Geoarchaeology of the Mineable Oil Sands Region, Northeastern Alberta, Canada

by

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ABSTRACT

This thesis contributes to the development of chronological and geological frameworks for the archaeological record of the mineable oil sands regions in northeastern Alberta, Canada. This area contains a rich pre-European contact archaeological record that has largely been documented through cultural resource management projects. Because of the impact mitigation focus of much of this work and a lack of radiocarbon-datable material from known sites, only nascent chronological and site taphonomic frameworks have been established for the region. This gap is addressed by using infrared stimulated luminescence dating, radiocarbon analyses, digital terrain analysis, and sedimentological studies to determine limiting ages for landscape stabilization and human occupation, and to identify key site formation processes in the region. Work at the stratified Quarry of the Ancestors site and elsewhere indicates that the post-glacial landscape was characterized by the emergence of low-relief bedforms that were formed by catastrophic flooding ca. 13,000 years ago. Climatic conditions were cold enough to support permafrost and aeolian processes were extensive immediately following the flood. The landscape began stabilizing ca. 12,000 years ago, near the end of the Younger Dryas, with initial human occupations occurring concurrently or shortly afterward. After stabilization peatland expansion and fluvial processes became the dominant geomorphic agents in the region.

Because stratified sites provide the most potential for the recovery of temporal information about landscape evolution and human occupation, a process-depositional model is developed to help isolate areas where stratified or deeply buried sites are more likely to occur. Using topographic parameters and wind directions, it is determined that landform elements that are most likely to contain deep or stratified deposits occur on the wind-leeward sides of raised landforms. Assessment of existing archaeological survey data indicates that current testing strategies are not focusing on these areas. This bias may be partially responsible for the lack of known stratified sites in the region, and a modified regulatory process focused on research-driven project design is forwarded to maximize the scientific value of future cultural resource management projects.

PREFACE

Chapter 2 of this thesis has been published as "Woywitka, Robin J., Duane G. Froese, and Stephen A. Wolfe. Raised Landforms in the East-Central Oil Sands Region: Origin, Age, and Archaeological Implications. *In* Ronaghan, B. (Ed.), *Alberta's Lower Athabasca Basin: Archaeology and Palaeoenvironments*. Athabasca University Press, Edmonton, Alberta. pp. 69-82." I was responsible for literature review, data collection, analysis and interpretation, and lead authorship of the manuscript. D.G. Froese was the supervisory author and was involved with concept formation. Both D.G. Froese and Stephen A. Wolfe contributed to manuscript composition and assisted with data collection, analysis and interpretation.

Chapter 3 of this thesis is in preparation for publication in Quaternary Research as "Woywitka, Robin J., Duane G. Froese, Stephen A. Wolfe, Michel Lamothe, and John Southon. Early (ca. 12,000 BP) post-glacial landscape stabilization and human occupation in the oil sands region, northeastern Alberta, Canada." I was responsible for field data collection, radiocarbon sample preparation, data analysis, and lead authorship of the paper. D.G. Froese was involved in concept design, and assisted in data collection and analysis, and manuscript composition. Stephen A. Wolfe assisted in data collection and analysis, and provided comments on the manuscript. Michel Lamothe conducted the IRSL analyses, and contributed to manuscript composition. John Southon performed the radiocarbon analysis.

Chapter 4 of this thesis is in preparation for publication in the Journal of Archaeological Science as "Woywitka, Robin J. and Duane G. Froese. A process-depositional model for the evaluation of archaeological potential and survey methods in the mineable oil sands region, northeastern Alberta Canada. I was responsible for data collection and data analysis and lead authorship of the manuscript. D.G. Froese was the supervisory author and was involved with concept formation and manuscript composition.

The introductory material in Chapter 1, the entirety of Chapter 5, and the concluding remarks in Chapter 6 are my own original work.

DEDICATION

This work is dedicated to Amanda Wagner, and to my parents Shirley Woywitka and Bill Woywitka. My parents have supported me throughout every educational endeavor I have undertaken from adolescent guitar lessons to this Ph.D., thirty years later. I leaned on them when I couldn't fret an A Major chord, and did the same when I fretted too much about this project. They got me through the gate both times. My partner Amanda never wavered in her support; often she bore the heaviest load when things got scrambled. Her incomparably empathetic ear and kind heart spurred me on even when I didn't know it. She is also an excellent copy editor.

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Chapter 2: We are grateful for the generous assistance of Ayo Adediran, of Shell Canada Energy, Chris Doornbos, formerly of Petro-Canada, and Dale Nolan and Rolly Boissonnault, of Athabasca Minerals Inc., who facilitated access to field sites. We benefitted from useful discussions with John Shaw, at the University of Alberta, about the form analogues of the features we describe in this chapter. We also thank Hazen Russell, of the Geological Survey of Canada, for his critical but constructive comments, which improved the chapter. Portions of this work were funded by Natural Sciences and Engineering Research Council (NSERC) and Canadian Research Chairs (CRC) grants to Duane G. Froese.

Chapter 3: Funding for fieldwork in 2012-2013 was awarded by the Canadian Circumpolar Institute (CCI) and Northern Scientific Training Program (NSTP) to Robin Woywitka. NSERC and CRC grants to Duane G. Froese supplemented field costs and provided analytical funds for IRSL and radiocarbon analysis. The Archaeological Survey of Alberta provided in-kind contributions to the fieldwork and funds for radiocarbon dating. Todd Kristensen, Reid Graham, Brittany Romano, Joel Pumple, Andrew Lints, and Darryl Bereziuk provided field and laboratory assistance of the highest technical skill, and were incredibly fun to work with.

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Robin Woywitka. NSERC and CRC grants to Duane G. Froese supplemented field costs. The Archaeological Survey of Alberta also provided fieldwork funds and equipment. Andrew Lints and Courtney Lakevold ably assisted in the field, compiling quality data and excellent entertainment.

Several people supported this project in diverse ways. Duane Froese provided the inspiration and means for me to take on this project, and I am very grateful for not only that, but also his guidance throughout the project. Together we took on questions that have significance to me as a scientist, and I am satisfied that we made meaningful strides toward their answers. I'm not sure I could have achieved this satisfaction without his mentorship. Other members of the Quaternary group at the University of Alberta provided comradery and all kinds of intellectual support – Lauren Davies, Alberto Reyes, Britta Jensen, Joe Young, Martin Margold, Sophie Norris, Sasiri Bandera, and Joel Pumple all helped keep myself or the project between the ditches. Staff members of Alberta Culture provided the time, expertise, money, equipment, and understanding I needed to complete this project. It simply would have been impossible to do this without the following people: Brian Ronaghan, Darryl Bereziuk, Todd Kristensen, Courtney Lakevold, Matthew Wangler, and David Link. I would like to thank Eric Damkjar of the Archaeological Survey in particular; he was steadfast in his support for the project. But he went above and beyond the call of duty, providing incredible understanding and encouragement when things got hairy. And of course great thanks to my co-authors and committee. It has been an honor to work with all of you, and I am a much better scientist as a result.

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CHAPTER 1: INTRODUCTION

1.1 Dissertation Summary

This dissertation focuses on late Quaternary landscape evolution and early human occupation in the lower Athabasca River drainage in northeast Alberta (Figure 1.1). Previous research has established the significance of this region in our understanding of late Quaternary natural and cultural history. Geological studies of the northwest outlet of Lake Agassiz have been pivotal in determining the effects of catastrophic drainage of glacial meltwater on regional environments and global climate (Fisher and Smith, 1994; Fisher et al., 2009; Murton et al., 2010; Smith and Fisher, 1993) Significant palaeontological specimens such as wapiti and bison have also been recovered from peat deposits in the region (Burns and Young 2011), and lake records have provided a regional framework of post-glacial vegetation succession (Bouchet-Bert and Beaudoin, 2017; Hutton et al., 1994; Vance, 1986).

Extensive cultural resource management (CRM) archaeological survey and excavation has also taken place in the area in response to extensive oil sands mining development. This has resulted in the recording of one of the highest concentrations of archaeological sites in northern Alberta, with over 1,000 sites occurring within the boundaries of the mineable oil sands area.

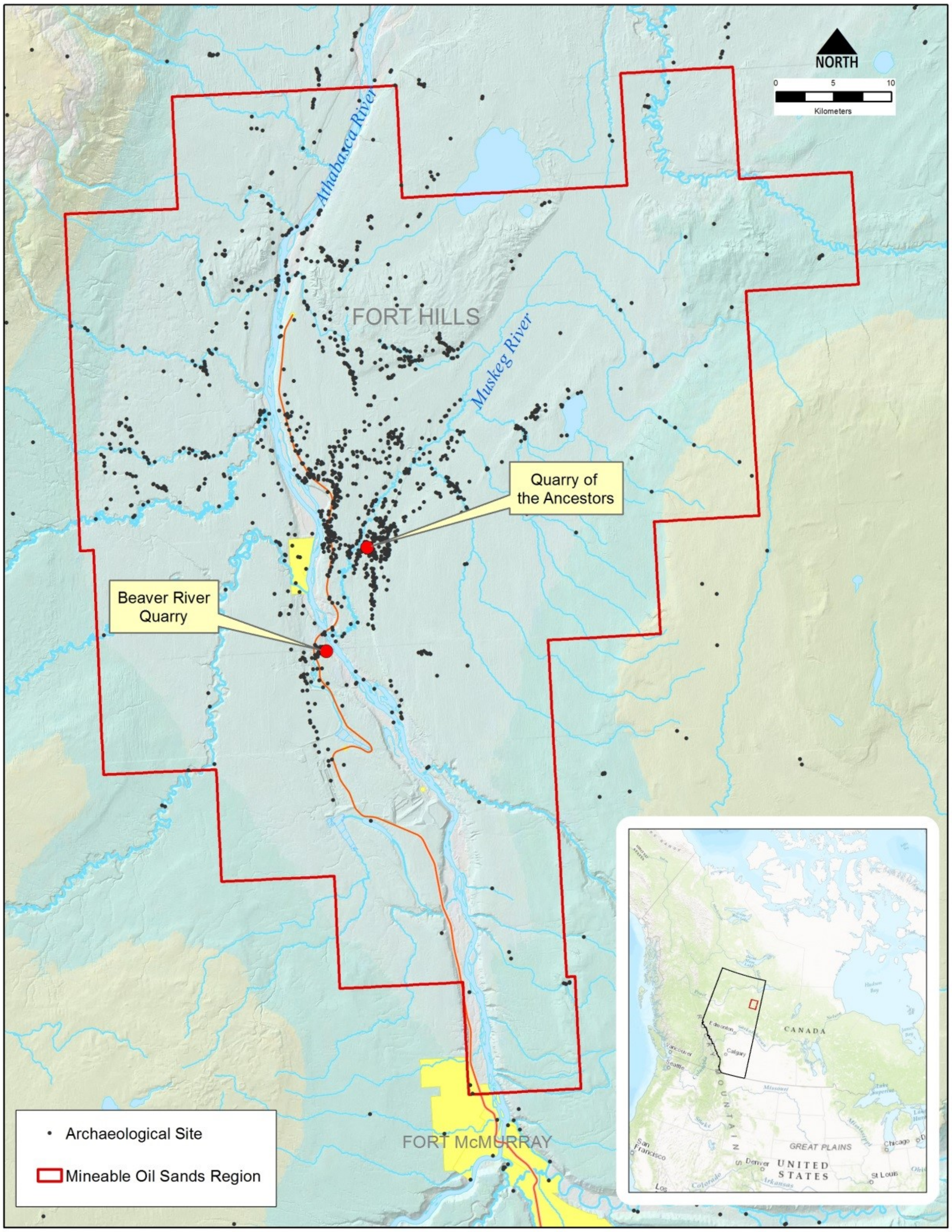

Figure 1.1 Mineable oil sands region with archaeological sites (Archaeological Survey of Alberta sites database, accesses November, 2017).

However, the impact mitigation focus of most of this work does not include detailed geological or palaeoenvironmental study, and current understanding of the effect and timing of environmental change on the archaeological and palaeontological record is formative. This knowledge gap has restricted most understanding of the archaeological record to lithic technology and raw material studies. This study establishes a stronger environmental and chronological context for this important archaeological record.

The goals of the dissertation are to establish a reliable age of initial human occupation of the region, to characterize the environments encountered by first inhabitants, and to provide a geomorphic process-deposition model that identifies areas with potential for deep or stratified sites. The themes examined in support of these goals include the relationship between site location and raised landforms related to the Lake Agassiz flood event, the role of wetland development and eolian processes in environmental change and site preservation, and the development of infrared stimulated luminescence (IRSL) dating methods that will help gain chronologic control on hitherto undated sediments in the area. These sedimentary and chronological data are incorporated into a model of archaeological potential aimed at identifying locations that are most likely to yield stratified deposits or at least deep sediment profiles. Together, these efforts can be used to help focus future archaeological research on areas and sites that are likely to yield some form of temporal information, the largest knowledge gap in the archaeological record.

The bulk of the dissertation consists of three interrelated manuscripts that have been published in an edited volume or submitted to peer-reviewed journals (Chapters 2, 3, and 4). Chapter 5 uses the results of the manuscripts to provide a framework for research-enhanced regulatory practices that will provide added social and scientific value to the work conducted under the *Historic Resources Act*.

Chapter 2, *Raised Landforms in the East-Central Oil Sands Region*, establishes the origin landforms in the study area as catastrophic flood bedforms formed during catastrophic drainage during deglaciation of the region. This determination is based on landform morphology observed in high resolution Light and Detection Ranging (LiDAR) digital elevation models (DEMs), form analogy with experimental features, and stratigraphic analysis. These features are the nodes around which the archaeological record is focussed, and this chapter introduces their fundamental geomorphic, and sedimentological characteristics. A version of this chapter was published in 2017 as a chapter in *Alberta's Lower Athabasca Basin: Archaeology and Palaeoenvironments* (Woywitka et al., 2017).

Chapter 3, *Timing of Post-glacial Landscape Stabilization and Early Human Occupation in the Oil Sands Region, Northeastern Alberta, Canada*, uses stratigraphic analysis, archaeological excavation, IRSL ages of eolian sands and radiocarbon ages of peat deposits to establish the ages of landscape stabilization and human occupation of the region. We found that flood bedforms were likely first exposed during the Younger Dryas interval ca. 12,000 years ago, and that eolian processes were active in the area from immediate post glacial times to around 9,700 years ago. Association of cultural material with relict permafrost features and dated eolian deposits at Quarry of the

Ancestors indicate human occupation as early as 12,000 years ago, roughly contemporaneous with some of the earliest sites in Alberta (Ives et al., 2013). Radiocarbon ages from basal peat deposits indicate people used Quarry of the Ancestors after 900 cal years BP, and that peatland expansion through the Holocene has buried archaeological sites in datable contexts. A version of this chapter will be submitted to *Quaternary Science Reviews* or *Quaternary Research* for publication consideration.

Chapter 4, *Using Process-deposition Models and LiDAR-based Digital Terrain Analysis to Evaluate High Sedimentation Potential Areas and Archaeological Survey Methods in the Mineable Oil Sands Region, Northeast Alberta*, examines the relation between raised landform morphology, eolian processes, and wetland expansion to identify areas that have potential for deeply buried or stratified sites that can provide the type of temporal information recovered from Quarry of the Ancestors. Using a conceptual process-deposition model centred on landform element shape and paleowind direction, we perform a LiDAR DEM based digital terrain analysis to map areas of potential for deep deposits. Comparison of these results with existing archaeological survey and site data indicate that these areas have not been representatively sampled, and we recommend measures to focus future survey in these potentially significant areas. A version of this chapter will be submitted to the *Journal of Archaeological Science* for publication consideration.

As noted above, Chapter 5, *Incorporating Geoarchaeological Perspectives in Mineable Oil sands Cultural Resource Management*, provides a practical synthesis of the dissertation results in the form of research-driven regulatory guidelines for future geoarchaeological research. It also includes closing remarks about the value this type of work, and marks potential paths for future study. A version of this chapter will submitted to the Archaeological Survey of Alberta for incorporation into a research bulletin or other policy document.

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CHAPTER 2: RAISED LANDFORMS IN THE EAST-CENTRAL OIL SANDS REGION - ORIGIN, AGE, AND ARCHAEOLOGICAL IMPLICATIONS

2.1 Introduction

A strong correlation exists between raised landforms and archaeological sites in the lowland between Cree Burn Lake and Kearl Lake, to the south of the Fort Hills portion of the Firebag Moraine (Figure 2.1). The origin of such landforms figures prominently in archaeological models proposed for the surface minable oil sands region north of Fort McMurray. Saxberg and Reeves (2003) have interpreted similar features as remnant shorelines and beaches related to the recession of catastrophic flood waters from the northwest outlet of Glacial Lake Agassiz, while others propose that these features are gravel bedforms formed during peak outflow from the lake through its northwest outlet (Clarke and Ronaghan 2000; Clarke, Ronaghan, and Bouchet, chapter 5 in this volume). According to the first model, human occupation of the region occurred fairly early, as the flood waned, with groups drawing on the rich resources of the littoral zones associated with the floodwaters and with remnant ponds and lakes (Saxberg and Reeves 2003). In the second model, human occupation would have been limited until the floodwaters had fully receded and a productive grassland environment had recolonized the scoured landscape, including the newly exposed gravel bedforms.

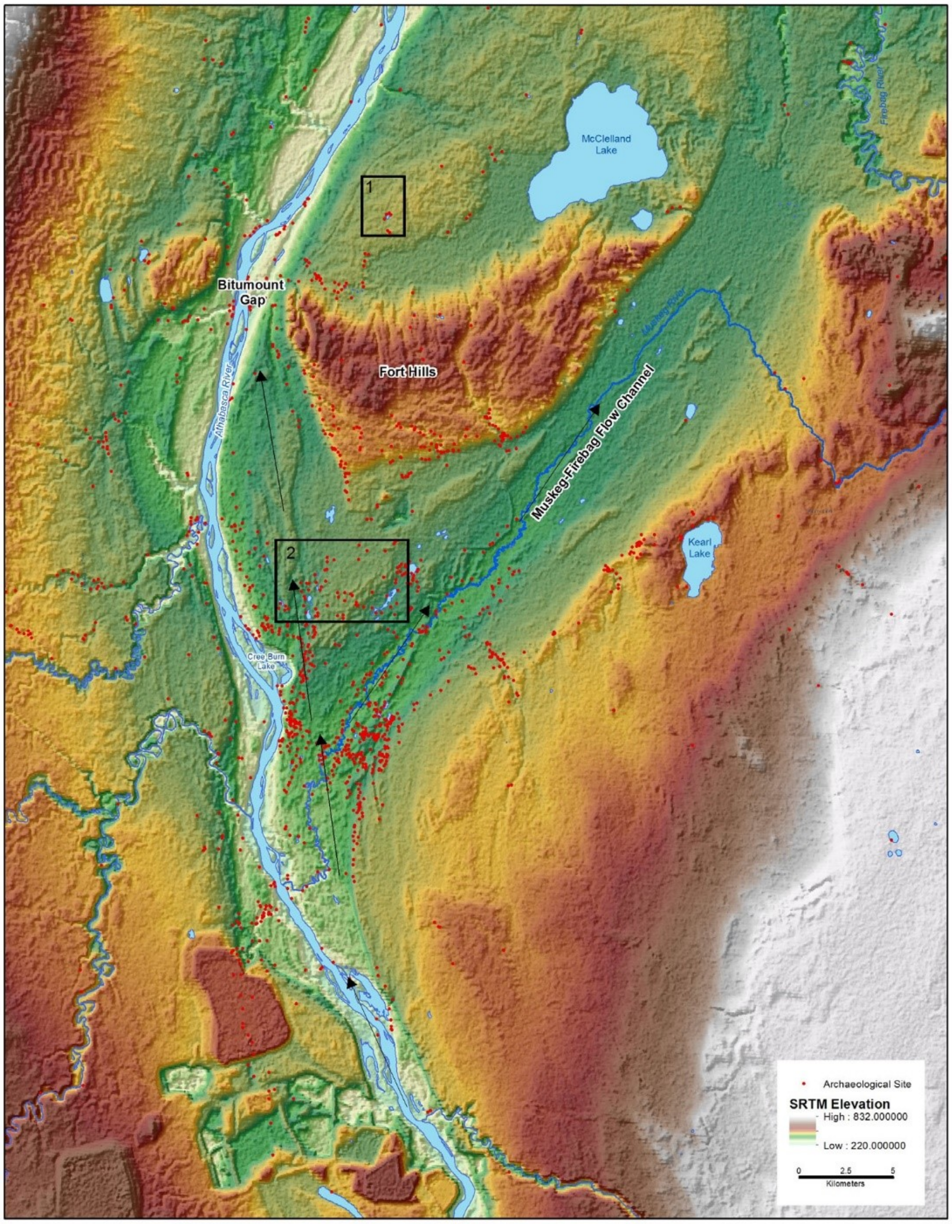

Figure 2.1. The CreeBurn Lake-Kearl Lake lowlands. To date, approximately four hundred archaeological sites (marked by red dots in the figure) have been identified in this area. Box 1 indicates the location of aeolian landforms north of the Fort Hills (see Figure 2.2). Box 2 shows the location of flow bifurcation to the north-northwest and to the northeast of the Fort Hills (see Figures 2.3 and 2.4).

The origin of the raised landforms in the Cree Burn Lake–Kearl Lake lowland has implications for how people used the landscape and for the timing of human occupation following the Lake Agassiz flood. However, no formal examination of landform morphology, sediment, or age has been conducted in support of archaeological models of human habitation. In what follows, we address this issue by examining the origin and age of a number of these landforms, using Light Detection and Ranging (LiDAR) images as well as geomorphological and sedimentary observations based on fieldwork. We then discuss the genesis of these deposits in relation to the northwestern outlet of Glacial Lake Agassiz and the aeolian landforms in the area.

2.2 Geological Setting and Methods

Smith and Fisher (1993, 10) observe that "sheets and long bars of boulder gravel" mantle the area south of the Fort Hills. As they note, the gravel is poorly sorted (ranging from sand to boulders) and poorly stratified and contains large ripups of oil sand and rounded diamicton blocks. This gravel unit has been interpreted as a high-velocity fluvial deposit related to catastrophic flows through the Lower Athabasca valley associated with the northwestern outlet of Lake Agassiz (Smith and Fisher 1993; Fisher 2007; Fisher et al. 2009; Fisher and Lowell 2017).

