flows in a valley much larger than its current floodplain. The sand hills in the area comprise eolian dunes which reach heights of up to 8 m, most of which are currently stable. Stabilized blowouts on the dunes point to their intermittent reactivation following their initial formation. Archaeological sites FaOm-1 and FaOm-22 occur within eolian dunes that overlie glaciolacustrine sediments which form the uplands along the southern margin of the valley (Figure 3). These dunes are likely derived from the abundant glacigenic sands and silts in the area that have undergone reworking throughout the early postglacial and Holocene periods (Bayrock 1967; David 1977; Mulira 1986; Shetsen 1990).

Modern lake levels and vegetation patterns in the region were established on the southern Canadian Plains by about 3000 ^{14}C years B.P. (1386 to 1123 cal B.C.; Hickman and Schweger 1993, 1996; Sauchyn and Beaudoin 1998) and Goosebery

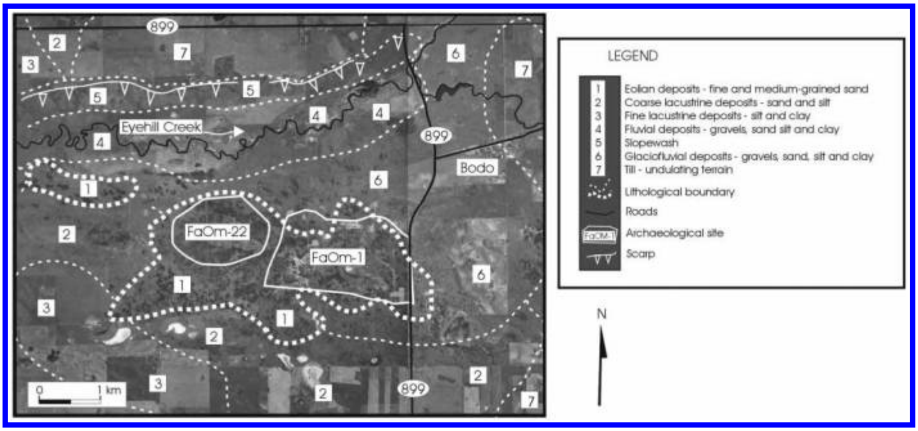

FIGURE 3 Physiography and surficial geology of the area around Bodo (modified from Shetsen 1990).

and Dillbery Lakes represent the largest permanent freshwater sources within the vicinity of the locality. Relict eolian dunes are a common landform in the Prairie Ecozone of western Canada. Together, with associated soils, these provide valuable paleoenvironmental records in eolian settings such as at Bodo. Research in the Palliser Triangle region (Figure 1B), for instance, has employed stratigraphic analysis and luminescence dating of sand dunes, including the Duchess dune field of south central Alberta, the Great Sand Hills, which straddle the boundary between southeast Alberta and southwest Saskatchewan, and dune fields in south-central Saskatchewan (Wolfe et al. 2000, 2001, 2002a). These studies demonstrate that mid-to-late Holocene climates of the region were characterized by oscillations between arid periods, landscape instability, and dune activity on the one hand, and episodes of humidity, landscape stability, and soil formation on the other. Some studies have identified at least seven severe droughts in the Prairie Ecozone during the past 2,500 years (Muhs and Wolfe 1999; Wolfe et al. 2006). However, the timing of these oscillations varies between regions, suggesting that localized conditions, such as groundwater depths, may have had an effect on dune mobilization (Muhs and Wolfe 1999). Excluding the historical period, the most recent periods of drought occurred around 950 to 1050 and 1450 to 1750 cal A.D. (Sauchyn and Beaudoin 1998). However, in addition to environmental change, there may have been other possible causes of landscape destabilization and associated erosion during the prehistoric period. Wolfe et al. (2007) suggest that human activities in sand dune areas prior to the arrival of Euro-Canadians may also have been a factor. The Bodo archaeological locality is thus an ecologically diverse region with a rich archaeological record in a sand dune dominated landscape that is sensitive to both environmental perturbations and cultural disturbances. Thus, it is an ideal study location for increasing understandings of cultural–environmental dynamics not only in the east-central Alberta region but also more broadly within the Canadian Prairie Ecozone (e.g., Nicholson and Wiseman 2007).

Methods

Site selection and sample collection

In this study, we focus primarily on locations within FaOm-22. Surface finds of a Hanna point (Wheeler 1954, part of the McKean complex; Davis and Keyser 1999) in this part of the archaeological locality as well as the identification of occupations thought to have Pelican Lake and Sandy Creek components suggest human occupation of the site extending into the Middle Prehistoric period (Gibson 2004). Additionally, field school excavations at FaOm-22 demonstrated the presence of several intact buried soils, indicating better preservation of the region's stratigraphic record in this part of the locality. Thus, the record from FaOm-22 provides an opportunity to perform reconstructions of environmental changes as well as to characterize associated cultural activities dating to about 4200 cal years B.P. (2250 cal B.C.) or earlier (Table 1).

Three pits (Pits I to III) were excavated in FaOm-22 (Figure 2). Pit I was excavated to a depth of 2.0 m during the 2005 and 2006 field seasons by the University of Alberta archaeological field school. The floor of the trench was then augered to a depth of 2.68 m to obtain sedimentological data for paleoenvironmental interpretation (Gilliland 2007). Pit II was an excavation to the south of Pit 1 and 2 m higher in elevation. This pit was excavated during the 2005 field season to a depth of about 1 m, where gravel and cobbles were encountered (Gilliland 2007). Pit III is located on the slope midway between Pits I and II (Figure 2), and was also excavated during the 2005 field school season. Methods used for excavation followed standard archaeological practices (Barker 1993) and collected artifacts were catalogued following conventional methods (Westman 1994). Interpretation of field stratigraphies (i.e., observed soil horizons and lithological units) guided sampling for bulk sedimentological analyses. Sampling for radiocarbon dating depended on the identification of datable artifacts whilst sampling for luminescence dating was directed at eolian sediment and is elaborated on below.

Sediment grain size and soil chemistry

Samples were analyzed for grain size distribution, pH, organic matter content, and phosphorus (P) concentrations. Standard hydrometer and dry sieving methods were used for grain size analyses (e.g., McKeague 1981). Statistical analyses of the dry sieve measurement results were performed using the GRADISTAT program (Blott and Pye 2001, 2006) and granulometric parameters were determined using the Folk and Ward (1957) method. Soil pH (H_2O) was determined for a 1:2 soil:solution ratio using an Accumet AR20pH/conductivity meter. Organic content was estimated using the loss-on-ignition method (Heiri et al. 2001).

Researchers have found a strong correlation between areas of human activity and P concentrations at archaeological sites (e.g., Dormaar and Beaudoin 1991; Lima et al. 2002; Parnell et al. 2001). Accordingly, the P content was measured for selected samples from Pits I and II. The samples were first ground to a fine powder using a ball-mill grinder and subsequently digested using the Kjeldahl method (Persson et al. 2008). The measurement was conducted using an automated Technicon

Autoanalyzer to determine total P, expressed as a percentage of soil weight (Bremner and Mulvaney 1982; Technicon Industrial Systems 1977).

Radiocarbon dating

To assist in the construction of our chronological framework, bone and one tooth were collected for radiocarbon dating from Pits I to III (Table 2). All samples were analyzed using accelerator mass spectrometry (AMS) at one of three labs: Beta Analytic (Beta, Miami, Florida, USA), Research Laboratory for Archaeology and the History of Art (OxA, Oxford University, UK) or Brock University Radiocarbon Lab (BGS, St. Catharines, Ontario, Canada). The radiocarbon ages were calibrated to calendar years B.C./A.D. with OxCal-4.2 (Ramsey 1995, 2009) using the IntCal04 calibration curve (Reimer et al. 2004) and are reported with a 2-sigma confidence interval. Throughout the paper, calibrated radiocarbon ages are presented in ranges representing the standard error.

A number of radiocarbon ages from Areas 7 and 5 in FaOm-1 constrain the most recent occupation level at the Bodo Archaeological Locality and are discussed here to enable the contextualization of the radiocarbon data from FaOm-22 (Figure 2; Blaikie 2005; Grekul 2007).

Luminescence dating

Optically stimulated luminescence (OSL) dating has developed over the last two decades into one of the methods of choice for dating eolian sediments (Aitken 1998; Wintle 2008). The abundance of eolian sands at the study site and an indication of periodic mobilization of the sands in the stratigraphy suggested that dating the deposits using OSL would provide an alternative chronological framework to that obtained from radiocarbon ages. The basics of luminescence dating and the types of measurements performed to obtain ages from samples collected in this study are briefly outlined below.

Principles of luminescence dating

Luminescence dating employs the characteristics of minerals such as quartz and feldspar to accumulate trapped charge resulting from exposure to energy emanating from the decay of radioactive isotopes within the surrounding sediment and incoming cosmic radiation (Aitken 1998; Lian 2007). Exposure to sunlight zeros any accumulated luminescence signal; therefore, the technique dates the last time sediment was exposed to light, presumably during transport prior to burial (e.g., Aitken 1998). The luminescence signal measured in the lab is proportional to the length of burial and environmental dose rate the sample was exposed to during burial (e.g., Aitken 1998; Wintle 2008). OSL ages are calculated by dividing the radiation dose acquired since the last exposure to light (referred to as the equivalent dose) by the dose rate. Recent comprehensive reviews of the luminescence methods have been given by Lian (2007), Rhodes (2011), Rittenour (2008), and Wintle (2008).