The route of the flood can be traced in the Clearwater–Lower Athabasca spillway as defined by Smith and Fisher (1993). The headwaters of the spillway lie in the upper reaches of the Clearwater River just east of the Alberta-Saskatchewan border. The spillway follows the Clearwater River west to its confluence with the Athabasca River at Fort McMurray, where it turns north, widens, and grades into the Late Pleistocene Athabasca braid delta, north of the Fort Hills (Rhine and Smith 1988). South of the Fort Hills, in the area of the Cree Burn Lake–Kearl Lake lowland, the spillway bifurcates, with one path of flow following the Muskeg River valley to the northeast, toward the Firebag River, and another following the present course of the Athabasca River through the Bitumount Gap (Figure 2.1). Flow divergence to either side of the Fort Hills is indicated by the direction of imbricate clasts in the flood gravels and by the orientation of a series of large bars and channels located along the southern margins of the upland (Smith and Fisher 1993). The landforms we examined are superimposed on one of these large gravel bars at the point of flow divergence (Figure 2.1, box 2). Radiocarbon dates from lake cores and deltaic sediments initially suggested that the Clearwater–Lower Athabasca spillway became active somewhere between 9,850 and 9,660 14C yr BP (Fisher et al. 2009); Fisher and Lowell (2017) revise these dates slightly, to 9,800 and 9,600 14C yr BP. However, an alternate chronology suggests that flooding may have begun somewhat earlier, prior to 10,000 14^{C} yr BP (Teller et al. 2005; Froese, Smith, and Reyes 2010; Murton et al. 2010).

To the north of the Fort Hills, archaeological sites are again concentrated on raised landforms, similar in morphology to those in the Cree Burn Lake–Kearl Lake lowland (Unfreed, Fedirchuk, and Gryba 2001; Woywitka, chapter 7 in this volume). However, these more northern landforms are aeolian features, consisting largely of stabilized sand dunes, both transverse and parabolic (Figure 2.1, box 1, and Figure 2.2; and see David 1981; Rhine and Smith 1988; Wolfe, Huntley, and Ollerhead 2004).

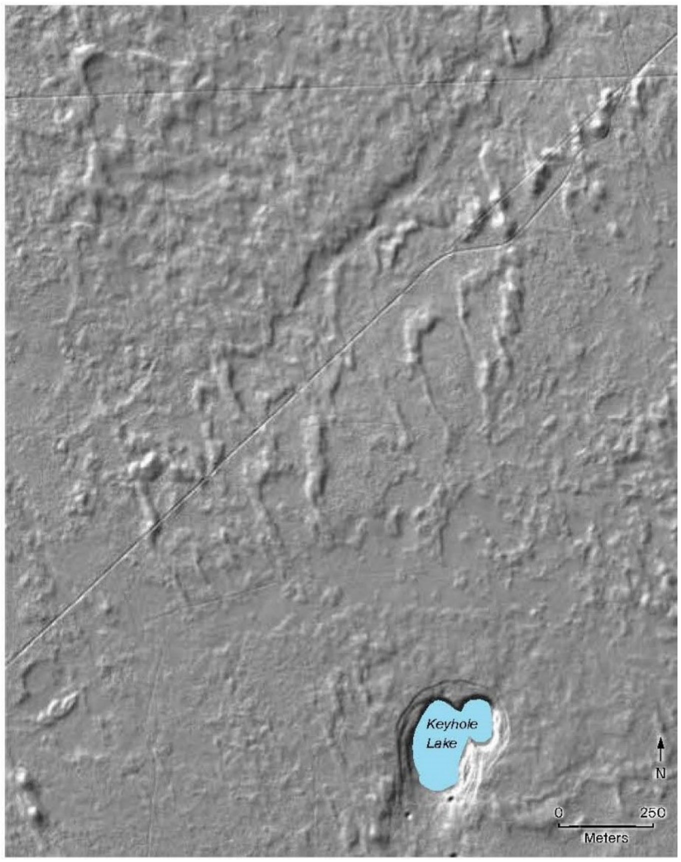

Figure 2.2. LiDAR image of aeolian landforms (parabolic sand dunes) in the oil sands region north of the Fort Hills.

The landforms we studied were initially identified by a visual examination of shaded relief images derived from a LiDAR bareearth digital elevation model (DEM) (Figure 2.3). The cell size of the DEM grid was 1-metre, and the vertical accuracy 0.6 metres. Relief images were calculated with a 1-metre cell size, an azimuth angle of 315°, and an altitude angle of 45°. Relief was estimated from 1-metre interval contours interpolated from the bare-earth DEM. Sediment exposures in the area had been directly examined several times since 2006, and in August 2010 we conducted field studies at some of the raised landforms identified in the LiDAR images. Firsthand observations were made at locations where access road rights-of-way, clearings for well pads, and other mining disturbances had already cut into the landforms. The sediment exposures were described and photographed, and samples of the sediment collected.

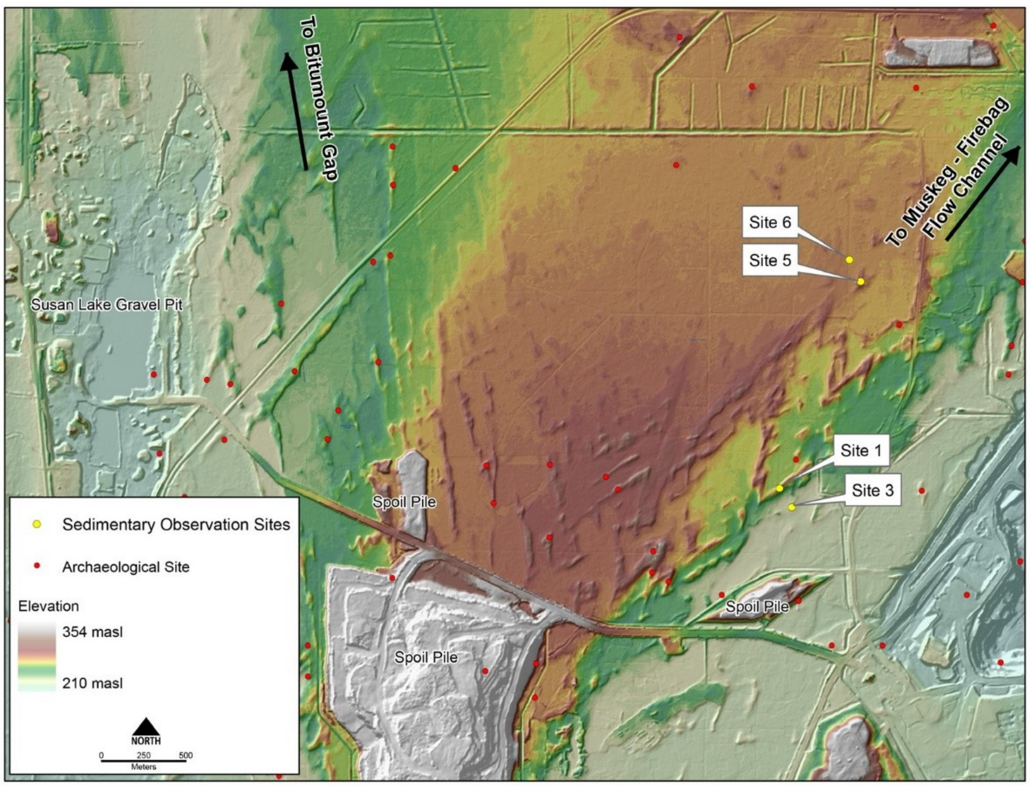

Figure 2.3. LiDAR image of the Cree Burn Lake–Kearl Lake lowland. Prominent raised linear landforms are common in the study area, with long axes oriented toward the northnorthwest, in the direction of the Bitumount Gap, on the west side of the area, and, on the east side, toward the northeast along the Muskeg- Firebag flow channel.

2.3 Landform Shape and Orientation

Raised landforms within the area of study are predominantly streamlined and range from linear to rhomboidal in shape. We recognize three primary landform types: linear landforms that trend to the northeast; linear landforms that trend to the north-northwest; and composite ridge-to-rhomboidal landforms (Figure 2.4, a, b, and c, respectively).

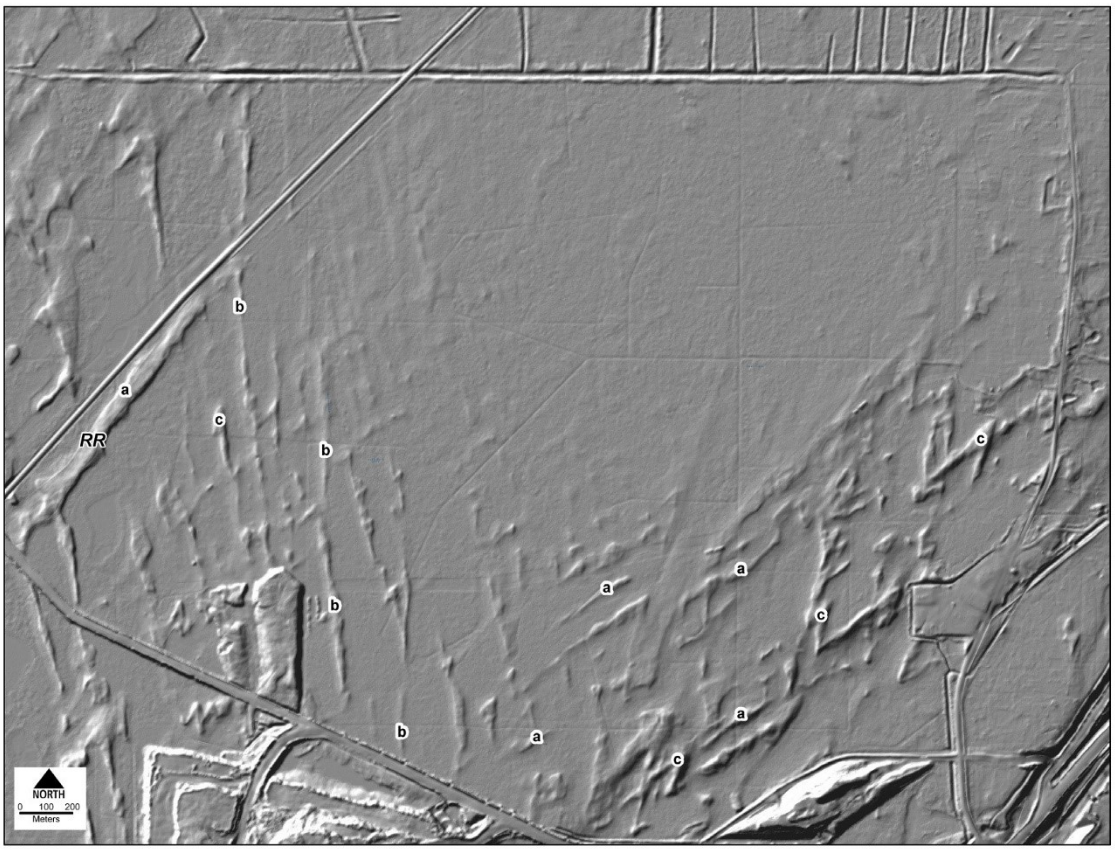

Figure 2.4. Detail of LiDAR image, showing raised landforms. At least three prominent varieties of landform can be recognized: (a) linear landforms that trend to the northeast; (b) linear landforms trending north-northwest; and (c) composite ridge-to-rhomboidal landforms. All the sites examined in this study consist of boulder-gravel cores with an aeolian mantle of sand on their surface. RR = Ronaghan's Ridge.Northeast-trending linear

landforms range from 30 to 350 metres in length and from 20 to 30 metres in width. One prominent northeast-trending landform, known as Ronaghan's Ridge ("RR" on the figure), considerably exceeds these dimensions, however, with a length of roughly 1,200 metres and a width of about 70 metres. Most of these landforms are located on the east side of the study area, with long axes oriented in the same direction as the Muskeg-Firebag flow channel (Figure 2.4, a). Relief on these features is up to 4 metres, and crests have a sharper gradient on their northwest-facing slopes, with crest elevations ranging from 297 to 302 metres above sea level.

The north-northwest-trending linear landforms are largely located on the west side of the study area, with a main longaxis orientation toward the Bitumount Gap, running roughly parallel to the Athabasca River (Figure 2.4, b). These features are generally somewhat longer and slightly wider than the north- east-trending ones, with lengths of up to 600 metres and widths of up to 50 metres, although most range from 30 to 35 metres in width. Relief on these features is up to 3 metres, with many rising only 1 metre above the surrounding peatland. The crests of these landforms have a sharper gradient on their east- north- east-facing slopes, and crest elevations range from 299 to 302 metres above sea level. In view of their lower relief, these north-northwest-trending features are generally more subtle on the LiDAR image than the northeast-trending ones.

Composite ridge-to-rhomboidal landforms (Figure 2.4, c) occur throughout the study area but are more common along the southeastern boundary. The landforms along this boundary are oriented to the northeast, toward the Muskeg- Firebag flow channel, and are variously linear, arcuate, or rhomboidal in shape, with pronounced heads.[1] Their length varies between 150 and

300 metres, with head widths of 50 to 60 metres and horn widths of 30 to 40 metres. Relief is up to 5 metres, and horns are of closely matching length, with sharper gradients on their northwest-facing slopes. On the west side of the study area, composite ridge-to-rhomboidal landforms are oriented to the north-northwest, toward the Bitumount Gap. Their length varies between 120 and 150 metres, with head widths of 40 to 50 metres and horn widths of 20 to 30 metres. These features are of a less pronounced arcuate or rhomboidal shape and frequently have one horn that is longer than the other. Relief is up to 3 metres, and the horns have a sharper gradient on their east-northeast-facing slopes. Crest elevations range from 299 to 302 metres above sea level.

2.4 Sedimentary Observations

Poorly sorted, coarse grained imbricate gravels are present at the base of all the sediment exposures we examined in the field. Rip-ups of bitumen occur in this gravel unit (Figure 2.5, a, b), and well-rounded boulders as large as 2 metres in diameter can be found in spoil piles nearby (Figure 2.5, e). At site 1, the gravel is locally overlain by approximately 1.2 metres of plane-bedded sands (Figure 2.5, d). At site 5, the plane- bedded sand is absent, and the gravel is instead covered with massive, well-sorted, fine-grained sand. This massive sand layer is up to 1.1 metres thick and is overlaid by a thin cover of organic litter. A ventifacted cobble was also found in a surface exposure of the gravel-sand contact at this site (Figure 2.5, f). In areas of low relief, peat deposits occur, typically overlying sands or a thin veneer of sands on gravel between raised landforms. At site 6, the peat is 1.5 metres thick and lies on top of a thin bed of clay over a massive layer of grey sand.

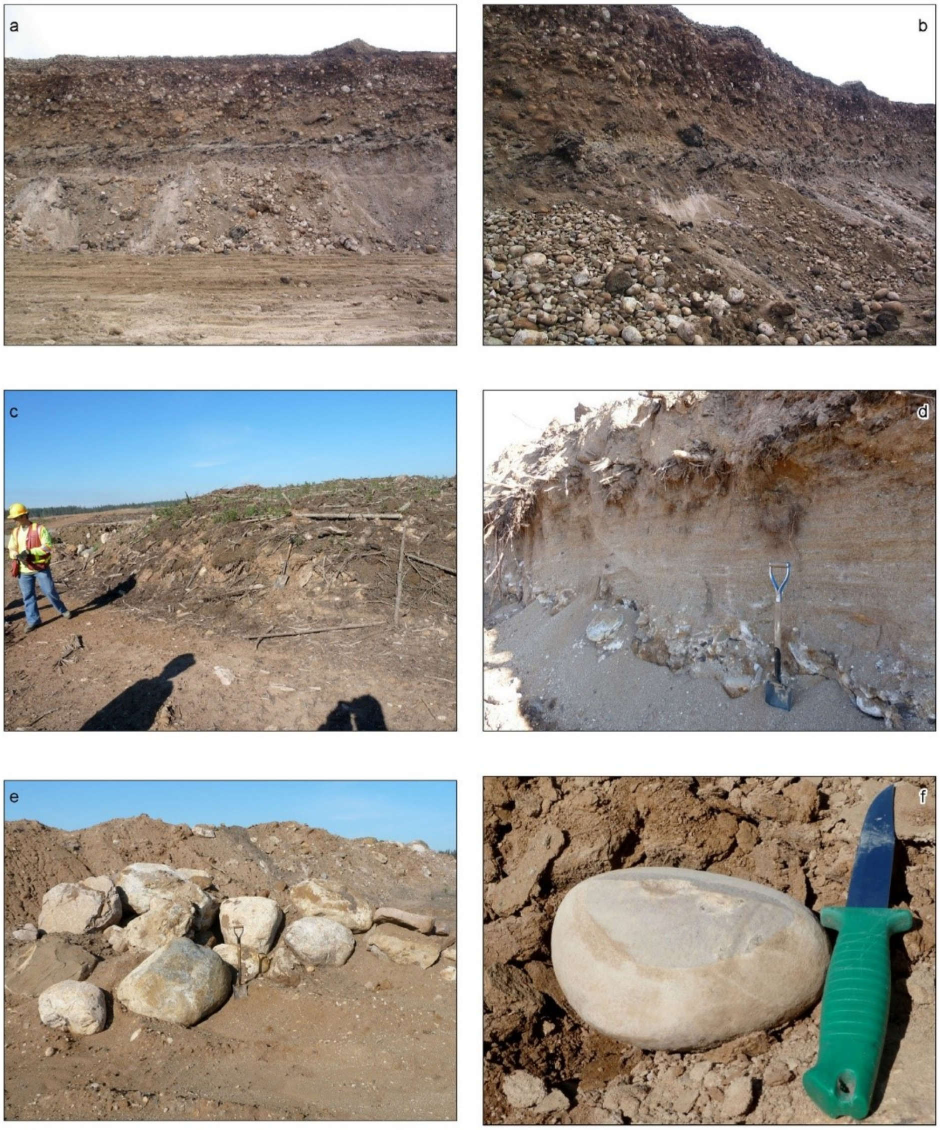

Figure 2.5 Photographs of the sites in the east-central oil sands: (a and b) exposures in the Susan Lake gravel pit showing catastrophic flood deposits with oil sand rip-up clasts; (c) approx. 2-metre relief on a linear landform at site 3; (d) plane-bedded sands overlying imbricate boulder gravel at site 1; (e) lag boulders in the study area dislodged by mining activities; and (f) a ventifacted cobble on the surface of a linear landform recording aeolian processes following the deposition of the landform. The relatively shallow relief on many of these

landforms, such as that illustrated in (c), makes these features rather subtle and thus difficult to observe in the field.

2.5 Interpretation

The coarse-grained gravel unit and plane-bedded sands observed at our field sites indicate deposition by high-velocity flows. The imbrication, grain size, and presence of bitumen rip-ups are all consistent with the Agassiz flood deposits described by Smith and Fisher (1993). The superposition of the landforms on the large gravel bar south of the Fort Hills indicates that they formed following the initial deposition of the bar.

The two differing landform orientations (northeast and north-northwest) are indicative of the divergence of flow around the Fort Hills, with the northeast-trending landforms representing flow toward the Muskeg-Firebag valley and the north-northwest- trending landforms representing flow that followed the Athabasca River through the Bitumount Gap (Figure2.1). These orientations are consistent with gravel fabric data presented by Smith and Fisher (1993). The shape of these landforms, their orientation, and the gravel fabric data suggest two possible interpretations. These landforms may reflect a sequence of events, in which an initial flow along one of the channels was followed by occupation of the second. Alternatively, they may represent synchronous flow both to the northeast and to the north-northwest, with the construction of ridge-to-rhomboidal landforms occurring during bifurcated flow. The closely similar crest elevations on landforms of both orientations (297 to 302 m) suggest that flow was synchronous. These elevations are slightly above estimates of the divide elevation between the Firebag and Muskeg rivers (289 to 292 m). The prevalence of the higher relief combined ridge-to-rhomboidal pattern in the northeast-trending landforms suggests that flow was stronger down the Muskeg-Firebag flow path.

The hydraulic processes underlying the formation of meso- to micro-scale depositional landforms during catastrophic floods is poorly understood (for a discussion, see Carling et al. 2009), and the use of LiDAR data to image these and other geomorphic features is still in its early stages. We know of no landform-scale examples that exhibit
a form immediately similar to the ridge-to-rhomboidal pattern observed in the study area. However, a variety of bedscale features display a similar pattern. These include rhomboid ripples found on bar tops and commonly in beach swash zones, which are typically on the order of a few grain diameters high and are associated with very shallow supercritical flows (Allen 1982, 404). In these flows, rhomboid ripples are the product of two hydraulic jumps oblique to the main direction of flow, with the crests of the ripples corresponding to the hydraulic jumps (Allen 1982, 404). As recent experimental work has shown, with more viscous flows, the rhomboid pattern may also be produced at subcritical velocities (Devauchelle et al. 2010). When they occur, however, these rhomboid bedforms tend to be quite homogenous, and the irregular ridge and rhomboidal forms in this study are at best partial analogues.

As far as we are aware, the forms most similar to those observed in the present study are the flow-aligned ridges and the ridge and rhomboidal patterns produced experimentally by Karcz and Kersey (1980). In these experiments, flow-aligned ridges were associated with laminar, subcritical flow, while combined ridge and rhomboidal patterns were associated with laminar, supercritical flow. There are several caveats to the form analogy, however, given the differences in the scale of bedforms produced from these experimental sand channels and the landforms observed in this study, not the least of which is the difference in grain size, as well as the presence of presumably sediment-laden waters during catastrophic flooding. However, despite the uncertainties surrounding the details of flow conditions, the bedform examples all consistently indicate high- velocity flows during bedform generation.

The massive layer of well-sorted sand overlying the gravel unit at some of our field sites is best interpreted as aeolian sediment deposited after subaerial exposure of the landforms. The deposition of this sand unit, as well as the ventifacted cobble found at the sand-gravel contact, indicates that windy conditions prevailed after the recession of flood waters from the study area. Following the cessation of aeolian deposition, surfaces were stabilized by vegetation, with boreal communities eventually becoming established on uplands. The sediment exposure at site 6 indicates that peatlands also began to accumulate in lowlands following aeolian activity in the area.

2.6 Discussion and Conclusion

The raised landforms in the study area appear to be gravel bedforms created by flow related to the catastrophic flooding of Glacial Lake Agassiz through the Clearwater– Lower Athabasca spillway. The source and timing of flooding through the spillway is an area of ongoing research. Fisher et al. (2009) originally suggested that the spillway was created between 9,850 and 9,660 14C yr BP and may have drained a glacial lake independent of

Glacial Lake Agassiz. The spillway would have accommodated flow from this source until roughly 9,450 14C yr BP. Murton et al. (2010) postulate an earlier Lake Agassiz–related chronology for the flood, with an initial outburst event occurring before 10,000 14C yr BP. Our study does not provide information on the precise timing of landform development. However, the position of the study area near the upper margins of the Muskeg- Firebag and Bitumount Gap flow channels and the evidence of high-velocity flows suggest that the landforms were formed during the early stages of the flood, when large discharges occupied both channels.

Although flood-related bedforms are well known from glacial outburst events in a large variety of settings (see Burr, Carling, and Baker 2009), most of these previously studied landforms are of greater size and relief than the features we have described here (for comparisons, see Pardee 1942; Baker 1973; O'Connor 1993). For the most part, the landforms we examined appear as subtle features in the field (see fig 3.5, c). It is likely that forms of the relatively small magnitude that we describe here are in fact more common elsewhere but are difficult to recognize without the exceptional resolution of LiDAR-derived DEM data.