TABLE 2

RADIOCARBON DATA FROM THE BODO ARCHAEOLOGICAL LOCALITY (BLAIKIE 2005; GILLILAND 2007; GREKUL 2007)

Site	Lab number	Depth (cm)	Material	$\delta^{13}C$	Conventional ^{14}C age (years B.P.)	Calibrated age (cal years B.C./ A.D.)	Calibrated age probability (%)
Pit I (FaOm-22) (Figure 4)	Beta-214252	20	Bone collagen	–20.7	80 ± 40	1681–1738 A.D.	26.5
						1757–1762 A.D.	0.6
						1803–1937 A.D.	68
	OxA-19986	25	Bone collagen	–18.9	1137 ± 25	783–788 A.D.	0.9
						815–844 A.D.	5.2
						859–983 A.D.	89.3
	OxA-19898	25	Bone collagen	–18.4	1140 ± 33	780–792 A.D.	2.9
						806–984 A.D.	92.5
	Beta-241393	30	Bone collagen	–19.1	950 ± 40	1016–1182 A.D.	95.4
	Beta-214254	55	Bone collagen	–18.9	1100 ± 40	828–839 AD	1.0
						866–1021	94.4
	Beta-214256	70	Bone collagen	–19.4	1180 ± 40	716–744 AD	4.1
						768–971 AD	91.3
Pit II (FaOm-22) (Figure 5)	Beta-214251	15	Bone collagen	–20.6	79 ± 40	1682–1737 AD	26.5
						1758–1761 AD	0.4
						1804–1936 AD	68.6
	Beta-214253	30	Bone collagen	–20.1	930 ± 40	1023–1186 AD	94.5
						1201–1206 A.D.	0.9
	Beta-209522	70–80	Tooth dentine	–19.1	2430 ± 40	753–685- B.C.	19.9
						668–632 B.C.	7.7
						625–611 B.C.	1.8
						597–402 B.C.	66.0
Pit III (FaOm-22) (Figure 6)	Beta-222510	35	Bone collagen	–19.7	1040 ± 40	893–1043 A.D.	93.9
						1106–1118 A.D.	1.5
	Beta-222511	45	Bone collagen	–19.8	1100 ± 40	828–839 A.D.	1.0
						866–1021 A.D.	94.4
Area 7 (FaOm-1) (Figure 7)	BGS-2553	30–40	Bone collagen	–19.3	335 ± 35	1469–1643 A.D.	95.4
	BGS-2554	30–40	Bone collagen	–20.9	203 ± 35	1642–1694 A.D.	27.0
						1727–1813 A.D.	50.4
						1918–1955 A.D.	18.0
	BGS-2557	30–40	Bone collagen	–20.9	198 ± 35	1644–1695 A.D.	25.0
						1726–1814 A.D.	50.7
						1839–1842 A.D.	0.3
						1853–1867 A.D.	1.1
						1918–1955 A.D.	18.3
Area 5 (FaOm-1) (Figure 7)	BGS-2654	10–30	Bone collagen	–18.6	290 ± 40	1482–1666 A.D.	93.3
						1784–1795 A.D.	1.9
	BGS-2655	10–30	Bone collagen	–20.3	460 ± 40	1401–1498 A.D.	93.2
						1508–1511 A.D.	90.2
						1601–1616 A.D.	2.0
	BGS-2656	10–30	Bone collagen	–19.7	330 ± 40	1465–1645 A.D.	95.4
	BGS-2657	10–30	Bone collagen	–20.4	500 ± 40	1320–1351 A.D.	9.6

Stratigraphic positions of the ages are indicated in Figures 5–8. Depth is below surface.

Luminescence sample collection

Samples for luminescence dating were collected by hammering opaque plastic tubes into freshly exposed stratigraphic profiles. Once retrieved, the pipe ends were sealed with light-proof tape to enable transportation without exposure to light. In Pit I, samples were taken from the wall of the excavation at depths of 0.39 m

TABLE 3

LUMINESCENCE DATING RESULTS

Lab number	Depth (m)	K_2O (%)	Th (ppm)	U (ppm)	Cosmic dose (Gyr/ka)	Total dose rate (Gyr/ka)	Equivalent dose (Gyr)	OSL age* (years B.C./A.D.)
USU-901	6.5	1.14 ± 0.03	2.5 ± 0.2	0.7 ± 0.1	0.01 ± 0.01	1.27 ± 0.06	2.10 ± 0.37	350 ± 310 A.D.
USU-902	0.39	1.20 ± 0.03	2.5 ± 0.2	0.7 ± 0.1	0.23 ± 0.02	1.44 ± 0.07	2.48 ± 0.56	290 ± 410 A.D.
USU-903	0.97	1.22 ± 0.03	3.1 ± 0.3	0.9 ± 0.1	0.21 ± 0.02	1.50 ± 0.07	13.48 ± 3.46	6960 ± 2380 B.C.

*OSL ages are reported in years B.C./A.D. to be consistent with calibrated radiocarbon ages.

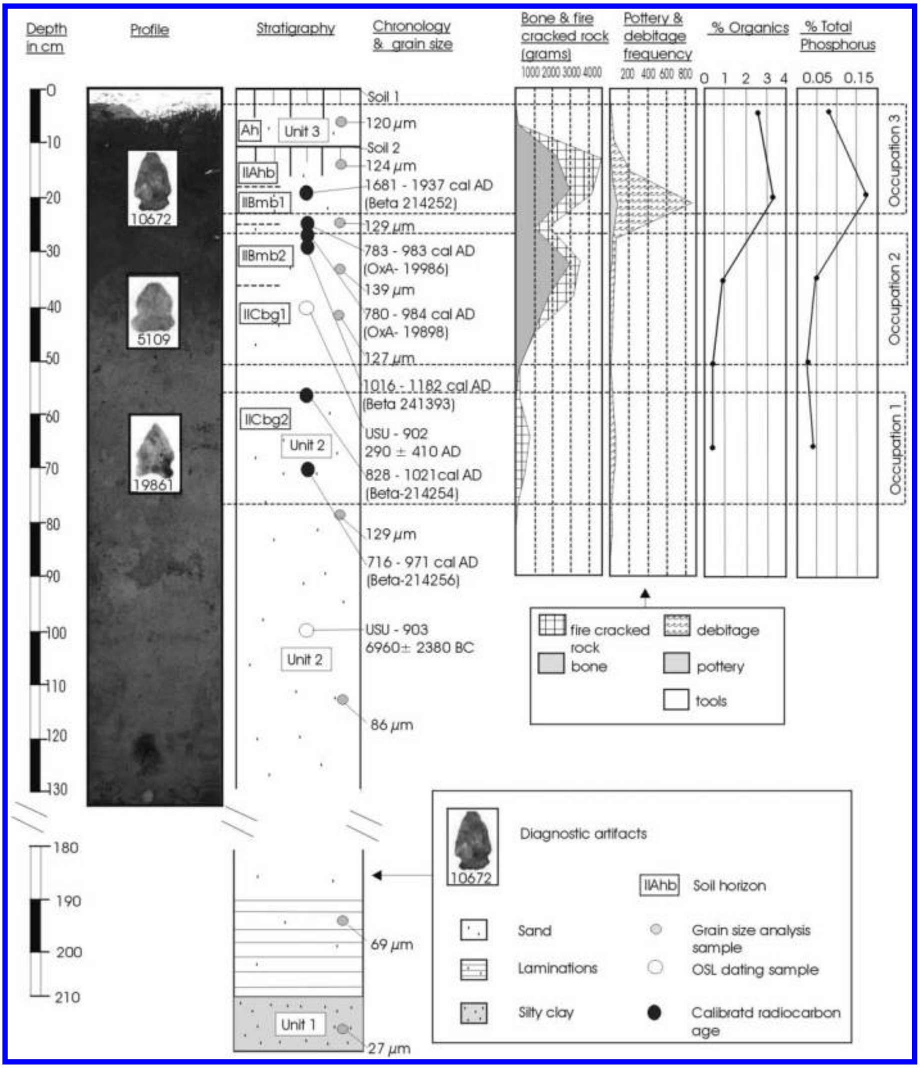

FIGURE 4 Stratigraphy, chronology, and sediment chemistry from Pit I. Projectile point types: 19861-Sandy Creek; 5109-Avonlea; 10672-Late side-notched.

(USU-902) and 0.97 m (USU-903; Figure 4, Table 3). Sampling was also carried out on an 8 m eolian dune located within FaOm-1 (52°08.260′N; 110°07.487′W; USU-901) by drilling using a Dormer Drillmite^{TM} hydraulic auger (e.g., Munyikwa et al. 2011). A sample was extracted for luminescence dating from a depth of 6.5 m from the surface of the dune. All samples for luminescence dating were submitted to the luminescence dating laboratory at Utah State University.

Dose rate determination

To determine the dose rates for each sample the concentrations of U, Th, and K were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) and inductively coupled atomic emission spectroscopy (ICP-AES) techniques and conversion factors from Adamiec and Aitken (1998) and Aitken (1985). The contribution of cosmic radiation to the dose rate was calculated using sample depth, elevation, and latitude/longitude following Prescott and Hutton (1994). Water content was also taken into consideration when calculating the dose rate (Aitken 1998).

Paleodose determination

All luminescence samples were processed in the laboratory under safe light conditions. Processing methods followed standard procedures involving sieving, gravity separation, and acid treatments with HCl and HF to isolate the quartz component in the 90 to 150 µm size range (Aitken 1998; Rittenour et al. 2003, 2005). The purity of the samples was checked by measurement with infra-red stimulation to detect the presence of feldspar.

OSL measurements were performed on the quartz sand separates using a Risø DA-20 system and following the single-aliquot regenerative protocol (Murray and Wintle 2000, 2003; Wintle and Murray 2006). Equivalent dose values were calculated using the Central Age Model of Galbraith et al. (1999). The OSL ages are reported at 2-sigma standard error. In order to align the OSL ages with calibrated radiocarbon ages, the OSL ages are reported as AD/BC.

Results

This section presents, the data used to construct stratigraphic and chronological frameworks that formed the basis of our interpretation of the cultural and environmental dynamics at the Bodo archaeological locality. Results of soil chemical analyses within an archaeological context are examined first, after which a description of the stratigraphy at each of the sampling pits as well as the nature of the artifacts recovered and their distributions are given. The section concludes with a look at the results of the radiocarbon and luminescence age determinations.

Interpretation of soil chemistry

Organic content is typically most abundant in Ah horizons (due to surface accumulations) and decreases with depth. Increases in the abundance of organic material in buried sediments relative to adjacent overlying or underlying material is interpreted here as indicating a buried soil, particularly when in combination with other lines of

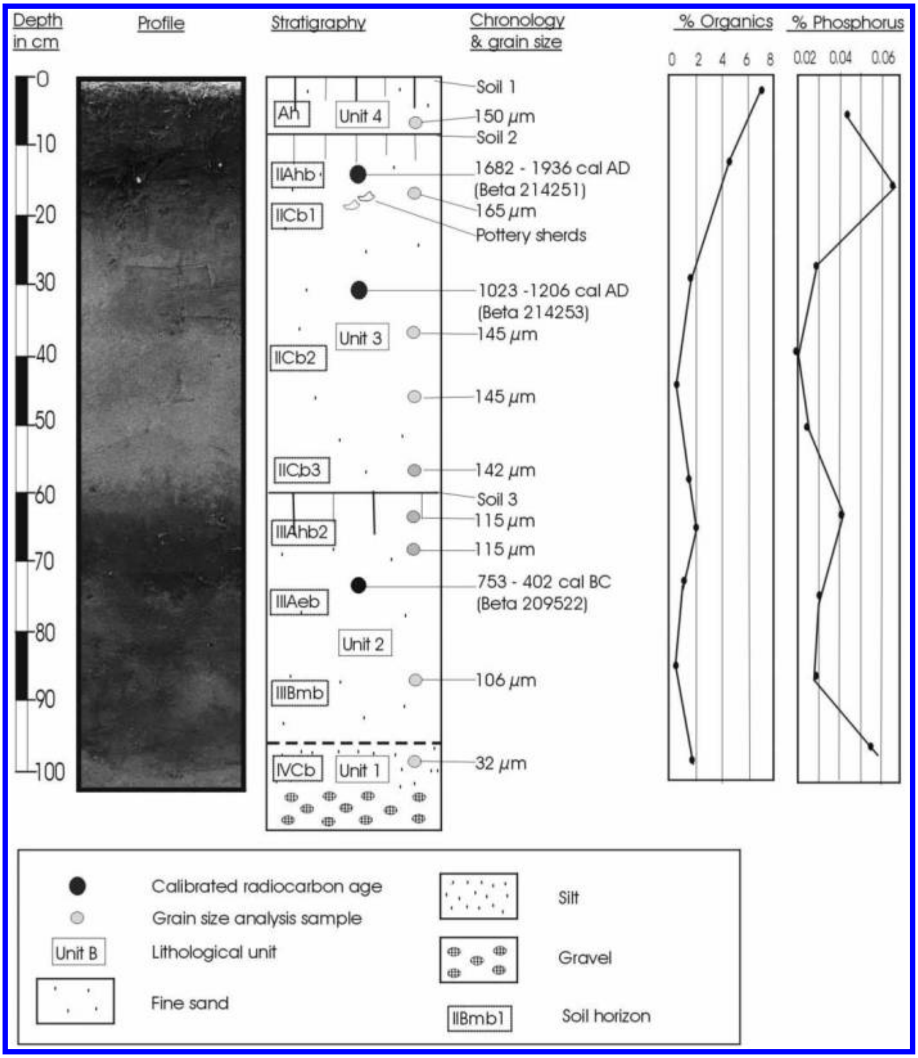

FIGURE 5 Stratigraphy, chronology, and sediment chemistry from Pit II.

evidence, such as the presence of a buried horizontal dark horizon. However, the organic content of buried soils is generally lower than that of surface soils due to losses during leaching and microbial oxidation (Birkeland 1999). Additionally, episodes of landscape destabilization and erosion following soil formation, a process common in aeolian-dominated environments (Wolfe et al. 2002b), frequently results in complete or near-complete removal of surface organic accumulations. Because aeolian processes (including erosion) dominate at Bodo, discontinuous buried soils are expected. Therefore, the buried soils exposed in each of the stratigraphic pits in this study do not necessarily correlate with soils exposed in any of the other pits. Soils are correlated between pits only if there is sufficient evidence linking them (e.g., similar age, observed continuity across the landscape).

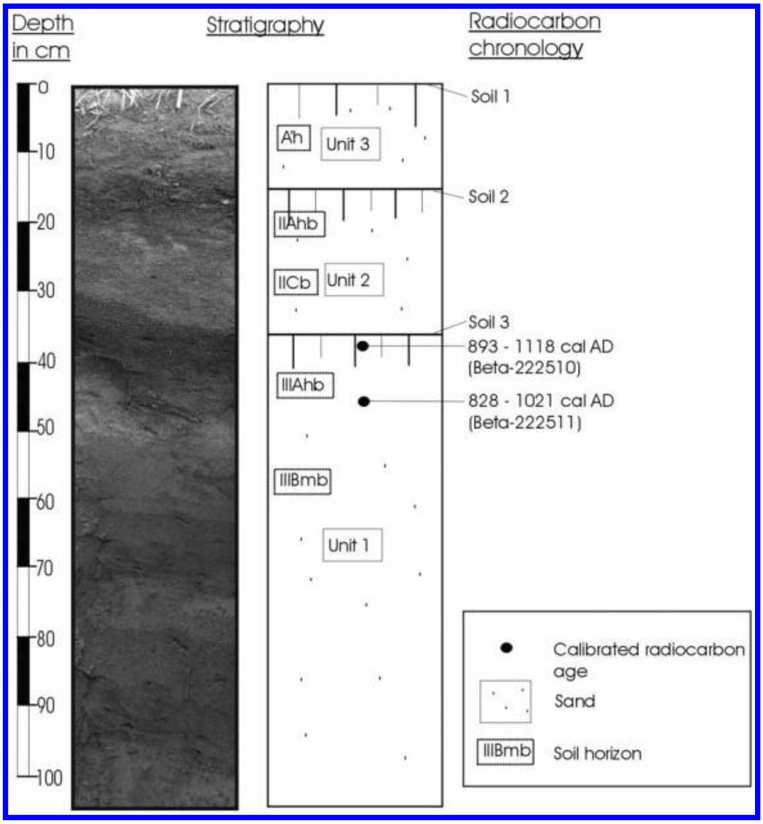

FIGURE 6 Stratigraphy and radiocarbon chronology obtained from Pit III.

Soil P measurements are frequently employed as a tool for interpreting human activities at archaeological sites, even in areas where low artifact concentrations limit archaeological inferences (Parnell and Terry 2002). This is possible because there are few natural sources of soil P (i.e., parent material and soil organic matter), and because P becomes insoluble relatively quickly within most soil environments, although in neutral or near-neutral soils, the tendency for more P in solution means that leaching may occur (Birkeland 1999). Major losses of P from the soil environment occur largely through the removal of surface vegetation (i.e., harvesting), or loss of soil particles during erosion. Non-agricultural human activities that add P to soil include inputs of excrement, bone, and other organic waste (Eidt 1977; Kuo 1996). Given that the area surrounding the Bodo Archaeological Locality has never been cultivated, an increase in soil P over natural levels, in association with buried soil horizons and/or artifact concentrations, is interpreted as reflecting past human behavior (Eidt 1977).

Stratigraphy and identified artifacts

To aid our interpretation of the evolution of the environment of the study area, the stratigraphy observed in the five sampling pits examined in this study is outlined

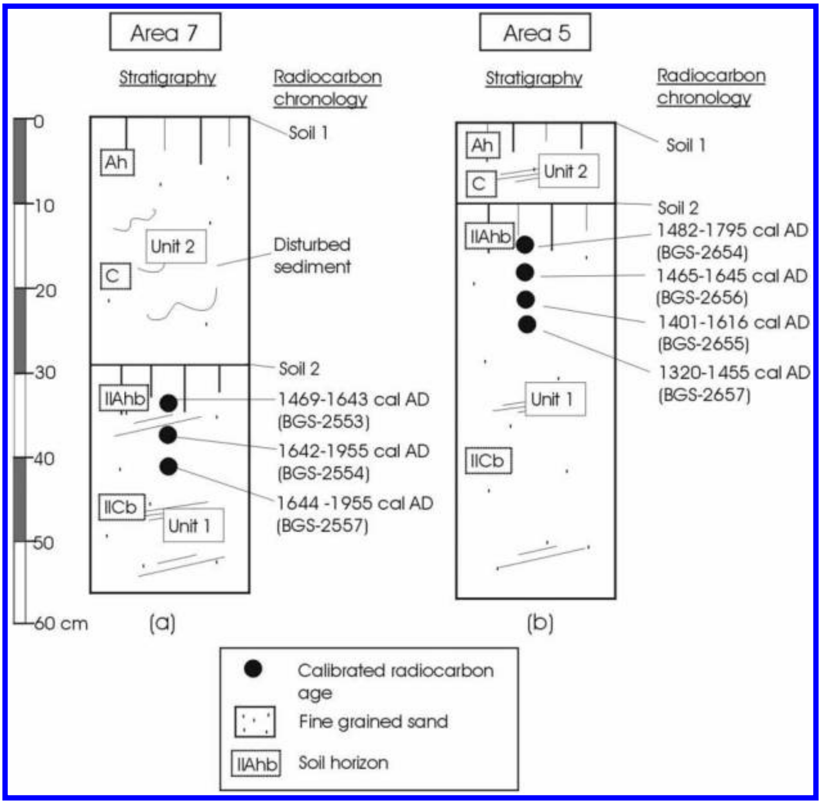

FIGURE 7 Stratigraphy and radiocarbon chronology from Areas 7 and 5 (after Blaikie 2005; Grekul 2007).

below. The discussion focuses first on the three pits located in FaOm-22 (Pits I to III), followed by the two pits excavated in FaOm-1. Also described are the artifacts identified in the respective pits.