A thin, discontinuous mantle of windblown sediments was deposited across the newly exposed landscape following the recession of flood waters. The lack of well- defined aeolian landforms (such as sand dunes) in the area could be due to the dominance of very coarse-grained material, although it could also reflect the prevalence of low to moderate wind speeds. The former explanation is more likely, given the ubiquity of coarse-grained gravel deposits in the local environment and the well-established presence of strong postglacial wind regimes throughout northern Alberta (Wolfe, Huntley, and Ollerhead 2004). The exact age of landscape stabilization following the cessation of aeolian deposition is unknown, but pollen records in the region indicate that forests were established in upland areas shortly after flooding (Bouchet and Beaudoin 2017) and that wetlands began to accumulate approximately 8,000 to 6,000 years ago (Halsey, Vitt, and Bauer 1998).

The oil sands region preserves diverse landforms that are closely associated with the archaeological record. Raised landforms in the lowland areas hold special significance, however, since the majority of archaeological sites in areas such as the Cree Burn Lake–Kearl Lake lowland are found on these features. In contrast to areas to the northwest of the Fort Hills, in which aeolian landforms pre- dominate, these landforms are subaqueous gravel bedforms created by the extraordinary flows associated with the northwest outlet of Glacial Lake Agassiz. The lack of directly dated archaeological deposits in the area prevents a definitive determination of the timing of initial human occupation of the Cree Burn Lake– Kearl Lake lowland. However, these landforms would have been available for human occupation only after recession of the floodwaters. On the basis of other studies of flood chronology (Fisher et al. 2009; Murton et al. 2010), the emergence of these landforms can be dated to the transitional terminal Pleistocene–early Holocene period. The frequent preservation of archaeological materials in the aeolian sands that drape these landforms also suggests that human occupation occurred during and/or following the deposition of the windblown sediment. Future research aimed at determining the timing of landscape stabilization will help us to develop a precise chronology for human occupation of the oil sands region.

Note

[1] The "head" is the point of highest elevation on a landform, while "horn" refers to the trailing arms of arcuate or rhomboidal landforms.

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CHAPTER 3: EARLY (CA. 12,000 BP) POST-GLACIAL LANDSCAPE STABILIZATION AND HUMAN OCCUPATION IN THE OIL SANDS REGION, NORTHEASTERN ALBERTA, CANADA

Abstract

The mineable oil sands region of northeastern Alberta contains one of the highest concentrations of prehistoric archaeological sites in the boreal forests of western Canada. This is largely due to the presence of abundant sources of lithic raw material stone. Typological studies have suggested immediate post-glacial occupations that were contemporaneous with, or immediately followed, the glacial lake Agassiz outburst flood event that affected the area at the end of the Pleistocene. Here we use stratigraphic relationships, infrared stimulated luminescence dating of aeolian material, and radiocarbon dating of peat deposits to determine the age of initial human occupation, and to reconstruct the environment encountered by the first inhabitants of the mineable oil sands region. We find that the first occupations occurred ca. 12,000 years ago, shortly following catastrophic flooding, and that the post-flood environment was dominated by cold climatic conditions that supported permafrost and underwent significant aeolian processes.

3.1. Introduction

Research in the lower Athabasca River drainage of northeastern Alberta, Canada plays a key role in our understanding of late Quaternary natural and cultural history. Examinations of the routing, timing, and climatic effects of catastrophic drainage from glacial Lake Agassiz are the most widely known Quaternary studies from the region (Fisher and Smith, 1994; Murton et al., 2010; Smith and Fisher, 1993), and palaeoecological work has offered insight into post-glacial ecological change in western Canada (Bouchet-Bert and Beaudoin, 2017; Bouchet-Bert, 2002; Vance, 1986). A less well-known aspect of the late Quaternary history of this region is its rich archaeological record. Extensive archaeological survey and excavation has taken place in the area, mostly in advance of oil sands mining development (Ronaghan, 2017). This work has documented one of the highest concentrations of archaeological sites in the western Canadian boreal forest, with over 1,000 sites occurring within the boundaries of the mineable oil sands region near Fort McMurray, Alberta (Figure 3.1; Ronaghan, 2017). Nearly 3.8 million artifacts have been recovered since 1973, including hundreds of formed tools and projectile points (Kristensen et al., 2016). The breadth of the archaeological record and the amount of cultural resources management (CRM) work carried out in the region is unprecedented in northern Alberta, and perhaps in western Canada (Ronaghan, 2017). Published archaeological research in the area has focused on lithic raw material studies (Fenton and Ives, 1990; Kristensen et al., 2016; Tsang, 1998), and lithic technology (Ives, 2017, 1993; Le Blanc and Ives, 1986; Reeves et al., 2017; Saxberg and Robertson, 2017; Younie et al., 2010). Most chronological studies to date have been based on lithic typology and landform associations (Reeves et al., 2017; Saxberg and Reeves, 2003; Saxberg and Robertson, 2017; Woywitka, 2017; Woywitka et al., 2017), mainly due to the low number of available radiocarbon dates from archaeological contexts (Woywitka, 2016).

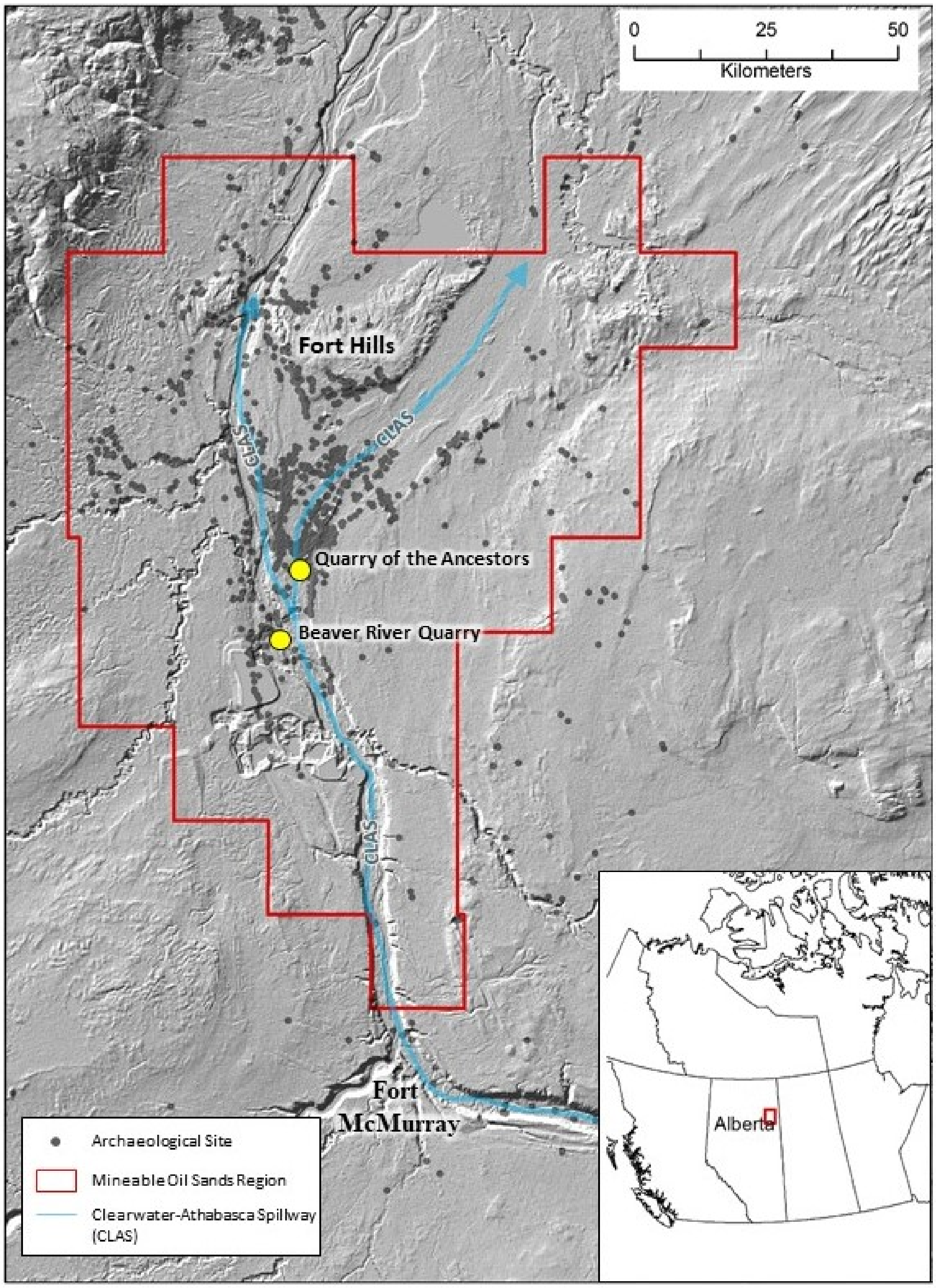


Figure 3.1 Location of the mineable oil sands region, the Clearwater-

Athabasca Spillway (CLAS), and associated archaeological sites.

The regional archaeological record lacks a well-developed temporal framework based on radiometric dates and stratigraphic relations. To fill this knowledge gap, we report stratigraphic sequences, radiocarbon dates, and infrared stimulated luminescence (IRSL) ages from archaeological and non-archaeological contexts in the region. This work focuses on the immediate post-glacial period, and aims to determine when the landscape became available for human occupation, and to characterize the environmental conditions that existed during initial occupations. In particular, we address whether the area was initially occupied shortly following late Pleistocene catastrophic drainage, or if it was delayed until the landscape was stabilized by vegetation during ameliorating climatic conditions.

3.2. Archaeological setting

Artifact assemblages are dominated by lithic tools and debitage formed from Beaver River Sandstone (Fenton and Ives, 1990), a ubiquitous raw material in the mineable oil sands region. This material occurs as a silicified facies in the oilsands-bearing McMurray Formation, and the finer grained components are well suited to the manufacture of stone tools (Kristensen et al., 2016). The richness of the archaeological record has been explained by the presence of two source areas for this stone: Beaver River Quarry and Quarry of the Ancestors (Figure 3.1). Both provide surface or near surface access to Beaver River Sandstone in primary context within bedrock, or as reworked gravel deposits (Fenton and Ives, 1990; Saxberg, 2007). Although masked by dense boreal forest today, Beaver River Sandstone sources may have been more apparent to past inhabitants due to the scouring of overlying glacial deposits by catastrophic flooding (Ronaghan and Clarke, 2000; Saxberg and Reeves, 2003; Woywitka et al., 2017) and more open vegetation (Bouchet-Bert, 2002).

Little is known about the timing of human occupation in the mineable oil sands region. Most sites contain shallow (< 1.0 m) cultural deposits that have been mixed by natural processes (e.g., tree root growth, tree stump throws, rodent burrowing), resulting in sediment profiles that contain palimpsests of several occupations (Ives, 1993). The weathering of most organic materials by boreal forest soils has also limited radiocarbon dating to more degradation-resistant calcined bone samples from 25 sites (Woywitka, 2016). These dates indicate that humans occupied the area from at least 8,000 cal yr BP to present. Saxberg and Robertson (2017) indicates a late Pleistocene-aged occupation at Quarry of the Ancestors based on stratigraphic relationships (discussed further below). A projectile point typology based cultural history also suggests an early deglacial age (ca. 13,000 to 11,000 years BP) for the initial occupation of the region (Reeves et al., 2017; Saxberg and Reeves, 2003). This cultural chronology proposes human presence from ~11,000 to 13,000 cal yr BP, shortly following the retreat of the Laurentide Ice Sheet (LIS) from the area, to modern time (Saxberg and Reeves, 2003; Reeves et al., 2017). Typological studies such as these provide valuable knowledge about lithic technology, mobility patterns, and subsistence practices. However, the chronological information in these frameworks is based on correlation with radiocarbon dated sites from adjacent and distal localities. This type of temporal analysis has proven to yield uncertain results in other parts of the northwestern Canadian boreal forest (Hare et al., 2008; Ives, 2017), emphasizing the need for radiometric and stratigraphic ages to complement these frameworks.

3.3. Geological Setting

Archaeological deposits in the mineable oil sands region lie near the surface of a sequence of Late Pleistocene glacially derived deposits that overlie the oil sands bearing McMurray and Clearwater Formations of the Early Cretaceous (Hein and Cotterill, 2007). Glacial deposits consist of till, glaciolacustrine sands and silts, and coarse boulder gravels and sands (Dyke, 2004; Fenton et al., 2013). The boulder gravel and associated sand units have been interpreted as glacial lake outburst deposits (Smith and Fisher, 1993), and are observed in the Clearwater River, Athabasca River, and Muskeg River valleys. This distribution forms the basis for the extent of the Clearwater-Athabasca Spillway (Figure 3.1; Smith and Fisher, 1993). The spillway represents the path of catastrophic flooding brought on by the establishment of a glacial lake outlet in northwestern Saskatchewan after the LIS had retreated from the Fort McMurray area. There are currently two general schools of thought on the timing of ice retreat and catastrophic flooding in the region: 1) The LIS had retreated from the area by 13,000 cal yr BP, and that catastrophic flooding originated from the northwestern outlet of glacial lake Agassiz at the outset of the Younger Dryas (Murton et al., 2010); or 2) that the LIS retreated from the area after ca. 11,300 cal yr BP, and that flooding originated from a smaller glacial lake in northwestern Saskatchewan (Fisher et al., 2009).

Buried archaeological sites within the spillway commonly occur in association with boulder gravel-cored linear landforms identified as outburst flood bedforms (Woywitka et al., 2017). Site matrices on these landforms are medium to fine massive sands that overlie the flood facies described by Smith and Fisher (1993). North of the Fort Hills, sites are commonly situated in massive to weakly stratified sands atop landforms that have been interpreted as stabilized sand dunes (Rhine and Smith, 1988; Woywitka et al., 2017). Artifacts are usually recovered at depths from the near surface to one-metre below surface in both settings.

Based on these landform associations, the age of flood bedform exposure and the onset of sand dune deposition should represent the maximum age for human occupation of the mineable oil sands region. Our determination of the age of the cessation of aeolian deposition on uplands represents initial landscape stabilization, and the establishment of vegetation communities. This landscape would have provided more predictable subsistence opportunities than the earlier open, windblown conditions, and likely represents the earliest time that humans could have consistently exploited extensive plant and game resources. Basal radiocarbon dates from adjacent peatlands provide insight into when wetlands began to develop on lower parts of the landscape and cover previously open terrain, altering the immediate post-glacial landscape, and possibly preserving archaeological material during the Holocene.

3.4. Methods

Sediment exposures at raised landforms, peat exposures and archaeological excavations were logged and photographed in 2006 (DF), 2010 (RW, DF and SW), and 2012-2014 (RW). Archaeological excavation within Quarry of the Ancestors was carried out at HhOv-319, Locus 1, on the eastern flank of a raised gravel-cored landform (Quarry-1 on Panel B, Figure 3.2). This expanded on the work of Saxberg (2007). Lithic analysis of the material recovered is presented in Woywitka and Lints (2017).

In order to obtain maximum landform origin ages, we collected sediment samples for IRSL analysis at five different landforms, including three stabilized dunes north of the Fort Hills

(FHNW-1, NWFH-3, UTS-1; Figure 3.2) and two boulder-cored bedform features (Quarry-1, Shell-1; Figure 3.2). IRSL dating is an assessment of time elapsed since feldspars were last exposed to sunlight, hence their age of deposition for sediments. IRSL samples were taken at depths between 25 and 155 cm, below visible indicators of bioturbation. At sites Shell-01 and Quarry of the Ancestors, the IRSL samples were taken from sands that overlie boulder gravels (Figure 3.3). The samples from Quarry of the Ancestors were in direct association with archaeological material. At the remaining sites, samples were taken from massive and weakly stratified sands on the crests of one transverse dune, one stabilized parabolic sand dune, and the stabilized blowout of a parabolic dune (Figure 3.2).

The dunes are oriented northwest-southeast, with the parabolic lee sides facing southeast and the transverse lee sides facing northwest (Figure 3.2). The IRSL samples were processed for dating in the Université du Québec à Montréal luminescence laboratory (by LM). Sand-sized (150-250 um) feldspars were extracted using routine laboratory protocols. The equivalent doses were measured using a SAR methodology adapted to feldspar (Lamothe, 2004). Anomalous fading (AF) correction followed that developed by Huntley and Lamothe (2001). All measurements were carried out in a Riso TL-DA-15 automated reader. Luminescence was detected using a Corning 7-59/Schott BG39 filter combination. AF-corrected IRSL ages were estimated using the Central Age Model (Galbraith et al., 1999). Basal peat radiocarbon samples were collected from organic deposits as near the mineral/organic interface as possible (Figure 3.3). Three of the ages were from backhoe tests excavated on the edges of very low relief peat-capped ridges near Ronaghan's Ridge (RJW01, RJW02, and RJW03; Figure 3.2).

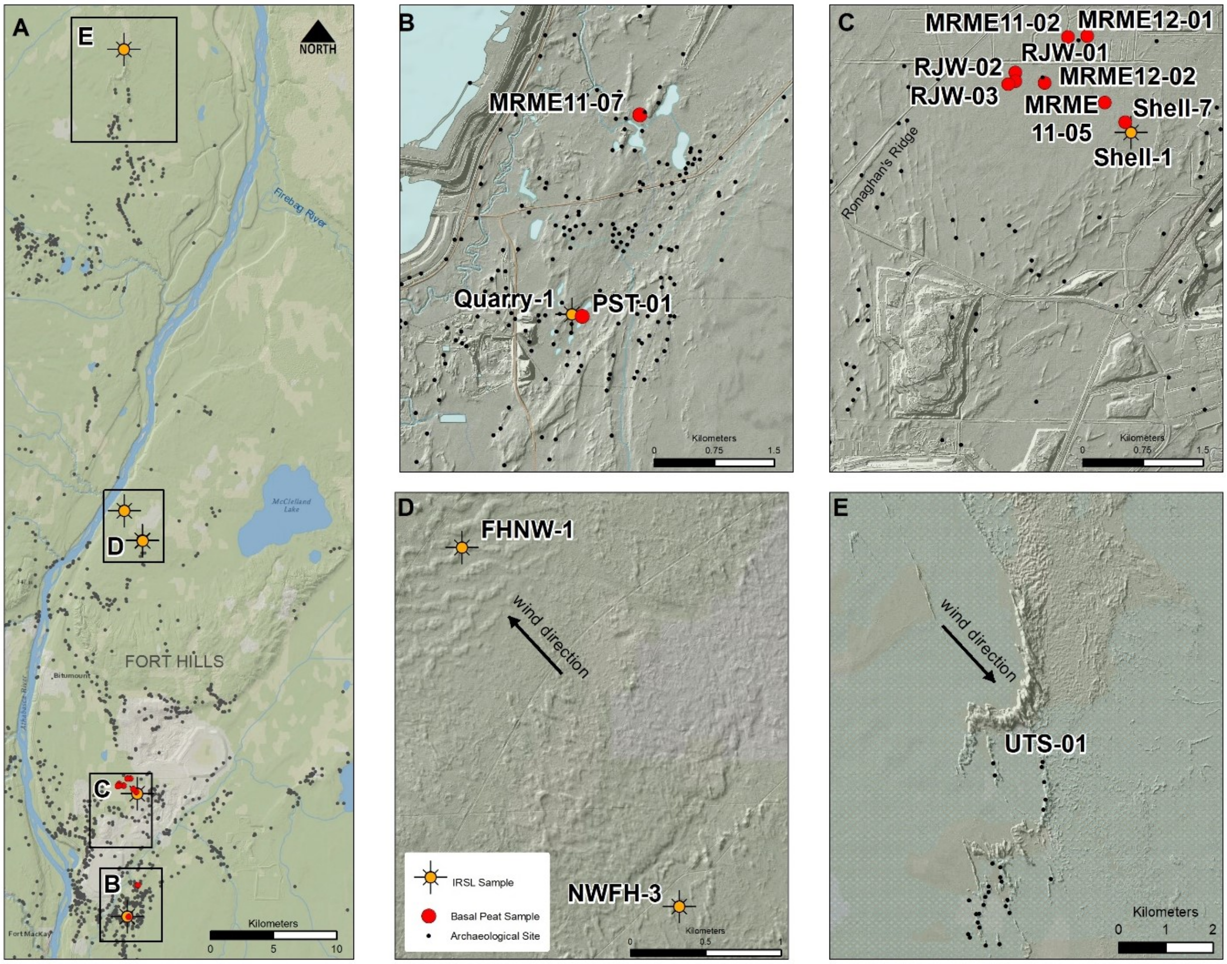


Figure 3.2 (a) Map showing the location of all IRSL and peat sampling locations (b) gravel cored bedform, IRSL and peat sample locations in Quarry of the Ancestors, peat samples near Sharkbite Lakes (c) LiDAR image of gravel cored bedforms near Ronaghan's Ridge and IRSL and peat sampling locations, (d) transverse and parabolic dune forms north of the Fort Hills and IRSL sampling locations, (e) parabolic dunes west of the Athabasca River and IRSL sampling locations.

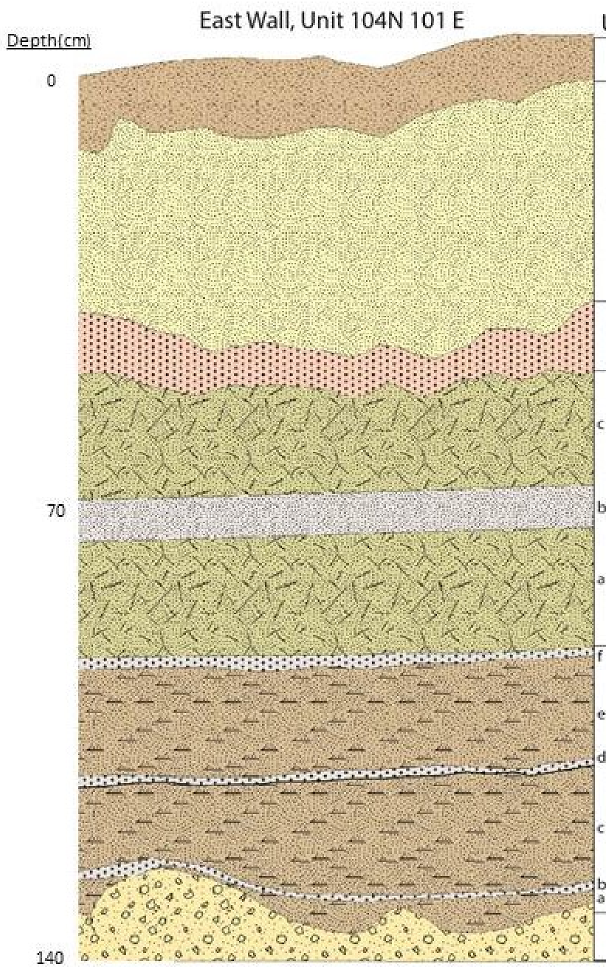
Figure 3.3 Basal peat sample location PST-01 at the Quarry of the Ancestors. The lowermost pink flag indicates the position of the wood macrofossil dated from this location.