FaOm-22 Pit I

Three lithological units (1 to 3) were identified in the stratigraphy at Pit I (Figure 4). The lowermost, Unit 1, 268 to 210 cm below surface (b.s.), consists primarily of poorly sorted silty clay with a mean grain size of 27 μm. Unit 2 overlies Unit 1 and its lower portion (210 to 189 cm b.s.) displays laminations of very fine sand and silt with a mean grain size of 69 μm. The upper portion of Unit 2 (189 to 11 cm b.s.) is composed of moderately to well sorted fine sands in the size range 86 to 139 μm; these are laminated from the depth of 189 to 84 cm b.s. A buried soil (Soil 2) is in the upper part of Unit 2 and the soil has a 10 cm thick Ahb horizon, very dark gray in color (10YR 3/1), resulting from organic enrichment (Gilliland 2007:96). Below the Ahb horizon is a 20 to 30 cm thick Bm horizon, dark grayish brown to very dark gray in color (10YR 4/2 to 10YR 3/1), reflecting the enhancement of organic matter (Gilliland, 2007:96) and possibly also iron oxides (Figure 4) as a result of oxidation processes or illuviation. Below the B

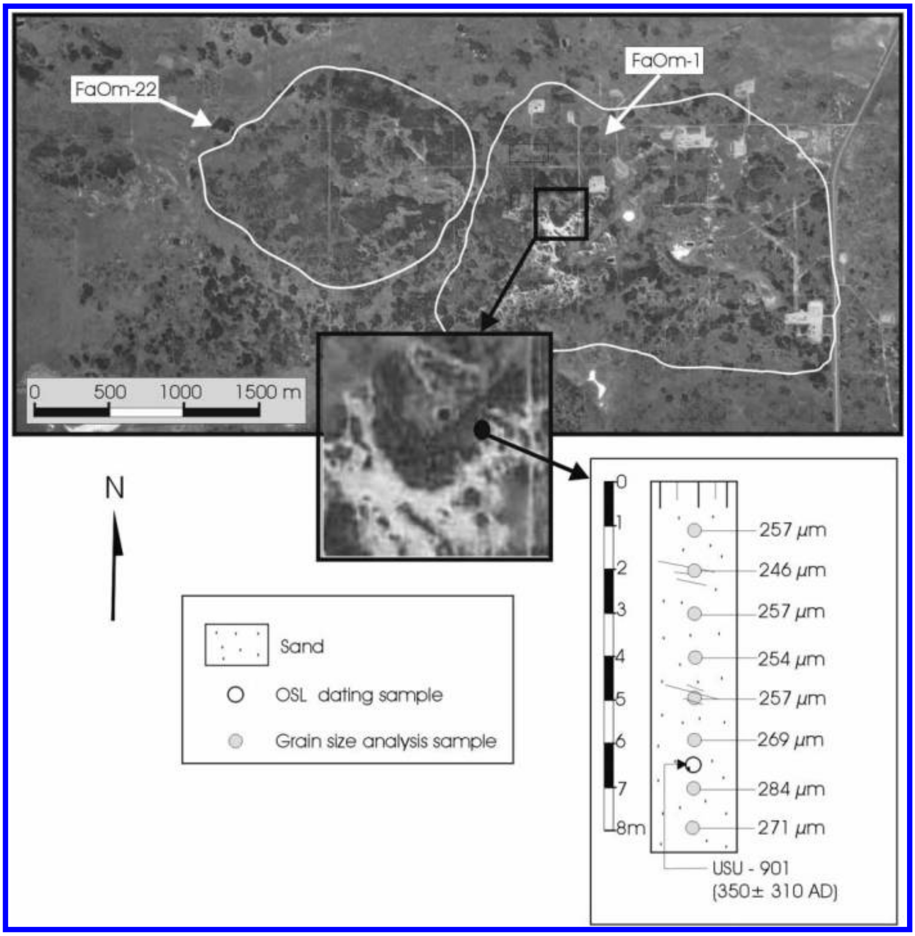

FIGURE 8 Location and stratigraphy of eolian dune sampled in FaOm-1.

horizon is the C horizon, consisting of brown to light olive brown sand (10YR 5/3 to 2.5YR 5/3) with common (≤50 percent) gray and strong brown to yellowish brown mottling, indicating periods of reduction and oxidation, possibly due to seasonal fluctuations in groundwater levels. Filled-in animal burrows (krotovinae) are noted in soil Soil 2 between the depths of 32 to 11 cm from the current surface. Test pits and excavations demonstrate that Soil 2 is continuous across both FaOm-22 and FaOm-1. Unit 3 (11 cm to surface) is comprised of moderately sorted fine sand with a mean grain size of 120 μm. The upper part of the unit marks the contemporary surface on which the modern soil is developing (Soil 1). The soil has a very dark gray (10YR 3/1) Ah horizon about 10 to 15 cm in thickness. This soil is also continuous across the entire archaeological locality. We think Soil 1 actually represents a thickening of Soil 2 due to the addition of eolian material at the same rate as soil development (Peter Crown, personal communication 2006). Soils 1 and 2 may thus be described as a single accretionary soil (Canarache et al. 2006). However, based on the visual and chemical characteristics of Soil 2 as well as the artifact content (see below), we interpret Soil 2 as a former land surface. Thus, we treat Soil 2 as distinct from Soil 1 and this facilitates the interpretation of the paleoenvironmental and cultural records contained therein.

The average pH for soils and sediments in Pit I is 6.5, ranging from 6.2 in Soil 2 to 6.8 in the Bb and Cb horizons (Gilliland 2007). Organic content is lowest at the bottom of the profile, at 0.5 percent between 130 and 60 cm b.s. in Unit 2 (Figure 4), increasing up the profile beginning at 50 cm b.s., to peak at 3.43 percent between 20 and 15 cm b.s. in Soil 2 (Unit 2). The surface soil (Soil 1, Unit 3) contains 2.71 percent organic matter. Total P displays a pattern similar to that of organic content, with lowest concentrations (0.05 percent or less) from the bottom of the profile to about 35 cm b.s. At 20 to 15 cm b.s., Soil 2 (Unit 2) demonstrates the highest concentration of total P, at 0.177 percent, while the surface soil (Soil 1, Unit 3) has a concentration of 0.087 percent between 10 and 5 cm b.s.

Three concentrations of artifacts were identified in Pit I. The deepest of these occurs in Unit 2, between 65 and 50 cm b.s. The majority of the artifacts identified here are lithics such as debitage, utilized flakes, and scrapers. Small bone fragments are also present. Many of the artifacts are characteristically rounded, suggesting they may have experienced wind abrasion prior to burial (Schiffer 1996:274 to 275). Identified points and the associated stratigraphy suggest a Sandy Creek occupation (Dyck and Morlan 1995; Gilliland 2007).

The second concentration of artifacts within Unit 2 occurs at depth 40 to 30 cm b.s. The range of objects found includes possible Avonlea and Late side-notched points, bison bone, and lithics such as scrapers. Upright fragments of a bison ulna were also excavated at this depth and are interpreted as a tie-down peg for some form of habitation structure (Gilliland 2007).

The uppermost concentration of artifacts in Unit 2 (and throughout the Bodo Archaeological Locality) is also the densest and occurs in Soil 2 around the depth of 20 to 10 cm b.s. The range of artifacts associated with Soil 2 includes bison bone, debitage, scrapers, Late side-notched projectile points, and Old Women's phase and Mortlach phase pottery. An intact hearth was also recovered at this depth that contained burnt lithics and bison bone as well as two small fragments of iron (Gilliland 2007).

FaOm-22 Pit II

Four stratigraphic units (1 to 4) and three soils were identified in Pit II (Figure 5). Unit 1 (101 to 95 cm b.s.) comprises clayey silt (mean grain size of 32 μm) with inclusions of cobbles up to 20 cm in diameter. Unit 2 (95 to 60 cm b.s.) consists of poorly sorted very fine sand with coarse sand inclusions. A buried soil (Soil 3) is found in the upper part of Unit 2. The soil comprises a 10 to 15 cm very dark gray (10YR 3/1) Ahb horizon that overlies a dark grayish brown (10YR 4/2) slightly eluviated Aeb horizon (IIIAeb) that is about 5 to 10 cm thick (Figure 5). Below the Aeb horizon is a very dark grayish brown (2.5YR 3/2) horizon (IIIBmb) pointing to the enrichment of iron oxides through oxidation or illuviation. Krotovinae occur in the upper part of the buried soil, testimony to biological activity that likely existed during the development of Soil 3. A unit of moderately sorted fine sand (Unit 3) overlies Unit 2 up to a depth of 8 cm b.s. A buried soil (Soil 2) is found in the upper part of Unit 3. Soil 2 comprises a 5 to 10 cm thick black (10YR 2/1) Ahb horizon, below which it transitions into a very dark gray to brown (7.5YR 3/1 to 10YR 4/3) 30 to 45 cm thick Cb horizon (IICb). The uppermost 8 cm of the section exposed in Pit II consists of moderately sorted fine sand (Unit 4) with a mean grain size of about 150 μm. Soil 1, at the surface, is developed in Unit 4 and comprises a black (10YR 2/1) 10 cm thick Ah horizon.