These features are consistent in orientation and shape with exposed flood bedforms identified nearby (Woywitka et al., 2017), and are interpreted as buried bedforms. The other five were collected from fortuitous mining exposures or shovel probes near Ronaghan's Ridge, Sharkbite Lakes, and Quarry of the Ancestors (Figure 3.2). Visible macrofossils were collected when possible, and bulk peat samples were used in situations where visible macrofossils were not present. The bulk samples were then examined microscopically and subsampled for seeds and other macrofossils suitable for radiocarbon dating. Seven sub-samples of wood and one seed were obtained from basal peat deposits. These items were prepared for ^{14}C dating by accelerator mass spectrometry (AMS). Pre-treatment at the University of Alberta followed standard acid-base-acid procedures, with solutions heated to 70 °C: 30 min in 1M HCl, 60 min in 1 M NaOH with the solution changed until clear, 30 min in 1 M HCl, and rinses with ultrapure water until neutral. CO_2 production, graphitization and measurement of ^{14}C abundance of all peat samples were completed at the Keck-Carbon Cycle AMS facility (UCIAMS). To determine background ^{14}C abundance, all samples were pre-treated and analyzed concurrently with sub-samples of comparable mass of Queets-A and AVR-07-PAL, internal standards of last interglacial age. One well-dated international standard, FIRI-D, was used to verify age quality.

3.5. Results

3.5.1 Lithostratigraphy description

Six sedimentary units were observed in the study area (Table 3.1). Archaeological excavations at Quarry of the Ancestors exposed all six units (Figure 3.4 and Figure 3.5; Table 3.1). The lower four units were observed in association with gravel cored-bedforms south of the Fort Hills, and a massive sand cap occurred at all locales, including the stabilized dunes north of the Fort Hills. Peat and organic silts were observed in low lying areas adjacent to raised gravel cored bedforms, and at the three locales where peat overlies lower relief ridges near Ronaghan's Ridge. Artifacts are present only in the massive sand caps and organic deposits. Because the most complete sedimentary sequence was observed at Quarry of the Ancestors, the following descriptions are based on observations made at that site, except where otherwise noted.



Unit	Description	Interpretation	IRSL Age
LM	Organic matter	forest litter mat	n/a
5	loosely compacted medium grained sand, massive structure	eolian sand	12.0 ka cal +/- 1.0 ka cal BP
4	compact pink diamicton, clasts < 1cm, blocky structure	Fluvial (waning stage flood)	n/a
3	3b: compact coarse sand 3a and 3c: compact medium grained sand, massive structure, fining upward, placic horizon at base	Fluvial (waning stage flood)	14.3 ka cal +/- 1.0 ka cal BP
2	2b, d ,f: compact grey clay; dessication cracks present in 2d 2a, c, e: medium sand, massive to weak horizontal bedding and crude normal grading; grey sand veins	Fluvial (waning stage flood)	12.8 ka cal +/- 1.0 ka cal BP
1	matrix poor boulder gravel	Fluvial (peak flow flood)	n/a

Table 3.1 Unit descriptions and ages from Quarry of the Ancestors.

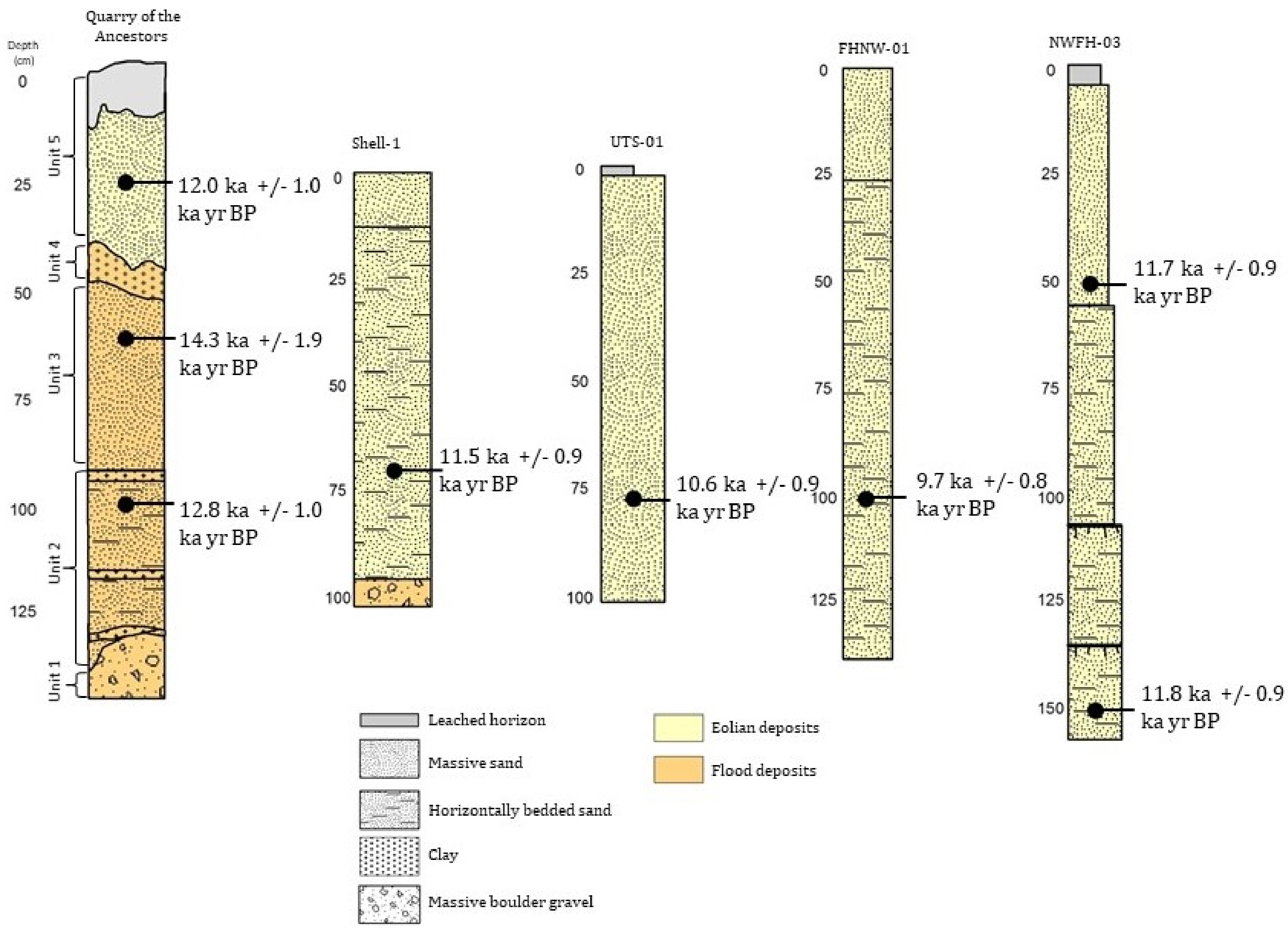


Figure 3.4 Stratigraphic profiles and ages from IRSL sampling locations.

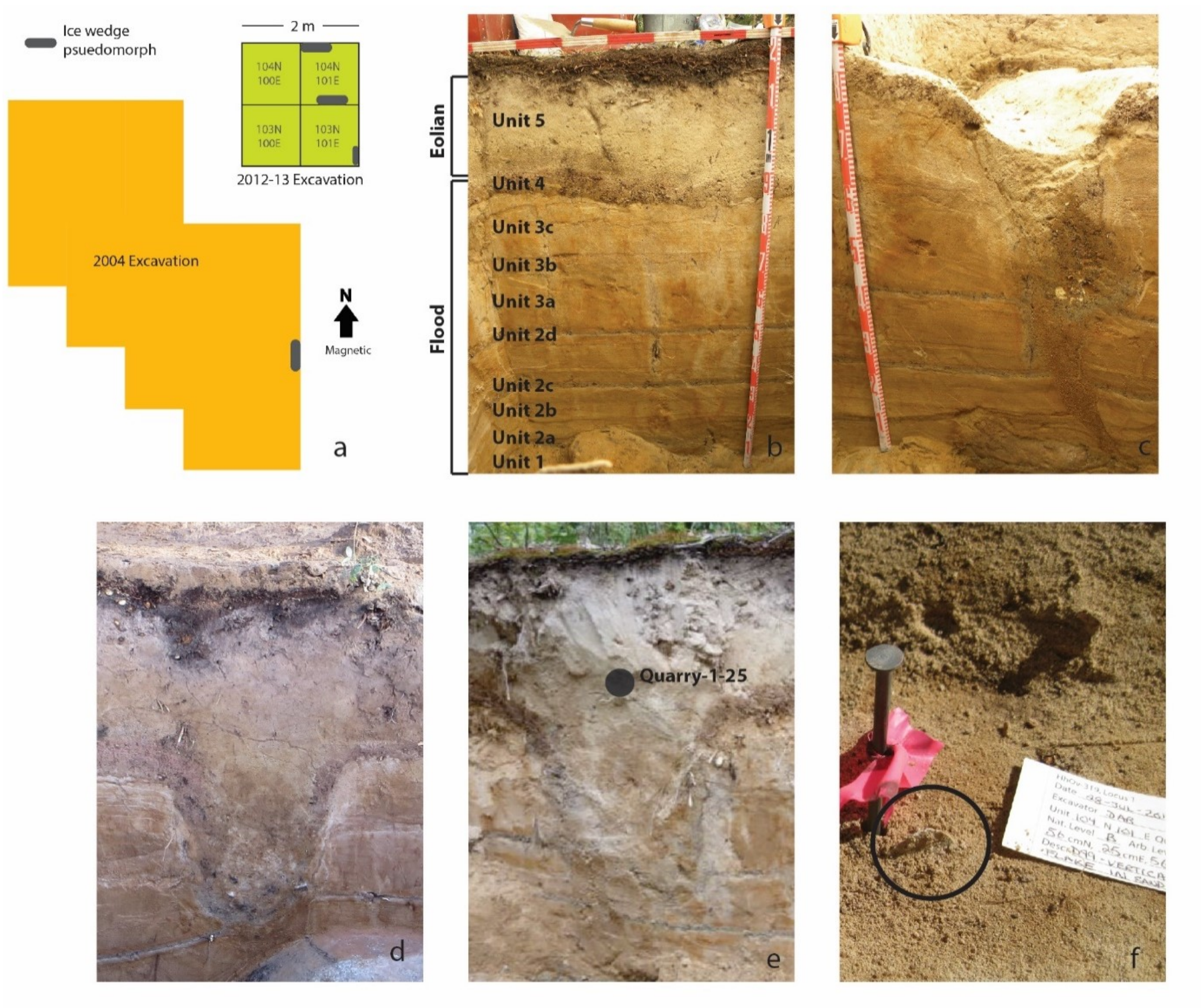


Figure 3.5 a) Excavation layout at HhOv-319, Locus 1, Quarry of the Ancestors (corresponds to Quarry-1 on Figure 3), (b) east wall profile Unit 104N 101E, with IRSL ages (c) ice wedge cast south wall of Unit 104N 101E, (d) ice wedge cast east wall of Unit 103N 101E, (e) ice wedge cast east wall of Unit 100N 100E and position of IRSL sample Quarry-1-25, (f) vertically emplaced flake (circled) in ice wedge cast, Unit 103N 101E.

The basal unit observed in the study area is a clast supported, imbricate boulder gravel (Unit 1; Table 3.1, Figure 3.5). The largest boulders measure approximately 100 by 100 cm, and are of quartzite, ironstone, bitumen, and granite lithology. A discontinuous, dense grey clay occurs in the upper portion of the unit at Quarry of the Ancestors but is absent at other locations. At Quarry of the Ancestors this gravel is overlain by three sand/clay rhythmites (Unit 2; Table 3.1, Figure 3.5). The clay layers are grey, massive and about two cm thick. Saxberg (2007) recorded desiccation cracks on the surface of the uppermost clay layer in the rhythmite sequence. The sand layers are orange in colour, medium to coarse in texture, have massive to weak horizontal bedding and crude normal grading. The upper one to two centimetres of the sand layers are lighter in colour than the deeper sands. Vertical white sand veins are present in the two upper rhythmites, and appear to originate from these light coloured sands (Figure 3.5). The veins do not crosscut the enclosing clay layers. The lower portions of the sand layers are cemented and reddened at their contacts with the underlying clays.

Two massive, medium-textured sand layers conformably overlie the sand/clay rhythmites at Quarry of the Ancestors (Unit 3; Table 3.1, Figure 3.5). Each fine upwards to very thin, white sand and have placic horizons at their base. A coarse massive sand layer separates these finer layers. Unlike the other placic horizons in the profile, the coarse sand layer, rather than clay, underlies the one at the base of the upper massive sand in this unit. White sand veins occur throughout the unit in multiple orientations. A discontinuous, undulating unit of pink clay overlies these massive sands at Quarry of the Ancestors (Unit 4; Table 3.1, Figure 3.5), but was not present at any other locales. The clay has a blocky texture, varies in thickness from 0 to 10 cm, and is laterally discontinuous. The material is compact when moist.

The uppermost mineral sediment unit is a massive to crudely stratified medium grained sand varying in thickness from 20 to 60 cm (Unit 5; Table 3.1, Figure 3.5). A discontinuous placic horizon occurs at its base at Quarry of the Ancestors. This horizon is well defined where Unit 5 is in direct contact with the underlying pink-red clay. Where the clay is thin or absent and the upper massive sands grade with massive sands underlying the clay, the placic horizon is absent or not well defined. At other gravel cored landforms the upper massive sands conformably overlie boulder gravels or weakly horizontally bedded sands (Figure 3.4). At site Shell-1, thin clay lamellae occurred in these horizontally bedded sands. Previous archaeological work and shovel tests excavated during the current study exposed the upper massive sand unit in stabilized sand dunes north of the Fort Hills to depths of at least 175 cm. At site NWFH -3, massive sand overlies crudely stratified sands, and two thin (~ 2 cm) desiccated clay layers were observed at depths of 110 cm and 140 cm.

In lower lying sites organic silt and peat deposits varying in thickness from 120 cm to 20 cm, directly overlie boulder gravels or the upper massive sand. East of Ronaghan's Ridge (Figure 3.2) well preserved logs lay at the base of the peat, conformably overlying boulder gravels (Figure 3.3). Unlike the other study sites, shovel probes in the wetland adjacent to archaeological excavations in Quarry of the Ancestors exposed an organic silt layer capped by peat. Grey sand cumulic layers were common in the organic silt, along with several woody macrofossils, including intact branches (Figure 3.3). At this site the organic layers overlie massive sand in the centre of the wetland, and boulder gravel near the edges. At the other lowland sites peat directly overlies Unit 1 gravel or Unit 5 sand.

A wedge shaped feature crosscut the archaeological excavation at Quarry of the Ancestors. The feature was observed on the eastern and northern excavation walls and crosscut depositional units below the massive pink-red clay (Figure 3.5). The average width of the mouth of the trough was 25 cm, and the structure was filled with the overlying and surrounding sediments, including lithic debitage entrained in upper massive sands, some of which were vertically emplaced. Beds adjacent to the feature were deformed, mostly in upturned inflections, although downturned inflections were also present (Figure 3.5).

The upper massive sands contain the majority of artifacts recovered during archaeological excavations at Quarry of the Ancestors. The artifacts recovered were nearly entirely Beaver River Sandstone, and represent a biface workshop (Woywitka and Lints, 2017). Some unmodified pebbles were observed in this unit along with the archaeological material, and polished clasts were also observed. Lithic debitage was reported from the lower massive sands (Unit 3; Table 3.1; Figure 3.5) during initial work at the Quarry of the Ancestors (Saxberg and Reeves, 2005), but the vertical provenience of these items is uncertain. This is because the excavation was conducted in arbitrary 10 cm levels, and did not map the discontinuous sedimentary contacts between the clay and enclosing sediments or the lateral extent of the wedge feature in detail (Saxberg, 2007). It is therefore not possible to determine whether an artifact found at a given depth was above or below the pink-red clay. In our excavation, no artifacts were recovered from within or below the clay (Woywitka and Lints, 2017). One scraper and ten pieces of lithic debitage were recovered from organic silts at the edge of the wetland in Quarry of the Ancestors, where the peat is thinner, and cumulic layers more common (Figure 3.4). In the stabilized sand dunes north of the Fort Hills, archaeological material is contained in the upper 30-40 cm of massive sands (Woywitka, 2017).

3.5.2 Lithostratigraphy interpretation

The gravel at the base of most sites is a local occurrence of the regional boulder gravel described by Smith and Fisher (1993) that represents peak flow of catastrophic flooding in the region. We interpret the overlying weakly laminated sands and clays (Units 2, 3, and 4; Table 3.1, Figure 3.5) as waning stage catastrophic flood sediment deposited as discharge ebbed from the glacial lake outlet. Local flow conditions promoted deposition of these units in topographic lows, and pulses in discharge produced the sand/clay rhythmites. In at least one instance discharge was low enough that water receded enough to subaerially expose a clay surface, as evidenced by desiccation cracks in one of the clay layers (Saxberg and Robertson, 2017). The hard red sand layers in the rhythmites are interpreted as pan formations caused by post-depositional blocking of water infiltration by underlying clay units.

Previous researchers at Quarry of the Ancestors have identified the basal gravels as catastrophic flood deposits, with the directly overlying sands and clays (Units 2 and 3 in Table 3.1) interpreted as fluvial deposits related to post-flood backflow down the Muskeg River valley and subsequent interdune sands and pond clay deposits. In this scenario, the red-pink clay (Unit 4 in Table 3.1) is interpreted as lacustrine deposits associated with a second, separate meltwater event (Saxberg and Robertson, 2017). Although we agree with the catastrophic flood interpretation of the basal gravels, we did not observe any flow direction indicators in the overlying massive to horizontally bedded sands of what would be expected in a backflow scenario, and residual luminescence in IRSL samples from these deposits (see Section 5.3) indicate that aeolian deposition of sands below the red-pink clay is unlikely. In addition, known occurrences of the red-pink clay are restricted to localized areas in the region (Saxberg and Robertson, 2017; Turney, 2014) rather than in the more continuous and widespread distribution that would be expected of lake deposits. The sedimentary characteristics and relations evident at Quarry of the Ancestors are more consistent with localized deposition during the waning stages of a single catastrophic flooding event rather than the two meltwater events scenario presented by Saxberg and Robertson (2017).

The upper massive sand (Unit 5; Table 3.1, Figure 3.5) is interpreted as aeolian sand based on its looser compaction, massive to crudely stratified structure, and the presence of well-bleached feldspars (discussed below). The crudely stratified sands and desiccated clay surfaces that underlie massive sand at Shell-1 and in the parabolic dune blowout at NWFH-3 are interpreted as interdune sandsheet deposits and sediments deposited in short-lived interdune ponds. The organic deposits in low lying areas are interpreted as peat deposits and humified organic silts related to wetland development.

The wedge shaped feature at Quarry of the Ancestors is interpreted as an ice wedge cast. The u-shaped involution at the top and tapering near the bottom of the feature are characteristic of infilled ice wedge casts, as are the inflections of surrounding sediment (French, 1996; Murton and French, 1993). The cast is filled with overlying and surrounding sediment, with the upper u-shaped area containing a fill of mostly sand (Units 3 and 5; Figure 3.5), with deformed red-pink clay lining the margins. The lower v-shaped portion is filled primarily with sand derived from the unit directly overlying gravel (Unit 2; Figure 3.5). No visible vertical stratification is apparent in this fill, indicating secondary infilling of an ice-wedge cast, rather than primary infilling of a sand wedge (French, 1996; Murton and French, 1993). The wedge crosscuts units below the red-pink clay, indicating it was formed following deposition of the clay. Several pieces of lithic debitage were excavated from massive sands that infilled the upper portion of the cast, including a vertically emplaced flake (Figure 3.5). The orientation of this flake indicates that artifacts and the upper aeolian sands were deposited contemporaneously when the ice was still present, and slumped into the fill following thaw. The presence of this feature and a similar one identified three metres south of our excavation in 2004 (Saxberg 2007; Saxberg and Robertson, 2017), along with sand veins underlying the red-pink clay suggest that the site was subject to climatic conditions cold enough to support permafrost following the deposition of catastrophic flood deposits, and likely during the deposition of the aeolian sands. Our interpretation of the feature as an ice-wedge cast is consistent with previous descriptions (Saxberg, 2007; Saxberg and Robertson, 2017).

3.5.3 Chronology

A total of eight IRSL ages were obtained from the five sampled landforms (Table 3.2; Figure 3.6). Three were recovered from the archaeological excavation on the flank of a gravel-cored bedform at the Quarry of the Ancestors site, one from a gravel-cored bedform near Ronaghan's Ridge, and the remaining four ages from stabilized dune contexts north of the Fort Hills (Table 3.2; Figure 3). At Quarry of the Ancestors, the samples were recovered from the waning stage flood deposits overlying basal gravels and the upper aeolian sands (Figure 3.4). The ages from the flood deposits are (12,800 +/- 1,000 years BP and 14,300 +/- 1,100 years BP) are stratigraphically inverted, but within error (Figure 3.4). These samples also contain residual luminescence, indicating that feldspar grains were not completely bleached prior to burial. As noted in Section 3.5.3, these results lend support to the interpretation that the lower weakly stratified sands were deposited in a fluvial environment during the waning stages of catastrophic flooding. The upper massive sand sample contained well-bleached sands with minimal residual luminescence, and yielded a date of 12,000 +/- 1000 cal years BP (Table 3.2; Figure 3.6). We consider this date a reliable minimum age for landscape stabilization and human occupation at

Quarry of the Ancestors. An age of 11.5 ± 0.9 ka was recovered from well-bleached, horizontally bedded eolian sands that overlie boulder gravels at Shell-1 near Ronaghan's Ridge (Table 3.2; Figure 3.6).

Table 3.2 IRSL ages from this study.