The average pH for soils and sediments in Pit II is 6.1, ranging from 5.5 in the Ah horizon of Soil 1 to 6.4 in the Ahb horizon of Soil 3 (Gilliland 2007). Soils 1 to 3 all demonstrate elevated organic content and P concentrations compared to the intervening sediments (Figure 5). Soils 3 and 2 have concentrations of organic matter at 1.89 and 4.35 percent, respectively (Figure 5), while Soil 1 has the highest organic content at 7.49 percent. Soil 3 (Unit 2) and Soil 1 (Unit 4) have total P levels of 0.045 and 0.044 percent, respectively, while Soil 2 (Unit 3) demonstrates the highest P concentration at 0.065 percent.

A range of artifacts including lithic tools and pottery were identified in Pit II. Bone and lithic artifacts such as knives, scrapers, and other utilized flakes are present from the surface throughout the section down to a depth of 90 cm b.s. Notably, however, the artifacts are primarily concentrated in Soil 3 (Unit 2) and Soil 2 (Unit 3). Pottery sherds (possibly from the Mortlach phase) were found in Unit C at a depth of 25 to 15 cm b.s. However, apart from the pottery, none of the artifacts from Pit II were diagnostic of any archaeological phase (Gilliland 2007).

FaOm-22 Pit III

The stratigraphy at Pit III (Figure 6) consists of three lithological units (1 to 3). Unit 1 (100 to 38 cm b.s.) comprises fine-grained sand, ranging from 80 to 150 μm in size. A buried soil (Soil 3) about 10 to 15 cm thick occurs at the top of Unit 1. The upper part of the soil comprises a very dark greyish brown (10YR 3/2) 10 to 15 cm thick Ahb horizon. Below the A horizon is a pale brown (10YR 6/3) 40 to 50 cm thick mottled Cg horizon with frequent (≤30 percent) faint iron mottles, suggesting periods of oxidation and reduction, likely due to alternating wet/dry periods during seasonal groundwater fluctuations.

Unit 2 (38 to 18 cm b.s.) also consists of fine-grained sand with a mean grain size of around 90 to 150 μm. Soil 2, developed in Unit 2, comprises a very dark gray (10YR 3/1) 10 to 15 cm thick Ah horizon that overlies a 10 to 15 cm thick pale brown (10YR 6/3) C horizon. Unit 3 (18 to 0 cm b.s.) is the uppermost unit, and it too consists of fine-grained sand (90 to 150 μm). The modern soil (Soil 1) was developed in Unit 3 and consists of a 10 to 15 cm thick Ah horizon. No diagnostic artifacts were recovered from Pit III.

FaOm-1

Surface finds of diagnostic artifacts pointing to settlements older than the Late Prehistoric period were not recovered from Areas 7 and 5 in FaOm-1 (Blaikie 2005; Grekul 2007). Hence, apart from exploratory shovel tests carried out as part of the reconnaissance survey (Figure 2), no deep excavations were made in FaOm-1 as part of this study. At Area 7, excavations covering an area of 25 m^2 and to a depth of up to 50 cm (Figure 7A) exposed two depositional Units 1 and 2. Unit 1 (50 to 30 cm b.s.) comprised fine-grained eolian sands above which was Unit 2 (30 to 0 cm) which displayed signs of post-depositional disturbance. A buried soil (Soil 2) occurs in the upper part of Unit 1 and comprises a 5 to 10 cm thick very dark brown Ahb horizon below which is a pale brown Cb horizon. Soil 2 is associated with a thick layer of artifacts containing lithics, ceramics, and faunal remains (Blaikie 2005). Late side-notched projectile points and sherds of Saskatchewan Basin complex: Late Variant pottery (defined by Byrne 1973) suggests that the site was used during the Old Women's phase of the Late Prehistoric period. Faunal remains consisted primarily of bison, however, canid as well as a variety of bird and fish bones and mollusc shells was also recovered. Blaikie (2005) interpreted the evidence at the site as consistent with a location where secondary bison processing, habitation, or food preparation took place. Soil 1 which is developing on the contemporary surface comprises a dark brown 5 to 10 cm Ah horizon, developed in pale brown sands (Unit 2) that form the C horizon.

Excavations at Area 5 extended over an area of 4 m^2 and the stratigraphy here consists of two units. A buried soil (Soil 2) is observed in the upper part of Unit 1 and comprises a very dark brown Ahb horizon, 10 to 15 cm in thickness, overlying a pale brown Cb horizon (Figure 7B). Artifacts were recovered from a dense bone bed within Soil 2. The majority of the faunal remains consisted of bison, and the range of other identified artifacts included 62 fragmentary or complete Late side-notched projectile points and fragments of Saskatchewan Basin complex: Late variant-type pottery, all indicative of a Late Prehistoric Old Women's phase settlement (Grekul 2007). The site was interpreted as a bison kill site where primary butchering occurred. As at Area 5, Soil 1 has formed on the current surface and consists of a 5 to 10 cm dark brown Ah horizon developing in Unit 2. Below the Ah horizon in Unit 2 is the C horizon (Figure 7B).

Also within FaOm-1, an archaeological deposit was excavated in its entirety in 2001 (Gibson and Grekul 2010). Referred to as PL1, the remnant deposit measured only 2.5 m × 8 m in extent (Figure 2). Over 100,000 artifacts were recovered from the excavations and the cultural remains appear to represent a well-used camp area, possibly a sheltered residence, surrounding a hearth and adjacent to a rock filled pit. Faunal remains suggest a winter occupation (Gibson and Grekul 2010). Pottery, projectile points, horse skeletal remains, and three radiocarbon dates indicate a Protohistoric occupation, representing an unusual mix of Mortlach and Old Women's Phase artifacts, suggesting cultural interactions, with at least peripheral contact, with populations of European descent.

Chronological data

Radiocarbon and luminescence chronology were acquired to provide a temporal framework to the stratigraphy identified in the study area. Below, radiocarbon ages obtained from organic artifacts recovered from each of the five sampling pits in FaOm-22 and FaOm-01 are presented first, after which OSL ages from eolian samples from FaOm-01 are examined.

Radiocarbon ages from Pits I-III (FaOm-22) and Areas 5 and 7 (FaOm-1)

From Pit I, two samples recovered from Unit 2 from depths of 70 and 55 cm b.s. (Beta-214256 and Beta-214254, Figure 4) were AMS dated at 716 to 971 and 828 to 1021 A.D. respectively, with the range spanning the standard deviation from the mean age (Table 2). Another radiocarbon sample (Beta-214393) was retrieved from a depth of around 30 cm b.s. and AMS dated at 1016 to 1182 cal A.D. Other data from Unit 2 include two bone samples (OxA-19898 and OxA-19986) from around 25 cm b.s., which returned AMS ages of 780 to 984 and 783 to 983 cal A.D. respectively. Finally, sample Beta-214252 from a depth of 20 cm b.s., also in Unit 2, was dated at 1681 to 1937 cal A.D. Units 1 and 3 did not produce any datable artifacts.

In Pit II, a bison tooth recovered from Soil 3 (Unit B) from a depth of around 80 to 70 cm b.s. returned an age of 753 to 402 cal B.C. (Beta-209522). Bone samples were also collected from Unit 3 at around 30 cm b.s. (Beta-214253) and 15 cm b.s. (Beta-214251). These produced ages of 1023 to 1206 cal A.D. and 1682 to 1936 cal A.D., respectively. No datable artifacts were recovered from Units 1 and 4.

From Pit III, two bone samples that were collected from within Soil 3 at depths of around 45 to 38 cm b.s. These yielded ages of 828 to 1021 cal A.D. (Beta-222511) and 893 to 1118 cal A.D. (Beta-222510), respectively. No datable artifacts were recovered from Units 2 and 3.

In both pits in Areas 7 and 5, the datable artifacts were recovered from the lower unit (Unit 1). In Area 7 (Figure 7A), radiocarbon data from a range of bones combined with an absence of Euro-Canadian artifacts were interpreted as indicating that the site was Late Prehistoric in age and was possibly intermittently occupied from 1450 to 1700 cal A.D. by progenitors of modern Blackfoot people. From Area 5, the radiocarbon data range from 1350 to 1750 cal A.D. (Figure 7B), confirming that the occupation of the site took place during the Late Prehistoric period.

Luminescence chronology from Pit I (FaOm-22) and from the eolian dune (FaOm-1)

Two luminescence ages were obtained from quartz sand collected from Unit 2 of Pit I (Figure 4). Sample USU-903, collected from a depth of 97 cm b.s. was dated at 6960 ± 2380 B.C. (Table 3). Sample USU-902 from a depth of 39 cm b.s. returned an age of 290 ± 410 years A.D.

The eolian dune studied in FaOm-1 was selected for its size and location as an appropriate repository for environmental records that would help contextualize past human activity at the Bodo locality (Figure 8). Sample USU-901, retrieved from a depth of 650 cm b.s., returned an age of 350 ± 310 years A.D. Grain size measurement of samples collected from the base of the dune to its surface indicates that the sands are medium grained, ranging from 284 to 246 μm.

Discussion

This study aims to integrate stratigraphic and chronological data from the Bodo archaeological locality, together with the archaeological records from the site, in order to reconstruct a holistic view of the human-environmental dynamics of the region over time. A basic assumption of this approach is that the stratigraphy is a reflection of environmental conditions that prevailed at the time of formation. Accordingly, below, the depositional stratigraphy and chronology of human settlement reconstructed from sampling pits in FaOm-22 are discussed first after which corresponding reconstructions from test pits in FaOm-1 are examined. Finally, the observations from both FaOm-22 and FaOm-1 are synthesized to produce a composite stratigraphy for the area.

Depositional stratigraphy and chronology of human settlement in FaOm-22

The three sampling pits excavated in FaOm-22 provided the most extensive depositional records as well as evidence of human settlement examined in this study. In the following sections, records from Pits I–III are discussed. In all instances the relationship between landscape evolution and the causative agents, including human settlement is explored.