Sample	Depth (cm)	Landform	Stratigraphic Unit	Stratigraphic Description	Age (ka yr BP)	Error (1 sigma)
FHNW-1-100	100	Stabilized transverse dune	Unit 5	Massive sand, eolian	**9.7**	0.8
NWFH-3-55	55	Stabilized blowout	Unit 5	Massive sand, eolian	**11.7**	0.9
NWFH-3-125	125	Stabilized blowout	Unit 5	Massive sand, eolian	**11.8**	0.9
Shell-1-70	70	Gravel cored ridge	Unit 2	Stratified sand, fluvial	**11.5**	0.9
UTS-01	78	Stabilized parabolic dune	Unit 5	Massive sand, eolian	**10.6**	0.9
Quarry-1-25	25	Gravel cored ridge	Unit 5	Massive sand, eolian	**12.0**	1.0
Quarry-1-60	60	Gravel cored ridge	Unit 3	Massive sand, fluvial	**14.3**	1.1
Quarry-1-98	98	Gravel cored ridge	Unit 2	Massive sand, fluvial	**12.8**	1.0

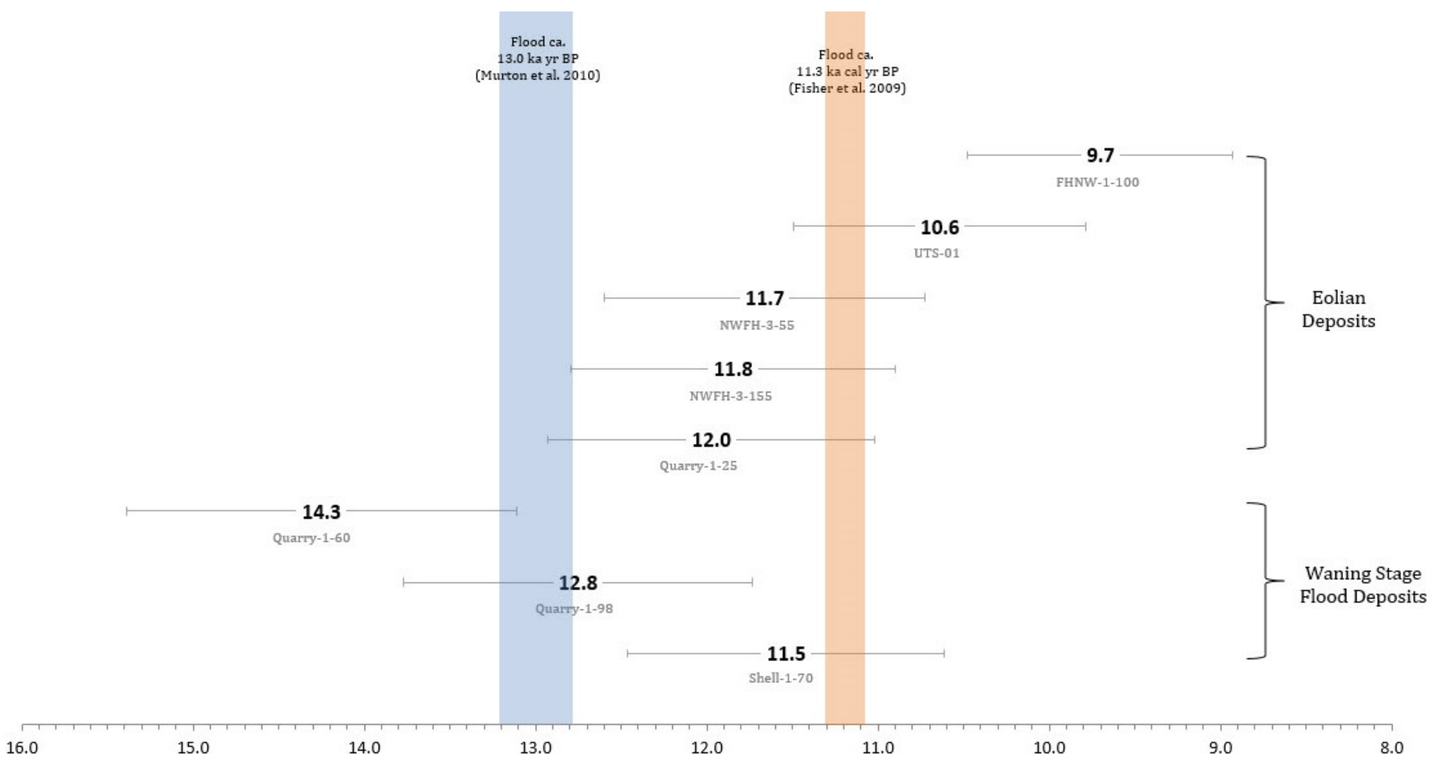


Figure 3.6 IRSL age timeline. Ages are in ka years BP, with one sigma error bars. The earlier flood age is from Murton et al. (2010), and the later flood age is from Fisher et al. (2009).

All samples recovered from stabilized dune areas were from Unit 5 aeolian sands, and were well-bleached prior to burial, indicating that the ages reliably date dune stabilization (Figure 3.6). The Quarry of the Ancestors, Shell-1, and dune ages show that aeolian deposition was occurring prior to 11,500 years BP, and continued in some areas until ca. 9,700 years BP. (Table 3.2). Ages from NWFH-3, a stabilized dune blowout, bracket two interdune pond clay deposition that occurred between ca. 11,700 and 11,800 years ago (Table 3.2; Figure 3.4).

Eight basal peat ages were obtained from a drainage ditch and other mining exposures east of Ronghan's Ridge and near the Sharkbite Lakes (Figure 3.2; Table 3). Ages from buried bedforms near Ronaghan's Ridge ranged between 3,000 to 2,300 cal yr BP (RJW01 and RJW03), and between 900 and 740 cal yr BP (RJW02; Table 3). The other five ages from fortuitous exposures near Ronaghan's Ridge and the Sharkbite Lakes range from 9,195 +/- 25 ^{14}C BP (10,480 to 10,252 cal BP) to 2,190 +/- 20 ^{14}C BP (2,309 to 2,142 cal BP; Table 3).

Table 3.3 Basal peat radiocarbon dates.

UCIAMS #	Sample Name	Nearby Site	Batch	Fraction Modern	±	D^{14}C (‰)	±	^{14}C age (BP)	±	Calibrated One Sigma Age Range (cal years BP)
122307	PST-01	Quarry of the Ancestors	7	0.8948	0.0020	-105.2	2.0	895	20	907 to 740
122310	RJW-02	Ronaghan's Ridge	7	0.8865	0.0021	-113.5	2.1	970	20	932 to 798
101870	MRME11-07	Sharkbite Lakes	4	0.7614	0.0016	-238.6	1.6	2190	20	2309 to 2142
122306	RJW-03	Ronaghan's Ridge	7	0.7398	0.0017	-260.2	1.7	2420	20	2679 to2356
122309	RJW-01	Ronaghan's Ridge	7	0.7018	0.0018	-298.2	1.8	2845	25	3056 to 2872
122303	MRME12-02	Ronaghan's Ridge	7	0.5256	0.0014	-474.4	1.4	5165	25	5990 to 5896
101874	MRME11-05	Ronaghan's Ridge	4	0.5079	0.0016	-492.1	1.6	5440	25	6294 to 6205
122304	MRME12-01	Ronaghan's Ridge	7	0.4313	0.0018	-568.7	1.8	6755	35	7669 to 7572

Table 3.3, cont'd

UCIAMS #	Sample Name	Nearby Site	Batch	Fraction Modern	±	$D^{14}C$ (‰)	±	^{14}C age (BP)	±	Calibrated One Sigma Age Range (cal years BP)
101872	MRME11-02	Ronaghan's Ridge	4	0.3183	0.0010	-681.7	1.0	9195	25	10480 to 10252
101878	AVR-07-PAL	Standard	4	0.0041	0.0002	-995.9	0.2	44130	380	-
122308	AVR-07-PAL	Standard	7	0.0074	0.0004	-992.6	0.4	39410	390	-
101879	Queets-A	Standard	4	0.0019	0.0001	-998.1	0.1	50290	620	-
101877	FIRI-D	Standard	4	0.5700	0.0013	-430.0	1.3	4515	20	-
122305	FIRI-D	Standard	7	0.5666	0.0043	-433.4	4.3	4560	70	-

A portion of a branch recovered at the base of Unit 6 deposits in the centre of a wetland in Quarry of the Ancestors yielded an age of 895 +/-20 14C BP (907 to 740 cal years BP; PST-01; Table 3; Figure 3.3). The recovery of flakes above the base of the organic silts from tests near the edge of the wetland indicates human occupation at some time after this date at Quarry of the Ancestors.

3.6. Discussion

3.6.1 Post-glacial aeolian deposition and initial human occupation

Our results indicate that aeolian deposition was active in the study area following retreat of the LIS and subsequent catastrophic flooding. In the Clearwater-Athabasca Spillway, aeolian sands were likely sourced from waning stage flood deposits that originally capped the peak flow boulder-gravel deposits. These waning stage sands would have presented a smaller sediment supply than the deposits to the north of the Fort Hills, where even during peak flow conditions sand sized sediment would have dominated the depositional regime due to expanding flow. This difference in sediment supply is likely the reason why few prominent dunes formed within the spillway, but are abundant north of the Fort Hills.

The stratigraphic position of aeolian sands above catastrophic flood deposits and their associated IRSL age indicate that aeolian deposition at Quarry of the Ancestors began shortly following the flood event, and continued until ca. 12,000 years BP in this part of the Clearwater-Athabasca Spillway. This age of initial post-flood landscape exposure falls prior to 11,300 cal year BP, and is not therefore not consistent with the flood chronology of Fisher et al. (2009). Although our results do not provide clear evidence for the age of the onset of catastrophic flooding, they are more consistent with the ca. 13,200 years BP flood age estimate of Murton et al. (2010), which allows a roughly 1,200-year period of aeolian deposition between the flood event and eventual stabilization of the landscape at Quarry of the Ancestors.

The collapse of overlying aeolian sediment and artifacts into the ice wedge cast at Quarry of the Ancestors indicates that temperatures cold enough to maintain continuous permafrost for decades to centuries persisted in this period. This is consistent with the climate of the Younger Dryas cold interval, rather than the Early Holocene, and with the hypothesis that catastrophic flooding from the northwest outlet of glacial Lake Agassiz may have been a trigger for this event (Murton et al., 2010). Relations between relict permafrost features and cultural material along with the 12,000 +/- 1,000 years BP at Quarry of the Ancestors indicate that intial human occupation of this part of the spillway also likely occurred during the Younger Dryas. Although our stratigraphic analyses differ, these results agree with earlier interpretations that ice wedge formation and early occupation of the site occurred during the Younger Dryas (Saxberg and Robertson, 2017). During this time, it is probable that Beaver River Sandstone sources were readily visible in the lightly vegetated, windswept landscape of Quarry of the Ancestors.

North of the Fort Hills, our IRSL ages on dune stabilization range from 11,800 years BP to 9,700 years BP (Table 3.1). The dune ages were acquired from landforms oriented in a direction consistent with southeasterly winds (Figure 3). Wolfe et al. (2004) attribute southeasterly trending dunes in other parts of western Canada to the prevalence of anticylconic winds around the waning LIS caused by a persistent low pressure cell over the ice sheet. These winds were most prevalent within a 200 km belt of the ice margin. Based on a series of optically stimulated luminescence (OSL) and IRSL ages, Wolfe et al. (2004) propose that anticylonic circulation began to dominate ice marginal wind regimes ca. 13,000 cal years BP, when the LIS had retreated far enough to the east to allow anticylclonic flow to overtake the influence of westerly winds from Pacific air masses. This belt of anticyclonic winds retreated along with the LIS through time, with northwesterly winds eventually re-establishing dominance in an area once the ice sheet had retreated further to the northeast. In this framework, dunes oriented with winds originating from the southeast represent the oldest, immediately post glacial landforms, and dunes oriented with winds originating from the northwest represent a later phase of aeolian deposition. The dune IRSL ages and orientations in this study are consistent with early post-glacial deposition, both in age and orientation, and indicate that anticyclonic winds were active until ca. 9.700 years BP. The LIS margin was likely within about 200 km of the mineable oil sands region from immediately after ice recession to ca. 9,700 years BP. These ages also indicate that landscape stabilization was patchy through the immediate post glacial, with some areas becoming stable as early as ca. 11,700 to 12,000 cal years BP, and other areas remaining active until ca. 9,700 cal years BP.

The IRSL ages from Quarry of the Ancestors and the dunes constitute a ca. 3,300-year period (~13,000 - 9,700 cal years BP) in the mineable oil sands region during which aeolian deposition was a prevailing geomorphic process in the region. Palaeoenvironmental work completed at Kearl Lake, five kilometers east of the study area show that the regional vegetation during the period from ca. 12,000 to 9,000 cal years BP was a non-analogous open spruce and birch forest with a considerable herbaceous component (Bouchet-Bert and Beaudoin, 2017). Other lake records in the region indicate that prior to 12,000 cal years BP tundra-like conditions were prevalent (Hutton et al., 1994; Vance, 1986). The immediate post-glacial landscape was likely a mosaic of stable vegetated areas of shrub-tundra and early boreal parkland (Dyke et al., 2004) with pockets of aeolian deposition in active dune fields to the north of the Fort Hills, and in isolated areas within the Clearwater-Athabasca spillway. As previously discussed, continuous permafrost would have also been present during earliest post-glacial times. Significant aeolian deposition ceased in the mineable oil sands region by ca. 9,700 cal years BP, when boreal forest conditions began to be established and peatlands begin to nucleate (Figure 3.7). Typological studies (Reeves et al., 2017) and radiocarbon ages from archaeological bone (Woywitka, 2016) show that the mineable oil sands region was subsequently occupied throughout the Holocene, and that Beaver River Sandstone was exploited through the entire prehistoric record.

The initial Quarry of the Ancestors occupation is among the earliest evidence of human habitation in northwestern Canada, roughly contemporaneous with early sites in the deglacial corridor to the south and west including Wally's Beach (ca. 13,300 cal years BP; Waters et al., 2015), Vermilion Lakes (ca.12,200 cal years BP; Fedje et al., 1995), Lake Minnewanka (ca. 12,700 cal years BP; Landals, 2008), and Charlie Lake Cave (ca. 12,200 cal years BP; Fladmark et al., 1989; Ives et al., 2013).

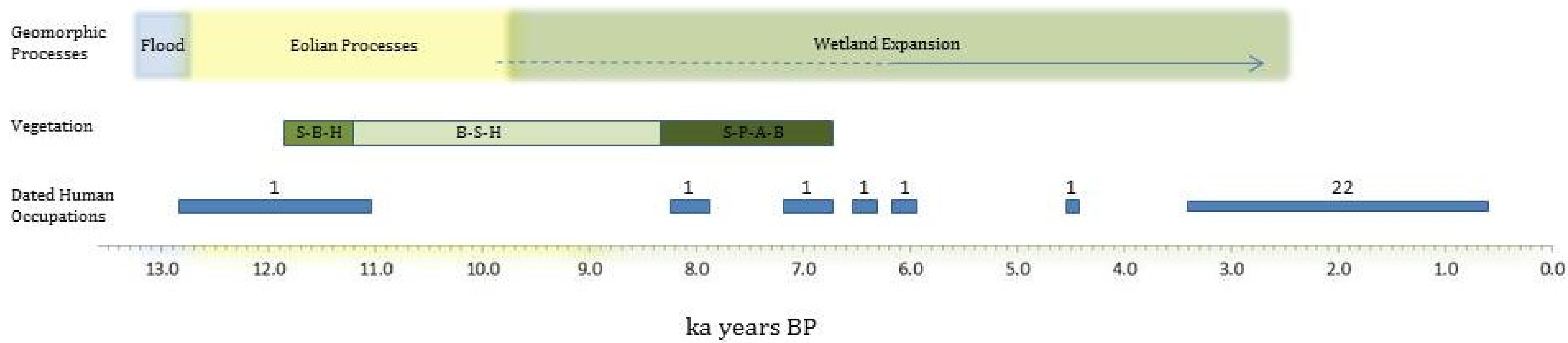


Figure 3.7 Chronological framework for the oil sands region highlighting radiometric dates of human occupation, primary geomorphologic processes, and vegetation conditions. Vegetation communities (S-B-H: Spruce-Birch-Herbaceous; B-S-H: Birch-Shrub-Herbaceous; S-P-A-B: Spruce-Pine-Alder-Birch) are from (Bouchet and Beaudoin, 2017). Blue blocks indicate date ranges of human occupation, with the numbers above representing the number of dates within the range. The earliest age is the IRSL from Quarry of the Ancestors (this study), the others are compiled from calcined bone radiocarbon dates (Woywitka, 2016).

These dates indicate that the LIS had retreated nearly the entire breadth of the Province by ca. 12,000 to 13,000 years ago, and that most of this area, including the northern forests, would have been available to Clovis and other early Paleoindian groups. This period is well represented in undated sites and collections from northern Alberta, including potential early blades (Ives, 1993) from the mineable oil sands region, and a Clovis point made of Beaver River Sandstone from Cold Lake, approximately 300 km south Quarry of the Ancestors (Ives et al., 2013). It is likely that northeastern Alberta contains additional sites that could provide insight into late Pleistocene and early Holocene dispersal relative to the retreating ice sheet and concomitant ecological changes. Our results show the potential of stratigraphic analysis and IRSL dating to provide crucial temporal context to these earliest human activities in western North America.

3.6.2 Peatland expansion and implications for archaeology

Basal peat ages show that wetlands began to form as early as 10,480 cal years BP, and continued to expand throughout the Holocene. This is mostly consistent with other studies of peatland initiation in the region, although our earliest ages predate ages in the Birch Mountains and Caribou Mountains by about 1,000 years (Gorham et al., 2012; Halsey et al., 1998). Previous work has suggested that peatland initiation began earlier in upland settings like the Birch and Caribou Mountains, where cooler, moister conditions remained even during climatic amelioration in the early Holocene (Halsey et al., 1998). Most peatland initiation in the lowlands began around 7,000 to 9,000 cal years BP, when modern boreal forest conditions began to develop in the region (Gorham et al., 2012; Halsey et al., 1998; Vance, 1986; Yu et al., 2014). The early dates we acquired in the lowlands overlap slightly with pre-boreal open spruce and birch forest. It appears that some peatlands began to nucleate this early, and although lateral growth of wetlands is not well studied in the region, it has been shown that most peatlands in the region have expanded by paludification, burying mineral sediment through time (Bauer et al., 2003; Bloise, 2007). The buried bedforms near Ronaghan's Ridge are evidence of this process in the mineable oil sands region, and basal peat dates from these features show that they were exposed until the late Holocene (ca. 3,000 to 900 cal years BP; Table 3). Although no cultural material was found at the mineral sediment/peat interface in the limited testing conducted for this project, there remains good potential for the identification of archaeological sites in this stratigraphic position. If peatland distributions did not reach modern extents until the mid to late Holocene, (Bauer et al., 2003; Halsey et al., 1998; Yu et al., 2014), the mineable oil sands region landscape prior to ca. 3,000 years ago would have been characterized by more upland terrain, with a succession of upland/wetland ecotones expanding through time. Given that archaeological sites are commonly found at these ecotones (Ives, 1993), and typological and radiocarbon evidence that shows a strong mid to late Holocene occupation of the region (Ives, 1993; Reeves et al., 2017; Turney, 2014; Woywitka, 2017, 2016), it is likely that archaeological material has been preserved by encroaching peat throughout the mineable oil sands region. This is significant because organic artifacts may be preserved in these poorly drained conditions, and overlying basal peat ages can provide minimum ages of occupation. Similarly, peat ages can provide temporal context for artifacts recovered from wetlands themselves. Artifacts recovered from peat at Quarry of the Ancestors illustrate this possibility, with a basal peat age providing a maximum age of ~900 cal years BP for this occupation. This young age of peatland initiation within the

Quarry of the Ancestors also indicates that near surface sources of Beaver River Sandstone at that locale may have been exposed well into the Holocene. The potential for recovering archaeo-temporal data in boreal wetland environments is high, and this topic will be a useful avenue for future research in the mineable oil sands region.

3.7. Conclusion

IRSL ages from windblown sediment in the mineable oil sands region indicate that aeolian deposition occurred shortly after the retreat of the LIS from the region. In the Clearwater-Athabasca spillway, this deposition started following the recession of catastrophic flood waters from glacial Lake Agassiz, and ceased by ca. 12,000 +/- 1,000 cal years BP. In braided delta deposits at the northern terminus of the spillway, delta sands were reworked into dunes, with some stabilizing as early ca. 11,800 years BP, and deposition continuing until ca. 9,700 years BP.

Human occupation within the Clearwater-Athabasca spillway occurred shortly after the recession of catastrophic flood waters from the area, ca. 12,000 years BP. The initial post-flood occupation occurred during a time when climatic conditions were cold enough to support permafrost. This is consistent with a Younger Dryas (ca.13,000 to 12,000 years BP) aged flood and human occupation (Murton et al., 2010; Saxberg and Robertson 2017), and does not support a flood age of ca. 9,000 cal years BP to 11,300 cal years BP (Fisher et al., 2009). The Quarry of the Ancestors occupation is among the earliest recorded in northwestern Canada, contemporaneous with other late Pleistocene sites at Lake Minnewanka (Landals, 2008), Charlie Lake Cave (Fladmark et al., 1989), and Vermilion Lakes (Fedje et al., 1995b).

The lithic assemblage at Quarry of the Ancestors indicates that Beaver River Sandstone was utilized during initial post-flood occupation. The environment at this time would have included a mosaic of stable, vegetated areas of tundra or thin spruce/birch forest, and open areas of aeolian deposition. Near surface and surface sources of Beaver River Sandstone were likely readily visible at this time. Late peatland development (ca. 1,000 cal years BP) at Quarry of the Ancestors suggests that Beaver River Sandstone sources may have been exposed well into the Holocene. Beaver River Sandstone continued to be the primary lithic raw material used in the mineable oil sands region throughout the prehistoric record (Kristensen et al., 2016; Reeves et al., 2017; Woywitka, 2016).

Peatlands began to form ca. 10,000 cal years BP, and continued to expand through to the late Holocene. Paludification has likely buried archaeological material on former mineral sediment surfaces, and artifacts recovered from peat deposits at Quarry of the Ancestors show that people used wetland environments.

Stratigraphic analyses, IRSL dating, and radiocarbon dating of non-cultural deposits provides important information about landscape evolution and can provide limiting ages for archaeological sites. Future research focussed on these approaches and the recovery of datable material in boreal wetlands will increase our understanding of cultural change through time and build a stronger temporal framework for this archaeologically significant region.

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CHAPTER 4: A PROCESS-DEPOSITIONAL MODEL FOR THE EVALUATION OF ARCHAEOLOGICAL POTENTIAL AND SURVEY METHODS IN THE MINEABLE OIL SANDS REGION, NORTHEASTERN ALBERTA, CANADA

Abstract

Over 1,000 Precontact period archaeological sites occur within the mineable oil sands region of northeastern Alberta. Many of these sites occur within the Clearwater-Athabasca Spillway, a large relict channel that routed catastrophic drainage from glacial lake Agassiz to glacial lake McConnell during deglaciation of the region. The density of sites and demonstrated late Pleistocene to early Holocene occupation are rare in the region, and provide significant insight into ancient cultural dynamics of the Canadian subarctic. Artifact assemblages are large due to the presence of abundant sources of lithic raw material, including Beaver River Sandstone, but are rarely preserved in stratified or deeply buried deposits. This lack of depositional context coupled with a paucity of datable organic material has hindered the establishment of cultural chronologies for the region. To help address this issue, we develop a process-depositional model and digital terrain analysis to identify where deeper sediments may have accumulated, and assess whether archaeological survey strategies have adequately tested these areas. We conclude with recommendations for survey strategies that are more focused on identifying sites with deeper sedimentary profiles that increase knowledge of temporal trends in the archaeological record.