Pit I

The absence of coarse clasts and other unsorted debris in the silty clay that comprises Unit 1 in Pit I (i.e., below 210 cm b.s., Figure 4) suggests that these sediments were most likely deposited in a glaciolacustrine setting. This indicates the presence of a glacial lake dammed by an ice sheet margin. Reconstructions of the retreat of the Laurentide Ice Sheet from western Canada (Dyke et al. 2002, 2003) have shown that the ice sheet margin was in the vicinity of the Bodo region sometime between 12,100 and 11,500 cal B.C. Therefore, we interpret the deposits as dating to the early postglacial period, around about 11,500 cal B.C.

Unit 1 in Pit I is overlain by a sandy unit (Unit 2). The lower part of Unit 2 comprises very fine-grained sands ranging from about 69 µm at the bottom to about 139 µm in the upper part suggesting an increase in the depositional energy with time. Grain size sorting also increases up the unit. Deposits within this size range can be emplaced by wind as eolian dune sand or by water as glaciofluvial deposits. The lack of depositional structures that would be associated with running water, such as crossbeds, combined with the surrounding eolian landscape suggests that these deposits are most likely eolian in origin. The luminescence sample extracted from the pit at a depth of 97 cm b.s. (USU-903) produced an age of 6960 ± 2380 B.C., indicating that these sands were emplaced during the early Holocene. Even though the error range of this sample is high, with the possible ages lying in the range 9340 to 4590 B.C., it would still be early Holocene in age even if its age fell on the tail end of the error range. Hence, the high uncertainty does not change our interpretation. Further up Unit 2, at a depth of 39 cm b.s., sample USU-902 produced an age of 290 ± 410 A.D. The large difference in age (about 7,000 years) between samples USU-903 and USU-902 could be interpreted as suggesting a very slow sedimentation rate. However, this difference may document a gap in the sedimentary record due to repeated episodes of erosion and redeposition during periods of landscape instability, as is common in eolian settings (Hopkins and Running

2000; Wolfe et al. 2002a). Consistent with this interpretation, the artifact concentration around 65 to 60 cm b.s. (Figure 4) is dominated by rounded lithics and bone fragments, which points to eolian abrasion at the former surface. Total P levels are slightly elevated at this depth, which hints at a former land surface, but organic levels are low and visible soil horizons are absent, suggesting deflation. The projectile points from this artifact concentration are interpreted as representing a Sandy Creek occupation (approximately 550 cal B.C., see Table 1; Dyck and Morlan 1995:389 to 405).

Bone fragments collected from around 70 and 55 cm b.s. in Pit I both produced radiocarbon ages ranging from 700 to 1000 cal A.D. (Beta-214256 and Beta-214254, respectively), which appears stratigraphically inconsistent with the OSL sample USU-902 dated to about 290 ± 410 A.D. and recovered from a depth of around 39 cm b.s. If the error range in the OSL age is taken into account, however, the radiocarbon ages (Beta-214256 and Beta-214254) can be deemed comparable to the tail-end of the OSL age uncertainty. Alternatively, the radiocarbon samples could be contaminated with younger carbon or, more likely, are intrusive due to bioturbation. Such bioturbation, if it occurred, does not appear to have affected the OSL sample by transporting younger sediment from above downwards because the sample returned an age that is older than the radiocarbon ages from the same elevation. Similarly, no signs of burrowing from underneath which would have brought older sediment upwards were observed at the sampling positions. Importantly, OSL analysis of samples that have grains of mixed age, which would most likely occur in a setting where sediment is moved upwards or downwards by burrowing animals, would cause large scatter in the equivalent doses of the samples (e.g., Wallinga 2002). Equivalent dose scattering could also be caused by incomplete zeroing of the luminescence signal prior to deposition (partial bleaching) which can produce age overestimates. All samples dated in this study, however, did not show significant scattering, suggesting that neither sediment mixing nor partial bleaching occurred. Also notably, the OSL age of 290 ± 410 cal A.D. that we report from Pit I corresponds closely with the age of 350 ± 310 cal A.D. from the eolian dune in FaOm-1 which points to a period of sustained eolian deposition at the site around that period. Hence, due to the stratigraphic coherence of the OSL ages at the study site, we place more weight on OSL sample USU-902 than on radiocarbon samples Beta-214256 and Beta-214254.

A second artifact concentration in Pit I (around 40 to 30 cm b.s.) includes points identified as Avonlea and Late side-notched types (600 to 850 and 700 to 1700 cal A.D., respectively; Vickers 1986). As mentioned above, the luminescence age of the associated sediments is 290 ± 410 A.D. indicating a period of landscape instability at that time and providing a maximum age for human occupation. The elevated organic content and total P concentration in this part of the profile suggests that occupation took place during a period of soil development (i.e., a stable landscape) following eolian deposition, but the lack of a distinct soil horizon indicates renewed eolian activity and landscape instability following occupation.

Samples recovered from 30 to 25 cm b.s. in Pit I date to between 780 and 1182 cal A.D. (Beta-241393, OxA-19898, and OxA-19986). These samples overlie the second artifact concentration and underlie the third concentration, and the range in age suggests that they represent the terminal phase of the second occupation.

Soil 2 in Pit I (depth around 18–11 cm b.s.) is developed in Unit 2 and marks a depositional hiatus during a period of landscape stability. As indicated this soil is continuous across the archaeological locality and is associated with the uppermost and most abundant artifact concentrations at the site. The soil is also characterized by noticeably elevated levels of organic material and total P concentrations, indicating that this period represents the most intense or prolonged episode of cultural activity at the locality. The associated artifacts include bison bone, lithics (Late side-notched projectile points), and Mortlach phase pottery, all of which are consistent with the interpretation of a Late Prehistoric occupation. A radiocarbon date from bone collected from within Soil 2 (Beta-214252) that dates to 1681 to 1937 cal A.D., provides a minimum age for soil formation and further supports the interpretation of an Old Women's occupation. Unit 3, which caps the section at Pit I, is comprised of fine-grained sand and signifies a return to landscape instability and eolian deposition prior to the current phase of stability, indicated by the modern soil (Soil 1).

Pit II

The lowermost stratigraphic unit (Unit 1) of Pit II comprises silty clay and cobbles and is interpreted as glacigenic in origin (Figure 5). It most likely represents till deposited in a near-ice environment during the late Pleistocene/early postglacial period around about 11,500 cal B.C. (Dyke et al. 2002, 2003). Hence, Unit 1 in Pit II is interpreted as dating to generally the same period as the glaciolacustrine clays in Unit 1 of Pit I (Figure 4). Unit 2 in Pit II consists of well sorted fine-grained sand with a massive structure. Although sand in this size range could be emplaced by fluvial activity, the degree of sorting, the lack of depositional structures, and the geomorphological context (i.e., an elevated landform within an eolian dune environment) suggest the sands are eolian in origin.

Soil 3, developed in the upper part of Unit 2 in Pit II, indicates a period of landscape stability and a halt to sedimentation at the site. This soil demonstrates distinct horizon development (i.e., Ah, Ae, and Bm), indicating a more intense and/or prolonged pedogenic phase at this land surface compared to subsequent episodes of soil formation at the locality. Elevated concentrations of organic material and total P in Soil 3 suggest cultural activity during this period. A bison tooth recovered from the lower part of the soil produced an age that suggests the soil and the associated occupation date from ca. 753 to 402 cal B.C. (Beta-209522; Figure 5, Table 2). Lithic artifacts are present throughout the Pit II profile to a depth of 90 cm b.s., but the highest concentrations are from Soils 3 and 2, suggesting human activity was most intense during these episodes of landscape stability.

The fine sands of the overlying Unit 3in Pit II are also interpreted as eolian. A bone sample from within Unit 3 dated at 1023 to 1206 cal A.D. (Beta-214253, around 30 cm b.s.) is not associated with a visible soil horizon. However, sediment at this depth demonstrates elevated levels of organic material and total P, suggesting a soil that was eroded during subsequent eolian activity.

Soil 2 in Pit II developed in the upper portion of Unit 3 and is characterized by elevated organic and total P concentrations. Bone from within Soil 2 produced an age of 1682 to 1936 cal A.D. (Beta-214251), which is almost identical to the age for bone from Soil 2 in Pit I. As such, the occupation period represented by the artifacts in Soil 2 in Pit II is interpreted as the same occupation period as that documented in Soil 2 in Pit I, an Old Women's phase occupation.

Pit III

The lowermost stratigraphic unit in Pit III (Unit 1), comprised of fine sands, is likely eolian in origin (Figure 6). The lowermost soil (Soil 3) developed in the upper portion of Unit 1, suggesting a depositional hiatus and a period of landscape stability. Two radiocarbon ages obtained from bone samples from this soil produced dates of 828 to 1021 and 893 to 1118 cal A.D. (Beta-222511 and -222510), respectively). These dates provide a minimum age for soil development and a date for human occupation and correspond well with dates of the second occupation period from Pit I. The dates also slightly precede the timing for the formation of the possible eroded soil in Unit 3, Pit II. The human occupation represented by the dates in Pit III is therefore interpreted as either terminal Avonlea phase (600 to 850 cal A.D.) or more likely an early Old Women's phase occupation. Although no dates were obtained from Soils 1 and 2 of Pit III, they are continuous across the entire archaeological locality. Thus, these soils are thought to represent breaks in eolian deposition coincident with landscape stability that corresponds to Soils 1 and 2, observed in both Pits I and II.

Depositional stratigraphy and chronology of human settlement in FaOm-1

Reaching depths of only 50 cm b.s., the two sampling pits excavated in FaOm-1 (Areas 7 and 5) were relatively shallower than the three pits from FaOm-22. However, Area 7 had a notably larger surface area (25 m^2) compared to the pits in FaOm-22 and a significant amount of materials were recovered from the pit. The stratigraphy, the artifacts, and the chronology obtained from the two pits are examined below. Also discussed is the luminescence chronology obtained from samples from FaOm-1.