4.1. Introduction

The mineable oil sands region of northeastern Alberta is host to one of the richest archaeological records in the Boreal forest of northwest Canada (Ronaghan 2017). Although sites are plentiful and often produce large numbers of artifacts, stratified or deeply buried deposits are rare (Ives 1993; Ronaghan 2017; Woywitka 2017). This is due to low rates of post-glacial sedimentation and rapid decomposition of organic material in forest floors. Despite this rarity, analyses of stratified deposits at the Quarry of the Ancestors (Saxberg 2007; Turney 2014; Woywitka et al., Chapter 3), Cree Burn Lake (Head 1988), and deeply buried deposits at Beaver River Quarry (Gilliland and Woywitka 2014) have provided significant information about the temporal, environmental, and taphonomic aspects of the archaeological record that are difficult to obtain from shallow sites.

This study provides an aid in identifying these important, but uncommon locales in the lowlands directly south of the Fort Hills, the area with the highest concentration of sites in the mineable oil sands region (Figure 4.1). The main questions addressed are: 1) Where are stratified or deeply buried sites most likely to occur in the mineable oil sands region? and 2) Are current archaeological survey strategies focusing on areas where deeper sedimentation is expected to occur? We address these problems by developing a process-depositional model based on known sediment-landform associations, and map this conceptual model using digital terrain analysis of Light and Detection Ranging (LiDAR) elevation data. The model results are compared to known site and sediment probe data to assess if the areas we identify as higher sedimentation zones do contain deeper sediments and to determine to what degree these zones have been tested in previous studies. We conclude with recommendations for field strategies that include more targeted survey for deep deposits.

4.2. Background

4.2.1. Mineable oil sands prehistory

Archaeological work in the mineable oil sands region began in the 1970s, shortly after the passage of the Alberta *Historical Resources Act* (Ronaghan 2017). Work since then has been largely tied to oil sands mine development. Archaeological sites are numerous and artifact rich (Ives 1993; Ronaghan 2017; Saxberg and Reeves 2003), with over 1,000 prehistoric sites currently known within the region (Figure 4.1). Abundant sources of a tool stone called Beaver River Sandstone (BRS) at the Quarry of the Ancestors and Beaver River Quarry were a major factor in use of the area (Fenton and Ives 1990; Kristensen et al. 2016; Ronaghan 2017; Saxberg and Robertson 2017). Ives (1990) suggests the BRS sources and the linkage of the Athabasca River with the Birch Mountains and surrounding river basins would have made the region an ideal location for large annual gatherings where economic exchanges, marriage arrangements and other social agreements were made.

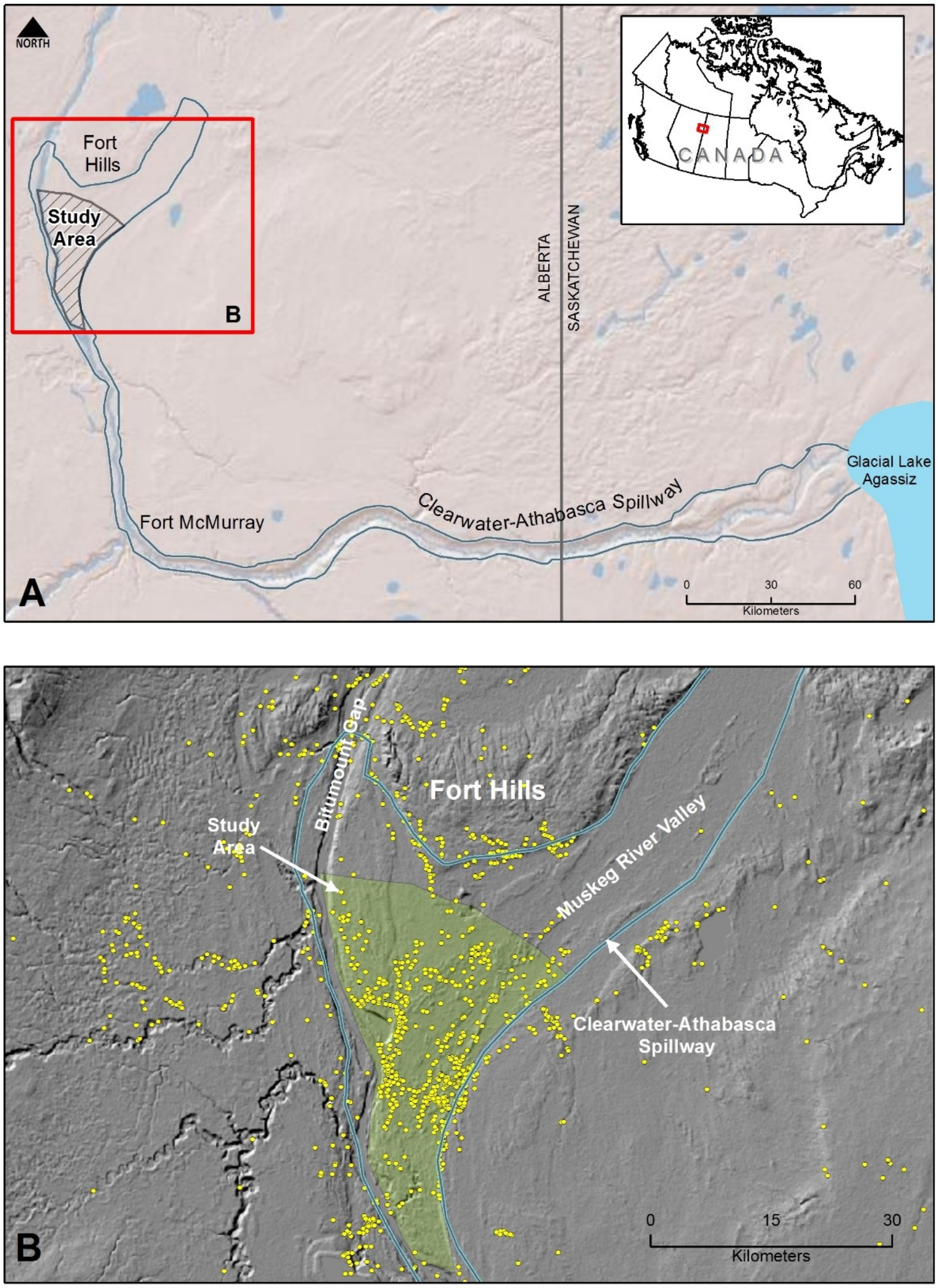


Figure 4.1 Location of the study area. Panel A shows the regional context, including the Clearwater-Athabasca Spillway as defined by Fisher and Smith (1993) and the extent of Glacial Lake Agassiz at 10,000 ^{14}C years BP (Dyke et al.

2004). Panel B shows the distribution of archaeological sites in the study area and significant topographic features. Base data provided by Esri (2014).

Most sites are shallowly buried lithic scatters or campsites consisting of tools and debitage made from BRS, although other raw materials and calcined bone occur in small proportions (Ronaghan 2017; Woywitka 2017). Debitage, formed tools, and expedient tools occur throughout the region, but sites nearer to the main quarry locations tend to have larger proportions of artifacts related to raw material procurement, and higher proportions of BRS (Saxberg and Robertson 2017). Saxberg and Robertson (2017) suggest that the Quarry of the Ancestors was a significant focal point in the region, and may have been occupied semi-permanently. The identification of such intense use areas in the Boreal forest of Canada is rare, and attests to the significance of the mineable oil sands region in our understanding of past cultural dynamics in northern settings.

4.2.2. Geomorphic setting of archaeological sites

Sites are densely concentrated in the northeastern branch of the Clearwater-Athabasca Spillway south of the Fort Hills (Figure 4.1). The spillway was formed by catastrophic flooding from Glacial Lake Agassiz during deglaciation of the region (Figure 4.1; Fisher and Smith 1993a; Fisher et al. 2002; Murton et al. 2010). It originates at the northwestern outlet of glacial lake Agassiz in northwestern Saskatchewan and follows the modern Clearwater River and Athabasca River valleys to the Fort Hills, where flow bifurcated into a northern branch flowing through the Bitumount Gap, and a northeastern branch flowing up the Muskeg River valley (Figure 4.1). Archaeological sites in the northeastern branch are commonly associated with raised, gravel-cored streamlined landforms that have been interpreted as catastrophic flood bedforms (Figure 4.2; Woywitka et al. 2017). Several studies note that these landforms are favored habitat of moose and other game animals, and that they served as ideal hunting nodes for humans (Ives 1993, 2017; Ronaghan and Clarke 2017; Woywitka 2017).

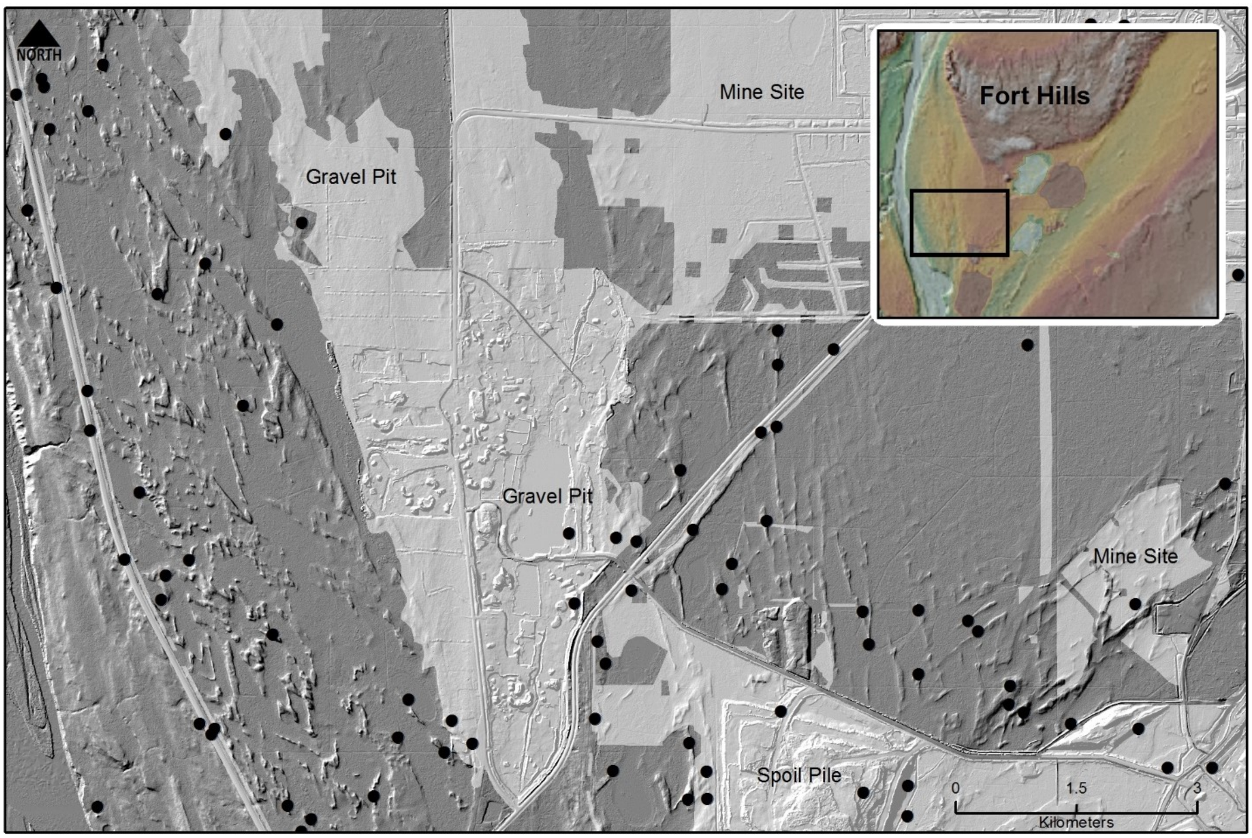


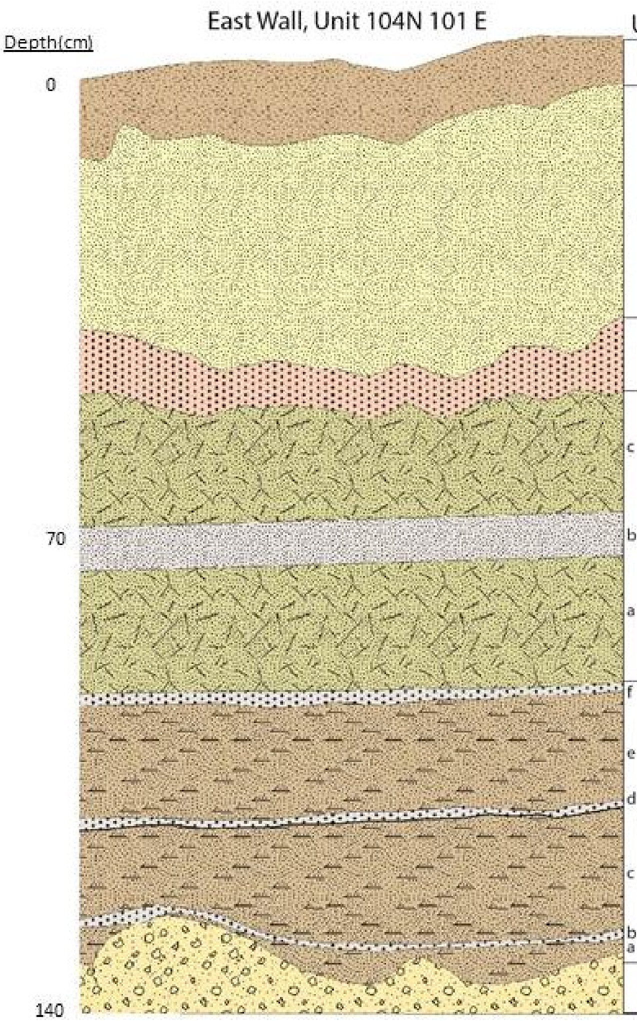
Figure 4.2 LiDAR image of streamlined landforms. Black dots are archaeological sites. White areas indicate disturbed ground ca. 2009 (ABMI 2012).

4.2.3. Cultural chronology

Proposed dates for the flood event range from 13.0 ka BP (Murton et al. 2010) to 11.3 ka BP (Fisher et al. 2009). Infrared Stimulated Luminescence (IRSL) ages from cultural deposits at Quarry of the Ancestors indicate that the earliest occupation of the region occurred shortly after the flood, around 11.5 ka BP (Woywitka et al. in prep). Radiocarbon dates from 28 archaeological sites range from ca. 8,000 cal yr BP to historic times (Woywitka 2016), and projectile point typologies correlate in size and shape to Holocene aged specimens observed on the Great Plains, and to some extent the Norwest Territories (Reeves et al. 2017). Together the radiocarbon dates and point typologies indicate occupation of the region throughout the Holocene.

4.2.4. Depositional context of archaeological sites

Archaeological materials on the streamlined landforms in the Clearwater-Athabasca Spillway are most commonly shallowly buried (< 0.40m) in massive sand caps that overlie gravel flood deposits (Woywitka et al., Chapter 3). Paleosols and vertical separation of cultural components is not common, and sites are usually interpreted as mixed or single component assemblages of undetermined age (Ronaghan 2017). IRSL and Optically Stimulated Luminescence analyses of sands at Quarry of the Ancestors, Fort Hills, and Beaver River Quarry indicate the presence of well-bleached quartz and feldspar grains, and these units have been interpreted as eolian in origin (Unit 5, Figure 4.3; Woywitka et al., in prep; Gilliland and Woywitka 2014). However, flood-related massive sand deposits also directly overlie the basal gravel in the region (Unit 2 and Unit 3, Figure 4.3; Woywitka et al., in prep), as do upper flow regime stratified sands (Fisher and Smith 1993b).



Unit	Description	Interpretation	IRSL Age
LM	Organic matter	forest litter mat	n/a
5	loosely compacted medium grained sand, massive structure	eolian sand	12.0 ka cal +/- 1.0 ka cal BP
4	compact pink diamicton, clasts < 1cm, blocky structure	Fluvial (waning stage flood)	n/a
3	3b: compact coarse sand 3a and 3c: compact medium grained sand, massive structure, fining upward, placic horizon at base	Fluvial (waning stage flood)	14.3 ka cal +/- 1.0 ka cal BP
2	2b, d ,f: compact grey clay; dessication cracks present in 2d 2a, c, e: medium sand, massive to weak horizontal bedding and crude normal grading; grey sand veins	Fluvial (waning stage flood)	12.8 ka cal +/- 1.0 ka cal BP
1	matrix poor boulder gravel	Fluvial (peak flow flood)	n/a

Figure 4.3 Quarry of the Ancestors sedimentary profile and unit descriptions. IRSL ages from Woywitka et al. (Chapter 3).

It is possible that some bedform sand caps are reworked late stage flood deposits. In these cases artifacts could have been incorporated into near surface deposits by trampling, bioturbation and other soil formation processes. Eolian deposition is estimated to have largely ceased by ca. 9,000 ka yr BP (Woywitka et al., in prep). Very little sedimentation other than wetland expansion has occurred in the region since the early Holocene (Woywitka et al., Chapter 3).

Geoarchaeological investigations at Beaver River Quarry have demonstrated the presence of two occupations within an eolian sand unit with no visible strata (Gilliland and Woywitka 2014). Similarly, the immediate post-flood age of the initial Quarry of the Ancestors occupation was determined by IRSL analysis and visible stratigraphic relationships between eolian and waning stage flood deposits (Woywitka et al., in prep). Despite their rarity, these examples highlight the need to find more locations with deep or stratified deposits that have clear contacts between depositional or cultural components.

4.3. Process-depositional model

We developed a process-depositional model that conceptualizes where stratified sediments may occur based on current understanding of landform genesis, paleowind directions, and previously established sediment-landform associations in the region (Fisher and Smith 1993b; Woywitka et al. 2017; Woywitka et al., in prep). This conceptual model was used to guide a semi-automated digital terrain analysis that maps where we expect deeper sediments to occur. Because of the lack of mid to late Holocene sedimentation, our focus is the geomorphic dynamics of the immediate post-glacial period ca. 13.0 to 9.0 ka BP, with emphasis on eolian processes.

We expect that deeper fine-grained sediments associated with streamlined landforms occur in areas that have level to concave geometry, and that are sheltered from wind and water erosion. Land surfaces with concave geometry are likely to collect sediment because they contain space for potential sedimentation (i.e., positive accommodation space). This is particularly the case when local surface flow directions are convergent and 'funnel' sediment into them. At the scale of our target streamlined landforms, concave elements occur at the bases of slopes and in small depressions in otherwise level areas (Figure 4.4). Deep deposits are more likely at these locations than on ridges or side slopes, where accommodation space is limited, and sediment transport is more likely. We therefore expect deeper sediment to occur most commonly on the lower margins of streamlined landforms, especially in areas of convergent surface flow directions.

We postulate that deeper eolian deposits are more likely to accumulate in areas on the leeward sides of the streamlined landforms, where the land surface is more sheltered from the erosive potential of strong early post glacial winds. The leeward sides of the landforms would have varied with the shifting wind regimes of the deglacial period, with northwesterly Pacific air mass driven winds replacing earlier anticylconic southeasterly winds (Wolfe et al. 2004). Southeasterly winds were dominant in northern Alberta during the immediate post-glacial (Wolfe et al. 2004) when anticyclonic winds were driven by circulation around a low-pressure system centred over the Laurentide Ice Sheet (Wolfe et al. 2004).

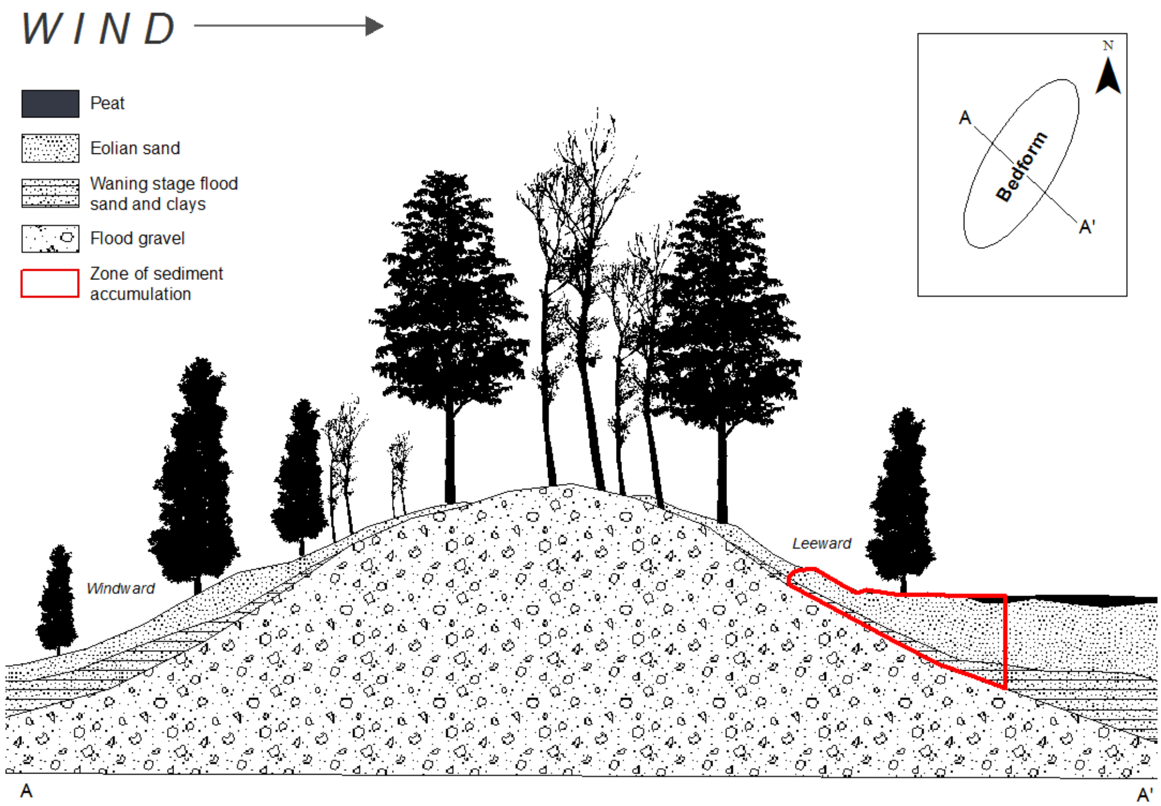


Figure 4.4 Idealized stratigraphic cross section of a flood bedform.

The winds extended in a ~200 km belt from the ice sheet margin, and as the ice sheet receded, the anticyclonic belt receded with it. The southeast winds passed through northern Alberta in the period between ca. 13.0 ka BP and 9.0 ka BP (Wolfe et al. 2004). Northwesterly winds were established in an area when the ice sheet had moved far enough away to reduce the influence of anticyclonic circulation on prevailing winds (Wolfe et al. 2004). Dates from the Quarry of the Ancestors and dunes north of the Fort Hills indicate that southeasterly winds were active until ca. 11.5 ka BP (Woywitka et al., Chapter 3) in our study area. Northwest winds are not directly dated, but the region would have been outside of the range of anticylconic winds by about 10.2 ka BP, and eolian deposition would have ceased by at least 9.0 ka BP (Wolfe et al. 2004). When the morphology and wind direction dynamics are considered together, we expect that deeper sediments are more likely to occur on in concave-convergent areas on the southeast and northwest paleowind-leeward sides of streamlined landforms (Figure 4.5).