Areas 7 and 5

Based on Blaikie's (2005) study the range of artifacts recovered from Soil 2 at the Area 7 excavation (Figure 7A) includes Cayley Series Late side-notched projectile points, ceramics, and Saskatchewan Basin complex-Late Variant pottery. The artifacts and the radiocarbon chronology from 1450 to 1950 cal A.D. (BGS-2553 and BGS-2557) were interpreted as an Old Women's phase occupation (Blaikie 2005:127–132). This timing is also consistent with the ages for Soil 2 in Pits I and II. A similar conclusion was reached for Area 5 (Grekul 2007:154) where the range of artifacts recovered included Late side-notched projectile points and Late Saskatchewan Basin complex-Late Variant-type pottery. Here the chronology spanned 1320 cal A.D. (BGS-2657) to 1795 cal A.D. (BGS-2654).

Eolian dune luminescence chronology

The sample near the base of the dune at FaOm-1 returned an OSL age of 350 ± 310 A.D. (USU-901), which correlates well with the OSL date of 290 ± 410 A.D. from FaOm-22 Pit I (USU-902). Both ages point to a major period of landscape destabilization, erosion, and sediment recycling in the Bodo region, indicating drought conditions (Wolfe et al. 2006). Eolian dune activity in the southern Canadian prairies is thought to have begun during the early postglacial period and existing depositional records from the region (Wolfe et al. 2001, 2002b) document the onset of dune deposition in some areas as early as 9500 cal B.C. However, intact records of early Holocene eolian activity are relatively scarce because older deposits were frequently reworked throughout the Holocene. Despite this reworking, the sample of dune sand from Pit I (USU-903), extracted from a depth of 97 cm, was dated at 6960 ± 2380 B.C. This sample could be representative of a former interdune area, as sediment from interdune areas can remain intact during periods of dune reworking (Pye and Tsoar 2009).

Composite stratigraphy at Bodo: evolution of the environment

The profiles in Pits I–III of FaOm-22 and in Areas 5 and 7 of FaOm-1 demonstrate that most stratigraphic units and soil horizons at the Bodo archaeological locality are discontinuous, and that no single profile contains a complete sequence (Figure 9). This is not an unusual characteristic of terrestrial depositional sequences where stratigraphies may be truncated or be completely eliminated by erosive episodes that follow depositional phases (Lowe and Walker 1997). Fragmentary sequences are particularly common in eolian landscapes where dunes migrate through erosion and deposition (Pye and Tsoar 2009). In such settings, composite stratigraphies can be employed to reconstruct paleoenvironmental history over a longer period than that contained in any single profile. Accordingly, a composite stratigraphic framework (Figure 10) that forms the basis for our interpretations of environmental variability and cultural activity at the Bodo archeological locality is discussed below.

Early-to-middle Holocene

Until this study, early postglacial-aged sediments at Bodo had not been dated. Now with relative dating and stratigraphic analysis (i.e., Unit 1, Pits I and II), we can infer that the early postglacial landscape at the site was characterized by abundant surface water conditions. The OSL age from the laminated sediments in the lower part of Unit 2, Pit I demonstrates that the landscape had dried out sufficiently by about 7000 cal B.C. to allow eolian transport and the accumulation of sandy deposits. The chronology is consistent with previous studies that document regional landscape instability and early eolian activity in south-central Saskatchewan between 9500 and 6500 cal B.C. (Wolfe et al. 2002b).

The absence of in situ deposits from the archaeological locality dating to the early or middle Holocene suggests that any soil development or dune-building activity during these periods was subsequently extensively reworked prior to the late

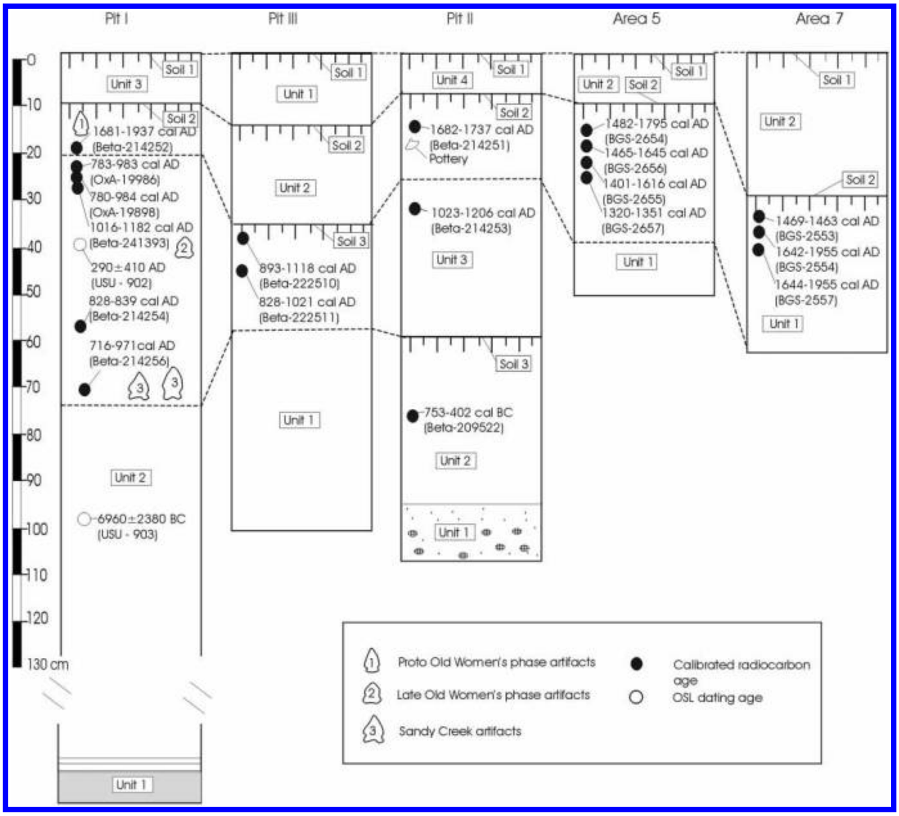

FIGURE 9 Correlation of sequences from five pits excavated at Bodo. Soils 1 and 2 are continuous across the site and may be correlated between pits. Correlations of other soils and lithological units are based on interpretations of chronometric ages, artifact typologies, and/or lithological similarities.

Holocene. In this respect, the evidence at Bodo differs with some areas in the Prairie Ecozone such as the Lauder Sand Hills in southern Manitoba (Boyd 2000; Havholm and Running 2005) or the Cypress Hills in southern Alberta and Saskatchewan (Robertson 2002; Robertson and Klaasen 2006). Both of these regions retain middle Holocene records of landscape stability and instability (Robertson and Klaasen 2006). However, surface finds of Oxbow and McKean complex projectile points at Bodo indicate that the region likely experienced episodes of landscape stability during the middle Holocene (Vickers 1986). Boyd (2000) suggests that McKean people preferred a prairie-wetland mosaic landscape. If Boyd's (2000) inference is accurate, then Bodo may have experienced a period (or periods) of increased moisture during the middle Holocene. The wet period would have been followed by a climatic shift resulting in widespread landscape destabilization including erosion and recycling of existing sediments and soils. Middle Holocene instability in the Bodo region was likely due to a prolonged period of aridity that occurred throughout most of the Prairie Ecozone between 6000 and 2000 cal B.C. (Robertson and Klaasen 2006; Wiseman et al. 2002; Wolfe et al. 2006).

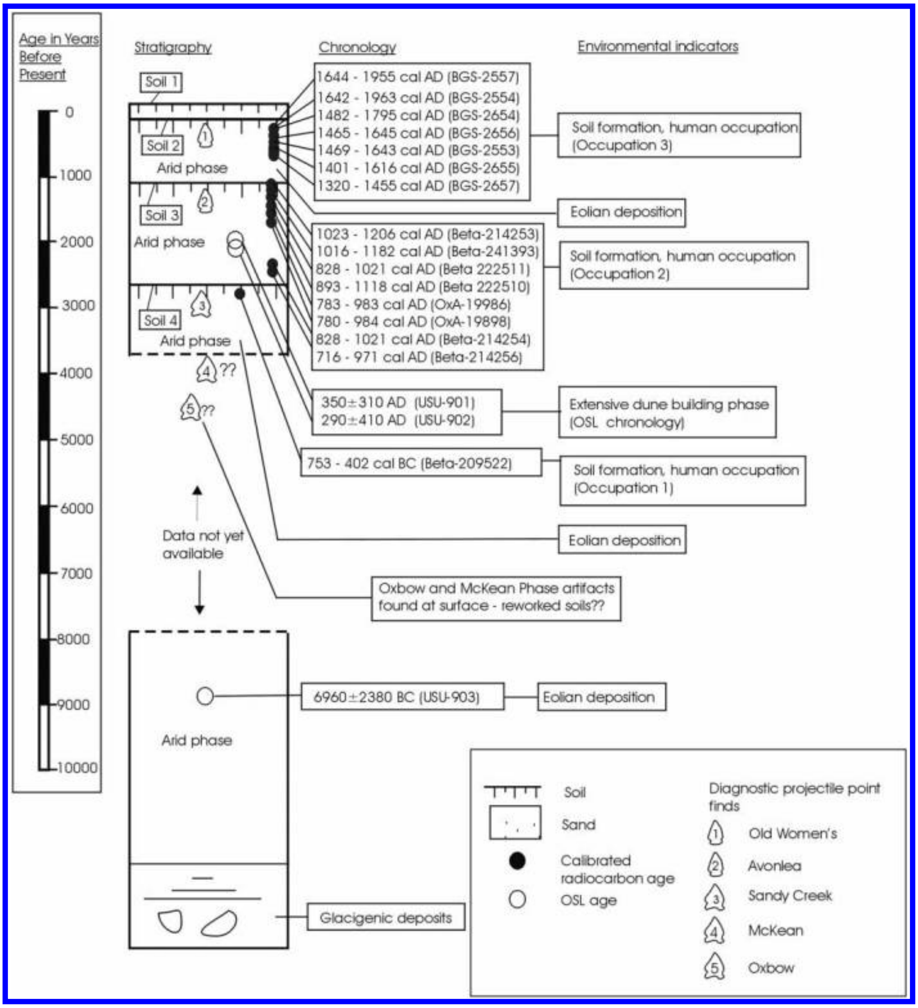

FIGURE 10 Composite stratigraphy constructed using sequences from the five pits excavated at Bodo.

Late Holocene

In our composite stratigraphy of the Bodo area, we document three buried soils associated with three primary periods of human occupation during the late Holocene (Figure 9). The earliest date for soil formation at the site (i.e., Soil 4) is the tooth from Soil 4, Pit II, at 753 to 402 cal B.C. Although this soil has no associated diagnostic artifacts, Sandy Creek-type points, previously established as dating to this period (Dyck and Morlan 1995; Wettlaufer 1955) were recovered from Unit 2 sediments in Pit I, suggesting an archaeological phase that correlates to this period of stability. Previous studies indicate that Soil 4 dates to a period of widespread regional soil development and established vegetation patterns at distributions approximating those of modern times (Hickman and Schweger 1993, 1996; Schweger and Hickman 1989). Environmental proxy evidence also demonstrates increased humidity and peaks in groundwater and freshwater lake levels throughout the northern Great Plains between 1050 cal B.C. and 50 cal A.D. (Sauchyn and Beaudoin 1998).

From 350 cal B.C. to 650 cal A.D., there is no record of soil formation at Bodo. While it is possible that soils formed and were subsequently eroded, a more likely scenario is that this period was intensely arid and characterized by an unstable landscape. Luminescence samples USU-902 (Pit I) and USU-901 (base of eolian dune, FaOm-1) document landscape instability at about 290 and 350 cal A.D., respectively, supporting the latter interpretation. The record at Bodo also correlates well with previously established regional environmental records that indicate increased landscape instability and eolian activity in east-central Alberta and west-central Saskatchewan beginning about 50 cal B.C. (Hopkins and Running 2000; Running et al. 2002; Wallace 2002; Wolfe et al. 2002a, 2002b, 2006).

AMS ages for Soil 3, Pit III (Figure 9) indicate a subsequent period of landscape stability around 800–1100 cal A.D. (Beta-222510 and -222511). This soil is discontinuous across the site. However, comparable ages were yielded by bones recovered from Unit 2 sediments in Pit I (780–984 cal A.D.; OxA-19986 and -19898) and a roughly comparable age was obtained from bone in Unit 3 sediments of Pit II (1023 to 1206 cal A.D.; Beta-214253). Again, these dates correlate well with established records of regional soil development dating between 550 and 950 cal A.D. (Hopkins and Running 2000, Wolfe et al. 2002a, 2002b, 2006). An artifact concentration in Pit I associated with the sampled bone includes Avonlea (600–850 cal A.D.) and Late side-notched points (850 to 1700 cal A.D.), indicating that people occupied the area during this stable episode. The fact that at Bodo this soil is discontinuous documents landscape instability and soil erosion following a period of stability between 750 and 1000 cal A.D.

The most recent buried soil (Soil 2) is present in all profiles and is continuous throughout the site. In Pits I and II (FaOm-22), bone recovered from Soil 2 yielded radiocarbon ages in the range of 1681 to 1937 cal A.D. In Areas 5 and 7 (FaOm-1), bone recovered from Soil 2 was dated between 1350 and 1750 cal A.D. (Blaikie 2005:127–132; Grekul 2007:154). This soil contains Late side-notched points and Old Women's and Mortlach-phase ceramics, in addition to more recent artifacts such as iron fragments, demonstrating a Protohistoric human occupation.

Although more data are required with regard to the context of the radiocarbon ages obtained from Soil 2, we tentatively suggest that the soil represents a period of landscape stability that may have lasted for 300 years. Additionally, the difference in ages between FaOm-22 and FaOm-1 indicates that the dense artifact concentrations within Soil 2 represent different episodes of human activity across the Bodo archaeological locality, rather than one spatially extensive occupation period. This observation is borne out in previous stratigraphic work along the southern and eastern boundaries of the archaeological locality (Grekul et al. 2009). Although Soil 2 appears homogenous in all of the documented profiles presented in this paper, there are places on the landscape where the A horizon of Soil 2 is intercalated with several thin layers of sand (Grekul et al. 2009). We suggest that these intercalations represent brief episodes of localized instability of the eolian landscape similar to what occurs when a blowout develops on a fossil dune. The combined strong anthropogenic signal within Soil 2 (i.e., the total P data and abundance of cultural artifacts) and the dates indicating occupation over at least 300 years suggest that the episodes of instability may have been culturally induced. Therefore, we interpret the several intercalations of eolian sand in Soil 2 as representing multiple occupations and periods of associated landscape instability, reflecting environmentally induced and/or cultural dune destabilization due to bison procurement and related activities. Similar landscape destabilization through anthropogenic and environmental influences was suggested by Wolfe et al. (2007) at the Elbow Sand Hills, Saskatchewan. The near absence of associated Euro-Canadian goods suggests an upper limit for the age of the occupation and associated soil occurring at the boundary of the Late Prehistoric/Protohistoric periods around 1750 cal A.D. or later in this part of western Canada. Additionally, this contrast between intensive, repeated occupation during the Late Prehistoric period and sparse cultural activity during the period that followed is interpreted as reflecting social and economic changes occurring at the time of the arrival of Euro-Canadians in the area, marking a major change in the regional cultural landscape.

Discontinuous soils are commonly observed in eolian-dominated environments and they record episodes of re-working and recycling of earlier deposits during periods of landscape instability (Mulira 1986; Wolfe et al. 2006). The discontinuous nature of Soils 3 and 4 thus provides a record of cycles of sediment reworking within the archaeological locality. However, Soil 2 differs from Soils 3 and 4 in that it is observed in all profiles and is intact and continuous across the entire locality. This fundamental difference suggests that, unlike Soils 3 and 4, Soil 2 was buried by sediment originating from outside the study area, upwind from the Bodo locality. Possible sources include sediment exposed by landscape destabilization in the regions bordering Bodo due to cultural activity during the late nineteenth century. For example, Sauchyn and Beaudoin (1998) document increases in lake sedimentation following the introduction of agriculture into the southern Canadian Plains around 1880 cal A.D. Additionally, the Sullivan Lake soil survey (Wyatt et al. 1938) documents severe erosion of cultivated soils near the Neutral Hills southwest of Bodo during the 1930s. Hence, since the Bodo archaeological locality itself has never been tilled, the likelihood that sediment overlying Soil 2 originates from outside the Bodo area is high.

Conclusions

In this study, we document Holocene environmental fluctuations and human occupation periods at the Bodo archaeological locality, situating this formerly poorly understood region of east-central Alberta within its wider regional environmental, cultural, and temporal contexts. Our composite stratigraphic sequence demonstrates that sediments of glacigenic origin underlie the site, reflecting the previous presence of the Laurentide Ice Sheet and associated meltwater as it retreated from the region beginning about 11,500 cal B.C. Overlying these deposits are eolian sands which contain buried soils, forming a sequence that points to recurring cycles of landscape instability and stability. Surface finds of Oxbow and McKean complex projectile points across the Bodo archaeological locality suggest occupation of the area during the middle Holocene. However, apart from the single luminescence age reported in this study indicating eolian deposition during the early Holocene, an intact record of early-to-mid Holocene eolian and cultural activity at Bodo is absent. This is likely due to sediment recycling, as documented by the presence of discontinuous soils dating to the late Holocene. If eolian recycling did occur, however, the lack of any early Holocene archaeological material concentrated as lag deposits would suggest that human settlement did not occur.

The three buried soils identified in this study have minimum ages of ca. 750 to 400 cal B.C., 750 to 1000 cal A.D., and 1450 to 1750 cal A.D., and these ages correlate well with the existing record of regional environmental fluctuations in the southern Canadian plains. The ages for all three soils correspond also to established ages for diagnostic artifacts recovered from the soils and sediments at the site (i.e., Sandy Creek, Avonlea, and Old Women's phase occupations, respectively), and demonstrate that periods of cultural activity took place during episodes of landscape stability. The characteristics of the most recent buried soil (1450 to 1750 cal A.D.) suggest that cultural activities related to indigenous occupation and bison procurement may have contributed to landscape destabilization during the Late Prehistoric and Protohistoric periods. The relative scarcity of indicators of subsequent occupation of the site by indigenous peoples in the overlying deposits, accompanied by the near absence of Euro-Canadian artifacts from deposits of Protohistoric age or younger, contrasts with the abundant evidence for intensive and repeated human activity during the Late Prehistoric period. This trend attests to significant social and economic changes reflected in the cultural landscape at the site following the arrival of Euro-Canadians in the region. Although the Bodo archaeological locality has never been tilled, the stratigraphic evidence presented in this study also indicates that the onset of regional agricultural activities during the late nineteenth and early twentieth centuries caused destabilization of the wider landscape, resulting in sediment deposition at Bodo during the period of Euro-Canadian settlement in the area.

While radiocarbon dating has provided invaluable temporal controls for the stratigraphy at Bodo, there are cases when the radiocarbon ages in vertical sequences appear to be inverted. The incorporation of the OSL ages in such cases has helped provide an alternative chronometer. Hence, our chronological framework is rendered more robust, demonstrating the benefit of this approach when applied to archaeological sites in eolian settings.

The discontinuous character of the stratigraphic sequences at the study site also highlights the necessity of increasing the number of sampling exposures when aiming to construct more complete records of environmental fluctuations and human activities in eolian landscapes.

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