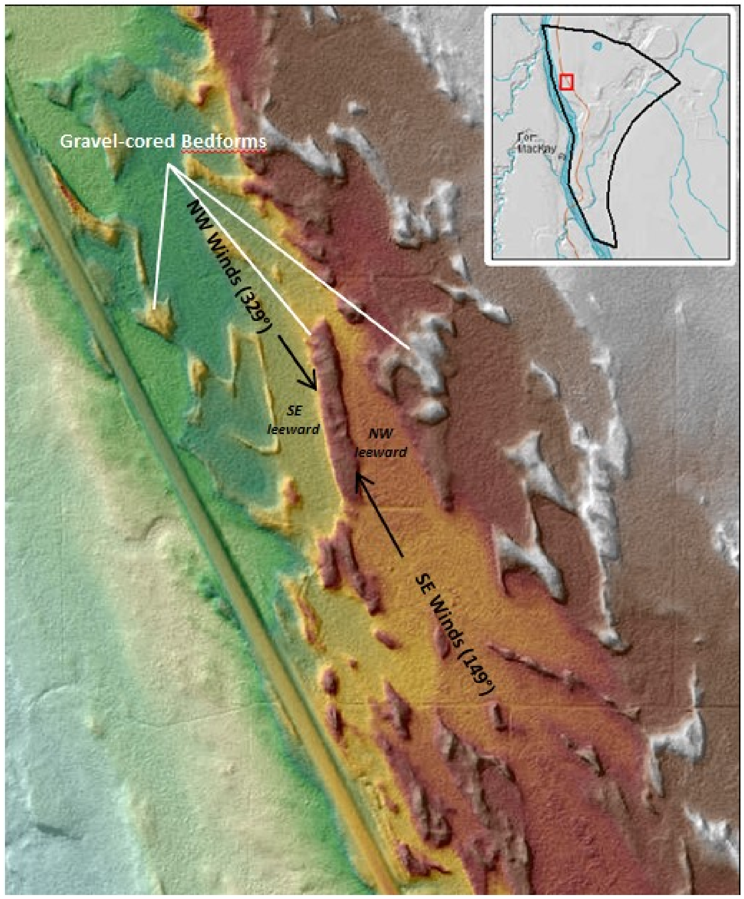


Figure 4.5 Relationship of paleowind directions and raised gravel-cored bedforms. Leeward sides for the two dominant paleowind directions are nearly opposite each other. Southeast paleowinds were in effect from initial retreat of the Laurentide Ice Sheet to ca. 11.5 ka BP (Woywitka et al., in prep). Northwest winds were likely active after ca. 10.2 ka BP, with eolian deposition ceased ca. 9.0 ka BP (Wolfe et al. 2004).

4.4. Digital terrain analysis methods

Following the principles of the process-depositional model, our digital terrain analysis isolates landform elements that have concave/convergent geometry and that would have been likely to undergo eolian deposition during the early post-glacial. Other common variables used in archaeological potential models such as distance to water and vegetation maps are not included because the known site distribution in the study area appears independent of these (Ives 1993; Woywitka et al. 2017; Ronaghan and Clarke 2017), and our focus is on identifying areas where informative sediments are located. The input data for the terrain analysis was a two metre horizontal resolution Light and Detection Ranging (LiDAR) bare earth digital elevation model (DEM), with a vertical accuracy of 0.60m. Digital terrain analysis was carried out using Whitebox Geospatial Analysis Tools version 3.4 'Montreal' (Lindsay 2016), and ESRI's ArcGIS 10.3.1 (ESRI 2015).

4.4.1. Landform element classification

A topographic classification based on the Pennock et al. (1987) system was used to divide the study area into landform elements based on slope and curvature metrics (Figure 4.6). Any slope lower than two degrees was considered level in the anlysis, and a profile profile curvature threshold of 0.75 was used to classify areas as concave/convex and a plan curvature threshold of 0.10 was used to determine convergent/divergent areas. Because the Pennock et al. (1987) approach does not differentiate between level ridge tops and broad plains, we added an element to the original scheme called "Level Ridge Top." This element includes level areas that have local relief above 0.4 m. as calculated by the

Difference From Mean Elevation (DFME) tool in Whitebox GAT (Lindsay 2015) using a 15x15 (ca. 30x30m) convolution window. The landform elements were used as a measure of likelihood for deposition, with areas of convergent flow direction and concave shape more likely to trap sediment than those of divergent flow and level or convex shape. The scale factors in the weighted overlay discussed in Section 4.4.3 reflect this scheme.

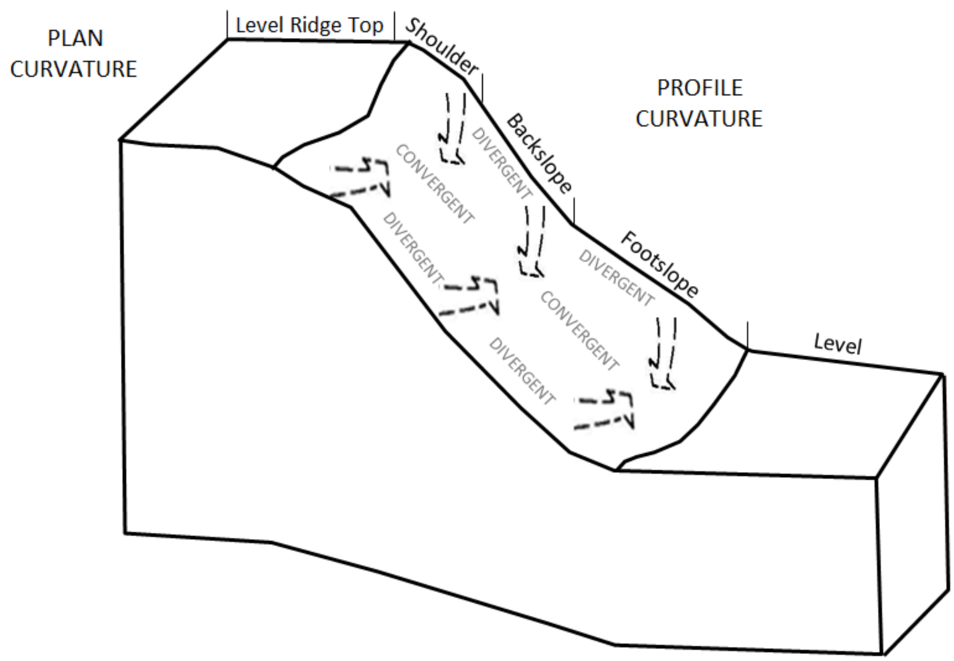


Figure 4.6 Schematic of the Pennock landform element classification system (redrawn and modified from Pennock 1987).

4.4.2. Paleowind classification

To isolate likely locations of deeper eolian deposits, the landform element ranking was combined with wind exposure metrics that measure the leeward and windward aspects of each cell in the DEM. Because paleowinds varied from southeasterly during the earliest post-glacial to northwesterly during the early Holocene (Wolfe et al. 2004), we ran a "southeasterly" and a "northwesterly" model. We used stabilized dune orientation data from Pfeiffer and Wolfe (2002) for the Richardson, Ronald Lake, and Fort Bay Sand Hills and newly collected orientations from a stabilized dune field located north of the Fort Hills, near McClelland Lake to determine paleowind orientations. Following Pfeiffer and Wolfe (2002), average orientations were calculated from a sample of 20 dunes from the McClelland Lake Sand Hills. The resultant paleowind directions were 149 degrees and 315 degrees.

The windward and leeward aspects of landform elements were calculated using relative aspect for the two main wind directions derived from dune orientations. Relative aspect is the angular distance between the land-surface aspect and a wind direction defined by the user (Lindsay 2015; Bohner and Antonic 2007). It varies between 0° (windward) and 180° (leeward). The script in Whitebox does not consider deflection of wind by topography, but this is not likely a factor in the study area, given the low relief (< 5m) of most raised landforms. Areas of more leeward exposure were ranked as more likely to contain deeper eolian sediment, as reflected in the scale factors of the weighted overlay discussed below.

4.4.3 Weighted Overlay

The final model outputs were generated by combining the ranked landform element and ranked wind exposure layers for each dominant paleowind direction in a weighted overlay (Table 4.1; ESRI 2015). The landform element and wind layers received equal weighting (i.e., % influence; Table 4.1). The digital terrain analysis model has an output for each paleowind direction showing landform elements most likely to contain eolian sediments.

Table 4.1. Weighted overlay parameters

Input	% Influence	Category	Scale Value
Landform Element	50	Level Ridge Top (8)	5
		Level (7)	3
		Divergent Backslope (6)	6
		Convergent Backslope (5)	4
		Divergent Shoulder (4)	3
		Convergent Shoulder (3)	4
		Divergent Footslope (2)	8
		Convergent Footslope (1)	9
Relative Aspect	50	Exposed (-1.0 to 63.6 deg)	1
		Partially Sheltered (63.6 to 121.8 deg)	4
		Sheltered (121.8 to 180.0 degrees)	9

4.4.4. Assessment of shovel test and known site patterning

We used sediment probe and site data to determine if there is a relationship between known deep deposits and our model results. Sediment probe data was collected in the field during 2014, and compiled from the Archaeological Survey of Alberta spatial database of cultural resource management projects (n=755). The data pulled from the database covers the period 2014-2017 because individual shovel test depths were not recorded electronically prior to this period. Known site data included 111 sites that were subject to controlled excavation tied to cultural resource management and research projects. Only excavated sites were sampled because depth measurements have been consistently recorded as maximum depth of cultural material. Sites that have not been excavated may have preliminary depths assigned to them, and are not as consistently recorded. All depth data was binned to 10cm levels because this is the finest common level of depth data in the records, and many researchers still record shovel test data to the nearest 10cm level. Any site or shovel test deeper than the mode of Level 4 (40cm) was considered a 'deep' site in this analysis. There are 125 deep shovel tests and 54 deep sites in our sample.

4.4. Results

Areas with higher potential for deep sedimentation covered about 12% of the study area in the southeasterly model, and about 8% of the study area in the northwesterly model. In both models the high potential areas were concentrated around lower lying margins of raised landforms, and to a lesser extent on level ridge tops. Because the two dominant wind directions are nearly opposite, these areas occur on opposite sides of landforms, with overlap occurring in enclosed or u-shaped areas (Figure 4.7).

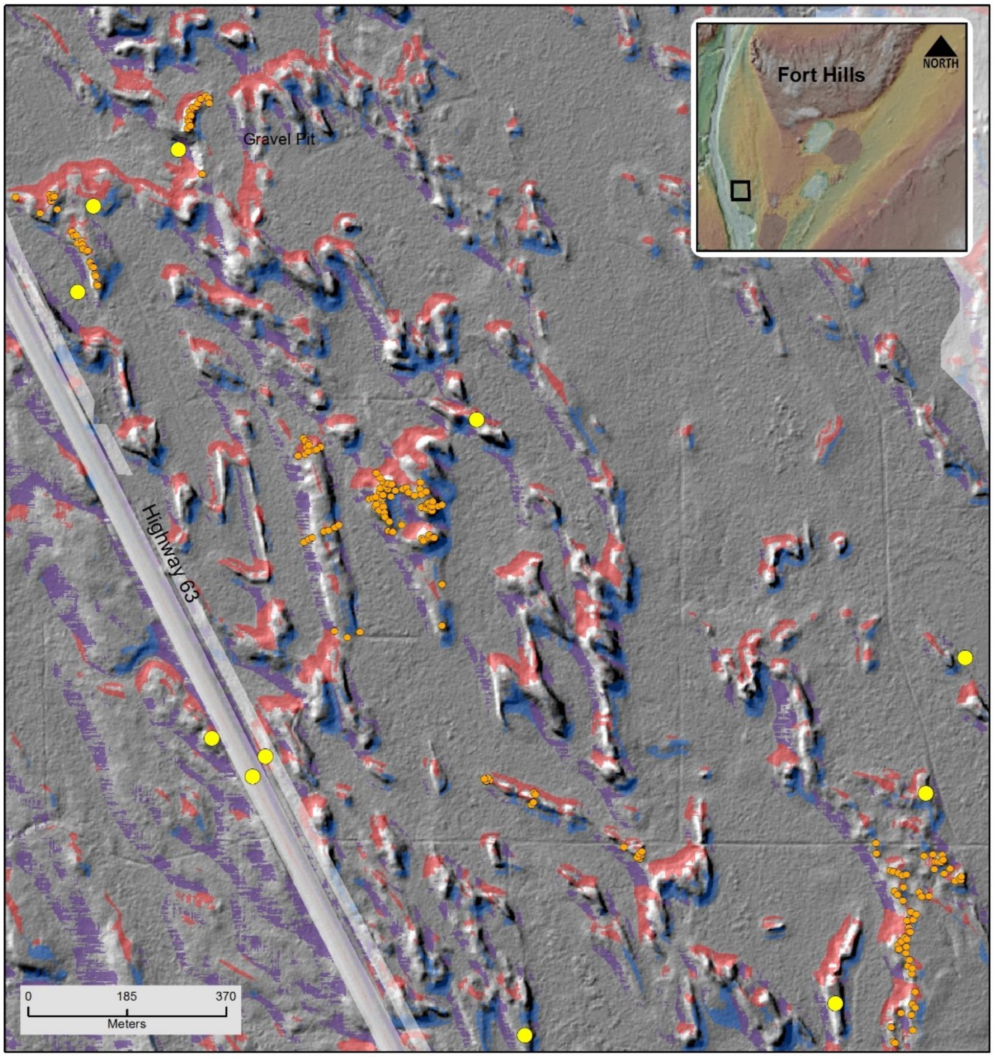


Figure 4.7 An example of the digital terrain analysis results. High sedimentation potential areas are indicated in red for the southeasterly model, blue for the northwesterly model, and purple for areas that overlap both models. Yellow dots are archaeological sites, orange dots are shovel tests. Raised features are gravel-cored flood bedforms.

Both models contained comparable proportions of the 755 known shovel tests, and comparable proportions of deeper tests (Table 4.2). Thirteen shovel tests occurred in areas where the models overlapped, six of which were deep tests. Shovel test densities were also similar in both models and higher than the average density across the entire study area (Table 4.2). The proportion numbers indicate that archaeologists have not focused testing in these areas, and the density numbers indicate that they have been tested in relatively equal intensity since 2014. Deep tests appear to be equally likely in either model setting, although this may reflect data collection standards for shovel test probes (see Discussion below).

Table 4.2. Proportion and density of total shovel tests (n=755) and deep tests (n=125) relative to digital terrain analysis results.

Sample	Proportion of Shovel Tests (n=755)	Shovel Test Density (per km^2)	Deep Shovel Test Proportion (n=125)	Deep Shovel Test Density (per km^2)
Southeast Model	0.17 (126)	9.0	0.23 (29)	2.1
Northwest Model	0.15 (112)	11.1	0.18 (23)	2.3
Study Area	1.00 (755)	6.3	1.0 (125)	1.0

The southeasterly model captured 25 known sites, while the northwesterly model only captured six, accounting for 23% and 5% of the total site sample (n=111), respectively (Table 4.3). Only one site occurred in overlap areas. The southeasterly model also had a much higher density of known sites, including ones with deeper sediment (Table 4.4). Because both the northwesterly and southeasterly models have been surveyed at similar intensities (Table 4.2), this trend indicates that sites may be more likely to occur in areas we have identified as high potential for deeper sedimentation in the southeasterly model.

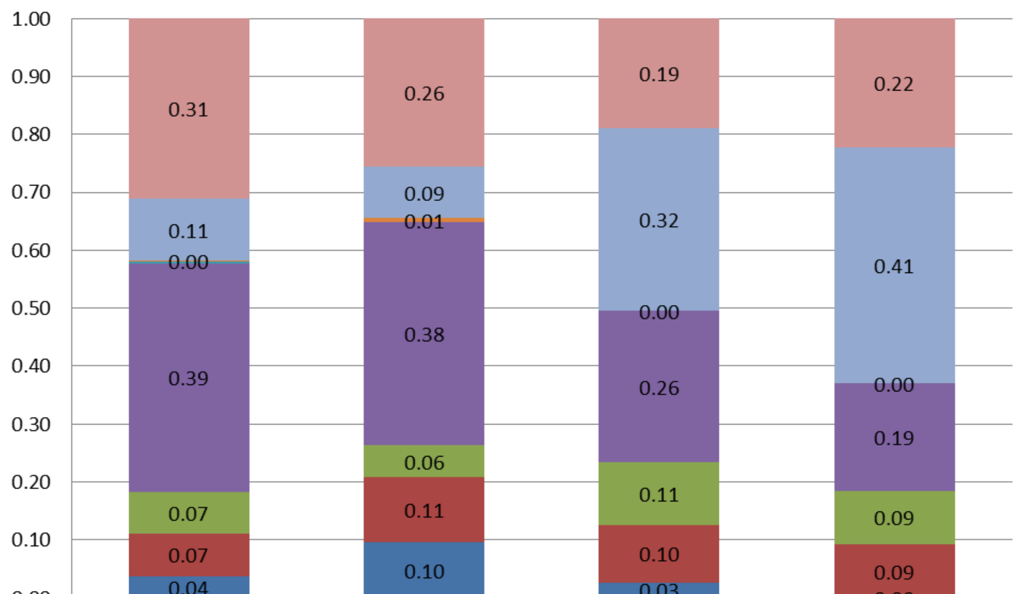
Table 4.3. Proportion and density of all known sites (n=111) and deep sites (n=54) relative to digital terrain analysis results.

Model	Proportion of Excavated Sites (n=111)	Site Density (per km^2)	Proportion of Deep Sites (n=54)	Deep Site Density (per km^2)
Southeast	0.23 (25)	1.8	0.24 (13)	0.9
Northwest	0.05 (6)	0.6	0.04 (2)	0.2
Study Area	1.00 (111)	0.9	1.00 (54)	0.4

4.5 Discussion

4.5.1. Shovel testing and known site patterns

Our analysis shows that current testing strategies are not focused on areas we have identified as having the highest potential for deeper eolian sedimentation. An examination of shovel test location by landform element indicates that over 80% of tests were excavated on divergent shoulders, level ridge tops, and level elements; areas predominantly unsheltered from SE and NW prevailing wind direction (Figure 4.8 and Figure 4.9). This bias helps explain why so few tests have been excavated in areas identified in our models; these elements are weighted low for sedimentation potential (Table 4.1). Archaeologists preferentially test these areas for four main reasons: 1) They are well-drained topographic highs that are easy to travel compared to the lowlands, 2) they provide good lookouts for game in nearby wetlands or on trails atop the raised landforms themselves, 3) past inhabitants of the study area may have encountered knappable cobbles and boulders of Beaver River Sandstone in surface exposures of flood gravels on the ridgetops, and 4) it is easier to excavate shovel tests in high, dry terrain. The known site record reflects this preference, with 77% (n=85) of sites located on these three landform elements (Figure 4.8). This pattern is discussed further in Section 4.5.3.



	Proportion of shovel tests	Proportion of deep tests	Proportion of Sites	Proportion of Deep Sites
Level Ridge Top (8)	0.31	0.26	0.19	0.22
Level (7)	0.11	0.09	0.32	0.41
Divergent Backslope (6)	0.00	0.01	0.00	0.00
Convergent Backslope (5)	0.00	0.00	0.00	0.00
Divergent Shoulder (4)	0.39	0.38	0.26	0.19
Convergent Shoulder (3)	0.07	0.06	0.11	0.09
Divergent Footslope (2)	0.07	0.11	0.10	0.09
Convergent Footslope (1)	0.04	0.10	0.03	0.00

Figure 4.8 Proportion and density of shovel tests and known sites in each landform element category.

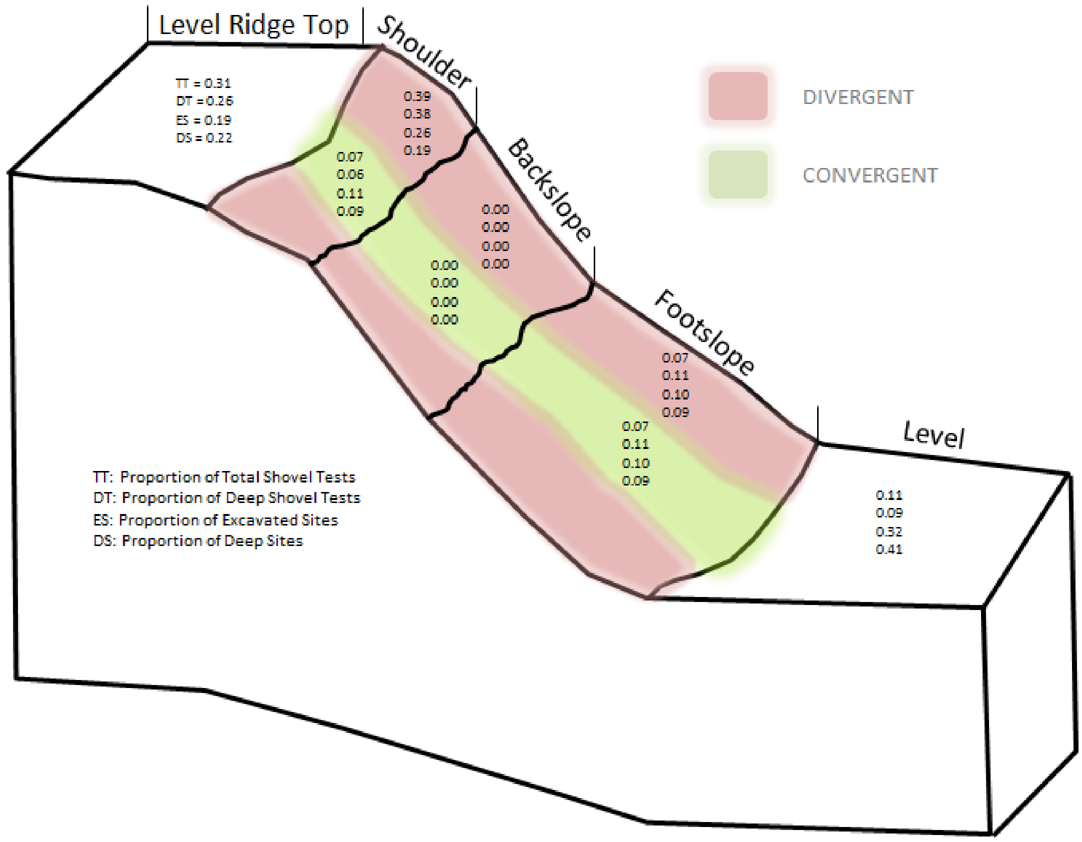


Figure 4.9 Schematic showing shovel test and site proportions per landform element.

Shovel tests with deeper sediments also had similar densities for both models, returning a value of just 2.0/km^2 (Table 4.4.2). The initial impression of these numbers is that deeper deposits do not occur in shovel tests in our modelled areas in a meaningful way. However, depths in the shovel test data contain a spurious number of values in factors of five and 10cm, particularly 40cm depth values. This suggests that many researchers are rounding depth values to the nearest factor of five or ten. Although not ideal, this circumstance is workable because most controlled excavation data is recorded to ten or five centimeter levels, and shovel test data in this format can be easily harmonized to the excavation data. More troublesome is the fact that nearly every shovel test in one permit was assigned a 40 cm depth. This indicates that some researchers may be terminating shovel tests at arbitrary depth limits in the field, rather than excavating to an impermeable layer or recording the maximum depth of cultural material. As a result, we consider the shovel test location data trustworthy, but the associated depth data include some added uncertainty. We cannot therefore determine whether the areas identified as high sedimentation potential in our model are accurate based on existing shovel test data. We conclude that testing strategies carried out to date have not adequately assessed areas that are likely to contain deeper sediments.

4.5.2. Known site patterns

Known sites are more abundant and more densely distributed in the southeasterly model (Table 4.3). The sample size is low, but these numbers suggest sites (including deeper ones) could be more likely to occur in areas sheltered from southeasterly winds. Given the shovel test sampling bias noted above, this trend is not currently testable using existing data, because known site locations are dependent on the biased shovel testing record. Unlike the shovel test data, excavation block depths have been consistently recorded as maximum depth of cultural material, usually rounded to the nearest factor of 10 (Courtney Lakevold, pers comm). This enables confident identification of deeper cultural material. Although this measure is a serviceable indication of sediment depth. it does not provide a way to determine if stratigraphically significant non-archaeological deposits occur below cultural components as seen at Quarry of the Ancestors (Woywitka et al., Chapter 3).

4.5.3 Survey effort and site returns

Comparison of the level of survey effort (i.e., proportion of total shovel tests) and site returns per landform element provides insight into the effectiveness of current survey strategies. The difference between shovel test proportions and known site proportions measures how site returns deviate from expected values. A difference of zero indicates equal site return for level of shovel testing effort (i.e., the expected return), a positive difference indicates areas where site returns are higher than expected, and negative differences indicate areas where site returns are lower than expected (Table 4.4).

Table 4.4 Proportion difference between shovel tests and all excavated (n=111) and deep sites (n=54). Positive difference values in the two far right columns indicate higher than expected site returns relative to survey effort, negative values indicate lower than expected site returns relative to survey effort.

Landform Element	Proportion of Shovel Tests (n=755)	Proportion of All Excavated Sites (n=111)	Proportion of Deep Sites (n=54)	Proportion Diff All Sites	Proportion Diff Deep Sites
Convergent Footslope (1)	0.04	0.03	0.00	-0.01	-0.04
Divergent Footslope (2)	0.07	0.10	0.09	0.02	0.02
Convergent Shoulder (3)	0.07	0.11	0.09	0.04	0.02
Divergent Shoulder (4)	0.39	0.26	0.19	-0.13	-0.21
Convergent Backslope (5)	0.00	0.00	0.00	0.00	0.00
Divergent Backslope (6)	0.00	0.00	0.00	0.00	0.00
Level (7)	0.11	0.32	0.41	0.21	0.30
Level Ridge Top (8)	0.31	0.19	0.22	-0.12	-0.09

Level of effort mirrors overall site return relatively closely for the convergent footslopes, divergent footslopes, and convergent shoulders, with values ranging between -0.01 and 0.04 (Table 4.4). Backslopes have not been tested in appreciable numbers and are excluded from the analysis. The negative returns for level ridge tops (-0.12) and divergent shoulders (-0.13) not only support the conclusion made above that these landform elements are preferentially tested by archaeologists, but also indicates that these areas are being slightly over-sampled, with lower than should be expected site returns. Deep site returns follow a similar pattern, although with a more marked deviation from expected for the Divergent Shoulder element (-0.21; Table 4.4). As discussed above, shoulders are more likely to shed than accumulate sediment, so a lack of deep sites in these settings is not unexpected.

The higher than expected overall and deep site returns for the Level landform element (0.21 and 0.30, respectively; Table 4.4) was a surprising result; we weighted this landform element low in our models envisioning it as large areas of flat Boreal plain or muskeg removed from raised landform spheres of influences. However, most sites in this element (n=30/34), are within 30m or less of a raised linear landform, either on saddles between landforms or directly adjacent to the footslope of a landform (Table 4.5). The failure of our model to capture these sites could be due to the curvature metrics used to calculate landform elements. Decreasing the threshold used to define concave areas may expand the footslope category laterally and capture these sites. However, it is also likely that the sites are in areas that would be considered level in the field as well as our model. In this case, a refinement to our model would be the application of a buffer to footslope elements where they abut level areas. In either case, it is apparent that areas next to uplands were used by people as refuse or work areas. This type of use is consistent with the notion that the raised landforms acted as nodes for past inhabitants, but that not all activity occurred on the ridge tops (Ives 1993; Saxberg 2007). This is especially the case in settings like the giant gravel bar that forms the substrate of Quarry of the Ancestors, where Beaver River Sandstone exposures occur independently of topographic setting (Saxberg 2007). The high site return (including deep sites) for minimal effort expended so far in these settings shows that increased testing of these landforms is likely to identify additional significant sites in the region.

Table 4.5 Distance to raised landforms of sites located in the Level landform element.

Site	Maximum Level	Distance to Raised Landform (m)	Site	Maximum Level	Distance to Raised Landform (m)
HhOu-94	Level 02	46	HhOv-528	Level 12	14
HhOv-538	Level 03	36	HhOv-200	Level 07	14
HhOv-524	Level 07	34	HhOv-523	Level 05	14
HhOv-164	Level 08	34	HhOv-319	Level 07	13
HhOv-525	Level 05	30	HhOv-36	Level 04	12
HhOv-199	Level 04	28	HhOv-463	Level 02	12
HhOv-530	Level 04	26	HhOv-498	Level 05	11
HhOv-159	Level 08	26	HhOv-305	Level 07	11
HhOv-401	Level 03	24	HhOv-353	Level 05	10
HhOv-161	Level 03	23	HhOv-359	Level 06	8
HhOv-307	Level 04	22	HhOv-531	Level 07	7
HhOv-400	Level 08	21	HhOv-354	Level 08	6
HhOv-350	Level 07	18	HhOv-433	Level 05	4
HhOv-535	Level 06	18	HhOv-522	Level 05	4
HhOv-118	Level 04	16	HhOv-351	Level 03	3
HhOv-55	Level 05	16	HhOv-328	Level 02	2
HhOv-449	Level 02	16	HhOv-355	Level 05	2

4.5.3. Archaeological implications

The historical and current focus on shoulders and ridges in archaeological survey has confirmed extensive use of upland environments in the mineable oil sands region, with over 600 archaeological sites identified in these settings (Ronaghan 2017). This is consistent with established patterns recorded elsewhere in Alberta's boreal forest (Le Blanc and Ives 1986; Ives 1993; Le Blanc 2005; Younie et al. 2010; Woywitka 2016; Woywitka 2017;). However, our results show that lower, level areas adjacent to raised landforms have high site returns relative to the minimal survey effort expended in them to date. This is consistent with other evidence that this type of terrain was used by Precontact period Indigenous groups in the region. Artifacts recovered from lower topographic settings, including deep eolian sediments and peat deposits, at Quarry of the Ancestors (Saxberg 2007; Woywitka et al., Chapter 3) provide examples of ancient use of these settings within our study area. These sites attest to the possibility of stratified and/or datable deposits in these locations (Woywitka et al., Chapter 3). Similarly, Ives (2017) obtained a limiting age of 2,030 +/- 105 ^{14}C years BP on a site in the nearby Birch Mountains by dating organic wetland deposits that buried an archaeological site in a low-lying, flat area. Studies of wetland expansion in northern Alberta show that paludification of the landscape proceeded over most of the Holocene, with formerly well drained areas being overrun by organic terrain gradually over hundreds to thousands of years (Bauer et al. 2003; Bloise 2007). There is potential that this process has buried other archaeological sites like those found at Quarry of the Ancestors and in the Birch Mountains. Use of muskeg and lower lying terrain is also recorded in ethnographic studies (Winterhalder 1978, Ives

1993). Current upland-focused survey approaches have resulted in a significant archaeological record, and a good understanding of the use of these areas. However, an important aspect of ancient land use may be underrepresented in the archaeological record because of this upland bias.

The potential positive relationship between areas of likely high eolian sedimentation under prevailing southeasterly winds has potential chronological implications for the archaeological record. Southeasterly winds were dominant in only during the immediate post-glacial (Wolfe et al. 2004). It is therefore likely that sands deposited in the high potential sedimentation areas in the southeasterly model were emplaced shortly after deglaciation, and predate those in the high potential areas identified in the northwesterly model. Infrared Stimulated Luminescence (IRSL) ages from Quarry of the Ancestors indicate that eolian sands there were deposited around 11.5 ka yr BP (Woywitka et al., in prep), and the initial human occupation occurred concurrently or shortly following deposition. Is it likely that sands identified in our SE model are of early deglacial age, and have the greatest potential for preserving similarly aged archaeological materials? Or are other factors influencing site location? Testing of our models may help answer these questions.

4.5.4. Regulatory implications

The gap in our knowledge of site distribution in non-ridge, upland settings should be addressed in cultural resource management practices for the region. The existing upland record provides an excellent baseline case, but new information is needed to expand our understanding of cultural chronology and past land use patterns in the region. A shift in archaeological survey techniques to include a wider variety of landform elements, particularly footslopes and level areas adjacent to raised landforms, will aid in this endeavor. Refined depth recording methods for shovel tests and excavations will also help refine models and survey strategies to identify more significant sites. We recommend recording two types of depths: 1) an "archaeological bottom" that represents the maximum depth of cultural material at a site, and 2) a "sedimentological bottom" that represents depth to an impermeable surface, or the maximum depth that could be safely reached with available tools. These depths should be recorded for both shovel tests and excavation units to the nearest five centimeters. Data gathered in this manner will help to test and refine models like the ones we created in this study.

We recognize that testing the margins of wetlands and the bases of raised landforms can be uncomfortable because of heavier vegetation and higher soil moisture content. But conventional shovel testing can be used in these settings to some degree, particularly during the dry season. For more challenging areas farther removed from the lowland/upland interface or with higher water content, feasibility studies of other wetland testing techniques (e.g., winter testing, muskeg removal monitoring) should be conducted. From a broader perspective, we also recommend that the archaeological impact assessment and mitigation regulatory frameworks be more aligned to specific research questions, rather than the current inventory based approach.

4.6. Conclusion

The low number of stratified or datable sites in the oil sands region of northeastern Alberta has limited archaeologists' ability to answer important temporal questions like, "when did people first occupy the area?" "how was lithic raw material accessed, used and traded?" "how did human land use change through time?" We developed a process-depositional model that conceptualized environmental settings where deep or stratified sites are most likely to occur. This model focused on the relations between eolian processes and topographic shape. Using digital terrain analysis, we mapped these areas, and compared known site data and sediment probe locations to our modeled areas. We found that current testing strategies in the region are focused on areas that are not likely to contain deeper deposits according to our model. Known site distributions appear to cluster in areas that are likely to have collected eolian sediment under early post glacial wind regimes, but sample sizes and depth data are not adequate to quantify this relationship. We recommend that cultural resource management regulators and practitioners include a broader sample of landform types in future surveys, and record more detailed sediment depth data. In this way, archaeological practice in the region may identify more deeply buried and stratified sites that can address important questions about the timing and nature of past human use of the region.

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CHAPTER 5: INCORPORATION OF GEOARCHAEOLOGICAL PERSPECTIVES IN MINEABLE OIL SANDS CULTURAL RESOURCE MANAGEMENT

5.1 Introduction

The archaeological record of northeastern Alberta is under persistent pressure from oil sands mining and other developments. During economic booms, cultural resource management (CRM) work proceeds at an extremely high volume and rapid rate. The current approach to CRM in the region is largely reactive, with a focus on site inventory and project-specific impact mitigation. This method has resulted in the recording of thousands of sites and the production of hundreds of permit reports that have provided the basis for this study and the first published cultural chronologies and lithic analyses of the region (Clarke et al., 2017; Reeves et al., 2017; Ronaghan, 2017; Saxberg and Reeves, 2003; Saxberg and Robertson, 2017; Woywitka, 2017, 2016; Younie et al., 2010). The recent publication of an edited volume on the archaeology and palaeoenvironments of the region (Ronaghan, 2017) and the results of this dissertation show that an adequate baseline dataset has been established for the region. To effectively build on this body of knowledge, we argue that regulatory practice needs to move beyond the current reactive framework. A new, more research-focused approach will increase the scientific and social value of CRM by providing insightful results that are readily translatable to academic and public dissemination. This strategy can also provide the flexibility needed to incorporate methodological improvements that will improve management of physical site impacts.

Overall, it can be argued that a more collaborative and research-driven regulatory process will better fulfill the mandate of the Alberta *Historical Resources Act*.

In this chapter, we propose a modified approach to oil sands region CRM that is based on four research themes: geoarchaeology, lithic analysis, cultural landscapes, and Indigenous perspectives. Using the results of the work presented in Chapters 2, 3, and 4, we elaborate on the geoarchaeology theme, providing key research questions and broad methodological considerations that can be addressed in future work. Although beyond the scope of our work, similar guidelines can be created for the other three research themes. The chapter concludes with a discussion of the role that increased collaboration between private archaeological consulting firms, regulatory bodies, academic institutions, and Indigenous communities can bring to the improvement of CRM practices in Alberta.

5.2 Modified regulatory process

In addition to the existing evaluations that focus on physical impacts to sites, we propose that large-scale, non-routine Historical Resources Impact Assessments (HRIAs) address specific research questions in four main themes: geoarchaeology, lithic analysis, cultural landscapes, and Indigenous perspectives. In this system, review of proposed projects at the Archaeological Survey would culminate in *Historic Resources Act* requirements that detail how specific research questions can be addressed in the HRIA process. Using their existing oil sands project management system, the Archaeological Survey would coordinate this work, ensuring that efforts are not duplicated, and that the project-specific research goals are tailored to the current state of knowledge for the region. The Survey also publishes an

Occasional Paper series that can serve as a public forum for distribution of significant HRIA results (Woywitka 2016; Peck 2018). This change would represent a shift in focus in how the Archaeological Survey formulates requirements and how CRM archaeologists approach research design and field operations, but it would not require any technological changes to the existing electronic permit system. The system should be flexible, with new foci and methods incorporated as knowledge increases and technology advances. The sections below detail the questions and broad methodological considerations drawn from our research that can form part of the geoarchaeological research theme in a modified regulatory approach.

5.3 Geoarchaeological research foci

Archaeological sites within the Clearwater-Athabasca Spillway between the Athabasca River-Muskeg River confluence and the Fort Hills are commonly associated with raised linear landforms that we have interpreted as catastrophic flood bedforms (Chapter 2). North of the Fort Hills, sites are more commonly associated with stabilized sand dune and sand sheet deposits adjacent to wetlands, pothole lakes, and stream valley margins (Woywitka, 2017). Our work indicates that eolian processes and wetland expansion were influential factors in preserving archaeological sites in these settings, and that landform elements where these deposits can accumulate have not been the focus of previous archaeological survey. Some of the key questions raised by our research are:

- Are deposits deeper and/or stratified in areas sheltered from early post glacial paleowinds? Are sands deposited by winds originating from the southeast older than those originating from the northwest? What are the implications for the age of cultural material recovered in these settings?
- Undisturbed sediments in dune blowouts have provided reliable IRSL dates for landscape stabilization (Chapter 3). Is there potential for the identification of human occupation in these stratified and dated deposits?
- How common is archaeological material in wetland settings?
- Are there sedimentary units other than those identified in our study that contain cultural components?
- What effects do bioturbation, cryoturbation and other taphonomic processes have on cultural deposits?
- When was the initial occupation of the region?
- What effects did peatland expansion have on land use and site preservation?
- Is there a correlation between projectile point typology and age of occupation?

Using geoarchaeological methods, our work successfully provided insight into the origin and age of landforms that host archaeological sites, the timing of initial occupation at Quarry of the Ancestors, and the distribution of deep deposits in the region. These results demonstrate that geoarchaeological methods can be used to gain the palaeoenvironmental, geological, and geochronological knowledge needed to address the questions posed above. However, most HRIA work to date has not incorporated a systematic approach to geoarchaeological aspects of the archaeological record. More formal integration of geoarchaeological studies in oil sands CRM will help address the questions above and provide a more robust scientific framework for the regional archaeological record. Three aspects of our research are integral to future research design in this regard: 1) characterization of Quaternary sediments, 2) broadened survey sampling methods, and 3) increased focus on radiometric dating.

5.3.1 Quaternary sediment characterization

Archaeologists should systematically describe sediments at sites and shovel test areas. Interpretations derived from the sedimentological characteristics observed should focus on palaeoenvironmental indicators, sedimentary sequences, and geological processes that have affected or contextualize cultural deposits. Our work in Chapter 2 includes this type of approach, and may serve as a useful example to inform future studies. We describe six lithofacies that may be encountered in the region, and others have been described in Fisher and Smith (1993) and Smith and Fisher (1993). Archaeologists working in the oil sands region should be able to demonstrate if sediments they encounter in the field correlate with these previously identified facies or represent hitherto undescribed units.

5.3.2 Modified shovel testing strategies

The results of our study in Chapter 4 indicate that some landform elements are preferentially tested in HRIAs. Most testing takes place on the crests of megaflood bedforms, with far less testing conducted on footslopes. Despite the lower level of sampling, footslope areas have demonstrated potential for the recovery of archaeological material associated with deeper, stratified deposits and datable organic wetland deposits (see Chapter 2). We recommend that future survey include a broader sample of landform elements, including footslopes and level areas adjacent to raised landforms. Areas where wetland organic deposits may interfinger with upland mineral deposits are of particular interest, given the increased likelihood of radiocarbon datable organic material. Both the input data and results of our model can be used to guide sampling strategies, and monitoring of their results can form the basis for adaptive survey strategies in the future.

5.3.3 Radiometric dating

Radiocarbon dating of weathering-resistant calcined bone, comparative analysis of projectile point types, applications of luminescence dating, and dating of organic-rich peat deposits have given us initial insight into the timing of human occupation of the oil sands region. But uncertainty remains, and models like the one presented in Chapter 3 of this dissertation and the typological framework of Reeves et al. (2017) require further testing. To properly address chronological issues, future research should include a closer focus on using stratigraphic position to provide relative ages and increased use of radiocarbon and luminescence dating. Multiple ages should be obtained for cultural components where possible. Consistently reproducible results increase the confidence in age estimates, and archaeologists should be conservative in assigning ages to cultural complexes on the basis of a single age. Acquiring the sample size needed to obtain a representative ages may require the use of more detailed excavation techniques at sites that hold potential for the recovery of bone or other organic remains.

5.4 Discussion and Conclusion

The shift from an inventory style regulatory process to a research driven one would represent a significant change in Alberta cultural resource management. Although not stated in official government documents, a position that proponents of industrial developments should not pay for "research" is deeply embedded in the regulatory process. Instead, developers are expected to pay for salvage work that transforms the site from an entity in the ground to an entity comprised of curated artifacts and excavation records at the Royal Alberta Museum. In this approach, these curated entities can be used by academics and other researchers for their own purposes using their own funding sources. But the research value of an archaeological site is not just in the items collected from the site and the records produced during its excavation. It lies also in the physical, cultural, and temporal context in which the site occurs. A strange thing about archaeological excavation is that it destroys much of this context itself, and the way a site is excavated can preserve one aspect of a site while simultaneously destroying another. To properly manage this complexity, excavations and surveys need to be conducted within a research framework that balances what is lost and gained when different field and analytical methods are used.

The salvage ethos that currently underlies the regulatory process is also outmoded. Oil sands companies now face increased responsibility to show that their operations are being conducted ethically and with respect for other stakeholders on the land. A research driven regulatory process can aid in maximizing what is learned in the CRM process, and provide more meaningful recompense for the permanent physical destruction of the archaeological record. By participating in this type of process, developers can better meet their obligation to Indigenous communities, the scientific community and the general public.

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CHAPTER 6: CONCLUSION

In the absence of a robust archaeological radiocarbon dataset, we examined the sedimentary record for evidence of the age of immediate post-glacial landscape stabilization and initial human occupation in the mineable oil sands region. Using sediment-landform associations and IRSL analysis, we determined that after late-glacial catastrophic flooding and a subsequent period of eolian deposition, landscape stabilization began ca. 12.0 ka BP in the region, and continued until ca. 9.7 ka BP in some areas. Association of cultural material with eolian sands and periglacial features dated to ca. 12.0 ka BP within the Clearwater-Athabasca spillway indicate initial subaerial exposure of the landscape and earliest human occupation likely occurred during the Younger Dryas period. This evidence is consistent with the Younger Dryas aged glacial Lake Agassiz outburst flood described by Murton et al. (2010). Humans began utilizing exposed catastrophic flood bedforms shortly after flood waters receded, during a cold climatic interval that was likely triggered by the outburst event that sculpted the local environment (Murton et al., 2010). These initial inhabitants reached northeastern Alberta around the same time people occupied early Paleoindian sites at Charlie Lake Cave in northeastern British Columbia (Fladmark et al., 1989) and Lake Minnewanka in southwestern Alberta (Landals, 2008).

Outside of valleys, very little significant clastic sedimentation has occurred since the cessation of eolian deposition in the early Holocene. Millennia of human reoccupation and bioturbation processes have mixed shallowly buried cultural components on ridge tops and other exposed settings, emphasizing the significance of deeply buried, undisturbed deposits found in lower topographic settings like those found at Quarry of the Ancestors.

Using a process-deposition model and digital terrain analysis of high resolution LiDAR DEMs, we mapped areas that have potential for deeper eolian sediments, and observed that current archaeological survey strategies are not targeting these areas in a representative manner. Basal peat ages recovered from organic deposits at Quarry of the Ancestors and elsewhere indicate that wetlands have expanded over formerly dry terrain throughout the Holocene, and may have also buried archaeological materials in lower topographic settings than have been traditionally tested. At Quarry of the Ancestors, lithic debitage recovered from peat deposits above a basal age of ca. 900 cal years BP indicate that people occupied the area after that time, and that sources of Beaver River Sandstone could have been exposed late into the Holocene.

From a regulatory perspective, this study shows that CRM work to date has provided an excellent baseline analytical dataset for geoarchaeological study. It is my opinion that the inventory-focused methods used to build that dataset can now be augmented by research-driven approaches that will increase the social and scientific value of work conducted under the *Historical Resources Act*. To that end, insights from Chapters 2, 3, and 4 have been used to formulate some nascent guidelines for future research in mineable oil sands geoarchaeology. It is hoped that similar guidelines can be established for the other main archaeological research foci in the region.

Archaeologists have long proposed that people have used the mineable oil sands region for the entirety of the post-glacial period, drawn by readily available raw materials for stone tool manufacture, among other natural and cultural factors. This study helps confirm the deep antiquity and continuity of human presence in the region, and provides understanding of how geological processes can preserve, obscure, and destroy archaeological evidence of that presence. It my hope future researchers also see the value of studying these processes, and use this work to as a basis to refine or refute the interpretations herein.

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